Exploring Ancient Skies

An Encyclopedic Survey of Archaeoastronomy

David H. Kelley ■ Eugene F. Milone

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Foreword by Anthony F. Aveni

With 392 Figures, 8 in Full Color, and 95 Tables

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Foreword

A third-millennium academic cliché worth repeating is that the questions we pose and the problems we now attempt to solve seem to have the effect of blurring the lines that demarcate the traditional disciplines. This is true not only among the sciences, in which universities now routinely offer interdepartmental courses in biophysics, neuropsychology, and astrogeology, but also across the traditional academic divisions of science, social science, and the humanities. The study of ancient astronomies is a perfect example of the latter case. Once partitioned into the traditional *history of astronomy*, which dealt exclusively with the underpinnings of Western scientific astronomy, and its upstart adopted child *archaeoastronomy*, which treated all other world cultures, it has now been subsumed by *cultural astronomy*, which, in addition, envelops the astronomical practices of living cultures.

The problems treated in *Exploring Ancient Skies* are as follows: What did ancient people see in the sky that mattered to them? How did they interpret what they saw? Precisely what knowledge did they acquire from looking at the sky, and to what ends did they employ this knowledge? In short, what were they up to and why?

You hold in your hand a weighty tome, the product of an enduring collaboration between a pair of seasoned veterans: one an observational astronomer of great expertise, and the other an archaeologist/epigrapher, well known among his Mesoamerican colleagues for his significant contributions to the problem of decipherment of ancient Maya script. What an ideal blend of expertise to produce a true interdisciplinary synthesis that treats the problems posed by these engaging and complex questions! *Exploring Ancient Skies* combines a deep and thorough treatment of relevant empirical naked-eye astronomy with sweeping cultural coverage from peoples of the Arctic to Oceania, from the unwritten astronomy encoded in ancient standing stones to what would become the platform on which Western astronomical tradition yet rests.

Daring in the presentation of some of its hypotheses and somewhat unorthodox in the treatment of certain long-standing problems, *Exploring Ancient Skies* may cause some scholars to bristle, for example, at the readings of certain pages of the Maya codices, the treatment of the calendar correlation problem, the universality of world ages, and the diffusion of astronomical ideas and concepts both north-south and east-west. But a foreword is not a review. Let any reader's reactions not diminish an appreciation of the way Kelley and Milone have delivered fresh knowledge and created a challenging synthetic approach that can only derive from years of experience in a variety of related fields.

Will *Exploring Ancient Skies* help solve our problems? Only time will tell. Seminal progress in the development of all fields of scholarship depends on our capacity to listen and to learn the lesson of history.

Hamilton, New York

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Preface

Exploring Ancient Skies: An Encyclopedic Survey of Archaeoastronomy brings the perspectives of the modern sciences to bear on the practices of pretelescopic astronomy in cultures around the world. In doing so, it traces the path of development of modern society and sheds light on the timeless questions: "Who are we?" and "How did we get here?"

Few previous works have attempted to cover the entire scientific, geographical, and historical spectrum of the subject, and for good reason. The present work has taken a quarter century to prepare as we have struggled to keep up with the voluminous and growing scholarship in this field. As we progress into the third millennium, it is time for such a comprehensive work on the broad spectrum of ancient astronomy to appear, even if, inevitably, incomplete.

This work is intended foremost as a textbook. It arose out of a need to develop a cogent body of scholarly materials and of practical knowledge for undergraduates in our course, Archaeoastronomy, at the University of Calgary, which we have taught, off and on, since 1976. The course has had no specific prerequisites, but has always been recommended for students beyond their first year of study. In most years, the class has been composed about equally of students with some background in archaeology or astronomy and those who have neither. In addition, *Exploring Ancient Skies* is intended to be a reasonably concise source and guide to a large and growing body of literature. A special feature is the somewhat more detailed chapter on Mesoamerica. There are several reasons for this: First, Mesoamerica is the only New World area from which we have written records; second, it is one of the few areas anywhere for which literary evidence is linked to astronomical alignments and to light and shadow phenomena; third, it has possibly the largest range of astronomically related phenomena recorded in literature, architecture, and building and site placements; and finally, it is an area that had been relatively neglected in most books on the treatment of ancient astronomy when we began, with the notable exception of Anthony F. Aveni's work. The abundance of scholarly material on the cultures of the Mediterranean precluded an exhaustive treatment by us, but because it provides antecedents of our present technological world, we have discussed what we feel to be the most representative and significant details. In dealing with areas and cultures that have already received a great deal of attention, we try to provide sufficient links to previous writings to convey the vitality of the scholarship and to encourage further examination.

The present text now represents more than 25 years of effort. Some areas in which we provide interpretation had been relatively unexplored when these sections were first drafted but have now been reached by the rising tide of scholarship. EFM originally wrote the first five chapters with the help of a Killam Resident Fellowship at the University of Calgary in the academic year 1988–1989, but we have revised them continually ever since. The bulk of the bibliography dates to about 1996, when we stopped trying to systematically update it in order to bring this extensive project to a close; yet critical references to work we knew about continued to be added through 2000.

We mentioned that we intend *Exploring Ancient Skies* to be a textbook. It is, however, not a standard textbook in certain ways because much interpretation is still, of necessity in this field, controversial, and judgments about content and value must be made. Nonetheless, the book must contain basic data on astronomical phenomena and must put archaeoastronomical materials in a cultural and archaeological context. The judgments that are made must be justified and hence must contain more scholarly apparatus than is usually presented in an introductory text. Relationship to mythology must be considered, but this makes both astronomers and mythologists uneasy. Many astronomers think that mythology, in and of itself, deals with "nonscientific" matters, and in the present context, it is probably related to the contemptible belief system of astrology. Mythologists may think that a "reductionist" bias is introduced, phrased in esoteric formulas that no proper humanist should have to consider. We have no doubt that our own presuppositions have entered in and influenced both what we write about and how we write about it. This can scarcely be avoided, but where we are conscious of it, we have tried to discuss alternative standpoints or interpretations. Having said this, we now review the details of the book's structure and indicate why we present the material that we have.

Pedagogically, there are two books here. Chapter 1 is a general introduction to the field and applies to both parts. Part I consists of Chapters 2 to 5, which emphasize the astronomy and are illustrated with examples of astronomical practices of other times and places. Part II consists of Chapters 6 to 14, which emphasize the varieties of pretelescopic astronomy as practiced by cultures around the world, with references to the fundamental principles of Part I. Chapter 15 underscores parallels and differences in astronomical thought among world cultures and offers possible explanations.

Abundant cross-references make it possible to skim the early chapters to see what is there, and to use them as technical resources for the cultural chapters. For general-interest readers, and for classes to be taught over only a single term, whose need for the underlying astronomical principles may not be paramount, a concentration on Part II may be a suitable approach. For anyone planning to do field work in archaeoastronomy, but who may have some acquaintance with archaeology, ethnology, or other closely allied fields, initial concentration on Chapters 1 to 5 may prove the more useful strategy. For physical science students, close study of the early chapters is essential; we believe they will provide the necessary physical underpinning for further work in most of the areas discussed in the second part. In Astronomy 301 at the University of Calgary, we have usually gone through all chapters in sequence, spending about one-third (or more) of a semester on the first five chapters and two-thirds (or less) on the culture areas. We have tried alternative procedures, but this procedure has been received best by the students, although it requires a strenuous pace. A year would be about right, but at the University of Calgary, we have never had that option. In this broadly interdisciplinary course, however, a wide mix and choice of questions on examinations can make the lives of students much easier than if they are required to master a fixed set of topics. The important point is that every student should master a significant corpus of material in order to do well. In the interest of fairness, what constitutes a significant corpus is a question that an instructor must weigh carefully.

Now we briefly review the contents of each chapter.

Chapter 1 defines the field and discusses its development, its significance, and its relationship to other disciplines.

Chapter 2 provides an overview of the naked-eye objects in the sky and of the phenomena with which they are connected. The basic motions of objects on the sky, the coordinate systems by which their locations are specified, and the means to transform from one coordinate system to another are treated in detail. Chapter 2 begins with an exposition of very basic positional astronomy; this is not the stuff of bestsellers, but it is the heart of practical astronomy, ancient or modern. Consequently, we provide more examples in the text here than in any other chapter. We go on to discuss each of the basic classes of astronomical objects and their motions.

Chapter 3 deals with the observation of these objects, providing the reader with the vocabulary to discuss the brightness and colors, and the variation in position due to precession and proper motion. The important corrections to altitude and azimuth measurements of objects due to refraction, dip, and parallax are described. We discuss the conditions affecting the light and color of astronomical objects, and how these can change for various intrinsic and extrinsic reasons. The effects of the Earth's atmosphere are among the extrinsic reasons. Aside from the obvious need to reduce and standardize astronomical data, such an exposition is needed to apply corrections in reverse to reveal what might have been seen in ancient contexts. The implicit basic question in this chapter is, "Was it visible?" We provide the principles with which such a question may be approached. Recent scholarship has indicated some promising directions for an even more quantitative approach to visibility, and we try to highlight the work in this area without committing to a rigid approach to observational questions.

Chapter 4 is given over to an exposition of time and its measurement, the historical and present-day units of time and time intervals, and the whole concept of scientific dating of artifacts and structures. Calendrics requires such an exposition. In particular, this material, along with that of §§2 and 3, should provide useful background on the astronomical dating of events and monuments.

Chapter 5 describes transient phenomena of the air and the sky, and explores the underlying physical principles. It deals with the characteristics of transient phenomena such as auroras and other upper and lower atmospheric phenomena, eclipses, comets, meteors and meteorites, novae, supernovae, and other variable stars. Here is where we treat such mysteries as the "missing Pleiad," the color of Sirius, the apparent deficiency of European records of observations of the supernova event of 1054 A.D., and the craters of Wabar. Additionally, the value of eclipses for historical dating and the use of ancient eclipse records to explore the deceleration of the Earth's rotation (and the acceleration of the Moon) are explored. This chapter completes the basic astronomical exposition.

Part II starts by defining the spacial and temporal roots of cultural interest in astronomy. Frequent cross-references throughout attempt to refer the reader back to fundamentals in the first five chapters, and from these chapters, to the cultural contexts in which they apply. Chapter 6 begins with what can be said about the Palaeolithic, goes through the Neolithic, and ends with the medicine wheels and similar constructs of North America.

Chapter 7 treats the antecedents of the modern Western world: Mesopotamia and Greece, and subsequent developments down to pretelescopic Europe. It emphasizes the background of Western astronomy and helps to explain the origins of the scientific method and, therefore, of our current understanding of the universe. We briefly discuss the attacks on the integrity of Claudius Ptolemy in the context of modern investigations of his work. The observations of particular cometary and eclipse observations are discussed (as they are in each cultural group in which records of such phenomena are recorded). We also discuss relevant cosmological aspects of the mystery religions, Judaism, Islam, and Christianity.

In Chapter 8, we begin with ancient Egypt, spring from there to the rest of Africa, and from there to native astronomy around the world. The Dogon "Sirius mystery" is described and discussed here.

Chapter 9 treats India and the cosmological aspects of Buddhism, Jainism, and Hinduism. The extent of the influences of these religions on other areas is discussed, as well as the migration of astronomical ideas between India and the Middle East. We also describe the cosmological aspects of other Near Eastern religions, such as Zoroastrianism.

Chapter 10 deals with China, Korea, and Japan and the development of astronomical ideas in the context of the Chinese sensibility to harmony in Heaven and on Earth. The continuing importance of early astronomical records from this region is emphasized.

Chapter 11 deals with the cultures of the Pacific, beginning with the Dream Time of Australia. The techniques used by the native navigators and their "voyaging stars" are highlighted, and the use of astronomy to understand the terms and legends of the islands is described.

The next three chapters cover the early astronomy of the Western Hemisphere. In Chapter 12, we discuss the extensive details known about Mesoamerica, to which we have already referred, but discuss new aspects of the relationships between the gods and the planets. Astronomy north of Mexico is discussed region by region in Chapter 13, and the burgeoning material of South America is treated in Chapter 14. Alignments of structures again appear as important topics in these discussions, as well as ethnoastronomy among many groups.

Finally, universal aspects are touched on in Chapter 15. Here, we deal with the ultimate purposes in the cultures of astronomy, and discuss the evidence for the independent development of ideas or, in some cases, the derived development through diffusion of ideas. We conclude with a summary of what we regard as the main purposes of ancient astronomy: astrology, navigation, calendar regulation, and that ultimate goal of so much of human activity—to know and to reach harmony with the forces that control the universe.

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Sharon Hanna contributed directly to or supervised the creation of more than 110 sketches and provided several useful photographs of megalithic sites and medicine wheel sites. Other personnel at the University of Calgary Department of Archaeology contributing to this effort include Sean Goldsmith and Rea Postolowski. Dr. David Fry of the Physics and Astronomy Department of the University of Calgary allowed the use of his excellent slides of eclipse phenomena. David Mouritsen provided the map of Mesoamerica, and Bryan Wells contributed some of the computer-drawn figures. Danny Zborover provided the beautiful slide of Alta Vista at dawn near the summer solstice and provided sketches. Dr. Ronald Angione contributed a number of critical slides of Mesoamerica. Dr. A.R.F. (Eric) Williams contributed most of the illustrations of temples in India. Dr. Frank Prendergast provided the shadow-play image of Newgrange. James T. Himer, Roland Deschesne, and Tammy Dugan of the Calgary Centre of the Royal Astronomical Society of Canada contributed superb sky photographs. Mrs. Joan Greene Smith was kind enough to reproduce and provide copies of a photograph of the Suchow star chart and "instructions for a future emperor" that was given to her father, in China, by Joseph Needham. Other photographs were supplied by Dietrich Wegener (Samarkand), David Rodger (Moose Mountain), Tom Head (Majorville), and Professor F.S. Murphree (auroras) and Professor Emeritus T. Alan Clark (star trails, sundials, and solar phenomena), both of the Physics and Astronomy Department of the University of Calgary. Dr. Rita Boreiko (University of Colorado) provided the fine lunar eclipse photograph. Michael Kelley and Marie Jack contributed important photographs of megalithic sites, and Dennis Kelley typed many of DHK's notes for easy incorporation. Helen Milone offered critical comments on the text as it developed over the years. The photography of Dr. Peter Mathews (Latrobe University, Melbourne, Australia) and that of Dr. Gerald Newland (the University of Calgary) are also appreciated. The History of

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Historical Perspectives

1.1. Perpectives of Ancient Astronomy

We deal in this book with the broad and burgeoning subject of pretelescopic astronomy. People around the world have been deeply interested in the sun, moon, and stars for millennia. Of central interest to historians are answers to the questions, "What did they know and when did they know it?" In this section, we discuss why we want to know the answers to these questions, and the means by which scholars have attempted to provide the answers.

What we know of ancient cultures stems from their writings, artifacts, representations, monuments, tombs, and even the organization of their cities. In one way or another, each of these cultural expressions demonstrates interest in an aspect of the heavens. The deciphering of Babylonian cuneiform and of Egyptian hieroglyphic writing and the decoding and interpretation of astronomical texts and tables are long-standing scholarly activities. The newer science of *archaeoastronomy* deals mainly with astronomical discoveries *outside* of the writings.

As a discipline, archaeoastronomy stems from the publication of J.N. Lockyer's *Dawn of Astronomy* in 1894. Working with little regard to the findings of archaeology, Lockyer attempted to date structures by purely astronomical criteria. With this approach, he at once illumined a fresh path for scientific exploration and incited such criticism that few dared to venture on that path again for more than half a century. The renaissance of the subject is more than a little due to the publication in 1968 of *Stonehenge Decoded* by Gerald Hawkins. This helped to draw popular attention to the astronomical practices of earlier cultures, and interest has continued to grow. As a science, where successful, it has had to be open to the contributions of many disciplines, as diverse as ancient poetry and quantitative mathematics.

An aspect of ancient astronomical study deals with trying to find solutions to astronomical and astrophysical problems from early data. Thus, the discovery that the bright star Sirius was once described as red, when it is now clearly white, may light up formerly obscure paths of stellar evolution. Early descriptions of the "seven sisters" may help us to find out something about long-term variability among the Pleiades star cluster, because the normal unaided human eye now detects only six stars. Records of ancient eclipses provide evidence of the length of the month (and the changing distance of the Moon) on the one hand, and of the length of the day (and the slowing of the Earth's rotation) on the other. Records of ancient supernovae provide dates of initial explosions, and thus ages, and when coupled with current measures of the angular sizes and rates of expansion, provide distances, and luminosities of these objects. Because supernovae are among the brightest single stars known, they provide "standard candles" for the determination of distances to remote galaxies, thus, aiding the determination of the size and age of the universe.

A branch of ancient astronomy, called "astroarchaeology" by Hawkins, deals with the application of astronomy to archaeological problems. The term has not achieved wide currency, but the aspect of archaeoastronomy it represents has not been ignored. The astronomical dating of structures (or complexes of structures) that may have incorporated astronomical alignments is an example of such application. The success of any such enterprise, depends, therefore, on the genuine astronomical intent of the builders. This question is still moot in many cases, but in others, the evidence for intent appears to be strong.

Most contemporary practitioners of archaeoastronomy seem to be interested in the subject for itself, in order to understand the astronomical activities of ancient cultures. Investigations of the use to which astronomy is put in the religious and social contexts of particular groups has produced still another area of contemporary study: *ethnoastronomy*.

It is difficult enough to work in a field such as the history of mathematical astronomy, as exemplified by the prolific work of the late great scholar Otto Neugebauer, in which the scholarly materials required to understand completely the ideas and workings of a culture are still undiscovered in the debris of destroyed cities or in caches of forgotten caves. It is even more difficult to recover ancient astronomy practices from the remnants of cultures that were systematically destroyed, as in post-Columbian Mesoamerica, or from cultures for which no written material at all is known, as in Stone Age Britain. Mesoamerican scholars and astronomers have long had mutual interest in studying eclipses and calendars, among other phenomena in which the Mayans and other peoples of the region had remarkably strong interest. Multidisciplinary scholars such as Anthony Aveni have done much to demonstrate astronomical alignments at Mesoamerican and South American sites. The study of megalithic Britain by the survey-engineer Alexander Thom and his son Archibald has helped to reveal the capabilities of the megalith builders. More recent archaeoastronomy has been characterized by close scrutiny of the uncertainties in the observational data and a strong emphasis on the limitations of measurements in the field due to various effects, such as parallax shifts, or the bending and dimming effects of the Earth's atmosphere, or the intrinsic motions of the stars. Much greater attention also is being paid to the archaeological and cultural contexts of the cultures. Measurements of great accuracy, investigations of the precision and accuracy of those measurements, and attention to context are in large part what distinguishes archaeoastronomy from Lockyer's (1894/1973) early efforts. If we know, for example, that a certain group of people was interested in the " dark constellations" of the Milky Way, we should not limit our study of potential astronomical alignments of their geoglyphs or structures to the brightest objects in the sky or even to the brightest stars. As it continues to mature, archaeoastronomy can be regarded as an increasingly important component of ancient astronomy.

Whatever the emphasis, the end result of attention to detail of any of these approaches is a richer appreciation of the cultures that provide the data and of the advance of the arts and sciences that are needed to complete the study. In the present work, we try to consider evidence from all the approaches to ancient astronomy.

Aside from purely scholarly reasons for studying the subject, to seek an understanding of ancient astronomy is to encounter deep well-springs of religion, life-energizing forces of sex and eroticism, and, frequently, cosmic aspects of games and sports. In discovering the astronomy of the ancients, we also discover much about their cultures and their intellectual capabilities, accomplishments, and limitations, and in discovering these things, we discover much about ourselves.

1.2. Archaeological, Anthropological, and Historical Contexts

People behave in ways that reflect cultural patterns, including belief systems. These may include naive or sophisticated ideas of the real or imagined influences of astronomical events on human affairs. The regulation of daily and seasonal activities by the relative positions of earth and sun is an obvious reality, conditioning a great deal of human behavior. Likewise, the movements of the moon affect the tides, which are a major factor in the lives of coastal dwellers throughout the world, and the changing phases that produce dark nights or moonlit nights have affected most of humankind until very recently. In many cultures, people postulate a tremendous range of astrological effects and partially pattern their behavior to conform to or to modify the postulated influences. To the extent that this behavioral response to the astronomical environment involves structural patterns or objects that may be recognized or recovered archaeologically, we are dealing with *archaeoastronomy*. The structural patterns may take the form of alignments and layouts of tombs, monuments, buildings, or cities, in cosmological patterns that may also be incorporated in calendrical tables or in other artifacts.

Where belief in the importance of astronomical influences on human affairs was important, people made more precise observations, and it is now often possible to find and recognize observational instruments and structures. A less direct, but culturally more important, process is the patterning of many facets of life because of presumed associations or causal connections between astronomy and daily life. An example of such a patterning is the development of the astrologically based 7-day week. Human behavior may be governed by a belief that life on earth is a model of celestial happenings, or that individual or collective behavior is determined by celestial happenings. The cosmological pattern of a particular group was normally constructed in terms of human activities and beliefs so that the stars and planets, individually or in groups, may be identified as humans, animals, deities, souls of the dead, artifacts, or natural phenomena. The relative movements of the heavenly bodies were often thought of as interrelationships comparable to human activities, and humans frequently responded appropriately by prayers, offerings, ceremonial drunkenness, ritual abstinence, and so on. The alignment of burials is one practice that can be recognized archaeologically and may throw some light on cosmological beliefs and astronomical interests, although it is seldom of high astronomical precision. Temples are frequently regarded as partial models of the universe constructed to embody cosmological beliefs. Alignments to the rising of the sun at specified days of the year, or to the heliacal rising of some star are apt to be the most obvious astronomical features, but they may be much less important in the local cosmology. Where alignments are found, their purpose was often to cause some particular effect. In Mesoamerica, Motolinia (quoted by Long 1948) said that the sun was supposed to rise at the vernal equinox, at a certain festival, between the two temples of the great pyramid in Tenochtitlan and that Montezuma wanted to pull down the temples because the line was not quite straight. Wriggling serpents at the corners of the temple of Kukulcan at Chichen Itza are observed in a spectacular hierophany of light and shade at the equinoxes.

The widespread interest in astronomy among the peoples of the historic world has its roots in ancient times. There is some evidence for calendar keeping in the Palaeolithic, perhaps as far back as 50,000 years or more, and in the Megalithic, such evidence is strong. In the fifth millennium

B.C., we find evidence for archaeologically recognizable cultures in which astronomy played an important role.

In Alberta, on the western Canadian prairie, we find the earliest of the large rings and cairns of stone known as medicine wheels. Later constructs are found both east and south of Alberta. Interpretation of these "wheels" has been diverse: memorials to dead leaders, markers for trails, religious or ceremonial, or astronomical markers.

Wheels showing at least some structural similarity continued to be built into the last century, and some seem to be aligned on the equinoxes and solstices. One of the most notable of the recent structures is the Big Horn Medicine Wheel in Wyoming. Jack Eddy's (1974) study suggested that the spokes were aligned on particular prominent stars, the first rising of which before sunrise would provide calendar markers. At Moose Mountain in Saskatchewan, a similar wheel seems to show spoke alignments to the same stars, but at an earlier date, in accord with the precession of the equinoxes. If these two wheels, separated by nearly 2000 years represent a common tradition, it is surprising that other wheels resembling these two more closely are not (at present) known.

In Europe, a somewhat similar tradition is assigned to the megalithic cultures. Here, the consistency of some alignments created by placing large stones in lines or circles or making tomb chambers is considerable. Few scholars dispute alignments on the solstices and equinoxes, but competent scholars disagree on the extent to which lunar and stellar alignments are deliberately incorporated into these structures. The distribution of monuments of the megalithic culture seems to be suggestive of sea-farers, but this is far from certain. One of the earliest structures anywhere in the world that shows a solstitial alignment is the *Brugh-na-boinne* (Newgrange) in Ireland. This site is alleged in Irish mythology of a much later time to be the burial place of *Aongus mac nOg* (Aongus, the ever young), usually identified as a sun god. Many later cultures identify the winter solstice as the point of the annual death and rebirth of the Sun. A shaft of sunlight penetrates into the inner chamber of Brugh-na-boinne at winter solstice sunrise, in fitting tribute to such a belief. The best-known megalithic monument is undoubtedly Stonehenge, in southern England. Hawkins (1963, 1965a) has argued that a series of holes associated with the monument was used to predict eclipses, and certainly someone with a modern knowledge of eclipses could have used Stonehenge for such a purpose. Indeed, Schlosser, Schmidt-Kaler, and Milone (1991/1994) have included this exercise among their astronomical laboratory challenges. Of all the megalithic monuments, that which most suggests a working observatory is an array of stones in northern Scotland called *Hill a' Many Stanes*. Here, the stones are small enough to be easily moved and so could have been adjusted to achieve a precision alignment. The Thoms have argued that the site was used to study movements of the Moon. No serious attempts have been made to relate these megalithic monuments to later or modern myths or stories, although there seem to be some folk-beliefs and practices of possible relevance.

A third tradition that began about the same time is that of Mesopotamia. Here, urban civilization and writing appear for the first time. This gives us direct evidence of gods and myths. We know that the Mesopotamian gods of later periods were directly identified with the planets. Recorded myths let us see the interaction of gods in a heavenly framework, which strongly suggests the creation of constellations as a sort of geographic backdrop for the movements of the gods. Although Mesopotamian scholars have been reluctant to regard the earliest myths as astronomically patterned, recent work by Hostetter (1982), Adamson (1988), and Tuman (1984) generically support such a view. Adamson (1988) presents evidence that the goddess Inanna or *Ishtar* was associated with the planet Venus in the earliest texts. Hostetter (1982) presents a convincing argument that the entire structure of the early myth is astronomical. Tuman (1984) argues that deity and symbolic representations corresponding to planets and constellations arise substantially earlier than has usually been believed.

The Mesopotamian system of constellations, planetary gods, and accompanying myths spread to the Greeks probably before 1400 B.C. and later reached the Romans, with substantial modifications in both cultures. Eventually, a further modified system dominated the Mediterranean and then spread north and west throughout Europe (see Figure 1.1). A late Babylonian form, somewhat modified by Egyptian ideas and mythology, spread into India in the early centuries A.D., where it came into contact with a local Indian tradition. A mixed set of astronomical practices intimately tied to cosmology still bears this Egypto-Babylonian imprint, as does much of the Greco-Babylonian technical astronomy, in much of southeast Asia. The astronomical content of the Hindu, Jain, and Buddhist religions of India resulted in the carrying of that astronomy into China, Korea, and Japan with Buddhism.

A tradition that started only slightly later than the Mesopotamian but that was markedly distinct was that of Egypt. Here, constellations were envisaged that depicted animals that lived on the fertile lands adjacent to the Nile and in the desert beyond. Mesopotamian boats, architecture, textiles, ceramics, other trade goods, and ideas stimulated changes and further developments in the Nile valley. A local writing system appeared. Curiously, the later Greeks claimed to derive great knowledge of technical astronomy from the Egyptians, a conclusion that currently available evidence certainly does not support. There is, however, much evidence for the use of astronomy at less technical levels. The great stone pyramids, which were funeral monuments, were aligned to the cardinal points, even if this alignment did not require tremendously sophisticated astronomy. The great temples dedicated to the Sun god have both texts and alignments to show astronomical associations. Egyptian culture was carried south to Meroe, in current day Sudan, where a temple was built with an entrance aligned on the winter solstice sunrise. In calendrical studies, the Egyptians put a great deal of emphasis on the heliacal rising of the star Sirius (which they called *Sopdet*) that was for a long period of time associated with the annual flooding of the Nile, upon which Egyptian agriculture depended.

The Egyptians recognized a series of stars (*decans* is the Greek term) whose first rising before dawn marked periods

(a)

Figure 1.1. *The Northern and Southern Celestial Hemispheres* ((a) and (b), respectively) as rendered by the great Renaissance and Reformation artist Albrecht Dürer. Many representations of the sky by post-Renaissance Europe derive from Dürer's rendition of 1515, in which the star positions from Ptolemy's catalogue were set down by the Nürnberg mathematician Heinvogel. The positions were subsequently improved and more stars added, but the woodcut figures of Dürer essentially remained the same through the charts of Bayer (1603), Flamsteed (1729), and Argelander (1843). Note the lack of stars near the SCP. Black-and-white prints from the Rosenwald Collection, Photograph © 2001 Board of Trustees, National Gallery of Art, Washington [1954.12.233.(B-21421)/PR (Meder 260) and 1954.12.234.(B-21422)/PR]. Reproduced here with permission.

(b)

FIGURE 1.1. *Continued.*

of approximately ten days, so that there were 36 stars or asterisms in the series. As will be explained later, this leads directly to a concept of a 24-hour day, which had been developed in Egypt by about the XII dynasty (about 2000 B.C.). The series of decans was taken by Hellenistic astrologers and used in India, so that they became a regular feature of later astrology as practiced from Britain to the Malay peninsula, well into the Middle Ages. The 24-hour day also spread widely, and the Egyptian year of 365 days, without leap year adjustments, was called the "astronomers' year" by medieval Europeans, because of the relative ease with which periodicity calculations could be made with it.

Another major component in Eurasian astronomy and calendrics was the system of 28 asterisms known as the *lunar mansions*, because the Moon is among a different group of stars each night. Internal evidence suggests that the system may have originated about 2500 B.C. It is directly attested in India at about the 8th century B.C., and at about the same date in China, from which it traveled to Korea and Japan. It was supposed by the scholars of the *pan-Babylonismus* school to have originated in Mesopotamia, but there is no trace of such a system in Sumer, Babylon, or Assyria. The 28 asterisms were, however, known to the Arabs before the writing of the Koran, and a Greco-Coptic series is known from a manuscript of the 5th century A.D. It was spread through Jewish scholars into medieval Europe. The Arab version was spread wherever Islam penetrated, including mid-Africa. Finally, it will be argued that it is likely that elements of this system were incorporated in the ancient Mesoamerican calendar.

Now we begin with an exposition of the basic astronomy required to understand the perceptions and knowledge of the ancients. In Chapter 6, we again take up the cultural contexts of astronomy.

Part I
Astronomical Background

2 Principal Features of the Sky

2.1. Star Patterns: Asterisms and Constellations

2.1.1. Stellar Pattern Recognition

About 15,000 stars are detectable by the human eye, most of them near the limit of visibility. At any one time, we may be able to see a few thousand stars in a dark sky, but we tend to remember only striking patterns of them—asterisms such as the Big Dipper or whole constellations such as Ursa Major (the Big Bear) or Orion (the name of a mythological hunter)—and so it has been for millennia. Today, the entire sky has been divided into constellations; they are not defined according to appearance alone but according to location, and there are no boundary disputes. The modern names and locations are more or less those of Argelander (1799–1875) for the Northern Hemisphere and John Herschel (1824–1896) for the Southern, but the present divisions of the constellations[1] were adopted by the International Astronomical Union (IAU), the chief authority on such matters as astronomical nomenclature, in 1930. The IAU has established 88 constellations in the sky; many reflecting an ancient heritage.

The names of the constellations recognized in antiquity were based on

- Mythological figures
- Animals or inanimate objects as perceived in the sky
- Geographical or political analogues
- Associations with seasonal phenomena, or some other basis

As we will show in later chapters, non-Western traditions have perceived a rich variety of star patterns; some include the *absence* of stars, the "dark constellations."[2] Chinese constellations were different from and far more numerous than were those of the Mediterranean area. As far as we are aware, the oldest extant Chinese star chart on paper is contained in a 10th-century manuscript from Dunhuang, but there is far older evidence for sky charting from this area of the world (see §10 and §2.2.3); a compilation by Chhien Lu-Chih listed 284 constellations containing a total of 1464 stars and is said to be based on a Han catalogue (see §10.1.2.3; and Yi, Kistemaker, and Yang (1986) for new maps and a review of historical Chinese star catalogues).

Western constellations in current use largely derive from ancient Mediterranean sources, mainly the Near East and Greece, as we show in §7. The earliest surviving detailed description of the Greek constellations is in the poem *Phaenomena* by the Greek poet Aratos (*Aratus* in the Roman sources), ~250 B.C. (Whitfield 1995, p. 23). The constellations portrayed in the poem derive from a work also called *Phaenomena*, which has not survived, by the Greek astronomer Eudoxos (or Eudoxus) (4th century B.C.). One of the later sources that discusses this work is that of the sole remaining manuscript of Hipparchos (~150 B.C.), one of the greatest astronomers of antiquity. Many of the constellations can be seen as raised images on the Farnese Globe, the oldest extant celestial globe, dated to the 2nd century B.C., but representing a copy of an older work. Aratos mentioned 47 constellations, whereas Claudius Ptolemy (~150 A.D.), the source of much of our knowledge about Hipparchos, referred to 48 in the major astronomical work that we know today as the *Almagest*.

In ancient Greek usage, the constellations *were* the figures. For example, in the constellation of Cassiopeia, the star ζ Cassiopeiae (abbreviated ζ Cas) is described as "the star on the head"; α Cas, as "the star in the breast"; and

[1] Boundaries are along coordinates of right ascension and declination referred to the equinox of 1875.0. See sections below for explanations of these terms.

[2] See §14.2.5, for a Peruvian example.

η Cas as "the star over the throne, just over the thighs." In Perseus, the variable star Algol (β Per) is described as the "bright one" in the "Gorgon's head." Not all naked eye stars fitted neatly into these groupings, so many stars were omitted from the constellations. Those outside the accepted figures were referred to as "unformed" (αμόρφωτοι; our word "amorphous" derives from a related word), or "scattered" (σποράδες, related to the Greek word for seed, σπορά, broadcast during sowing, and our cognate word, "sporadic"). The IAU reorganization created constellation "homes" for these "unformed" stars.

2.1.2. Star Charts

The depictions of the Greco-Roman constellations as they were known in Ptolemy's time (~150 A.D.) were preserved in Arabic sources, one of the best known being that of the astronomer al-Sūfī (10th century). R.H. Allen (1963) states that the sky representations of post-Renaissance Europe derive from those of Albrecht Dürer (1471–1528) of 1515 (Figure 1.1), in which the star positions from Ptolemy's catalogue were set down by another resident of Nürnberg (Nuremberg), a mathematician named Heinvogel. The positions were subsequently improved and more stars added, but the figures of Dürer essentially remained the same through the charts of Bayer (1603), Flamsteed (1729), and Argelander (1843). More details about star charts from 1500 to 1800 can be found in Warner (1979), and an even wider range of charts is found in Stott (1991/1995) and Whitfield (1995).

The representations of the more obvious asterisms differed widely from culture to culture. A familiar example is the Big Dipper, still known in England as the plough, and in Germany and Scandinavia as the *Wagen* (wagon). In the Roman republic, it was the plow oxen. On many pre-19th-century maps and star charts, the term *Septentrion* or some variety of this term appears. The expression became synonymous with the North, or northern regions, but originally meant the seven plow oxen. R.H. Allen (1963) says that the Big Dipper was known as a coffin in parts of the Mideast, a wagon or bear in Greece, and a bull's thigh in pre-Hellenistic Egypt. Systematic attempts were made to rename the constellations at various times. Giordano Bruno (1548–1600) sought to invest the sky with figures representing Moral Virtues. Julius Schiller of Augsburg produced the most widely known type of Bible-inspired charts in 1627. R.H. Allen's (1963) encyclopedic search into the origins of star names and constellations reveals several other European attempts to recast the constellations, although the various sources used by him are not always treated critically.

2.1.3. Modern Nomenclature

Today, *constellations* refer to specified areas on the celestial sphere, whereas an *asterism* is any apparent grouping of stars. Indeed, one could be forgiven for describing the ancient "constellations" as asterisms. With some exceptions, in modern usage, an asterism is usually smaller than a constellation; for example, the Little Dipper asterism is in the constellation of Ursa Minor, the Little Bear, and the Pleiades is a well-known asterism in the constellation Taurus, the Bull. An exception is the Summer Triangle, composed of the bright stars Vega, Deneb, and Altair in the constellations Lyra, Cygnus, and Aquila, respectively. Even a single star may constitute an asterism. The star Spica, for example, the brightest star in the constellation of Virgo, has been envisaged as a spike of wheat.

Modern common names of naked eye stars, derive from European and Arabic usage, as well as proper names devised by Johann Bayer in 1603. The Bayer designations use lower-case Greek letters and, after these are exhausted, small Roman letters, to identify stars in a given constellation, for example, u Herculis or i Bootis. When these were exhausted, capital Roman letters were used. The lettered type of designation was later extended to the Southern Hemisphere by Nicolas Louis de Lacaille (1763) and John Herschel (1847). The Greek letters are universally accepted, but an alternative designation to the Bayer letters for the fainter stars is that of the Flamsteed numbers (Flamsteed 1725, Vol. 3), as, for example, 44 Bootis = i Bootis. Giuseppe Piazzi (1803) also published star catalogues in 1803 and 1814 (see Piazzi/Foderà Serio 1990). The Flamsteed numbers increase with right ascension, a coordinate that increases from west to east (see §2.2.3). Many catalogues of stars and other objects use positional or sequence numbers, usually increasing with right ascension. The best known star catalog of this kind is the Bright Star Catalog (Hoffleit 1982), which uses the positional sequence numbers of the Harvard Revised Photometry Catalog (Pickering 1908); thus, BS 7001 = HR 7001 = α Lyrae.

Usually, the Greek letter designates the relative brightness of the star within the constellation, but occasionally they were assigned to a positional sequence, as in Ursa Major. In the list of modern constellations, Table 2.1, the star names are in Latin, with the historically earliest names referring to Latin forms of Greek originals. The columns contain both nominative and possessive[3] cases of the names, English equivalents, notable stars and other objects, and both modern and ancient asterisms that are within the modern boundaries. Only objects that can be seen unaided under clear and dark sky circumstances are included.

"Double stars" are stars that appear close to each other in the sky; sometimes they are indeed physically close to each other and interact gravitationally, but not always. The pair of stars Mizar and Alcor (ζ Ursae Majoris and 80 Ursae Majoris, respectively), in the handle of the Big Dipper, is an example of a naked-eye double.

Types of "variable stars" are named after their prototypes, such as delta Cephei or RR Lyrae. In the Bayer designations, no visible star had been assigned a letter later in the alphabet than Q; consequently, Argelander suggested that designations of *R* and later would be used solely for variable stars. This scheme has been followed dogmatically to a logical conclusion ever since. When designations to Z became

[3] The possessive or genitive case is used in formal star names, e.g., α *Canis Majoris*, β *Scorpii*, β *Lyrae*, or *S Doradus*, literally, the stars labeled α of the constellation Canis Major, β of Scorpius, and so on.

TABLE 2.1. Modern constellations.

Name	Meaning	Possessive[a]	Asterisms/features
Andromeda	Mythological figure (chained lady)	Andromedae	Spiral galaxy M31.
Antlia	Air pump	Antliae	
Apus	Bird of paradise	Apodis (Aps)	
Aquarius	Water bearer	Aquarii (Aqr)	Planetary nebula NGC 7293.
Aquila	Eagle	Aquilae (Aql)	Vultur volans ($\alpha + \beta + \gamma$ Aql); Altair = α Aql part of the "summer triangle".
Ara	Altar	Arae	
Argo[b]	Jason's ship		
Aries	Ram	Arietis	
Auriga	Charioteer	Aurigae	Goat and kids; Capella = α Aur, goat star,
Boötes	Herdsman	Boötis	Arcturus = α Boo, bear keeper, Job's star.
Caelum	Sculptor's chisel	Caeli	
Camelopardalis	Giraffe	Camelopardalis	
Cancer	Crab	Cancri (Cnc)	M44 = the beehive, open star cluster.
Canes Venatici	Hunting dogs	Canum Venaticorum (CVn)	
Canis Major	Big dog	Canis Majoris	Sirius = α CMa, dog star, Isis; M41 open star cluster.
Canis Minor	Small dog	Canis Minoris	Procyon = α CMi.
Capricornus	Ibex/goat-fish	Capricorni	
Carina	Argo's keel	Carinae	Eta Car, unstable variable star & nebula; NGC 2516, IC 2602 star clusters.
Cassiopeia	Mythological figure (lady in the chair, mother of Andromeda)	Cassiopeiae	The "W." Tycho's supernova.
Centaurus	Centaur	Centauri	ω Cen globular cluster.
Cepheus	Mythological figure (king, husband of Cassiopeia)	Cephei	δ Cephei variable star.
Cetus	Whale	Ceti	Mira = o Ceti, variable star.
Chamaeleon	Chamaeleon	Chamaeleontis	
Circinus	Pair of compasses	Circini	
Columba	Dove	Columbae	
Coma Berenices	Berenices's hair	Comae Berenices	Melotte 111, cluster.
Corona Australis	Southern crown	Coronae Australis (CrA)	
Corona Borealis	Northern crown	Coronae Borealis (CrB)	
Corvus	Raven	Corvi (Crv)	
Crater	Cup	Crateris (Crt)	
Crux	Cross	Crucis	Coal Sack (dark nebula); Southern Cross.
Cygnus	Swan, Orpheus	Cygni	Northern Cross; "great rift" (dark nebulae); Deneb = α Cyg, part of "summer triangle."
Delphinus	Dolphin	Delphini	
Dorado	Doradus fish	Doradus	Large Magellanic Cloud; 30 Dor = Tarantula Nebula.
Draco	Dragon	Draconis	
Equuleus	Foal	Equulei	
Eridanus	Mythological river Po River	Eridani	
Fornax	Furnace	Fornacis	
Gemini	Twins	Geminorum	Castor = α Gem, Pollux = β Gem.
Grus	Crane	Gruis	
Hercules	Mythological figure (kneeler, son of Zeus)	Herculis	"keystone"; M13, globular cluster.
Horologium	Clock	Horologii	
Hydra	Water snake	Hydrae (Hya)	
Hydrus	Small water snake	Hydri (Hyi)	
Indus	North American Indian	Indi	
Lacerta	Lizard	Lacertae	
Leo	Lion	Leonis	Regulus = α Leo regal (kingly) star.
Leo Minor	Small lion	Leonis Minoris (LMi)	
Lepus	Hare	Leporis	
Libra	Balance scale	Librae	
Lupus	Wolf	Lupi	
Lynx	Lynx, tiger	Lyncis	
Lyra	Lyre, harp of Orpheus	Lyrae	Vega = α Lyr, part of "summer triangle."
Mensa	Table	Mensae	
Microscopium	Microscope	Microscopii	
Monoceros	Unicorn	Monocerotis	
Musca (Apis)	Fly (bee)	Muscae	

TABLE 2.1. *Continued.*

Name	Meaning	Possessive[a]	Asterisms/features
Norma	Level, rule	Normae	
Octans	Octant	Octantis	South Celestial Pole.
Ophiuchus	Snake bearer	Ophiuchi	Kepler's supernova.
Orion	Myth. figure (giant hunter)	Orionis	Great Nebula (M42); belt stars; Betelgeuse = α Ori, red, variable.
Pavo	Peacock	Pavonis	
Pegasus	Winged horse	Pegasi	The Great Square.
Perseus	Mythological figure	Persei	(rescuer of Andromeda) χ h Persei Double cluster; Algol = β Per, var. star = head of Medusa, Gorgona.
Phoenix	Myth. bird	Phoenicis (Phe)	
Pictor	Easel	Pictoris	
Pisces	Fishes	Piscium (Psc)	
Piscis Australis (or Austrinus)	Southern fish	Piscis (PsA) Australis (or Austrini)	Fomalhaut = α PsA.
Puppis	Argo's stern	Puppis	M47 open star cluster.
Pyxis	Argo's compass	Pyxidis	
Reticulum	Net	Reticuli	
Sagitta	Arrow	Sagittae (Sge)	
Sagittarius	Archer	Sagittarii	Teapot; M25 open star cluster; M8 nebula; M17 nebula & star cluster.
Scorpius (or Scorpio)	Scorpion	Scorpii	Antares = α Sco; M7, NGC 6231 open star clusters.
Sculptor	Sculptor's studio	Sculptoris (Scl)	
Scutum	Shield	Scuti (Sct)	Ω Nebula; star clouds.
Serpens	Serpent	Serpentis	
Sextans	Sextant	Sextantis	
Taurus	Bull	Tauri	Hyades, Pleiades star clusters; supernova remnant, Crab Nebula near ζ Tau.
Telescopium	Telescope	Telescopii	
Triangulum	Triangle	Trianguli	Spiral galaxy M33.
Triangulum Australe	Southern triangle	Trianguli Australis (TrA)	
Tucana	Toucan	Tucanae	Small Magellanic Cloud; 47 Tuc globular cluster.
Ursa Major	Big bear	Ursae Majoris (UMa)	Big Dipper; horse and rider = ζ + 80 UMa.
Ursa Minor	Small bear	Ursae Minoris (UMi)	Little Dipper; North Star = Pole Star = Polaris = α UMi.
Vela	Argo's sails	Velorum	IC 2391 open star cluster.
Virgo	Young girl	Virginis	Spica = α Vir.
Volans	Flying fish	Volantis	
Vulpecula	Fox	Vulpeculae	

[a] The standard abbreviations are the first three letters; where this is not the case, the abbreviation is given.
[b] Ancient but now defunct constellation, sometimes called Argo Navis, now divided into Carina, Puppis, Pyxis, and Vela.

exhausted, the sequence began again with RR, and proceeded through the sequences, RS, RT, . . . , RZ, SS, . . . , SZ, . . . ZZ, AA, . . . , AZ, . . . , . . . , QZ. At this point, the naming scheme switches to V335, V336, . . . , and so on. See §5.8 for a discussion of the various types of variable stars.

Some asterisms are "nebulae" (clouds) because of their diffuse appearance. A nebula may be a real dust or gas cloud (in space!), a star cluster, or a distant galaxy. Gas and dust clouds, usually illuminated by bright stars embedded in them, are also represented among the asterisms. Examples include the Orion Nebula (M42) and the η Carinae nebula. "Star clusters" are families of stars that were born near the same location in space, travel on parallel orbits around the Galaxy, and generally have similar chemical compositions. There are two types of star clusters: open (also called "galactic") and globular clusters. Open clusters, typically, are located in or near the Milky Way, are irregular in shape, and are composed of hundreds of stars. Examples are the *Pleiades* and the *Hyades* clusters in Taurus and the "Beehive" cluster (also called *Praesepe* or M44) in Cancer. Globular clusters are more widely distributed around the sky, appear spherical in shape, and are composed of hundreds of thousands of stars. Examples are M13 in Hercules, and 47 Tucanae. Finally, there are the galaxies beyond the Milky Way that can be perceived by the naked eye and thus could be considered asterisms, such as "M31" in Andromeda and the *Large* and *Small Magellanic Cloud*s. The "M" designations in some of our examples are entries in the Messier Catalogue, a collection of nonstellar objects compiled by Charles Messier (1730–1817), a noted comet discoverer of his time. The purpose of the compilation was to avoid false identifications of new comets with diffuse-looking objects in the sky, with which they could be confused in small telescopes.

Figures B.1 and B.2 in Appendix B place the modern constellations and asterisms on the sky in a coordinate framework, provided for general reference. Figure B.1 are bisected by the *celestial equator* into northern and southern halves. The chart is a Mercator projection[4] of a variant of the equatorial system, one way of viewing the celestial sphere independently of the observer. Figure B.2 provides views of the regions around the north and south celestial poles.

Star charts, regardless of the superimposed constellation and asterism associations, are most useful when they permit identification of precise positions in the sky. Stott (1991/1995, p. 9) informs us that the first (Western) star atlas with sets of (modern) stellar coordinates was that of Paolo Galluci (from 1588). In this case, the coordinates were with respect to the path of the Sun, the *ecliptic* (see §2.3.3 for a discussion of this system of coordinates). Chinese atlases and charts used measurements somewhat akin to hour angles measured from the beginnings of *xius* (lunar mansions), and polar distance angles much earlier than this (Needham/Ronan 1981 = Needham 1981a, p. 116). Even in the *Almagest*, Ptolemy gives a position of a star in a kind of ecliptic coordinate; referring to the beginning of the first point of a zodiacal sign, he also gives an ecliptic latitude. Moreover, Ptolemy describes a device (see §3.3) with which some coordinates can be measured, and the existence of some kind of spherical coordinates is implied by relatively accurate placements of stars on the external surface of a sphere, such as the Farnese globe (§2.1.1). Yet when Galileo noticed a faint object while studying the satellites of Jupiter, he was unable to track and follow the object because his telescope mounting lacked coordinates to record and rediscover it once Jupiter's relatively large motion had moved away from the field. The faint object was not knowingly discovered until after calculations by John Couch Adams (1819–1892) and Urbain Jean Joseph Leverrier (1811–1877) in the 19th century. The object was the planet Neptune. If Galileo had obtained access to some of the classic instruments of antiquity, he could have replaced a sighting tube with his telescope and been able to record positions relative to the nearby stars.

In the following sections, we will show how coordinate systems enable us to find objects on the celestial sphere, in catalogues, and in the sky.

[4] This is a projection of spherical coordinates onto a cylinder in such a way that lines of latitude and longitude remain perpendicular. It has the property that longitude lines farther from the equator enclose larger areas. The projection is credited to the Flemish cartographer, Gerhardus Mercator (1512–1594).

2.2. The Sphere of the Sky

2.2.1. Daily Sky Motions

Time exposure photography of the sky readily reveals the movement of the sky. Uniform exposures (say, one hour each) under a cloudless sky at each of the cardinal facings will confirm the impression of the unaided eye—that the stars wheel about a hub at constant angular rate. Figure 2.1 shows typical *diurnal* (daily) arcs traced out by stars during such exposures. Traced with a stylus on a graphics tablet, the arc lengths can be shown to be systematically larger with increased angular distance from the center of motion—the *celestial pole*. The longest arcs are 90° from the celestial pole—on what is called the *celestial equator*, which divides the sky into northern and southern halves.

The apparent direction of turning is *counterclockwise*—as we view the North Celestial Pole. It is *clockwise* for Southern hemisphere observers viewing the South Celestial pole. The motions are consistent. As one faces North, the stars rise in arcs from one's right hand and set at one's left hand. Facing South, they rise at the left hand and set at the right hand. The observations imply that either the sky is rotating from East to West above the earth or that the earth is rotating from West to East below the sky.

In antiquity, which condition was true was the subject of much discussion and, in the end, could not be determined definitively. In the absence of a knowledge of the correct physics, misinterpretations of common experience gave many writers the idea that a rotating earth would force unanchored objects to be thrown off (see Chapter 7, especially §7.2).

Although the sense of the turning sky is the same all over the earth, the diurnal arcs have a different character for observers at the equator compared to those nearer the poles. For an observer on the equator, the North and South Celestial poles are on opposite sides of the sky; all stars rise at right angles to the horizon and move across the sky in semicircles, spending half the time above, and half the time below, the horizon. For observers elsewhere, stars that have diurnal circles between the pole and the horizon do not rise or set. They are called *circumpolar* stars. Stars equally distant from the opposite pole never appear above the horizon. In modern parlance, these two regions are called the north and south *circumpolar zones*, respectively. The diurnal arcs of stars that rise and set make acute angles (<90°) with the horizon, and this angle becomes smaller with the observer's proximity to the pole. At the North and South Poles, this angle becomes 0°, as the stars move in circles that are concentric with the horizon and are circumpolar. At the equator, it is 90° for all stars, and none are circumpolar.

The notion that the heavens constitute a great sphere surrounding the observer is an ancient one. It seems likely to have been present among the early Pythagoreans. It is associated with the Ionian Greeks, especially Eudoxos of Cnidus who lived in the 4th century B.C. It was known in China by the 2nd century B.C. The heavens were sometimes depicted as an external sphere, such as that shown in the Etruscan depiction of Atlas holding up the sky sphere. Not every culture, however, depicted the sky as a hemispherical bowl;

FIGURE 2.1. Diurnal arcs traced out by stars during a time exposure near the North Celestial Pole. Trails further from the pole appear straighter because the radii of curvature of their diurnal circles is larger. Photo courtesy of T.A. Clark.

in ancient Egypt, the sky was pictured as the body of the goddess *Nut*, for example. The shape of the sky as we perceive it depends on several factors: physiological, psychological, and cultural. We can even measure the perceived shape (see Schlosser et al. 1991/1994, pp. 1–3). For the purposes of locating objects on the sky, however, we use, even today, the concept of the celestial sphere.

2.2.2. The Horizon or "Arabic" System

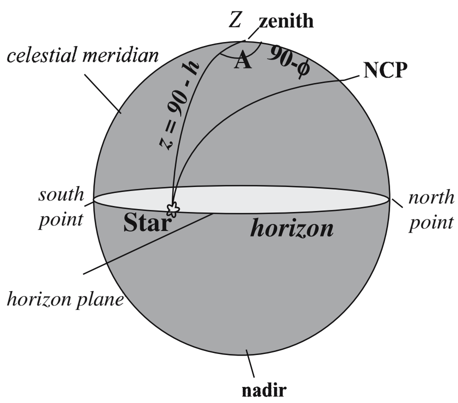
The image of an Earth surrounded by pure and perfect crystalline spheres[5] was emphasized by Aristotle, among others. Astronomers have made continual use of this image for more than two millennia; we refer to a *celestial sphere*, on which all objects in the sky appear, at any given instant, to be fixed. It does not matter in the slightest that such a sphere is borne of perception only, or that it exists only in our imagination. Everything that undergoes diurnal motion is assumed to lie on this sphere; the consequence is that they are assumed to be at the same distance from the observer. This is not strictly true, of course, but for locating very distant objects on the celestial sphere, it is a reasonable approximation. To the naked eye, the Moon is the only one of all the permanent bodies in the sky that seems to shift position among the stars as an observer shifts from one place on Earth to another.[6] For nearer objects, such as the Sun, Moon, and planets, relative motions on the sky can be studied and the predicted positions tabulated for each day, as, for example, in Babylon and Ur (see §7.1). This means that only two coordinates suffice to describe the position of an object on the surface of such a sphere.

On the celestial sphere, we will place the markings of the *horizon* system. We also refer to this system as the *Arab* system, because it was in wide use in the Arab world during the European Dark Ages. Not all the terms currently used in the English description of it stem directly from the Arabic language. Its salient features are indicated and labeled in Figure 2.2, which also includes relevant elements of the equatorial system which is described in §2.2.3.

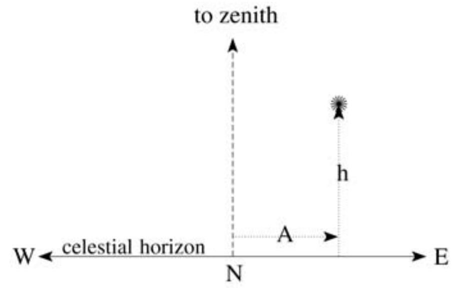
The highest point, directly overhead, is the *zenith*, a name that reaches us through Spain (*zenit*) and the Arab world of the Middle Ages (*samt ar-ra's*, road (over) the head). Directly below, unseen, is the *nadir* (Arabic *nazir as-samt*, opposite the zenith). The zenith and the nadir mark the *poles* of the horizon system. The *horizon*, which comes from a Greek word meaning to separate, basically divides the earth from the sky. We adopt the modern definition here: The *astronomical horizon* is the intersection with the celestial sphere of a plane through the observer and perpendicular

[5] Indeed, ancient Greek astronomers held that the motions of "wandering stars" or planets could be explained with the turnings of many such transparent spheres. See §7.2.3.

[6] From the place where the Moon appears overhead to the place where it appears on the horizon, the Moon appears to shift by about 1° with respect to the stars. The shift is called the *horizontal parallax*. Parallax shifts are very important in astronomy and are a primary means of determining astronomical distances.



(a)



(b)

FIGURE 2.2. The horizon system: The main features of the horizon system of spherical astronomical coordinates. (a) The outside-the-sphere view. The azimuth coordinate, A, is represented as a polar angle measured at the zenith; A is measured eastward or clockwise (looking down from outside the sphere) from the *north point* of the horizon. An observer facing any direction on the horizon sees the azimuth increasing to the right. The north point is defined as the intersection of the vertical circle through the north celestial pole, *NCP*, and the horizon. The zenith distance, z, is shown as an arc length measured down from the zenith along a vertical circle through the star; z may be measured also as an angle at the center of the sphere. An alternative coordinate is the altitude, h, measured up from the horizon along the vertical circle. (b) The observer's view. The azimuth also can be measured as an arc along the horizon; it is equivalent to the angle measured at the center of the sphere between the North point of the horizon and the intersection of the horizon and a vertical circle through the star. Drawings by E.F. Milone.

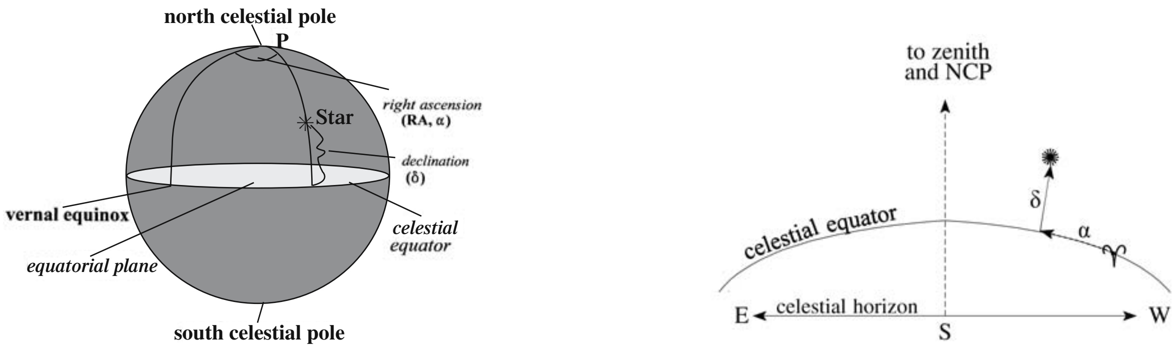
to the line between the observer and the zenith. A family of circles (*vertical circles*) may be drawn through the zenith and the nadir. The centers of these circles must be the sphere's center, where the observer is located (for the time being, we ignore the distinction between the center of the Earth and the observer, i.e., the difference between what modern astronomers call the geocentric and the topocentric systems, respectively). Degrees of *altitude* are measured up from the horizon toward the zenith along a vertical circle to the object. This gives us one of the two coordinates needed to establish a position on the celestial sphere. The other coordinate is called the *azimuth*, a term derived from the Arabic *as-sumut*, "the ways." It is related to the *bearing* of celestial navigation (such as 22.°5 east of North for NNE). Throughout this book, we will use the convention of measuring degrees of azimuth from the North point of the horizon eastward around the horizon to the vertical circle that passes through the star whose position is to be measured.[7] From the use of azimuth and altitude, the horizon system is sometimes called the *altazimuth* system. We will use A for azimuth and h for altitude in formulae, and occasionally, we will refer to the system in terms of this pair of coordinates: (A, h).

The North Point of the horizon is defined as the point of intersection of the horizon with the vertical circle through the North Celestial Pole (*NCP*), the point about which the stars in the sky appear to turn. The opposite point on the celestial sphere defines the South Point. For southern hemisphere observers, the South Point of the horizon is defined analogously with respect to the *SCP*. The visible portion of the vertical circle through the NCP (or SCP) has a special name: It is the *celestial meridian* or simply the observer's meridian. It has the property of dividing the sky into east and west halves. Objects reach their highest altitude (*culminate*) as they cross the celestial meridian in the normal course of their daily motions. Circumpolar objects may culminate below as well as above the pole. At *lower culminations*, the altitudes are lowest, and at *upper culminations*, they are highest. If neither *upper* or *lower* is indicated, the upper is intended in most usages. Another important vertical circle is perpendicular to the celestial meridian. It intersects the horizon at the east and west points. Therefore, a star that is located at the midpoint of a vertical circle arc between the east point of the horizon and the zenith has an azimuth of 90° and an altitude of 45°. Note that no altitude can exceed 90° or be less than –90°, and that the azimuth may take any value between 0° and 360°.

The azimuth coordinate may be considered in any of three ways:

(1) The angle subtended at the center of the celestial sphere between the North point of the horizon and the intersection of the vertical circle through the object and the horizon
(2) The arc length along the horizon subtended by the angle at the center (the observer)

[7] An alternative convention is to measure the azimuth from the South point of the horizon *westward*.



(a) (b)

Figure 2.3. The equatorial or "Chinese" System of spherical astronomical coordinates: (a) The outside-the-sphere view. Note that the *right ascension* (α or *RA*) is measured eastward (counterclockwise as viewed from above the north celestial pole) from the vernal equinox. The declination, δ, is measured from the celestial equator along the *hour circle* through the star. (b) The observer's view. A south-facing observer sees the right ascension increasing along the celestial equator to the left from the Vernal equinox. This is the (RA, δ) version of the equatorial system. Drawings by E.F. Milone.

(3) The polar angle at the zenith, between the vertical circles through the North point and that through the object

The altitude coordinate may be considered in either of two ways:

(1) The angle at the center of the sphere between the intersection of the vertical circle through the object and the horizon
(2) The arc length along the vertical subtended by the angle

This second way of considering the altitude, together with the third way of considering the azimuth, permit transformations to be performed between this system and an equatorial system, which we describe below.

The horizon system depends on the observer's location, in the sense that observers at different sites will measure different azimuth and altitude coordinates for the same sky object. One can, however, envisage the sky independent of the observer, so that the stars are fixed in a framework and can be assigned coordinates that may be tabulated for future use. The equatorial and ecliptic systems are examples of such systems.

2.2.3. The Equatorial or "Chinese" System

In ancient China, another system was in use that is similar to the modern equatorial system. The modern equatorial system enables a transient object to be located precisely among the stars at a particular time. The reference great circle in this system (illustrated and labeled in Figure 2.3) is the *celestial equator*, the sky analog of the Earth's equator. It is midway between the poles of the equatorial system, the north and south celestial poles, the sky analogs of the North and South Poles of Earth. This is the system that is traced out by the stars' diurnal circles, which are concentric with the celestial equator. The angular distance away from the celestial equator and toward the poles is called *declination* (from the Latin *declinatio* or "bending away") and originally referred to the distance from the celestial equator of a point on the ecliptic, the Sun's apparent annual path in the sky. The declination is marked in degrees. The small circles through the object and concentric with the celestial equator are called *declination circles* because each point on such a circle has the same declination. These small circles for all practical purposes trace out the diurnal motions; only the infinitesimally small intrinsic motions of objects on the plane of the sky during their diurnal motions makes this an inexact statement. The centers of all the declination circles lie along the polar axis, and the radius of each declination circle can be shown to be $R \cos \delta$, where R is the radius of the celestial equator (and the celestial sphere), taken as unity, and δ is the declination in degrees of arc. The declination is one of the two coordinates of the equatoral system. It is the analog of terrestrial latitude, which similarly increases from 0° at the equator to ±90° at the poles. Declinations are negative for stars south of the celestial equator. The analog relationship is such that a star with a declination equal to the observer's latitude will pass through the zenith sometime during a 24-hour day.

Great circles that go through the poles in the equatorial system are called *hour circles*. They intercept the celestial equator at right angles and are carried westward by the diurnal motions. The celestial equator rises at the east point of the horizon (and sets at the west point), so that successive hour circles intersecting the celestial equator rise later and later from the east point. A coordinate value may be assigned to each hour circle—indeed, if, as is usually the case, the term is interpreted loosely, there are an infinite number of such "hour" circles, rather than merely 24, each with a slightly different time unit attached. An hour circle can be numbered, as the name suggests, in hours, minutes, and seconds of time in such a way that the number increases, moment by moment, at a given point in the sky, other than exactly at a pole. At any one instant, an hour circle at the celestial meridian will have an associated number 6 hours different than that at the east point, or at the west point. The second coordinate of the equatorial system makes use of the hour circles. There are two varieties of this second coordinate. One variety is called the *right ascension*, and the other is the *hour angle.*

In modern terms and usage, the right ascension is measured from a point called the *vernal equinox*[8] eastward along the celestial equator to the hour circle through the object. The Sun is at the vernal equinox on the first day of spring (in the Northern Hemisphere); from here, the Sun moves eastward (so that its right ascension increases), and for the next three months, it moves northward (so that its declination increases). The term *right ascension* derives from the Latin *ascensio* and from the Greek αναφορα (*anaphora*), a rising or ascension from the horizon. It originally described the time required for a certain arc on the ecliptic (like a zodiacal sign) to rise above the horizon. The time was reckoned by the rising of the corresponding arc of the celestial equator. At most latitudes, in classic phrasing, the risings or *ascensions* of stars were said to be "oblique" because an angle with the horizon made by a rising star's diurnal arc is not perpendicular to the horizon; but, at the equator, where all objects rise along paths perpendicular to the horizon, the celestial sphere becomes a "right sphere" (*sphaera recta*) and the ascension a "right" one.

The right ascension increases to the east (counterclockwise around the celestial equator when viewed from above the north celestial pole), starting from the vernal equinox. Objects at greater right ascensions rise later. The analog of the right ascension in the terrestrial system is the longitude, which may also be expressed in units of time, but may also be given in angular units. The analogy here is imperfect because terrestrial longitude is measured E or W from the Greenwich meridian, but right ascension is measured only eastward from the vernal equinox.

As for the azimuth coordinate in the horizon system, the right ascension can be considered in any of three ways:

(1) As the angle measured at the center of the sphere between the points of intersection with the celestial equator of the hour circle through the vernal equinox and the hour circle through the star
(2) As the arc along the celestial equator between the hour circles through the vernal equinox and that through the star
(3) As the polar angle at the celestial pole between the hour circles

Similarly, as for the altitude coordinate in the horizon system, the declination can be considered in either of two ways:

(1) As the angle measured at the center of the sphere between the celestial equator and the star
(2) As the arc length, along the hour circle through the star, between the celestial equator and the star. This second way of considering the declination and the third way of considering right ascensions permit transformations among the equatorial and other coordinate systems to be made.

The declination is always given in angular measure (degrees, minutes of arc, and seconds of arc). The symbols for right ascension and declination are α and δ, but the abbreviations *RA* and *Dec* are often used.

The celestial equator has a special significance because objects on it are above the horizon for as long a time as they are below the horizon. The word *equator* derives from *aequare*, which means equate. When the Sun is on the celestial equator, therefore, day and night are of nearly equal length.

The equatorial system just outlined is completely independent of the observer—it is not directly tied to the horizon system, but there is another equatorial system that has such a connection. Figure 2.4 shows this observer-related equatorial system. In the ancient world, at least some separations of objects on the sky were measured by differences in their rise times. The modern system that derives from this is identical to the first equatorial system except for the longitudinal coordinate and the reference point. Instead of right ascension, it uses the *hour angle*, an angular distance measured along the celestial equator *westward from the celestial meridian*. The hour angle can be symbolized by H, or HA (we reserve h for the altitude) and usually is also expressed in units of time. It indicates the number of hours, minutes, and seconds since an object was on the celestial meridian. It therefore varies from 0 to 24 hours, but for convenience, it is often taken positive if west of the meridian and negative if east. The connection between the right ascension and the hour angle is the sidereal time (see §4).

Analogously with the azimuth, and the right ascension, the hour angle can be considered in any of three ways. The use of the polar angle between the celestial meridian and the hour circle through the star permits transformations between the horizon and the (H, δ) equatorial system (recall that we sometimes refer to a coordinate system by its coordinates expressed in this way). The transformation equations and procedures are described and illustrated in the next section.

The hour angle is also an analog of terrestrial longitude, in that it is measured along the celestial equator, but, again, the analogy is limited—in this case, because the hour angle is measured only from a local celestial meridian, whereas

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[8] The terms *vernal equinox* and *autumnal equinox* derive from the times of year (in the Northern Hemisphere) when the Sun crosses the celestial equator. "Equinox" is from the Latin *aequinoctium*, or "equal night." The actual point in the sky was called *punctum aequinoctialis*. In modern usage, "equinox" applies to both the time and the point. References to the times of year are more appropriately given as "March" and "September" equinoxes, and "June" and "December" solstices, at least at the current epoch and in the present calendar. In the distant past, this usage could be confusing because historically civil calendars have not been well synchronized with the seasons, and given sufficient time, the month in which the equinox or solstice occurs will change (see §4). We will use the terms as defined for the Northern Hemisphere in their positional meanings generally and in their seasonal meanings only to avoid ambiguity in the distant past.

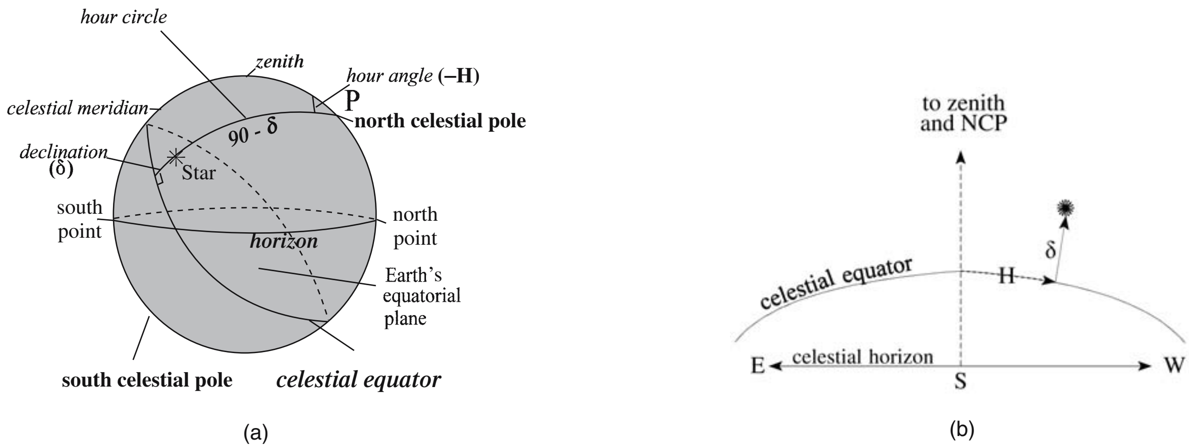

FIGURE 2.4. A variant equatorial system, in which the observer's *hour angle*, H, is used instead of the *right ascension*: (a) The outside-the-sphere view. Note that H is measured westward from the celestial meridian. The declination is defined as in the (RA, δ) system. Note that the altitude of the north celestial pole is equal to the latitude, and the limiting (minimum) declination for circumpolar objects is 90 – ϕ. (b) The observer's view. A south-facing observer sees the hour angle increasing to the right. This is the (HA, δ) system. Drawings by E.F. Milone.

terrestrial longitude is measured from the Prime Meridian, at Greenwich, England.

Note that the connection between the horizon and (H, δ) systems is the celestial meridian, where $H = 0$. Figure 2.4a illustrates how the hour angle and the declination are defined, and how the "declination limit" of circumpolar stars for a given latitude, ϕ, can be determined.

Chinese star maps were commonly laid out in the (α, δ) manner of an equatorial system. Such a chart can be seen, for example, in Needham 1959, Fig. 104, p. 277). In this chart, a horizontal line though the chart represented the celestial equator. A hand-drawn curve arcing above the celestial equator represents the ecliptic or path of the Sun between the vernal equinox and the autumnal equinox. Everything on this chart represents a two-dimensional mapping of the interior of a celestial sphere onto a two-dimensional surface. Such charts have been found from as early as the 4th century A.D. in China. The data in them are older still; polar distances (90° – δ) found in Chinese catalogues have been used to date the catalogues themselves. The coordinates are a kind of hour angle, measured with respect to the edge of a *xiu* or lunar mansion, and a polar angle, a kind of anti-declination (Needham/Ronan 1981, p. 116). It is possible to date such catalogues and charts because the right ascensions and declinations of a star change with time, a phenomenon arising mainly from the *precession of the equinoxes* (see §3.1.6). According to Needham (1981a, p. 115*ff*), the chart has a probable date of ~70 B.C.

The equatorial system became widespread in Europe only after the Renaissance. Figure B.2 shows the polar views of the equatorial system, looking outward toward the north and south celestial poles. The sky centered on the north celestial pole is also depicted in one of the most famous of all historical star charts: the *Suchow* star chart of 1193 A.D. (Figure 10.7). The circle about halfway from the center is the celestial equator, which the inscription that accompanies the chart calls the "Red Road." It "encircles the heart of Heaven. . . ."

2.2.4. Transformations Between Horizon and Equatorial Systems

All students of archaeoastronomy should know how to transform coordinates between systems. It is easy to get equatorial system (H, δ) coordinates from horizon system (A, h) coordinates, given the observer's latitude and some knowledge of spherical trigonometry. Using the "sine law" and the "cosine law" of spherical trigonometry, that are described and illustrated in Schlosser et al. (1991/1994, Appendix A) and basic trigonometric definitions and identities also given there, we depict the appropriate spherical triangle, the "astronomical triangle," in Figure 2.5.

The resulting transformation equations are

$$\sin\delta = \sin\phi\cdot\sin h + \cos\phi\cdot\cos h\cdot\cos A \tag{2.1}$$

from application of the cosine law, and

$$\sin H = \frac{-\cos h\cdot\sin A}{\cos\delta} \tag{2.2}$$

from application of the sine law.

Suppose at a latitude, $\phi = 30°$, the altitude of a certain star, $h = 20°$, and the azimuth, $A = 150°$. From (2.1),

$$\begin{aligned}\sin\delta &= \sin(30°)\cdot\sin(20°) + \cos(30°)\cdot\cos(20°)\cdot\cos(150°)\\ &= 0.50000\cdot 0.34202 + 0.86603\cdot 0.93969\cdot(-0.86603)\\ &= -0.53376\end{aligned}$$

so that $\delta = -32\overset{\circ}{.}260$.

Substituting this value into (2.2), we find that

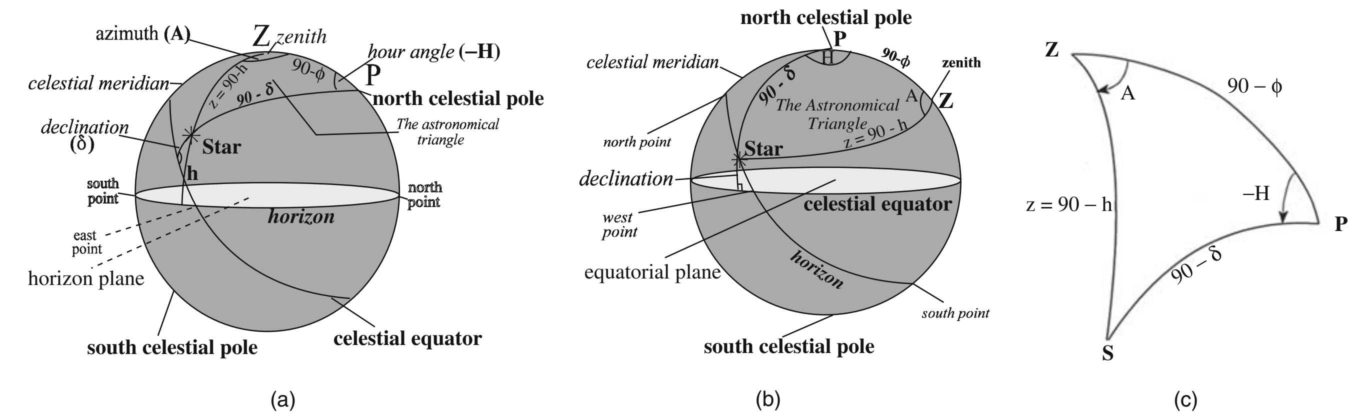

FIGURE 2.5. (a) The horizon system and the hour-angle variant of the equatorial system superposed. The definition of the astronomical triangle for a risen star is illustrated. (b) The equatorial and horizon systems, but now seen from the western side of the celestial sphere and for a slightly different point of view, for a star at the western horizon. (c) The astronomical triangle extracted from its context on the celestial sphere. Drawings by E.F. Milone.

$$\sin(H) = \frac{-\cos(20°)\cdot\sin(150°)}{\cos\left(-32\overset{\circ}{.}260\right)}$$

$$= \frac{-0.93969\cdot 0.50000}{0.84563} = -0.55562$$

so that $H = -33\overset{\circ}{.}753$ or $-33.753/15°/\text{h} \simeq -02^{\text{h}}\ 15^{\text{m}} = 02^{\text{h}}\ 15^{\text{m}}$ east.

These values make sense because of the location of the star, low in the southern part of the sky. Because the sine function is double valued, i.e., two angles have the same function value: $\sin\Theta = \sin(180 - \Theta)$, there is another mathematical solution for H, however. In the above example, therefore, a possible solution is $H = 180° - (-33\overset{\circ}{.}753) = 213\overset{\circ}{.}753$, but this second solution does not make sense physically. The angle is equivalent to $14^{\text{h}}\ 15^{\text{m}}$ west or (noting that $213\overset{\circ}{.}753 - 360° = -146\overset{\circ}{.}247$), $-9^{\text{h}}\ 45^{\text{m}}$, nearly ten hours *east* of the meridian. It is not possible for a visible star so near the southern horizon to be so far from the celestial meridian at this latitude. So the alternative solution can be ruled out "by inspection" in this case. As a rule, however, the other quadrant solution cannot be dismissed without further calculation. To resolve the question of quadrant, $\cos H$ may be computed from (2.5); the actual value need not even be calculated (although a numerical check is always a good idea) because the sign of $\cos H$ alone can resolve the ambiguity.

The cosine function is double valued because, $\cos\Theta = \cos(360 - \Theta) = \cos(-\Theta)$, where Θ is a given angle, but examination of $\sin\Theta$ resolves the ambiguity. The sine function is non-negative in both the first (0° to 90°) and the second (90° to 180°) quadrants, whereas the cosine function is non-negative in quadrants one and four (270° – 360°). In quadrant three (180° – 270°), both are negative. Therefore, the quadrant can be determined by the signs of both functions (see Table 2.2).

From the same spherical triangle and trigonometric rules, it is possible to express the transformation from the equatorial to the horizon system:

TABLE 2.2. Sine and cosine quadrants.

Quadrant	Sign (sin)	Sign (cos)
1	+	+
2	+	−
3	−	−
4	−	+

$$\sin h = \sin\phi\cdot\sin\delta + \cos\phi\cdot\cos\delta\cdot\cos H, \tag{2.3}$$

$$\sin A = \frac{-\cos\delta\cdot\sin H}{\cos h}. \tag{2.4}$$

Solving (2.3) for cos H, we can test our solution:

$$\cos H = \frac{\sin h - \sin\phi\cdot\sin\delta}{\cos\phi\cdot\cos\delta} \tag{2.5}$$

$$= \frac{0.34202 - 0.50000\cdot(-0.53376)}{0.86603\cdot 0.84563}$$

$$= \frac{0.60890}{0.73234} = 0.83144.$$

Note that $\sin H < 0$ and $\cos H > 0$, a condition that holds only in the 4th quadrant (between 270° and 360°, which is equivalent to being between −90° and 0°). Therefore, $H = -33\overset{\circ}{.}753 = -02^{\text{h}}\ 15^{\text{m}}$ is the correct answer.

The quadrant ambiguity also arises in computing the azimuth A from (2.4). The quantity cos A may be computed from (2.1), and the signs of sin A and of cos A from Table 2.2 will decide the quadrant. The numerical values of A computed from (2.1) and (2.4) should agree, and computing them both provides a check on the calculation. A difference between the two values indicates either a miscalculation or lack of precision (insufficient number of digits) used in the calculations. The basic point, however, is that the signs of the sine and cosine functions are sufficient to resolve the quadrant question of both H and A. The same remarks hold for any longitudinal-type coordinate that can range from 0° to 360°.

Consider the reverse of our earlier example. Now we are given the latitude, $\phi = 30°$, the declination, $\delta = -32.263°$, and the hour angle, $H = -33.753°$. Then, from (2.3), we find the altitude, h:

$$\begin{aligned}\sin h &= \sin(30)\cdot\sin(-32.260°) + \cos(30°)\\ &\quad\cdot\cos(-32.260)\cdot\cos(-33.753°)\\ &= 0.50000\cdot(-0.53376) + 0.86603\cdot 0.84563\cdot 0.83114\\ &= 0.34202,\end{aligned}$$

from which we get $h = 20.000°$.

Solving (2.4), we can also recover the azimuth:

$$\begin{aligned}\sin A &= \frac{-\cos(-32.260°)\cdot\sin(-33.753°)}{\cos(20.000)}\\ &= \frac{-0.84563\cdot(-0.55561)}{0.93969} = 0.50000,\end{aligned}$$

from which we get either $A = 30.000°$ or $(180° - 30.000°) = 150.000°$.

In the present case, we know that the star is near the southern horizon, because the star is south of the equator and more than 2 hours east of the celestial meridian. Therefore, the second answer is correct, $A = 150°$. Many cases are less easy to decide by inspection. Equation (2.1) can be solved for cos A, and the correct quadrant then be determined. This is left to the student as a recommended exercise to gain experience in spherical astronomy! In the chapters to come (especially Chapter 6), we will make frequent use of the transformation relations to explore the possibilities of deliberate astronomical alignments of monuments.

2.3. Basic Motions of the Sun and Moon

2.3.1. The Sun, the Year, and the Seasons

Now we must separate the diurnal motion shared by all objects in the sky from the additional motions of seven distinctive objects known in antiquity: the Sun, Moon, and naked-eye planets. We take for granted that the diurnal motion of everything in the sky is due to the rotation of the earth on which we stand. In the ancient world, this was a radical view, and few astronomers held it. Diurnal motion is perceived moment by moment, whereas the effects of the relative movement of the Sun, Moon and planets with respect to the stars are far more gradual. This made diurnal motion of the fixed stars far more intuitive than any other motion. Nevertheless, an unmoving Earth was not the only option, and ancient astronomers knew it.

Figure 2.6 provides the alternative frameworks for understanding the motions: the Earth-centered and Sun-centered systems. The geocentric perspective has been historically dominant in human cultures, and yet the heliocentric viewpoint leads to a far more economical model to account for the relative motion of the Sun, Moon, and planets in the sky. Prior to the Copernican revolution, and indeed throughout most of known history, the geocentric universe was the accepted cosmic model notwithstanding that the Greek scholar Aristarchus (~320 B.C.) argued for a heliocentric universe and the medieval Islamic scholar al-Beruni (~11th century) said that all known phenomena could be explained either way. Both the constellation backdrop and the direction of the Sun's apparent motion are predictably the same in the two world systems, as Figure 2.6 reveals. In both models, the Sun's annual motion (as viewed from the north celestial pole region) is counterclockwise. We have known

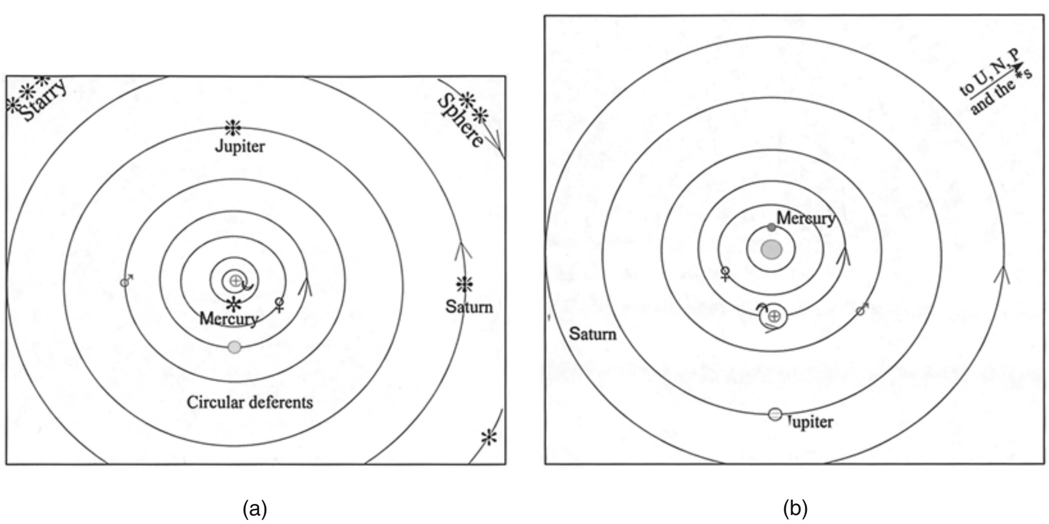

FIGURE 2.6. The classic cosmological frameworks: (a) Earth-centered and (b) Sun-centered views of the solar system. Drawings by E.F. Milone.

since Newton's time that a less massive object like the Earth is accelerated by the Sun more quickly than a more massive body like the Sun is accelerated by the Earth.[9] Neither the true physical natures of the planets nor the physical principles that ruled their motions were known in the ancient world.[10] The ancient models were designed specifically to predict these apparent motions and were basic to ancient Greek astronomy. The successes and failures of ancient models can be gauged precisely and accurately only if their predictions can be compared with those of modern methods. We start with the most familiar case, the Sun, which undergoes reflexive motions in the sky as the Earth moves.

From the geocentric perspective, that the earth's rotation axis is tilted by 23.°5 with respect to its axis of revolution about the Sun, and that the direction of the rotation axis is fixed[11] while the Earth revolves about the Sun is equivalent to saying that the Sun's path is inclined to the celestial equator by the same 23.°5 angle, so that the Sun's declination varies by about 47° during the year. Except possibly in deep caves and on ocean floors, the effects of the Sun's annual movement are dramatic for life everywhere on Earth. In fact, the large annual variation in declination has profoundly affected development and evolution of life on Earth (especially, if, as is sometimes speculated, the angle of tilt has changed greatly over the age of the Earth).

The obvious diurnal westward movement of the Sun is shared by the Moon, planets, and stars. However, the diurnal westward motions of the Sun, Moon, and planets are different from those of the stars and from each other. The Sun and Moon always move eastward relative to the stars, so that the angular rates of their westward diurnal motions are always less than that of the stars. The planets' apparent motions are more complex, sometimes halting their eastward motions and briefly moving westward before resuming eastward motion. Thus, their diurnal motions are usually slower but sometimes slightly faster than are those of the stars.

To describe the Sun's behavior, we can say that the diurnal motion of the Sun is accomplished in a day and is very nearly parallel to the celestial equator; relative to the stars, the Sun has a slow average motion, $\sim 360°/365\frac{1}{4}\,\mathrm{d} \approx 1°/\mathrm{d}$ eastward, and it requires a year to complete a circuit. Moreover, except for two instants during the year, the Sun's annual motion is *not* strictly parallel to the celestial equator. We can elaborate this motion and then find an explanation for it, or, as the Greeks would put it, "save the phenomenon."

The Sun's eastward motion is easily tracked on the celestial sphere. Figure B1 illustrates the annual path of the Sun (the *ecliptic*) as it appears on an equatorial star chart. The sinusoid shape is the consequence of mapping the path onto a Mercator projection of the equatorial system. The process can be visualized by imagining the celestial sphere cut in two along an hour circle and opened outward. In this projection, in which all hour circles become parallel vertical lines, great circles that intersect the celestial equator at an acute angle appear as sinusoids. The Sun's most northern declination (+23.°5 at present) occurs at the positive maximum of this curve, the June *solstice* (the northern hemisphere's *summer solstice*), at $\alpha = 6^h$, and its most southern declination (–23.°5 at present) at the December *solstice* (the Northern hemisphere's *winter*, and the Southern hemisphere's *summer solstice*), at $\alpha = 18^h$. Like the term *equinox*, *solstice* also has two meanings. It is a positional point on the ecliptic *and* an instant of time when the Sun "stands still" (the literal meaning of the Latin). A solstice, therefore, marks a N/S turning point. At the equinoxes, where (and when) it crosses the celestial equator, the Sun rises at the east point of the horizon, and sets at the west point. The azimuth of rise (or set) of the Sun on any given day depends both on its declination and on the observer's latitude. Solving Eqn. (2.1) for $\cos A$,

$$\cos A = \frac{\sin\delta - (\sin\phi\cdot\sin h)}{\cos\phi\cdot\cos h} \tag{2.6}$$

and on the horizon,[12] h = 0, so that

$$\cos A_{\text{rise/set}} = \frac{\sin\delta}{\cos\phi}. \tag{2.7}$$

At $\delta = 0°$, $\cos A = 0$, so that $A = 90°$ and $270°$, the azimuths of the east and west points of the horizon, respectively. Beginning at (Northern Hemisphere) winter solstice, the Sun rises further to the North each day, with decreasing azimuth, until it reaches summer solstice. At that midsummer[13] date, it has the smallest azimuth of rise (i.e., most northern). It stops decreasing and thereafter rises at greater

[9] Isaac Newton (1642–1727) embodied this idea in the second of his three laws of motion in the *Philosophiae Naturalis Principia Mathematica* (1687). His first law states that an object in motion (or at rest) maintains that state unless acted on by an external force. The second law more fully states that the acceleration of a body is directly proportional to the force acting on it and is inversely proportional to its mass. The third law states that every force exerted by one body on another is matched by a force by the second on the first.

[10] It goes almost without saying, however, that this circumstance does not relieve dedicated students of ancient astronomy from an obligation to obtain at least a rudimentary understanding of the nature and true motions of planetary bodies, so that their relative motions with respect to the Earth can be understood.

[11] Ignoring the long-term phenomena of *precession* (q.v. §3.1.6) and the variation of the *obliquity* (see §2.3.3 and §4.4, respectively).

[12] There is a slight complication in the statement that $h = 0$ indicates an object *on* the horizon. This is true of the astronomical definition of altitude and of the horizon, but the Earth's atmosphere acts as a lens, the refractive properties of which raise both the horizon and the object toward the zenith by an amount that depends on the true altitude and that varies with the temperature and pressure of the atmosphere along the path to the object. Because the light from the object travels a greater path length through the atmosphere, it is lifted higher than the horizon, sometimes dramatically so. Thus, the *apparent* altitude at the astronomical instant of rise is greater than zero; a common value is ~0.°5. See §3.1.3 for further discussion. For the time being, we ignore the effects of atmospheric refraction.

[13] Technically, modern astronomy assigns the *beginning* of the season to the date of solstices and equinoxes, but the older usage is still common. "Midsummer's eve" is the night before the sunrise of the summer solstice. When the terms "midwinter" and "midsummer" are used here, they refer to the dates of the solstices.

azimuths (i.e., more and more to the south). It continues to rise further South each day until it reaches winter solstice again. In the Southern Hemisphere, the Sun rises further to the South each day, its azimuth increasing until summer solstice, and thereafter decreasing again (this follows if the azimuth keeps the same definition we have adopted for the Northern Hemisphere).

Near the equinoxes, the solar declination changes rapidly from day to day so that the points on the horizon marking sunrise and sunset also vary most quickly at those times; at the solstices, the change in declination from day to day is very small, and so is the azimuth change.[14]

The oscillation of its rising (and setting) azimuth on the horizon is one clearly observable effect of the Sun's variable declination during the year. Half of the total amount of oscillation, the largest difference (N or S) from the east point, is called the *amplitude*.[15] We will designate it ΔA. Note that the amplitude of rise is also the amplitude of set. The amplitude depends on the latitude [see Eqn (2.7)]. At the equator, $\phi = 0°$ and $\Delta A = 23.5°$. At any latitude, ϕ, at rise,

$$\Delta A = \arccos\frac{\sin\delta}{\cos\phi} - 90°. \qquad (2.8)$$

Note that the Sun's motion along the ecliptic includes a north/south component that changes its declination, which has been shown to vary the sunrise and sunset azimuth. Because the changing declination of the Sun causes the seasons, the azimuth variation can be used to mark them; a good case can be made that this was done in the Megalithic (§§6.2, 6.3).

The seasonal change in declination also changes the time interval the Sun is above the horizon. This day-time interval is twice the hour angle of rise or set (ignoring, again, the effect of refraction and other physical effects described in §3); so the Sun is above the horizon longer in summer than in winter at all latitudes except the equator. Solving Eqn (2.5) when $h = 0°$, we get

$$\cos H_{\text{rise/set}} = -\tan\phi\cdot\tan\delta. \qquad (2.9)$$

At the equinoxes, when $\delta = 0°$, $H_{\text{rise/set}} = 90°$ and $270°$, equivalent to 6^h and 18^h (-6^h), the hour angles of set and rise, respectively. At such a time, the Sun is above the horizon half the day, so that the numbers of daylight and night-time hours are about equal, hence, the Latin *aequinoctium*, whence *equinox*. At winter solstice, the Sun spends the smallest fraction of the day above the horizon; and its noon altitude (its altitude on the celestial meridian, where $H = 0$) is the lowest of the year. At summer solstice, the Sun spends the largest fraction of the day above the horizon and its noon altitude is the highest of the year. The symmetry in the last two sentences mimics the symmetry of the Sun's movements over the year. The larger fraction of the Sun's diurnal path that is below the horizon at winter solstice is the same fraction that is above the horizon at summer solstice. That the ancient Greeks worked with chords subtended at the centers of circles rather than with sines and cosines did not deter them from discovering and making use of these wonderful symmetries, as we show in §7.3.

A high declination object has a larger diurnal arc above the horizon than below it, and by a difference that increases with latitude (see Figure 2.7). The result of the low altitude of the winter Sun means that each square centimeter of the ground receives less solar energy per second than at any other time of the year, as Figure 2.8 illustrates, resulting in lower equilibrium temperatures. In practice, the situation is complicated by weather systems, but the seasonal insolation of the Sun, as the rate of delivery of solar energy to a unit area is called, is usually the dominant seasonal factor. The effects of seasonal variations and the association of these changes with the visibility of certain asterisms (especially those near the horizon at sunrise or sunset) was noticed early. This association may have been a crucial factor in the development of ideas of stellar influences on the Earth. The changing visibility, ultimately due to the orbital motion of the Earth, shows up in the reflexive motion of the Sun in the sky. The Sun's motion among the stars means that successive constellations fade as the Sun nears them and become visible again as it passes east of them.

References to seasonal phenomena are common in the ancient world. From Whiston's Josephus,[16] writing about the followers of the high priest John Hyrcanus, who was besieged by the Seleucid king Antiochus VII:

> [T]hey were once in want of water, which yet they were delivered from by a large shower of rain, which fell at the setting of the Pleiades. *The Antiquities of the Jews*, Book XIII, Ch. VIII, paragraph 2, p. 278.

Whiston's footnote to the line ending with the "Pleiades" reads:

> This helical setting of the Pleiades was, in the days of Hyrcanus and Josephus, early in the spring, about February, the time of the latter rain in Judea; and this is the only astronomical character of time, besides one eclipse of the moon in the reign of Herod, that we meet with in all Josephus.

The "helical" (heliacal) setting (see §2.4.3) indicates a time when the Pleiades set just after the Sun. Due to the phenomenon of precession (see §3.1.6), the right ascension of the Pleiades in the time of John Hyrcanus, ~132 B.C.,

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[14] This can be seen by taking the rate of change of azimuth due to a change in declination, in Equation 2.7:

$$\sin A_{\text{rise/set}}\cdot dA_{\text{rise/set}} = \frac{-\cos\delta\cdot d\delta}{\cos\phi},$$

so that

$$dA_{\text{rise/set}} = \frac{-\cos\delta}{\cos\phi\cdot\sin A_{\text{rise/set}}}\cdot d\delta.$$

Near the equinoxes, $\delta \approx 0$, so that $\cos\delta \approx 1$ and near the solstices, $\delta \approx \pm 23.5°$, so that $\cos\delta \approx 0.9$. Moreover, when $\cos\phi$ is small, $\sin A$ is large and vice versa, so that dA changes proportionally with $d\delta$, but with opposite sign, at all times of year. Near the solstices, when $d\delta \approx 0$, $dA \approx 0$ also, so that the Sun is at a standstill, roughly keeping the same azimuth from night to night for several nights.

[15] Not to be confused with the term as used in variable star astronomy, where *amplitude* refers to the range of brightness variation. See §5.8.

[16] More properly, "The Works of Flavius Josephus."

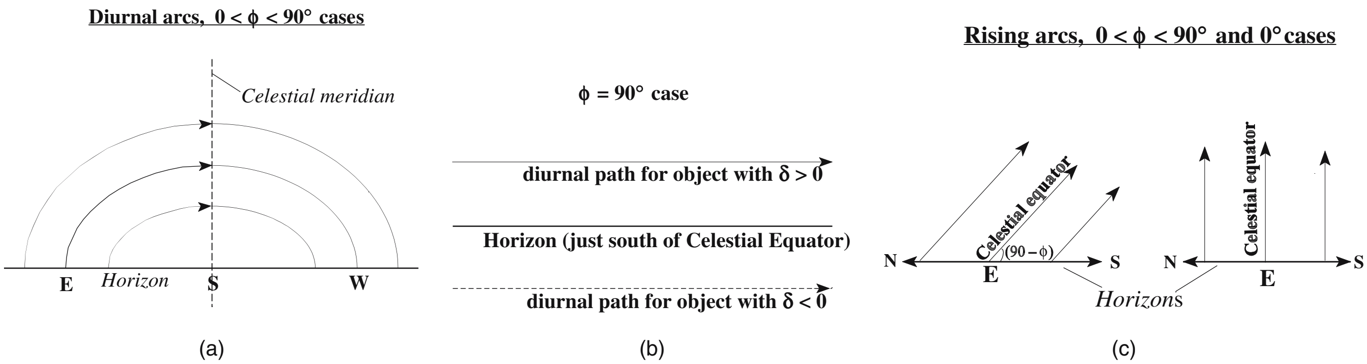


FIGURE 2.7. Horizon sky views of diurnal arcs as a function of declination and latitude (a) as seen at intermediate northern latitudes, looking south; (b) at the North Pole; (c) as seen at intermediate northern latitudes (left) and at the equator (right), looking east. Drawings by E.F. Milone.

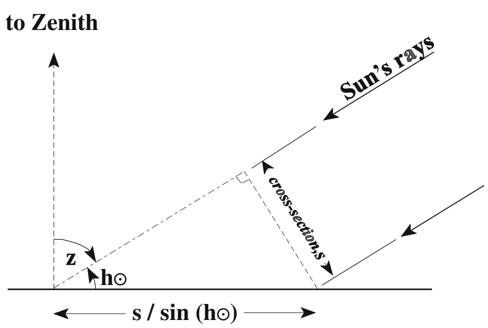


FIGURE 2.8. The effects of solar altitude on ground warming. Note that a given cross-section of sunlit area is spread out on the ground by a factor that increases with solar zenith distance. Drawing by E.F. Milone.

would have been ~01^h45^m, which is ~2 hours smaller than today, and its declination would have placed it further south, at $\delta \approx 15°$ compared with about 24° today. Thus, the Sun would need to be east of the vernal equinox and just west of the Pleiades for the Pleiades to be seen setting just after the Sun. As a rule of thumb, stars as faint as the Pleiades are required to be ~5° or more above the horizon to be seen clearly by the naked eye in an otherwise dark sky because of the dimming of star light by the long sightline through the atmosphere of an object near the horizon. The Sun must be sufficiently below the horizon (~10°) for these relatively faint naked eye stars to be seen above the twilight. See §3.1 for discussions of the visibility of astronomical objects and particularly §3.1.2.2 on atmospheric extinction and §3.1.2.5 on sky brightness and visibility. A simulation of the sky (Figure 2.9) shows that these conditions would last apply in early-to-mid-April, and thus early spring, as indicated by Whiston, but not in February!

From Hesiod's *Works and Days*, (8th century B.C.), we find the use of seasonal signs among the stars:

When first the Pleiades,
Children of Atlas,
arise,
begin your harvest;
plough,
when they quit the skies,

In West's (1978) translation. We can see that these verses provide calendrical references: the visibility of well-known asterisms at important times of day, typically sunup or sundown. Two and a half millennia ago, the Pleiades had a right ascension, $\alpha \approx 1^h\ 15^m$, nearly two and a half hours less than it has today. However, we must ask what Hesiod meant by the first rising of the Pleiades. If they were seen to rise as the Sun set, an "acronychal rising" as we call this phenomenon,[17] the Sun must have been almost opposite in the sky or at $\alpha \approx 13$–14 h, and this implies the time of year—about a month past the Autumnal equinox, a suitable enough time for harvesting, one might think. Then when the Sun approached the Pleiades so closely that they were no longer visible, and they disappeared before the end of evening twilight ("heliacal" or "acronychal setting"), the Sun's RA must have been ~1–2 hours; so the time of year must have been early spring, not an unsuitable time for planting. If a heliacal rising is intended, then the Sun must be least 10–20 minutes further east than the Pleiades, and so at $\alpha \approx 2^h$; this places the time of year a month after vernal equinox, in late April or early May. However, a contrary reading of the "begin your harvest" passage is possible and turns out to be more likely (see Pannekoek 1961/1989, p. 95; and Evans 1998, pp. 4–5), *viz*, that the heliacal rising of the Pleiades signifies the season for *harvesting* a *winter* wheat crop. Moreover, if "plough when they quit the skies" implies that the Pleiades set as the Sun rises, the autumn planting of a winter wheat crop would have been implied. It is well known that

[17] See §2.4.3 for a full discussion of the terms "heliacal" (referring to a rise/set close to the Sun), "acronychal" (associated with the setting sun), and "cosmic" (connected with the rising Sun).

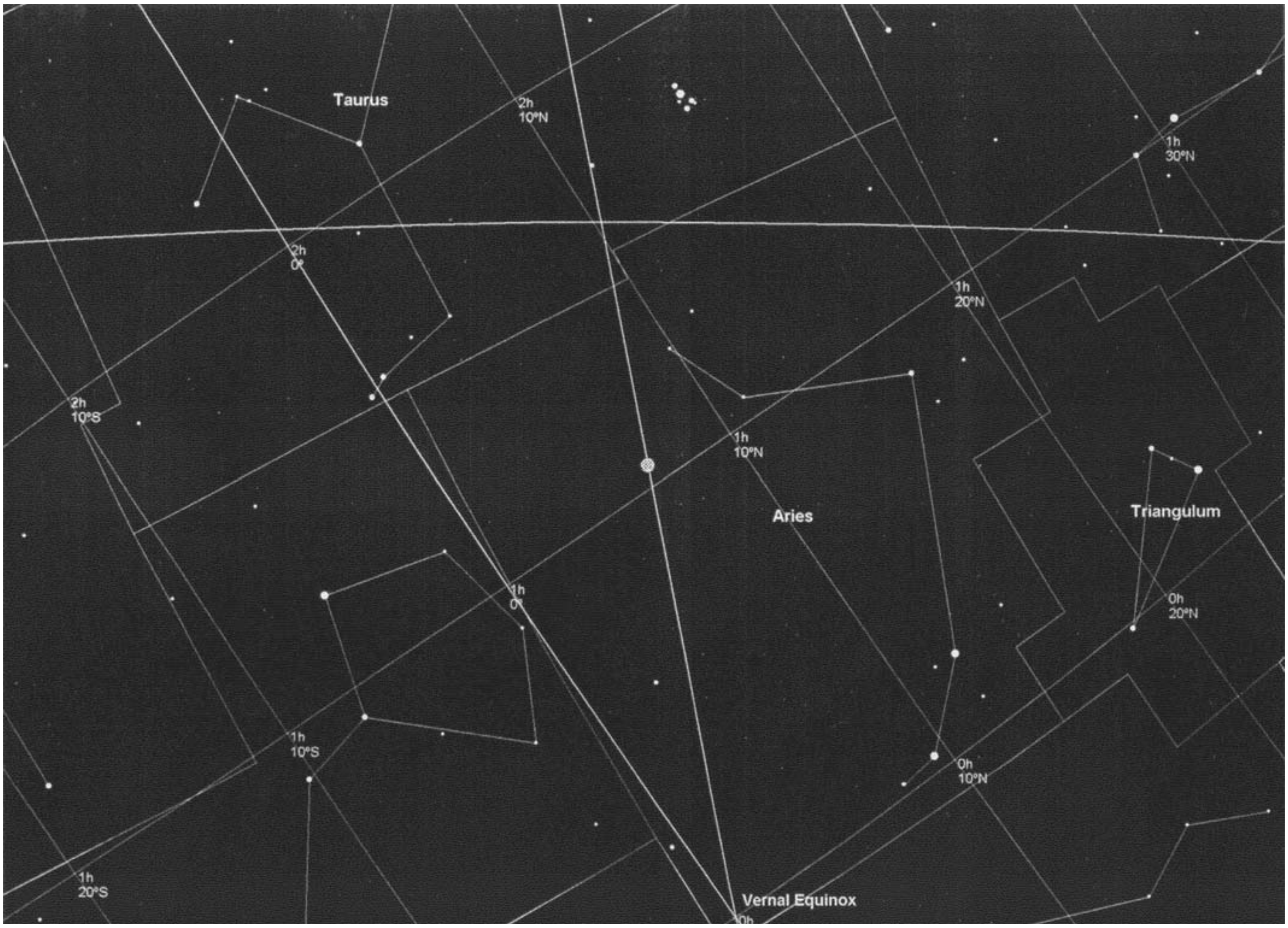


FIGURE 2.9. The heliacal setting of the Pleiades in Jerusalem in 132 B.C. would have occurred no later than ~April 10, according to the Red Shift planetarium software package (Maris, London). The simulation sky map of that date shows the Pleiades to be 4° to 5° above and the Sun ~9° below the western horizon at ~6:40 p.m., Local Time.

winter wheat was grown in the ancient world, even though at some point summer wheat was also (see, e.g., Pareti, Brezzi, and Petech 1965, p. 385). Hesiod instructs his brother, "Plough also in the Spring," and in a later passage, he cautions against waiting until the Sun reaches its "winter turning point," thus resolving the issue for the main planting time.

Another passage from the same work,[18] indicates an important late-winter/early-spring activity:

> When from the Tropic, or the winter's sun,
> Thrice twenty days and nights their course have run;
> And when Arcturus leaves the main, to rise
> A star shining bright in the evening skies;
> Then prune the vine.

Here, the season and time are delineated, and we can interpret the comment directly. The Sun has now and had then a right ascension of ~18 h at winter solstice, and moves ~2 h east each month; thus, 60 days after the solstice, $\alpha_\odot \approx 22$ h. As the Sun sets, Arcturus (currently $\alpha \approx 14^h\ 16^m$, $\delta \approx +19\overset{\circ}{.}2$; 2500 years ago, $\alpha \approx \sim 12^h\ 18^m$, $\delta \approx \sim +31\overset{\circ}{.}3$) rose in the east; in the Mediterranean region, it could well have arisen from the sea. Here, Arcturus's higher declination in the past would have caused it to rise earlier than it does today at a site with the same latitude.

A late-night talk-show host in the 1990s garnered a number of laughs by showing through interviews how few students understood the astronomical cause of the seasons (hopefully they were not astronomy students!). Most thought that the varying distance of the Earth from the Sun was the primary cause. Had they lived in the Southern hemisphere, they could have been forgiven for this incorrect view, because the Earth is closest to the Sun in January, but they still would have been wrong. The varying distance does have an effect on the seasons, but it is a secondary one (it would have a greater effect if the Earth's orbit were more eccen-

[18] Translation by T. Cooke, cited in R.H. Allen 1963 ed., p. 95.

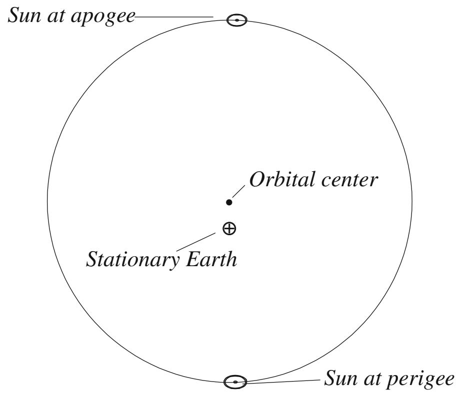


FIGURE 2.10. The off-center circle Hipparchos model for the eccentric solar orbit.

TABLE 2.3. Changes in lengths of the seasons over millennia.

Date	Spring	Summer	Autumn	Winter	Year length[a]
2001 B.C	$94^{d}.29$	$90^{d}.77$	$88^{d}.39$	$91^{d}.80$	365.25
1 B.C.	$93^{d}.97$	$92^{d}.45$	$88^{d}.69$	$90^{d}.14$	365.25
2000 A.D.	$92^{d}.76$	$93^{d}.65$	$89^{d}.84$	$88^{d}.99$	365.24

[a] The year lasts slightly more than 365 civil days (the numbers of days as recorded by civil authorities), requiring the inclusion of an extra day almost every 4 years to keep the calendar in step with the astronomical seasons.

tric than it is). The main cause is that the Sun does not travel along the celestial equator but along the ecliptic. Its declination changes with season and, consequently, so do the mid-day altitude and the length of time spent above the horizon and so does the insolation, as we have shown. The distance of the Sun from the Earth does indeed vary around the year, but at the present time the Earth's passage through *perihelion*, or nearest point to the Sun, occurs during the Northern Hemisphere winter.

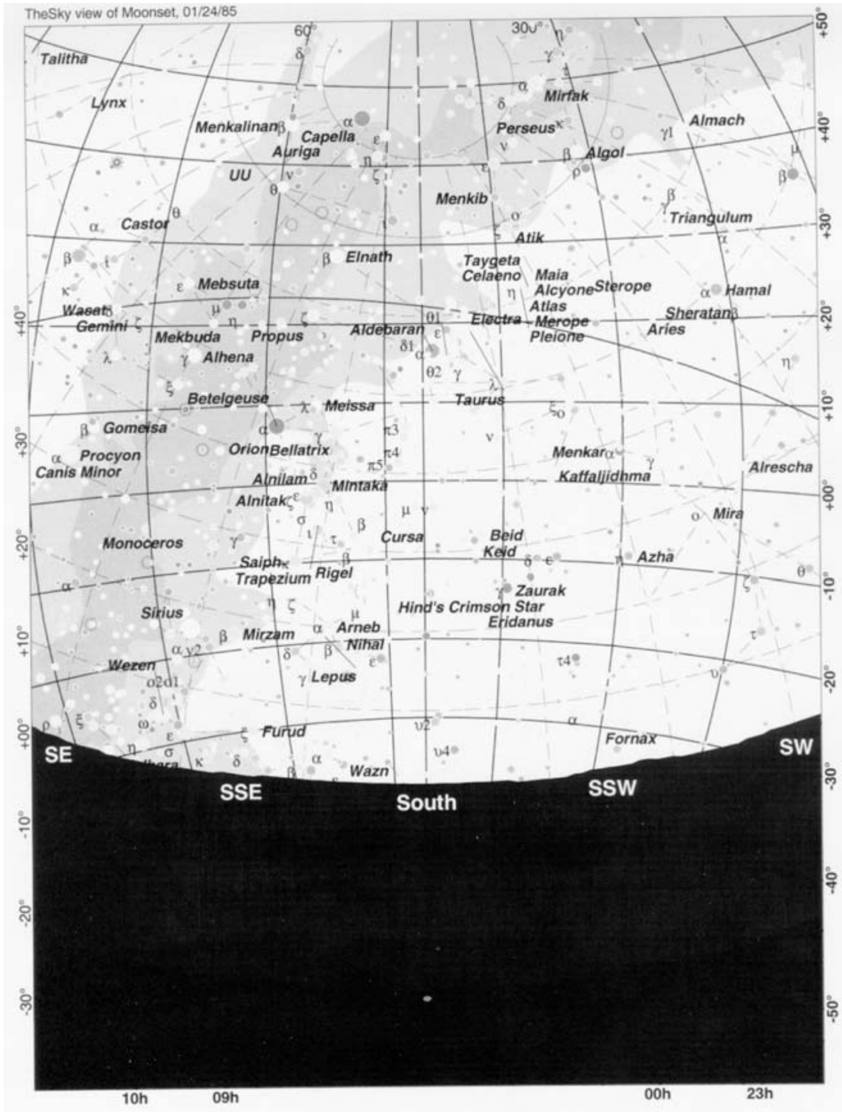
The primary and secondary causes for seasonal effects were understood in antiquity. Ptolemy correctly defines the equinoxes and solstices with respect to the relations between the ecliptic and the celestial equator. He also states (*Almagest*, Toomer tr., 1984, p. 258) that both Sun and Moon vary in distance, and he proceeds to calculate their parallaxes (shift in position as viewed, for example, by observers at different places on Earth). That the Sun's motion on the ecliptic is not uniform throughout the year was also known, and this was modeled in terms of the varying distance of the Sun from Earth. Hipparchos detected the inequality of the seasons and deduced that the Sun moves slower in some parts of its path than it does in others. Because in keeping with all ancient Greek astronomers he believed that planetary bodies moved on circular paths, he had to devise a way to explain why the rate should be different from season to season. His explanation was that the Earth did not lie at the center of the Sun's orbit. As viewed from the Earth, therefore, the Sun's orbit, although circular, appeared eccentric. Such an orbit was referred to as an *eccentre* (or sometimes by the adjective form, *eccentric*). The model is illustrated in Figure 2.10. Hipparchos's observation was correct, and his explanation was a reasonable approximation for his time.

The lengths of the seasons vary slightly from year to year as the Earth's orbit slowly rotates. Meeus (1983b) has tabulated the lengths of the seasons for each millennium year beginning with –3000 (3001 B.C.), when autumn was the shortest season, and notes that winter has been the shortest only since the year 1245. The lengths of the (Northern Hemisphere) seasons for three important epochs among others tabulated by Meeus (1983b) are shown in Table 2.3.

Now we can tie in the motions of the Sun to the seasonal visibility of asterisms. Because the Sun must cover 360° in the course of a year, it must move eastward at slightly less than 1°/day on average. As a consequence, the groups of stars that can be seen during the night, change slowly from night to night, amounting to an angular displacement of about 1/12 of the sky's circumference or 30° in a month. Suppose a particular group of stars on the celestial equator will be seen to rise at sunset; 10 days later, another group of stars about 10° to the east will appear to rise at that time. In the same interval, the stars in the westernmost 10° will disappear in the evening twilight. Figure 2.11 compares the constellations on the meridian at evening twilight, but two months apart. Over the course of a year, Hesiod's seasonal signs follow. The Egyptians used asterisms to keep track of hours, days, months, and, indeed, years! (See §4.) These decans[19] were about 10° apart.

The seasonal variation of the Sun in both right ascension and declination creates an interesting pattern in the sky over the course of the year. The Sun's eastward motion, combined with its apparent northern motion from winter to summer (and southern motion from summer to winter), appears to spiral through the sky; some cultures saw the weaving of a pattern. With sufficient patience and endurance, it can be demonstrated! A camera recording the noon position of the Sun a regular number of days apart over the course of a year will produce a figure-eight pattern called an *analemma*. This figure marks the variation in the Sun's instant of arrival at the meridian and its variation in declination, and so it is a marker of the seasons and of solar time. It will be discussed in later chapters (e.g., §4.1.1.2) for both reasons. For many cultures, from Britain to Egypt, the return of the Sun from its winter quarters and its return from darkness every morning were direct analogs of an endless cycle of death and rebirth. As such, they became mystical, religious events to be observed and celebrated and, in the highest plane of the human spirit, appropriated.

[19] The decans were depicted as two-legged beings, sentries guarding the portals of the night. From the tomb of Seti I (~1350 B.C.) (Neugebauer and Parker, 1969, plate 3).

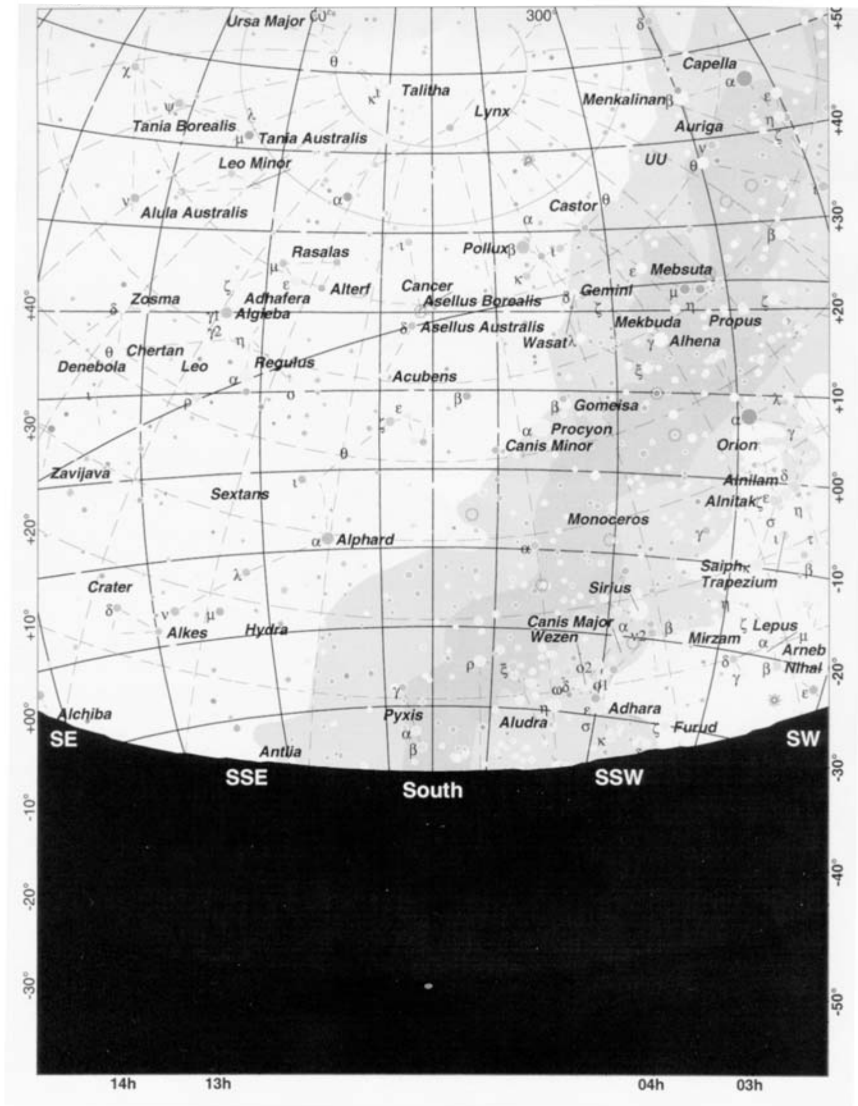


(a)

Figure 2.11. Simulation of constellations centered on the meridian at the same mean solar time in the evening (2100 MST), but two months apart: (a) Jan. 24, 1985, (b) Mar. 24, 1985, as seen from Calgary, Alberta. The equatorial grid is shown with the solid line, with declinations indicated on the extreme right and a few right ascensions at the bottom. The ecliptic is shown arching across the field. The horizon grid is shown with a lightly broken line, with altitudes indicated on the extreme left and a pair of azimuths marked on the vertical circle arcs radiating from the zenith. Produced by E.F. Milone with TheSky software package (Software Bisque, Golden, CO).

2.3.2. The Zodiac

The Sun's annual journey involves visits to successive areas of the sky. Twelve constellations follow one another in a band around the sky. They straddle the ecliptic, the path of the Sun during its annual journey among the stars. The band of constellations is called the *zodiac*, from the Greek ζωδιακὸς κύκλος (zodiacos kuklos), "circle of the animals"). The naming of most of the zodiacal constellations took place in Mesopotamia. According to Neugebauer (1969, p. 102ff), the subsequent assignment of the zodiacal constellation names to a series of 30° segments of the sky along the ecliptic was probably first carried out in the 4th century B.C. (for alternative views, see §7.1.2.3). The uniform lengths of exactly 30° each created a longitude-like coordinate by which positions could be assigned to the stars. These



(b)

FIGURE 2.11. *Continued.*

12 constellations were thus turned into signs.[20] The Greco-Roman zodiac (with the symbol for each sign) is shown with the Mesopotamian and Indian equivalents in Table 2.4, in the order in which they are visited by the Sun during the year. This is also the order in which the constellations rise and the order of increasing right ascension. The series starts with Aries and progresses eastward. Although the attested date of the zodiac's origin is late, the fact that the spring equinox was actually in Aries between 2000 and 100 B.C. provides evidence for a much earlier, if undocumented, usage. The boundaries of the modern zodiacal constellations as established by the International Astronomical Union are not uniform in extent, but the boundaries of the zo diacal *signs* are. Each zodiacal sign is 18° high, centered on the ecliptic. The Greeks fixed the widths of each of the signs at 30°. The zodiac had an important mathematical use in the ancient world: The number of degrees from the beginning of each sign was used to record planetary positions. This measurement scheme, in use in Ptolemy's

[20] A similar shift from 28 (sometimes 27) zodiacal asterisms (representing lunar "houses," "lodges," or "mansions," that is, places for the Moon to "stay" among the stars during its monthly sojourn around the Earth), to 27 *signs*, beginning with the vernal equinox, occurred in India.

TABLE 2.4. Zodiacal constellations.

Latin (Ptolemaic)	Babylonian	Indian	Symbol	Celestial/ ecliptic longitude[a]
Aries	LU.HUN.GA	Mesa	♈	0°
Taurus	MUL	Vrsabha	♉	30°
Gemini	MASH	Mithuna	♊	60°
Cancer	NANGAR	Karka	♋	90°
Leo	UR.A	Simha	♌	120°
Virgo	AB.SIN	Kanya	♍	150°
Libra	zi-ba-ni-tu	Tula	♎	180°
Scorpio	GIR.TAB	Vrscika	♏	210°
Sagittarius	PA	Dhanus	♐	240°
Capricorn	SUHUR	Makara	♑	270°
Aquarius	GU	Kumbha	♒	300°
Pisces	zib	Mina	♓	330°

[a] In ancient use, (celestial) longitude was measured according to placement within each sign, although the 0° longitude origin was not always taken at the western edge (or "first point") of the signs because of the westward shift of the vernal equinox over time, with respect to the stars.

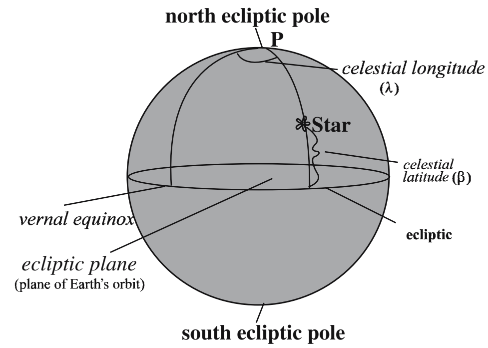


FIGURE 2.12. The ecliptic or "Greek" system of celestial coordinates. The ecliptic is the reference circle, representing the annual path of the Sun. The poles are the north and south ecliptic poles, from which longitude circles radiate. The origin of the coordinates is the vernal equinox, from which the celestial (or ecliptic) longitude increases to the east. The celestial (or ecliptic) latitude is measured positive north and negative south of the ecliptic. Drawing by E.F. Milone.

time,[21] was used in star catalogues well into the 19th century. Subsequently, this expanded into the celestial longitude system,[22] which we discuss next.

2.3.3. The Ecliptic or "Greek" System

The path of the Sun, the *ecliptic*, is the reference great circle for this coordinate system. The ecliptic is the sinusoid crossing the celestial equator in Figure B.1, and in Figure 10.7, it can be seen as the off-center circle crossing the celestial sphere. In ancient China, the ecliptic was known as the "Yellow Road."

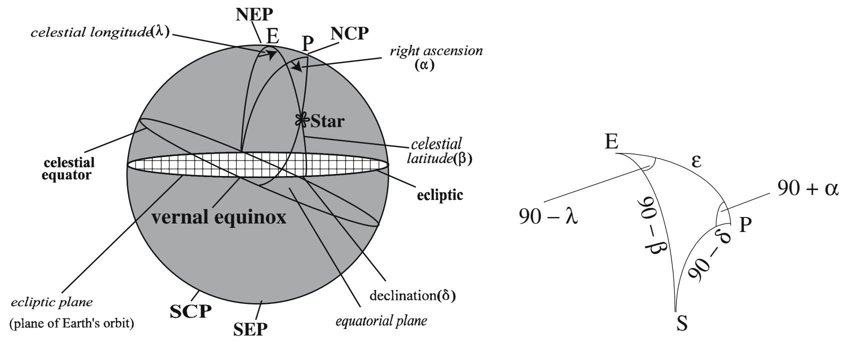
The word "ecliptic" (from Latin, "of an eclipse") can be traced back to Greece. It is the path on which eclipses can and do occur, because it is the path of the Sun, and the Moon intercepts this path in two places. Curiously, for the Sun's path, Ptolemy does not use the term ἐκλειπτικός ("eclipticos"—he reserves this term to mean exclusively "having to do with eclipses"), but the phrase "ὁ λόξος και διὰ μέσων τῶν ζῳδίων κύκλος" ("ho loxos kay dhia menon ton zodion kuklos"; "the inclined circle through the middle of the zodiacal signs") (Toomer 1984, p. 20). Figure 2.12 illustrates the system, showing the north and south ecliptic poles, the secondary circles, called celestial longitude circles, and the coordinates, celestial longitude (λ) and latitude (ß).

Celestial longitude is measured in degrees from the vernal equinox, eastward, along the ecliptic, i.e., counterclockwise as viewed from outside the sphere looking down on the north ecliptic pole. Celestial latitude is measured in degrees north (+) or south (–) of the ecliptic. The terms "longitude" and "latitude" (from the Latin *longitudo*, "length," and *latitudo*, "width") ultimately derive from the Greeks, but Ptolemy uses the term πλάτος ("breadth") for any vertical direction, i.e., declination as well as celestial latitude (Toomer 1984, p. 21). The use of the modern qualifier "celestial" is to avoid confusion with the unrelated terrestrial system, which has a closer counterpart in the equatorial system; "ecliptic longitude" and "ecliptic latitude" are also in current use. Circles parallel to the ecliptic are called celestial latitude circles. They are "small" circles, parallel to, but not concentric with, the ecliptic. An arc contained between two celestial longitude circles is smaller than is the corresponding arc on the ecliptic by the factor $\cos\beta$. As for the other coordinates we have discussed thus far, the quantity celestial longitude can be considered in either of three ways, including a polar angle measured at one of the ecliptic poles. Similarly, the celestial latitude can be considered in either of two ways, including the length of arc between the ecliptic and the object of interest along a longitude circle. With them, we can now consider transformations to and from the (RA) equatorial system. The link between them is the "obliquity of the ecliptic."

Figure B.1 illustrates the ecliptic as it is seen on an equatorial chart. The angle between the celestial equator and the ecliptic is called the *obliquity* of the ecliptic. This is the cause of the seasons, as we have noted above, because when $0 < \delta_\odot \le +\varepsilon$, the Sun's rays fall more directly on the northern latitude zones, and when $-\varepsilon \le \delta_\odot < 0$, they fall more

[21] Thus, in the *Almagest* (described in §7.3.2), the longitude of α Ori (Betelgeuse), "The bright, reddish star on the right shoulder" with magnitude "<1," is given as "II [Gemini]" 2°, and its latitude is given as –17°; that of β Ori (Rigel), "The bright star in the left foot, . . ." with magnitude "1," is given as ♉ [Taurus] $19\frac{5}{6}$°, and its latitude $-31\frac{1}{2}$°; and that of α CMa (Sirius), "The star in the mouth, the brightest, which is called 'the dog' and is reddish", of magnitude "1," is given as II [Gemini] $17\frac{2}{3}$°, and its latitude as $-39\frac{1}{6}$°.

[22] The *Berliner Jahrbuch* changed usage in 1829, the British *Nautical Almanac* and the French *Connaissance de Temps* in 1833, to the modern ecliptic system of continuous degrees of celestial longitude from the vernal (March) equinox.



(a) (b)

FIGURE 2.13. The equatorial and ecliptic systems (a) superposed on the celestial sphere and (b) the spherical triangle from which the transformations are derived. Drawings by E.F. Milone.

directly on southern latitude zones. With spherical trigonometry, it can be demonstrated that the maximum and minimum declinations along the ecliptic are +ε and –ε, respectively. In the IAU 1976 System of Astronomical Constants, the value of the obliquity of the equinox was ε = 23° 26′ 21.448″ = 23°.439291 for the epoch 2000 A.D., but it varies with time [cf. §4.4, (4.22) for the rate of variation of ε].

Figure 2.13 shows both equatorial and ecliptic systems together and the spherical triangle used to transform the coordinates of one system into the other.

The transformation equations may be obtained from applications of the sine and cosine laws of spherical astronomy to yield

$$\sin\beta = \cos\varepsilon \cdot \sin\delta + \sin\varepsilon \cdot \cos\delta \cdot \sin\alpha, \qquad (2.10)$$

$$\cos\lambda = \cos\alpha \cdot \frac{\cos\delta}{\cos\beta}, \qquad (2.11)$$

$$\sin\delta = \cos\varepsilon \cdot \sin\beta + \sin\varepsilon \cdot \cos\beta \cdot \sin\lambda, \qquad (2.12)$$

$$\cos\alpha = \frac{\cos\beta \cdot \cos\lambda}{\cos\delta}, \qquad (2.13)$$

where α is the right ascension (here, expressed in angular measure: $15° = 1^h$), δ is the declination, β is the celestial latitude, λ is the celestial longitude, and ε is the obliquity of the ecliptic (see §2.4.5 for variations in this quantity over time).

The caution regarding quadrant determination that we urged earlier (§2.2.4) is appropriate here too. Table 2.2 should resolve any ambiguities.

As an example, suppose we wish to find the ecliptic coordinates of an object at $\alpha = 18^h00^m00^s$ or 270°.00000 and δ = +28°00′00″ or 28°.00000. At the current epoch, assuming a value ε = 23°.441047, from (2.6),

$$\sin\beta = 0.917470 \cdot 0.469472 - 0.397805 \cdot 0.882948 \cdot (-1.000000)$$
$$= 0.430726 + 0.351241 = 0.781967,$$

so that

$$\beta = \arcsin(0.781967) = 51°.44103 \text{ or } 180° - 51°.44103$$
$$= 128°.55897,$$

from the rules described in §2.2.4. It is obvious that the first value is correct because ß ≤ 90° by definition. From (2.7),

$$\cos\lambda = \frac{0.000000 \cdot 0.882948}{0.623320} = 0.$$

Therefore, λ = 90° or 270°.

Because the object is not too far from the celestial equator and $\alpha = 18^h$, 270° is the correct value. If the quadrant were not so obvious, however, one could use (2.8) to resolve the issue:

$$\sin\lambda = \frac{\sin\delta - \cos\varepsilon \cdot \sin\beta}{\sin\varepsilon \cdot \cos\beta}$$
$$= \frac{0.469472 - 0.917470 \cdot 0.781967}{0.397805 \cdot 0.623320}$$
$$\simeq -1,$$

confirming that λ = 270°.

The use of celestial longitudes spread over 360° is a relatively modern development. The Babylonians and Greeks used degrees of the zodical sign, measuring from the western edge. Ptolemy, for example, gives the position of the star ε UMa as "The first of the three stars on the tail next to the place where it joins [the body]" as ♌ [Leo] 12⅙° of longitude, and +53½° of latitude (Toomer 1984, p. 34). The equivalent value of celestial longitude is λ = 132°10′. Ptolemy's values differ from current values because of precession (§3.1.6) and the variation of the obliquity of the ecliptic (§4.4), and possibly other factors (see §7.3.2 for an extensive discussion of *whose* data were included in this catalogue).

2.3.4. The Motions of the Moon

The Moon orbits the earth on a path close to, but not on, the ecliptic, changing phase as it does so and basically replicating the motion of the Sun but at a much faster rate, and more variable celestial latitude. The Sun travels its path in a year, and the Moon in a month. In Figure 2.14, the

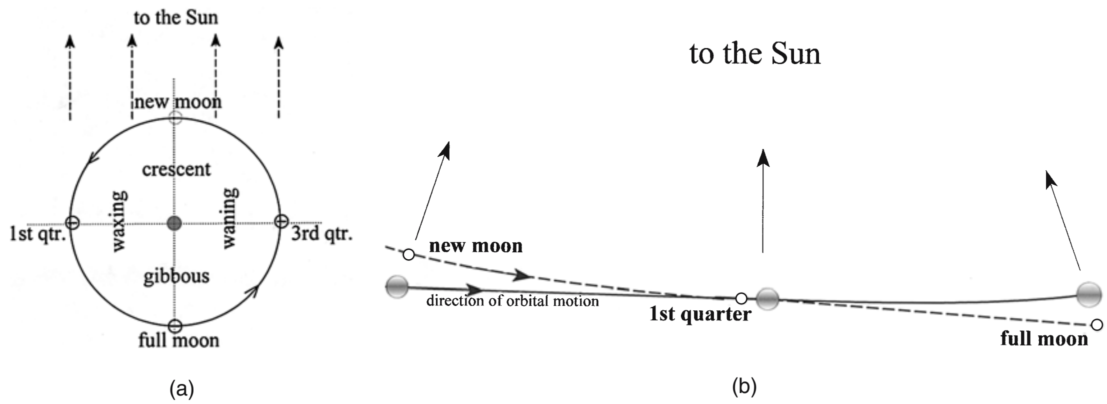


FIGURE 2.14. Lunar phases during the synodic month: (a) The synodic month as viewed geocentrically. (b) Lunar phases for a portion of the month as the Moon-Earth system orbits the Sun. Drawings by E.F. Milone.

phase advancement of the Moon during its revolution is chronicled.

Divided vertically, the figure differentiates crescent (less than a quarter Moon) from gibbous phases (more than a quarter Moon). Divided horizontally, it separates waxing from waning phases. The diagram serves to demonstrate the relative motion of the Moon with respect to the position of the Sun in the sky; one full cycle is the *synodic month*, or the month of phases.

As the Moon revolves around the earth, its declination changes in the course of a month, and as it does so, its diurnal arc across the sky changes, just as the Sun's diurnal arc changes over the course of a year. The full Moon, because it is opposite the Sun, rides high across the (Northern Hemisphere) midwinter sky, and low across the midsummer sky. The diurnal arcs of the Moon at other phases can be understood similarly. Although the Sun's rise and set points on the horizon vary slowly from day to day, those of the Moon change much more rapidly from day to day. As the Moon circuits the Earth, the Earth and Moon are circuiting the Sun; in a geocentric context, in the course of a month, the Sun moves East among the stars by ~30°. This means that the synodic month must be longer than the time it takes for the Moon to encircle the Earth with respect to a line to the distant stars. This affects lunar and solar calendars (see §4.2, especially, §4.2.1), and the occurrence of eclipses (§5.2).

The motion of the Moon is even more complex and interesting than that described thus far. For one thing, the Moon's declination is sometimes less and sometimes more than is the Sun's extreme values (±23°.5 at present). This means that the amplitude of its azimuth variation over the month varies from month to month, in an 18.6-year cycle. This fact is of importance in studying alignments to the Moon, as we show throughout §6. For another, the Moon's distance changes during the course of the month by about 10%, and this affects its apparent (angular) size.[23] In addition, the place in the orbit where the Moon achieves its closest point to orbit shifts forward with time. These changes also affect eclipse conditions. To appreciate the full complexity of its behavior in the sky and the roles these play in calendar problems and in eclipse prediction, the moon's orbit must be examined.

2.3.5. Orbital Elements and the Lunar Orbit

In ancient Greece and indeed up to the time of Johannes Kepler [1571–1630], all astronomers assumed the orbital motions of Sun, Moon, planets, and stars either to be circular or a combination of circular motions. Modern astronomy has removed the stars from orbiting Earth and has them orbit the galactic center, which itself moves with respect to other galaxies. The Sun's motion is reflexive of the Earth's and comes close to that of a circle, but not quite. The orbits of the other planets can be similarly described; two of them, Mercury and Pluto, show wide departures and some asteroids and most comets, even more. The combination of a sufficient number of circular terms can indeed approximate the motions, but the physical orbits are more generally elliptical.[24]

One can show from a mathematical formulation of Newton's laws of motion and the gravitational law that in a two-body system, an elliptical or hyperbolic orbit can be expected. If the two objects are bound together (we discuss what this means in §5), the orbit must be an ellipse. Such an ellipse is characterized usually by six unique elements, which we describe and discuss in the next section.

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[23] The geometric expression is $r\,\theta = D$, where r is the distance of an object, θ its angular diameter in radian measure ($= \theta° \times \pi/180$), and D is its diameter in the same units as r. This can be called a "skinny angle formula" because it is an approximation for relatively small values of θ. A more general expression would be $D/2 = r\sin(\theta/2)$.

[24] An ellipse can be described geometrically as the locus of all points such that the sum of the distances from the two foci to a point on the ellipse is constant. One may construct an ellipse by anchoring each end of a length of string between two points and, with a pencil keeping the string taut, tracing all around the two points, permitting the string to slide past the pencil in doing so. In orbits, only one focus is occupied, and the other focus and the center are empty.

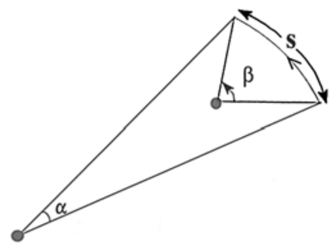


FIGURE 2.15. The relationship between the angular speed of an object and distance. Drawing by E.F. Milone.

As an object moves in an ellipse, its distance from a focus changes. When nearer the Sun, the planets move faster than they do when they are further away from it. These facts are encapsulated in the first two "laws" (limited "descriptions," actually) of the planets' behavior, first formulated by Kepler in 1602. The speed variation arises because the line joining planet to Sun sweeps out the area of the orbit in a uniform way: The areal speed is constant. So the Earth moves faster when it is closer to the Sun, and the Moon moves faster when it is closest to Earth. And this is what seems to occur in the sky: From the Earth, the Sun's motion appears to carry it to the east at a faster rate when it is closer to earth, both because of Earth's orbital motion and because the angular speed of an object moving across our line of sight at a given linear speed increases as the distance to it decreases. The motion of the Moon is also more rapid near perigee. Figure 2.15 illustrates the effect.

In the year 2000, the Earth was at *perihelion* (geocentrically, the Sun was at *perigee*) on Jan. 3 and at *aphelion* (Sun at apogee) on July 4. In the same year, the Moon was at perigee 13 times: Jan. 19, Feb. 17, Mar. 15, Apr. 8, May 6, June 3, July 1, July 30, Aug. 27, Sept. 24, Oct. 19, Nov. 14, and Dec. 12; it was at apogee 14 times, starting on Jan. 4, and ending on Dec. 28. The daily rate of motion of the Sun along the ecliptic was ~1°1′10″ in early January but only ~57′13½″ in early July compared with an average motion of 360°/365.ᵈ24 = 59′8.″3 (see Section C of the Astronomical Almanac for the year 2000). The Moon's motion is much more rapid, and because the eccentricity is higher than for the solar orbit, the difference in motion is greater from perigee to apogee.

The orbital elements are illustrated in Figure 2.16:

(1) The *semimajor axis*, a, half the major axis, is the time-averaged distance of the orbiter to the orbited. This element defines the size of the orbit and depends on the orbital energy; the smaller the distance, the greater the energy that would have to be supplied for it to escape from the Sun.

(2) The *eccentricity*, e, of the ellipse may be obtained from taking the ratio of the separation of the foci to the major axis, which is just the length of the line joining the perihelion and aphelion. Although a scales the orbit, e defines its shape. From Figure 2.16a, it can be seen that the perihelion distance is $a(1 - e)$ and the aphelion distance is $a(1 + e)$. For the Earth's orbit, $e \approx 0.017$, so that its distance from the Sun varies from the mean by $\pm 0.017a$ or about ±2,500,000 km. The eccentricity of the Earth's orbit is not so important a factor in determining the climate as is the obliquity, but it does cause a slight inequality in the lengths of the seasons, as we noted earlier. The orbit of the moon is sufficiently eccentric that its angular size varies sharply over the anomalistic month (the time for the Moon to go from perigee to perigee; see below).

(3) The *inclination*, i or ι, the angle between the reference plane—in the case of the Moon and planets, the ecliptic plane—and that of the orbit, partially fixes the orbital plane in space, but another is needed to finish the job (see Figures 2.16b and c).

(4) The *longitude of the ascending node*, Ω, is measured along the ecliptic from the vernal equinox to the point of orbital crossover from below to above the ecliptic plane. This element, with i, fixes the orientation of the plane in space.

(5) The *argument of perihelion* (for the moon, perigee is used), ω, measured from the ascending node in the direction of orbital motion. This element fixes the orientation of the orbital ellipse within the orbital plane.

(6) The epoch, T_0, or T or sometimes E_0, is the sixth element. In order to predict where the object will be in the future, a particular instant must be specified when the body is at some particular point in its orbit. Such a point may be the perihelion for planets (or perigee for the Moon) or the *ascending node*, where the object moves from south to north of the ecliptic plane; however, it may be an instant when the object is at any well-determined point in its orbit, such as the *true longitude* at a specified instant.

(7) Sometimes a seventh element is mentioned—the *sidereal period*, P_{sid}, the time to complete a single revolution with respect to a line to a distant reference point among the stars.[25] P_{sid} is not independent of a because the two quantities are related through Kepler's third law,[26] but the Sun's mass dominates the mass of even giant Jupiter by more than 1000 : 1. For the high precision required of orbital calculations over long intervals, it is necessary to specify this or a related element (the mean rate of motion).

[25] A sidereal period usually is not expressed in units of sidereal time; mean solar time units such as the mean solar day (MSD) are used, in general, and the designation is *day* (d, sometimes in superscript). This need not be the same as the local civil day, i.e., the length of a day in effect at a particular place. See §4.1 for the distinctions.

[26] The third law relates the period, P, to the semimajor axis, a. In Kepler's formulation, the relation was $P^2 = a^3$, if P is in units of the length of the sidereal period of Earth and a is in units of the Earth's semimajor axis. In astronomy generally, $a_\oplus$ defines the *astronomical unit*. From Newtonian physics, it can be shown that the constant of proportionality is not 1 and is not even constant from planet to planet: $P^2 = \{4\pi^2/[G(\mathfrak{M} + \mathfrak{m})]\}\, a^3$, where G is the gravitational constant, $6.67\ 10^{-11}$ (MKS units), and $\mathfrak{m}$ and $\mathfrak{M}$ are the masses of the smaller and larger mass bodies, respectively.

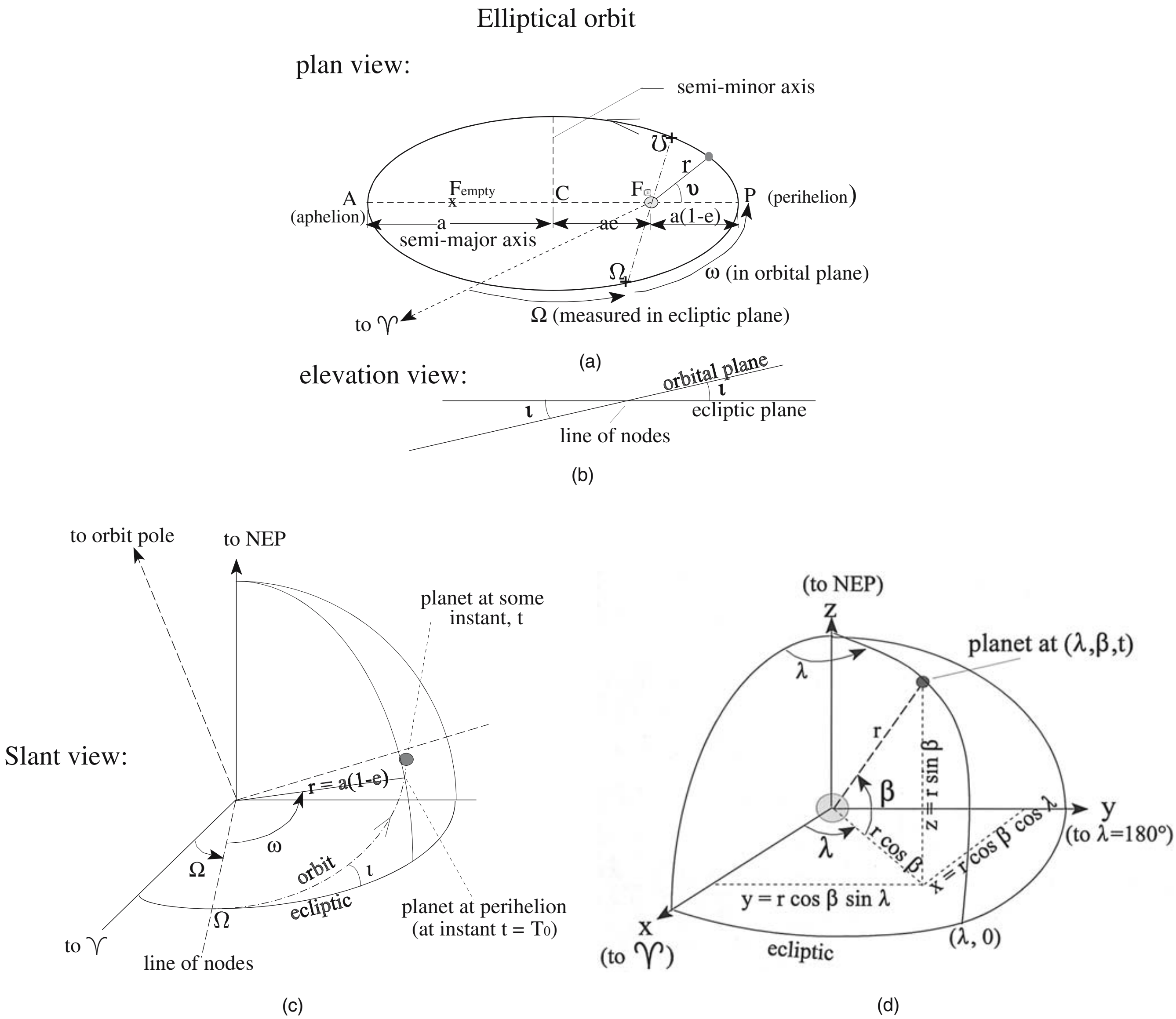


FIGURE 2.16. Elements and other properties of an elliptical orbit: (a) "Plan" and (b) "elevation" views, respectively—The scale and shape of the orbit are established by the semimajor axis, a, and the eccentricity, e. The orientation of the orbital plane with respect to the ecliptic is set by the inclination, i, and the longitude of the ascending node, Ω; the orientation of the orbit within the plane is fixed by the argument of perihelion, ω. The instant of the location of the planet at the perihelion, $r = a(1 - e)$ (or, when $e = 0$, at the ascending node), T_0, is the sixth element; the seventh, the period, P, is not an independent element since it is related to a by Kepler's third law. (c) "Slant view"—The position of the planet in Cartesian coordinates aids the transformation from the orbit to the sky. The relationship between the orbital and ecliptic coordinates are found by successive rotations of the axes shown. (d) The relations between the celestial longitude and latitude and the Cartesian ecliptic coordinates—A further transformation to equatorial coordinates can be carried out through spherical trigonometry or through a transformation of Cartesian coordinates. See Schlosser et al. (1991/1994) for further details. Drawings by E.F. Milone.

The elements of the lunar orbit at a particular date are shown in Table 2.4. Given the elements, one may find, in principle, the position of an object in the orbit at any later time. The angle swept out by the Sun-planet line is called the *true anomaly* (υ in Figure 2.16b). The position of the object in its orbit at any time t since perihelion passage (T_0) can be specified through a quantity called the *mean anomaly*:

$$M = \frac{2\pi}{P}(t - T_0). \tag{2.14}$$

This angle describes the position of a planet that would move at the same average rate as the planet, but in a circular orbit. The mean anomaly is related to the *true anomaly* by the approximation

$$\upsilon - M = 2e - \frac{1}{4}e^3 \cdot \sin M + \frac{5}{4}e^2 \cdot \sin 2M + \frac{13}{12}e^3 \cdot \sin 3M + \cdots. \quad (2.15)$$

This is merely the difference between the actual position of the object in the orbit and the position it would have if it moved at a constant rate. The elements Ω, ω, and T_0 and are sometimes combined with each other or with the true or mean anomaly to produce *longitudes*. For example, the *longitude of the perigee* (or *longitude of the perihelion*),

$$\tilde{\omega} = \Omega + \omega, \quad (2.16)$$

is a very curious angle because it is measured first in the ecliptic, from the vernal equinox to the ascending node, and then in the orbit, in the direction of orbital motion. Another example is the *mean longitude*, ℓ (called in the Astronomical Almanac, L),[27]

$$\ell = \tilde{\omega} + M = \Omega + \omega + n(t - T_0), \quad (2.18)$$

where n is the *mean motion* = 360°/P, and t is the time of observation or calculation. Therefore, the *mean longitude of the epoch*, ε, is merely the value of ℓ when t is T_0 (the instant that defines the epoch):

$$\varepsilon = \ell(t = T_0) = \tilde{\omega} \quad (2.19)$$

(Danby 1962, p. 156). Please note that *this* epsilon is *not* the obliquity of the ecliptic. Another parameter that is sometimes mentioned is the *argument of the latitude*, u, the angle between the ascending node and the object in its orbit, so that we can also express the true longitude in terms of the argument of latitude:

$$L = \Omega + u. \quad (2.20)$$

The mean elements of the Moon's orbit are given in Table 2.5. Only mean or average elements can be given because they vary with time, usually both secularly (rate change with constant sign, i.e., always increasing or always decreasing) and periodically. Danby (1988, App. C, pp. 427–429) provides for higher order terms for the time variation of the elements of the major planets. Now we are in a position to discuss why the elements change with time.

We can approximate the orbits of the Moon or some planet with a set of orbital elements for an instant of time (for some planets, considerably longer), but the elements of the ellipse vary over time because of perturbations of the other bodies (and, especially in the case of the Earth-Moon system, nonuniform mass distributions in the bodies themselves). The fly in the ointment is that the Earth-Moon is really an Earth-Moon-Sun system, a three-body system, for which there is no complete general solution.

TABLE 2.5. Lunar orbit mean elements (2000.0).

Element	Mean value	Main variation
Semimajor axis (a)	384,400 km	+3 cm/yr
Eccentricity (e)	0.054900489	±0.0117
Inclination[a] (ι)	5.°1453964 = 5°8′43″	±9′
Longitude of ascending node[b] (Ω)	125.°123953	−0.°052 953 76/day
Argument of perigee[b] (ω)	83.°186346	+0.°111 403 55/day[c]
Epoch[d] (T_0)	2000 Jan 19.9583	

[a] With respect to the ecliptic; the inclination w.r.t. the celestial equator varies from 18.°28 to 28.°58. The period of the 9′ variation is 17.ᵈ33.
[b] The value and its variation are correct only for 2000; the current Astronomical Almanac should be consulted for accurate calculation. The major periodic variation of Ω is ±100′.
[c] This also includes the motion of the ascending node and is thus the variation of the *longitude* of perigee. The major periodic variation of ω is ±12°20′.
[d] An instant of perigee during the year 2000.

If an infinitesimally small but fully massive Moon moved around an infinitesimally small but fully massive Earth (i.e., the mass of each body was fully concentrated at its center) and if the effects of the Sun and all other planets could be ignored, the Moon's orbit would be a simple ellipse with the Earth at one of the two focuses of the ellipse. These conditions are not met, and as a consequence, the orbit is anything but simple. Newton used to say that his head ached when he thought about the Moon.

The perturbations on the Moon are particularly great because it moves nearly on the ecliptic, but not exactly on it. That the orbit should be near the ecliptic is curious, because as a satellite of the Earth, we could expect it to move near the plane of the earth's equator, which is the case for most of the other major satellites of the planets. Our satellite is, however, far enough from the Earth at present that its motion is effectively dominated by the Sun, so that the Earth and Moon form a kind of double-planet system. Even so, it is close enough to the Earth to undergo, as well as cause, tidal effects that have slowed the Moon's rotation to equal its orbital period, and to result in an increasing distance from the Earth, and an increasing length of month. Tidal effects on the Earth are resulting in a slowing down of Earth's rotation (see §4.5), which affects the timing of ancient phenomena, such as eclipses (see §5.2, especially, §5.2.1.3).

The solar system is an n-body system, and each object is accelerated by all the other objects. Whereas for a three-body system, a special solution is found for the circular orbit case, when the third body has negligible mass, there is no analytic solution for $n > 3$, and no general solution for $n > 2$. By Newton's gravitational law, the force acting on an object depends on the mass of the perturber and on the inverse square of the distance from the perturber. The acceleration depends on the size of that force and inversely on the mass of the object undergoing the acceleration. The

[27] Danby uses L to define the "true longitude" of the planet:

$$L = \tilde{\omega} + \upsilon = \Omega + \omega + \upsilon. \quad (2.17)$$

acceleration due to each perturber adds in vector fashion; this means that the direction of each perturber must be taken into account. The net acceleration of the body is slightly different from that due to the Sun alone. In the next instant, the acceleration causes a change in the speed and direction of motion (together called the velocity, a vector). In the next instant, the slightly altered velocity causes a slight shift in position of the object, causing its orbit to change. In this way, the orbit of each object is perturbed away from the elements that characterize it at some particular epoch. In the Earth-Moon system, the Earth may be considered a major perturber of the Moon's orbit about the Sun; the Earth's slightly irregular mass distribution is an additional source of perturbation. There are two types of perturbation effects: those which cause an element to oscillate about a mean value over time, and those which cause a variation of constant sign with time; these are called *periodic* and *secular* variations, respectively. Table 2.5 gives both types, although only the largest of the periodic variations are shown. The perturbations must be taken into account in lunar orbit calculations; without them, the results could be wrong by several degrees.

The average variations in the elements (from Danby 1962, p. 278; 1988, p. 371) are e: ±.0117; ι: ±9 arc min; Ω (variation about its average motion): ±100 arc min; and ω (variation about its average motion): 12°20′. The average motion of the ascending node is about $-19\overset{\circ}{.}35$/y and that of the perigee is about +40°/y. The average rates given in Table 2.5 are appropriate only for the year 2000; for high-precision purposes, data should be taken from the current almanac.

Even though they lacked an adequate physical theory to understand the motions they observed, the astronomers from ancient Greek times to those of the Copernican era were capable of discerning the effects of the perturbations. The variations in some of the elements of the Moon's motion are large enough to have been noticed in the ancient world.

The most important term in the difference between the true and mean anomaly expressed in (2.15) is

$$2e \sin M = (6°17') \cdot \sin M, \tag{2.21}$$

but because of the perturbations in ω and e, an additional term should be included to describe $\upsilon - M$ adequately:

$$(1°16') \cdot \sin(2\omega - 2\lambda_{\odot} + \lambda_M), \tag{2.22}$$

where $\lambda_{\odot}$ and λ_M are the celestial longitudes of the Sun and Moon, respectively. The perturbations in e and in ω are caused by the Sun's position[28] at perigee and apogee. These result in a large perturbation in the Moon's celestial longitude, with an amplitude of ~1°16′ and a period of $31\overset{d}{.}80747$ (Brouwer and Clemence 1961, p. 329). The effect was noted by Ptolemy on the basis of observations by himself and Hipparchos (cf. Toomer 1984, p. 220) and is known as the *evection*.

Another large effect on the Moon's celestial longitude, the *variation*, was discovered by the Danish astronomer Tycho Brahe [1546–1601]. It has an amplitude of 39′ and a period of $P_{syn}/2$; it is maximum at the quadratures (quarter Moon phases) and vanishes at oppositions and conjunctions (full and new Moons) (Brouwer and Clemence 1961, p. 626). The "variation" is large enough to have been detected in the ancient world; yet there is no explicit mention of it by Ptolemy. This has been attributed to the circumstance that the Greeks were working mainly with eclipse data—and therefore with data taken at oppositions (for lunar eclipses) and conjunctions (solar eclipses). In any case, the possibility that Ptolemy discovered this effect has been discounted (cf. Pedersen 1974, p. 198). It is interesting to note that Ptolemy's theory of the Moon's motion predicted a variation in angular size of the Moon that was clearly contradicted by observational data that must have been known to him. See §7.3.2 for a further discussion. We also consider the observability of the variation of the inclination by much earlier observers (Megalithic!) in §6.2.

The month is a unit of time associated with the Moon, and we will discuss the month in the context of time and time intervals in §4.14, but there are actually several kinds of months, which help to highlight aspects of the Moon's complex motions. With one exception, they are the periods of the Moon in its orbit with respect to particular reference points or directions:

(1) The *sidereal month* is the orbital or the sidereal period; it is the period of revolution of the Moon around the Earth with respect to a line to a distant star.

(2) The *tropical month* is the interval between successive passages of the Moon through the vernal equinox. Due to *precession* (from the long-term wobbling of the Earth, as the Moon and Sun act to pull the equatorial bulge into the ecliptic plane; see §3.1.3), the vernal equinox is slowly moving westward in the sky at a rate of about 50″/year. Therefore, the tropical period is slightly shorter than the orbital or sidereal period.

(3) The *draconitic*, *draconic*, or *nodal month* is the interval between successive lunar passages through the ascending node. Because the node is regressing at a relatively high rate, the Moon meets it much sooner than it would a line to a distant star. It is therefore much shorter than the sidereal month. Figure 2.17 illustrates the changing appearance of the lunar orbit with respect to the (a) horizon and (b) ecliptic because of the regression of the nodes, and the changing diurnal arcs during the month from major to minor standstill.

(4) The *anomalistic month*, the period from perigee to perigee. The *argument of perigee*, the angle between ascending node and the point of perigee in the orbit, is advancing, i.e. moving eastward in the direction of the Moon's orbital motion, and so the anomalistic month has a longer length than the sidereal month.

(5) The *synodic month* is the month of phases, the interval from new Moon to new Moon. It is the period with respect to a line between the Earth and the Sun. The Earth's motion around the Sun shows up in the eastward shift of the Sun, that is, in the direction of the Moon's orbital motion. The Moon's catching up to the Sun causes the synodic month to be longer than the sidereal month.

[28] The Sun takes ~$205\overset{d}{.}9$, not half a tropical year ~$182\overset{d}{.}6$ to move from the longitude of lunar perigee to that at apogee because of the advancement of the apsidal line of the Moon's orbit.

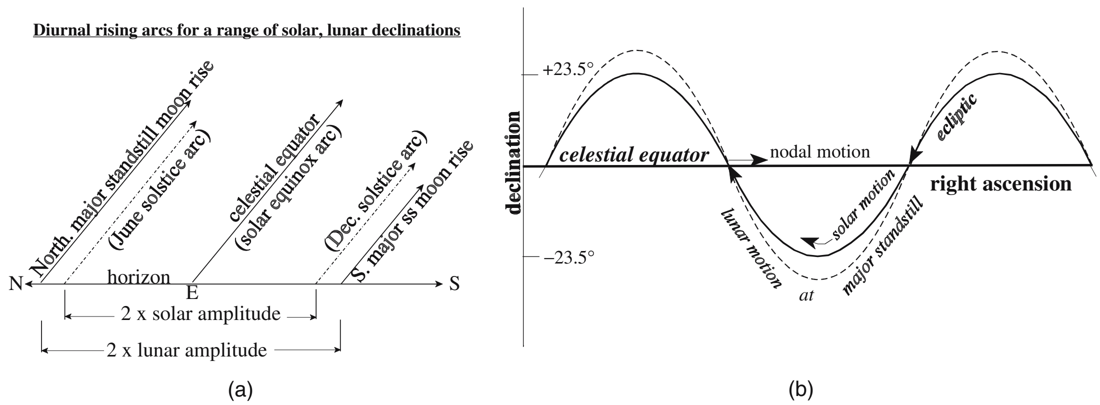


FIGURE 2.17. The changing appearance of the lunar orbit with respect to (a) the horizon and (b) the ecliptic because of the regression of the nodes. For clarity, only the major standstill of the Moon is illustrated. Drawing by E.F. Milone.

TABLE 2.6. Lengths of lunar months.

Type of month	Length
P_{sid}	$27^{d}.321\,662 = 27^{d}07^{h}43^{m}11^{s}.6$
P_{trop}	$27^{d}.321\,582 = 27\ 07\ 43\ 04.7$
P_{drac}	$27^{d}.212\,221 = 27\ 05\ 05\ 35.9$
P_{anom}	$27^{d}.554\,550 = 27\ 13\ 18\ 33.1$
P_{syn}	$29^{d}.530\,589 = 29\ 12\ 44\ 02.9$

Because it is not an integral number of days, this has had important consequences for calendars involving the moon. When we mention the word *lunation*, we usually refer to the synodic month.

(6) The *civil month* is the unit of month in use within a certain political jurisdiction. The modern civil month has 28, 29, 30, or 31 integral days, depending on the particular month and year. It evolved from the synodic month (see §4.2).

The lengths of these various types of months are summarized in Table 2.6; the synodic and civil months will be further discussed in §4.1.4, whereas the implications of the lunar motions for the azimuths of rise and set and the visibility of the Moon will be discussed in §3.2 and for eclipses in §5.2.

The Moon's motions are difficult to follow, and it is to the great credit of the ancient observers that they made as much sense of these motions as they did. In addition, they were able to find several examples of regularity in lunar motion.

It is sometimes said that the Moon "comes back to the same place" after not one but 3 sidereal months. After one sidereal month, the Moon is at the same position among the stars; so if the phrase has meaning, it must refer to the location in the sky of the observer. After one sidereal month, the Moon will not be at the same hour angle because the sidereal month interval is not an integral number of days. Three sidereal months, however, amount to nearly an integral number of days. From Table 2.6, where the units for all months are in mean solar days (MSDs),

$$3 \cdot P_{sid} = 81^{d}.96499 = 81^{d}23^{h}9^{m}35^{s}.$$

Thus, the Moon will be about an hour east of the meridian after three sidereal months at the same time of night—and in the same constellation—but it will be at a different lunation phase. An interval of three synodic months covers $88^{d}.59177$, at the end of which, the lunar phase is repeated, so that the phase after three sidereal months will be earlier by an angle of roughly

$$\Delta\Phi = \frac{88^{d}.59177 - 81^{d}.69499}{29^{d}.530589} = 0.23355 \text{ lunation}.$$

Thus, if the Moon was initially full, three sidereal months later, it would be in a waxing gibbous phase, just after first quarter, having slipped back not quite a quarter phase. For every subsequent three-month interval, the Moon's phase will slip by an additional 0.234 lunation on average. In 12 sidereal months, [4 × (0.23355) = 0.9342], the phase repeats more closely, but results in a slight phase shift for each such 12-sidereal-month interval.

The movement of the Moon among the stars requires that the Moon traverse a different region each day for the approximately 27 days of its sidereal period. In an anthropomorphic sense, it spends each night in a different "house."[29] The perception and transmission of lunar mansions from one culture to another will be discussed throughout §§6–15 and in some detail in §§7 and 15.

The regression of the nodes of the Moon's orbit has a major consequence for the behavior of the Moon in our sky; one that is spectacular at high latitude locations on Earth. Over an 18.6-year period, the shifting node alters the range in declination achieved by the Moon during the month: from ~±18½° to ~±28½°; this variation changes the azimuthal

[29] Or "lodge" or "mansion."

TABLE 2.7. The ancient planetary names.

Modern	Greek	Babylonian	Persian	Indian	Chinese
Sun	Helios/Apollo	Shamash	Mithra	Surya	Thai Yang (Greater Yang)
Moon	Selene	Sin	Mâh	Soma	Thai Yin (Greater Yin)
Mercury	Hermes/Apollo	utu	Tîra/Tîr	Budha	Chhen hsing = Hour Star
Venus	Aphrodite	dili-pát Ishtar	Anâhitâ	Śukra	Thai pai = Great White One
Mars	Ares/Herakles	an, ^{d}sal-bat-a-ni Nergal	Verethragna	Kārrtikeya	Ying huo = Fitful Glitterer
Jupiter	Zeus	múl-babbar Marduk	Ahura Mazda/Oromasdes	Brhaspati	Sui hsing = Year Star
Saturn	Kronos/Chronos	genna	Zervan (Zurvan)	Prajapati (Śanaiścara)	Chen hsing = Exorcist

amplitude, resulting in a striking weaving movement of the rise and set points of the Moon on the horizon over an 18.6-year interval. The phenomenon bears strongly on the question of megalithic lunar alignments discussed in §3.2.1 and at length, in applications, in §6.

That there is a difference between the anomalistic and sidereal periods implies the rotation of the orbit of the Moon such that the line of apsides (the major axis) moves forward (i.e., eastward, in the direction of the Moon's motion in its orbit). This motion was also known in ancient China, apparently. Needham (1959, Fig. 180, p. 393) shows a diagram with a series of overlapping orbits called "The Nine Roads of the Moon," which, he writes, are due to apsidal motion, as it was understood in the Han.

The physical appearance of both Sun and Moon over time, eclipse phenomena, and association of these bodies with tides, we leave to later chapters; these phenomena too have had profound effects on the history of astronomy and, indeed, of civilization.

2.4. The Planets

2.4.1. Wanderers

Compared with the constellations and other relatively fixed stars, some are "wandering stars," the translation of the Greek words (αστέρες) πλανῆται or πλάνητες ἀστέρες (singular: πλανήτης, sometimes πλάνης, or πλάνητος) from which we derive our word *planets*. In Wagner's opera *Die Walküre*, Wotan is called simply "the wanderer," the still powerful, but fatally limited, lord of the heavens. Because they took certain liberties compared with the fixed stars, the astral entities we know as planets appeared to have intelligence. Moreover, they were far above the Earth, apparently immune from local plagues and disasters and, therefore, were of a higher order of being than was mankind. Because they were evidently immortal beings, they were necessarily gods.[30] We know the names of these gods. In the Greek world of the 3rd century B.C., there were seven planetary gods: Selene (the Moon), Hermes (Mercury), Aphrodite (Venus), Helios (the Sun), Ares (Mars), Zeus (Jupiter), and Kronos (Saturn).

In India, there were two dark, and therefore invisible, additional planets—the head and tail of the dragon, *Rahu-head* and *Rahu-tail*, or *Rahu* and *Ketu*. These invisible planets were later interpreted as the ascending and descending nodes of the moon's orbit respectively, which caused eclipses.

The planetary names given by the German tribes can be found in several of the days of the week as expressed in English and in several other languages. The days of the week arise from a scheme for the order of the planetary orbits (cf. §4.1.3). The names by which the planets, or their associated gods (Ptolemy refers to each planet as "the star of . . .") were known to various cultures can be found in Table 2.7. They include the Sun and Moon, which in antiquity were considered among the planets, because they too wander among the stars.

The Greek list is from late antiquity (after ~200 B.C.). A Hellenistic list dating from the latter part of the 4th century B.C. is given by Toomer (1984, p. 450 fn. 59): Stilbon (Στιλβων) for Hermes; Phosphorus (Φωσφωρως) for Aphrodite; Pyroeis (Πυροεις) for Ares; Phaethon (Φαεθων) for Zeus; and Phainon (Φαινων) for Kronos, at least sometimes identified with Chronos (time) [van der Waerden (1974, pp. 188–197)]. At still earlier times (and in Ptolemy's Almagest), they were called by their *late antiquity* sacred names but with the prefix "star of."

The Persian names are widely attested. The spelling used here is from van der Waerden (1974). See Cumont (1960) (and §§7.3.3 and 15) for further discussion of the role of Mithras.

The Babylonian names, from Neugebauer (1955/1983) and van der Waerden (1974), include both the names of their cuneiform signs first, and, following, the names of the associated gods. The name for Jupiter literally means "star white."

Yano (1987, p. 131) provides parallel lists of the planets ordered in weekday order in Sogdian, and in Indian Sanskrit, from a Chinese text of the 8th century, entitled *Hsiu-yao Ching*. In addition to the known planets, *The Book of Master Chi Ni* (*Chi Ni Tzu*) names an invisible "counter Jupiter," *Thai Yin* (Needham/Ronan 1981, p. 190), which had primarily astrological purposes. The Moon was given this name by the 1st century (Needham/Ronan 1981, pp. 89, 90), but apparently has nothing to do with the invisible planet.

[30] DHK thinks it is truer to say that the characteristics of the planets determined the nature of what came to be called "gods." EFM thinks the point is moot.

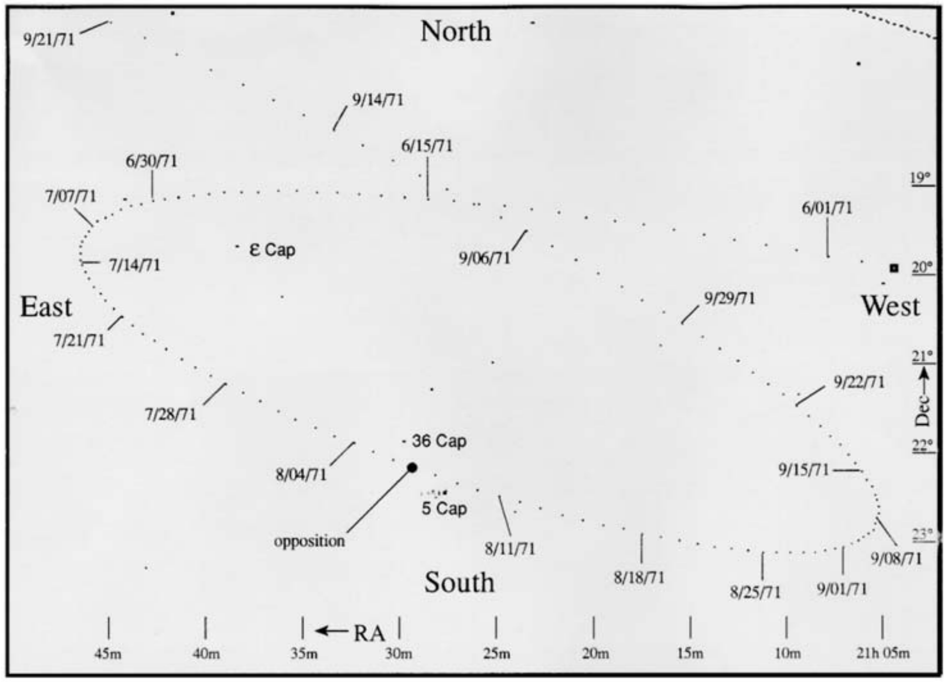


FIGURE 2.18. The movement of the planet Mars, showing its retrograde motion between July 14 and September 10, 1971. The position of opposition is marked. Produced by Bryan Wells with the Voyager II software package (Carina Software).

The wandering of the planets is primarily eastward among the stars, although the eastward motion is less dominant for Mercury and Venus, as those planets pass between the Earth and the Sun moving rapidly westward. The eastward motion is called *direct* motion. The average eastward motion is slower as one descends Table 2.7. For any planet, there are times when the motion is westward, or *retrograde*. In order to accomplish this result, the planet must slow its eastward motion and stop, thereby displaying variable speed across the sky. This behavior was carefully noted by the Babylonian astronomers, and later, by others. The motion of Mercury relative to the ecliptic is depicted as a circle in the *Thu Shu Chi Chhëng* of 1726, as described by Needham/Ronan (1981, p. 189).

An example of retrograde motion for an exterior planet, Mars, is shown in Figure 2.18. The positions of Mars over a 4.5-month interval are shown along with its location at opposition and a few of the stars in the vicinity. The explanation of this motion in the geocentric framework that dominated attention in antiquity required extensive geometrical modeling. Combinations of circular motion succeeded, to various degrees, with the developments of concentric spheres (§7.2.3) and eccentric circles and epicyles. The latter marked the climax of Ptolemy's astronomy (§7.3.2).

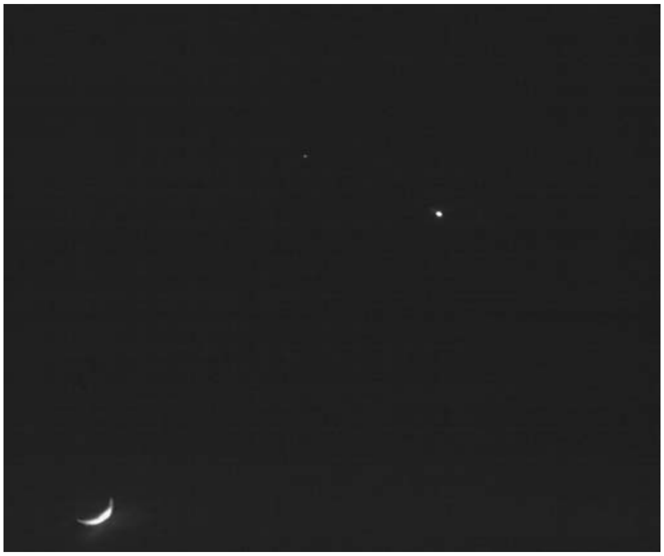
2.4.2. Morning and Evening Stars

Any object that rises within a few hours before sunrise will be seen in the eastern, morning sky. Such an object, particularly a bright object, can be called a *morning star*. Similarly, any object setting within a few hours following sunset, and therefore visible in the western, evening sky, can be called an *evening star*. Planets are among the brightest objects in the sky and, because of their wanderings, will noticeably appear and disappear in both roles. Venus is particularly dominant as an evening or a morning star: It can be the brightest object in the sky after the Sun and Moon. Venus can cast shadows in an otherwise dark sky, and it can be seen by a sharp eye sometimes even in daylight. In a twilight sky, it can dominate all other celestial objects. Often in popular and classical literature, and in the arts, "the evening star" refers solely to Venus. In Figure 2.19, the brilliance of Venus in evening twilight shows us why.

In Wagner's epic opera *Tannhäuser*, the goddess of love makes an onstage appearance. Curiously, though, the evening star is not equated with the divine sexpot, but rather with the pure and noble Elisabeth, her opposite pole. The dichotomy is between the beauty and inspiration of the evening star and the lusty Venus of Venusberg, the cause of Tannhäuser's downfall, as it were. For similar reasons, "the morning star" may indicate Venus alone of all potential dawn twilight candidates.

The Greek world identified the two appearances of (Aphrodite): As evening star, it was *Hesperus*, to which our word "vespers" (evensong) is related. In its morning star role, it was known as *Phosphorus*, "bearer of light." It may be startling to some to realize that its Latin counterpart is *Lucifer*, "bringer of light."[31]

[31] Among others, Gray (1969/1982, pp. 132–133) traces the concept of Lucifer as fallen angel (that of Milton's *Paradise Lost*) to Isaiah



(a)

(b)

(c)

FIGURE 2.19. At maximum brightness, Venus is the brightest object in the sky after the Sun and the Moon: (a) Venus as an evening star, shown here with the Moon and Mars in a 1-second, 210-mm exposure, Calgary, Jan. 24, 1985. (b) Venus at dusk at the European Southern Observatory, Chile, Jan. 1977. Photos by E.F. Milone. (c) A telescopic (41-cm) view of Venus taken at the RAO at elongation, from the archives (no other details recorded).

Galileo (1610) first observed that "the mother of loves emulates Cynthia" (the Moon) on the basis of his telescopic studies. Venus undergoes changes of phase, angular size and distance, seen by the unaided eye as a waxing and waning of its brightness—like the fortunes of love (see Figure 2.19c). The planet was considered the visible manifestation of the goddess in the Mediterranean region (Roman *Venus*, Greek *Aphrodite*, Babylonian *Ishtar*, etc.) (van der Waerden, 1974, p. 57), but the depiction of Venus as a female deity was not universal. *Athar* was the

(14:12–20): "[12]How art thou fallen from heaven, O Lucifer, son of the morning! *how* art thou cut down to the ground, which didst weaken the nations! [13]For thou hast said in thine heart, I will ascend into heaven, I will exalt my throne above the stars of God" (King James version). According to Gray, this is not a direct reference to Satan, but to the king of Babylon (most likely Sargon II or Sennacherib); Isaiah is referring to a Babylonian myth that describes the attempt of Athar, the Venus god among the Arabs, to take Baal's place while the god was absent. We think that a direct astronomical identification with Venus as evening star becoming morning star is, however, likely here. The subsequent Christian view of Lucifer derives partly from a definition of Satan in the Council of Braga, 563 A.D. (Metzger and Coogan 1993, p. 679).

name of the Semitic Venus god; it was not the only male Venus god.

In Mesoamerica, which also had a male Venus god, the growth of brilliance of Venus as evening star, its eventual decline, and its return as a bright morning star were powerful symbols of struggle, death, and rebirth. There is a possible depiction of the Venus legend of Mesoamerica on the wall of a ballcourt in El Tajin.[32] In Western culture, the analogy between the morning star and resurrection is not as widespread or explicit, but these references to the morning star in the New Testament[33] are metaphors for the second coming:

> For we did not follow cleverly devised myths when we made known to you the power and coming of our Lord Jesus Christ, but we were eye-witnesses of his majesty. For when he received honor and glory from God the Father and the voice was borne to him by the Majestic Glory, 'This is my beloved Son, with whom I am well pleased,' we heard this voice borne from heaven, for we were with him on the holy mountain. And we have the prophetic word made more sure. You will do well to pay attention to this as to a lamp shining in a dark place, until the day dawns and the morning star rises in your hearts. [2 Peter 1:16–19]
>
> Behold, I am coming soon, bringing my recompense, to repay every one for what he has done. I am the Alpha and the Omega, the first and the last, the beginning and the end.
>
> I Jesus have sent my angel to you with this testimony for the churches. I am the root and the offspring of David, the bright morning star. [Revelation 22:14, 16]

The passage from Revelation invokes the completion of a cycle, and the "Morning Star" reference applies the metaphor of the Venus cycle.

The visibility of an object in the evening or morning sky depends mainly on its angular distance from the Sun, but also on the observer's latitude and the time of year. It is reported that Venus was actually observed as an evening star on one evening and as a morning star the next day by observers on the Yucatan peninsula in Mexico. Although unlikely under most circumstances, it does occur. If Venus or Mercury are far north of node while they are passing between the Earth and the Sun, thanks to the tilt of the Sun's diurnal path near the horizon, they can be seen to the north of the Sun just after sundown, and again north of the Sun the following morning. Figure 2.20 illustrates various orientations of the ecliptic and celestial equator to the east and west points of the horizon at the equator and at mid-latitude sites for the important turning points of the seasons: the solstices and the equinoxes. We deal with the related question of the visibility of an object close to the Moon or Sun in §3.1.2.5.

[32] DHK finds this interpretation by C. Cook de Leonard (1975) of the ballcourt panels in this Gulf-coast city of ancient Mexico unconvincing.

[33] See also: Revelation 2:27, based on the Messianic symbolism based on Numbers 24:17 ("A star shall come out of Jacob and a Sceptre shall rise out of Israel"); Matthew 2:2 and 2:10; and our discussion of the Star of Bethlehem in §15. All citations are from the Revised Standard Version (Thomas Nelson and Sons: New York, Edinburgh), 1946.

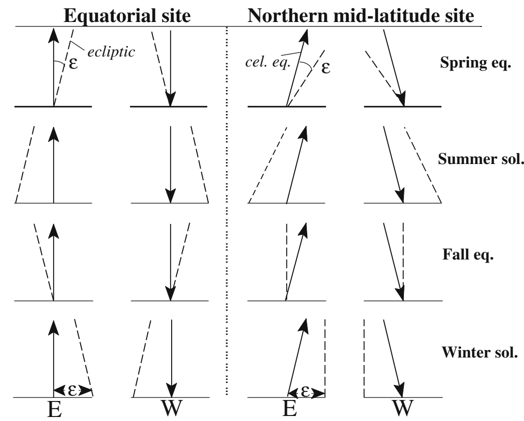


FIGURE 2.20. The orientations of the ecliptic and celestial equator to the horizon near the east and west points of the horizon as seen from the equator and from mid-latitude sites for the important turning points of the seasons: the solstices and the equinoxes. These are views from inside the celestial sphere. Drawn by E.F. Milone.

TABLE 2.8. Planetary phenomena.

Elongation[a]	Phenomenon	Symbol
0°	Conjunction	☌
60°	Sextile	∗
90°	Quadrature	□
120°	Trine	Δ
180°	Opposition	☍

[a] Elongation from the Sun or relative separation between planets.

2.4.3. Planetary Phenomena

Morning and evening stars are only aspects of a more general class of observed events collectively known as *planetary phenomena*. The configurations that the planets achieve with the Sun, stars, or with each other, enabled early observers to keep track of the planets' motions and, from these, to discover periodicities. The phenomena were summarized in terms of elongations or differences in celestial longitude (see Table 2.8). Astrologers make use of all the configurations, but the sextile and trine configurations are not often referenced in modern astronomy. Among other astrological terms that are used to refer to the positions of planets in the sky are *ascendancy* (rising), *descendancy* (setting), *medium caelum* or *mid-heaven* (where the object traverses the celestial meridian),[34] and *imum caelum* or *anti-heaven* (where the object traverses the portion of the celestial meridian below the horizon). Figure 2.21 demonstrates the geocentric planetary configurations, viewed from the north ecliptic pole.

[34] For a circumpolar object, the "mid-heaven" refers to the upper of the two meridian transits, namely, the *upper culmination*.

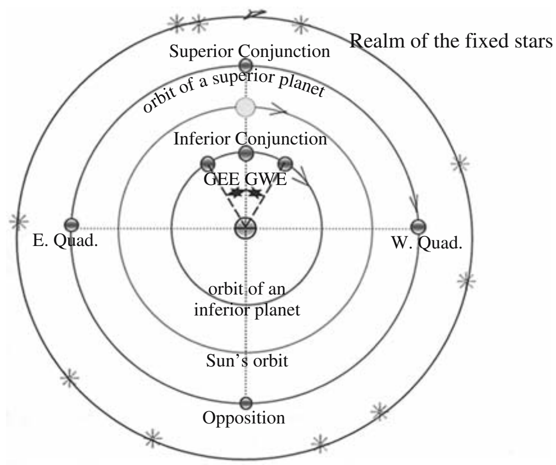


FIGURE 2.21. The geocentric planetary configurations—and cosmology—of antiquity. Drawing by E.F. Milone.

Note that an object at a conjunction will rise at the same time as the Sun,[35] whereas an object at opposition will be opposite the Sun in the sky and so will set as the Sun rises, and rise as the Sun sets. Planetary phenomena may involve another planet, the Moon, or a star, but in such cases, the other object is always named. The Sun is intended implicitly when no other object is stipulated. Several other terms that depend on sky location are the sextile (separation of 60°), quadrature (90°), and trine (120°). At quadrature, a planet will rise ~6 hours before (if at eastern quadrature) or after (if at western quadrature) the Sun. The sextile and trine are little used in astronomy, but are frequently used by modern astrologers and, more important for us, were extensively used by ancient astrologers.

Several terms are used to describe the visibility of the an object. When a star or planet formerly invisible due to proximity to the Sun first becomes visible in the morning sky, it is said to be at *heliacal rising*. When the object is last seen to set in the west after the Sun in the evening sky, it is said to be at *heliacal setting*. Two other pairs of terms are often confused with heliacal risings and settings. Either the rising or setting of a star in the evening, i.e., at or just after sunset, is referred to as *acronychal*[36] and either the rising or setting of a star at sunrise is said to be *cosmical*. Thus, a star that is first seen to rise as the Sun sets is said to be at *acronychal rising*, and if it sets with the Sun, *acronychal setting*; one that sets as the Sun rises is at its *cosmical setting*, and if it rises as the Sun rises, it is at *cosmical rising*. Astronomers do not always follow these definitions strictly, however; so the context must be used to understand what the terms are intended to mean. Parker and Neugebauer (1960, pp. 55, 57, 72) unambiguously identify the term "acronychal setting" to mean setting right after the Sun, i.e., seen in the west just after sunset, in accord with the definitions. In *Sky Watchers of Ancient Mexico*, Aveni (1980, p. 325, *n.* 16) correctly uses the term "cosmic rising" to indicate rising at the same instant as the Sun (and "cosmic setting" to indicate setting at the instant that the Sun sets). However, he also defines "achronic" to indicate rising when the Sun sets (in agreement with the standard definition of "acronychal") but also a setting as the Sun rises (which disagrees). Elsewhere in *Sky Watchers*, the applications of "heliacal rising" and "heliacal setting" are consistent with both our and Aveni's definitions (e.g., pp. 87, 99, 109*ff*), except for one discussion in which "heliacal setting" is used to describe a setting at sunrise in a discussion of the behavior of the Pleiades at Teotihuacan (Aveni 1980, p. 112). Indeed, many authors use this broader usage of "heliacal" to encompass both the restricted sense of the word and the acronychal definition (because they are both, in a sense, heliacal phenomena). However, in the current work, we try to be consistent with the stricter definitions.

As we note in §3.1.5, the hour angle difference from the Sun and the altitude of the object at first and last visibility depend on its brightness and on sky conditions; it is more difficult to see the light of most celestial objects when they near the horizon because the light-scattering path through the atmosphere is the longest at such times. The relationship between the first and last visible phenomena and the true instants when the star/planet and the Sun rise/set together was the topic of a book in the ancient world written by Autolycus of Pitane: *On the Risings and Settings*.

Because the Moon, Mercury, and Venus were considered to be below the orbit of the Sun, they were called *inferior* planets; those beyond the Sun were *superior* planets. Heliocentrically, they are *interior* and *exterior*, respectively, to Earth's orbit. There are important differences between the apparent motions of these two types of planets.

For Mercury and Venus, the elongation reaches maximum values both east and west: the *greatest eastern elongation* (GEE) and *greatest western elongation* (GWE), respectively. When at eastern elongation, the planet is visible east of the Sun, therefore, after sunset and in the western part of the sky. At western elongation, the object is west of the Sun, and there visible before sunrise, and in the eastern part of the sky.

The geometry of the planetary configurations can be understood from Figure 2.22, which, although presented in a heliocentric framework, shows how the planetary configurations are generated relative to the earth.

It will be noticed that only interior planets go through an *inferior conjunction* and only exterior planets can achieve *quadrature* and *opposition*. Both types of planets can go through *superior conjunction*, although in current usage, superior planets are merely said to be at "conjunction" at such times, because this is the only type of conjunction (with the Sun) that they can achieve; i.e., they can never be at inferior conjunction. Exterior planets move eastward through the configurations: superior conjunction, eastern quadrature, opposition, western quadrature, and superior conjunc-

[35] Or nearly so: *Conjunction* is sometimes taken to mean identical celestial longitude, and sometimes, right ascension; in either case, if the declination of the two objects is not the same, they will almost certainly rise at slightly different instants of time.

[36] *Or acronycal*. Additional spellings that have been used for this word include *acronical*, *achronical*, and *achronichal*!

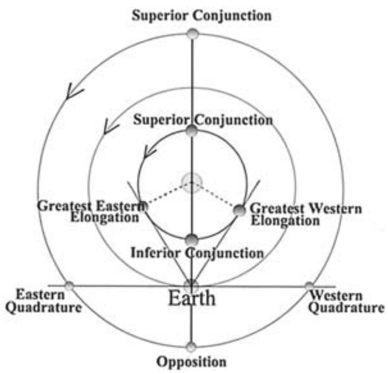


FIGURE 2.22. Successive positions of exterior and interior heliocentric planetary orbits, relative to an arbitrary position of the Earth, and showing how they give rise to the planetary configurations. Drawn by E.F. Milone.

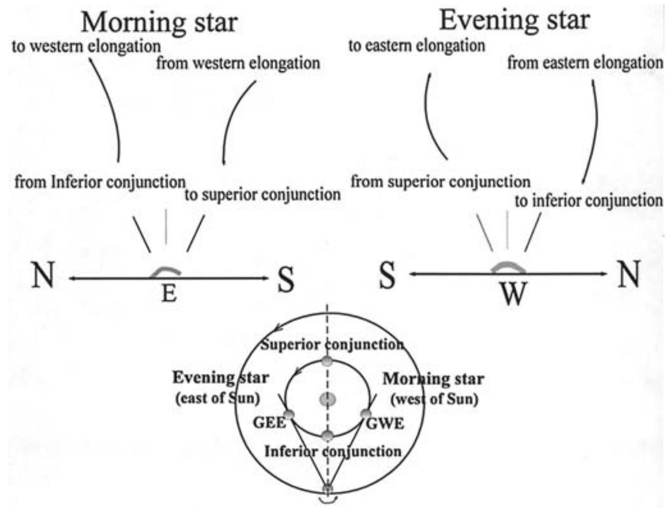


FIGURE 2.23. The motions of an interior planet in the (a) eastern and western skies and (b) in a heliocentric frame of reference. Note the ready explanation in the heliocentric system for the apparent limitation in the motion of an inferior planet. Drawn by E.F. Milone.

tion. Their motion is eastward all the time except during an interval around opposition when they briefly appear to show *retrograde* (westward) motion.[37] Interior planets may be in conjunction with the Sun, but most of the time, they are at some elongation less than GEE or GWE. Interior planets move from superior conjunction through increasing eastern elongations to GEE to decreasing elongations to inferior conjunction to increasing westward elongations to GWE to decreasing western elongations to superior conjunction. Following maxiumum eastern elongation (when they are *evening stars*), Venus and Mercury seem to fall toward the Sun at an increasing rate, and then move rapidly into the morning sky, where they continue westward at a decreasing rate until maximum western elongation is reached. Figure 2.23 illustrates their motions in the western and eastern skies and associated locations in a heliocentric sketch.

The order of the configurations over a synodic cycle, arbitrarily beginning at its heliacal rising, is as follows (with associated phenomena shown below each configuration). For an interior planet,

(1) First visibility in the morning sky (retrograde motion continuing) (heliacal rising, morning star)
(2) Greatest western elongation (onset of prograde motion) (morning star)
(3) Last visibility in the morning sky (prograde motion continuing) (morning star)
(4) Superior conjunction (prograde motion continuing) (rises and sets with the Sun)
(5) First visibility in the evening sky (prograde motion continuing) (heliacal/achronical setting, evening star)
(6) Greatest eastern elongation (onset of retrograde motion) (evening star)
(7) Last visibility in the evening sky (retrograde motion continuing) (evening star)
(8) Inferior conjunction (retrograde motion continuing) (rises and sets with the Sun)
(9) First visibility in the morning sky (retrograde motion continuing) (heliacal rising, morning star)

so that the interior planet moves westward from its GEE evening star appearance (through inferior conjunction) to its GWE morning star appearance; and it moves eastward from GWE (through superior conjunction) to GEE. For an exterior planet, again from heliacal rising:

(1) First visibility in the morning sky (prograde motion continuing) (heliacal rising, morning star)
(2) Western quadrature (prograde motion continuing) (morning star)
(3) First stationary point (beginning of retrograde motion)
(4) Opposition (acronychal rising)
(5) Second stationary point (end of retrograde motion)
(6) Eastern quadrature (prograde motion continuing) (evening star)
(7) Last visibility in the evening sky (prograde motion continuing) (evening star, heliacal/acronychal setting)
(8) Superior conjunction (prograde motion continuing) (rises and sets with the Sun)
(9) First visibility in the morning sky (prograde motion continuing) (heliacal rising, morning star)

Note that the average ecliptic motion of exterior planets is less than that of the Sun and, consequently, get passed by the Sun. The only retrograde motion that these planets undergo is around opposition, when the Earth, in a faster, interior orbit, passes these planets.

[37] It is important to note that in the ancient world, our "direct" or "prograde" (eastward) and "retrograde" (westward) terms for these motions were not in use. Ptolemy uses the term "εἰζ τὰ ἑπόμενα," "toward the rear," to mean eastward motion. He uses the term "εἰζ τ ὰ προηγούμενα," "toward the front," to mean westward. To Ptolemy, the "forward" direction was that of the diurnal motion. See Toomer (1984).

The observations of specific configurations, especially of first and last visibility in ancient Mesopotamia, will be elaborated in §7.1.2.1. See Aveni (1980, pp. 109–117) for a similar treatment of configuration visibility in Mesoamerica. The apparent path of a planet in the sky varies from cycle to cycle because of the relative changes in ecliptic latitude as well as in longitude due to orbital inclinations. Thus, for example, the retrograde motion of an exterior planet may be a loop of various degrees of flattening or a zigzag. The looping pattern of an interior planet also varies during its pass through inferior conjunction. The relative periods of motion may be used to determine repetitions of these motion patterns.

2.4.4. Periodicities, Cycles, and Interrelationships

The periodicities in the motions of the planets were studied intently by astronomers from many cultures. Detailed records are available from Mesopotamia, India, China, and Mesoamerica. According to Neugebauer (1969, p. 127), the main interest of the Babylonian astronomers was the first and last visibility of the planets due to their motions and that of the Sun.[38] The earliest observational records from Mesopotamia date from the middle of the second millenium B.C.; from China, they are slightly later. See §§7.1.3 and 10.1.4 for further discussion of these sources.

There are two basic periods by which we characterize the motion of a planet in the sky: the *sidereal* and the *synodic periods*. The modern sidereal period is the time interval between successive passages of the planet through a line between a distant star and the Sun. The synodic period, on the other hand, is the (average) time interval between successive passages of the planet through a Sun-Earth line; it is therefore a relative period. These periods are analogous to the lunar sidereal and synodic months. The difference between the two types of period arises, in the case of an interior planet, from the time required for the interior planet to lap the earth as both revolve counterclockwise around the Sun. In the case of an exterior planet, the Earth moves faster, and the difference arises from the time required for earth to lap the exterior planet. Calculation[39] of the relative rate of motion of a planet in terms of orbital motions of the planet and Earth gives the following expressions for the synodic periods (P_{syn}) of interior and exterior planets, respectively:

$$\text{Interior:} \quad \frac{1}{P_{\text{syn}}} = \frac{1}{P_{\text{sid}}} - \frac{1}{P_{\oplus}}, \tag{2.23}$$

$$\text{Exterior:} \quad \frac{1}{P_{\text{syn}}} = \frac{1}{P_{\oplus}} - \frac{1}{P_{\text{sid}}}, \tag{2.24}$$

where P_{sid} is the planet's sidereal period and $P_{\oplus}$ is that of the earth. Note the reciprocal relations among the synodic and sidereal periods. If the periods are taken in units of the Earth's sidereal period of revoution around the Sun, the expressions simplify further.

Neugebauer (1969, p. 172) gives "synodic periods" of Saturn and Jupiter: 28;26,40 and 10;51,40, in the sexigesimal (base-60) notation of the Babylonians used by Neugebauer. These quantities, $28\overset{\text{y}}{.}444$ and $10\overset{\text{y}}{.}861$ in decimal-based notation, are approximately equal to $P_{\text{sid}} - 1$; by setting $P_{\oplus} = 1$ in (2.24), one finds that this quantity is the *ratio* of the two periods, viz., $P_{\text{sid}}/P_{\text{syn}}$ when they are expressed in units of the Earth's period of revolution. They are not, therefore, the *synodic periods* as usually defined in astronomy. They are, however, very interesting nevertheless.

In an ancient astronomy context, one can draw a distinction between the time interval for a planet to come to the same configuration, e.g., from opposition to opposition, and the time for it to reappear in the same asterism or at the same celestial longitude. The former is the synodic period as defined astronomically, whereas the latter is a kind of sidereal period, although the motion of the earth around the Sun creates a moving platform and the observation therefore suffers from *parallax*. Figure 2.24 illustrates the effect of parallax on the apparent direction to the planet in space.

Even with the complication of parallax, ancient astronomy was capable of giving relatively high precision in the periodicities of the planets; the way they did this was to make use of large numbers of cycles. The number of years required for a planet to reach the same configuration, *in the same star field*, had to be recorded. The number of times the planet moved around the sky through a particular star field provided an integer multiple of the sidereal period. The number of years required for the planet to reach this point in the sky and have the same configuration (with the Sun) is a multiple of the synodic period. The relationship is one of a ratio: $mP_{\text{sid}} = nP_{\text{syn}} = N$ years. Hence, if m and n are observed, the ratio of the two type of periods follows. For Saturn, we have $m = 9$, $n = 256$, $N = 265$ y; whence, $P_{\text{sid}}/P_{\text{syn}} = 256/9 = 28.444$. For Jupiter, $m = 36$, $n = 391$, $N = 427$ y, so that $P_{\text{sid}}/P_{\text{syn}} = 391/36 = 10.861$. Given the total number of years required for the same configuration to be observed[40] at the same place among the stars, we can compute, in theory, both P_{sid} and P_{syn}. For instance, a complete cycle for Saturn would take 265 years. Therefore, $P_{\text{sid}} = N/9 = 265/9 = 29.444$ y, and $P_{\text{syn}} = N/256 = 265/256 = 1.0352$ y. These results can be compared with the modern values, $P_{\text{sid}} = 29.458$ y and $P_{\text{syn}} = 1.0352$ y (see below). For Jupiter, $P_{\text{sid}} = N/36 = 427/36 = 11.8611$ y, and $P_{\text{syn}} = N/391 = 427/391 = 1.0921$ y, compared with modern values, $P_{\text{sid}} = 11.8622$ y and $P_{\text{syn}} = 1.0921$ y.

The results are excellent for the synodic periods, and the derived sidereal periods are reasonable approximations, but they are not exact. One of the reasons for deviations from modern values is the effect of the shape of the orbit—the orbital eccentricity (others include the accuracy and preci-

[38] The heliacal risings and settings of stars are analogous, but simpler because, unlike planets, their annual changes in position are not detectable to the naked eye.

[39] The difference between the mean angular rates ω_{planet} and $\omega_{\oplus}$ is the relative rate: ω_{rel}. Because $\omega = 2\pi/P$ and $P_{\text{rel}} = P_{\text{syn}}$, we obtain equations (2.23) and (2.24), after division by 2π.

[40] Or, as in Mesopotamia, *calculated*, based on the differences between observed and exact ecliptic longitudes in near-repetitions of the phenomena.

sion of length of the year, and the use, exclusively, of the ecliptic longitude and exclusion of the ecliptic latitude). The time interval between repetition of celestial longitude coordinate values (and the mean sidereal period) depends on the traveled portion of the orbit of the planet involved: Near perihelion, the interval will be shorter than near aphelion. It also depends on the change in position of the earth in its orbit. The length of the synodic period that is specified in most planetary tables is a period that a planet would have if both it and the earth moved at constant, average rates of motion in their respective orbits. The lap difference involves different portions of the orbit and therefore different velocities, reflected in the change of angular motion of the planet across the sky. Of course, the larger the number of cycles that are involved, the smaller is the effect of the remaining segment of the orbit. The ancients were interested in such problems, and we consider the matter somewhat further in §7. At this point, we need to discuss how to characterize orbits.

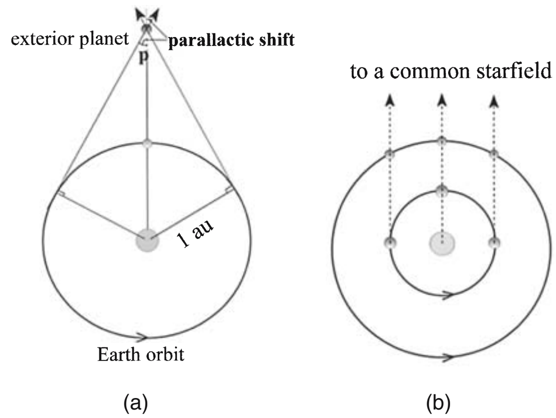


FIGURE 2.24. The effect of parallax on the apparent direction to a planet: (a) The shift of an exterior planet against the starry background. (b) Compensating motions of the planet and Earth may reduce the parallax shift: The positions of alignment of earth and planet to a distant star are not unique but may occur at nearly any planetary configuration. The three positions of the outer planet shown here place it in the same star field. See Figure 2.18 for the positions of Mars near an opposition. Drawn by E.F. Milone.

Table 2.9 lists the mean sidereal and mean synodic periods as well as other orbital parameters for the planets. The sources of the data in Table 2.9 are the Astronomical Almanac for the year 2000 and earlier editions and Allen's Astrophysical Quantities (Allen 1973, pp. 140–141; updated by Cox 2000). The elements refer to the mean equinox and ecliptic for the year 2000. The rates $d\Omega/dt$ and $d\omega/dt$ and the values of the periods are long-term average values. The precision in the elements actually exceeds the number of significant figures that are shown, but because of the gravitational perturbations produced by the other planets, the elements will vary with time. Following the modern planetary names are the adopted symbols, the semimajor axis or mean distance to the Sun in units of the *astronomical unit*, a (and, below, the date of a recent passage through perihelion T_0), the orbital eccentricity e (and, below it, the mean longitude ℓ), the orbital inclination, the longitude of the

TABLE 2.9. Planetary orbital parameters.[a]

Planet/element	a (AU) T_0	e ℓ	ι	Ω $d\Omega/dt$	ω $d\omega/dt$ (″/y)	n (°/d)	$\langle P_{sid}\rangle$ (MSD)	$\langle P_{Syn}\rangle$ (MSD)
Mercury	0.38710	0.20563	$7^{\circ}.0050$	$48^{\circ}.33$	$29^{\circ}.12$	4.09235	$87^{d}.969 = 0^{y}.24085$	$115^{d}.8775$
(☿)	2000 Feb 16	$119^{\circ}.37582$		+42.67	+55.96			
Venus	0.72333	0.00676	3.3946	76.68	55.19	1.60215	$224.699 = 0^{y}.61521$	$583.9214 \approx \oplus +219^{d}$
(♀)	2000 Jul 13	270.89740		+32.39	+50.10			
Earth[b]	0.99999	0.01670	0.0001	143.9	319.04	0.98562	365.256363 = 1SY	. . .
(⊕)	2000 Jan 3.2	155.16587		. . .	+61.8		$= 0^{y}.99997862$JY	
							= 1.000038804TY	
Mars	1.52376	0.09337	1.8498	49.56	286.54	0.52400	$686.980 = 1^{y}.8809$	$779.9361 \approx 2\oplus +49^{d}$
(♂)	1998 Jan 7	24.53534		+27.7	+66.26			
Jupiter	5.20432	0.04879	1.3046	100.49	275.03	0.08305	$4332.589 = 11^{y}.8622$	$398.8840 \approx \oplus +34^{d}$
(♃)	1987 Jul 10	38.98221		+36.39	+57.98			
Saturn	9.58189	0.05587	2.4853	113.64	336.23	0.03323	$10759.22 = 29^{y}.4578$	$378.0919 \approx \oplus +13^{d}$
(♄)	1974 Jan 8	51.87716		+31.42	+70.50			
Uranus[c]	19.22354	0.04466	0.7725	73.98	96.30	0.01169	$30685.4 = 84^{y}.0138$	369.6560
(⛢)	1966 May 20	314.13799		+17.96	+54.			
Neptune[c]	30.0917	0.01122	1.7681	131.79	267.67	0.00597	$60189. = 164^{y}.792$	367.4867
(Ψ)	1876 Sep 2	305.53768		+39.54	+50.			
Pluto[c]	39.2572	0.24459	17.1533	110.28	113.71	0.00401	$90465. = 247^{y}.685$	366.7207
(♇)	1989 Sep 5	239.27437						

[a] Heliocentric osculating orbital elements, referred to the mean ecliptic and equinox of J2000.0. T_0 is a recent date of passage through perihelion.
[b] Elements are for the barycentre of the Earth-Moon system. SY, JY, and TY are Sidereal, Julian, and Tropical years, respectively, and are given in units of mean solar days (cf. §4.1.2). A Julian year has a length of 365.25 days, exactly.
[c] Years of discovery for Uranus, Neptune, and Pluto, respectively: 1781, 1846, 1930.

TABLE 2.10. A selection of premodern planetary parameters.[a]

Planet/element	a (AU)	n T_0 = A.D. 1/ T_0 = A.D. 1549	e	ω (°/d)
Sun	1.	0.985635	0.0417	65°.60
{Earth}	1.	0.985608	0.0369	211.32
Moon	—	13.176382	0.8281	—
	—	13.176356	0.0237	207.12
Mercury		3.106699	0.0500	188.63
	0.3573	3.106730	0.0736	187.54
Venus		0.616509	0.0208	53.63
	0.7193	0.616518	0.0164	48.33
Mars		0.524060	0.1000	114.13
	1.5198	0.524032	0.0973	107.75
Jupiter		0.083122	0.0458	159.62
	5.2192	0.083091	0.0458	154.06
Saturn		0.033489	0.0569	231.63
	9.1743	0.033460	0.0570	225.00

[a] Ptolemaic values are in the top line and the Copernican on the lower for each planetary entry.

ascending node, Ω (and, below, its variation in arc-seconds per year), the argument of perihelion, ω (and, below, its variation in arc-seconds per year), the mean motion in degrees per day, n, the average sidereal period in mean solar days, and the average synodic period in mean solar days (and the number of integral Earth sidereal years, ⊕, and remainder in days). The mean motion is not independent of other elements, but it directly indicates the orbital motion of the planet; so we include it here. As we have noted, a combination of angles, the *longitude of perihelion* ($\tilde{\omega}$) is sometimes given in place of the *argument of perihelion* (ω): $\tilde{\omega} = \Omega + \omega$. The data for the telescopic planets Neptune and Pluto are included only for completeness. Uranus is marginally visible to the unaided eye. It is conceivable that the motion of Uranus could have been noticed during an *appulse* or close approach to a star, but its motion is so small, only 20 arc-minutes per month, that this is unlikely to have been noticed in antiquity. Whether it was or was not noticed by someone (see Hertzog 1988), to the present day, no evidence for early nontelescopic observations of Uranus has been found.

The data of Table 2.9 can be used to find the position of a planet in its orbit at subsequent times and its position in the ecliptic and equatorial systems. The mean longitude, ℓ, is related to the mean anomaly through the relation, $M = \ell - \tilde{\omega} = \ell - \omega - \Omega$ [(2.16) to (2.18) in §2.3.5]. A full discussion of the required procedures is beyond the scope of this book, but is provided by several sources.[41] Appendix A provides lists of published tables of planetary positions for the remote past, as well as some of the currently available commercial software packages for computing them.

Some of the elements of Table 2.9 may be compared with those of Table 2.10, which lists planetary parameters as reckoned by Ptolemy (2nd century) and by Copernicus (16th century), extracted from values provided by Gingerich (1993, p. 128, fn. *38*; p. 214, Table 4). The Ptolemaic values are on the top line, and the Copernican are on the lower, for each planetary entry. The solar distance parameter a is given in units of the average Earth-Sun distance and is tabulated only for the heliocentric model; n, e, and ω follow. The parameters that were used to characterize orbits in antiquity are not always the same as the modern elements. All orbits were circular, but a planet's orbit was not centered on the Earth (or, in the Copernican model, on the Sun), so that the Copernican "eccentricity," e, for instance, is the mean distance between the center of the orbit and the Sun and expressed in units of a. In Copernicus's model, this "eccentricity" varies with time, because the center of the orbit moves on a circle (the mean value is given in Table 2.10). As a consequence, the argument of perihelion also varies and adds to the perturbation-induced variation. Altogether, the model of Copernicus required at least six parameters to compute each planet's longitude and five additional parameters to include the effects of his (incorrect) theory of precession (see §§3.1.6, 7.7).

The periodicities that were most noticable and most noted by ancient astronomers were the synodic periods of the planets and those that were commensurate with the solar calendar or other calendars. The formulation of Kepler's Third Law, which relates the sidereal period to the semi-major axis, had to await understanding of the difference between the synodic and sidereal periods, correct planetary distances from the Sun, and, of course, the heliocentric perspective.

Finally, we supply positions of a planet at a particular configuration. Table 2.11 (based on information provided by Jet Propulsion Laboratory astronomer E. Myles Standish) is a partial list[42] of dates of inferior conjunctions of Venus. The dates indicated are Julian Day Numbers and decimals thereof and Julian calendar (36,525 days in a century) dates and hours; the uncertainty is about 3 hours. There is a cycle of 251 tropical years for Venus conjunction events. Purely bold-faced dates indicate entries for one such series, and the bold-italicized dates those for another; the latter is carried forward into the 20th century at the end of the table. The 20th century dates, however, are given in the Gregorian calendar (see §4.2.3). Note that the difference in JDN (an accurate indication of the number of days between the conjunctions) is only about 0.03^d/cycle.[43] Although they certainly did not use the Gregorian or Julian calendars, Mayan astronomers were well aware of these sorts of periodicities of Venus, and of the tropical year, and tied some of them into their sacred calendar (see §12, where the repetitions of Venus phenomena are discussed in the context of the Mesoamerican calendar). Calendrical and iconographic evidence strongly suggests that the complicated series of motions of Venus in the sky over many years were observed carefully. The motion of the perihelion of a planet means

[41] For example, Brouwer and Clemence (1961), Danby (1962/1988), or for less-critical determinations, Schlosser et al. (1991/1994, pp. 70–76 and Appendix E).

[42] This is an updated version of part of a table from Spinden 1930, pp. 82–87.

[43] This can be seen as follows: 251 × 365.2422 = 91675.79, while 1955664.29 − 1863988.47 = 91675.82, for example.

Table 2.11. Venus inferior conjunctions.

JDN	Julian date	JDN	Julian date	JDN	Julian date
1863988.47	**0391^y APR 28^d 23^h**	1864572.51	0392^y DEC 03^d 00^h	1865154.11	0394^y JUL 07^d 14^h
1865741.85	0396 FEB 15 08	1866321.64	0397 SEP 17 03	1866908.16	0399 APR 26 15
1867492.01	0400 NOV 30 12	1868073.78	0402 JUL 05 06	1868661.46	0404 FEB 12 22
1869241.20	0405 SEP 14 16	1869827.85	0407 APR 24 08	1870411.51	0408 NOV 28 00
1870993.46	0410 JUL 02 22	1871581.07	0412 FEB 10 13	1872160.77	0413 SEP 12 06
1872747.53	0415 APR 22 00	1873331.02	0416 NOV 25 12	1873913.12	0418 JUN 30 14
1874500.68	0420 FEB 08 04	1875080.34	0421 SEP 09 20	1875667.21	0423 APR 19 17
1876250.53	0424 NOV 23 00	1876832.80	0426 JUN 28 07	1877420.28	0428 FEB 05 18
1877999.92	0429 SEP 07 10	1878586.90	0431 APR 17 09	1879170.03	0432 NOV 20 12
1879752.47	0434 JUN 25 23	1880339.87	0436 FEB 03 08	1880919.50	0437 SEP 05 00
1881506.59	0439 APR 15 02	1882089.53	0440 NOV 18 00	1882672.14	0442 JUN 23 15
1883259.46	0444 JAN 31 23	1883839.09	0445 SEP 02 14	1884426.26	0447 APR 12 18
1885009.03	0448 NOV 15 12	1885591.82	0450 JUN 21 07	1886179.05	0452 JAN 29 13
1886758.68	0453 AUG 31 04	1887345.95	0455 APR 10 10	1887928.53	0456 NOV 13 00
1888511.50	0458 JUN 18 23	1889098.63	0460 JAN 27 03	1889678.28	0461 AUG 28 18
1890265.63	0463 APR 08 03	1890848.03	0464 NOV 10 12	1891431.18	0466 JUN 16 16
1892018.21	0468 JAN 24 17	1892597.88	0469 AUG 26 09	1893185.30	0471 APR 05 19
1893767.53	0472 NOV 08 00	1894350.86	0474 JUN 14 08	1894937.79	0476 JAN 22 07
1895517.48	0477 AUG 23 23	1896104.98	0479 APR 03 11	1896687.04	0480 NOV 05 12
1897270.55	0482 JUN 12 01	1897857.36	0484 JAN 19 20	1898437.08	0485 AUG 21 13
1899024.65	0487 APR 01 03	1899606.54	0488 NOV 03 01	***1900190.24***	***0490 JUN 09 17***
1900776.92	0492 JAN 17 10	1901356.69	0493 AUG 19 04	1901944.31	0495 MAR 29 19
1902526.05	0496 OCT 31 13	1903109.91	0498 JUN 07 09	1903696.49	0500 JAN 14 23
1904276.30	0501 AUG 16 19	1904863.99	0503 MAR 27 11	1905445.56	0504 OCT 29 01
1906029.60	0506 JUN 05 02	1906616.03	0508 JAN 12 12	1907195.92	0509 AUG 14 10
1907783.65	0511 MAR 25 03	1908365.06	0512 OCT 26 13	1908949.28	0514 JUN 02 18
1909535.59	0516 JAN 10 02	1910115.55	0517 AUG 12 01	1910703.31	0519 MAR 22 19
1911284.58	0520 OCT 24 01	1911868.97	0522 MAY 31 11	1912455.15	0524 JAN 07 15
1913035.17	0525 AUG 09 16	1913622.97	0527 MAR 20 11	1914204.09	0528 OCT 21 14
1914788.65	0530 MAY 29 03	1915374.68	0532 JAN 05 04	1915954.79	0533 AUG 07 07
1916542.63	0535 MAR 18 03	1917123.60	0536 OCT 19 02	1917708.35	0538 MAY 26 20
1918294.22	0540 JAN 02 17	1918874.43	0541 AUG 04 22	1919462.28	0543 MAR 15 18
1920043.13	0544 OCT 16 15	1920628.03	0546 MAY 24 12	1921213.76	0547 DEC 31 06
1921794.06	0549 AUG 02 13	1922381.93	0551 MAR 13 10	1922962.65	0552 OCT 14 03
1923547.72	0554 MAY 22 05	1924133.29	0555 DEC 28 18	1924713.70	0557 JUL 31 04
1925301.58	0559 MAR 11 01	1925882.18	0560 OCT 11 16	1926467.41	0562 MAY 19 21
1927052.81	0563 DEC 26 07	1927633.34	0565 JUL 28 20	1928221.23	0567 MAR 08 17
1928801.71	0568 OCT 09 05	1929387.10	0570 MAY 17 14	1929972.35	0571 DEC 23 20
1930552.99	0573 JUL 26 11	1931140.88	0575 MAR 06 09	1931721.24	0576 OCT 06 17
1932306.78	0578 MAY 15 06	1932891.86	0579 DEC 21 08	1933472.63	0581 JUL 24 03
1934060.52	0583 MAR 04 00	1934640.77	0584 OCT 04 06	1935226.48	0586 MAY 12 23
1935811.39	0587 DEC 18 21	1936392.29	0589 JUL 21 18	1936980.15	0591 MAR 01 15
1937560.32	0592 OCT 01 19	1938146.17	0594 MAY 10 16	1938730.91	0595 DEC 16 09
1939311.93	0597 JUL 19 10	1939899.77	0599 FEB 27 06	1940479.87	0600 SEP 29 08
1941065.86	0602 MAY 08 08	1941650.42	0603 DEC 13 22	1942231.59	0605 JUL 17 02
1942819.40	0607 FEB 24 21	1943399.41	0608 SEP 26 21	1943985.55	0610 MAY 06 01
1944569.93	0611 DEC 11 10	1945151.25	0613 JUL 14 18	1945739.03	0615 FEB 22 12
1946318.97	0616 SEP 24 11	1946905.24	0618 MAY 03 17	1947489.44	0619 DEC 08 22
1948070.91	0621 JUL 12 09	1948658.65	0623 FEB 20 03	1949238.53	0624 SEP 22 00
1949824.92	0626 MAY 01 09	1950408.94	0627 DEC 06 10	1950990.58	0629 JUL 10 01
1951578.27	0631 FEB 17 18	1952158.08	0632 SEP 19 13	1952744.61	0634 APR 29 02
1953328.45	0635 DEC 03 22	1953910.25	0637 JUL 07 17	1954497.88	0639 FEB 15 09
1955077.65	0640 SEP 17 03	**1955664.29**	**0642 APR 26 18**	1956247.96	0643 DEC 01 10
1956829.91	0645 JUL 05 09	1957417.49	0647 FEB 12 23	1957997.22	0648 SEP 14 17
1958583.97	0650 APR 24 11	1959167.47	0651 NOV 28 23	1959749.58	0653 JUL 03 01
1960337.10	0655 FEB 10 14	1960916.79	0656 SEP 12 06	1961503.66	0658 APR 22 03
1962086.97	0659 NOV 26 11	1962669.25	0661 JUN 30 18	1963256.70	0663 FEB 08 04
1963836.37	0664 SEP 09 20	1964423.35	0666 APR 19 20	1965006.47	0667 NOV 23 23
1965588.92	0669 JUN 28 10	1966176.29	0671 FEB 05 18	1966755.96	0672 SEP 07 10
1967343.02	0674 APR 17 12	1967925.97	0675 NOV 21 11	1968508.60	0677 JUN 26 02

TABLE 2.11. *Continued.*

JDN	Julian date	JDN	Julian date	JDN	Julian date
1969095.89	0679 FEB 03 09	1969675.54	0680 SEP 05 01	1970262.71	0682 APR 15 04
1970845.47	0683 NOV 18 23	1971428.28	0685 JUN 23 18	1972015.47	0687 JAN 31 23
1972595.13	0688 SEP 02 15	1973182.39	0690 APR 12 21	1973764.97	0691 NOV 16 11
1974347.96	0693 JUN 21 11	1974935.06	0695 JAN 29 13	1975514.73	0696 AUG 31 05
1976102.06	0698 APR 10 13	1976684.48	0699 NOV 13 23	1977267.64	0701 JUN 19 03
1977854.65	0703 JAN 27 03	1978434.32	0704 AUG 28 19	1979021.74	0706 APR 08 05
1979603.98	0707 NOV 11 11	1980187.32	0709 JUN 16 19	1980774.21	0712 AUG 26 10
1981941.41	0714 APR 05 21	1982523.49	0715 NOV 08 23	1983107.01	0717 JUN 14 12
1983693.78	0719 JAN 22 06	1984273.53	0720 AUG 24 00	1984861.08	0722 APR 03 14
1985442.99	0723 NOV 06 11	1986026.69	0725 JUN 12 04	1986613.35	0727 JAN 19 20
1987193.15	0728 AUG 21 15	1987780.75	0730 APR 01 06	1988362.49	0731 NOV 03 23
1988946.36	0733 JUN 09 20	1989532.90	0735 JAN 17 09	1990112.76	0736 AUG 19 06
1990700.42	0738 MAR 29 22	1991282.00	0739 NOV 01 11	***1991866.06***	***0741 JUN 07 13***
1992452.47	0743 JAN 14 23	1993032.38	0744 AUG 16 21	1993620.08	0746 MAR 27 13
1994201.51	0747 OCT 30 00	1994785.74	0749 JUN 05 05	1995372.03	0751 JAN 12 12
1995952.00	0752 AUG 14 11	1996539.74	0754 MAR 25 05	1997121.02	0755 OCT 27 12
1997705.43	0757 JUN 02 22	1998291.57	0759 JAN 10 01	1998871.62	0760 AUG 12 02
1999459.40	0762 MAR 22 21	2000040.54	0763 OCT 25 00	2000625.12	0765 MAY 31 14
2001211.12	0767 JAN 07 14	2001791.25	0768 AUG 09 17	2002379.05	0770 MAR 20 13
2002960.06	0771 OCT 22 13	2003544.81	0773 MAY 29 07	2004130.65	0775 JAN 05 03
2004710.88	0776 AUG 07 09	2005298.71	0778 MAR 18 05	2005879.58	0779 OCT 20 02
2006464.49	0781 MAY 26 23	2007050.19	0783 JAN 02 16	2007630.51	0784 AUG 05 00
2008218.37	0786 MAR 15 20	2008799.10	0787 OCT 17 14	2009384.18	0789 MAY 24 16
2009969.72	0790 DEC 31 05	2010550.16	0792 AUG 02 15	2011138.01	0794 MAR 13 12
2011718.63	0795 OCT 15 03	2012303.86	0797 MAY 22 08	2012889.25	0798 DEC 28 18
2013469.80	0800 JUL 31 07	2014057.65	0802 MAR 11 03	2014638.15	0803 OCT 12 15
2015223.55	0805 MAY 20 01	2015808.78	0806 DEC 26 06	2016389.44	0808 JUL 28 22
2016977.30	0810 MAR 08 19	2017557.69	0811 OCT 10 04	2018143.24	0813 MAY 17 17
2018728.31	0814 DEC 23 19	2019309.09	0816 JUL 26 14	2019896.93	0818 MAR 06 10
2020477.23	0819 OCT 07 17	2021062.93	0821 MAY 15 10	2021647.82	0822 DEC 21 07
2022228.74	0824 JUL 24 05	2022816.57	0826 MAR 04 01	2023396.77	0827 OCT 05 06
2023982.62	0829 MAY 13 02	2024567.34	0830 DEC 18 20	2025148.39	0832 JUL 21 21
2025736.20	0834 MAR 01 16	2026316.32	0835 OCT 02 19	2026902.31	0837 MAY 10 19
2027486.85	0838 DEC 16 08	2028068.05	0840 JUL 19 13	2028655.83	0842 FEB 27 07
2029235.86	0843 SEP 30 08	2029821.99	0845 MAY 08 11	2030406.36	0846 DEC 13 20
2030987.71	0848 JUL 17 04	2031575.45	0850 FEB 24 22	2032155.41	0851 SEP 27 21
2032741.68	0853 MAY 06 04	2033325.88	0854 DEC 11 09	2033907.37	0856 JUL 14 20
2034495.08	0858 FEB 22 13	2035074.97	0859 SEP 25 11	2035661.37	0861 MAY 03 20
2036245.39	0862 DEC 08 21	2036827.03	0864 JUL 12 12	2037414.69	0866 FEB 20 04
2037994.53	0867 SEP 23 00	2038581.06	0869 MAY 01 13	2039164.89	0870 DEC 06 09
2039746.70	0872 JUL 10 04	2040334.30	0874 FEB 17 19	2040914.10	0875 SEP 20 14
2041500.74	0877 APR 29 05	2042084.41	0878 DEC 03 21	2042666.36	0880 JUL 07 20
2043253.91	0882 FEB 15 09	2043833.67	0883 SEP 18 04	2044420.42	0885 APR 26 22
2045003.91	0886 DEC 01 09	2045586.04	0888 JUL 05 12	2046173.52	0890 FEB 13 00
2046753.24	0891 SEP 15 17	**2047340.11**	**0893 APR 24 14**	2047923.40	0894 NOV 28 21
2048505.71	0896 JUL 03 04	2049093.12	0898 FEB 10 14	2049672.83	0899 SEP 13 07
2050259.79	0901 APR 22 06	2050842.91	0902 NOV 26 09	2051425.39	0904 JUN 30 21
2052012.72	0906 FEB 08 05	2052592.40	0907 SEP 10 21	2053179.46	0909 APR 19 23
2053762.41	0910 NOV 23 21	2054345.06	0912 JUN 28 13	2054932.31	0914 FEB 05 19
2055511.99	0915 SEP 08 11	2056099.15	0917 APR 17 15	2056681.92	0918 NOV 21 09
2057264.74	0920 JUN 26 05	2057851.90	0922 FEB 03 09	2058431.58	0923 SEP 06 01
2059018.82	0925 APR 15 07	2059601.42	0926 NOV 18 22	2060184.42	0928 JUN 23 22
2060771.48	0930 JAN 31 23	2061351.17	0931 SEP 03 16	2061938.50	0933 APR 13 00
2062520.92	0934 NOV 16 10	2063104.10	0936 JUN 21 14	2063691.06	0938 JAN 29 13
2064270.77	0939 SEP 01 06	2064858.18	0941 APR 10 16	2065440.42	0942 NOV 13 22
2066023.78	0944 JUN 19 06	2066610.63	0946 JAN 27 03	2067190.38	0947 AUG 29 21
2067777.85	0949 APR 08 08	2068359.93	0950 NOV 11 10	2068943.46	0952 JUN 16 22
2069530.20	0954 JAN 24 16	2070109.99	0955 AUG 27 11	2070697.52	0957 APR 06 00
2071279.43	0958 NOV 08 22	2071863.14	0960 JUN 14 15	2072449.77	0962 JAN 22 06
2073029.60	0963 AUG 25 02	2073617.19	0965 APR 03 16	2074198.94	0966 NOV 06 10

Table 2.11. *Continued.*

JDN	Julian date	JDN	Julian date	JDN	Julian date
2074782.83	0968 JUN 12 07	2075369.34	0970 JAN 19 20	2075949.21	0971 AUG 22 16
2076536.85	0973 APR 01 08	2077118.45	0974 NOV 03 22	2077702.52	0976 JUN 10 00
2078288.89	0978 JAN 17 09	2078868.82	0979 AUG 20 07	2079456.51	0981 MAR 30 00
2080037.96	0982 NOV 01 11	2080622.20	0984 JUN 07 16	2081208.45	0986 JAN 14 22
2081788.44	0987 AUG 17 22	2082376.18	0989 MAR 27 16	2082957.48	0990 OCT 29 23
2083541.89	***0992 JUN 05 09***	2084127.99	0994 JAN 12 11	2084708.08	0995 AUG 15 13
2085295.83	0997 MAR 25 07	2085876.99	0998 OCT 27 1	. . .	
. . .					
2415795.46	1902 FEB 14 22	2416375.38	1903 SEP 17 21	2416962.91	1905 APR 27 09
2417544.72	1906 NOV 30 05	2418128.65	1908 JUL 06 03	2418715.01	1910 FEB 12 12
2419295.00	1911 SEP 15 11	2419882.57	1913 APR 25 01	2420464.23	1914 NOV 27 17
2421048.33	1916 JUL 03 19	2421634.57	1918 FEB 10 01	2422214.62	1919 SEP 13 02
2422802.23	1921 APR 22 17	2423383.75	1922 NOV 25 06	2423968.02	1924 JUL 01 12
2424554.13	1926 FEB 07 15	2425134.25	1927 SEP 10 17	2425721.89	1929 APR 20 09
2426303.26	1930 NOV 22 18	2426887.69	1932 JUN 29 04	2427473.69	1934 FEB 05 04
2428053.87	1935 SEP 08 08	2428641.55	1937 APR 18 01	2429222.77	1938 NOV 20 06
2429807.38	1940 JUN 26 21	2430393.23	1942 FEB 02 17	2430973.50	1943 SEP 06 00
2431561.20	1945 APR 15 16	2432142.30	1946 NOV 17 19	2432727.07	1948 JUN 24 13
2433312.78	1950 JAN 31 06	2433893.13	1951 SEP 03 15	2434480.85	1953 APR 13 08
2435061.81	1954 NOV 15 07	2435646.76	1956 JUN 22 06	2436232.32	1958 JAN 28 19
2436812.77	1959 SEP 01 06	2437400.49	1961 APR 10 23	2437981.34	1962 NOV 12 20
2438566.45	1964 JUN 19 22	2439151.86	1966 JAN 26 08	2439732.40	1967 AUG 29 21
2440320.13	1969 APR 08 15	2440900.86	1970 NOV 10 08	2441486.13	1972 JUN 17 15
2442071.39	1974 JAN 23 21	2442652.05	1975 AUG 27 13	2443239.77	1977 APR 06 06
2443820.40	1978 NOV 07 21	2444405.81	1980 JUN 15 07	2444990.92	1982 JAN 21 10
2445571.69	1983 AUG 25 04	2446159.42	1985 APR 03 21	2446739.93	1986 NOV 05 10
2447325.50	1988 JUN 12 23	2447910.45	1990 JAN 18 22	2448491.35	1991 AUG 22 20
2449079.05	1993 APR 01 13	2449659.46	1994 NOV 02 23	***2450245.18***	***1996 JUN 10 16***
2450829.97	1998 JAN 16 11	2451411.00	1999 AUG 20 11		

that its anomalistic period will be different from that of its sidereal period in the same way that the Moon's anomalistic period differs from its sidereal period. Similarly, planets can be said to have "nodal" periods. When any of these are multiples of the synodic periods, cyclic similarity in sky movement patterns can be expected.

This concludes our discussion of the basic movements of the sky and of the Sun, Moon, and planets. We now move to the problems associated with the observation of these objects and touch on such topics as the discernment and measurement of their positions, motions, and brightnesses.

3 Observational Methods and Problems

In this chapter, we deal with the ways in which the objects described in Chapter 2 can be observed and the conditions affecting those observations.

The light of distant objects is perceived differently by each individual, both physically and intellectually. Moreover, the interpretations given them were (and maybe to a certain extent still are) grounded in the observer's cultural milieu. These facts, well known to students of the humanities, must have influenced what was considered important, and thus recorded, by ancient astronomers. Here, we concentrate on physical and physiological effects on perception, but we must remain aware that physical perceptions are not easily separated from what the mind's eye perceives.

We begin with the effects of the transparency of the atmosphere, first in the context of global climate variation, and later in the specifics of atmospheric extinction and reddening, and refraction. These effects have consequences for research into the stellar alignments of monuments, temples, and pairs or lines of rocks or stones. In between, we describe the intrinsic nature of the light, how we perceive it, and how this changes from person to person. We also briefly discuss other phenomena, such as precession that changes the apparent locations of objects in the sky with respect to the equinoxes and over time alters both the pole star and the visibility of circumpolar objects. Finally, we describe the particular ways in which observations were carried out. A list of bright objects with their modern positions, measures of brightnesses, and colors is also provided for reference.

3.1. Visibility of Phenomena

Modern astronomers attempt to find dark and clear skies. Unless they are working on bright objects or have special compensating devices of some kind,[1] modern-day astronomers who work in urban centers must travel to acquire their data. It seems reasonable to assume that at least some ancient astronomers would have preferred to carry out their observations far from the smoke of cooking and hearth-warming fires that characterized life in population centers in past millennia. Just as light pollution in industrialized societies is a severe problem for modern astronomy, the cooking fires and attendant smoke would have made observations of faint objects difficult in the past. However, although ancient cities were not good sites for observatories, some observations of the Sun or Moon could be carried out in all but the most extreme conditions. Ptolemy, for instance, carried out his observations from Alexandria (*Almagest*, Toomer trs., p. 247). Observations in late antiquity were carried out from Athens, Alexandria, Rhodes, Seleucus (a city on the Tigris River), and Sicily (see, for instance, Sarton 1970, II, p. 54). Note that three of these sites were in/near large cities, so that astronomers' travel for observational data was limited for reasons that may well have involved resources, convenience, local duties, or even safety considerations. We leave this question for future research projects!

Still, haze due to smoke is one problem, and cloud is another.

3.1.1. Climate and Weather Conditions

What do we know about the climate in various regions of the world over the past 6000 years? There is ample evidence of changing conditions in most of the world over this period of time. The evidence is in several forms:

[1] For example, one could compare the observations of a variable star to a star known not to vary, observed under identical circumstances, and at the same time. One such device is a two-star photometer, in which automatic and precise measurements are taken of the two objects at the same or nearly the same instant. The *Rapid Alternate Detection System* (Milone et al. 1982) in use since the early 1980s at the Rothney Astrophysical Observatory of the University of Calgary measures consecutively the light of two stars and samples the sky near them as well, permitting the measurement of relative brightness even through light cloud, and sky measurements to correct the results for sky brightness.

(1) Biological data in the form of pollen and other plant spores in living sites
(2) Changes in the distribution of fauna known from historical and archaeological sources
(3) Forest and other vegetation limits
(4) Stable isotope studies suggesting changes in precipitation patterns, ice coverage, and ocean salinity
(5) Geophysical data such as widths of river beds and sea level heights
(6) Geographical and historical data such as the absence of ice on sailing routes

Results of climatic investigations by Lamb (1974) for the Northern Hemisphere indicate a pattern of fluctuating wet and dry periods that lasted many years but which accompanied global retreat from a glacial period and subsequent stabilization about 5000 years ago. Although wet intervals might have been more conducive to better agricultural yields and increased populations, dry intervals would probably have permitted more systematic investigations of the sky. The forest limits of 2000 B.C. compared with those of today show that conditions appear to be slightly cooler at present with both cooler and warmer intervals between (Lamb 1974). As ingenious as such reconstructions are, we do not have astronomical records in the normal sense of the term (see §6.2). From Mesopotamia (§7.1), at a somewhat later time, however, we have a rich store of such information. In Babylonian "diaries," cuneiform records on baked mud bricks, we have detailed information about precisely what objects were "observed," although clouds were no impediment because, in general, planetary positions were computed using prescribed methods (see §7.1.4 for the flavor of that work). The diaries functioned as a kind of daily news report, including commodity prices, meteorological phenomena, and historical occurences, as well as astronomical phenomena. Coe (1962/1972) summarizes some of the broader changes in pre-Columbian Mexico. It can be said that sufficiently clear viewing opportunities, when extensive series of astronomical observations could have been made, did exist sometimes at sites in these areas. We next describe the empirical properties of light from astronomical objects before discussing the atmospheric effects.

3.1.2. Brightness and Color of Astronomical Objects

The atmosphere of the Earth absorbs virtually all of the γ-rays, x-rays, and most of the ultraviolet and infrared radiation, and the ionosphere reflects and scatters away much of the radio frequencies from space. Even in the absence of cloud, however, the atmosphere is an absorbing and scattering medium for visible light. Atmospheric molecules scatter blue light much more strongly than red light, resulting in a yellow or reddish sunset and a blue sky. This type of scattering is called "Rayleigh scattering," after Lord Rayleigh (the title of John William Strutt, 1842–1919), who first explained the phenomenon in 1871. The scattering is inversely proportional to the fourth power of the wavelength (i.e., we may write, $\sigma \propto 1/\lambda^4$). The moon and other

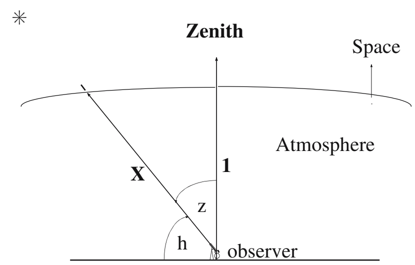


FIGURE 3.1. The geometry of the plane-parallel atmosphere approximation and the definition of *air mass*. Drawing by E.F. Milone.

objects are similarly reddened, and the closer the object is to the horizon, the longer the path length through the atmosphere and, thus, the greater the scattering and the redder the object appears.

Dust and smoke also scatter light, but the ash created by forest fires may sometimes cause different color effects (there are reports of distant forest fires causing a literal "blue moon" effect[2]—causing more scatter in the red region of the spectrum, due to the large size of the scattering particles). Under normal circumstances, at sites near sea level, it is not uncommon to find even a totally clear sky blocking more than half the near-ultraviolet light from an object at the zenith. At larger zenith distances, still more light is lost. Astronomers use the term *extinction* to describe the diminution of light caused by its passage through the atmosphere and discuss the extinction of starlight in terms of magnitudes of extinction per air mass (*magnitudes* are defined below). *Air mass* refers to the thickness of the column of atmosphere through which the light passes compared with that at zenith. Very roughly for low altitudes, but a good approximation for higher altitudes (greater than ~45°), the extinction is proportional to the inverse cosine (or the secant) of the zenith distance (or *90-h*). Figure 3.1 illustrates the basic geometry, ignoring a correction for the curvature of the Earth's atmosphere, which is important for objects near the horizon. The dimming and reddening of starlight (and sunlight and moonlight) has important consequences for the visibility and the ancient descriptions of these objects. Schaefer (1993a, b) summarizes and discusses the visibility of objects due to various effects, and he may be the best source of information about the class of problems that he calls "celestial visibility."

In dry, high-altitude sites, the total visual extinction in an otherwise clear sky may amount to little more than 10%, but at low, moist sites, it may exceed 30% to 40%. As a consequence, Schaefer has challenged the capability of establishing precision alignment at such sites. In order to be quantitative about these matters, and to be able to compare

[2] Perhaps because this term connotes rarity, it has also been applied recently to the second of two full moons within a civil calendar month. Because there are either 30 or 31 days in all months but February, the average $29^d.53$ length of the Moon guarantees that it will occur whenever the full moon occurs on the first day of the month.

observations from different observers and different times, it is helpful to understand a few observational concepts. The next few sections introduce these concepts. An excellent general source for this material, and one that relates general usage to astronomical photometry, is Sterken and Manfroid (1992).

3.1.2.1. Magnitudes and Color Indices

Here, we define the brightness and color of a star. The traditional way to describe brightness is by *magnitudes*. Astronomers in antiquity, and even much later, did not hesitate to refer to the brighter and fainter stars as "bigger" or "smaller," respectively. However, the word *magnitude* in modern contexts has nothing to do with size, despite its etymology[3] and common usage, because the actual surface area of a star other than the Sun cannot be resolved by the human eye. *Magnitude* is an index of the *faintness* of light from an astronomical source: The fainter the star, the bigger the magnitude. The visual magnitude of the total collected light of the Solar disk is ~−27, that of the star Sirius, −1.6, that of Vega, ~0.0, and that of Barnard's Star (invisible to the naked eye), ~+10.

Systematic estimates of star brightness were first recorded according to current knowledge by Hipparchos[4] [~146–~127 B.C.], who assigned a magnitude of *6* to the faintest stars visible to the eye and *1* to some of the brightest. The response of the eye can be modeled by a logarithmic function to changes in light; so the ratio of the brightest to the faintest star represented by Hipparchos's five magnitude difference is about 100. The present magnitude scale now in use was suggested by Norman Pogson in 1856. It sets a difference of 5 magnitudes exactly equivalent to a ratio of 100:1 in brightness. A difference of 2.5 magnitudes is then equivalent to a ratio of 10:1, a 7.5 magnitude difference equivalent to 1000:1, and so on.

The magnitude, m, is related to the detected light, ℓ (its units will be discussed below) by the following expression in terms of base 10 logarithms:

$$m = -2.5\log(\ell) + \text{constant}. \tag{3.1}$$

The relationship between the brightness of two objects is expressible in the following equation:

$$m_2 - m_1 = -2.5\log\frac{\ell_2}{\ell_1}. \tag{3.2}$$

The quantities ℓ_1 and ℓ_2 represent energy in the form of light received per second per unit area and in some *passband*, a particular region of the color spectrum, from two astronomical point-like sources.

Before the development of photography, the implied passband was the entire range visible to the eye. These "visual magnitudes" are commonly designated m_{vis}. Amateur organizations such as the American Association of Variable Star Observers encourage observations of variable stars by providing observers with star charts with calibrated (standard or constant) stars to assist in gauging the relative brightness of variable stars, although amateur astronomers today increasingly use detectors other than the eye to make such observations. The measurement of the brightness of naked eye variable stars such as Algol or β Lyrae (see §5.8.1) is sometimes assigned by astronomy instructors as an exercise in basic astronomical observing. Because the eye's color and sensitivity varies from person to person, a "personal equation" needs to be applied in combining observations from different observers. Such an equation contains a "color term" and a zero point, typically. We discuss this "transformation" problem more generally below.

The use of photographic plates, beginning in the latter part of the 19th century, permitted more restricted spectral regions to be studied. The first one was essentially created by the natural, somewhat bluer sensitivity of the emulsion compared with the eye. Magnitudes in this system are designated m_{pg}. By means of special dyes added to the emulsion, other regions could be defined. One of these was the photovisual, replicating that of the eye: m_{pv}.

The modern photoelectric photometer and, more recently, the "charge coupled device" (CCD), provide higher precision in the measurement of the energy in starlight. A problem in comparing data from different observers is that the data are typically obtained with different equipment and under different observing conditions. To overcome the uncertainties in interpretation of the results, modern observers need to "standardize" their data. It is helpful to bear this in mind when dealing with ancient observations too. So, how do we do this?

Standarization requires measurements to be made in precisely defined passbands, which are defined by the spectral sensitivity of the detection system (these days): the telescope, detector, and color filters; or (throughout most of human history) the eye, alone. One of the most widely used modern systems is the UBV system of Johnson and Morgan (1953). In the 1960s, the Johnson system was extended to five passbands in the optical part of the spectrum: the ultraviolet (U), blue (B), visual (V), red (R), and near infrared (I) (Johnson 1966; Landolt 1983/1992). Johnson extended his system to include infrared (>1 µm) passbands also, but these were badly placed with respect to the transparency windows of the atmosphere,[5] and they are difficult to standardize, especially at sites where the water vapor content varies strongly with time. The passbands most important for our purposes here are the B (centered at ~0.440 µm or 4400 Å wavelength) and V (~0.550 µm or 5500 Å), because of the large numbers of published observations in these passbands, and in the closely related visual and photographic systems. The V band is calibrated to approximate the

[3] From the Latin *magnus* from the Greek *megas*, size; Ptolemy used the related word *megathos* for magnitude.

[4] "Hipparchus" in its Latin form. See §7.2 for a discussion of Hipparchos's many other contributions to astronomy.

[5] Water vapor, carbon dioxide, ozone, and other atmospheric constituents absorb light in the infrared, creating regions of high opacity broken by regions of relative transparency—the atmospheric "windows" in the infrared spectrum. See Milone (1989) for a discussion of the problems of standardization in the infrared and Young, Milone, and Stagg (1994) for solutions to some of them.

old visual and photovisual magnitudes and is thus most relevant for comparison to naked eye estimates. The B band approximates photographic magnitudes. The difference between magnitudes in two different passbands is called a "color index." In the Johnson system, B-V is a widely used color index. The redder the star, the larger the color index; thus, the color index can be considered a "redness index." For a blue star such as Spica, B-V ≈ –0.2; for a white star such as Vega, B-V ≈ 0.0; for a yellow star such as the Sun, B-V ≈ +0.6; and for a very red star such as Antares, B-V ≈ +1.8.

The value of the constant in (3.1) depends on the wavelength of the light under consideration, the width of the passband, and the amount of light received from the stars adopted as calibrating standards. The constant is thus the luminous energy arriving in the vicinity of the earth, per second, per unit area of the receiver, and per unit wavelength interval, corresponding to a magnitude of zero. Note that this quantity is *not* a direct measure of energy emitted *at* the source. We use the definitions of Meyer-Arendt (1972/1995), Sterken and Manfroid (1992), and Cohen and Giacomo (1987) to draw the distinctions and provide definitions. First, we note that energy expended per second (say, in joules/second, abbreviated J/s, or in ergs/s) is called *power*. A common unit of power is the watt,[6] abbreviated *W* (1 W = 1 J/s), equivalent to 10^7 erg/s.

The amount of energy radiated per second at the source is called the *radiant power* or, sometimes, *radiant flux* (in units of watts), or, considering only the power in a spectral region centered around the wavelength 0.555 µm (micrometer or micron) equivalent to 555 nm (nano-meters) or 5550 Å (angstroms: 1 ≈ 10^{-10} m), which is the approximate wavelength of peak sensitivity of the human eye in daylight, *luminous power*. The unit of luminous power is, naturally enough, the *lumen* (abbreviated *lm*), equivalent to about 1/680 W (see Meyer-Arendt 1995, p. 351, and remarks below; the sensitivity of the human eye to different wavelengths makes this conversion factor vary with wavelength and bandwidth). *Radiant* (*luminous* for the visual region) *exitance* is the power emitted per unit area in units of W/m^2 (and in the visual, lm/m^2); *radiant* (again, *luminous* for the visual region) *intensity* is the amount of *radiant* (*luminous*) power emitted into a solid angle cone of a certain solid angle, Ω, and has units of W/sr (for the visual, lm/sr). If a source emitting monochromatic radiation at a frequency of 540×10^{12} Hz (i.e., at a wavelength of 555 nm) into a given direction, has a radiant intensity of (1/683) W in that direction, the luminous intensity would be 1 lm/sr, a quantity also called a *candela* (cd). Finally, the amount of radiation through a unit area and unit solid angle[7] at the source is the *radiance*; *luminance* refers to the visual component of the radiance. Radiance and luminance are used to describe the power emitted at different regions of the emitter's surface, and they are sometimes referred to as "brightness" or "surface brightness." They have units of W m^{-2} sr^{-1} for radiance, and cd/m^2, called *nit* (for the Latin *nitere*, "to shine"), for luminance. Alternatively, the luminance is given in units of lamberts ($10^4/\pi$ cd/m^2).

In contrast to the light produced at a source, the light that we receive, incident on the surface of a telescope or of the human eye, is the *irradiance* or the *illuminance*. The irradiance is often called *flux* or *flux density* in astronomy; it has units of W m^{-2}. The irradiance in a small spectral region is the spectral irradiance; the illuminance in a unit frequency or wavelength interval is the monochromatic flux, with units of W m^{-2} Hz^{-1} or, for example, W m^{-2}/µm. In astronomy, magnitudes may be used to describe a logarithmic form of an irradiance; visual magnitudes may describe a logarithmic form of an illuminance. We should emphasize that in the disparate fields of radiometry, photometry, and astronomy (and even among optical, radio, and infrared astronomy), the names, symbols, usages, and units of the technical terms may differ somewhat. For example, in radio astronomy, a common unit of monochromatic flux is the Jansky (Jy) equal to 10^{-26} W m^{-2} Hz^{-1}.

For the V band, the constant of (3.1), in Systèm International d'Unités (SI units), is

$$-2.5 \cdot \log_{10}\left[3.92 \cdot 10^{-8} \frac{\text{watts}}{\text{m}^2 \cdot \mu\text{m}}\right] = -18.517,$$

and for B, it has the value

$$-2.5 \cdot \log_{10}\left[7.20 \cdot 10^{-8} \frac{\text{watts}}{\text{m}^2 \cdot \mu\text{m}}\right] = -17.857,$$

when ℓ in each case is expressed in the same units. Because the *Watt* is a unit of *power*, energy per unit time, we are talking about the amount of energy in the form of light passing through an area of 1 square meter every second. The amount of light is restricted by the passband, indicated by the micron (µm) unit. The zero point of the V magnitude coincides approximately with that of the photovisual magnitude, m_{pv}, which in turn approximates that of m_{vis}. That of B is slightly displaced from that of m_{pg}. Thus,

$$V \approx m_{vis}, \quad B \approx m_{pg} + 0.11. \tag{3.3}$$

Equations such as (3.3) are called transformation equations, because they permit us to transform data from one system (here, the photographic) into another (the UBV or Johnson system).

For visual (naked eye) observations, of point (i.e., unresolved) sources, magnitudes are approximated by the simple expression,

$$m_v = -13.98 - 2.5 \log E, \tag{3.4}$$

where E is the illuminance, expressed in SI units of *lux* (lm/m^2). In these units, 1 foot-candle (fc) ≡ 1 lm/ft^2 ⇔ 10.76

[6] Named for James Watt (1736–1819), a Scottish engineer. The joule is named after James Prescott Joule [1818–1889], a British scientist.

[7] Angles are measured in degrees or radians (2π radians = 360°). Solid angles are measured in square degrees or steradians (sr). Generally, Ω = area/(distance)^2. The surface area of a sphere of radius *R* meters is $4\pi R^2$ square meters, so that from the center, Ω = 4π steradians. A 1 sr solid angle is that subtended by an area of one square meter at a distance of 1 m (N.B.: the area can be any shape). Also, 1 sr = $(180/\pi)^2$ ≐ $(57.296)^2$ = 3282.8 deg^2, and the entire sphere subtends at the center 4π sr ≐ 41,252.88 square degrees.

lux ⇔ ~0.01576 W/m^2), and 1 phot ≡ 1 lm/cm^2 ⇔ 10^4 lux (Allen 1973/1976, p. 26). A source for which $m_v = 0$ (about that of the star Vega) has an illuminance of ~2.54×10^{-6} lux = 2.36×10^{-7} fcs = 3.72×10^{-9} W/m^2. From (3.4), and C.W. Allen (1973/1976, pp. 197), a star with an illuminance of 1 lux has a visual magnitude of −13.98. The values of the quantities mentioned here apply outside the atmosphere. The effect of the atmosphere will be considered in the next section, but for now, we mention that it both dims and scatters light, therefore, dimming, making redder, and obscuring astronomical objects. Generally, such data need to be "reduced" to outside the atmosphere. Note that by "visual," we imply that the light has been integrated (collected) over the visual "bandpass," i.e., the range of wavelengths equivalent to the net sensitivity of the eye and centered near the peak wavelength of this range. The range of wavelengths to which the eye is sensitive differs with illumination level, and it differs somewhat from person to person. Thus, this type of formulation, although often helpful, needs to be applied cautiously to ancient observations because it requires that allowance can somehow be made for the effects of the atmosphere, general lighting conditions, and differences among observers. For example, someone studying the brightness of the sky as viewed in the past needs to consider that open fires, lamps, and torches were common near cities and the spectrum of this illumination would have varied from place to place, depending on population density and the predominant fuels—the types of wood/peat/oil—that were available. Except, possibly, for observations in some parts of the third world, these conditions would be different from conditions almost anywhere in the world today (where some degree of artificial lighting exists). The sky background and the extinction due to the soot would be more akin to observing conditions in the vicinity of local fires, which are highly variable, as every photometrist who has tried to observe under such conditions can attest. A redder sky also means a different sensitivity level for the eye as well. The photopic sensitivity level for a wavelength of 600 nm, for instance, is only ~63% that at 550 or 560 nm, for an average individual (Meyer-Arendt 1995, p. 352). See §3.1.4 for differences between day and night vision, which have different color sensitivities. A full formal discussion of the personal equation involved for the conditions under which ancient photometric observations must have been carried out needs to be made.

For extended objects, the situation is somewhat more complicated. In dealing with extended sources, the *radiance* or *luminance* must be considered. The perception of the brightness differences from point to point of a nonuniform source such as the Moon, or a limb- or spot-darkened Sun (§5.3.1), depends on the spatial resolution and brightness and contrast sensitivity of the eye, which we take up in §3.1.4. It is interesting, though, that the irradiance at a detector (the eye or a photometric instrument of some kind) of an extended source such as a dense star cluster or galaxy is in fact independent of distance. This is because the flux density falls off with the inverse square of the distance, but the image area at the detector depends on the solid angle of the source, which has the same inverse square dependence on the distance; hence, they cancel out. Distance sources with the same radiant power will appear smaller, and the total radiation received from them will be less, but the surfaces of those sources will look equally bright; i.e., the irradiance of those sources at the detector will be the same. Finally, we note that for uniformly bright, extended sources, the irradiance (in astronomy, the *flux* or *flux density*), F, is equal to the product of the radiance (in astronomy, the *intensity*), I, and the solid angle, Ω:

$$F = I \times \Omega. \tag{3.5}$$

Recall that I is in Wm^{-2}sr^{-1}, and F is in Wm^{-2}. At the mean distance of Earth (1 "astronomical unit" = 1.5×10^{11} m), the mean intensity of the Sun's disk is 2.000×10^7 Wm^{-2}sr^{-1}, and the Sun occupies a solid angle of 6.8000×10^{-5} sr, so that F = 1360 Wm^{-2}. This quantity is in fact measured (the "solar constant") and is the flux of total radiation received by the Earth at its mean distance from the Sun. When F is multiplied by the area of a sphere at this distance, the total radiant power (*luminosity* in astronomy) of the Sun is $4\pi a^2 F = 2.8 \times 10^{23}\,m^2 \times 1360\,Wm^{-2} = 3.8 \times 10^{26}$ W. Schaefer (1993a, p. 319) gives a formula for the illuminance of an extended source. It involves an integration over the solid angle of the source. Rewriting this in terms of the illuminance, F and mean luminance (surface brightness), $<\beta>$,

$$F = 2.95 \times 10^{-7} \times <\beta> \times \Omega \text{ fcs}, \tag{3.6}$$

or, in terms of a visual magnitude, $m_v = -16.57 - 2.5 \log F$, where the constant applies for Schaefer's units: β is given in nanolamberts,[8] Ω in steradians, and F is in units of foot-candles (lm/ft^2) [= 10.76 lux]. Further discussion of extended sources can be found in Schaefer (1993a).

An example of the importance of relating the energy to the observed brightness will be seen in our discussion of the visibility of meteoritic impacts on the Moon (§5.6). We now discuss the correction of observations for extinction and the standardization of photometric observations.

3.1.2.2. Correction for Atmospheric Extinction

As we noted earlier in this chapter, the brightness and color of an object are affected by atmospheric transparency. This section deals with the details of the extinction process.

The atmospheric extinction in magnitudes is usually assumed to be linear with air mass. This is not strictly true, but the approximation in the optical region of the spectrum is not bad. That means that if the light of a star (or other luminous object) traverses twice the thickness of the vertical column of air, its extinction in magnitudes will be twice as great. Equation (3.7) shows the commonly used relation between observed magnitude, m, outside-atmosphere magnitude, m_0, and the air mass, X:

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[8] The *lambert*, named for the Swiss scientist Johann Heinrich Lambert (1728–1777), is the brightness of a surface emitting (as for the Sun, or reflecting, as for the Moon and planets in visible light) one lumen per square centimeter. In SI units, 1 lambert = 10^4 lumen/m^2 so that one nanolambert (≡ 10^{-9} lambert) = 10^{-5} lumen/m^2. For reflection cases, the surface is assumed to be be fully diffusing. See modern optics texts such as Meyer-Arendt (1972/1995) or Jenkins and White (1957) for further discussion.

$$m_0 = m - k'X - k''\cdot Xc, \tag{3.7}$$

where k' is called the *first-order extinction coefficient* and k'' is the *second-order* (or, more accurately, the *color*) *coefficient*, and c is the observed (and uncorrected) color-index of the object. The quantity k' has a typical value at a sea-level site of about 0.25 for visible light, and it is generally less at higher altitude sites. Its value depends strongly on the wavelength and weakly on the color index of the object observed. The value of k' depends also on atmospheric conditions, so that it varies from site to site, night to night, and often even during a night at the same site. Because of the dependence on the color of the observed object, a color-term is sometimes subtracted from the right side, as shown in (3.7). The quantity k_c'' usually has a value less than 0.01. The color indices can be treated in a way similar to the magnitudes:

$$c_0 = c - k_c'X - k_c''Xc. \tag{3.8}$$

Typical values for the B-V color coefficients at sites where astronomical photometry is carried out are $k_c' \approx 0.15$; $k_c'' \approx -0.02$. One might think that if atmospheric extinction were due solely to molecular scattering effects, then the wavelength-dependence of Rayleigh scattering could be used to predict the extinction in one passband given the extinction in another. This would be true if (1) there were no aerosol (water vapor, dust), or specific absorber content to the atmosphere (e.g., terpenes near forests, discrete chemicals near smelter works, etc.), and (2) all photometry systems were identical (i.e., with the same effective wavelength and bandwidth). For clear air conditions and for one and the same stable system, however, correlations of extinction in the several passbands can be determined (see, for an example in the infrared, Glass and Carter 1989). For the naked eye, sensitivity to color varies widely, and because the atmosphere strongly reddens light, the perception of brightness of a star can be expected to vary from individual to individual (even from eye to eye!). Careful and controlled experimental work to establish or qualify this would be of interest.

The air mass may be precisely computed for most observations. It is related to the zenith distance, z, or the altitude, h, through the expression:

$$X \approx \text{secant } z = \text{cosec } h \tag{3.9}$$

for relatively small values of z. For altitudes down to about 10°, an approximation for the curvature of the atmosphere close to the horizon must be used. One such approximation is given by Bemporad and reproduced by Hardie (1962):

$$X \approx \sec z - a(\sec z - 1) - b(\sec z - 1)^2 - c(\sec z - 1)^3, \tag{3.10}$$

where $a = 0.0018167$, $b = 0.002875$, and $c = 0.000808$.

For objects even closer to the horizon, the extinction is much more difficult to determine. Detailed modeling of the scattering and absorption properties of the atmosphere are needed on the night of the observations. For rising stars and planets, an approximation that is in wide use is to assume that the altitude in degrees at which an object can be first observed with the naked eye (i.e., brighter than about visual magnitude *6*) is equal to its magnitude: a 4th magnitude star would be first visible at an altitude of about 4°. This affects the measured bearing of the object and hence archeological alignments that depend on it.

Atmospheric extinction in several forms:

(1) Selective absorption by atmospheric gases
(2) Continuous scattering by atmospheric molecules
(3) Scattering and absorption by suspended particles in the air (aerosols)

Selective absorption removes radiation at certain specific wavelengths. A star's spectrum has features that originate in its atmosphere, in the interstellar medium through which the starlight travels, and, finally, in the Earth's atmosphere. The latter include water vapor bands at ~590 nm (in the orange region of the spectrum) and 650 nm (in the red region), and molecular oxygen bands at 627, 687, and 760 nm. The near infrared contains many features of water vapor and carbon dioxide, among many other molecules. In the ultraviolet, ozone is an important absorber.

The continuous scattering by atmospheric molecules (mainly nitrogen and oxygen that together make up ~98% of the Earth's atmosphere by weight) removes the bluer components of starlight relative to the redder. The radiation is scattered into the night sky. Thus, sunlight is reddened and the sky made blue during daylight hours.

Finally, there is the atmospheric aerosol content, the most variable of the extinction components at low altitude sites. Examples of aerosols are ocean spray, dust from deserts and volcanoes, pollen from trees, and smoke. Aerosol particles, which are generally much larger than the wavelength of light, scatter light more or less equally at all wavelengths.

The very high air mass value near the horizon causes a large uncertainty in the observed magnitude for even small changes in the extinction coefficient. Suppose, for instance, that the extinction coefficient varies by ~ ±0.05 magn. Then, for $X >$ ~20, the uncertainty in the extinction, $\Delta k \times X$, will vary by ~ ±1 magnitude or more. For assumed values of extinction, sky brightness, humidity, and for the altitude of a site near the Big Horn Medicine Wheel, Wyoming, Schaefer (1993a, p. 343) calculates an extinction of 0.85 magn. for the star Aldebaran at the extinction angle, which he computes as 0.6°. At the South pole, at an altitude of 3 km, he finds an average k_v of 0.14 for both summer and winter, whereas in a site in Athens, Greece (altitude 107 m), he finds 0.25 and 0.31 for summer and winter, respectively. Values for some other sites are 0.22 and 0.28 for Tucson (770 m altitude), 0.18 to 0.28 for Jerusalem (775 m), and 0.28 to 0.46 for Los Angeles (100 m). The fact that the setting sun may sometimes appear white with only a yellow tinge, a common sight in a clean, dry, western site such as Alberta, for instance, and sometimes a deep crimson, particularly at sea-level coastal sites, shows that color coefficients may vary greatly.

For more detailed work in this area, Schaefer (1989) provides a program to compute the air mass for relevant atmospheric conditions and (Schaefer 1993a, pp. 315–319) provides formulae and tables for X and extinction coefficient k computed from formulae for the Rayleigh scattering, ozone absorption, and aerosol scattering contributors to extinction.

The sensation of color varies from individual to individual, and in the same individual, it varies with light level and other variables. This is so apart from the variation in precision of language used to describe those sensations. The question of the true color of astronomical objects arises in ancient astronomy. For example, the dog star, Sirius, was described by most ancient astronomers (except possibly the Chinese) as some color in the range of yellow to red; yet today it is clearly white. This discrepancy has resulted in much discussion about whether the ancients were describing the true color of the star. Because there is a strong possibility that they were, serious questions about stellar evolutionary time scales then arise. We discuss the Sirius question in §5.8.4.

3.1.2.3. Standardization

Standardization of data can be thought to be a thoroughly modern aspect of astronomy, primarily because we associate such an activity with the scientific method. Scientists try to recreate the conditions of an experiment to test hypotheses by varying one variable at a time. In astronomy, systematic observations of brightness require a further correction for site-induced variation. Observed values of magnitudes and color indices, even after correction for extinction, are still not the same as catalogue values. Each telescope system is different in its sensitivity to the brightness and colors of the stars, and so the data have to be transformed to a standard system. Yet this too is relevant to a discussion of ancient observations because observations made with the human eye may require a "personal equation" to correct for different sensitivies to brightness and color. The transformation equations usually have the form:

$$m_{\text{std}} = m_0 + \varepsilon \cdot c_{\text{std}} + Z, \tag{3.11}$$

$$c_{\text{std}} = \mu \cdot c_0 + Z_c, \tag{3.12}$$

where ε and μ are called *transformation coefficients*, Z and Z_c are zero points, and m_0 and c_0 are the local system magnitudes and color indices, as above. When m_{std} is V, the quantity c_{std} in (3.11) and (3.12) is often $B - V$. The determination of the extinction and transformation coefficients and zero points is beyond the scope of our discussion, but the reader is referred to one of many articles on the subject (such as Hardie 1962 for the general idea, or Young 1974 for strong qualifications and refinement of methods). As we note below (§3.1.4), the color perception of the human eye depends on three types of cone receptors that act rather like the photographic or photoelectric detectors discussed above and can detect color in sources if they are brighter than ~1500 nanolamberts. The spectral sensitivity of the three types of cones varies with the individual, but normally peaks in the regions 600, 550, and 450 nm, for the red-, green-, and blue-sensitive cones, respectively, and the sensitivity curves overlap. See Schaefer (1993a; 1993b, pp. 87–88) for a terse summary and Cornsweet (1970) for detailed discussion. In principle, one can try to transform data from one individual to a "standard observer." In practice, this is difficult to do, partly because we have too little data about observing conditions from observers in the remote past, so that important complicating effects are not known, and partly because few modern astronomers attempt to perform the time-consuming visual experiments needed to make such a study. One of the exceptions to the latter is Art Upgren (1991), who studied the effect of increasing light pollution on the visibility of stars labeled "blue" and "red" over a 14-year interval; in that study, however, no strong color-effect was noted, and the detailed dependence of visibility on color index was not investigated. More such studies are needed to isolate the complicating effects of extinction and sky brightness from observer color sensitivity.

3.1.2.4. Modern Star Data

In order to discuss the brightness changes of such objects as the "lost Pleiad," the brightness of Sirius, the pretelescopic detection of variability of the demon star *Algol*, and so on (cf. §5.6), it is useful to have a list of stars at their current brightnesses. This is provided in Table 3.1, which lists the positions of some of the brighter stars in right ascension and declination coordinates with respect to the equinox of 2000 A.D. [a particular equinox must be specified because of the precession of the equinoxes that changes these coordinates with time (see §3.1.6)]. The brightnesses are expressed in V magnitudes and B – V color indices. All stars of visual magnitude ~3 or brighter, and a few that are fainter (like the seven brightest stars of the Pleiades star cluster), are included. The common names for the stars are given just after their constellation designations; translations and alternatives may be found in C.W. Allen (1963) or in the *Bright Star Catalog* (Hoffleit 1982). The *spectral classification* is given in the column marked "Sp." The spectral classification is based on the features in visible spectrum of the star, and these are primarily determined by the star's surface temperature. In order of decreasing surface temperature, the major classes are *O*, *B*, *A*, *F*, *G*, *K*, and *M*. The lettered class is followed by arabic numbers (0–9) that mark progression within each spectral class. The designation of a Roman numeral following the spectral class indicates the luminosity of the star: V = dwarf (sometimes called a *main sequence star*); IV = subgiant; III = giant; II = lesser luminosity supergiant; and I = greater luminosity supergiant; gradations a and b are applied to supergiants. Older designations of luminosity include "c" for supergiant, "g" for giant, and "d" for dwarf. Other nuances of spectral classification include "p" for peculiar and "e" for emission features. The star γ^2 Velorum is classified as "WC8," which means it is a *Wolf-Rayet* star, a very hot star thought to be the core of a luminous, evolved star that has lost its outer atmospheric envelope. The Sun, a yellow star, has the spectral classification G2V. As in other contexts, a color following an entry such as the spectral class indicates uncertainty. Note the relationship between spectral class and color index in Table 3.1. The bluest stars are O and B stars, and the reddest are K and M stars, but color can be affected by *interstellar reddening*, even if the *atmospheric reddening* produced by the extinction coefficient term k_{BV}. has been corrected. Stars can therefore show a *color excess*, defined as

$$E_{BV} = (B - V) - (B - V)_0, \tag{3.13}$$

where $(B - V)$ is the observed color index and $(B - V)_0$ is the *intrinsic* color index (at the source). If the star has been reddened by the interstellar medium, it has been dimmed as well, by an amount of interstellar extinction, $A_V \approx 3.1 \times E_{BV}$. The interstellar extinction is due to the additive contributions of individual dust clouds and averages about 1 magnitude per 1000 parsecs (3260 light years) of distance in the galactic plane. Intrinsically blue stars that are very far away may be reddened by interstellar matter, but their spectral classification will not change. Such a cause is unlikely to effect color changes of stars within millennia, but circumstellar matter can and does vary over much shorter time scales. In an interacting binary star system, for instance, matter from one star, expanding as it moves toward a red giant phase, may stream around the companion. This may dim the companion, and thus the system as a whole, as well as redden it. No corrections for interstellar extinction or reddening have been applied in Table 3.1. Stars that are unresolved doubles (either a bound binary star system or merely near each other in the apparent plane of the sky), are designated "D" in the "Comment" column; variable stars are designated "*Var*." Many of the stars marked "D" have only very faint optical companions, which may not be gravitationally bound to the naked eye star at all, but located at a much different distance from us; the designation merely serves as a warning that changes in color and brightness recorded in pretelescopic times must be carefully examined to ensure that the effect did not involve a companion star. In those cases of double stars in which the components can be resolved by small telescopes, and for which the component magnitudes and colors are available, the magnitudes and color indices of the combination, V_C and $(B - V)_C$, have been computed. The formula is

$$V_C = V_2 - 2.5 \cdot \log[1 + 10^{-0.4 \cdot (V_1 - V_2)}]. \tag{3.14}$$

A similar expression holds for B_C, and from these the difference, $(B - V)_C$ can be calculated. The B magnitudes are obtained by adding V and $(B - V)$.

Notice that in computing the combined brightness, magnitudes are not additive: Two stars of magnitude 5 do not have a combined brightness of 10 magnitudes, but of ~4.247.

The stars of Table 3.1 have been incorporated in the star charts of the appendices. Table 3.2 lists the brightness in magnitudes and the color in color indices of solar system objects. In addition to the planets, four *minor planets*, sometimes called *asteroids*, are included: Ceres, the first discovered,[9] and Pallas, Juno, and Vesta. At their brightest, these objects are just visible to the unaided eye. Included also in Table 3.2 are the four brightest moons of the planet Jupiter (Io, Europa, Ganymede, and Callisto); called the Medicean moons by their discoverer, Galileo, they are today called the *Galilean* satellites. Were they not so close to Jupiter, they would be visible to the unaided eye. The magnitudes shown are for mean opposition for the exterior planets and the moons of Jupiter. *Mean opposition* refers to an opposition when the object and the earth are at their average distances from the sun. For the inferior planets and minor planets, the brightest magnitudes that these objects can attain as seen from earth are tabulated. The solar and terrestrial distances of each planet vary, and so its brightness varies, with the inverse square of those distances. Moreover, the reflected light may vary with *phase angle* (the angle between the direction to Earth and the Sun as viewed from the planet). The magnitudes corresponding to the configuration at which a planet may be seen at any particular time may be calculated by formulae given by Harris (1961, p. 276ff). Greatest brilliancy for the planet Venus occurs about 1.1 months after greatest eastern elongation and before greatest western elongation. At the present time, Pluto is near perihelion and its opposition magnitude is about 13.7. One major mystery is why Uranus was not observed in antiquity, a question first raised by the 18th century astronomer J.E. Bode (1784, p. 217). See Hertzog (1988) for a response.

The B – V color index quantifies the redness of Mars (compare it to the red stars in Table 3.1). The redness of Mars is due to an iron oxide in the surface soil. The redness of Mars, the yellowness of Saturn, and the relative whiteness of Jupiter and Venus provide a kind of scale of color to compare the colors of other objects, such as the stars *Antares* (rival to Mars) or *Sirius*, the historical color of which has been the source of much controversy. We will return to the issue of the color of Sirius in §5.8.4. Here, we note only that the present color of Sirius is white; yet, Seneca, writing ~25 A.D., commented that Sirius was redder than Mars (Brecher 1979, p. 97). See Bobrovnikoff (1984) for further discussion of color descriptions of astronomical objects in antiquity.

3.1.2.5. Sky Brightness and Visibility

The usual limiting magnitude for naked eye detection is ~6, but in practice this limit is too optimistic unless the site is exceptionally dark and clear; of course, superior acuity helps. Observations of astronomical objects are limited not only by the atmospheric conditions (cloud, fogs and mists, atmospheric Rayleigh scattering, and absorption), but they are limited also by the brightness of the sky.

The brightness of the sky is the sum of several contributions:

(1) Intrinsic brightness of the sky (the combined direct light of faint stars and distant galaxies and starlight scattered by the atmosphere)
(2) Sunlight (daylight or twilight)
(3) Moonlight (earthshine as well as solar reflection)
(4) Atmospheric emissions
(5) Artificial lighting
(6) Scattering efficiency of the atmosphere

The classic source for the effects of these sources on the visibility of stars is Minnaert (1954), but more recent sources may be more useful. Schaefer (1993a, p. 321) gives formulae for the sky brightness in units of nanoLamberts (see fn 8, §3.1.2.1) for each of these sources. Most practically, Upgren (1991) provides empirical data of the altitudes at which stars of particular magnitudes are visible. At high latitudes, both north and south, the summer season is marked by increased hours of sunlight; north of the Arctic Circle (south of the Antarctic Circle), (the "land of the midnight Sun"), the Sun

[9] The discovery was made on the first night of the 19th century, January 1, 1801, by the astronomer Giuseppe Piazzi, in Palermo, Sicily.

TABLE 3.1. Positions, brightnesses, and colors of selected stars.

Name(s)	α (2000)	δ	V	B – V	Sp	Comments
α And = *Alpheratz*, *Sirrah*	$00^h08^m23^s$	+29°05′26″	2.06	–0.11	A0p	D
= δ Peg (formerly)						
β Cas = *Caph*	00 09 11	+59 08 59	2.27	+0.34	K0III	D
α Phe	00 26 17	–42 18 22	2.39	+1.09	K0III	D
α Cas = *Schedar*	00 40 30	+56 32 15	2.23	+1.17	K0II–III	D, *Var*
β Cet = *Diphda*	00 43 35	–17 59 12	2.04	+1.02	K0III	
γ Cas	00 56 42	+60 43 00	2.47	–0.15	B0IV	D, *Var*
β And = *Mirach*, *Mizar*	01 09 44	+35 37 14	2.06	+1.58	M0III	D
δ Cas = *Ruchbah*	01 25 49	+60 14 07	2.68	+0.13	A5V	D, *Var*
α Eri = *Achernar*	01 37 43	–57 14 12	0.46	–0.16	B5IV	
β Ari = *Sheratan*	01 54 38	+20 48 29	2.64	+0.13	A5V	D
α Hyi	01 58 46	–61 34 12	2.86	+0.28	F0V	
γ^1 And	02 03 54	+42 19 47	2.26	+1.37	K2III	D
γ^2 And	02 03 55	+42 19 51	4.84	+0.03	A0p	D
$\gamma^1 + \gamma^2$ And = *Almak*			V_C = 2.16, $(B-V)_C$ = +1.17			
α Ari = *Hamal*	02 07 10	+23 27 45	2.00	+1.15	K2III	D
β Tri	02 09 33	+34 59 14	3.00	+0.14	A5III	D
o Cet = *Mira*	02 19 21	–02 58 39	*2–10*	+1.42	M5e–M9eV	*Var*
α UMi = *Polaris*	02 31 51	+89 15 51	2.02	+0.60	F5-8Ib	D, *Var*
Θ^1 Eri = HR 897	02 58 16	–40 18 17	3.24	+0.14	A4III	D
Θ^2 Eri = HR 898	02 58 16	–40 18 16	4.35	+0.08	A1V	
$\Theta^1 + \Theta^2$ Eri			V_C = 2.91, $(B-V)_C$ = +0.125			
α Cet = *Menkar*	03 02 17	+04 05 23	2.53	+1.64	M1.5III	
γ Per = *Mekab*, *Menkar*	03 04 48	+53 30 23	2.93	+0.70	G5III + A2V	D
β Per = *Algol*	03 08 10	+40 57 21	2.12	–0.05	B8V	D, *Var* (eclipsing binary)
α Per = *Mirfak*	03 24 19	+49 51 41	1.80	+0.48	F5Ib	
δ Per	03 42 55	+47 47 15	3.01	–0.13	B5III	D, *Var*
17 Tau = *Electra*	03 44 53	+24 06 48	3.70	–0.11	B6III	D, Pleiad
19 Tau = *Taygeta*	03 45 12	+24 28 02	4.30	–0.11	B6IV	D, Pleiad
20 Tau = *Maia*	03 45 50	+24 22 04	3.88	–0.07	B7III	D, Pleiad
23 Tau = *Merope*	03 46 20	+23 56 54	4.18	–0.06	B6IV	Var?, Pleiad
η Tau = *Alcyone*	03 47 29	+24 06 18	2.87	–0.09	B7III	Pleiad
27 Tau = *Atlas*	03 49 10	+24 03 12	3.63	–0.08	B8III	D, Pleiad
28 Tau = *Pleione*	03 49 11	+24 08 12	5.09	–0.08	B8p	D, *Var* (Shell star)
ζ Per	03 54 08	+31 53 01	2.85	+0.12	B1Ib	D
ε Per	03 57 51	+40 00 37	2.89	–0.18	B0.5III	D
γ Eri	03 58 02	–13 30 31	2.95	+1.59	M0.5III	D
α Tau = *Aldebaran*	04 35 55	+16 30 33	0.85	+1.54	K5III	D
ι Aur	04 57 00	+33 09 58	2.69	+1.53	K3II	
ε Aur	05 01 58	+43 49 24	2.99	+0.54	F0Ia	D, *Var* (eclipsing binary)[a]
β Eri = *Cursa*	05 07 51	–05 05 11	2.79	+0.13	A3III	D
β Ori = *Rigel*	05 14 32	–08 12 06	0.12	–0.03	B8Ia	D
α Aur = *Capella*	05 16 41	+45 59 53	0.08	+0.80	G8III	D
γ Ori = *Bellatrix*	05 25 08	+06 20 59	1.64	–0.22	B2III	D?
β Tau = *Nath*	05 26 18	+28 36 27	1.65	–0.13	B7III	D
β Lep = *Nihal*	05 28 15	–20 45 34	2.84	+0.82	G2II	D
δ Ori = *Mintaka*	05 32 00	–00 17 57	2.23	–0.22	O9.5II B2V	D, west Belt star of Orion
α Lep = *Arneb*	05 32 44	–17 49 20	2.58	+0.21	F0Ib	D, *Var*?
ι Ori = *Nair al Saif*	05 35 26	–05 54 36	2.76	–0.23	O9III	D, Sword star of Orion, in nebulosity.
ε Ori = *Alnilam*	05 36 13	–01 12 01	1.70	–0.19	B0Ia	center Belt star
ζ Tau	05 37 39	+21 08 33	3.00	–0.19	B2IVp	D, *Var* (Shell star)
α Col = *Phakt*	05 39 39	–34 04 27	2.64	–0.12	B8Ve	D
ζ Ori	05 40 46	–01 56 34	2.05	–0.21	O9.5V	east Belt star.
= HR 1948 + HR 1949	05 40 46	–01 56 34	4.21	–0.2	B0III	D, *Var*
= *Alnitak*			V_C = 1.76, $(B-V)_C$ = –0.21			
κ Ori = *Saiph*	05 47 45	–09 40 11	2.06	–0.17	B0.5Ia	Right knee of Orion
α Ori = *Betelgeuse*	05 55 10	+07 24 25	0.50	+1.85	M2Iab	D, *Var*
β Aur = *Menkalinan*	05 59 32	+44 56 51	1.90	+0.03	A2IV	D, *Var*
Θ Aur	05 59 43	+37 12 45	2.62	–0.08	A0p	D, *Var*
ζ CMa = *Furud*	06 20 19	–30 03 48	3.02	–0.19	B3V	D
β CMa = *Mirzam*	06 22 42	–17 57 22	1.98	–0.23	B1II–III	D
μ Gem = *Pish Pai*	06 22 58	+22 30 49	2.88	+1.64	M3III	D
α Car = *Canopus*	06 23 57	–52 41 44	–0.72	+0.15	F0Ia	

TABLE 3.1. *Continued.*

Name(s)	α (2000)	δ	V	B – V	Sp	Comments
γ Gem = *Alhena*	06 37 43	+16 23 57	1.93	+0.00	A0IV	D
ε Gem = *Mebsuta*	06 43 56	+25 07 52	2.98	+1.40	G8Ib	D
α CMa = *Sirius*	06 45 09	–16 42 58	–1.46	+0.00	A1V	D (with Sirius B)[b]
τ Pup	06 49 56	–50 36 53	2.93	+1.20	K0III	D
ε CMa = *Adara*	06 58 38	–28 58 20	1.50	–0.21	B2II	D
o^2 CMa	07 03 01	–23 50 00	3.03	–0.09	B3Ia	D
δ CMa = *Wezen*	07 08 23	–26 23 35	1.86	+0.65	F8Ia	D, *Var*?
π Pup	07 17 09	–37 05 51	2.70	+1.62	K5III	D
η CMa = *Aludra*	07 24 06	–29 18 11	2.44	–0.07	B5Ia	D
β CMi = *Gomeisa*	07 27 09	+08 17 21	2.90	–0.09	B8V	D
α Gem	07 34 36	+31 53 18	2.88	+0.04	A1V	D[c]
= HR 2890 + HR 2891	07 34 36	+31 53 18	1.98	+0.03	A5Vm	D, *Var*
= *Castor*, *Apollo*			V_C = 1.59, $(B-V)_C$ = +0.03			
α CMi = *Procyon*	07 39 18	+05 13 30	0.38	+0.42	F5IV–V	D
β Gem = *Pollux*	07 45 19	+28 01 34	1.14	+1.00	K0III	D
ζ Pup	08 03 35	–40 00 11	2.25	–0.26	O5I	
ρ Pup	08 07 33	–24 18 15	2.81	+0.43	F5II	D, *Var*
γ^1 Vel	08 09 29	–47 20 44	4.27	–0.23	B1IV	D, *Var*?
γ^2 Vel	08 09 32	–47 20 12	1.78	–0.22	WC8	D, *Var*
$\gamma^1 + \gamma^2$ Vel			V_C = 1.71, $(B-V)_C$ = –0.22			
ε Car = *Avior*	08 22 31	–59 30 34	1.86	+1.28	K0II	D, *Var*?
δ Vel	08 44 42	–54 42 30	1.96	+0.04	A0V	D
λ Vel = *Alsuhail*	09 08 00	–43 25 57	2.21	+1.66	K5Ib	D
β Car	09 13 12	–69 43 02	1.68	0.00	A1III	
ι Car = *Turais*	09 17 05	–59 16 31	2.25	+0.18	A9Ib	
κ Vel	09 22 07	–55 00 38	2.50	–0.18	B2IV–V	D
α Hya = *Alphard*	09 27 35	–08 39 31	1.98	+1.44	K3III	D
Θ UMa	09 32 51	+51 40 38	3.17	+0.46	F6IV	D
ε Leo = *Algenubi*	09 45 51	+23 46 27	2.98	+0.80	G1II	
υ Car	09 47 06	–65 04 18	2.97	+0.27	A8Ib	D
R Leo	09 47 33	+11 25 43	4–10	+1.4	M7e	*Var*
α Leo = *Regulus*	10 08 22	+11 58 02	1.35	–0.11	B7V	D
γ^1 Leo = HR 4057	10 19 58	+19 50 30	2.22	+1.15	K0IIIp	D, *Var*?
γ^2 Leo = HR 4058	10 19 59	+19 50 25	3.47	+1.10	G7III	
$\gamma^1 + \gamma^2$ Leo = *Algieba*			V_C = 1.92, $(B-V)_C$ = 1.14			
μ UMa	10 22 20	+41 29 58	3.05	+1.59	M0III	D
Θ Car	10 42 57	–64 23 40	2.76	–0.23	B0.5V	D
μ Vel	10 46 46	–49 25 12	2.69	+0.90	G5III	D
β UMa = *Merak*	11 01 50	+56 22 56	2.37	–0.02	A1IV–V	D, Big Dipper (pointer)
α UMa = *Dubhe*	11 03 44	+61 45 03	1.79	+1.07	K0III	D, Big Dipper (pointer)
Ψ UMa	11 09 40	+44 29 54	3.01	+1.14	K1III	
δ Leo	11 14 06	+20 31 25	2.56	+0.12	A4IV	D
β Leo = *Denebola*	11 49 04	+14 34 19	2.14	+0.09	A3V	D
γ UMa = *Phecda*	11 53 50	+53 41 41	2.44	0.00	A0V	D, Big Dipper (bowl)
δ Cen	12 08 22	–50 43 20	2.60	–0.12	B2V	D
ε Crv	12 10 07	–22 37 11	3.00	+1.33	K2III	
δ Cru	12 15 09	–58 44 56	2.80	–0.23	B2IV	*Var*, Southern Cross star
δ UMa = *Megrez*	12 15 26	+57 01 57	3.31	+0.08	A3V	D, Big Dipper (bowl)
γ Crv = *Gienah*	12 15 48	–17 32 31	2.59	–0.11	B8III	D
α^1 Cru = HR 4730	12 26 36	–63 05 56	1.33	–0.24	B0.5IV	D
α^2 Cru = HR 4731	12 26 37	–63 05 58	1.75	–0.26	B3n/B0.5Vn	D
$\alpha^1 + \alpha^2$ Cru = *Acrux*			V_C = 0.76, $(B-V)_C$ = –0.24			"Pointer" star to SCP
δ Crv = *Algorab*	12 29 52	–16 30 56	2.95	–0.05	B9V	
γ Cru	12 31 10	–57 06 47	1.63	+1.59	M3III	D, Southern Cross star
β Crv	12 34 23	–23 23 48	2.65	+0.89	G5II	
α Mus	12 37 11	–69 08 07	2.69	–0.20	B3IV	D
γ Cen	12 41 31	–48 57 34	2.17	–0.01	A0III	D
γ Vir	12 41 40	–01 26 58	3.65	+0.36	F0V	D
= HR 4825 + HR 4826	12 41 40	–01 26 58	3.68	+0.36:	F0V	
= *Porrima*			V_C = 2.91, $(B-V)_C$ = +0.36			
β Cru	12 47 43	–59 41 19	1.25	–0.23	B0III	Southern Cross star
ε UMa = *Alioth*	12 54 02	+55 57 35	1.77	–0.02	A0p	D?, Big Dipper (handle)
α^2 Cvn = *Cor Caroli*	12 56 02	+38 19 06	2.90	–0.12	A0V	D, *Var*

Table 3.1. *Continued.*

Name(s)	α (2000)	δ	V	B – V	Sp	Comments
ε Vir = *Vindemiatrix*	13 02 11	+10 57 33	2.83	+0.94	G9III	D
γ Hya	13 18 55	–23 10 18	3.00	+0.92	G5III	D
ι Cen	13 20 36	–36 42 44	2.75	+0.04	A2V	
ζ UMa	13 23 56	+54 55 31	2.27	+0.03	A1Vp	D, Big Dipper (handle)
= HR 5054 + HR 5055	13 23 56	+54 55 18	3.95	+0.13	A1m	D
= *Mizar*			$V_C = 2.06$, $(B - V)_C = +0.05$			"Horse" to Alcor's "rider"
α Vir = *Spica*, *Azimech*	13 25 12	–11 09 41	0.97	–0.24	B1V	D, *Var*
80 UMa = *Alcor*	13 25 13	+54 59 17	4.01	+0.16	A5V	D, +double with ζ UMa
ε Cen	13 39 53	–53 27 59	2.30	–0.22	B1V	D
η UMa = *Alkaid*	13 47 32	+49 18 48	1.86	–0.19	B3V	D, Big Dipper (handle)
μ Cen	13 49 37	–42 28 26	3.04	–0.17	B3Ve	D, *Var*
η Boo = *Muphrid*	13 54 41	+18 23 52	2.68	+0.58	G0IV	D
ζ Cen	13 55 32	–47 17 18	2.55	–0.22	B2IV	D
β Cen	14 03 49	–60 22 22	0.61	–0.23	B1II	D
α Dra = *Thuban*	14 04 23	+64 22 33	3.65	–0.05	A0III	D, former pole star
Θ Cen = *Menkent*	14 06 41	–36 22 12	2.06	+1.01	K0III–IV	
α Boo = *Arcturus*	14 15 40	+19 10 57	–0.04	+1.23	K2IIIp	
γ Boo = *Seginus*	14 32 05	+38 18 30	3.03	+0.19	A7III	*Var*
η Cen	14 35 30	–42 09 28	2.31	–0.19	B3III	D
α^2 Cen = HR 5460	14 39 35	–60 50 13	–0.01	+0.71	K1V	D, Nearest star system[d]
α^1 Cen = HR 5459	14 39 37	–60 50 02	1.33	+0.88	G2V	
$\alpha^1 + \alpha^2$ Cen = *Rigel Kent*			$V_C = -0.28$, $(B - V)_C = +0.75$			
$^{\alpha}$ Lup	14 41 56	–47 23 17	2.30	–0.20	B1III	D
ε BooA +	14 44 59	+27 04 27	2.70		K0II–III	D
ε BooB	14 44 59	+27 04 30	5.12		A2V	
A + B = *Izar* = *Mirach* = *Mizar* = *Pulcherrima*			$V_C = 2.59$, $(B - V)_C = +0.97$			BSC gives Vc = 2.37
α^1 Lib = HR 5530	14 50 41	–15 59 50	5.15	+0.41	F5IV	*Var*
α^2 Lib = HR 5531	14 50 53	–16 02 31	2.75	+0.15	Am	D
$\alpha^1 + \alpha^2$ Lib = *Zuben el Genubi*			$V_C = 2.64$, $(B - V)_C = +0.17$			
β UMi = *Kocab*	14 50 42	+74 09 20	2.08	+1.47	K4III	D
β Lup	14 58 32	–43 08 02	2.68	–0.22	B2V	D
β Lib = *Zuben el Chamali*	15 17 00	–09 22 59	2.61	–0.11	B8V	D, *Var*
γ TrA	15 18 55	–68 40 46	2.89	+0.00	A0V	
α CrB = *Alphecca*, *Gemma*	15 34 41	+26 42 53	2.23	–0.02	A0V	D, *Var*
γ Lup	15 35 08	–41 10 00	2.78	–0.20	B3V	D
α Ser = *Unukalhay*, *Cor Serpentis*	15 44 16	+06 25 32	2.65	+1.17	K2II	D
β TrA	15 55 08	–63 25 50	2.85	+0.29	F2V	
π Sco	15 58 51	–26 06 51	2.89	–0.19	B1V	D
T CrB	15 59 30	+25 55 13	2–11	+1.4	M3III + p	*Var*
δ Sco = *Dschubba*	16 00 20	–22 37 18	2.32	–0.12	B0V	D
β^1 Sco = HR 5984	16 05 26	–19 48 19	2.62	–0.07	B0.5V	D
β^2 Sco = HR 5985	16 05 26	–19 48 07	4.92	–0.02	B2V	
$\beta^1 + \beta^2$ Sco = *Acrab*, *Graffias*			$V_C = 2.50$, $(B - V)_C = -0.07$			
δ Oph = *Yed Prior*	16 14 21	–03 41 40	2.74	+1.58	M1III	D
σ Sco = *Al Niyat*	16 21 11	–25 35 34	2.89	+0.13	B1III	D, *Var*
η Dra	16 23 59	+61 30 51	2.74	+0.91	G8III	D?
α Sco = *Antares*	16 29 24	–26 25 55	0.96	+1.83	M1Ib	D, *Var*
β Her = *Kornephoros*	16 30 13	+21 29 22	2.77	+0.94	G8III	D
τ Sco	16 35 53	–28 12 58	2.82	–0.25	B0V	
ζ Oph	16 37 09	–10 34 02	2.56	+0.02	O9.5V	
ζ Her	16 41 17	+31 36 10	2.81	+0.65	G0IV	D
α TrA	16 48 40	–69 01 40	1.92	+1.44	K2III	
ε Sco	16 50 10	–34 17 36	2.29	+1.15	K2III	
μ^1 Sco	16 51 52	–38 02 51	3.08	–0.20	B1.5V	D
ζ Ara	16 58 37	–55 59 24	3.13	+1.60	K5III	
η Oph = *Sabik*	17 10 23	–15 43 29	2.43	+0.06	A2V	
α^1 Her = HR 6406	17 14 39	+14 23 25	3.48:		M5Ib–II	D, *Var*
= *Ras Algethi*	17 14 39	+14 23 24	5.39		G5III	D
+ α^2 Her = HR 6407			$V_C = 3.08$, $(B - V)_C = +1.44$			
β Ara	17 25 18	–55 31 47	2.85	+1.46	K3Ib	
β Dra = *Rastaban*	17 30 26	+52 18 05	2.79	+0.98	G2II	D

Table 3.1. *Continued.*

Name(s)	α (2000)	δ	V	B – V	Sp	Comments
υ Sco = *Lesath*	17 30 46	–37 17 45	2.69	–0.22	B3Ib	D
α Ara	17 31 50	–49 52 34	2.95	–0.17	B3V	D
λ Sco = *Shaula*	17 33 36	–37 06 13	1.63	–0.22	B2IV	D, *Var*
α Oph = *Ras Alhague*	17 34 56	+12 33 36	2.08	+0.15	A5III	D?
Θ Sco	17 37 19	–42 59 52	1.87	+0.40	F0I–II	
κ Sco	17 42 29	–39 01 48	2.41	–0.22	B2IV	D
β Oph = *Cebalrai*	17 43 28	+04 34 02	2.77	+1.16	K2III	
ι Sco	17 47 35	–40 07 37	3.03	+0.51	F2Ia	D
γ Dra = *Rastaban*, *Eltanin*	17 56 36	+51 29 20	2.23	+1.52	K5III	D
γ^2 Sgr = *Al Nasl*	18 05 48	–30 25 27	2.99	+1.00	K0III	D, *Var*
ε Sgr = *Kaus Australis*	18 24 10	–34 23 05	1.85	–0.03	A0II	
λ Sgr = *Kaus Borealis*	18 27 58	–25 25 18	2.81	+1.04	K2III	
α Lyr = *Vega*	18 36 56	+38 47 01	0.03	0.00	A0V	D, *Var*?
β Lyr = *Sheliak*	18 50 05	+33 21 46	3.45	0.00	B7V + p	D, *Var* (eclipsing binary)
σ Sgr = *Nunki*	18 55 16	–26 17 48	2.02	–0.22	B2.5V	
ζ Sgr = *Ascella*	19 02 37	–29 52 49	2.60	+0.08	A2IV–V	D
ζ Aql = *Deneb*	19 05 25	+13 51 48	2.99	+0.01	B9V	D, *Var*?
π Sgr	19 09 46	–21 01 25	2.89	+0.35	F2II	D, *Var*?
δ Dra = *Alsafi*	19 12 33	+67 39 42	3.07	+1.00	G9III	D
β^1 Cyg = HR 7417	19 30 43	+27 57 35	3.08	+1.13	K3II	D
β^2 Cyg = HR 7418	19 30 45	+27 57 35	5.11	–0.10	B8V	D
$\beta^1 + \beta^2$ Cyg = *Albireo*			$V_C = 2.92$, $(B - V)_C = 0.87$			
δ Cyg	19 44 58	+45 07 51	2.87	–0.03	A0III	D
γ Aql = *Tarazed*	19 46 15	+10 36 48	2.72	+1.52	K3II	D
α Aql = *Altair*	19 50 47	+08 52 06	0.77	+0.22	A7V	
β Cap = *Dabih*	20 21 01	–14 46 53	3.08	+0.79	F8V	D
γ Cyg = *Sadr*	20 22 14	+40 15 24	2.20	+0.68	F8Ib	D
α Pav	20 25 39	–56 44 07	1.94	–0.20	B3IV	D
α Ind	20 37 34	–47 17 29	3.11	+1.00	K0III	D
α Cyg = *Deneb*	20 41 26	+45 16 49	1.25	+0.09	A2Ia	D
ε Cyg = *Gienah*	20 46 13	+33 58 13	2.46	+1.03	K0III	D
α Cep = *Alderamin*	21 18 35	+62 35 08	2.44	+0.22	A7IV–V	D, *Var*?
β Aqr = *Sadalsuud*	21 31 33	–05 34 16	2.91	+0.83	G0Ib	D
ε Peg = *Enif*	21 44 11	+09 52 30	2.39	+1.53	K2Ib	D, *Var*
δ Cap1 = *Deneb Algiedi*	21 47 02	–16 07 38	2.87	+0.29	Am	D, *Var*
γ Gru	21 53 56	–37 21 54	3.01	–0.12	B8III	
α Aqr = *Sadalmelik*	22 05 47	–00 19 11	2.96	+0.98	G2Ib	D
α Gru	22 08 14	–46 57 40	1.74	–0.13	B5V	D
α Tuc	22 18 30	–60 15 35	2.86	+1.39	K3III	D
β Gru	22 42 40	–46 53 05	2.11	+1.62	M3II	
η Peg	22 43 00	+30 13 17	2.94	+0.86	G2II–III	D
α PsA = *Fomalhaut*	22 57 39	–29 37 20	1.16	+0.09	A3V	
β Peg = *Scheat*	23 03 46	+28 04 58	2.42	+1.67	M2II–III	D
α Peg = *Markab*	23 04 46	+15 12 19	2.49	–0.04	B9V	D

[a] The cooler star in this system is one of the largest known stars, as large as the orbit of Mars.
[b] The fainter component in this system is a white dwarf star, about the size of the Earth.
[c] There are altogether six stars in the Castor system; a faint visual component, Castor C, is an eclipsing binary of which both components are flare stars.
[d] The third component of this system is Proxima Centauri, a faint red dwarf and flare star.

will not set at all for an interval of time lasting from about one day near the circles to slightly more than six months at the poles. The interval of twilight (the time between sunrise and when the Sun is a specified number of degrees below the horizon) is lengthy at high-latitude sites. There are three types of twilight:

(1) *Civil twilight*, for terrestrial visibility purposes, occurs when $h_{Sun} \geq -6°$, i.e., when the Sun is 6° or less below the horizon
(2) *Nautical twilight*, when $h_{Sun} \geq -12°$
(3) *Astronomical twilight*, when $h_{Sun} \geq -18°$

Note that the inequalities are algebraic so that the solar altitude must be less negative than the limit shown for a given category of twilight to apply. At any particular latitude, the length of time of twilight depends on the latitude of the observer and the declination of the Sun. The duration of twilight can be calculated with applications of (2.5). The hour angle of the Sun at the beginning (or end) of twilight can be compared with the time of sunrise (or sunset), and the difference in hour angle, in time measure, is the duration of twilight. Glare, or the scattering of light of a bright object, reduces the visibility of a fainter object in its vicinity still further. The full moon makes naked eye observations of

TABLE 3.2. Brightness and color in the solar system.

Object	V_{max}	B – V
Moon	–12.7	0.92
Sun	–26.7	0.63
Mercury	–1.5	0.93
Venus	–4.6	0.82
Mars	–1.5	1.36
Ceres	7.5	0.72
Pallas	7.6	0.65
Juno	11.0	0.82
Vesta	7.1	0.78
Jupiter	–2.7	0.83
Io	5.0	1.17
Europa	5.3	0.87
Ganymede	4.6	0.83
Callisto	5.7	0.86
Saturn	0.7	1.04
Uranus	5.5	0.56
Neptune	7.8	0.41
Pluto	15.1	0.80

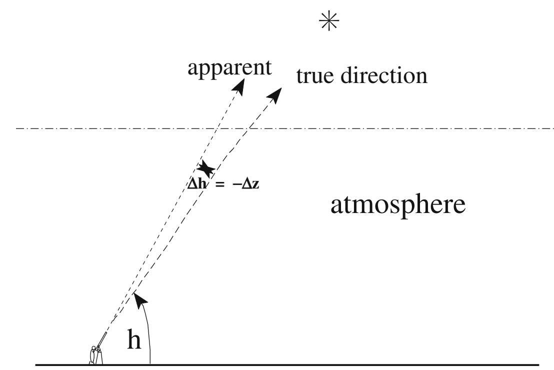

FIGURE 3.2. The geometry of atmospheric refraction. Drawing by E.F. Milone.

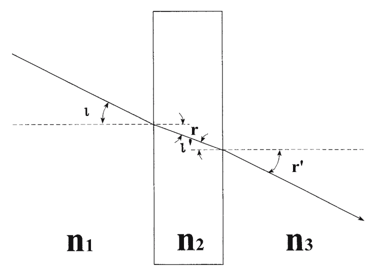

FIGURE 3.3. Snell's law: Refraction changes with medium. The relations between the angles of incidence, *i*, and refraction, *r*, and the indices of refraction, *n*, in the two media are $n_1 \sin i = n_2 \sin r$ for the incoming ray, and $n_2 \sin i' = n_1 \sin r'$ for the outgoing ray. Note that if the incoming and outgoing surfaces are not parallel, neither will be the entering and exiting rays. Drawing by E.F. Milone.

all but the brightest stars difficult; even at large angular distances, scattered moonlight usually precludes direct observation of objects fainter than about 4th magnitude, and if there is any haze or high cloud, the situation is worse. Because the moonlight is widely scattered, a cloud temporarily hiding the Moon is insufficient to reveal the stars (Minnaert 1954, pp. 103–104). The mechanism that renders starlight invisible to the naked eye in the daytime and dimmed in moonlight is almost certainly what Minnaert (1954, pp. 102–103) refers to as the "veil effect." The eye's sensitivity adjusts to the brightest object it sees, whether direct or scattered, and the loss of sensitivity renders the much fainter stars invisible.

In addition to twilight, zodiacal light, airglow and aurorae (all described in §5), starlight, and the Milky Way, all contribute to sky brightness on moonless nights. Given otherwise dark conditions, the intrinsic background light can be surprisingly revealing. William Keel (1992) describes seeing from Mt. Pastukhov the snow-capped peaks of the Caucasus illuminated solely by starlight.

3.1.3. Effects of Refraction, Dip, and Parallax

The atmosphere not only affects the amount of light transmitted to the eye, but it also changes the position in the sky at which objects can be seen. The bending of light in an optical medium like air is known as *refraction*. The phenomenon has been known for centuries. It is mentioned by the Greek astronomer Cleomedes (1st century A.D.), and Ptolemy (~150 A.D.) independently describes the effect of refraction on starlight in his book *Optics*. Augustine (~340 A.D.) mentions the apparent bending of a stick in water as evidence of the deception of the senses—an argument that was still being made by traditionalists to discredit the telescope findings of Galileo in the 17th century.

Atmospheric refraction causes the altitudes of distant terrestrial and astronomical objects to appear higher than they would if viewed from an airless world (see Figure 3.2). It is a consequence of the behavior of light in optical media: Light travels slower through a medium other than vacuum. The ratio of the speed in vacuum to that in the medium is called the *index of refraction*, n. Snell's law summarizes the bending of light as it passes from a medium of index n_1 into a medium of index n_2. If α_1 is the angle with respect to the surface normal of the light incident at the boundary between the two media, and α_2 is the angle with respect to the same normal inside medium 2, the relation between the two angles is

$$n_1 \sin\alpha_1 = n_2 \sin\alpha_2. \tag{3.15}$$

The relationship is illustrated in Figure 3.3.

If the atmosphere were a plane-parallel layer, and the optical density of the atmosphere were uniform, this expression could be used directly to obtain the refraction. The index of refraction of airless space, $n_1 = 1$, and the index of refraction of air is slightly greater than 1.00, the exact amount depending on temperature and air pressure. Thus, $\alpha_2 < \alpha_1$, and the ray bends toward the normal as it enters the atmosphere. The difference between the two angles, for values of $\alpha_{1,2} \lesssim 45°$ (see Tricker 1970, pp. 11–13), is

$$\Delta\alpha \equiv \alpha_1 - \alpha_2 \approx (n_{\text{air}} - 1) \cdot \tan\alpha_2. \quad (3.16)$$

By comparing the refraction at many successive levels of the atmosphere, one may arrive at a slightly more general result. For relatively small zenith distances, or large altitudes, an approximate correction to the zenith distance for refraction is given by Woolard and Clemence (1966, p. 84):

$$\Delta z = 60.29'' \tan z - 0.06688 \tan^3 z. \quad (3.17)$$

Expressed as a change in altitude, $\Delta h = -\Delta z$. For STP (standard temperature and pressure conditions, $T = 0°C$ and sea-level pressure of 1000 mbars), it amounts to about 1 arcminute at 45° altitude. For substantially higher zenith distances, or lower altitudes, the Pulkovo Observatory tables, first published in 1870, have often been used, but the results are strongly dependent on ambient weather conditions, particularly water vapor content. Garfinkel (1944) published a theoretical treatment that is valid to $z > 90°$ (i.e., below the horizon) but was not easily applied; this work was extended, and a table of extinction at large zenith distances was provided in Garfinkel (1967). Schaefer (1993a, p. 314) cites for the refraction down to the horizon two formulae given by Saemundsson (1986) that contain the true and refracted altitudes, respectively, but contain no explicit terms for temperature or pressure. Thom (1971/1978) measured current values in the British isles and concluded that the refraction varies widely enough to provide a slight but measurable uncertainty in the hour angle and azimuth of rise of objects on the horizon. In §6.2.12, we describe Thom's use of an assumed value of the refraction to determine the date when certain assumed alignments were in use. Thus, refraction affects our interpretation of archeological alignments.

The refraction nominally amounts to ~34′ or 0°.57 at the horizon, but sometimes can greatly exceed this value. This means that at first *gleam*, the moment when the upper limb of a rising Sun or Moon is first seen, it is still a full diameter below the horizon; even when it appears fully risen with the lower limb on the horizon, the unrefracted Sun is still below the horizon. The effect of refraction causes the Sun to appear slightly oblate at the horizon. Refraction is slightly greater for the lower limb (~35 arcmin) than for the upper (by ~29 arcmin); hence, the vertical dimension of the Sun will be smaller than its width (~20%). It does not, however, cause the Sun to appear larger at the horizon than at the zenith. Theoretically, the angular width of the disk diameter at sunrise is slightly smaller due to a slightly greater topocentric distance at the horizon compared with the meridian, the diameter being largest for a zenith Sun. In practice, refraction is important in naked eye astronomy only for the Moon, for which the geocentric parallax amounts to ~1°. Measurements consistently confirm this expectation. Refraction phenomena of rising or setting objects can be complicated, however, by the presence of temperature inversions in the atmosphere. Because this commonly occurs along coastlines, particularly in desert areas, unusual shapes and colors sometimes result. See Greenler (1980, Plates 7-10, 7-11, and pp. 160–162) for a series of illustrations of the appearance of the setting Sun under differing refractive conditions and for the refractive effects of differences between air and ground/water temperatures leading to mirages. Greenler (1980, pp. 158–159) notes that *inferior mirage*s, which occur when the air temperture is lower than the ground, are best known as desert mirages but are seen as well in much colder climates over bodies of water. Anomalously high atmospheric refraction has been reported for observations in the high arctic, again attributed to an inversion layer. This optical ducting phenomenon is called the *Novaya Zemlya effect*, after observations of the midnight Sun from the south coast of Novaya Zemlya ($\phi \approx 76°.5$) were reported by an expedition led by Willem Barentsz in 1597. The Sun should have been below the horizon at the expedition's location on the dates reported, and this subsequently aroused controversy. Subsequent observations of the effect were reported by Shackleton (1920), Liljequist (1964), and Lehn and German (1981), among others. On May 16, 1979, at Tuktoyaktuk in the Canadian arctic, Lehn and German (1981) found a distorted image of the Sun above the horizon when it should have been 94 arc-minutes below the horizon! They were able to model the observations by means of a temperature inversion layer, which creates a kind of light pipe over the altitude range of rapid temperature rise and the horizon. Images of the Sun that show the effect and distortions in solar appearance are reproduced in Figure 3.4.

The common perception that the Moon appears to be larger at the horizon has been attributed (Pernter and Exner 1922) to the human impression that the horizon seems further away from the observer than is the zenith, so that objects of the same angular size will appear larger. Kaufman and Rock (1962a,b) discuss in detail a series of experiments on the Moon illusion and show that the effect disappears when the terrain is blocked from view. The 2nd century A.D. (Han period) Chinese astronomer Chang Hêng attributed the phenomenon to an optical atmospheric effect. Rees (1986) summarizes the explanations for the illusion, but there is no consensus for which, if any, is the cause. The current view is that several causes may contribute to the illusion (Schaefer 1993a, p. 340). In so far as physical explanations apply, it is curious that we have seen no reference to a "big Sun" effect; perhaps this in itself lends weight to the psychological explanation for the "big Moon" effect.

The index of refraction is wavelength dependent, which means that it changes with light of different wavelength. Most media bend blue light more strongly than red. This dispersive effect gives rise to a wealth of phenomena, including prism-produced spectra. "Wedge refraction," as the dispersive effect of the Earth's atmosphere is known, causes low-altitude star images to take on the appearance of tiny spectra, with the blue end of the spectrum shifted higher, toward the zenith. This phenomenon can be seen through even small telescopes. Woolard and Clemence state that the red and green images are separated by 2″.2 at $z = 75°$. The dispersive effects of parcels of air on sunrise or sunset images may give rise to a "green flash" (§5.1.2), in which the blue-green components left in the Sun's light are momentarily visible to the observer. Dispersive refraction effects also play a role in the colors of rainbows, which involve refraction in water droplets, and of sundogs, which involve

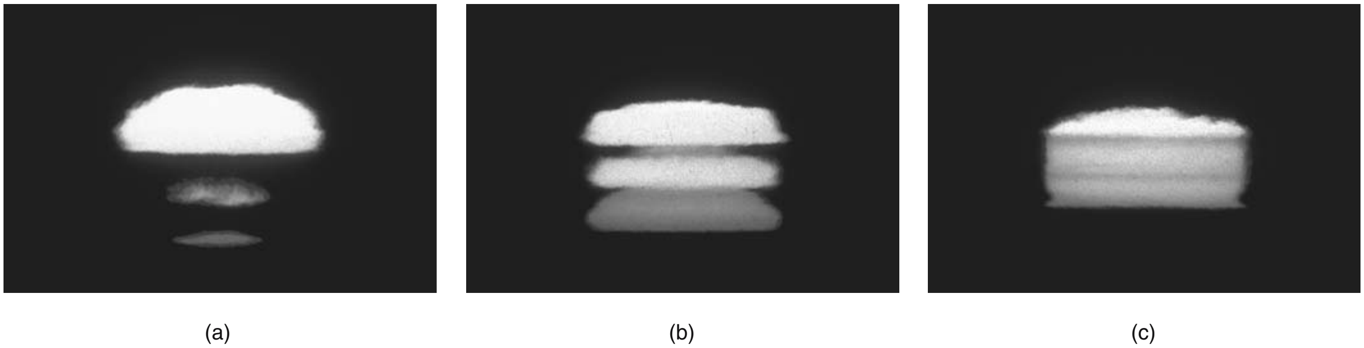

FIGURE 3.4. Refracted images of the setting Sun as seen at Tuktoyaktuk, in Canada's Northwest Territories, on May 16, 1979, that demonstrate the Novaya Zemlya Effect. Shown are the Sun's appearances at (a) 1:34 a.m., MDT, $h = -35'$; (b) 1:41:30, $h = -46.5'$; (c) 1:49, $h = -57'$; (d) 2:06, $h = -75'$; and (e) 2:44, $h = -94'$. The altitude, h, refers to the center of the Sun's disk. Photos courtesy of Professor W. Lehn.

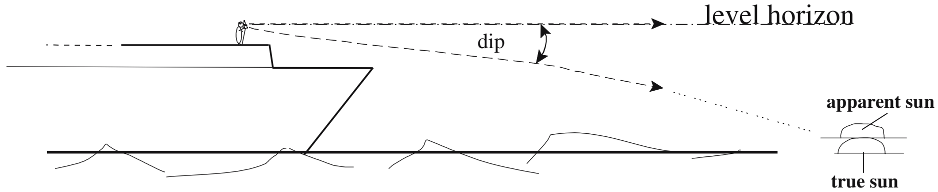

FIGURE 3.5. The effect on the altitude of the horizon of the combination of dip and refraction. Drawing by E.F. Milone.

ice crystal refraction. More thorough discussions of these effects can be found in Minnaert (1954), Meinel and Meinel (1983), and Greenler (1980).

In addition to corrections for refraction, observations need to be corrected for *dip* and for *parallax*. The higher we are, the more we can see "over" a level horizon. Observations of objects on the horizon made from a mountain top or from a high shipboard mast must be corrected for the depressed horizon, but dip is already appreciable for an observer standing at the shoreline. Figure 3.5 shows the effect on the altitude of the horizon of the combination of dip and refraction, but without the curvature of the Earth.

A commonly used expression for the dip correction to the observed altitude is

$$\Delta h(\text{arc-mins}) = k \times \sqrt{\ell(\text{feet})}, \tag{3.18}$$

where ℓ is the height of the eye above sea level, examining a sea-level horizon. The constant k, which depends on refraction and indirectly on ℓ, because the degree of refraction depends on ℓ, would be 1.07 in the absence of refraction; for $\ell < \sim 250$ ft, $k \approx 1$. If the observation is being made for navigational purposes, the correction, which is negative, is made to the observed altitude, which is too large. If the observer is depressed below the true, level horizon, the correction is positive. The dip correction is a compensation for a non-level observational horizon and it is strongly affected by, and so must be corrected for, refraction. A classic reference to this treatment is Helmert (1884).

According to Young (1998, private communication), a more correct expression for the dip is

$$\Delta h = \left[\left(\frac{h}{R_{\oplus}}\right) + \alpha \Delta T\right]^{1/2}, \tag{3.19}$$

where $\Delta T = T$ (at the observer) $- T$ (at the horizon). Note that in this expression, the temperature correction may be negative, and although Eqn (3.19) holds only for $\Delta h \geqslant 0$, in fact, *elevations* of several arcminutes may occur. The observed azimuth and altitude must be corrected for dip and refraction, before being used to compute the declination of

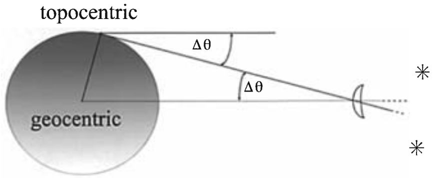

FIGURE 3.6. Topocentric versus geocentric coordinate systems, and the geocentric parallax of the Moon. Drawing by E.F. Milone.

the object [see (2.1)]. There is one more correction to apply, however, for observations of the nearest of the heavenly bodies, the Moon.

The effect of parallax is a familiar one in everyday life: As we blink first one eye then the other, close objects appear to shift against more distant objects. If one moves sideways, the angular shift is larger. It is also larger for the nearer objects. The amount of parallax observed therefore depends both on the distance of the object and on the size of the observer's baseline. In the astronomical context, observations are normally reduced to the center of the Earth because the catalogued positions of objects are given in *geocentric* coordinates, whereas the observer measures *topocentric* coordinates in the local (*topocentric*) coordinate system (see Figure 3.6).

If an observed altitude has been corrected for dip and refraction, the parallax correction to be applied is

$$\Delta h \approx \cos h \times R_{\oplus}/d, \tag{3.20}$$

where $R_{\oplus}$ is the radius of the earth at the observer and d is the geocentric distance at the moment of observation. The effect of the parallax is to lower the observed altitude compared with that seen by a hypothetical geocentric observer. At the place on the Earth directly under the Moon (the *sublunar* point), the zenith distance of the Moon is zero. At all other locations from which the Moon is visible, the zenith distance must be greater; therefore, the Moon's altitude is smaller at all of those locations. Therefore, the correction to the observed parallax is positive in all cases. The geocentric parallax of the Moon is larger than that of any other natural object: The average equatorial horizontal parallax (i.e., the parallax at rising or setting for an observer on the equator, at average lunar distance) is about 57 arc-minutes. The solar horizontal equatorial parallax is ~8.8 arc-seconds. For some configurations of the inner planets, Mars, and several asteroids, the parallax is intermediate. Equation (3.20) can be used to calculate the parallax for those cases. Stellar parallaxes are measured with respect to the semimajor axis of Earth's orbit and are less than 1 arc-second.[10]

The final correction we mention here is that of the semidiameter. Tabulated positions of the Sun and moon are given (in modern catalogues anyway) for the centers of the disks. If we are interested in the upper *limb* (edge), the corrected angular radius (or *semidiameter* as it is called in some catalogues) must be subtracted from the observed altitude to reduce the observation to disk center.

To apply the corrections we have discussed correctly, remember that we have described corrections *to* observational data. If one is correcting values of the altitude, say, calculated from catalogue positions with the purpose of reproducing observational data, the corrections indicated must all be applied in the opposite sense. Finally, we note that although the corrections noted here suffice for most purposes, the occasional need for greater precision may require more rigorous treatment. Finer corrections for the effects we discuss here as well as other effects can be found in Woolard and Clemence (1966), for example, among other works on positional and practical astronomy.

An empirical study of refraction at the horizon through timings of risings and settings of the Sun, Moon, and Venus and unpublished sextant observations was reported by Schaefer and Liller (1990), who showed that significant variations from the expected shift due to local temperature and pressure conditions can be seen. They correct for the semidiameter and use a dip correction: D = arccos[1/(1 + A/6378)], where A is the altitude of the site above sea level, in kilometers. They compute the measured refraction: $R_0 = Z_t - 90° - D$. On the basis of 144 measurements from seven sites, Hawaii; Viña del Mar, La Serena, and Cerro Tololo (Chile); Nag's Head and Kitty Hawk (North Carolina); and O'Neill, Nebraska, they report (their Fig. 2, and pp. 802–803) an average R_0 value of 0°.551 over a total range of 0°.234 to 1°.678, an overall uncertainty figure of ±0°.16, and that 97% of their measurements fall within a range of 0°.64, and only 4 measurements are outside of the range 0°.23 to 0°.87. Although the larger-than-expected variations are attributable to a variety of observing circumstances (timing errors, effects of clouds, etc.), they conclude that differences in the atmospheric temperature profile are responsible. They use these results to argue against the validity of the precision measurements of lunar declination claimed by Thom (cf. §6), even though their results are not based on any measurements made in the British Isles or, of course, necessarily appropriate to atmospheric conditions present in the Megalithic.

3.1.4. Limitations of Vision

3.1.4.1. The Sensitivity and Acuity of the Eye

The human eye is the detector of ancient astronomy, and it is a powerful instrument. It has high sensitivity when fully dark-adapted and has a tremendous dynamic range, coping with a range in brightness of many powers of ten. Prior to the development of the photomultiplier tube in the 20th century, it was the most sensitive detector of optical light that was known. The sensitivity of a detection device is usually measured in terms of quantum efficiency: The percentage of light incident on the detector that is actually seen or detected. In the case of the eye, in the visible part of the spectrum, this quantity is about 10%—a value similar to that for many photomultipliers but a factor of ten more sensitive than photographic emulsions. The flux of sunlight at the

[10] That of α Centauri, the closest star system, is only 0.76 arc-sec.

Earth's distance from the Sun is ~$1.36 \times 10^7\,\mathrm{Wm}^{-2}$ and even less at the surface because of atmospheric extinction. For a pupil size of 2 mm, this amounts to less than 43 W of total power entering the eye. Of this amount, less than 35 W is in the visible part of the spectrum. These values are the rough equivalent of looking at a 100 W light bulb from a distance of ~6 inches.[11] Although we do not advocate even a blinked squint at the sun, this level of brightness is clearly within, if near the limit of, the eye's capability. Although these aspects of human vision are excellent, the diameter of the pupil determines the total light that it can collect; the light energy collected is proportional to the square of the diameter. Assuming a dark-adapted pupil of about 5 mm diameter, a 50-mm telescope lens can gather 100 times more light than can the eye, to reveal objects about five magnitudes fainter. This is, of course, why modern astronomers demand larger and larger telescopes. Nocturnal animals, with larger eyes than humans, are better adapted for night vision. Humans have two different types of detectors in their retinas: *cones* and *rods*. The *cones* are numerous and are found on the optic axis of the lens, the *fovea centralis* (or *fovea*).[12] They provide *photopic* or day vision. The rods are more sensitive, but they are concentrated on the periphery and are absent on the optical axis of the lens. These detectors provide *scotopic* or night vision. In attempting to detect a very faint object like a nebula, "averted vision," looking directly at some other object close enough to the target to still see the latter, can be used effectively. This vision, however, has lower acuity or sharpness because there are fewer *rods* than *cones* in the retina. The rods' placement at the margins gives rise to our averted vision. The rods have little color discrimination, but are somewhat more sensitive to blue light than are the cones. The latter property makes them useful in twilight, when scattered violet-blue sunlight dominates the ambient light.

3.1.4.2. *Color Sensitivity of the Eye*

Color vision arises from photopic vision. The cones have three types of photopigments, analogous to passbands of the Johnson UBVRI system (Schaefer 1993a, pp. 329–331). The long-wavelength–sensitive pigments appear to be the most numerous, and the short-wavelength the least numerous; they are not uniformly distributed. The perceived or effective brightness in each may be written as

$$R = \text{const.} \cdot \int f(\lambda) \cdot E(\lambda) \cdot d\lambda, \qquad (3.21)$$

where $f(\lambda)$ is the wavelength-dependent sensitivity function of the photopigment and $E(\lambda)$ is the wavelength-dependent brightness of the source. If E is expressed in CGS units of ergs/(cm$^2 \cdot$ s $\cdot$ Å), the const. is 6.80 lumens × s/erg. We leave the conversion to SI units as an exercise. The integral sign shows that the combination of these two functions must be summed over all wavelengths to give the total amount of perceived light. The three types of photopigments have peak sensitivities at ~6000, 5500, and 4500 Å, corresponding to red, yellow, and blue, respectively. Because each person's eyes are different in sensitivity and color perception, there are personal brightness and color equations, similar to that discussed for photoelectric instruments in §3.1.2.3, the coefficients and zero points of which vary with light level, and the physiological conditions of the various components of the eye.

Related to acuity is the ability of the lens of the eye to resolve fine detail. The smallest angular feature that can be resolved, the *resolving power*, is proportional to the wavelength and inversely proportional to the iris diameter.[13] For a perfect eye, assuming blue-green light at 500 nm (5000 Å or 0.500 μm), and a large dark-adapted diameter of 10 mm, this quantity is about 10 seconds of arc (hereafter, *arcsec*), about 0.2 arc-minutes (hereafter, *arcmin*). In practice, there are few perfect eye lenses and 1 to 2 arcmin is typical (although there are reports of remarkable acuity; see Bobrovnikoff 1984, pp. 2–7). The largest craters on the nearside of the moon have angular diameters of the order 1 arcmin, but they are very difficult to discern without optical aid. The maximum angular size of any of the planets is about 60 arcsec (for Venus, at inferior conjunction). For Mars, Jupiter, and Saturn, it is 18, 47, and 19 arcsec, respectively, at opposition. For Mercury, at inferior conjunction, it is 11 arcsec. It is conceivable that Venus can be seen transiting (crossing in front of) the disk of the Sun, when the Sun is close to the horizon and suffering sufficient extinction to lower the contrast greatly. The event is rare, however, and no observations have been recorded explicitly in the pretelescopic era, to our knowledge.

3.1.5. Visibility of Planetary Phenomena

In addition to the limitations of the eye, the observability of phenomena is determined to some degree by the longitude and latitude of the observer, time of night, time of month, and time of year. Most astronomical phenomena cannot be observed when the Sun is in the sky, eclipses and most lunar phenomena excepted. There are occasions when the brighter planets and even the brightest stars can be seen, even in competition with the full light of the Sun. The daytime visibility of objects is best where the scattered sunlight is least—at a high-altitude site on a clear day. Even under the best conditions, and at large elongations, daytime sightings are difficult, except perhaps for Venus. Thus, the long days of high-latitude summers are unfavorable to observations of objects other than the Sun and Moon. Twilight observations of the brighter planets, Venus and Jupiter, on the other hand, are not particularly difficult at any site or time of year. One measure of the visibility of objects at twilight is the *arcus visionis*, or *arc of vision*. It is the sun's altitude below the

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[11] *N.B.*, There is a difference in the retinal illumination for the two cases, because the image of the light bulb is much larger, and so the radiant power is spread over a larger area in the case of the light bulb. Assuming a focal length of 16 mm for the human eye, the image of the solar disk on the retina is only 0.15 mm across. Not surprisingly, therefore, staring at a solar image can produce at least temporary impairment.

[12] cf. Wyburn et al. 1964, p. 91ff.

[13] When a telescope is used, the diameter of the primary mirror (for a reflecting telescope) or objective lens (refracting telescope) is used.

horizon at which an object such as a star or planet can just be seen rising before sunrise (or setting after sunset). van der Waerden (1974, p. 19) states that this is 9° or 10° for bright stars such as Sirius, under favorable weather conditions. For a planet such as Venus moving through inferior conjunction, it can be smaller, and observers have claimed to have seen it as an evening star on one evening and a morning star the next morning. The Maya used an interval of eight days for the invisibility of Venus at inferior conjunction, a mean value with which most modern observers agree. The actual values of this interval of invisibility vary between 1 and 20 days.

The celestial equator rises from the east and west points of the horizon at an angle that depends on the latitude: At the equator, this angle is 90°; at the poles, it is 0°. At low-latitude sites like Yucatan (~20° N), the ecliptic, and planetary paths, may be inclined to the horizon at a large angle, facilitating planetary observations. Mercury can not be seen more than about an hour before sunrise nor more than about an hour after sunset, at the best of sites. The limited ranges of inner planet elongations are due to the apparent size of the orbit as seen from Earth (see Figure 2.24). The ability to account for such phenomena was perhaps the Copernican revolution's greatest triumph.

Mercury is particularly difficult to see at high latitudes because of the generally low arc of the ecliptic with respect to the horizon. Copernicus is supposed never to have seen this planet. One of us has seen Mercury several times, even at high latitude sites (see Figure 3.7), but it is not particularly easy under most circumstances. Clear skies down to a level or sublevel horizon, without fog, but perhaps with some cloud below the horizon to dim the scattered light of the sun and improve contrast could aid the resighting of a planet.

Venus is more easily seen than is Mercury, not only because it is often brighter but because its maximum elongation is greater. As we will see (§§12.7, 12.10), however, the Maya recorded the intervals of the Venus synodic cycle quite differently from the actual values, except for the period of invisibility at inferior conjunction. Also among the Maya, it was recognized that there are additional periodicities in the apparent motions of Venus in both its evening and morning forms. An eight-year cycle in the movement of Venus among the stars was incorporated into aspects of the calendar (see §12.7).

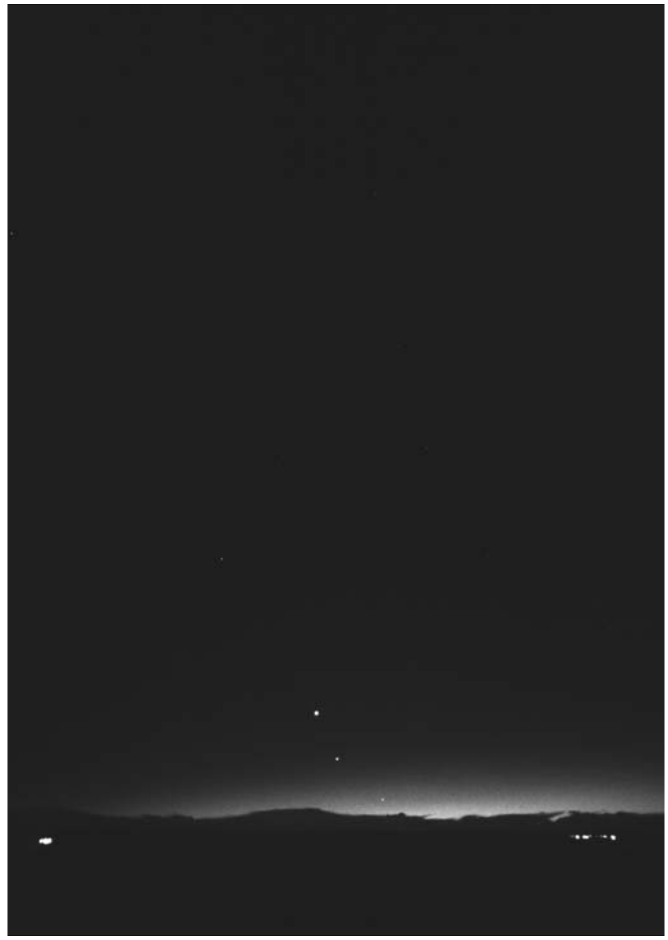


FIGURE 3.7. The planet Mercury along with other bright planets in the twilight sky of Calgary on February 28, 1999. Courtesy, Roland Dechesne, RASC, Calgary Centre. The photo shows Venus, Jupiter, and, closest to the horizon, Mercury.

3.1.6. Effects of Precession

The westward shift of the equinoxes among the stars due to the wobbling of the Earth's axis is known as *precession*. This top-like motion is caused by several factors, the main one being the pull of the Sun and Moon on the equatorial bulge around the Earth's equator,[14] and we discuss its effects first. There are three main results of this *luni-solar precession*.

First, the shifting position of the equinox causes stellar coordinates to change with time. The celestial longitude increases by 50.2 arc-seconds/year, as the equinox shifts westward along the ecliptic. Because this point is also the origin for one of the two equatorial systems of coordinates, the right ascensions and declinations of objects in the sky change also. By differencing the transformation equations between the equatorial and ecliptic systems (§2.3.3) and ignoring the change in the slow change in ε, one may find the formulae for the basic changes in declination and right ascension to be

$$d\delta = d\lambda \times \sin\varepsilon \times \cos\alpha, \quad (3.22)$$

$$d\alpha = d\lambda \times (\cos\varepsilon + \sin\varepsilon \times \sin\alpha \times \tan\delta), \quad (3.23)$$

where $d\lambda = (50''.2) \times dt$, $d\alpha$ and $d\delta$ are the changes (in arc-seconds) in right ascension and declination coordinates, respectively, and $d\lambda$ is the change in celestial longitude due to precession over the interval dt in years. Figure 3.8 illustrates the effect of precession on the right ascension and declination coordinates.

[14] The equatorial bulge is caused by the rotation of the Earth, which results in a slightly weaker gravitational pull on objects at the equator than at the poles.

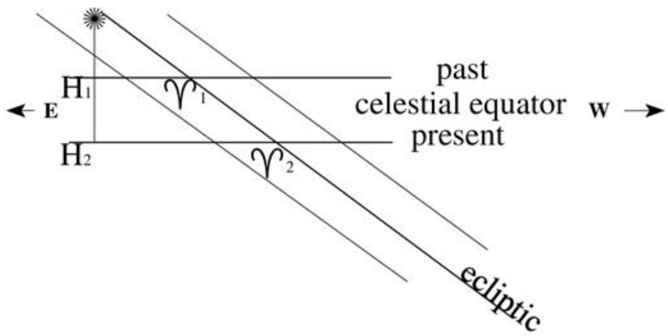


FIGURE 3.8. The effects of precession: The motion of vernal equinox and the changing right ascension and declination coordinates. Drawing by E.F. Milone.

The coordinates on the right-hand sides of (3.22) and (3.23) should be mean values, but these are not known before the calculation; so an iteration must be performed. The initial values of the right ascension and declination are assumed, and the changes $\Delta\alpha$ and $\Delta\delta$ are computed; the new (but not quite correct) values are found, mean values of α and δ computed and inserted in the right-hand sides of (3.22) and (3.23), and the whole process repeated until the last two sets of iterated values are in agreement. To be more accurate still, the value of ε should be computed for the initial and final dates as well. The process can be lengthy if the time interval between dates is substantial. The right ascension and declination for a date in the remote past may be computed more directly by means of rigorous formulae from the Astronomical Almanac[15]:

$$\sin(\alpha - z)\cos\delta = \sin(\alpha_0 + \zeta)\cos\delta_0, \tag{3.24}$$

$$\cos(\alpha - z)\cos\delta = \cos(\alpha_0 + \zeta)\cos\theta\cos\delta_0 - \sin\theta\sin\delta_0,$$

and

$$\sin\delta = \cos(\alpha_0 + \zeta)\sin\theta\cos\delta_0 + \cos\theta\sin\delta_0, \tag{3.25}$$

respectively, where α and δ refer to the date of interest, α_0 and δ_0 refer to the initial epoch, and the auxiliary quantities z, θ, and ζ (which fix the location of the equinox and equator of date with respect to that at the initial date). For an initial equinox at 2000.0, they may be computed as follows:

$$z = [(0.0000051 \cdot T + 0.0003041) \cdot T + 0.6406161] \cdot T, \tag{3.26}$$

$$\theta = [(-0.0000116 \cdot T - 0.0001185) \cdot T + 0.5567530] \cdot T, \tag{3.27}$$

$$\zeta = [(0.0000050 \cdot T + 0.0000839) \cdot T + 0.6406161] \cdot T, \tag{3.28}$$

where T is the number of centuries, measured positively after 2000.0 A.D. If t is the calendar date of interest and JDN the Julian day number (and decimal thereof) of that date of interest, $T = (t - 2000.0)/100 = (JDN - 245\ 1545.0)/36525$.

For most alignment purposes, the *declination* is the important quantity because it and not the right ascension determines the azimuth of rise or set.

The precession also produces a change in the direction of the north celestial pole (NCP) in space. The annual 50.″2 motion of the equinox results in a complete revolution in about 25,800 years. The shift in the NCP in half that period is 2<ε>,where <ε> is the mean obliquity of the ecliptic (see §2.3.3). The precessional circle around the north ecliptic pole is seen in Figure 3.9.

Note the motion of the NCP from the vicinity of the star Polaris over an interval of just a few hundred years. At around 2500 B.C., about when the largest of the Pyramids was constructed in Egypt, Polaris was nowhere near the pole. The pole star at that time was α Draconis (*Thuban*). This star may have played a role in the alignments of narrow shafts discovered between the royal burial chambers of the pyramid of Khufu to the northern face of the pyramid (see §8.1): The angle made by the shaft with the horizontal (~31°) approximates the latitude of the site and thus the altitude of the NCP (29°59′). In the Southern Hemisphere, there is no bright pole star at present, although there is a "pointer," the Southern Cross. Two thousand years ago, the southern pole star was a bright star, β Hyi. Figure 3.10 illustrates the polar motion of the north and south celestial poles, respectively. The sky of 2500 B.C. is shown for the northern hemisphere. That of 1 A.D. is shown for the southern hemisphere.

Finally, as the pole shifts among the stars, the circumpolar constellations change. Some stars that formerly rose and set now remain above the horizon. Some constellations toward the opposite pole that formerly never appeared above the horizon become visible, whereas constellations (at celestial longitudes 180° away) that formerly rose for a time above the horizon now remain invisible. Note the disappearance of the Southern Cross below the southern horizon at the latitude of Jerusalem between 6 B.C. and 1994 A.D. in Figure 3.11.

The effects that have been discussed are for the basic luni-solar precession only. Because the Moon is not on the ecliptic, there is an additional variation in the vernal equinox position. It undergoes a small oscillation that causes the celestial latitude as well as longitude to vary. It also has an additional small affect on α and δ. The NCP will appear to undergo an additional wobble with half-amplitude of 9.2 arc-seconds in an 18.6-year period. The effect, discovered by James Bradley in the 19th century, is known as *nutation*. There are still smaller effects due to the perturbations of the other planets, principally those on the plane of the Earth's orbit; thus, the ecliptic is slowly varying also, although the ecliptic pole variation has an amplitude much less than that of the celestial pole. The combination of luni-solar and this *planetary precession* is called the *general precession*. The discovery and treatment of precession will be described further in §7.

3.1.7. Stellar Proper Motions

All of the stars in the sky have intrinsic motions both in the line of sight (*radial velocities*) and on the plane of the sky

[15] In the section, "Reduction of Celestial Coordinates"; in the Astronomical Almanac of recent years (e.g., 2000), these formulae are located on p. B18.

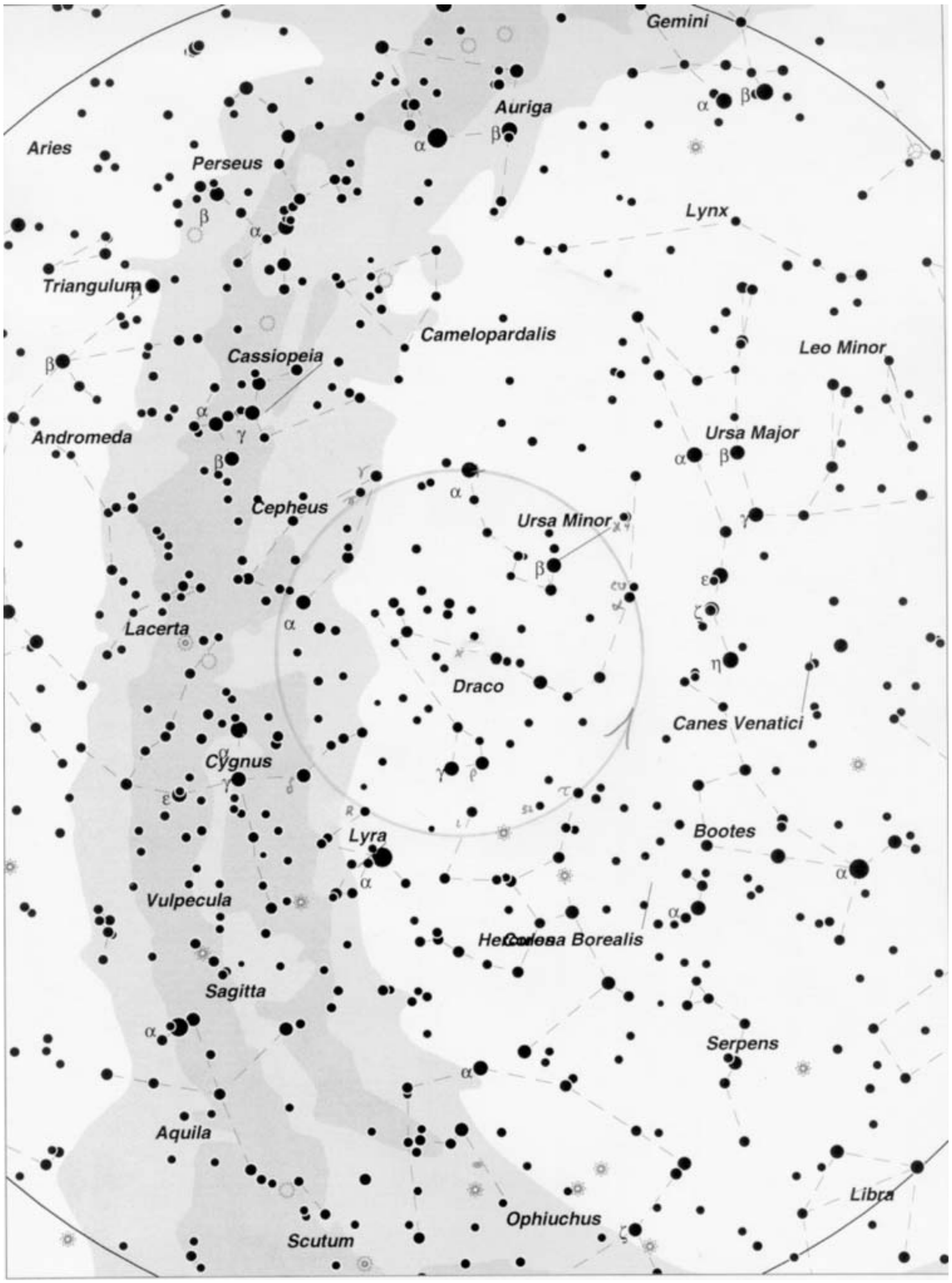


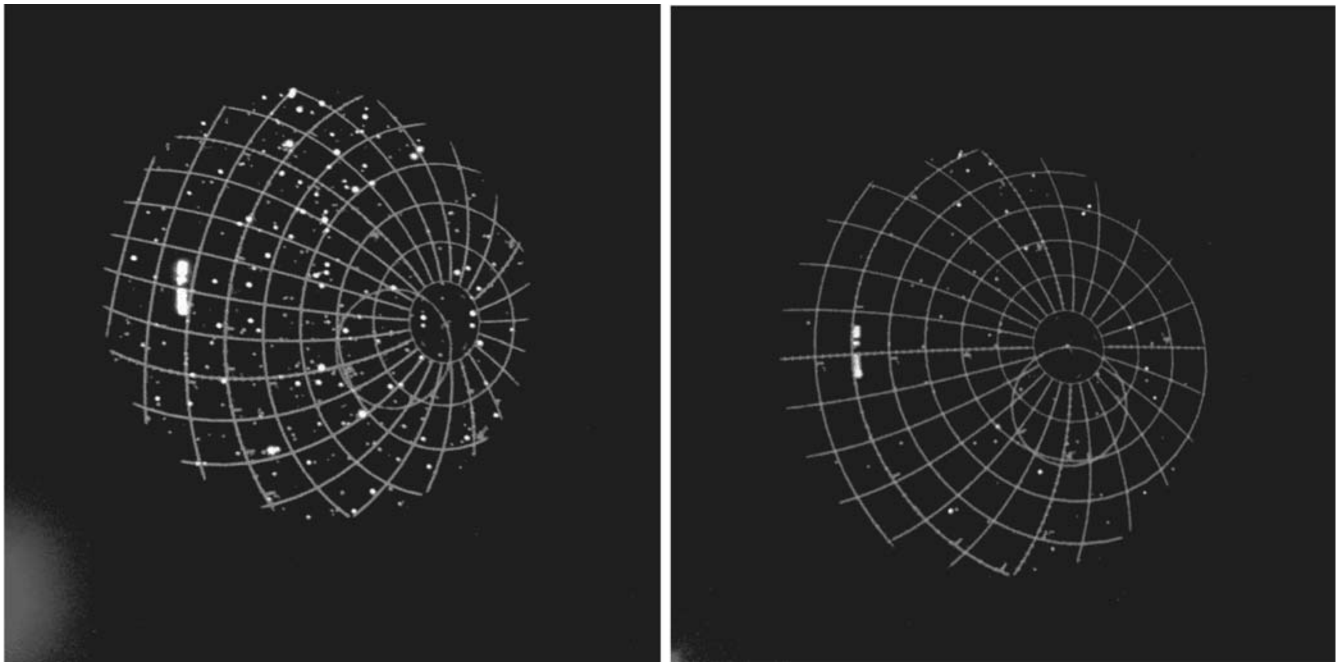
FIGURE 3.9. An effect of precession: The motion of the north celestial pole in 26,000 years. Simulation by E.F. Milone, with TheSky package.

(*transverse* velocities). The transverse velocities contribute to continuous and nonperiodic (or *secular*) changes in position of the stars over centuries. It is only their great distances from us that make these motions imperceptible to the unaided eye over shorter intervals. The change of position on the sky with time is called the *proper motion* and is expressed in arc-seconds/year. The proper motion, μ, is related to the distance r, and the transverse velocity, V_T, by the expression

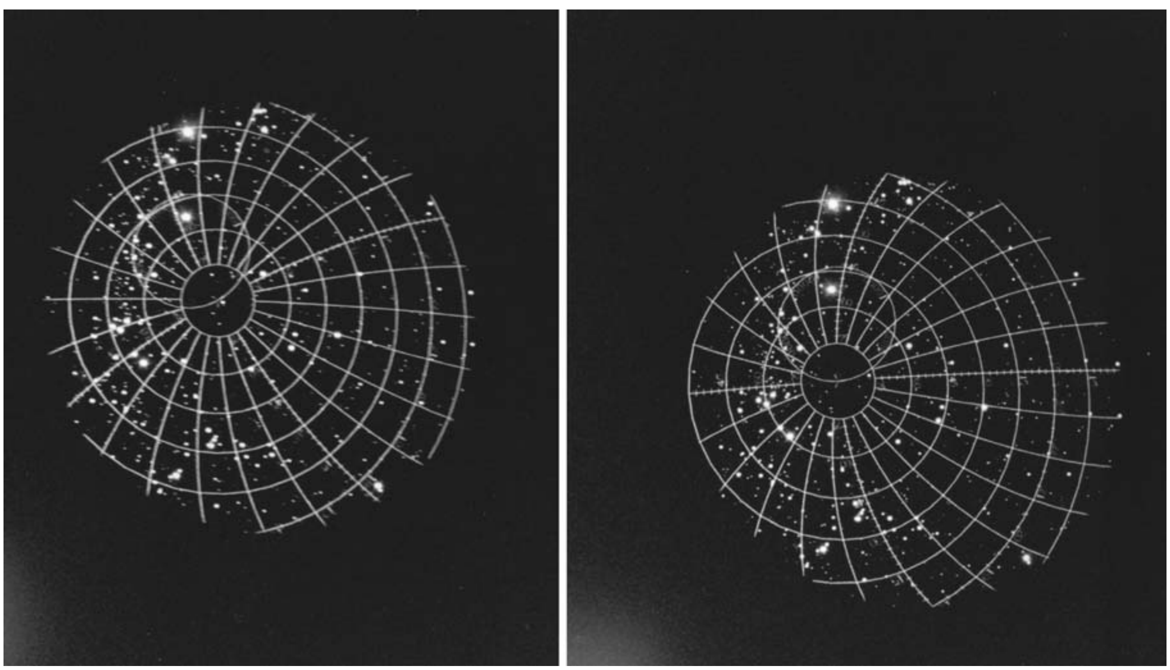
$$V_T = 4.74\mu r, \qquad (3.29)$$

where V_T is in km/s, μ in arc-seconds/year, and r is in *parsecs*, a unit of distance[16] equal to ~3.26 light-years. The proper

[16] A *parsec* is the distance at which the mean trigonometric parallax of the star is exactly 1 arc-second. This parallax uses the astronomical unit as the baseline; the parallax is therefore identical to the angular semi-major axis of Earth's orbit as viewed from the star. Thus, $r = 1/p$. In general, the measured parallax varies in size and direction during the year. Although both are small angular changes that grow smaller as stellar distances increase, the observed parallactic shift is periodic but the effect of proper motion grows with time.

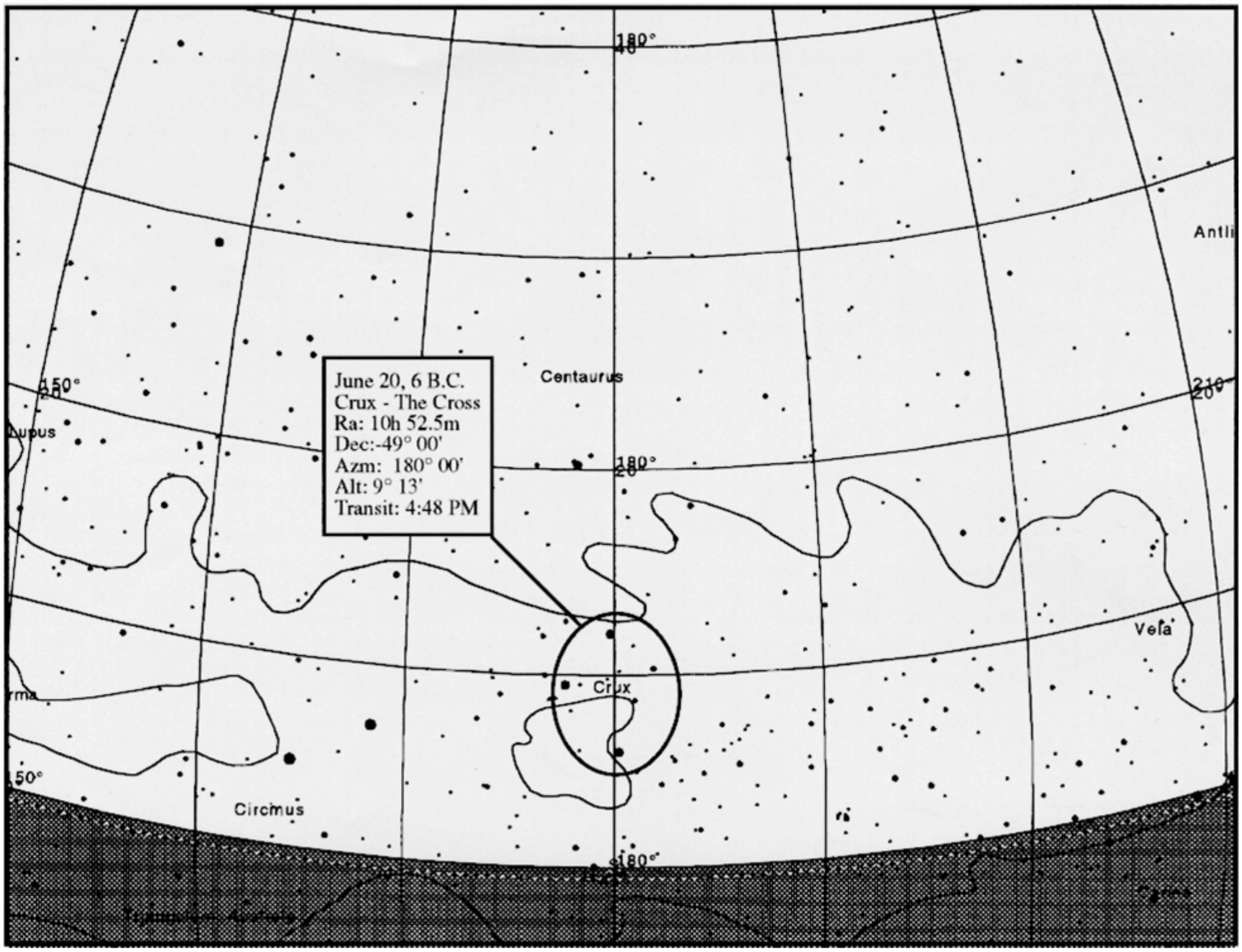


(a)



(b)

Figure 3.10. The NCP and SCP motion with respect to the north and south ecliptic poles, respectively, as photographed from the sky monitor of the Digistar planetarium projection system of the Calgary Science Centre: (a) The region of the sky near the NCP of 2500 b.c. (left) is compared with that of 2000 a.d. (right). (b) The SCP region of 1 a.d. (left) is compared with that of 2000 a.d. (right). Note the bright star (β Hydri) at the southern pole at the dawn of the Christian era. Photos by E.F. Milone with the cooperation of the Calgary Science Centre and Sid Lee.



(a)

FIGURE 3.11. Changing views of the southern horizon at Jerusalem between 6 B.C. and 1994 A.D. Note the disappearance of the Southern Cross below the southern horizon at the latitude of Jerusalem between 6 B.C. and 1994 A.D. Produced by Bryan Wells with the Voyager software package (Carina Software).

motion is measured and usually expressed in equatorial coordinates,

$$\mu_x = 15\mu_\alpha \cos\delta \text{ and } \mu_y = \mu_\delta, \tag{3.30}$$

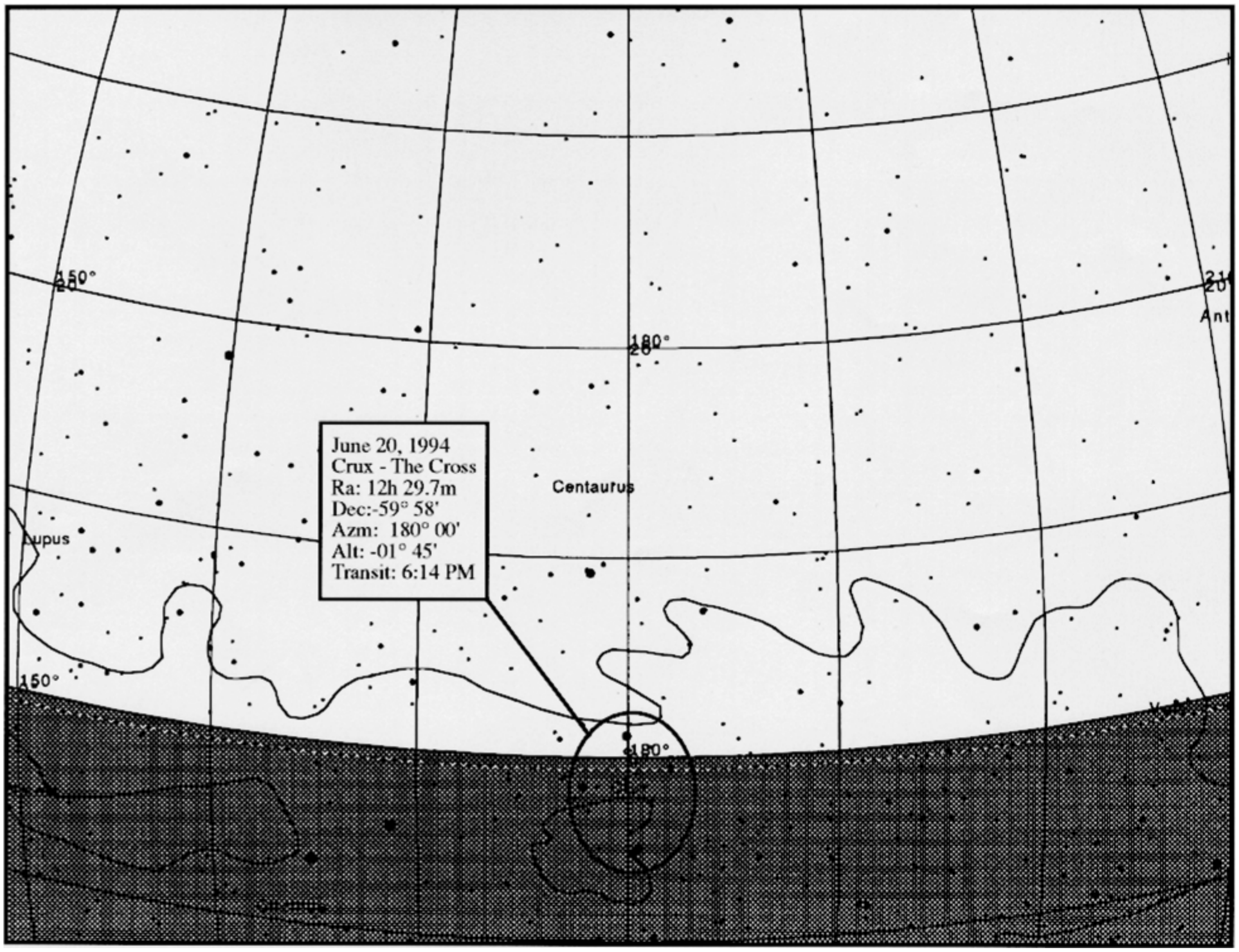
where μ_α is expressed in seconds of time per year and μ_δ in arc-seconds per year. The largest proper motion is that of *Barnard's Star* with $\mu \approx 10''$/year, amounting to the diameter of the Moon in 180 years, but this star is far too faint to be seen with the naked eye. Table 3.3 lists the visible stars with the largest proper motions.

The shift in positions of a few stars in a portion of the sky over a 6000 year interval (4000 B.C. to 2000 A.D.) can be seen in Figures 3.12. Perhaps some of the myths involving Sirius depicted as the point of an arrow or spear, for example, may have been dependent on a different placement of the stars than we see at present.

In Europe, proper motions were discovered by Edmund Halley [1656–1742], but prior credit perhaps should be given to the medieval Chinese astronomer (§10.1.6) I Hsing [682–747]. Recent studies of Palaeolithic pictographs have used proper motions to help to argue the case for alleged depictions of asterisms (see §6.1).

TABLE 3.3. Bright stars with large proper motions.

Star	μ (arc sec/y)
α Cen	3.68
α CMa	1.32
ε Eri	0.97
61 Cyg	5.22
ε Ind	4.73
α CMi	1.25
τ Cet	1.92



(b)

FIGURE 3.11. *Continued.*

3.2. Types of Ancient Observations

Solar, lunar, planetary, and stellar observations were all carried out by pretelescopic societies for a variety of reasons: the Sun for time reckoning, seasonal calendars for agricultural purposes and associated rituals; the Moon for its illumination to assist travel at night, and perhaps for tide predictions and eclipse warnings; the planets for astrological and religious reasons; the stars for navigational purposes. Our goal in this section must be to explore how an ancient astronomer with eye, hand, foot, and a few simple tools could do the job.

3.2.1. Solar and Lunar Observations

Observations of the Sun are needed for seasonal calenders and for solar time, and they can be used for navigation as well. The overwhelming importance of the Sun to life on Earth and the powerful symbolism inherent in its daily and annual rebirths have made it the most favored object of ancient astronomical study. The Sun is also the most easily studied, because being the brightest of all the objects in the sky, it casts strong shadows behind opaque objects. The shadows are not very sharp because of the Sun's finite angular size, but they are sharp enough to enable an hour angle to be read off a sundial. In its most basic form, a sundial is a stick (the *gnomon* or stylus), the direction of the shadow of which provides the time of day and the shortest length of the shadow—when the Sun is on the celestial meridian—indicates, with some ambiguity because it is a double-valued function except at the solstices, the time of year. These are relatively simple observations that could have been, and were, made in antiquity. An Egyptian "shadow clock" from the reign of Thutmose III (1490–1436 B.C.), for instance, measured the passage of the Sun for a 12-hour period (Parker 1974).

An even more obvious indication of season than the length of the Sun's shadow is the Sun's rising point on the horizon. On clear days when the Sun's rising can be observed, the rising location of the Sun on the horizon can be perceived to change day by day near the equinoxes, and

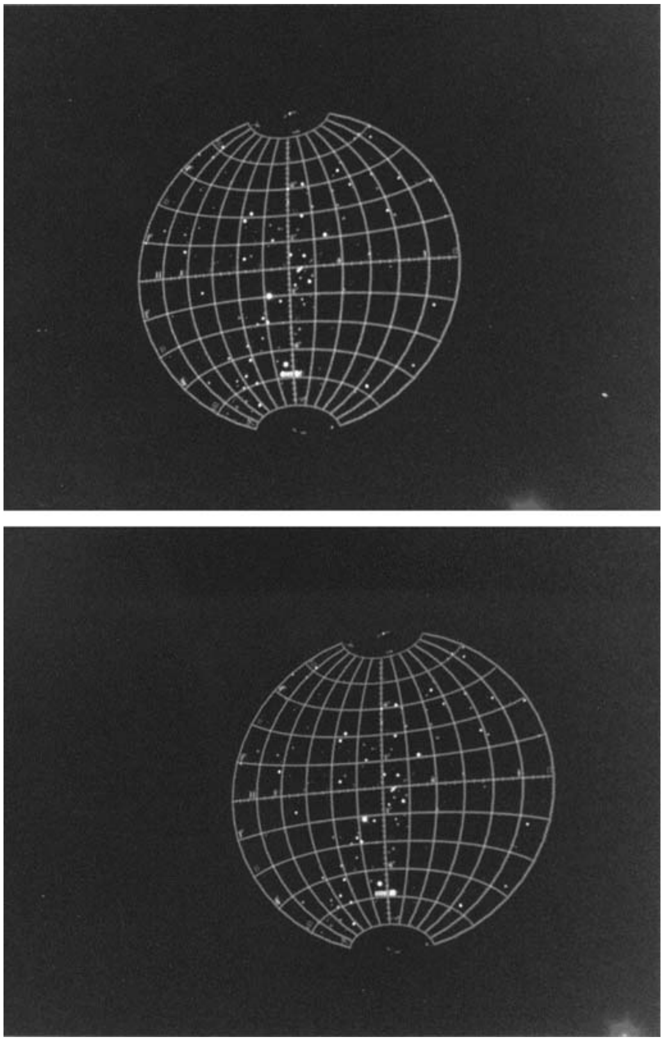


FIGURE 3.12. Proper Motion simulation: The sky as it would have appeared from a specific latitude in the years 4000 B.C. (top) and 2000 A.D. (bottom). The cumulative proper motions of all the visible stars in this region of sky are illustrated over this interval. Note the large motions of Sirius, Procyon, and Pollux. The photographs were taken from the monitor of the Digistar planetarium projector of the Calgary Science Centre by E.F. Milone, with the cooperation of the CSC and Sid Lee.

to vary very little near the solstices, as Figure 3.13 illustrates.

Twice a year, at its approach toward and at its recession from one of the solstices, the Sun would appear to rise at the same horizon location. The azimuth of rise is given by the expression, easily derivable from the astronomical triangle with $h = 0°$:

$$\cos A = \frac{\sin \delta}{\cos \phi}. \tag{3.31}$$

For example, for $\delta = 23.5°$, the declination of the Sun at summer solstice for the Northern Hemisphere $\phi = 51°$,

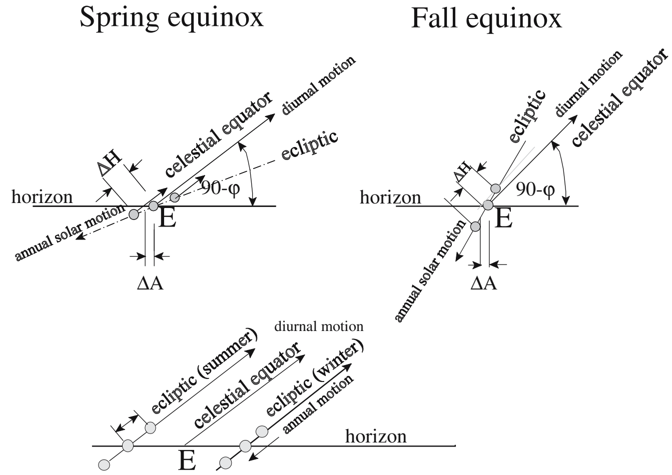


FIGURE 3.13. The day-to-day azimuth changes in the rising (and setting) Sun reach maximum near the equinoxes and minimum near the solstices. Drawing by E.F. Milone.

$\cos A = 0.63362$. Therefore, $A = 50.68°$. For $\delta = -23.5°$, at the same latitude, $A = 129.32°$.

At any given place, the azimuth of rise or set depends on the declination of the object. Therefore, objects such as the Sun, Moon, and planets over sufficiently long periods of time, which alternate between positive and negative values of the same maximum declination, undergo *standstills* (for the Sun: *solstice*) on the horizon as the declination reaches an extreme. The result is an oscillation of azimuth over the period of the declination variation. The *amplitude*, as Lockyer (1894) referred to the maximum difference of azimuth from the east point of the horizon (where $\delta = 0$ and $A = 90°$), is half the total range of any object's azimuthal variation. The amplitude has been the key to understanding the astronomy of ancient Europe. In the above example, the amplitude is 39.32°. It should be noted that the value of the solar declination given in this example is not what it would have been in Megalithic times, because of the variation of the *obliquity*, the angle between the ecliptic and the celestial equator (see §4.4). The value at ~2500 B.C. was ~24°. Figure 3.14 illustrates the solar amplitude for sites at latitudes 0° and 51°, respectively.

Among the oldest known examples of structures bearing solar alignments are passage graves in Ireland and Brittany. A well-known example is that of a tomb at *Brugh-na-Boinne* or *Newgrange* in Ireland. The box-like shaft has the azimuth of winter solstice sunrise (see Figure 3.15). This monument and the complex of which it is part are discussed at length in §6.2.6.

Alexander Thom found large numbers of possible solar and lunar site-lines in the British Isles and in France. Such site-lines used distant *foresights*, such as hills with notches, and relatively close *backsights* involving large stones (*megaliths*). Two well-known sites are the possible solar site *Ballochroy* near Jura and the possible lunar site *Temple Wood*, near Argyllshire, both in western Scotland. These sites and their possible uses as observatories are discussed in detail in

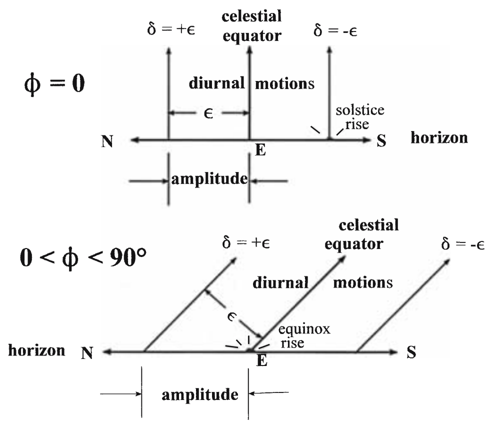


FIGURE 3.14. The amplitude of the azimuth variation of sunrise over the year. The amplitude or swing from one solstice to the other grows larger with latitude. Drawing by E.F. Milone.

FIGURE 3.15. The shaft of the passage grave at Newgrange, seen from inside the tomb. This is one of the earliest known indicators of interest in astronomical alignments. See also Figures 6.6 to 6.8. Photo by E.F. Milone.

§6.2. The basic idea is that the declination and the latitude of the observer determine the azimuth of rise/set (modified by refraction and dip considerations). In the analysis of megalithic monuments, Thom (1971) argued that he was able to detect the effects of three contributions to the variation of the declination of the Moon:

(1) The variation of the declination due to the motion of the Moon in its orbit with mean orbital period $27^{\mathrm{d}}.32$; at present, $\pm 28^{\circ}.5$.

(2) A modulation of the monthly variation due to the regression of the nodes of the Moon's orbit. The Moon's inclination, $i = 5°8'43''$. Consequently, the celestial (ecliptic) latitude of the Moon varies between $\pm i$ over a sidereal month. However, as the Moon's orbit regresses, the celestial longitudes at which the extremes of celestial latitude occur also slip westward. This change is reflected in changes in the declination of the Moon over the nodal regression period of $18^{\mathrm{y}}.61$. The lunar declination in the course of a month thus varies from $+\varepsilon + i$ to $-\varepsilon - i$ at major standstill and $+\varepsilon - i$ to $-\varepsilon + i$ at minor standstill.

(3) A variation in the inclination, which again contributes not quite fully to the declination variation in that it acts to change the celestial latitude. The period of Δi (Thom called the corresponding change in declination, Δ) is $173^{\mathrm{d}}.3$ over a range $\pm 9'$. See §6.2.15 for Thom's suggested method by which such measurements could have been carried out in megalithic times.

Examples of solar alignments of monuments are the Temple of Amon-Re at Karnak in Egypt; the columns at Persepolis; Ha'amonga-a-Maui on the Pacific island of Tonga; and at various temples, dating over a wide range, in the Mediterranean area. Alignments of buildings, and perhaps of whole cities, is a likely explanation for many orientations found in pre-Columbian America. One of the principal axes of the largest city of the ancient new world, Teotihuacan, was apparently aligned on the direction of the setting of the Pleiades, a notion reinforced by the presence of two well-separated *pecked crosses*, aligned in the same direction. There are many instances of astronomically aligned buildings in Mayan and other Mesoamerican cultures.

At *sunwatcher stations*, the North American Anasazi observed the turning of the Sun at the solstices, and some *medicine wheels* may have been constructed by other Native Americans to mark the azimuthal travel of the Sun and the rising points of certain stars. In the Incan capital city of Cuzco, there are a large number of *ceques* or lines of direction, radiating from a central location, the temple of the Sun, *Coricancha*. Some of the *ceques* may have marked the position of the horizon Sun during the year. Taken as a whole, all this evidence, although circumstantial and incomplete in many cases, demonstrates that the rise and set of astronomical objects was of profound interest to ancient humanity. Returning to our first example, the gnomon, we can easily show that with it, the directions of rise and set of the Sun during the year can be readily noted; however, the length of the noon shadow alone gives important information about the time of year also (see Figure 3.16). When the directions

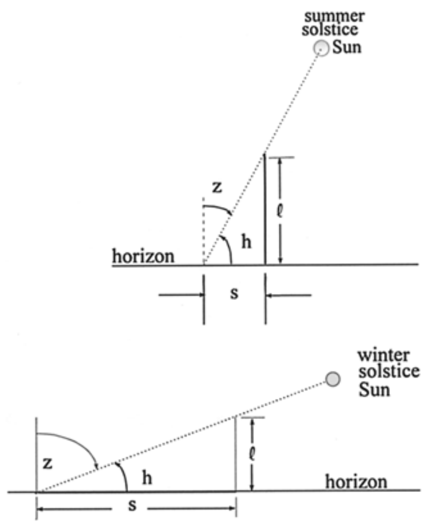


FIGURE 3.16. The use of the *gnomon* in solar measurements. The length of the noon shadow alone gives important information about the time of year. Drawing by E.F. Milone.

of rise and set are in the same line, the dates of the equinoxes and the east-west cardinal directions are simultaneously determined. This demonstrates that the skill involved in the alignment of the pyramids, although praiseworthy, did not require superhuman effort, merely the careful systematic observations of calendrical astronomers (see Neugebauer 1980, 1983).

The measurement of hour angles was probably not so widely carried out, but it was done. The Egyptian star clocks that relied on roughly equally spaced stellar asterisms called *decans* are examples of very early usage of the concept of hour angles. Sundials are another example, as we have already noted. The hour angle of rise may be found from (2.2) and (2.3):

$$\sin H = \frac{-\sin A}{\cos \delta}, \tag{3.32}$$

$$\cos H = -\tan \phi \times \tan \delta. \tag{3.33}$$

The hour angle of set is equal to the hour angle of rise except for the sign, which is always negative for a rising object.

For example, what are the hour angle and the azimuth of rise of the Sun on the day of the winter solstice at latitude +53°? On this date, $\delta = -23\overset{\circ}{.}5$. Therefore, by (3.33), $\cos H = -\tan(+53^\circ) \times \tan(-23\overset{\circ}{.}5) = -1.32704 \times (-0.43481) = +0.57702$ from which, $H = \pm 54\overset{\circ}{.}759 = \pm 3\overset{h}{.}6506$. An object on the celestial equator must rise at the east point with an hour angle $H = -6^{h}$; here, $H = -03^{h}\ 39^{m}$. Consequently, rearranging (3.32) and substituting, we have

$$\sin A = -\sin H \times \cos \delta = -0.81673 \times 0.91706 = 0.74899,$$

so that $A = 48\overset{\circ}{.}503$ or $(180^\circ - 48\overset{\circ}{.}503)$. Because the azimuth of the east point (where the celestial equator intercepts the horizon) is 90°, $A > 90^\circ$. Therefore, $A = 131\overset{\circ}{.}497$. The construction and use of sundials was carried out for obvious practical purposes. Neugebauer (1948) has argued that the study of the theory of the sundial may well have led to the discovery of the conic section and, thus, serendipitously, to the scientific revolution that continues today. Not everyone agrees with this interpretation, however.

Solar observations have been used for navigation. For naked eye navigation, the Sun is almost the only visible astronomical object when it is above the horizon. The Moon's more complicated motion must have made it less desirable for such a purpose, but if tides or illumination were concerns, the behavior of the Moon may have been studied sufficiently to make it of use (see §6.2). The declination of the Sun and the observer's latitude together determine the Sun's azimuth of rise and its altitude at culmination, when it crosses the celestial meridian at apparent noon. Therefore, given the time of year, and the circumstance of sunrise, sunset, or local noon, the latitude can be determined by the altitude of the Sun. This is demonstrated for the instant of apparent solar noon in Figure 3.17 and can be summarized in the relation among the true altitude of the Sun, h, its declination, δ, and the latitude, ϕ:

$$h = (90 - \phi) + \delta,$$

so that

$$\phi = \delta + (90 - h). \tag{3.34}$$

The true altitude is determined from the observed altitude and corrected for refraction; unless the Sun is very low, however, the error due to neglect of this quantity will not be great. A very low winter Sun is a characteristic of high-latitude sites (December solstice in the Northern Hemisphere and June solstice in the Southern), but in the Southern Mediterranean region, at latitudes of ≤20°, the error in the altitude of the noon Sun due to refraction does not much exceed about 1 arc-min.

The astronomical determination of relative longitude requires a measure of the time at some other place than the site from which the observations are being made, however. Aside from dead reckoning, where the rate of travel and the time interval are multiplied, east-west distances could not be determined across large sea distances before the invention of the chronometer. These comments hold also for stellar navigation, discussed below and in §11.3.

The determination of *bearing* was another matter, and any rising or setting astronomical objects could be used, if the azimuth of rise were known for particular sites. The determination of bearing in the ancient world sometimes required ingenious methods. Viking sagas mention a *solarstein*, literally "sun stone," alleged to have been used for navigation. Viking navigators may have used naturally occuring crystals of Icelandic spar to detect polarized, scattered sunlight to determine the direction of the Sun even under cloudy skies.[17]

[17] Atmospheric scattering produces a maximum polarization 90° from the Sun; Icelandic spar polarizes light and therefore acts as an analyzer. The direction normal to the Sun can be found by rotating the crystal while peering through it and repeating the process in many directions. A dark minimum will be seen in the direction of strongest atmospheric polarization. The reader can carry out the experiment with polarized sunglasses.

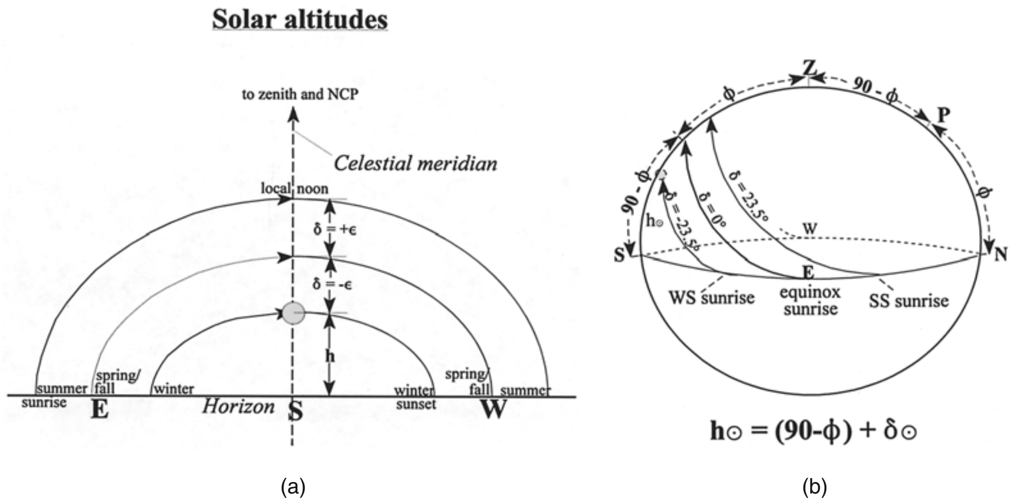


FIGURE 3.17. The measurement of the altitude of the noon Sun reveals the observer's latitude: (a) Horizon view at the four quarters of the year. (b) The general view on the celestial sphere of solar meridian crossing. Drawings by E.F. Milone.

Under certain circumstances and in certain individuals, the dichroic property of the retina may be developed to detect polarized sunlight from the sky. The cross-like image is called *Haidinger's brush* (or *bundle*). See Minnaert (1954, pp. 254–257) or Schlosser et al. (1991/1994, pp. 104–105).

Among Islamic astronomers, observing the first visibility of the lunar crescent was an important task. In the Islamic calendar, a new day begins at sundown, and the onset of a new month occurs at the first sighting of the crescent. In particular, the end of the month Ramadan marks the end of the fasting period. In clear skies, the crescent can usually be spotted a day after conjunction, but on occasion, it can be seen less than one day afterward. In the event of cloudy skies, the month can be assumed to be 30 days long. An important classic source for understanding the visibility of the crescent was *The Handbook of Astronomy* by al-Battani [850–920], who cited "ancient opinion" as well as methods for determining visibility. The geometry is straightforward, but the brightness of the background twilight sky, as well as the arc of vision, is involved. See Bruin (1977) for an exposition of the problem and useful translations of important sources.

3.2.2. Planet and Star Observations

Planetary observations were carried out in Mesopotamia as early as the reign of King Ammisaduqa. Venus observations are recorded in the 63rd tablet of an extensive series entitled *Enuma Anu Enlil*, a list of omens, which Neugebauer (1969, p. 101) likens to papal bulls of the Middle Ages. A more detailed list of observations of the Moon, planets, and stars from Babylonia from ~700 B.C. (the $^{\text{mul}}$APIN) is discussed in §7.1. These observations were probably for royal astrological purposes—to study and prognosticate the impact of planetary influences on kings and kingdoms. The quantities that were historically measured were a celestial longitude and latitude. The equivalent of celestial longitude (see §2.3.3) was expressed in degrees of the zodiacal signs; e.g., ♂ 12°♉ indicates that Mars is 12° east of the beginning of the sign of ♉, Taurus, or 42° from the first point of Aries, ♈. See §7.1.4 for the usage of this notation on the baked brick cuneiform tablets of ancient Babylon. The celestial latitude was measured more directly, with an armillary sphere or similar device (see §3.3).

The rise and set points of stars do not change periodically during the year like the risings of the Sun, nor on other short time scales like those of the Moon or planets. But, precession (see §3.1.6) changes the right ascensions and declinations of the stars, and the changing declinations cause secular changes (actually very long-term periodic changes) in their rise and set azimuths. The purely secular variation of the stars' proper motions change the right ascension and declination and, thus, the rise and set azimuths. The usefulness of pointing to the locations of star positions arises only because the visibility of the stars varies with season. One type of important date marker is the *heliacal rising*, when an object is visible for the first time in the dawn sky following (solar) conjunction. Others are *heliacal setting*, marking the last visibility before conjunction; *acronychal rising*, when an object is seen to rise at sunset; and *acronychal setting*, when an object is seen to set at dusk for the last time (thereafter it will be in conjunction with the Sun, and, later, rise heliacally). Some of these phenomena are illustrated in Figure 3.18.

Such phenomena apply to any object in the sky, of course, but early skywatchers may have used a more convenient stellar marker in case of hazy or cloudy conditions or generally when the object is intrinsically difficult to observe. A *paranatellon* is a bright star undergoing the same phenomenon (literally, to rise or appear beside) as a fainter star or asterism. An example of such use is suggested in §14, in relation to a celestial marker (Vega) for a "dark constellation," the "Dark Cloud Llama."

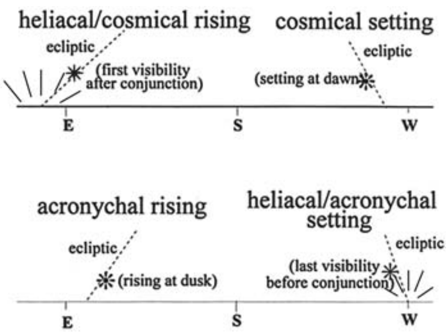


FIGURE 3.18. Horizon views of *heliacal, cosmical*, and *acronychal risings* and *settings*. Heliacal or cosmical rising is the occasion when an object is visible for the first time in the dawn sky following (solar) conjunction, and heliacal or achronychal setting is when it is last seen just after sundown. In the context of risings and settings, "cosmical" and "achronychal" refer to phemomena associated with sunrise and sunset, repectively. Drawn by E.F. Milone.

The Big Horn Medicine Wheel in Wyoming (Figures 6.38c–e) may contain terrestrial markers for heliacal risings of several bright stars (Eddy 1974, 1977; Robinson 1980). The azimuths of the stars correspond to declinations at ~1250 A.D., and underlying features of the site suggest even greater antiquity (Fries 1980). Other medicine wheels have had relatively few alignments, suggesting that they were not always constructed with accurate sky measurements in mind, at least in the same way.

A well-known use of the stars through the ages has been for navigation. The requirements for astronomical navigation are implicit in the discussions of spherical astronomy. The latitude can be determined from the altitude of the north celestial pole, and to within about 2°, with the altitude of Polaris, at the present epoch. It can also be determined by the declination of a star passing through the zenith, or which just skims the northern or southern horizon. For the longitude, one needs the instant of transit, or rise or set of a given star, bearing in mind the dimming that accompanies very low altitudes. The local time at sunset is readily obtained by the stars that rise heliacally or acronychally; at any time of night, the local sidereal time is obtained by observing the right ascension of stars that transit the celestial meridian. The difficulty is that to determine the longitude, one needs the time at some other meridian—a meridian whose longitude is known. The best one can do without a chronometer that records the time at that distant meridian is dead reckoning. The direction of travel can be determined, and by estimating the rate of travel, one can compute the distance traveled. There is ample evidence that the Polynesian travelers used just such methods, and their methods are discussed in §11.3.

The type of observations we have described thus far involve systematic study of the Sun, Moon, and the other planets of antiquity. The observational records of ancient Mesopotamia and China also contain references to transient phenomena such as eclipses, comets, novae, meteors, and atmospheric conditions. These are particularly valuable to modern science, and they will be discussed more extensively, beginning in §5.

3.3. Instruments and Observatories

The oldest observatories involved backsites and foresites and appear to be nearly as numerous in ancient Britain in megalithic times as town square clocks are in Europe today. This, at least, is the impression gained from a plot of the locations of those sites (Figure 6.1). The builders were concerned with the solar and lunar rising and/or setting azimuths. We will show in a later chapter that these types of observations could have been made for calendric purposes but also possibly for eclipse prediction.

Among the instruments used by astronomers in ancient Egypt (§8.1) were sighting instruments, shadow boards, and other types of shadow clocks, some very elaborate. The boards were leveled by plumb-bobs. Sundials were created with gnomons, and with a leveling device known as a *merkhet*. Essentially a string-supported plumb-bob, the device served as a portable sundial, the string of which provided the shadow. Instructions for constructing a shadow clock are provided in the funerary text on a cenotaph of the pharaoh Seti I in Abydos. The *benben* pillars, including later obelisks, were associated with the sun and could have been used as large gnomons or sighting devices. Unfortunately, we have no descriptive evidence suggesting such a use. Water clocks, of both "inflow" and "outflow" types, were used by astronomers and frequently have constellation designs. The so-called Ramesside star clocks show transit stars "measured" relative to a figure of a seated individual against a grid of 8 × 13 squares. These show a clear concept of a gridded star map, but the use of the grid seems crude and never seems to have been extended to the whole sky.

For an observer responsible for the measurement of time, a *decan* must have functioned as a star almanac entry, indicating the appropriate time of night in a given season when a particular asterism arose. Star clock tables from the tombs of Rameses VI, VII, and IX, kings of the 20th dynasty (~1500 B.C.), seem to use a scheme different from the successive risings implied by the decans (Neugebauer and Parker 1969, Vol. II, p. 74). Each table is associated with a seated man; vertical lines traversing the figure apparently mark the time that a star passes by that point. These star clock tables could not have been very precise: The references are to "on the shoulder," "on the Right (or left) ear," "opposite the heart" (the origin, which Neugebauer and Parker envisage to be on the celestial meridian), "on the right (or left) eye," apparent references to the seated figure who had to remain motionless for the entire night. If the figure was a statue, such a scheme would still not be very precise because a sentient observer had to mark the hours! Nor could this reckoning be very accurate, given the march of the seasons. Neugebauer and Parker (1969, Vol. I, pp. 107–113) find evidence of attempts to repair the decan scheme (in the asterisms that operated in the five epagomenal days) as the errors of the calender accumulated.

Nevertheless, as Neugebauer and Parker remark, the scheme was impressive enough to the ancient Egyptians to be enshrined forever in the Ramesside tombs. The purpose of including such depictions on the wall of a sealed tomb can only have had meaning for the soul of the pharaoh. The telling of the hours of the night must have been a necessary part of the dealing with the dangers of the underworld before being reborn at dawn with the rising sun. See §8.1 for detailed discussion of the background for, and the astronomy of, ancient Egypt.

Ptolemy mentions several instruments in the *Almagest* (cf. Toomer 1984, 61ff). He describes the construction of a meridian circle with which the noon zenith distance can be measured. He cites writings of Hipparchus, who mentioned a bronze ring located in the "Square Stoa" section of Alexandria. With this ring, which was accurately aligned in the plane of the celestial equator, Hipparchus said that it was possible to indicate the dates of the equinoxes by noticing when the face that is illuminated by the Sun changes from top to bottom (Fall) or bottom to top (Spring). Ptolemy describes the construction of what he calls an "astrolabon" instrument. The object Ptolemy describes resembles what we would call an *armillary sphere*, a series of nested, graduated rings, one set in the ecliptic, another in the equatorial plane (and perhaps a third in the plane of the horizon). The result is a means to measure the position of a heavenly object in any of several coordinate systems. The ecliptic longitude and latitude could be read off the graduated rings directly. What we today would call an *astrolabe* would have been referred to as a "small astrolabe," in Ptolemy's day, according to Theon of Alexandria (~375 A.D.).

The astrolabe, like our modern planisphere, was a two-dimensional representation of the celestial sphere, with the ecliptic projected onto it, and retaining a circular shape. By selecting the date, the time of night was then revealed by what stars were visible on the meridian; it served also as an instrument for the observation of both the Sun and the stars. It was equipped with a rotatable marker (called an *alidade*) that was fitted with sights. A measurement of the solar altitude could give the time from meridian passage for a given latitude (once the date had been dialed in). The measurement of the altitude of a star could be used similarly; alternatively, measurement of the altitude of the Sun or that of a known star when on the celestial meridian could reveal the latitude of the observer [refer to (3.34)]. A filigree metal star chart called a *rete* was included on the face of the astrolabe, and beneath this, visible through the filigree, was one of several plates (which could be interchanged for locales of different latitudes) marked with projections of altitude circles (*almucantar*s or *almucantur*s), as well as the equator and tropics, and sometimes other circles as well. The almucantars are circles of equal altitude that are projected stereoscopically[18] onto to a plane parallel to the equator. The almucantars remain circles (this is a characteristic of stereoscopic projection), but their centers shift along the line joining the projection of the north celestial pole and the zenith. The separation of the zenith and NCP depends on the latitude, and so the family of almucantars differs in placement with latitude also; hence, the need for more than one plate, if the user of the astrolabe was given to travel.

After a sighting on the Sun, the *rete* would be rotated until the Sun's position coincided with the appropriate altitude circle, and the hour of the day could then be read off. Its small size made the astrolabe popular among travelers, and it was used up to the mid-18th century when it was replaced by a forerunner of the modern sextant. Figure 3.19 illustrates a German astrolabe, constructed in 1537 by George Hartman.

There were four plates, each inscribed on both sides with the stereographically projected altitude circles appropriate for a particular latitude: 39°, 42°, 45°, 48°, 51°, and 54° are explicitly marked. The center of the astrolabe represents the NCP, and the tropics of Cancer and Capricorn flank the equator with which they are concentric. Around the outside of the body are the Latin names of the winds. Within these are the 24 equinoctial hours, in Roman numerals of 1 to 12, repeated; and a ring of four sets of altitudes in 1° intervals over the range 0° to 90°. The *rete* contains the ecliptic, marked with the zodiacal signs and subdivisions of 5°, and the locations of particular stars marked by perforated pointers. The index arm that pivots about the center (the NCP projection) marks off the location of the Sun on the ecliptic for a particular time of year. The intersection of this arm with the body of the astrolabe indicates the hour of the day (the Roman numerals). The arm is inscribed with degrees of declination, north and south of the celestial equator. The back view shows the alidade with collapsible sighting plates. On the body, proceeding from the rim inward, are altitudes, degrees (in Roman numerals) of the zodiacal signs, and the days of the months. The dates corresponding to the boundaries of the signs indicate that the first point of Aries occurred on March 10. Even more elaborate astrolabes are known. See, for example, Gibbs and Saliba (1984) for several interesting examples.

Ptolemy's description of the large "astrolabe" is in the context of his discussion of the lunar "anomalies"; i.e., the Moon's departures from Ptolemy's model. He was using the device to measure the longitude of the Moon relative to the Sun. One of the difficulties in measuring the position of the Moon is the presence of a large amount of parallax (see Figure 3.6). For this reason, Ptolemy built what he called a "parallactic instrument" (Toomer 1984, Fig. G, pp. 244ff),[19] with which he measured the zenith distance of the center of the Moon's disk at meridian passage.

First, he established the actual celestial latitude variation of the Moon by observing it when it was at its highest above the ecliptic (at such time it would have been close to the

[18] The focus of the projection is the south celestial pole. Thus, each projected point is the intercept of the equatorial plane with the line joining the SCP and the point of interest on the celestial sphere.

[19] According to Toomer, during the Middle Ages, this instrument was called a *triquetrum*, because it consisted essentially of three main components (see Figure 3.20).

(a) (b)

FIGURE 3.19. An astrolabe: (a) Front and (b) back views of a German 16th-century astrolabe, No. 262 [Smithsonian Catalog No. 33617] discussed by Gibbs and Saliba (1984). Such devices were two-dimensional representations of the celestial sphere that provided a practical method of navigation, or, alternatively, local date and time determination. Like the modern planisphere, it is a two-dimensional representation of the celestial sphere, with which the time of night on a given date is revealed by what stars are visible on the meridian. In addition, it permitted observations of the altitudes of the Sun and stars with a rotatable *alidade*, which was equipped with sights. The solar altitude provided the time of day (given the date), and the altitude of a star on the celestial meridian revealed the latitude of the observer. Beneath the filigree metal star chart (*rete*) on the face of the astrolabe is a site-specific plate on which altitude circles (*almucantars*) are marked. After a sighting on the Sun, the *rete* would be rotated until the Sun's position coincided with the appropriate altitude circle, and the hour of the day could then be read off. From Gibbs and Saliba [1984, Figure 12, pages 9, and 97, page 148, Smithsonian Prints #79-1769 and #82-8299] and reproduced here by permission of the Smithsonian Institution, Washington, D.C.

zenith at Alexandria) and subtracted $z = 2^1/_8°$ from the latitude, $\phi = 30.°97$ to get $\delta_{max} = 28.°85$, and, with $\varepsilon = 23.°85$, found $i = 5.°0$. He then measured the Moon's lowest z at the opposite solstice[20] and found the parallactic shift ($z_2 = 50.°92$ vs. $2\varepsilon + z_1 = 49.°83$). Ptolemy thus deduced a lunar parallax of ~1°07′, not too different from the modern value (57′). See Toomer (1984, pp 246–251) for more detail.

Graduated scales on quadrants were in use for centuries, culminating in the work of Tycho Brahe. This great 16th-century observer used massive instruments at the royal observatory on the island of Hveen in Denmark to measure the precise relative positions of the planets. He used a clever vernier scheme to read the scales: *transversals*, lines of ten uniformly spaced dots, were placed along lines angled upward from each side of every other base scale tick mark,

[20] These conditions are referred to as *major* and *minor standstills*, respectively, from the effect that the celestial latitude variations has on the declination variations of the Moon during the month and consequently on the amplitude of lunar rise and set azimuths. The evidence for the megalithic studies of the Moon is mainly from alignments to distant foresights allegedly marking the standstills (see §6.2).

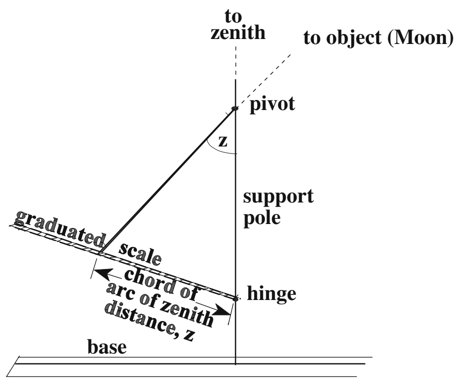


FIGURE 3.20. A rough sketch of the *triquetrum*, as it was called in the Middle Ages, consisted essentially of three main components; it is closely similar to the instrument described by Ptolemy as a "parallactic instrument," which was used to measure the meridian zenith distance of the Moon at each solstice (Toomer 1984, Fig. G, p. 245). The rod anchored at the top of the vertical rod was lined up with the object in the sky, and the position on the lower rod read off; in combination with the vertical length, it yielded the equivalent of the zenith angle. Drawing by E.F. Milone, after Pannekoek (1961/1989, pp. 154, 181).

forming a rough triangle with the base. A line-of-sight indicator extended into the triangle region would intersect the line of dots at the decimal fraction of the distance between the base marks. The leverage thus gained created an improved precision of angular measurement (Thurston 1994, Fig. 10.7, p. 215). Thurston (1994, p. 215) notes that the inventer of this scheme was not Tycho Brahe but Johann Hommel [1518–1562]; but Brahe used it to great effect.

In addition to the astrolabe, another instrument in widespread use for measuring angles was the *cross-staff*, sometimes called a *Jacob's staff* in the Middle Ages. Basically, this simple hand-held instrument consisted of two perpendicular sticks, both graduated, with the cross piece able to slide along the main shaft so that the angular extension of the cross-piece (or some part of it) could be made to match the angular separation of objects. Thus, the separation between a planet and a star could be measured, and from these, with the help of spherical trigonometry, the differential right ascension and declination could be obtained. It can also be used to find the altitude of an object. The construction and operation of the cross-staff is described in Schlosser et al. (1991, Appendix C, Ch. 1). The angle to be determined, α, can be obtained from the expression

$$w = 2 \times \ell \tan\frac{\alpha}{2}, \tag{3.35}$$

where w is the width of the cross piece that spans the angular distance in question and ℓ is the distance from the cross piece to the eye. A finely elaborated version, with several cross pieces can be found in the David M. Stewart Museum Collection in Montreal, a photograph of which has been published by Levy (1990, p. 120). See §7.6 for further discussion of astronomy in the Middle Ages.

In Mesoamerica, there are certain sites from which alignment observations could have been made. The *Caracol* in the Mayan city of Chichen Itza on the Yucatan peninsula is partially in ruins today, but from the existing windows on the upper floor of the remaining part of the structure, the inner and outer edges of the window casements define narrow slitted areas through which the amplitudes of the Moon and of Venus could have been observed (see §12.22). Venus and the Moon are both tied into a calendrical system that was used in Mesoamerica during the period of time in which Chichen Itza flourished. The city also contains a pyramid named for the god *Kukulcan*, and called by the Spaniards, *El Castillo*. A bas relief of a ruler who was named after the god and may have been regarded as identical with him is depicted inside a room at the top of the pyramid. Kukulcan has been associated with Venus, although Kelley (§12.6) has argued for an identification with Mercury. Solar alignments have also been claimed for certain window casement structures in North America, principally, at *Casa Grande* in Arizona and at *Casa Rinconada* in New Mexico, although it is less clear that the latter structures were exclusively used as observatories (§13.1).

In Asia, we have some of the oldest observatories still standing (cf. §10.2). The oldest structure known at the time of writing is the *Chomsongdae* or Star Tower (see Figure 10.9) at Kyungju (Chhing-Chow) in the ancient Silla kingdom (now part of South Korea) during the reign of Queen Sondok (632 to 647 A.D.). It has a single window facing south and could have supported a platform on the top holding an armillary sphere. The armillary sphere is a device that recreates the basic frame of the celestial sphere. Typically, it contained the celestial equator, the celestial meridian, the horizon, and perhaps the ecliptic. With it, observations could be made of the altitudes of celestial objects on the celestial meridian, as well as at other azimuths, and of declinations. If the ecliptic was included, ecliptic coordinates could be obtained. Azimuths and hour angles could have been measured also with such devices, with, however, limited precision. There are many existing armillary spheres and other devices, such as quadrants, that were used for altitudes and declinations, in China. See Figure 3.21. A 15th-century version of an equatorial armilla said to be designed by Kuo Shou-Ching (~1276) is now located in the courtyard of the Old Beijing Observatory (Figure 3.21a). A horizon circle is supported by dragons; the celestial equator and ecliptic can also be seen. Hour circles permit the measurement of angles around the celestial equator. An "abridged armilla" also from the 15th century, and also located in the courtyard, is seen in Figure 3.21b. Notice that this instrument is actually a collection of instruments, including a sundial, horizon and azimuth circles, and an equatorial circle. See §2 for details on the coordinates and how they are measured.

The tower of Chou Kung at Kao-chhêng near the important ancient imperial site of Loyang permitted measurement of the length of the Sun's shadow as it transited the meridian (Needham 1959, pp. 296–297, Figs. 115–117 from Tung Tso-Pin et al. 1939). This was therefore an observatory for the study of time and solar date (attested), and it was an ancient analog of such institutions as the Royal Greenwich

(a)

(b)

FIGURE 3.21. Chinese armillary spheres said to be from the 4th year of the reign of the Ming emperor Zhengtou, ~1439 A.D., and now located in the "Old Beijing Observatory," Beijing, China: (a) Based on the equatorial armilla of Kuo Shou-Ching (~1276) and (b) the "abridged armilla." Photos by E.F. Milone.

Observatory and the U.S. Naval Observatory. Figure 3.22 is a sketch of the structure of the tower with an opening providing a clear view of a graduated shadow scale 28 ft ($8\frac{1}{2}$ m) below, on which the length of the shadow cast by a 40-ft (~12 m) high gnomon indicated a solar calendar date. Rooms in this structure contained an armillary sphere and a water clock.

The Old Beijing Observatory houses a copy of an instrument known as a *chien i*, "simplified instrument," and apparently a basic type of *equatorial torquetum*, designed by Kuo Shou-Ching. A *torquetum* is a device equipped with graduated disks in both ecliptic and equatorial coordinates to facilitate conversion between the systems. The torquetum was probably invented by the astronomer Jābir ibn Aflah (b. ~1130; Spain) and possibly brought to China from the Maragha Observatory in Persia by Jamāl al Din ibn Muhammed al-Najjārī in 1267 (Needham 1959, Fig. 164; Needham/Ronan 1981, Figs. 106–109, pp. 174–178). Kuo Shou-Ching's device, however, lacks the ecliptic disks, and it would have been used only to measure stars' right ascension positions relative to the Xiu, which are marked on the equatorial circle along with 12 double hours, and declinations (graduated in degrees and minutes of arc); Needham describes it as "the precursor of all equatorial telescope mountings" (Needham/Ronan, Fig. 107).

The Mongol prince Ulugh Beg [1394–1449], grandson of Tamerlane, was a gifted mathematician who founded an observatory at Samarkand, now part of Uzbekistan, in 1424. Much of the instrumentation was copied from Maragha, an older, Persian observatory, but it included the largest instrument of the day, a meridian circle of 40-m radius. Piini (1986) discusses how the instrument could have been used and illustrates another instrument from this observatory, a parallactic ruler. Figure 3.23 shows the site and part of the now entombed meridian circle.

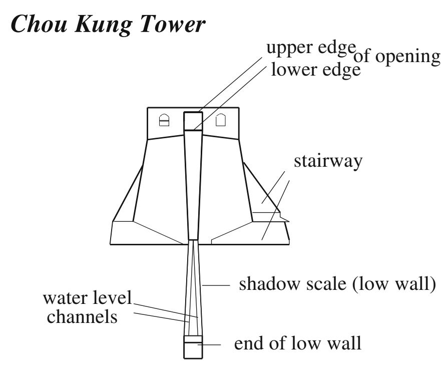
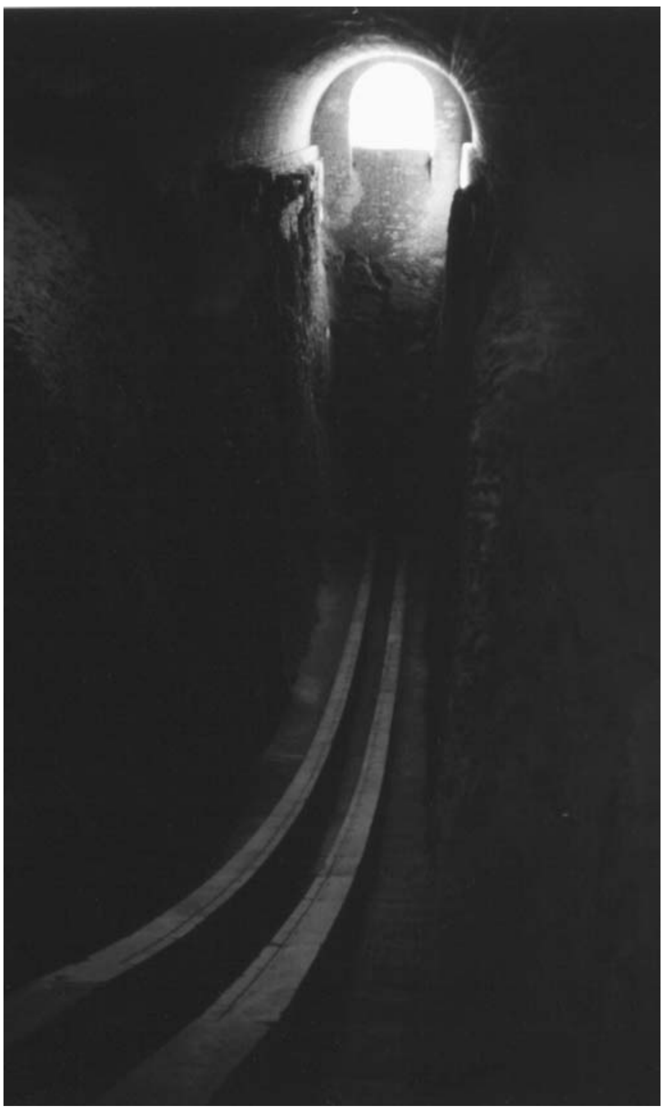


FIGURE 3.22. The tower of Chou Kung at Kao-chhêng near the important ancient imperial site of Loyang: View from the north end of the "Sky Measuring Scale," a 120-ft (36.5 m) low wall on which graduations permitted the shadow length cast by the noon Sun to be read off. Drawing by E.F. Milone, after Needham (1959, Plate XXXII, Fig. 116, p. 296).

References to early Indian instruments are cited by Subbarayappa and Sarma (1985). The earliest reference to such instruments is in the work of the astronomer Aryabhata (b. 476) and concerns various kinds of shadow clocks, water clocks, vertical circles (for solar altitude measurements), and a device using a plumb-bob and a water level to establish the horizon and zenith. More elaborate instruments include an armillary sphere, described by Lalla (b. 768) and in the *Suryasiddhanta* (cf. Sen 1966). Subbarayappa and Sarma mention an observatory at Mahodayapuram in the state of Kerala, dating from 860. The 18th-century observatories of

(a)

(b)



(c)

Figure 3.23. The meridian circle now partially entombed at the site of Ulugh Begh's observatory at Samarkand: (a) and (b) Exterior housing. (c) Graduated quadrant. Courtesy of Dietrich Wegener.

Maharaja Jai Singh [1699–1743] at Jaipur and at Delhi are well known to most of the world, because many of the instruments are still in place and tours are frequently conducted to them. They represent a recreated heritage—an attempt to build classic instruments to demonstrate the way observations were likely made in ancient India. At the Jantar Mantar in Delhi, there were four kinds of instruments, one of which is alleged to have had four purposes (Nath, undated, <1986):

(1) *Samrat Yantra*, a large triangular structure and two quadrantal arcs, acted as a giant sundial, which was used to measure hour angles and declinations of the Sun.
(2) *Rama Yantra*, two large circular structures, was used to measure altitudes and azimuths. According to Nath (undated), this instrument (as well as the *Dakshinobhitti* described below) may have required strings as site lines.
(3) *Jayaprakash Yantra*, two hemispherical bowls, to measure altitudes, azimuths, hour angles and declinations.
(4) *Misra Yantra*, an inverted heart-shaped structure, which was composed of
   (a) a *Samrat Yantra*;
   (b) *Niyat Chakra Yantra*, four semicircular arcs, onto which a gnomon could cast a shadow—with this structure, the declination of the Sun could be measured at four specified times of day, corresponding to noon at each of four observatories spread around the world;[21]
   (c) *Dakshinobhitti* with which meridian altitude or zenith distances could be measured; and
   (d) *Kark Rashivala*, which provided the zodiacal sign.

At least some of these instruments can be seen in Figure 3.24, which shows the Jaipur site as it looked in November 1985. See Figure 9.10 for details of the instruments at Jaipur and at the Majarajah's other observatory, the Jantar Mantar in Delhi. These instruments are hardly "ancient," but they are naked-eye instruments and provide us with valuable insight into how data could be obtained with precision by practitioners in early times (cf. §9.1.5).

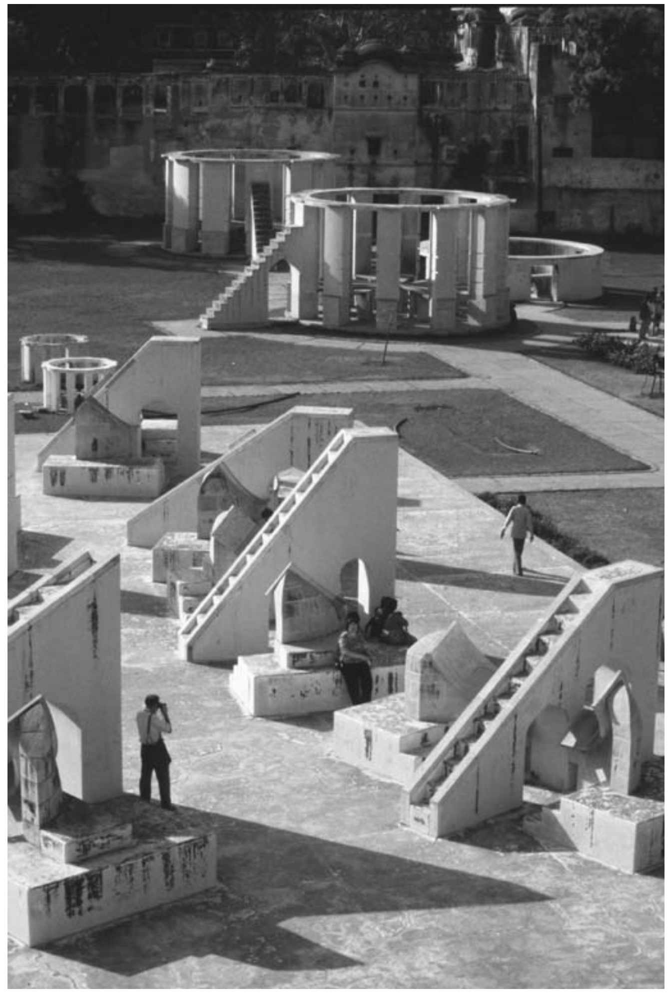


FIGURE 3.24. A selection of astronomical instruments at the Jaipur observatory of the Majarajah Jai Singh: Notice especially the *Samrat Yantras* that could be used to determine the moment of noon at each of several observatories around the world. The instruments would have been rotated to the hour angles equal to the longitude differences from the local observatory so that the different solar hour angles apply to the meridians of those places simultaneously. This is the equivalent of a wall of clocks registering the local times of different places in the world. Although the Jai Singh observatories were constructed in the 18th century, the instruments were built according to traditional specifications and thus represent classic Indian astronomical tradition. See Figure 9.10 for close-ups of the instruments at Jaipur and at the Majarajah's other observatory, the Jantar Mantar in Delhi. Photo by E.F. Milone.

3.4. Possibilities of Optical Aids

The limitations of normal human visual acuity would seem to preclude naked-eye discovery of such phenomena as Jupiter's moons. Yet Bobrovnikoff (1984) cites cases of individuals who were capable of such feats, and of one individual ("eagle-eyed Dawson") who actually claimed to have discerned both the disk of Jupiter and its Galilean satellites.[22] Presumably, individuals with this degree of acuity and the ability to record their discoveries were rare in ancient societies, because, as far as we know, no records were made of what we would describe as telescopic appearances, notwith-

[21] These were the observatories at Greenwich, Zurich, Notke (Japan), and Saritchen on Pik Island in the Pacific.

[22] Dawes' limit for the spatial resolution of two stellar discs is $\sim 1.22 \cdot \lambda / D$, where λ is the wavelength of light and D is the diameter of the instrument; in the case of the sky, the latter is the diameter of the dark-adapted pupil, between 5 and 10 mm. Taking 6 mm as a typical value, and yellow light, for which $\lambda \approx 0.0006$ mm, this limit is 0.0001 radians or ~20 arc-sec. The disk of Jupiter approaches 60 arc-sec.; hence, the discernment of the Jovian disk is theoretically possible.

standing extraordinary claims made for the Dogons of central Africa (§8.4).

The lack of telescopes is puzzling because several ancient cultures certainly had the technology to produce them. They did produce mirrors, and some knew about lenses as well.

Carlson (1976) describes the obsidian mirrors made and used by the Olmecs who lived on or near the Gulf coast of Mexico ~900–500 B.C. (Weaver 1981) and concludes that they had a symbolic rather than an astronomical value. A priest, wearing such a mirror, would appear to embody the Sun, especially because it could be used to reflect and focus sunlight, causing smoke, if not fire. In later Aztec times, the god *Tezcatlipoca* ("Smoking Mirror" from *Tezcatl*, "mirror," and *poca*, "smoking"), was able to divine events with the help of his "smoking mirror." His role as a Sun god is discussed in §12.15. The Maya also used mirrors, and Carlson says that the Chinese used mirrors similarly for shamanistic purposes and to provide a harmony between the inner soul (as reflected in the face) and the universe. It is reported that the Kogi (§14.1) of Colombia, who have a lengthy archaeastronomical history, currently use obsidian mirrors for astronomical observations.

One of the oldest references to mirrors in China is to one of bronze, ca. 627 B.C. (Needham 1981, p. 353). Although an important usage for Chinese mirrors was to start fires from focused sunlight, documents exist that indicate that the properties of concave mirrors were well known by the Chinese at a very early date. *Mo Ching*, written in the 4th century B.C. indicates that the magnification and reduction of an image were carefully observed (Needham 1981, pp. 350–352).

Refraction properties of materials had also been noted. By the 3rd century A.D., mention is made of round balls of ice and of pearl, which could be used to focus sunlight for burning (Needham 1981, pp. 358–361). Yet, as far as we know, eyeglasses did not appear in China earlier than in Europe.

The earliest extant European writing on mirrors is by Heron of Alexandria (ca. 100 A.D.). Ptolemy's *Optics* (ca. 130) deals substantively with both reflection and refraction. Ptolemy even discusses the refractive effects of the Earth's atmosphere and the corrections to the apparent positions of stars because of it. In Europe, the first recorded astronomical use of the telescope was by Galileo (1610). The devices he constructed were refracting telescopes, each of which consisted of two lenses: an objective lens (at the far end of a long tube) and an eyepiece lens, together giving a magnification of a few times. With experience, he constructed better telescopes, and noted that the "Medicean stars," as he called the moons of Jupiter, could be seen only with 20–30 power.

A device that the Chinese certainly possessed was the image-producing *camera obscura*, also mentioned in the *Mo Ching*. This is essentially a pinhole camera, the Latin name indicating the "darkened chamber" in which the image had to be viewed. The principle was certainly known to Aristotle; in his book *Problems* (Section xv, Ch. 5), a round image of the Sun is shown after traversing a rectangular aperture. He also mentions that the image of an eclipsed Sun can be seen through foliage or lattice. The frst clear description of the device appears in the *Book of Optics* of Alhazen [Islamic astronomer, d. Egypt, 1038], reproduced by Vitello [Polish philosopher, b. 1230] in his own work on optics. Roger Bacon [Franciscan scientist, b. ~1214] also discusses it in his *Perspectiva* (1614), in combination with a "specula." Maurolycus [mathematician, Messina, ~1521] applied it to observational study of the Sun. On a large scale, light from an illuminated scene may be passed through a narrow aperture into a darkened room where it may fall on a far wall and appear magnified in the process. The result can be spectacular. In a large congress hall in New Delhi in 1985, EFM witnessed scenes of the brightly lit lobby projected onto a large white screen at the front of the darkened hall whenever the door was just opened or had nearly shut. In Edinburgh, Scotland, near the top of the Royal Mile, there is a camera obsura projecting a magnificent view. It has been suggested that similar means was used to create a Jaguar (the Pleiades) map on the floor of a building at Teotihuacan in Mesoamerica in the early centuries A.D. (see §12.22), but experimental verification is desirable, because the greater the magnification, the lower the surface brightness of the image. If a lens is inserted at the aperture, magnification and a brighter image can be achieved. The *camera lucida*, a device that employs prisms to reproduce a virtual image superposed on a draughtsman's field of view, was not invented until the 19th century (by W.H. Wollaston).

FIGURE 3.25. The "man in the moon" depends on the inability of the human eye to discern features smaller than the maria on the Moon's surface.

We conclude this chapter with a question, previously raised by Schlosser et al. (1991/1993, p. 116). The influences on the pace of technological development of human societies have been the topics of many learned discussions. What would have been the consequences for such development if our eyes had just slightly better acuity ? (See Figure 3.25 for a deresolved photo of the Moon, to match normal human vision.) Perhaps Megalithic observers would have noticed such phenomena as the disks of some of planets—and the Venerian crescent, lunar mountains, and the brightest moons of Jupiter. Perhaps a scientific age would have dawned not merely centuries ago but several millenia before that. Or would it have?

From the spatial domain of human perception, we now proceed to the temporal.

4
Time and the Calendar

Time, like an ever-rolling stream,
Bears all its sons away;
They fly forgotten, as a dream
Dies at the opening day.[1]

4.1. The Perception and Measurement of Time

Time carries us along, willing or not, into, through, and out of the world relentlessly, without "time-out" to recover our breaths, wits, or fortunes. The perceived arrow of time points always in one direction, from the past to the possible, from the known to the unknown. This implicit nature of time is characterized in many different ways in different languages: Some recognize the past, present, and futures with conditional and subjunctive, preterite, and pluperfect nuances. On the other hand, among the Hopi, for example, the important distinction is between "near" and "far" time, whether past, present, or future. The perception of the meaning of time has changed much through history and across cultures, but the experience of time as an enslaving tyranny is common to many. Whatever its ultimate meaning or importance, the measurement of time has practical importance for many areas of human endeavor, enabling individuals and groups to coordinate their activities and thereby keep their societies functioning. This was fully recognized among ancient cultures too.

Our 24-hour day, sexagesimal system of measuring seconds and minutes, and our use of decimal fractions of seconds, record a curious blend of heritage from ancient civilizations, specifically, Egypt and Mesopotamia. The 24-hour day, we now believe, originated in Egypt, with the use of the decans (Neugebauer 1955, 1969 p. 81ff): During the shorter summer nights, a total of only about 12 decans (each roughly 10° apart on the ecliptic; see §3.3) could be seen. As each decan appeared at the southeastern horizon, it could serve as a marker of time. The scheme may have been extended to the winter nights and then to the days as well, resulting in the two 12-hour periods that characterize day and night, a derivative form of which is our ante- and post-meridian time-keeping.

Time units shorter than a day were mentioned in the Babylonian diaries (Sachs and Hunger 1988): the *UŠ* (pronounced 'oosh' and meaning 'length') or the "time degree," which measured the time for the sky to turn through 1° in right ascension; and the *NINDA*, 1/60 of an *UŠ*. The *UŠ* therefore marked four minutes of our time, and the *NINDA*, corresponding to a minute of arc, marked four seconds of time. According to Neugebauer (1941, 1983, p. 16), the *UŠ* had its origin as 1/30 of a unit of length, the *danna*, equivalent to about seven miles, and which was in use in Mesopotamia as early as 2400 B.C. The usage of a time-equivalent distance—a distance equivalent to the time it takes to travel this distance—is not unfamiliar today.[2] The *danna* was equivalent to a time interval of two hours, sometimes called a "double hour." The equivalence is, then, 12 double hours = 360 *UŠ* = 1 day. These units from ancient Babylon, then, are the origin of our "degrees" of angle, and of the astronomical usage of time units to measure distance on the celestial sphere. The base 60, and the use of sexagesimal fractions, used both for our minutes and seconds of time as well as for minutes and seconds of arc, has also a Babylonian origin. The 24^h/d, 60^m/h, and 60^s/m combination was in use by Hellenistic times.

Time could be measured by the length of equatorial arc (i.e., the length of arc along the equator as delineated by two

[1] St. Anne's, 5th verse; Isaac Watts [1674–1748].

[2] For example, we say that such a place is 10 minutes away by car. Time is usually a more important quantity than is distance for many travelers, so that the time to travel may be more meaningful for a given set of traveling conditions (traffic, road/track quality, weather, etc.) of a region.

or more stars) that had traversed a particular spot in the observer's horizon system. The spot could be on the meridian or at the east or west points of the horizon. Such measurements yielded what were called *equatorial times* (χρόνοι ἰσημερινοί), and the unit was the "time-degree," 1/15 of an hour or four minutes of time. This measure of time is directly analogous to our sidereal time, which marks the passage of stars across the celestial meridian and is defined formally as the hour angle of the vernal equinox:

$$LST = HA\Upsilon, \tag{4.1}$$

where *LST* is the local sidereal time because the meridian is different for each observer. This is equivalent to the sum of the hour angle and the right ascension of any object in the sky; i.e.,

$$LST = HA^{*} + RA^{*}. \tag{4.2}$$

When time was to be expressed explicitly in hours in the ancient world, solar times were used. As we discuss below, the Sun's motion is not constant during the year, but a uniform measure was sometimes used: Astronomers of antiquity used *equinoctial hours* as the Greek term (ὧραι ισημεριναί) is translated (Toomer 1984, p. 23). The equinoctial hour was 1/24 of the length of a solar day. It was roughly the equivalent of one of our hours of mean solar time, but not exactly the same, because the modern definition involves the mean rate of the Sun averaged over the year. The measure of time that we use is traditionally defined as the hour angle of a fictitious "mean sun" traveling on the celestial equator at average rate plus 12 hours:

$$LMSolT = HAMS + 12^{\mathrm{h}}, \tag{4.3}$$

where *LMSolT* is the local mean solar time and *HAMS* is the hour angle of the mean sun. The 12^h in (4.3) is arbitrary. It is a convenience for the modern world to have the day start at midnight rather than at noon. In ancient Mesopotamia, the day started at sundown.

In more common use in the ancient world were *seasonal hours* (in Greek, ὧραι καιρικαί) or *civil hours* (Toomer 1984, p. 23). Each such hour was 1/12 of the actual length of daylight at a given place and, therefore, varied in length with the season. They were obtained from the motion of the actual Sun, usually by means of a sundial. Ptolemy's *Almagest* (cf. Toomer 1984, p. 104ff and Appendix A) contains instructions for the conversion of equinoctial hours into seasonal hours and vice versa. Because the number of hours of daylight varies with latitude every day of the year except at the equinoxes, so did the length of a seasonal hour.

In the ancient world, time was local and immediate, and reckoned exclusively either by hour angle (of the Sun) or by reference to horizon phenomena or celestial meridian passage (of the Sun or stars). Ptolemy (*Almagest*, Book II, §9; Toomer 1984, p. 104) gives instructions for converting from one type to another. To convert from seasonal to equinoctial hours, multiply the time interval in seasonal hours by the length in time-degrees and divide by 15. For example (taken from the *Almagest*, Appendix A; Toomer 1984, p. 650), if the length of a seasonal hour at a given date and site is, say, 18;7 time-degrees, $5\frac{1}{2}$ seasonal hours is $5\frac{1}{2} \times 18;7/15 = 6;38$ equinoctial hours.[3] To convert from equinoctial hours to seasonal hours, multiply by 15 and divide by the length of the hour of the relevant time interval in time-degrees. For example (p. 649), given the longitude of the Sun as ♐28;18° (that is, 28°18′ in the sign of Sagittarius) and a site with the terrestrial latitude of Rhodes (14;30), find the length of a seasonal hour in the night. To do this, Ptolemy uses a look-up table of rising times (Book II, §8) that gives the time-degrees corresponding to 10° intervals on the ecliptic and totals accumulated since ♈0°.

For Rhodes, the accumulated rise time for ♐20 is 277;29° and that for its opposite (in the night sky), ♊20°, is 94;18°. The arc for a 10° stretch on the ecliptic is 11;16° between ♐20° and ♐30°, and 10;34° between ♊20° and ♊30°. The interval 8;18° is 0.833 of the 10° of zodiacal sign or 0.833 of these intervals, or 9;21,5 and 8;46,13 respectively. Adding these to the accumulated rise times at ♐20° and ♊20°, we get 286;50,5 and 69;27,13, respectively. The difference, Δ, between these values, corresponding to exactly one half-day, is 217;22,52. Dividing Δ by 12, we get the length of a seasonal hour, 217.3811/12 = 18.115 ≈ 18;7. Dividing Δ by 15, we get the length of the night in equinoctial hours: 217.3811/15 = 14.492 ≈ 14;29. Further division of the latter by 12 gives the length of one seasonal hour in equinoctial hours at Rhodes when the Sun is near the end of the sign of Sagittarius: 1.2077 ≈ 1;12,28.

4.1.1. Time and Time Intervals

4.1.1.1. Sundials

We have already mentioned the *gnomon*, essentially a rod, the permanent placement of which permits calibration of its shadow direction to time of day. A gnomon placed perpendicular in level ground must have constituted the first sundial, and there is indeed a very early "shadow-clock" from Egypt, which seems to be precisely this. It measures in projection the hour angle of the Sun. Many examples exist of horizontal sundials, although, according to Gibbs (1976, pp. 4, 78), Greek and Roman sundial makers preferred rounded surfaces. Of 256 sundials from the Greco-Roman world, of the 3rd century B.C. to the 4th century A.D., described by Gibbs, only 15 are flat and horizontal and only 25 vertical. There are conical, cylindrical, and spherical shapes in abundance. Among the most ingenious (*op. cit.*, p. 23) are the "roofed" sundials, which had a notch or a small carefully drilled hole on the midline of the roof that would act as a tip of a gnomon. Other sundials used the tip of a small pyramid-shaped metal gnomon, and not the side of the gnomon shadow, as in most modern sundials, to mark the hours (see Figure 4.1).

[3] $18;7° = 18 + 7/60 \doteq 18.11667°$. Multiplied by $5\frac{1}{2}$, this yields 99.64167°, and divided by 15 degrees/hour, the result is 6.64278 hrs. = 6^h + (60 × 0.64278 = 38.57) mins. = 6;38,34 or about 6;38. Apparently, Ptolemy is rounding off. The rate, 15°/hour, is from the equivalence between 360° and 24^h.

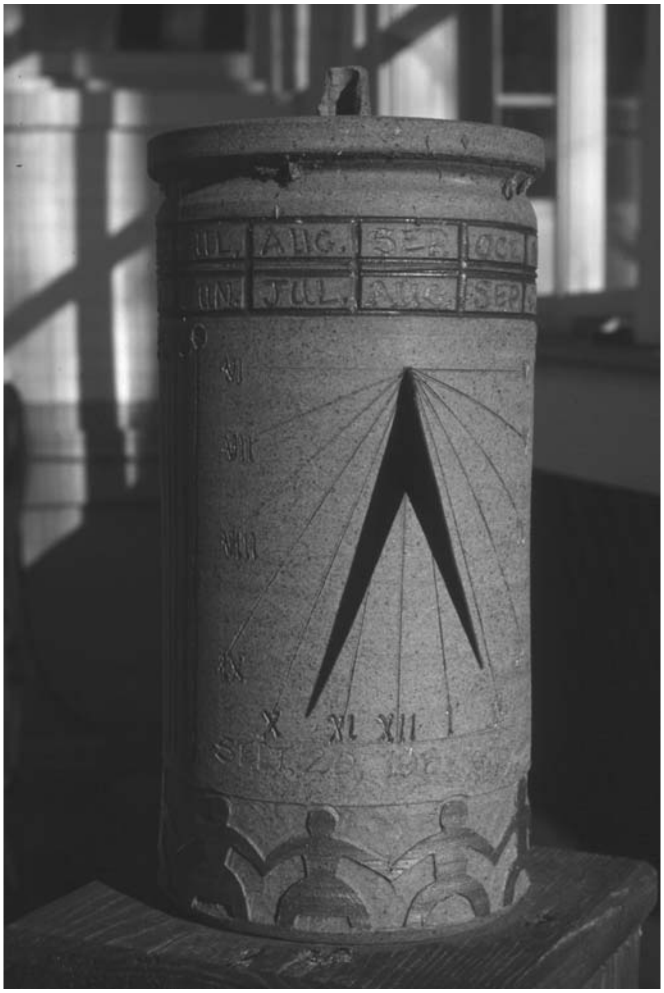


FIGURE 4.1. A modern cyclindrical sundial with a pyramidal stylus, from a private home in Calgary. Photo by Dr. T.A. Clark.

Much of the description of these sundials comes from Vitruvius's *De architectura*, which dates from about 80 B.C. The largest in this collection are the vertical sundials on the eight facings of the "Tower of the Winds" in the Plaka district, of Athens, below the Acropolis. This structure, still visible today (see Figure 4.2), was known in the first century B.C. as the *Horologium* of Andronikos (from Kyrrhos in Macedonia) or Andronicus Cyrrestes in Latin sources; we discuss this structure and its place in the culture of its time in §7 and report the informed speculation concerning a water clock in the structure in §4.1.1.3.

Figure 4.3 shows a 15th-century horizontal sundial now located in the courtyard of the "Old Beijing Observatory" in Beijing, China. A modern vertical sundial in Lucerne, Switzerland can be seen in Figure 4.4. A small vertical sundial dating from the Greco-Roman period was found in Luxor (Figure 4.5).

A stone sundial in a courtyard in the Forbidden City in Beijing, China is shown in Figure 4.6. In the latter case, the distortion due to the projection of the hour angle is avoided, because the dial is set in the plane of the equator, and the cursor is a narrow rod projecting through the center onto both faces. This type of sundial has an added advantage: Between the equinoxes, the Sun will illuminate only one of the two faces. At an equinox, the cursor shadow will appear on both faces equally, and thereafter, only one of the surfaces will be fully illuminated.

Sundials were among the elaborate reconstructions of astronomical instruments at Delhi and Jaipur (Figures 3.24 and 9.10) by the Maharajah of Jaipur in the 18th century (see Figure 4.7). Sundials came in an array of geometric styles, including the cylindrical (see Figure 4.1).

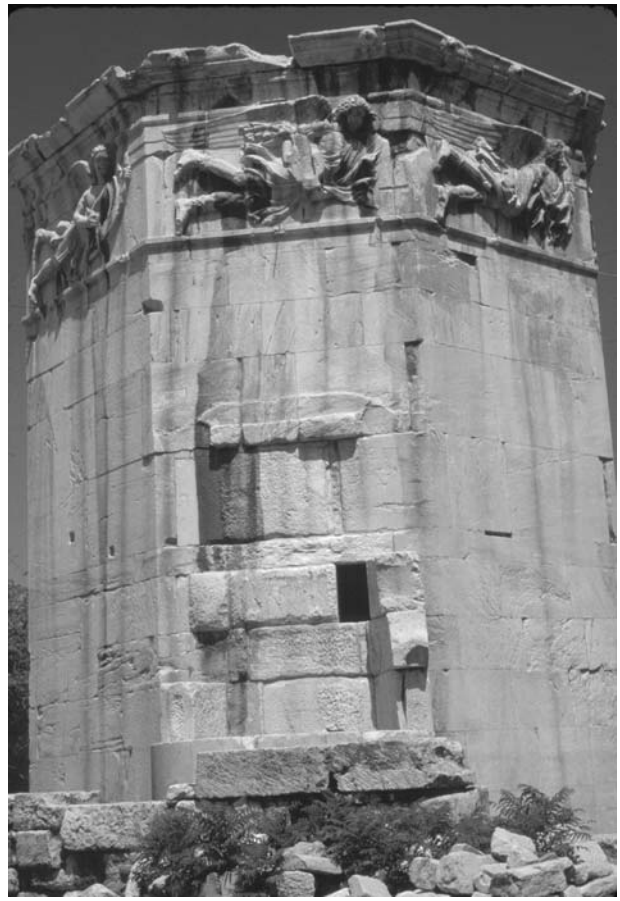
The sundial was widely used in the ancient Mediterranean world. Properly used,[4] it could be read to a few minutes or better, perhaps to one minute. Precision is ultimately limited by the lack of sharpness of the shadow because of the finite size of the solar disk, a shortcoming of which Ptolemy was well aware (*Almagest*, Book II, §5; Toomer 1984, p. 80).

The use of the shadow of a gnomon as an indicator of time requires in principle at least empirical knowledge of the altitudes of the Sun at particular times of day and seasons of the year. Where projections are involved, as in flat sundials, the effect at the latitude of the intended site must be known. Finally, the markings should be long enough to extend over the annual range of shadow length at each hour. As we noted in the previous section, the Greco-Roman world did not use mean solar time, and their hours were usually not of uniform length but literally varied over time scales of days. *Seasonal hours* divided the daylight interval into 12 hours, regardless of the season. This meant that a winter day had shorter seasonal hours than did a summer day. Moreover, at the same time of year, the seasonal hour had a different length as one traveled to a location with a different latitude. Table 4.1 lists the lengths of daylight ($2H_{\odot rise/set}$) and length of the seasonal hour for seasonal extremes at selected sites. Note that the ratio of the lengths of the longest to shortest days is a strong indication of the latitude of the site. The accuracy of a sundial reading depended on the time of year, and the suitability of the sundial for the latitude and maybe longitude of a particular place (the noon meridian of the sundial should have agreed with the celestial meridian of the site). In the ancient Mediterranean world, the establishment of the length of daylight was an important function of astronomy. Neugebauer (1957/1969, pp. 158ff.) shows that this was carried out by studying the "ascensions" of the zodiacal signs during the course of the night. For Alexandria, the night lasted about 10 hours in the summer (thus the day lasted 14 hours), and in the winter, the night lasted 14 hours (and thus the day, 10 hours). This ratio, 7 : 5, was determined in antiquity.

Table 4.1 contains no correction for atmospheric refraction, which lifts the Sun by slightly more than its diameter, on average (see §3 for a discussion of both the mean refraction and its variation from the mean value). Because the Sun

[4] Gibbs (1976) relates that a case is known of a sundial that was designed for use in Catania in Sicily but used quite happily in Rome for a considerable interval of time, although the markings were no longer quite right for the site.

(a)



(b)

(c)

(d)

(e)

FIGURE 4.2. Views of the Horologion designed by Andronicus Cyrrestes, in Athens: The upper parts of the eight external sides of this structure were vertical sundial faces from which projecting rods provided the gnomons. (a)–(b) six of the eight faces; (c) Notos, the South wind; (d) Lips, the SW wind; (e) the interior, showing evidence of water works. Photo (a) by Andrew Kyrgousious for E.F. Milone. Photos (b)–(e) taken on an early August afternoon in 1982 by E.F. Milone.

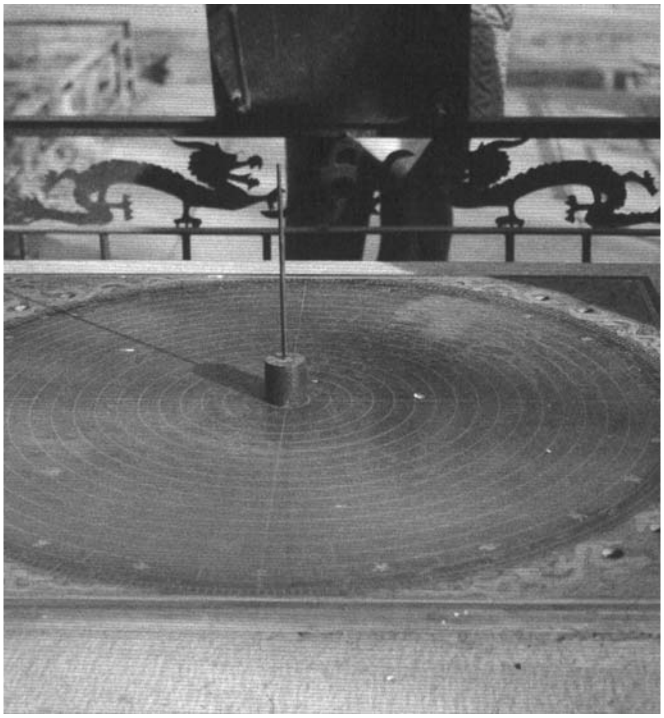


FIGURE 4.3. A 15th-century copy of a Chinese horizontal sundial from a design by Guo Fhoujing, Yuan Dynasty, 1279–1368; now located in the courtyard of the Old Beijing Observatory in Beijing, China. Photo by E.F. Milone.

rises earlier and sets later than it would on an airless world, a correction must be made to increase the computed hour angle. With an assumed refraction correction of 34 arcminutes, the range of effects on H for the sites given in Table 4.1 is 0.110 hour for Site 1, to 0.041 hour at the equator and +0.046 hours at the tropics of Cancer and Capricorn. An additional correction should be taken for the radius (the "semidiameter") of the solar disk, because daylight may be reckoned from the first gleam of the Sun, rather than the appearance on the horizon of the center of the disk. The total correction to the *HA* of rise is $dH \approx 1.5 \times (34/3437.7)/(\cos\phi \cdot \cos\delta_\odot \cdot \sin H_r)$, which, by symmetry, increases the setting hour angle by the same amount. Thus, the correction is added to both summer and winter *HA* values before the ratio is taken. The resulting corrected ratios are 2.875 for Callanish (Site 1), 1.511 for Rhodes, 1.404 for Alexandria, 1.272 for the tropics, and 1 for the equator.

The interval of time between the rising of a sequence of the zodiacal signs permits the number of hours of the night and, thus, the number of hours of daylight to be obtained. The correlation of the ratio of daylight to night hours with latitude permitted the ratio, or, alternatively, the number of degree-hours to be used to specify the latitude band or "climate" in which a site was located. There were traditionally seven "clima" (Greek κλίμα). Babylon had a ratio of longest to shortest day lengths of 3:2, and methods were devised ("System A" and "System B") to determine this ratio. Although the inventor of the interval ratio as a latitude indicator is unknown (Neugebauer 1975/1969, pp. 184–185), these ideas were being applied in Alexandria by Hypsicles in the 2nd century B.C. At this time, Alexandria

FIGURE 4.4. An example of a modern (1968) vertical sundial in Lucerne, Switzerland: The zodiacal constellations are prominent. Photo by E.F. Milone.

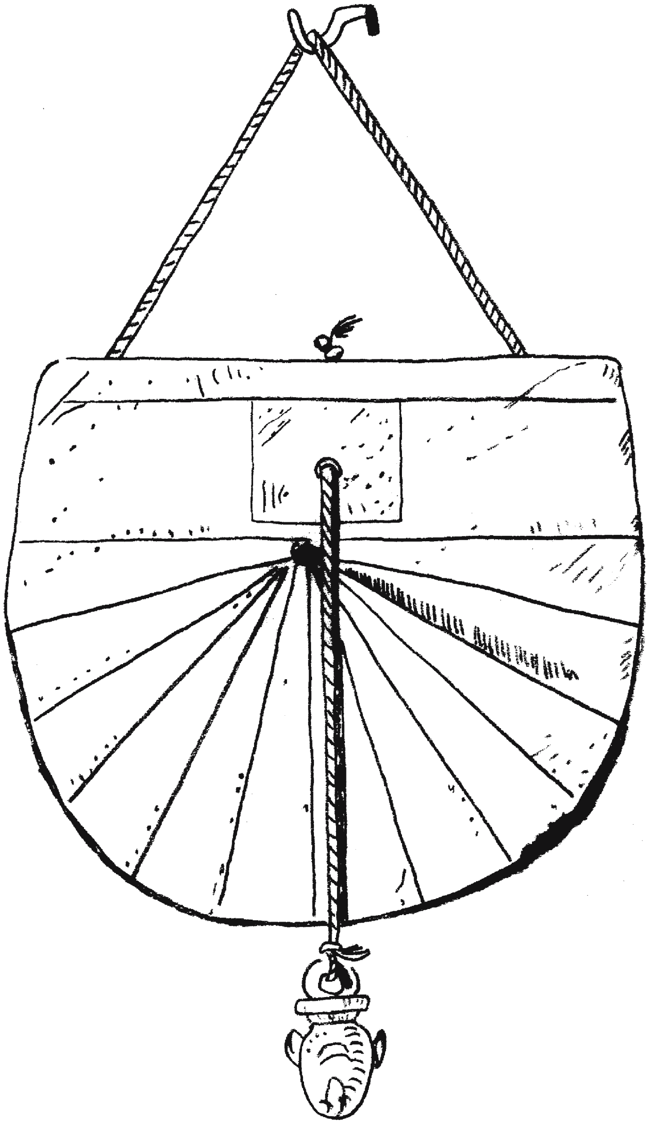


FIGURE 4.5. The style of a vertical sundial from Greco-Roman Egypt, found at Luxor. Drawing by Sharon Hanna, after Borchardt (1917).

FIGURE 4.6. A stone equatorial sundial in the Forbidden City in Beijing, China: The dial disk lies in the plane of the celestial equator and thus faces the north celestial pole. Photo by E.F. Milone.

FIGURE 4.7. A sundial at the Jaipur observatory of Maharajah Jai Singh, dating from the 18th century. Photo by E.F. Milone.

was in the first clima, "3,30" (= 14^h 00^m for the summer maximum of sunlit hours)[5] and other zones were defined by adding multiples of 4°, the second at 3,34, and so on, to 3,54. In this scheme, Babylon was squeezed out of the "clima," but another scheme existed in parallel in which Babylon appeared in the second clima, with 3,32, with the third clima at 3,36, the fourth at 3,40, and soon to the seventh at 3,52. Several centuries later, Ptolemy (*Almagest*, Book II), describes 20 parallels of geographic latitude beyond the equator, separated by quarter-hour intervals. He tabulates 10 of these zones (Book II, §13) in half-degree intervals. The 10 zones are designated according to the maximum hours of sunlight and are separated by multiples of a half-hour. The first zone beyond the equator was 12,30, the second 13,00, to a maximum of 17^h. Within this scheme, the first "climate" is at Meroe, near modern Asuan, with 13^h. There is no mention of a refraction or semidiameter correction in Book II of the *Almagest*. Toomer (1984, p. 421, fn. 8) says that the only reference to the effect of refraction (if that is what Ptolemy is talking about) is given in Book IX, §2, where, referring to the times of visibility or invisibility of planets, Ptolemy says, "but the times too can be in error, both because of atmospherical differences and because of the differences in the [sharpness of] vision of the observers" (the bracket is Toomer's). In addition to timings and arcs of the celestial equator, however, Ptolemy refers to the use of a gnomon to establish shadow lengths and uses the ratio of the meridian shadow length at winter solstice to that at the equinox (Book II, §5; Toomer 1984, pp. 80–82).

[5] "3,30" is to be read (3 × 60) + 30° = 210° (or 210/15 = 14 hours).

TABLE 4.1. Seasonal variation of day length at various sites.

Site	Latitude[a] +N, −S	Length of day ($2H_{\odot r/s}$) Winter	Summer	Seasonal hour length Winter	Summer	Max/min ratio
1. Callanish	58.3	6.033	17.967	0.503	1.497	2.978
2. Stonehenge	51.2	7.635	16.365	0.636	1.364	2.143
3. Rome	41.9	8.938	15.062	0.745	1.255	1.685
4. Samarkand	39.6	9.189	14.811	0.766	1.234	1.612
5. Athens	38.0	9.352	14.648	0.779	1.221	1.566
6. Nemrud Dag	38.0	9.352	14.648	0.779	1.221	1.566
7. Akragas	37.3	9.421	14.579	0.785	1.215	1.548
8. Rhodes	36.2	9.526	14.474	0.794	1.206	1.519
9. Ninevah	35.4	9.600	14.400	0.800	1.200	1.500
10. Kaifeng	34.8	9.655	14.345	0.805	1.195	1.486
11. Babylon	32.5	9.856	14.144	0.821	1.179	1.435
12. Jerusalem	31.9	9.906	14.094	0.826	1.174	1.423
13. Uruk	31.4	9.948	14.052	0.829	1.171	1.413
14. Alexandria	31.3	9.956	14.044	0.830	1.170	1.411
15. Giza	30.0	10.061	13.939	0.838	1.161	1.385
16. Luxor	25.7	10.389	13.611	0.866	1.134	1.310
17. Ujjain	23.2	10.568	13.432	0.881	1.119	1.271
18. Teotihuacan	19.7	10.806	13.194	0.900	1.100	1.221
19. Equator	00.0	12.000	12.000	1.000	1.000	1.000
20. Cusco	−13.5	12.799	11.201	1.067	0.933	0.875

[a] Latitudes are approximate, and for illustrative purposes only. The data shown do not contain corrections for refraction or for the radius of the Sun's disk (assuming daylight to be from first gleam to last gleam), both of which extend the time of daylight. See the text for details of these effects.

4.1.1.2. Types of Solar Time

The modern sundial provides an indication of *apparent solar time*:

$$AST = HA_{\odot} + 12^{h}, \tag{4.4}$$

where $HA_{\odot}$ is the hour angle of the Sun. Twelve hours are added because most communities prefer to start the day at midnight rather than at noon, when the hour angle is zero. Apparent solar time is not uniform throughout the year, however: As we indicate later in this section, the arrival times of the Sun at the celestial meridian may differ by up to about half an hour in the course of the year. Its progress is retarded or advanced by two effects: First, because it moves on the ecliptic (not on the celestial equator), and second, because it moves on the ecliptic at a variable rate. The last is a consequence of the eccentric orbit of the Earth around the Sun, discussed in §2.4.4.

To understand the significance of the first (more important) effect, consider the appearance of the celestial equator where it crosses the celestial meridian. Its orientation is constant from hour to hour and from day to day, and an object moving along the celestial equator, would, in a circular orbit (like the ancient view of the sphere of the fixed stars), move at a constant rate. On the other hand, the orientation of the ecliptic where it crosses the celestial meridian varies with time of day and year. The *diurnal* motion of objects in the sky, caused by the rotation of the Earth beneath them, is westward. The *annual* motion of the Sun, which is caused by the revolution of the Earth, and is eastward, effectively slows the diurnal motion, if ever so slightly. But the Sun's annual motion is along the ecliptic, not along the celestial equator. The small arc represented by the eastward angular motion on the ecliptic in the course of one day can be resolved into components along declination and hour circles. So, even if the motion along the ecliptic were uniform, there would be an apparent northward or southward component to the annual motion for all times of the year (except precisely at the solstices), and the remaining eastward motion would be variable from day-to-day (see Figure 4.8). The eastward component is greater at the solstices than it is at

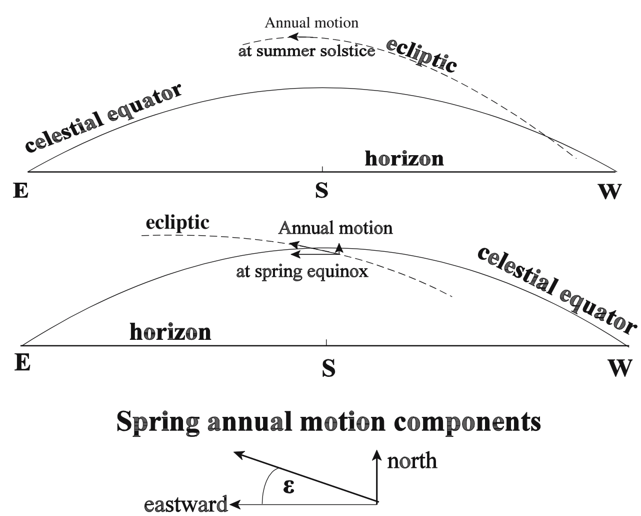


FIGURE 4.8. The ecliptic movement of the Sun resolved into N-S (declination) and E-W (right ascension) motions. Drawing by E.F. Milone.

the equinoxes, because the motion is then exclusively eastward, without a N-S component; at those times of year, it is also greater than the average speed of the Sun, because that motion is along a small circle of declination.

The second effect—the Sun's variable motion along the ecliptic—results from the Earth's orbital motion (see §2.3.5 and Figure 2.16 for definitions of the orbital elements)[6] and Table 2.9 for a list of the orbital elements of the Earth and planets.

The Earth moves most rapidly along its orbit in early January, and most slowly in early July; this effect is reflected

[6] The Earth's velocity around the Sun averages 30 Km/sec. However, the eccentricity of its orbit causes a variation in this velocity, which can be expressed as

$$v = \sqrt{\left\{G[M_\odot + M_\oplus]\times\left[\frac{2}{r} - \frac{1}{a}\right]\right\}}, \tag{4.5}$$

where the gravitational constant, $G = 6.67 \times 10^{-11}\,\mathrm{m^3Kg^{-1}s^{-2}}$, $M_\odot$ is the mass of the Sun, $M_\oplus$ is the mass of the Earth-Moon system, r is the instantaneous distance to the Sun, and a is the semimajor axis. The distance varies with location in the orbit:

$$r = \frac{a(1-e^2)}{1+e,\cos\upsilon}, \tag{4.6}$$

where e is the orbital eccentricity and υ, the true anomaly, is the angular distance of the Earth from perihelion. At perihelion, therefore, $\upsilon = 0$, so that

$$r = a\times(1-e)$$

and

$$v_p = \sqrt{\frac{G[M_\odot + M_\oplus]\times 1+e}{a\times(1-e)}}. \tag{4.7}$$

At aphelion, $\upsilon = \pi$,

$$r = a\times(1+e)$$

and

$$v_a = \sqrt{\frac{G[M_\odot + M_\oplus](1-e)}{a(1+e)}}, \tag{4.8}$$

so that the ratio of these two extremes, v_p/v_a, is $(1 + e)/(1 - e) = 1.034$, because the Earth's orbital eccentricity is 0.0167. The variation in Earth's speed is therefore about ±1.67% of the average speed, and the Sun's annual motion reflects this variation. The variation in the *observed* angular rate of the Sun, $d\Theta/dt$, is related to the velocity v and the distance r from the Earth-bound observer, over a short arc of the orbit by the expression:

$$d\Theta/dt = \frac{v}{r}. \tag{4.9}$$

Therefore, at perihelion,

$$d\Theta/dt = \frac{v_p}{a\times(1-e)}, \tag{4.10}$$

and at aphelion,

$$d\Theta/dt = \frac{v_a}{a\times(1+e)}, \tag{4.11}$$

and the ratio of these angular speeds is $[(1 + e)/(1 - e)]^2 = 1.069$, so that the angular speed of the Sun along the ecliptic varies by about ±3.34% from the mean.

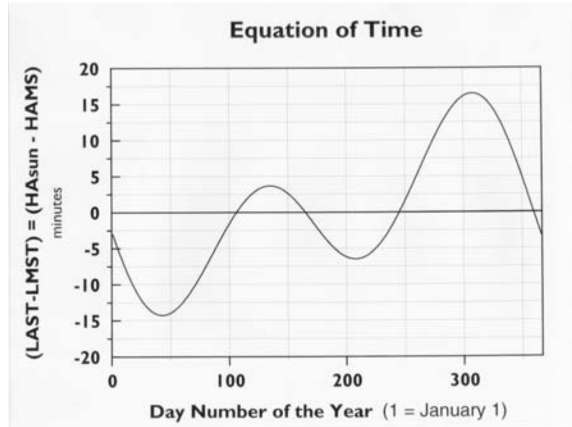


FIGURE 4.9. The equation of time: Apparent – mean time or $HA_\odot$ – $HAMS$. Drawing by E.F. Milone from a Lotus 1-2-3 spreadsheet (Lotus Development Corporation, an IBM company, Cambridge, Massachusetts).

in the apparent eastward motion of the Sun along the ecliptic and causes the "inequality of the seasons," described in §2.3.1 and in the context of Mediterranean cultures in §7.

In addition to the Sun's varying rate of eastward motion across the sky, there is another reason for the difference between Apparent Solar Time [as defined by (4.4)] (*AST*) and our modern Mean Solar Time (*MST*).[7] This reason is that *AST* is a *local* time; it is defined by the local hour angle of the Sun plus that concession to daylight chauvinism, 12^h. Modern time pieces carry a form of MST defined in terms of the hour angle of an imaginary body called the *Mean Sun*, which travels at the average angular rate on the celestial equator:

$$MST = HAMS + 12^h. \tag{4.12}$$

The difference between instantaneous or apparent solar time and mean solar time is called *the equation of time*:

$$E = AST - MST = HA_\odot - HAMS. \tag{4.13}$$

Here, *HAMS* is the hour angle of the Mean Sun. When E is plotted against time, a double-peaked curve is obtained, as shown in Figure 4.9. Because hour angle is measured positive to the west, when $E > 0$, $HA_\odot > HAMS$ so that the apparent Sun is running faster than the mean Sun. When $E < 0$, $HA_\odot < HAMS$, in which case, the apparent Sun is running slower than the Mean Sun.

A plot of the Sun's declination against the equation of time produces a figure 8 design, called the *analemma* (Figure 4.10a, from the same spreadsheet as in Figure 4.9). Its shape can be seen on the gnomon of a sundial that was designed for the University of Calgary's Rothney Astrophysical Observatory (RAO) by Prof. T.A. Clark and T. Kirkham. See Figure 4.10b.

[7] Mountain Standard Time, defined as the mean solar time on the the 7th-hour meridian west from Greenwich, is also abbreviated *MST*. The context usually determines which is meant.

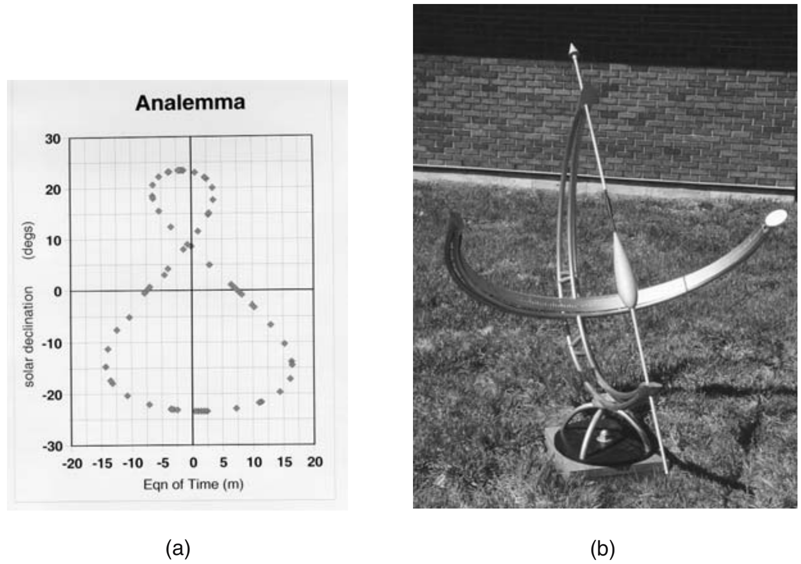


FIGURE 4.10. (a) The analemma for 2000 A.D. (b) A modern sundial incorporating the analemma on its stylus. Courtesy, Dr. T.A. Clark, who along with T. Kirkham, supervised its design and construction for the opening ceremony of the RAO.

The time on our watches is not a local time, in general, but is related to the Mean Solar Time at a particular meridian or longitude circle. By general agreement, most civic entities around the world assign the Mean Solar Time at particular meridians to zones surrounding those meridians. The difference between Local Mean Solar Time and the Local Civil Time (i.e., the time in effect at that place) is the time interval required for the Mean Sun to move through the longitude difference between the standard meridian and the local meridian. If the standard meridian is east of the observer, the standard time will be later than the observer's apparent time, and if it is west, the standard time will be earlier. The Mean Solar Time at the Greenwich meridian is called *Universal Time* (UT),[8] or, Greenwich Mean Time (GMT); it is related to the MST at any other meridian through the longitude, λ, of that meridian:

$$LMST = UT \pm \lambda, \tag{4.14}$$

where the positive sign applies for a site east of the Greenwich meridian, and the negative, west.

The actual source of UT is not the position of the Mean Sun, which, after all, can not be observed; it is taken from the positions of the "fixed" stars (fixed, that is, at a particular equinox and epoch). The basic relationship between Local Mean Solar Time and Local Sidereal Time is

$$LST = HAMS + RAMS = LMST - 12^{\mathrm{h}} + RAMS, \tag{4.15}$$

where *HAMS* and *RAMS* are the hour angle and right ascension of the Mean Sun, respectively. The relationship between the sidereal and mean solar time at Greenwich is tabulated in the *Astronomical Almanac* (see Appendix A). Greenwich Mean Sidereal Time is, or rather has been, derived from automated transit observations of stars. Corrections for the variation of the geographic pole (which lead to slight variations in the observer's meridian) are also derived from observations. At present, *Very Long Baseline Interferometry* techniques are used to determine precise positions in the sky of quasars and other effective point sources. The annual editions of the *Astronomical Almanac* provide other details regarding time corrections and should be consulted for further information in critical cases. See Woolard and Clemence (1966) for underlying principles of time-keeping, Green (1986, Ch. 10), Stephenson (1997), Cox (2000), the current year's edition of the *Astronomical Almanac*,[9] and the Reports and Transactions of the most

[8] There are three varieties of Universal Time in use: UT0, UT1, and UTC. Which "UT" is intended must be decided by context. The motion of the Earth's geographic pole causes a slight variation in the location of an observer's celestial meridian. UT0 is determined directly from stellar observations and takes into account neither the nonuniform rotation of the Earth nor the effect of polar motion; UT0 is therefore an approximation to the "true" UT, at a particular meridian, only. UT1 is the result of correcting UT0 for the effect of polar motion; UT1 is commonly used in navigation, and in, for example, tables of the *Astronomical Almanac*. Coordinated Universal Time (UTC) is the time that is broadcast as time signals around the world (cf. the preceding section). (UTC) is based on International Atomic Time (TAI) and differs from it by an integral number of seconds, which varies with time. The difference varies with time because UTC is kept within $0^{\mathrm{s}}.9$ of UT1 by the introduction of leap seconds when necessary, normally at the end of either December or June. $\Delta UT1 = UT1 - UTC$ is transmitted in code on the broadcast time signals.

[9] The projected modern system of time for many purposes is the Barycentric Dynamical Time or *TDB*, the French acronym. It is referred to as a dynamical time scale, but the gravitational theory on which such a time would depend is yet to be adopted. At the moment, the Terrestrial Dynamic Time (TDT), now more generally called "Terrestrial Time" (TT), based on the SI second, is in effect. TT differs from UT by $\Delta t = TT - UT$. We discuss this difference at the end of this chapter and in §5 because it affects the times and locations at which eclipses are visible.

recent General Assembly of the International Astronomical Union (IAU) for further details about what times scales are currently applied.

Modern sundials usually contain a correction for the equation of time and for the difference in longitude between the standard time zone boundary and the local site, in the form of an inscribed table. An additional, seasonal correction of $+1^h$ must be made in most places in North America and many places around the world for daylight savings time. The value for E can be read off Figure 4.9, or it can be found on the analemma, the figure 8 curve frequently found on terrestrial globes (see also §2.3.1). It indicates both E and the declination of the Sun as a function of date; it is also independent of latitude or longitude and is therefore appropriate for anywhere on Earth. The Greek astronomers of the 2nd century were fully aware of the nonuniform character of the Sun's movement due to the obliquity of the ecliptic and to the Sun's variable rate[10] on the ecliptic, and they made use of a correction analogous to our Equation of Time. The analemma and thus the Equation of Time as well as the annual declination variation of the Sun are illustrated in a sundial constructed by Prof. T.A. Clark for the opening ceremony of the Rothney Astrophysical Observatory on January 7, 1972.

4.1.1.3. Mechanical Devices

The sundial was and still is useful for keeping track of the time on a sunny day. Before the development of the magnificently elaborate town clocks of Europe, what was used for telling time on a cloudy day, or during the evening? The tower of Chou Kung (Needham 1981, p. 136) and the Tower of Winds (Robinson 1943; Noble and de Solla Price 1968; Bromley and Wright 1989; Kienanst 1993) likely held *clepsydras* or water clocks. Water clocks made use of regulated dripping of water from a large reservoir into a container, the weight of which increased as the water level in it rose. The container could be permitted to pull a rope downward or contain a float that would permit a different operation. The action would ultimately cause the rotation of a wheel or of an indicator. A water clock could be calibrated with the sundial when conditions permitted, so that timely business could be carried on as usual. For short intervals of time, hourglasses, filled with sand, could be used.

4.1.1.4. Uniform Time Intervals

Ways of reckoning time have changed greatly since ancient times. Although the rotation of the Earth is still the basis for civil time, we use atomic standards to measure precise intervals of time, because, compared with a perfect clock, the Earth runs "slow," as we discuss later. The most precisely determined time scale currently in use for astronomical purposes is called "International atomic time" or *Temps Atomique Internationale* (TAI), and the fundamental unit is the SI second (in the international system of units). By international agreement, it is equal to the interval of time that is measured by 9,192,631,770 oscillations of the radiation emitted by an atomic transition of the element Cesium 133. However, civil time-keeping is still tied to the rotation of the Earth.

The rotation of the Earth is not uniform, but varies randomly, periodically, and secularly. Short-term variations arise because of mass displacements caused by tidal deformations, ocean and atmospheric tides, and geophysical effects; the rotation of the Earth is slowing (the secular variation) because of tidal friction, although other causes may contribute also. The existence of uniform time intervals, by which we can measure the passage of time with precision and accuracy, permits us to correct our clocks for the nonuniform time-keeping provided by the Earth. The corrections are not applied to the observationally based Universal Time (UT1), however, but to a time based on International Atomic Time (TAI, the French acronym) (see fn. 6), namely, the Coordinated Universal Time (UTC). UTC is kept within $0^s.9$ of UT1 by adding a "leap second" when needed, usually at the end of December or of June. UTC is broadcast on selected short-wave frequencies by national time regulation agencies. In §4.5 and §5.2.1.3, we discuss the observational evidence for the gradual slowing of Earth's rotation.

4.1.2. Solar Date Determination

By "solar date" we mean the location of the Sun along the ecliptic, its annual path. The *celestial longitude* of the Sun will increase from day to day, although, as noted in §3.1.1, the rate varies over the course of the year. Differing positions on the ecliptic (i.e., different celestial longitudes) correspond to differing declinations as well as differing right ascensions. The variation in declination means that the Sun's *meridian altitude*—its altitude when it crosses the celestial meridian—will vary also during the year. Figure 3.17 shows that the meridian altitude of an object, the declination of which is known, can provide the latitude of the observer, by the expression

$$h_m = 90\,° - (\phi - \delta), \tag{4.16}$$

where ϕ is the latitude of the observer and δ is the declination of the Sun. In this equation, δ carries its own sign so that when the Sun is at southern (i.e., negative) declinations, $h_m = 90° - (\phi + |\delta|)$. To derive (4.16), consult Figure 3.17a and b.

The tower of Chou Kung, near Loyang, China, contains a 12-m gnomon that casts its noon shadow along a horizontal stone terrace that was marked by a scale (Needham 1981, Figs. 80–82). Such a device constitutes a solar calendar, capable of marking the passage of the days of the year, at the same time that it provides the instant of local noon.

Indeed, not only at noon, but at *any* given time of day, the altitude will change from one day to the next. The altitude of the Sun determines the length of the shadow. An historic example of the use of shadow lengths at particular times of day can be seen on the faces of the Tower of Winds (Figure 4.3; §7.3). Twice a year (except at each solstice) the Sun will

[10] Called by Ptolemy (Toomer 1984, p. 170) the Sun's "apparent anomaly."

TABLE 4.2. Solar year lengths for the epoch 1900.0.

Type of year	Length (mean solar days)	Variation
Anomalistic	$365^{d}.25964134 = 365^{d}06^{h}13^{m}53^{s}.0$	$0^{d}.00000304 \cdot T$
Sidereal	365.25636556 = 365 06 09 09.98	$0.00000011 \cdot T$
Tropical	365.24219878 = 365 05 48 45.97	$0.00000616 \cdot T$
Eclipse	346.620031 = 346 14 52 50.7	$0.000032 \cdot T$

have the same length of shadow at the same apparent solar time.

The ancient Mesopotamians produced ephemerides or tables of the position and motion of the Sun for each day. There were essentially two methods of computing the ephemerides of the Sun: Systems A and B. System A used a step function for the solar speed (i.e., its change in position per day): one value for the first half of the year, and another value for the second half. System B used different values for each month in first increasing and then decreasing series. The effect is what Neugebauer (1983, p. 28) has referred to as a linear zig-zag function. See Figure 7.14 for an illustration. A table of the solar longitude is, in effect, a solar calendar, and although Mesopotamians used a lunar calendar, tabulation of the progress of the seasons with their changing temperatures and rainfall is an important concern of any civilization. The development of a mechanism by which the lunar calendar could be regularly coordinated with the solar calendar was an important result. Systems A and B were used also to obtain the length of daylight throughout the year. Their main utility seems to have been to regulate the beginning of the month and to predict eclipses. Van der Waerden (1974) thinks that these clever systems were most likely created between ~540 and 440 B.C. They are discussed further in §7.1.

Even more ancient are the megalithic solar observatories, the alignments of which indicate solar calendar activity. The mechanism here is the variation of azimuth of rise or set of the Sun as the solar declination changes over the year. A similar kind of calendrics is seen in at least some of the Medicine Wheels of North America (§6.3), some of which may have been used for a much more extensive interval of time (that at Majorville for more than 4000 years). In addition to Medicine Wheels, spirals carved or painted on rock in the southwestern United States, and elsewhere, are seen to be so placed that a dagger of sunlight created by the passage of sunlight through crevices in intervening rocks, marked critical solsticial and/or equinoctial times of the year. The oldest known astronomically aligned sites are passage graves, such as those at Newgrange, County Meath, Ireland. Some of the monuments at this site and the site of Gav'rinis have spiral engravings, and sunlight at midwinter sunrise illuminated them (see §6 for an extensive discussion of Megalithic sites). Again in the New World, marked sunwatchers' stations are places from which observers studied the December solsticial Sun for indications that it was returning northward again to renew and warm the earth.

Related to the determination of solar dates is the determination of the length of the tropical year: the time for the Sun to reappear at the same celestial longitude (e.g., to return again to the vernal equinox). In the *Almagest*, Ptolemy gives the value obtained by Hipparchos[11]: 365 + 1/4 – 1/300 = 365.24667 mean solar days.[12] Compared with the correct value for his time, 365.2422 days, his result was too long by a little under 6.5 minutes. Ptolemy repeated the calculation using the same data and added his own recent observations with the same result. Pedersen (1974, p. 131) attributes the difference from the modern value ($365^{d}.24219$) to instrumental error and refraction.

There is more than one way to talk about the length of the year. Table 4.2 lists four lengths of the year according to different criteria. The value is for the epoch 1900.0, and the variation term is the change in days/century, with T given in Julian centuries from 1900. Note that T is negative for dates prior to 1900. The *anomalistic year* is the time for the Sun to return to perigee (i.e., for the Earth to return to perihelion), the *sidereal year* is the time for the Sun to return to a line to a particular distant star, and the *eclipse year* is the period for the Sun to return to the same node of the Moon's orbit. Note that the sidereal period is the true period of revolution of the Earth around the Sun, with respect to a line to a distant star. The *tropical year*, measured from successive passages of the Sun through the vernal equinox, is shorter than the sidereal year because of the westward precession of the equinoxes, whereas the anomalistic year is longer than the sidereal year because of the advance (eastward motion) of the major axis of the orbital ellipse. The eclipse year is very much shorter than is the sidereal year because of the rapid regression (westward) of the lunar nodes (see §1.3.4 and §5.2).

Many cultures have used a 365^{d} civil year, and some, like our own, have modified it by strategic, well-planned intercalation, to keep the civil calendar in step with the tropical year. Intercalation has not been a universal concern, however, and for particular purposes, different units were adopted. Egypt and Mesoamerica both had a 365^{d} year that cycled through the seasons. The simplicity of such a scheme was, and still is, important in the calculation of the number of days between, say, two New Year's days N years apart. In this calendar, it is merely $N \times 365^{d}$, with no worries about which intervening years had intercalations. For this reason, the Egyptian 365^{d} year was called the "astronomers' year," and Ptolemy among others used it. Neugebauer (1957/1969,

[11] Whose own discussions of the length of the year were contained in two books, now both lost: *On the Length of the Year*, and *On Intercalary Months and Days*.

[12] When we write a "d" following a number or in superscript above a decimal point, it can be understood to indicate units of the *mean solar day*, the time interval between two successive tranits by the *mean sun*.

p. 140) states that in Babylonian texts, the term "year" always refers to a sidereal year. He also notes that Ptolemy is the first to define the "year" as the *tropical year*. The term "year" has had other interpretations also: The *Book of Enoch*, known from Ethiopic sources and the Dead Sea Scrolls, cites a 364^d year, called the "year of Enoch." The number 7 divides evenly into such a year; so it is useful in finding the day of the week corresponding to a particular date. Modern scientists use Julian day numbers to solve both types of problems for which the Egyptian and Ethiopic years provided solutions. See §8.1 and §8.3 for further discussion of time measurement and the astronomy of these cultures.

A tie-in between the civil date and the equinoxes is provided by the stars. The heliacal rising of a particular star, e.g., Sirius was sufficient to tell ancient Egyptians what season it was, regardless of the date of the local calendar, and thus when to expect such seasonally linked occurrences as the flooding of the Nile. Ultimately, there are very nearly 366 sidereal days to each 365 solar-day year.[13]

4.1.3. The Days and Length of the Week

The week in some cultures did not always have seven named days in it. In Java, there was a five-day week, in mainland Asia, a nine-day week. A 3rd-century Hindu book shows both seven- and nine-day weeks. Parker (1974) writes of an early Egyptian 10-day week. In the Roman republic, there was an eight-day week (nine by their inclusive counting technique), the last day of which was a market day. See §15.4.4 for further discussion of the spread of the seven and nine-day weeks.

Although the days of the planetary week, in use in much of the world, are not older than the 1st century B.C., they have their roots in the seven planets of antiquity. By the time that Christianity became the state religion of the Roman Empire, the planetary week was so firmly entrenched that it defied all attempts to change it. The scheme is based on geocentric cosmology that places the spheres of the planets in the following order from Earth: Moon, Mercury, Venus, Sun, Mars, Jupiter, and, in the "seventh heaven," Saturn. Each hour was associated with and held to be ruled by a planetary god. Proceeding in descending order through the heavens, in endlessly repeated cycles, Saturn would rule the first hour, Jupiter the second, Saturn the eighth hour, and so on. A day belonged to the god that ruled the first hour of that day. The ruler of the 25th hour became the ruler of the first hour of the next day. Thus, beginning with Saturn, we have first Saturday, next Sunday, and so on. Figure 4.11 illustrates the progression.

The planetary seven-day week became widespread. It was in China by the 3rd century A.D., in Ireland with Christianity, and deep into Africa with Islam. The order of the names is the same as for the Mediterranean order, beginning with the Sun. It should be pointed out that not every culture has retained the planetary names, which were maintained in the Latin, western half of the Roman empire; in the eastern half, the days were called first, second, and so on, with the sixth (Sabbath) and seventh (*Κυριακή*, Kyriake: Lord's Day) accorded special status. The latter usage continues, but differs slightly from country to country.

Cosmic Order and the Planetary Week

THE STARRY REALM											
SATURN	1	8	15	22	5	12	19	2	9	16	23
JUPITER (THOR)	2	9	16	23	6	13	20	3	10	17	24
MARS (TIW)	3	10	17	24	7	14	21	4	11	18	1
SUN	4	11	18	1	8	15	22	5	12	19	2
VENUS (FREYA)	5	12	19	2	9	16	23	6	13	20	3
MERCURY (WOTAN)	6	13	20	3	10	17	24	7	14	21	4
MOON	7	14	21	4	11	18	1	8	15	22	5...

FIGURE 4.11. The cosmological scheme from which the ordered name days of the week derive: A planet rules each hour, and the planet that rules the first hour rules the day. In this tabular example, Saturn rules the first day. From it, count down through the rows (and then in successive columns to the right) until the 24th hour is reached. The Sun rules the first hour of the second day, the Moon the third, and so on. Diagram by E.F. Milone.

4.1.4. The Month

The month as a practical unit of time derives naturally from the cycle of phases of the Moon, the synodic period or synodic month. In §2.3.5, the several different periods of the Moon or months were defined. The two calendrical months were the sidereal and synodic months.

Sidereal months were used in a number of cultures, from India to California, but for various purposes and in different ways. The passage of the Moon through a particular asterism marks the length of a sidereal month. Sidereal intervals were used across Micronesia and Polynesia and in the southwestern United States. In India, the usage was in connection with the *nakshatras*, or lunar mansions, a series of 28 asterisms (sometimes 27, due to the omission of *Abhijit*, Vega). The purpose of the *nakshatra* system was to reconcile sidereal and lunar motions. The interval of 13 sidereal months, each of an assumed length of 28^d, gave a 364^d year in Southeast Asia.

The use of synodic months was much more widespread. There is evidence of the measurement of days using lunar phases from early human history. Marshack (1972a) has cited an elaborate serpentine pattern of crescent-like markings on the *Blanchard bone* as the earliest example of human notation and has argued that it seems to record the changing phases of the Moon over a two-month period during an Ice Age, more than 25,000–30,000 years ago. The reindeer

[13] This is because the Sun moves on average 1/365 of its annual motion each day, so this is the rate by which any mean solar time interval differs from its sidereal counterpart. More precisely, in a full tropical year, the number of sidereal revolutions of the Earth is 366.25639 (i.e., 365.25636/0.9972696). The quantity 0.9972696 is the ratio of an interval of mean solar time to the same interval in analogous units (seconds, for example) of sidereal time.

bone was excavated in 1911 from the Blanchard rock shelter near the southwestern French village of Les Eyzies, central among the known sites of Cro-Magnon man. Marshack has suggested several other possible Ice Age examples as well (see §6.1).

A much more recent possible record is that on a well-crafted pyrite mosaic excavated from an Olmec site at Las Bocas, Mexico, and dated ~1000 B.C. Marshack (1975) has argued that the mosaic patterns themselves constitute a (basically lunar) calendar, but the argument is not complete because part of the pendant is apparently missing. This is unfortunate because the pyrite is relatively well preserved. Although the Olmec heartland, including the major sites of La Venta and San Lorenzo, was in the northern half of the Isthmus of Mexico, this site is in western Puebla in central Mexico. The mosaic may have been worn on the chest as a pendant or pectoral, as were the pectoral mirrors of later Mesoamerican groups. More recently, Spackman (1996) has attempted a much more complex mathematical, calendrical, and astronomical analysis of the pendant, comparing it with other Olmec artifacts and with Mesoamerican mythology. Spackman argues that the ornament was designed for a headdress rather than a pectoral and that it was prepared for a particular ceremony of 21 March 1083 B.C. (JDN 1325947). The date is reached by an amplification of Marshack's techniques but rests on a substantial number of additional premises. At present, Spackman's analysis seems untestable.

Lunar calendars were widely used in the ancient world. In Mesopotamia, the civil calendar was lunar. Each month began with the first sighting of the waxing crescent. According to Neugebauer (1983, p. 1), the main goal of Babylonian lunar theory was the accurate prediction of the dates of such occurrences. To this end, ephemerides or tables of the lunar positions, much like those in the *Astronomical Almanac* of today, were produced. An example is shown in Figure 7.4 and Table 7.11. The tables contained such information as the year (in the Seleucid era[14]) and the month, the longitude (in zodiacal signs and degrees) and latitude (in units of barleycorns = 1/72 degree) of the Moon, the daily motion of the Moon (in °/d), the date and time of new or full Moons, and sometimes, the time between settings of the Sun and Moon at the start of the month and the time between risings of the Moon and Sun on the last day of the month. The tables also contained information related to eclipses, the duration of daylight, the previous month's duration, and corrections to the latter to permit a calculation of the current month's duration. See Table 7.3 for a list of Babylonian months. An average day-length, 1/30 of a mean synodic month, was also used.

Unlike the Babylonian months, the Egyptian months were not strictly lunar. There were 12 months, each of exactly 30 days, with 5 extra or "*epagomenal*" days added to make up a year of exactly 365^d (the *Egyptian Year*). It is clear that with such a fixed length, these months are no longer closely tied to any astronomical phenomenon. Because of the ease of use in calculation, Ptolemy used the Egyptian months to describe the dates of his observations, even the very old ones. The Egyptian months appear on a part of the Antikythera mechanism and were widely used throughout the Mediterranean world. The names of the months are given in Table 8.2. Even in the Middle Ages, the Egyptian year was called the *Astronomers' Year*, and it served the purpose of calculating intervals between astronomical events. In this respect, it provided a function similar to the current Julian Day Numbers.

Among the *Yuman* groups of the southwestern United States and adjacent Mexico, a combination of synodic lunar months and sidereal intervals approximating a month was in use. The six summer months were true lunations, whereas the six winter months, which repeated the summer month names, each began with the heliacal rising of stars. The stars were so selected that the heliacal rising intervals approximated the length of a lunar month. Further details about calendars can be found in Kelley and Stewart (*in preparation*).

4.1.5. Era Bases and Day Numbers

For keeping track of time over intervals longer than a year, era bases are used. They permit the reckoning of the number of days (as do the Julian Day Numbers of our present era) or the number of years from a particular event in the past. The year of the accession of a king was one traditional way of maintaining records. Thus, in Mesopotamia, the *era of Nabonassar* began on Feb. 26, 747 B.C., which had been back-calculated as the beginning of the first year of the reign of Nabonassar. Ptolemy used the Nabonassar era base because that was the era from which his oldest observational data came. The Greeks and other Near-Eastern cultures used the date of the royal accession of Seleukos Nikator, one of Alexander's generals, as year 1; in the case of Seleukos, however, this became the base of an era count that continued into the medieval period, and even later. Year 1 of the *Seleucid era base* begins at 312 B.C. The dynasty itself lasted from 312 to 64 B.C.

An important era base was that used by the Roman Empire—the founding of the city of Rome (753 B.C., according to a calculation of the birth of Christ by Dionysius Exiguus, writing in the 6th century)—a date adopted by the Synod of Whitby in 664 A.D. The use of this era base is identified by the phrase *ab urbe condita* ("from the founding of the city") or *AUC*.

The modern era base is also derived from the medieval calculation of the birth of Christ, hence, the designation for subsequent years, *Anno Domini* (now often referred to as the "Christian era" or "Common era," either abbreviated *CE*). In a later section, when we discuss the nature of the star of Bethlehem, we will review the evidence concerning the historicity and dating of that event. The base of the Christian era is the year 1 A.D. (or A.D. 1). The year before 1 A.D. is 1 B.C. Thus, the year 1 B.C. is 753 AUC, and the year 1 A.D. is 754 AUC. Many calendricists and astronomers, to maintain a mathematically continuous flow of time, refer to

[14] A year y in the Seleucid era is (to within a year) $y - 311$ in the Gregorian calendar. Because most relevant dates taken with respect to this era base are before Christ, we may also write the equation: B.C. date = 312 – y (see §4.1.5). A precise equivalent from Neugebauer (1955/1983, I, p. 7) is 188 B.C. July 17 = S. E. 124 III 28, where "III" is the third month.

the year 1 B.C. as year 0. The year 2 B.C. is thus the year –1, and so on. Although this is not normal practice among historians, calculations are much easier when no discontinuity occurs in the middle of the count. Regardless of which technique is used, the relationship is given by

$$x = y + 1, \tag{4.17}$$

where $y = |y|$, is the absolute value of the negative date and x is the B.C. date.

Another important era base is the *Kaliyuga* (also *Kali Yuga* or *Kalyuga*) era base used in India. The word "*yuga*" means cycle, but it now has another, more specific meaning as a particular interval of length: 4,320,000 years.[15] It is one of about 20 time divisions, the smallest of which is the time for a sharp needle to pierce the petal of a lotus flower [~1/10,000 of the "twinkling of an eye" to "100 years of Brahma", i.e., Brahma's lifetime (an interval of time amounting to $\sim 3.135 \cdot 10^{14}$ years)]. This cycle length exceeds by more than 15,000 times the modern scientific determination of the age of the known universe. The present Yuga is called "Kali." The Kaliyuga was supposed to begin when the Sun, Moon, and planets were at the vernal equinox. Ginzel (1906, p. 338) gives this date as either JDN 588 465 or 588 466, actually midnight, Thursday, February 17, 3102 B.C., or sunrise, Friday, February 18, 3102 B.C., at the meridian of Ujjain (see below for the definition of JDN). It appears that Ginzel applied the difference between Julian and Gregorian calendar dates in the wrong direction, however. The correct corresponding dates for the vernal equinox in 3102 B.C., would be April 16 and 17, in the Julian calendar. Unfortunately, it appears that a mass conjunction did not take place at either set of dates, but a broadly-defined "conjunction" occurring at other times in the year cannot be excluded. Of course, if the event were purely back-calculated, the actual occurrence is not critical to any astronomical or historical purpose. The Kaliyuga era base was used also as the start of a count of days (comparable to a Julian Day Number) by all Indian astronomers after Āryabhata (see §9).

The *Astronomical Almanac* lists the chronological eras and cycles in various historical calendars. In addition to announcing the start of the new year from the different era bases, it notes also the ecclesiastical parameters that are used to regulate some church calendars, for example, The "Dominical Letter (the letters A to G represent the first day of the year that falls on a Sunday; e.g., if January 2, the Dominical Letter is B)," the "Epacts (a set of numbers, indicating the Moon's age at the beginning of the year)," and the "Golden Number (year in a 19-year cycle)" of lunar cycles. Further discussion of these topics we leave to Ginzel (1906) and others.

One era base used by present-day astronomers is that from which the *Julian Day Numbers* (JDN) are measured: January 1, 4713 B.C. (Julian calendar). The JDN system was invented by Julius Caesar Scaliger (1484–1558). The JDN begins at noon, U.T., on the day beginning at the preceding midnight. Noon of the date December 31, 1949, was the onset of JDN 2,433,282, and on noon, December 31, 2050, the JDN will be 2,469,807; the difference in numbers of days between these two dates is exactly 36,525[d]. This scheme is extremely useful in computations that involve large intervals of time. Note that the JDN is not strictly speaking a calendar date; it is a tally of days. Despite widespread usage among astronomers of the term "Julian Date" for JDN (for example, in the *Astronomical Almanac*, in the 2000 edition on p. K4), under no circumstances should it be confused with the Julian Calendar. An interesting byproduct is that the integer remainder after division by seven yields the day of the week on which the JDN begins: 0 = Monday, 1 = Tuesday, . . . , 6 = Sunday. For example, on noon of January 1, 2000, JDN = 2451545.0000, which modulo 7 (an operation that is equivalent to dividing by seven and multiplying the decimal portion of the quotient by seven), the JDN remainder is five, and thus indicates a Saturday, which a glance at a calendar will confirm. In addition to the *Astronomical Almanac*, the *Handbook of the Royal Astronomical Society of Canada* also lists the JDNs for the various Gregorian calendar dates for the year of publication (but unlike the *AA*, only for a few other years). Formulae given by Muller (1975) and reproduced by Stephenson (1997) relate the JDN to Gregorian and Julian Calendar dates (expressed in Y year, M month, and D day number format) by the following approximation:

$$JDN = (367 \times Y) - 7 \times \frac{Y + \frac{(M+9)}{12}}{4} - 3 \times \frac{\frac{Y + \frac{M-9}{7}}{100} + 1}{4} + 275 \times \frac{M}{9} + D + 1721029 \tag{4.18}$$

for any A.D. Gregorian calendar date [with a correction, provided by E.M. Standish (private correspondence to EFM) and we note that adding 1 to the answer gives a closer approximation near Oct. 15, 1582, and for the past century], and

$$JDN = (367 \times Y) - 7 \times \frac{Y + 5001 + \frac{M-9}{7}}{4} + 275 \times \frac{M}{9} + D + 1729777 \tag{4.19}$$

Here, subtracting 1 gives a closer result over much of the range for any Julian calendar date. See Van Flandern and Pulkkinen (1979) for a Fortran version (which needs updating). Montenbruck (1989, p. 34) gives a more general formula for calculating JDN, which makes use of auxiliary parameters that are computed from the Y, M, and D numbers and are different for the Gregorian and Julian calendar dates. Such equations provide useful checks on calculations of intervals between events. As an example, consider January 1, 4713 B.C. (Julian calendar[16]):

[15] The earliest use of the term *yuga* was for an eight-year period.

[16] The Julian calendar is usually applied up to and including the date Oct. 4, 1582, the day before the Gregorian calendar was first introduced (in some countries). The latter day was Oct. 5, 1582, in the Julian calendar but Oct. 15, 1582, in the Gregorian. Formally, the Julian calendar came into effect on Jan. 1, 45 B.C. However, back-calculations of both Gregorian and Julian calendar dates are frequently done.

$$JDN = (-4712 \times 367) - 7\frac{-4712 + 5001 + \frac{1-9}{7}}{4}$$
$$+ 275 \times \frac{1}{9} + 1 + 1729777 = \sim 0.8$$

D = ϕ gives JDN = –0.2, closer to the correct value, –0.5. Montenbruck (1989, pp. 34–35) in addition provides a formula to compute the calendar date from a JDN. For precision work, tables are recommended.

4.2. The Bases and Functions of Calendars

In preceding chapters and sections, the bases of most calendars are the motions of the Sun and Moon, even if there are some calendars that are based primarily on the seasonal appearances of stars. The reason for using the Sun is fairly clear: The seasonal variations of climate, involving temperature changes in higher latitudes and mainly precipitation changes in lower latitudes, lead to changes in vegetation and in wildlife behavior. Such changes are usually seasonal, i.e., connected to the tropical year. With these variations, there are changes in the stellar asterisms that are visible at any particular time of night, hence, "the rainy Pleiades," which rose as the Sun set at the beginning of the rainy season. The Moon has played a strong calendrical role due to the obvious changes in phase and the useful light provided by a gibbous or full Moon and its tidal effects. There are also ample cultural connections between the Moon and rain, and between the Moon and woman (the approximation of the synodic month to the menstrual cycle). Its early (perhaps Ice Age) use may be surrounded by magic and cultural associations.

European calendars—from Julius Caesar's time to the present—are solar calendars, retaining the use of intervals called months, but paying no attention (in a calendrical sense) to the phases of the Moon at which the month begins. Caesar's reform was introduced on Jan 1, 45 B.C. and marked a clear departure from the luni-solar calendar in place until that time. As the inheritors of the European calendar, North Americans have also foregone the lunar calendar. The religious calendar of Islam, which is also the civil calendar in certain Moslem countries, is a pure lunar calendar. The year ends on the 12th lunar month so that the Feast of Ramadan cycles through the solar year. A lunar calendar that has been the subject of recent studies is the calendar of the Borana people of Ethiopia (Ruggles 1987).

4.2.1. The Reconciliation of Solar and Lunar Calendars

In this section, we deal with the attempts in Europe and the Near East to reconcile the motions of the Sun and Moon. The Mayan Calendar and its Mesoamerican variants, which dealt with the problem in an entirely different way, will be discussed in §12.

The basic calendar problem in this context is the fact that the tropical year[17] is not an integral multiple of the synodic month: 365.24219878/29.530589 = 12.36826664. The remainder, $0^{\mathrm{d}}.368266$, . . . , is not easily dealt with. If we approximate the length of the synodic month by $29^{\mathrm{d}}.5$, however, the problem is more easily grasped. In this case, the following solution arises: 12 months × $29^{\mathrm{d}}.5$/month = 354^{d}. This is 11^{d} short of a year whose length is only 365^{d} (such a year was used in ancient Egypt and was thus known as the *Egyptian year*[18]; see §8.1.4). In 3^{y}, the deficit is 33^{d}. The simplest solution is to add an additional month during some years in order to approximate a commensurability between the two periods. The process of adding an extra month to certain years is called *intercalation*. The problem in our example is that adding one month every three years would require that that intercalary month not be a synodic month interval, because it would be 33^{d} long, not $29^{\mathrm{d}}.5$. This may not strike us as a terrific problem today, but to most in the modern world, the Moon is not a god or goddess to be appropriately served and honored, and the goal of achieving harmony with the workings of the cosmos is not a particularly strong driving force. The earliest known successful attempt at intercalation is that of Meton of Athens, in 431 B.C. The Metonic cycle is 19^{y} long, an interval roughly equivalent to 235 lunations. The scheme was to employ 12^{y} of 12 months each (giving 12 × $29^{\mathrm{d}}.5$ = 354^{d}), and 7^{y} of 13 months each (giving $13 \times 29^{\mathrm{d}}.5 = 383^{\mathrm{d}}.5$) during this interval. In terms of total days, the 19^{y} would contain

$$\begin{aligned}[12 \times 354^{\mathrm{d}}] + [7 \times 383^{\mathrm{d}}.5] &= 4248^{\mathrm{d}} + 2684.5^{\mathrm{d}} \\ &= 6932.5^{\mathrm{d}} \\ &= 18.9932 \text{ years of } 365^{\mathrm{d}} \text{ each.}\end{aligned}$$

In terms of a slightly better approximation to the length of the tropical year, viz., $365^{\mathrm{d}}.25$, the interval $6932^{\mathrm{d}}.5$ amounts to $18^{\mathrm{y}}.980$; finally, with the value $365^{\mathrm{d}}.24219878$, we obtain $18^{\mathrm{y}}.981$. The Metonic cycle would seem to work best with the Egyptian year, although the Babylonians certainly knew the year to far better precision than this. The Metonic cycle actually works even better considering the actual accrual of time over the 19^{y} interval:

$$[12 \times 12 \times 29.530589] + [13 \times 7 \times 29.530589]$$
$$= 4252^{\mathrm{d}}.4048 + 2687.2836 = 6939^{\mathrm{d}}.688 \text{ or } 19^{\mathrm{y}}.000248$$

of true tropical-year length. The resulting error is only $0^{\mathrm{d}}.0902$/cycle, which accumulates to 1^{d} approximately 11 cycles later, a total span of ~210 tropical years. Even more

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[17] The period of time for the Sun to return to the same point on the ecliptic, for example, the vernal equinox. See Table 4.2 to distinguish this interval from other types of year.

[18] Such a length may seem to be hopeless as far as keeping in step with seasons was concerned. Yet the 365^{d} year was used in Egypt, Mesoamerica, and Hawaii. The Egyptians were aware of the slippage of their calendar with the seasons, however: The period of return to the same calendar date, the *Sothic period*, was 1460 years long. Over this interval, $532{,}900^{\mathrm{d}}$ elapsed. The slight variation of 1/4 day from year to year adds to 365^{d} in this interval (see 8.1.2 for further discussion). A similar effect may have been noted in Mesoamerica (cf. 12.6).

remarkably, $6939^{d}.688$ amounts to 18.999830 years of $365^{d}.25$ length for an error of only -0.0620^{d}/cycle, which accumulates to 1^{d} in 16.129 cycles or ≈306 Julian years, as the $365^{d}.25$-years are known. It is important to state that although it is valuable to be able to see how "good" a cycle may be on very long time scales—for which modern values are useful—in order to see how it was actually used and thought about, it is extremely important to test such cycles in the systems for which they were designed, inaccuracies and imprecisions and all. With a mean synodic month length of $29^{d}.53$, and a year length of $365^{d}.25$, for example, the Metonic cycle works very well (the error is $\sim 0^{d}.2$). However, we have it on good authority (from Hipparchos, quoted by Ptolemy; cf. Toomer 1984, p. 139) that Meton used a value for the length of the year of ($365\frac{1}{4} + 1/76$ d = $365^{d}.2631579\ldots$). With this value, we get in 19 years $6940^{d}.000$, compared with the value above, assuming a $29^{d}.5$-length month, namely, $6939^{d}.688$—a very good approximation. However, see §7.3 for Hipparchos's contribution to the intercalation problem and improvements to the determined length of the year.

The Metonic cycle, or a variant of it, the *Kallipic* cycle,[19] has been in wide use among Mediterranean cultures since its discovery. Neugebauer (1957/1969, p. 7) notes that Athens rejected Meton's proposal in the 5th century B.C., although it was incorporated into the Babylonian calendar. It was retained in the Seleucid empire of Babylonia and is still employed in both Jewish and East Indian religious calendars. Toomer (1984, pp. 337–340) has argued that Meton's purpose was not the reform of the Athenian calendar but the establishment of an astronomical chronology.

4.2.2. The Julian Calendar Reform

The dominant world calendar of the present derives from the lunar calendar of ancient Rome; we still retain the Roman names for the 7th through the 10th months.[20] Intercalations to bring it nearly in step with the seasonal calendar were inserted after February 23. Julius Caesar obtained the help of Sosiglines, an astronomer from Alexandria, to reform the previous civil calendar, the Roman Republican Calendar. The older calendar was subject to abuse because of collusion between some local priests, who declared when intercalations should occur, and local politicians, who sought to enjoy the spoils of office for as long as they could. The Julian calendar, which became the civil calendar wherever the Roman Empire or its successor governing entities (all of Europe, the Americas, and much of the rest of the world) held power, fixed the length of the civil year at 365^{d} for three of every four years, and at 366^{d} for the fourth year, for an average over any four-year interval of $365^{d}.25$. Plutarch (~120 A.D.) wrote that the priests alone understood the calendar and that they would insert the extra month (*Mercedonius*) into the calendar suddenly, without warning. The calendar reform was considered imperious by Caesar's critics. Plutarch (Warner trsl., 1958/1962, p. 266) says that Cicero responded to a comment that the constellation Lyra would rise the next day by saying, "No doubt. It has been ordered to do so."

4.2.3. The Gregorian Calendar Reform

Because the average tropical year length is $365^{d}.24219878$, each year the calendar slipped further behind the solar year. In 1000^{y}, the difference was $7^{d}.8$. By 1582 A.D., the difference became nearly 13^{d} and the shifting date was creating some difficulties for the ecclesiastical calendar, especially for fixing the date of Easter. In that year, Pope Gregory XIII introduced a calendar reform that changed both the era base and the average length of the civil year. First, the date was advanced by 10^{d}; the day Oct. 5, 1582, became Oct. 15, 1582. This moved the date of the vernal equinox back to March 21, where it was at the time of the Council of Nicaea, 325 A.D., when the formula[21] for computing the date of Easter was adopted. Second, the average length of the year (over an interval of 400 years) became $365^{d}.2425$; this was effected by restricting slightly the number of intercalary or leap years. Century years divisible by 400 (e.g., 1600 or 2000) would be leap years, whereas the intervening century years (e.g., 1700, 1800, and 1900) would not. Thus although there are $365.25 \times 400 = 146{,}100^{d}$ in four centuries of the Julian calendar, there are only $146{,}097^{d}$ in four centuries of the Gregorian calendar. In Protestant and Eastern Orthodox countries, the Gregorian calendar would not be adopted until the 18th century or later. In England and its colonies, this occurred on September 3, 1752, which became September 14, 1752, in the Gregorian calendar. As in any other major civil occurrence, the calendar change caused an uproar; riots ensued in London as many people demanded their 11 days back. Preventive laws were enacted, but disputes over payment for services/commodities by the week, month, or year could have been at the heart of the discontent.

The onset of the year was altered at the introduction of the Julian Calendar by the intercalation of three months in 46 B.C. to bring the date of vernal equinox to a traditional value of March 25. That year, which had 446^{d}, was called the "year of confusion." In Britain and its colonies, which had celebrated the start of the year on March 25, the introduction of the Gregorian calendar was preceded by starting the year 1752 on January 1. Therefore (in British jurisdictions), the year 1751 was only 282^{d} long.

4.2.4. A Calendar Problem: The Date of Easter

There are many historically interesting calendric problems. Among these is the calculation of the date of Easter. The

[19] Produced by Kallippos, student of Aristotle, in 329 B.C. Kallippos adopted a value for the length of the year of $365\frac{1}{4}$ day. See 7.3 for comparison of his value to that of Hipparchos.

[20] September through December, now the 9th through the 12th months, respectively.

[21] This rule states that Easter will fall on the first Sunday after the 14th day of the Moon that occurs on or after March 21. The 14th day of the Moon, is, on average, slightly earlier than the precise date of full moon, in our reckoning of dates.

traditional statement is that Easter is the first Sunday after the first full moon[22] following the vernal equinox. Neugebauer (1979) notes that astronomically, the solution requires the determination of the length of the tropical year and the ability to predict accurately the moment of full moon. In his study of an Ethiopian table giving the dates of Easter, Neugebauer found that the dates were simply computed from the dates of Passover (Easter would be a following Sunday). These dates were computed using the 19-year Metonic cycle, but without the refinements that the Babylonians employed (according to Neugebauer). The point to be made is that the computation of the dates of Easter usually involved computational schemes that sometimes differed in application among the ecclesiastical authorities. Moreover, the date of Easter can be different if one begins counting days from sundown, as in ancient Babylon [and in the later Jewish tradition (see Metzger and Coogan 1993, p. 744)], and controversies arose if some calculations indicated an Easter date that fell just one day after Passover. The question of the need to avoid a date prior to or coincident with Passover depends on the priority given one part of scripture over another. The distinction causes a difference between the dates of Easter as celebrated by Orthodox Christians, for whom the date of Easter must follow Passover, and by the Catholics and Protestants of the western churches, for whom Easter can precede Passover. Even among western churches, however, dates computed with different lunar theories have yielded different dates of Easter. Ginzel (1906) summarizes these difficulties and others. See Dershowitz and Reingold (1997) for a recent mathematical treatment.

4.2.5. A Pseudo-Problem: The Date of the Millennium

This section provides a useful example of the nature and use of an era base,[23] even if the particular issue involved is not a true calendar problem in any sense. As subscribers to the History of Astronomy internet list-serve in the years 1999 and 2000 could testify, few subjects inspire such passions as the date of "The Millennium." Despite news releases from august astronomical institutions around the world, many scientists joined news media, politicians, and various world leaders, in arguing that Jan. 1, 2000, marked the beginning of the "new millennium." Probably never before in the history of the world has so much money been spent on raising a hulabaloo over a jubilee calendar date, only, sadly to report, to get the occasion wrong!

Already in 1900, the London Times refused to accept letters to the editor arguing the issue of the beginning of the new century, the 20th. The editor argued that the matter was clear to anyone who could count. The same answer applies to the controversy about the beginning of the 21st century.

The heart of the matter is this: When a society commits to an era base, irrespective of whether or not the event on which the era base is founded is correctly dated, and irrespective even of whether the character of the event to which it is connected is mythic or historical, the decision about when 10 or 100 or 1000 or 2000 years have elapsed compresses to a counting problem.

To be sure, in the case of the Gregorian calendar, we employ the Roman counting scheme, but this is no difficulty because we are familiar with it in other contexts. Take the days of the week as an example. Suppose Monday is taken as day 1, Tuesday, 2, . . . and Sunday is then day 7. In this scheme, hopefully, there is no argument about when the 7th day of the week occurs! In the case of years, a similar scheme applies: 1 A.D. (recall that there is no 0 A.D. in this scheme) is the first year, followed by 2 A.D., and 10 is the tenth and final year of the decade. The beginning of the next decade is the year 11; similarly, the last year of the 1st century is the year 100, and 101 begins the second century; 1000 the last year of the first millennium, 1001 is the first year of the second millennium, 2000 is the last year of the 20th century and of the second millennium, and 2001 is the first year of the 21st century and of the third millennium. And that is all one needs to say about it.

4.2.6. Year Lengths and the Earth's Orbit

We conclude this subsection by noting that each of the types of years indicated in Table 4.2 will be of slightly different length from year to year; the reason is the Earth's variable speed in its orbit, and the variations that the orbit, and the Earth itself, undergo because of gravitational perturbations. The anomalistic year would be slightly more basic than the others, because in a two-body system, it is the cycle of orbital velocity variation, while the others involve some overlap and, therefore, different integrated values of cycle length. However, the Earth is not in a two-body system, and its orbital elements, including the semimajor axis and period, are continuously changing. The change in the anomalistic year is small, however, and can be ignored for relatively short intervals unless the highest precision is required. For most alignment and calendar questions, a four-place decimal precision in year length when expressed in days, and the use of the average mean solar tropical year length, will be sufficient for most applications.

We now review the general archeological and specifically astronomical methods of determining ages.

4.3. Chronology

The instant from which a sequence of events is reckoned (i.e., calculated or measured) is called an *epoch* in modern astronomy. For example, *epoch* is used to indicate the particular instant when a planet or other solar system body is located at a particular perihelion. Knowing the elements of the orbit, one can, in principle, henceforth compute the position of the object in its orbit at all other times. In the discipline of history, on the other hand, the term is used to mean

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[22] Some authorities suggest "the fourteenth day," which is not the same. In Babylonian usage, as cited by Neugebauer, and modern Islamic usage, however, they are the same.

[23] An instant from which a period of time is reckoned; see 4.3 for a full discussion.

an interval, for example, "la belle epoch." The term *era* is used by geologists and astronomers to refer to very large intervals of time, but the term is also used by others to denote briefer intervals. Historians, archeologists, and many others tend to use the term *era base* to denote an instant from which a period of time or sequence of events is reckoned. Because this discussion has more to do with history and archeology than with astronomy, we will use the historical term in this section. One important era base is the date of the mythical founding of Rome. Whether based on historical events or not, such era bases provide relative zero points in history. Provided that the experiences of a particular people living in a certain era are recorded by their historians with temporal accuracy, highlighted events can usually be tied into others' records of those or related events. Any record of historical events referred to a common era base is called a *chronology*. An important task for the historian, and for the interdisciplinary scientist who wishes to make use of historical data, is to be able to equate the events in one chronology with those in another. This becomes possible if the era base of one can be dated in the chronology of the other. In this process, astronomy can often play an important role, not so much because the measurement of time has been a largely astronomical duty throughout history, but because specific astronomical events such as eclipses have been recorded sometimes in different chronologies.

Archaeologists have used a wide range of techniques other than historical and astronomical records and calculations to establish chronologies. The most basic is the correspondence between classes, types, or styles made in a particular time period. Such correspondences may also involve particular techniques of manufacture or the use of materials from a known area. For archeological interpretation, the most helpful of all artifacts, once it came into use, was pottery. Changes in shape, color, decoration, and manufacturing techniques provide easily recognizable sequential markers. The order of these may be determined from their stratigraphy (deposition in layers) in dumps or habitation sites. There are also special stratigraphical chronologies such as those established by annual deposits of lake silt in certain areas. Where the deposits are clearly marked annually, they are known as varves. Varve chronologies have been established in many lake districts around the world. These are seldom directly associated with human activities, but are very useful for establishing chronologies of changing vegetation types, for pollen is normally found in varves. The types of vegetation are correlated, in turn, with changing climatic conditions. In glacial regions, there are annual variations in the deposition of snow layers, which was first recognized at Camp Century in Greenland. These ice layers are particularly important in cross-dating with other techniques and provide a firm sequence, world-wide, for volcanic eruptions, because ash from such eruptions remains in the upper atmosphere for several years and is subsequently deposited in the ice strata and can be chemically identified with its place of origin. When in the upper atmosphere, the ash produces summer cooling and has a negative effect on plant growth that may be recognized in tree rings. The variable pattern of good and bad conditions causes variation in widths of the tree rings that may be correlated from one area to another, giving dates especially for timbers used in construction. Tree ring dating or dendrochronology was first established in the hope of recognizing a reflection of the solar activity cycle. There does seem to be a correlation with sunspot cycles, but it appears to be rather weak.

As ice sheets began to melt toward the ends of ice ages, the continents were relieved of this excess weight and rose in a pressure adjustment ("isostatic readjustment"). In coastal regions, series of beaches were formed at progressively higher levels. In the Hudson Bay region, the last 8000 years are marked by a regular sequence of 185 beaches formed at intervals of about 45 ± 5 y as determined by ^{14}C dating (described below). The so-called "Double-Hale" cycle of 40–49 years has been linked with this cyclicity (Fairbridge and Hillaire-Marcel 1977); these authors in turn link the "Double-Hale" cycle with planetary conjunctions, especially of Jupiter with Saturn. Such "correlations" have been hotly disputed in the astronomical community, however, and, in any case, detailed mechanisms for any such claimed correlations have yet to be elaborated.

There are a substantial number of chronologies involving the statistically regular decay of various radioactive substances. The principle behind these techniques is as follows. Each chemical element (determined by the atomic number, i.e., the number of protons in the nucleus) has one or more isotopes, distinguished by different atomic weight (or the combined number of protons and neutrons in the nucleus). Radioactive isotopes, sometimes called "radioisotopes," are unstable nuclei that spontaneously decay, but given the very large number of atoms of any particular substance ($6.022 \cdot 10^{23}$ atoms per gram molecular weight), the statistics of such decay is strongly predictable, although the exact moment of decay of any individual atom is unknown. If N is the number of atoms of a radioactive isotope at some time t, N_0 is the number at some initial time t_0 when the material in the sample came together (for example, when a tree trunk grew and thus assembled the carbon atoms in place), and if N_D is the number of atoms at time t of the "daughter" element that is created by the decay of the radioisotope, then in the simplest case, these numbers are related by the expressions[24]

[24] For a radioisotope that can decay into more than one daughter atom, we may relate the number of atoms of a particular daughter at time t in terms of the initial number of atoms of the "daughter" species, N_{D0}, and the fraction, α, of N that decays into that particular daughter atom of interest by

$$N_D = N_{D0} + \alpha N\left[\exp\left(-0.693 \times \frac{t}{t_{1/2}}\right) - 1\right]. \tag{4.20}$$

Equation (4.20) is often divided by the number of atoms of a stable, abundant isotope of the daughter element, N_{Ds}, so that the number of daughter atoms produced by radioactive decay can be obtained relative to that isotope, by the techniques of mass spectroscopy. Thus, (4.20) may be rewritten

$$\frac{N_D}{N_{Ds}} = \left(\frac{N_D}{N_{Ds}}\right)_0 + \alpha\left(\frac{N}{N_{Ds}}\right) \times \left[\exp\left(-0.693 \times \frac{t}{t_{1/2}}\right) - 1\right]. \tag{4.21}$$

$$N_0 = N + N_D \tag{4.22}$$

and

$$N = N_0 \times \exp\left(-0.693 \times \frac{t}{t_{1/2}}\right), \tag{4.23}$$

where "exp" refers to the base of the natural logarithm system, $e = 2.71828\ldots$, and $t_{1/2}$ is called the *half-life* of the radioisotope, the time after which one can expect that half the atoms of N_0 will have decayed so that $N/N_0 = \frac{1}{2}$.

The most important of the radioisotope applications for archaeology is the measurement of the decay of the radioisotope of carbon, ^{14}C, with half-life of ~5700 y, which allows a rough dating of objects that contain carbon. ^{14}C is produced by several nuclear reactions, the most important being the interaction of neutrons with an atmospheric atom of nitrogen: $^{14}N + n = {}^{14}C + {}^{1}H$ (the neutron most likely originates from the interaction of cosmic rays with particles in the atmosphere, which produces cascading showers of particles; the cosmic ray flux oscillates over an 11-year cycle, reaching a minimum, "Forbush decrease," at solar cycle maximum). Minor fluctuations in the production of radioactive carbon may be determined by checking tree-ring dates against ^{14}C dates. The carbon may also be directly measured in the ice layers of the Greenland ice cap. In §6 and elsewhere, when we refer to ^{14}C dates, we will use "b.c." to indicate uncorrected and "B.C." to indicate corrected calendar dates.

As useful as it is, ^{14}C dating is not the only way. There are a variety of other, specialized techniques that may be useful in dating artifacts.

The Earth's magnetic field varies with time in both strength and direction, both of which may be used in dating. When iron-bearing rocks (often ferrous clays) are heated above the Curie point, the temperature at which the local magnetic domains in the material are free to align themselves along ambient magnetic field lines, they do so align themselves. As the material cools, the prevailing geomagnetic field is "frozen" in, creating a record of the geomagnetic field at that time. Thus, *archaeomagnetism* is a way to date fired sites, such as hearths and kilns, or buildings and even cities destroyed in conflagrations. The temporal variations in the direction of magnetic north and in the strength of the magnetic field allow the establishment of local chronologies wherever there are adequate samples that have been fired in place.

Another age-determining process that makes use of previously fired materials is *thermal luminescence*. In this technique, the pottery, fired flint, or hearth is reheated. Free electrons, which were released as a consequence of low-level radioactivity in the material, are trapped in the matrix material; the reheating permits recombination and interactions that result in light emission, the intensity of which is related to the time since previous heating.

One dating technique involves measurement of annual "rings" in glass materials due to the effects of sunlight on the glass surface. The formation of surface layers in glass is particularly important in dating artifacts made from obsidian, a naturally occurring glass of volcanic origin.

The development of styles of a historical sequence of pottery, weapons, jewelry, and other artifacts in association with certain layers of debris in an archaeological site provides a basic method of relative dating. A less exact method involves measurement of the degree of curl in archeologically recovered skins, including parchments. Although providing only rough dates, the technique is adequate to distinguish between medieval and Roman materials and was used to verify the age of the Dead Sea scrolls.

Altogether there are of the order of 70 archeological-geophysical techniques of dating objects and sites.

Finally, a linguistic technique, glottochronology, is useful in determining the history of the development of languages, sometimes correlated with archaeological evidence. The technique is based on the discovery that there is a statistically regular loss of vocabulary from a specified list of words in the basic vocabulary. This brief listing is intended to point out that archeologists now have a substantial body of techniques to determine dates.

4.4. Astronomical Dating of Artifacts and Cultures

There are two important astronomical quantities, the variation of which permits dating of artifacts and cultures to be carried out: the obliquity of the ecliptic, ε, which results in the variation of the maximum and minimum declinations of the Sun, Moon, and planets, and the precession of the equinoxes, which causes variation in the right ascension and declination of all objects in the sky, but most particularly affects the positions of the stars and constellations with respect to the vernal equinox. Precession has been discussed in §3.1.6, and its discovery will be described in §7.3; so we note here only that one of its effects is to cause the declinations of stars to change; this effect means that the azimuths of rise and set in the sphere of the fixed stars will vary with time in a systematic way and can yield dates of structures (or streets, like the *Avenue of the Dead* in the ancient Mesoamerican city Teotihuacan—see §12.21) that were aligned to them at the time of construction.

The variation in the obliquity of the ecliptic is slow, but the change is significant over millennia. The value of ε at any epoch is

$$\varepsilon = 23^\circ\!.439291 - 0.0130042 \times T - 16 \times 10^{-8} \times T^2 + 504 \times 10^{-9} \times T^3, \tag{4.24}$$

where $T = (t - 2000.0)/100 = (\text{JDN} - 2{,}451{,}545.0/36{,}525)$, t is the Gregorian date in years, and JDN is the Julian day

Thus, one may plot measured samples of the quantity on the left-hand side of (4.23) against α (N/N_{Ds}). The plot is a straight line with zero point equal to the relative initial abundance of the daughter isotope and a slope from which the time t, the age of the sample, can be calculated. Thus, for the decay of ^{87}Rb (a radioisotope of rubidium with half-life equal to 48.8 Gy) into ^{87}Sr, relative to the stable isotope of strontium, ^{86}Sr, the Soko-Banja chondritic meteorite is determined to have an age of 4.45 ± 0.02 Gy and an initial ratio, $^{87}Sr/^{86}Sr = 0.69959 \pm 0.00024$ (Minster and Allegre 1981, cited in Wasson 1985, p. 52).

number and decimal corresponding to that date. The variation of ε results in changes in the standstill declinations of both Sun and Moon. This in turn changes the *amplitude* of the azimuth variation (see §3.2.1). Therefore, if it can be assumed that the orientation of a certain structure was intended to be in line with the amplitude of the Sun, say, and if sufficient precision of construction can be assumed for the builders, then it is possible to provide a date for the construction. However, the variation in ∊ is not rapid; as noted in §2, the change amounts to ~7600 years/degree, or –0°.000 000 36/day. Lockyer (1894/1973, p. 113ff) had difficulty accommodating his alignment measurements to midsummer sunset with the range of dates assigned to the temple of *Amon-Re* at Karnak by the contemporary archaeologists, viz., 2400–3000 B.C., and preferred a date of 3700 B.C. Hawkins (1974, p. 161), however, notes that a rebuilding of the Hall of Festivals part of the temple at ~1480 B.C. by Thutmose III could accommodate an alignment with the sunrise of a midwinter Sun having a declination of –23°.9 ± 0°.2. We will return to the Egyptian alignments and the problems they raised again in §8.1.

The astronomical dating of structures is only one of several methods available to determine the dates of usage, as we noted in §4.3. Given the uncertainty in the motivation of the builders, it is most unwise to try to rewrite the archaeological record or the ethnological history of a people on the basis of alignments alone. On the other hand, when archaeoastronomy can be used in conjunction with other techniques, it may often substantially increase the precision of a date.

4.5. Causes and Effects of Secular Variation

4.5.1. The Slowing of the Earth's Rotation

The gradual slowing of the Earth is known from the geological record and from differences between the computed time of an event in the historical past and records from that time. The effect is cumulative. Suppose the length of the day were to be shorter by 1 second after 100,000 y. Then after only 4000 years, the decrease in the time for a complete Earth rotation would be 4000/100,000 = 0^s.04. From this, it follows that the time of day at which an event would occur 4000 years later would be different by several hours. The *average* decrease in daylength over the 4000 years would be (0.04 – 0.00)/2 = 0^s.02, so that after 4000^y, the cumulated "loss" over this interval would be 0^s.02 × 4000 × 365.25 = 29,400^s = 8^h.12. We can calculate the accumulation also as follows. If the Earth were slowing by 1^s per 100,000 years, every day it would slow at the average rate:

$$\frac{1}{(100{,}000 \times 365.25)} = 2.738 \times 10^{-8}\ \text{s/d}.$$

In n days, the accumulated loss of time in seconds would be

$$\begin{aligned}\delta T &= 2.738 \times 10^{-8} \times [1 + 2 + 3 + \ldots + n] \\ &= \tfrac{1}{2} \times (n + n^2) \times 2.738 \times 10^{-8} \\ &\approx 1.369 \times 10^{-8} \times n^2, \end{aligned} \tag{4.25}$$

where we make use of a series summation. The approximation sign arises because we have ignored the much smaller quantity $n/2$ term in the sum of the series 1 + 2 + 3 + . . . + n. In our example, n = 4000 × 365.25 = 1.461 × 10^6. Therefore, $\delta T \approx 2.92 \times 10^4$ seconds = 8.12 hours, over the span of 4000 years.

The cause of the long-term deceleration of the Earth's rotation is due to a number of circumstances, but principally due to (lunar) tidal friction. Before we discuss the effects of tidal friction, we must describe the origin of the tides, which were important to ancient navigators, as they are to navigators today.

4.5.2. Solar and Lunar Tides

Recall that the force of gravity depends inversely on the square of the distance, so that nearer objects are more strongly attracted to each other than are more distant objects. The Sun as well as the Moon exerts tides on the Earth, sometimes adding to create very large tides (the "Spring" tides, at new and full moon), and sometimes working 90° apart to create weaker tides (the "neap" tides, at 1st and 3rd quarter), but because the tide-raising force depends very strongly on the distance (the force varies as the inverse cube of the distance), the Sun's tidal effects are only half those of the Moon. In the Earth-Moon system, the side of the Earth facing the Moon experiences a stronger attraction than does its center, which in turn has a stronger attraction than has its far side. The result of this differential gravitational attraction is the creation of tides—one on the side nearer the Moon, and the other on the far side.[25] Early studies of the motions of the Moon may have been in part motivated by a need to predict the tides. See §6.2.2 for further discussion of the effects of the tides in the context of early cultures.

4.5.3. The Effects of Tidal Friction

If the movement of water on the surface of the Earth encountered no friction, the tidal bulges would remain along the Earth-Moon line as the Earth rotated beneath it. But there is friction, especially in shallow sea basins. This causes the tidal bulge of the Earth to be carried forward of the sublunar point by 2–3°, as Figure 4.12 illustrates (that is, the bulge *precedes* the Moon).

The Moon's gravitational attraction on the near-side tidal bulge of the Earth slightly exceeds that on the far side of the Earth. The result is that the Earth is very slightly braked in its rotation. At the same time, the nearer tidal bulge on the Earth accelerates the Moon forward in its orbit to a greater extent than the bulge on the far side retards it. This accel-

[25] As any navigator knows, the height and effects of "high water" and "low water," which occur roughly twice each as the Earth rotates under the Moon, are complicated by local currents, monsoon, or other seasonal occurrences, by the presence of local land masses, and by the shallowness of the water. For current purposes, however, this level of discussion will suffice.

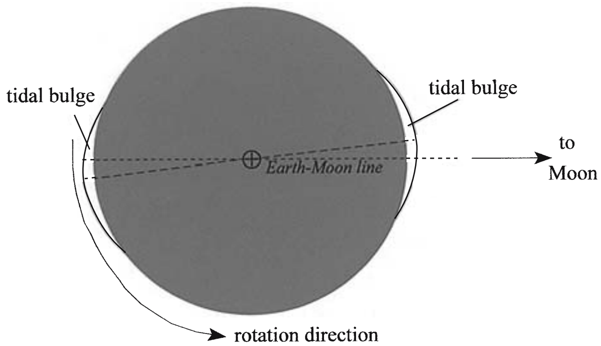

FIGURE 4.12. The tidal bulge is carried forward of the sublunar point by about 2° due to tidal friction. The direction of the Earth's rotation is shown as viewed from the north celestial pole. Drawing by E.F. Milone.

eration has the effect of increasing the Moon's distance (by an amount between 3 and 6 cm/year). As the Moon recedes, its mean angular motion decreases with time, and this slowing down causes departures from positions predicted from lunar and planetary theory. Thus the slowing of the Earth's rotation is accompanied by a slowing of the Moon's orbital motion. This affects the timing of events involving the Moon, and departures from predicted times of those events are observed (see §5 for descriptions of those events). From them, the rotation deceleration can be computed. The basis for the computation is the conservation of angular momentum. The angular momentum gained by the Moon is roughly lost by the Earth; however, the expressions are complicated by the friction involving the tidal effects of the Sun.

4.5.4. The Effects on Ancient Observations

The cumulative slowing of the Earth's rotation means that events in the far past actually occurred later than we would calculate them to have occurred on the basis of uniform time (see Figure 4.13 to understand how this happens). Although the computation of Earth's deceleration is determined from timed observations of lunar and planetary phenomena, observation of an event with a recorded local solar time provides an invaluable and necessary check. Indeed, there are other causes for rotation variation and the correction of mean solar to Ephemeris (now *Terrestrial*) Time depends on these empirical determinations.

Ancient eclipses are among the most useful events for checking the deceleration rate. The ancient lunar and solar eclipses used by several authors include Arabic, Greek, Babylonian, and Chinese sources; these are discussed in §5 in the context of eclipses; details of the eclipses are discussed in subsequent chapters in the contexts of the cultures in which the observational records were taken. This work has important consequences for historical studies: Chronologies are sometimes based on eclipse records, at least in part, so it is important to sort out what can be determined convincingly without using the very events that are to be calibrated! At this stage, we summarize the determinations of the deceleration.

The time difference, ΔT, between a uniform measure of time, effectively the "Terrestrial Time" (TT), and a measure of the moment of observation as given by the hour angle of the Sun at a specified location on Earth, the *Universal Time* (UT), is, in the notation[26] of Stephenson and Clark (1978),

$$\Delta T = TT - UT = b + c \times t - \frac{1}{2}\dot{e} \times t^2 \qquad (4.26)$$

where b and c are constants and $\dot{e}$ is a quantity called the deceleration parameter.[27] The quantity t is in Julian centuries measured from 1900 A.D., and ΔT is in seconds. Muller and Stephenson (1975) present the solutions of these data in which b and c are determined as well as $\dot{e}$. Their results (summarized also in Stephenson and Clark 1978) included the calculation of the lunar acceleration (the accelerations in the mean longitudes of the Moon, Sun, and Mercury were observed prior to the identification of the Earth's varying rotation), and in their notation are $\dot{n} = -37.5 \pm 5$ arc × sec/century^2, $b = +66^s.0$, $c = 120.38$ s/century, $\dot{e} = -91.6 \pm 10$ s/century^2 so that $= \frac{1}{2}\dot{e} \approx 40.8$ s/cy^2. Uncertainties are not given for b and c, but the combined result of short term variation of all terms aside from that due to tidal friction does not exceed $\pm 100^s$ (however, see below for evidence suggesting larger variation). In terms of relative change in angular velocity, where ω is the current angular rotation speed of the Earth,

$$\dot{\omega}/\omega = 3.17 \times 10^{-10}\,\dot{e} = -29.0 \pm 3 \times 10^{-9}\ \text{century}^{-1}. \qquad (4.27)$$

This corresponds to a rate of increase in the length of the day of $2.5(\pm 0.3) \times 10^{-3}$ s/century or 1 second in 40,000 years (recall our earlier example in which we assumed a rate of slowing of $1^s/100{,}000^y$). More recent work for the interval 700 B.C. to the present by Stephenson and Morrison (1995) suggests, however, that the slowing of the Earth's rotation has measurable variation, as evidenced by residuals to spline fittings, amounting to as much as 1000 s or more for specific, timed events (Stephenson and Morrison 1995, Fig. 6). They have revised estimates of the underlying deceleration. In particular, they (and others) have argued that action of tidal friction due to the Moon is, at present, partly offset by a negative (deceleration) term, the latter implying a speedup. With an adopted value[28] for the lunar acceleration, $\dot{n} = -26$

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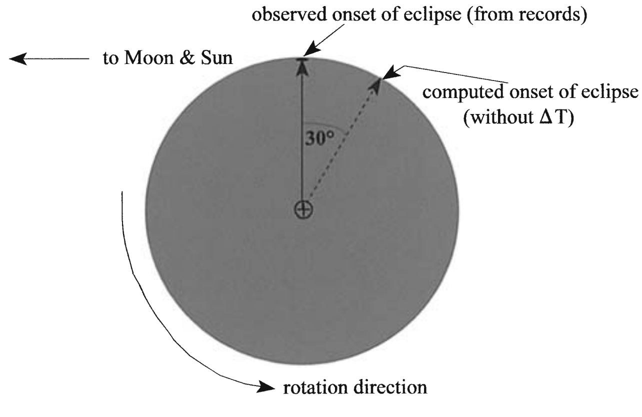
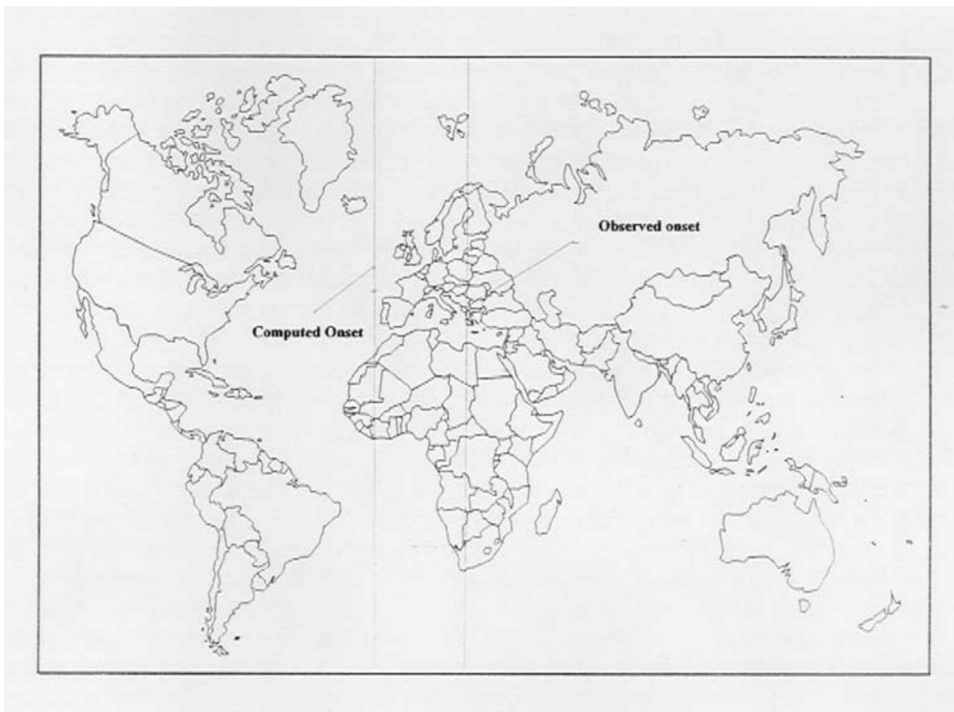
[26] The formula originally used Ephemeris Time (ET) rather than Terrestrial Time. The difference between ET and atomic time (TAI) was determined to be $32^s.184$ in 1984; the difference between the predecessor of TT (TDT) and TAI was also set at this value. Since then ΔT has increased (to ~85^s in 2004). See 4.1.1.2 for the relation between time and time intervals and Stephenson (1997) for a thorough discussion of the history of these different definitions of time.

[27] It should be noted that other works use different notation as well as different algebraic expressions. As a consequence, the coefficient of T^2 is sometimes called "c" with values of $\sim\frac{1}{2}\dot{e}$. Note that, in this context, e is neither an eccentricity nor an ellipticity.

[28] A value borne out by more recent determinations, such as that of Dickey et al. (1994), -25.88 ± 0.5 arcsec/century^2. A lunar acceleration of -26 arcsec/cy^2 results in a recession of the Moon from the Earth of 3.86 m/century, and an increase in the length of the month of 0.038 s/cy. See Stephenson (1997) for a much more complete discussion of the methods used to get these values.



(a)



(b)

FIGURE 4.13. The slowing of the Earth's rotation means that events in the distance past occurred later than calculated, and eclipses are seen at more easterly sites, under the assumption of uniform time ($\Delta T = 0$). Here, we depict the longitude shift of January 14, 484 A.D., as seen from space at the onset of the eclipse (at sunrise) in two ways: (a) a Polar sketch (drawing by E.F. Milone) and (b) Mercator view sketch (map from Liu and Fiala 1992 software; modified by E.F. Milone).

± 0.5″/cy² [based on Williams, Newhall, and Dickey, 1992 (25.9 ± 0.5″/cy²); Christodoulidis et al. 1988 (–25.27″/cy²)], Stephenson and Morrison (1995, p. 170) found a slowing of the Earth due to tidal friction alone of 2.3 ± 0.1 millisec/century (*ms/cy*), resulting in an accumulation

$$\Delta T_{tidal} \equiv TT - UT = q_T t^2 = +42(\pm 2) \times t^2 \text{seconds}, \quad (4.28)$$

where t is in centuries measured positively from 1800.

From Babylonian and other data, Stephenson and Morrison (1995, pp. 188–193), revise their preferred value for the observed ΔT to

$$\Delta T = +31.0(\pm 0.9)t^2 s, \quad (4.29)$$

which implies a rate of change of the length of the day of +1.70 ± 0.05 ms/cy. Because +2.3 ms/cy is the expected rate from tidal friction, the difference, –0.6 ms/cy, suggests a source of speedup. It is probably not due to variation in tidal friction in the "shallow seas" and deep ocean basins, where the friction supposedly has its greatest effects, because the average ocean depth over the past 2700 years has not varied by more than an estimated 1–2 m, and the areas of both deep oceans and shallow seas have remained approximately steady over that time. One possible source is a change in the Earth's oblateness as the Earth changes shape in response to the "post-glacial rebound" of melting ice sheets built during the last ice age. Studies of the orbital perturbations of artificial satellites suggest a change in the J_2 zonal harmonics term that describes the Earth's shape; this in turn implies a deceleration of –0.44 ± 0.05 ms/cy (the negative sign indicating a speedup). Further residuals in their fittings of Babylonian, Chinese, Arab, and European data lead Stephenson and Morrison (1995, p. 199) to conclude that there are periodic fluctuations of ±4 ms over a period of ~1500 y. These fluctuations provide a limitation on the usefulness of ancient records. We will continue the discussion of the importance of the determinations of ΔT in the context of eclipses in §5.2.1.3.

The periodicities of the diurnal motions of the stars and other objects and of the "wandering" motions of the Sun, Moon, and planets have been our main concern until now. Knowledge of the motions of both Sun and Moon leads to an understanding of eclipses, a subject to which we turn in Chapter 5. In §5.8, we describe variations in brightness among the stars, random as well as complex periodic effects, and the impacts these phenomena have had on the ancient world, and thus on ours.

5 Transient Phenomena

By *transient phenomena*, we mean impermanent effects or variable events in the sky. They range from atmospheric effects like the "green flash" to "guest stars," the ancient Chinese expression for novae or supernovae. Many ancient astronomers did not distinguish between astronomical and meteorological phenomena. For the Greeks, the distinction between the "lunar sphere," and the atmosphere ("sub-lunar") did not prevent Aristotle from assigning comets to the latter realm. They were, after all, transient objects, and in his view, clearly out of place in what he considered to be a perfect, changeless realm. This error, as well as the nearly general acceptance of the geocentric universe, can be laid primarily if not exclusively to a lack of parallax measurements of adequate precision. Although the measurement of parallax of even the nearest stars is beyond the capability of naked eye astronomy,[1] the parallax motions of comets were not, since Tycho Brahe (1546–1601) carried out a successful determination of the parallax of the comet of 1577 without the benefit of telescopes or photographic images. Much criticism has been leveled at ancient Greek astronomers for placing too little reliance on observation, and too much on preconceived notions, such as the perfection of the sphere and of spherical motion and the heavens as illustrating that perfection. Much of this is justified; yet, there were important exceptions, such as the careful observational work of Timocharis (~3rd century B.C.) and his school in Alexandria, of Eratosthenes who determined observationally the size of the Earth, and of Hipparchos, whose star catalog and theories of the Sun and Moon were founded on observation (see §7.2). In fact, in Hellenistic times, early eclipse and occultation observations were highly valued and aided the discovery of precession. These data are still of interest today, as are ancient observations of the Sun's activity and even its size. Eclipses were studied and predicted to some degree in several areas of the world. In general, variations of heavenly objects were carefully observed and recorded, especially when they were spectacular. Such events held then, as they hold now, intimations of the nature of the universe and of our place in it.

[1] The parallax of even the closest stars beyond the Sun, the triple star system α Centauri, is less than 1 arc second. The first successful stellar parallax determination was made in the 1830s. F.W. Bessel (1784–1846) measured the parallax of 61 Cygni; T. Henderson (1798–1844) measured that of α Centauri; and F.G.W. Struve (1793–1864) measured that of Vega.

5.1. Atmospheric Phenomena

5.1.1. Auroras

The *aurora* is a phenomenon widely experienced by people of high latitudes, although occasionally seen much closer to the equator. In the Northern Hemisphere, we call it the *Aurora Borealis* (or *Aurora Polaris*), "Northern Lights," and in the Southern Hemisphere, the *Aurora Australis*. The pale light, with its suggestions of blue, green, and sometimes red color, displays a variety of forms from pulsating parallel stripes to shimmering curtains (cf. Figure 5.1 for a particularly striking example).

The name derives from the Roman goddess of dawn, *Aurora*, corresponding to *Eos* in Greece. Her father, according to Hesiod,[2] was the titan Hyperion, and among her children were the winds *Zephyrus*, *Notus*, and *Boreas*; Hesperus, the evening star; and the stars. In Homer's epic poems (e.g., the *Iliad*, Ch. 1) dawn is rosy-fingered, and is driven out of the east every morning in a horse-drawn chariot.

The Aurora could hardly have been missed by ancient observers, although they could not have had any idea of its true nature. It was not clearly recognized as a unique phenomenon in China (for good reasons, as we indicate later) and so had many names, such as "coloured emanations,"

[2] Hesiod probably flourished in the 8th century B.C. and was reputedly from Boeotia, Greece.

FIGURE 5.1. The Aurora Borealis, as captured by Prof. J.S. Murphree, at Fort Yukon, Alaska: The exposure was 1/2s with 400 ASA Ektachrome slide film. Courtesy, J.S. Murphree.

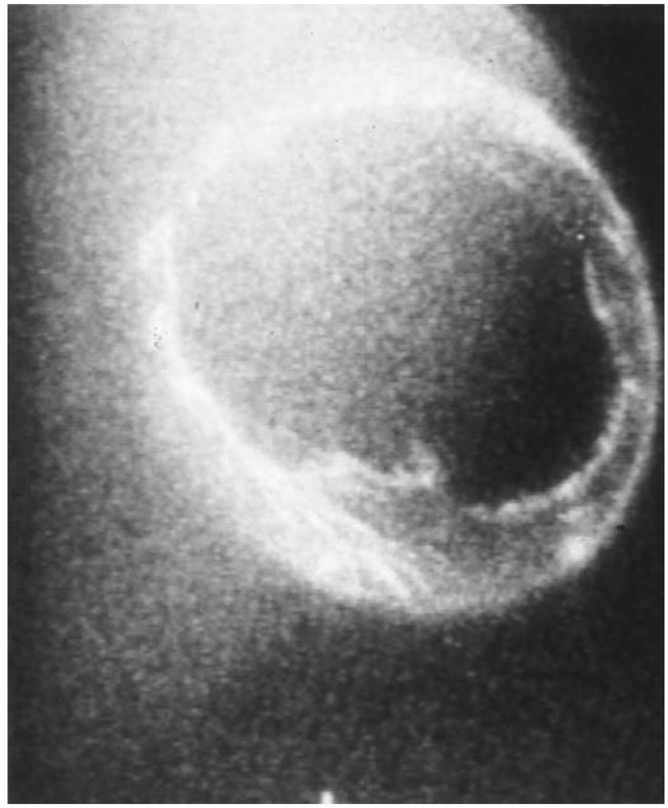


FIGURE 5.2. A Viking satellite view of the auroral oval, visible on the dark side of Earth, but present on the sunlit side as well. Courtesy, Space Science Group of the University of Calgary, from research sponsored by the Canadian Space Agency.

"strange lights," "red vapour," "north polar light," and "cracks in the heavens" (Needham/Ronan 1981, p. 233). The "Historical Record," *Shih Chi*, refers to them as "vapours." Pang et al. (1988) suggest that the phrase "the sky rained blood," found in both ancient European as well as Chinese texts, is a description of a "Type *A* Red Aurora," which has a deep "blood-red" color (see Stothers 1979). Of the five types of color patterning, three involve red colors (A, B, and D), but only one is entirely red—type D. See Davis (1992) for descriptions and photographs of each type. The phenomenon is often shrouded in folklore and myth; so a detailed description of its physical properties is appropriate.

The aurora is caused by the interaction of energetic, charged particles with the Earth's upper atmosphere. The bulk of the charged particles, which are mostly electrons and protons, originate in the Sun and are expelled in a "solar wind'; they are normally deflected by the Earth's magnetic field, sometimes into separate toroidal regions of electrons and protons several thousand kilometers above the Earth's surface. These radiation belt regions are together known as the *Van Allen belts*, after their discoverer, James A. Van Allen (1914–). After a large influx from the Sun, the particles may be "dumped" into the Earth's upper atmosphere along a broad annular region (the *auroral oval*) close to the geomagnetic poles.[3] Thus, it is mainly a high-latitude phenomenon. Although satellite photographs reveal that aurorae are nearly always present at some level of brightness (cf. Figure 5.2), increases in auroral activity occur with "gusts" in the solar wind, which is the rain of charged particles that is constantly evaporated from the outer atmosphere of the Sun. Solar flares can produce dramatic effects when the energetic ions emitted during these eruptions reach the Earth because they trigger *substorms*, resulting in large-scale dumping into the upper atmosphere. Collisions cause ionization and excitation of atmospheric atoms and ions, and these interactions lead to light emission. The color comes from the species of ions or atoms that are doing the emitting; the numbers of the different species[4] vary with height (as well as time) in the atmosphere—and so does their contribution to the light. The ions are constrained by lines of magnetic force, but can in turn alter them if sufficiently energetic. This accounts for their many curious patterns: rippling curtains, pulsating globs, traveling pulses, and many others. The aurora can vary in height from just below 100 to ~1000 Km, with maximum emission typically coming from

[3] The positions of the magnetic poles vary somewhat irregularly with time over several hundred kilometers. The Northern geomagnetic pole is currently in western Greenland; the Southern, near Tasmania. The auroral oval is located at about 23° from this point and has a width of less than ~1000 km. A further discussion of the effects of the changing geomagnetic field and its uses in archeological dating is given in §4.4.

[4] The most important contributors of emission lines are the atomic and molecular forms of oxygen and nitrogen; lesser contributions come from hydrogen, sodium, calcium, and other constituents of the upper atmosphere.

about 110 Km. Thus, the area of its visibility on the Earth's surface can vary greatly.

The occurrence of aurorae is regulated by the 11-year sunspot cycle (see §5.3.1). The numbers of sunspots vary with time, and as they increase, so does the frequency of spectacular aurorae. Consequently, there is both a seasonal and a long-term cyclicity in the appearance of the aurorae, but they are seen even at solar minimum, when sunspots are infrequent or even absent. In addition, the long winter nights of the high-latitude sites (where the aurorae are more frequent) make the phenomenon more visible in the winter. The Royal Navy's overland Arctic Land Expedition of 1820/1821 in northern Canada had among its duties the study of the Aurora Borealis. They recorded frequent auroral occurences (the journal of John Richardson, Richardson Houston, ed. 1984), despite the circumstance that the solar cycle was then near a minimum (Parker 1978, p. 20).

The North American Inuit, from Greenland to the Bering Strait, traditionally regard the aurora, which they describe as *aqsarniit* ("football players"), as the spirits of the dead who are playing football with the head of a walrus (MacDonald 1998, pp. 146–156). Such a description captures adequately both the relatively quiet and the rapid movements of the auroral streamers, the motions of which seem remarkably unpredictable although constrained by magnetic field lines. See §13.6 for a broader discussion of Inuit astronomy.

5.1.2. The Green Flash

The *green flash* refers to any of several types of atmospheric phenomena involving the color of the rising or setting Sun. They are brought about by a combination of refraction, absorption, and the dispersive action of the atmosphere. It is related to the phenomenon of *wedge refraction*, in which telescopic images of stars near the horizon are seen to be tiny spectra (see §3.1.3). The atmospheric refraction bends starlight upward toward the zenith, but the index of refraction for bluer wavelengths is slightly greater than that for the red so that the blue starlight is raised slightly higher. A similar situation holds for the Sun: The most violet spectral component of sunlight is scattered away by atmospheric molecules ("Rayleigh scattering," see §3.1); but of the remaining light, the blue-green images of the Sun are lifted higher than are the yellow-red images. Minnaert (1954, p. 63) reports that the Moon, Venus, and Jupiter have exhibited the same phenomenon. Some mythological references suggest the possibility that the green flash was observed and noted by ancient groups.

The frequency of the green flash phenomenon depends on the viewing location. The green flash is a relatively rare naked eye phenomenon, but telescopically it is more frequent. DHK saw it only a few times during a year at the Blue Hill Meteorological Observatory, Massachusetts, using only the naked eye. It is easiest to see over a sea horizon, and some optical aid (projected or carefully filtered to avoid temporary insensitivity or blindness) is a prudent precaution. EFM has had the most success at spotting the green flash telescopically from Mt. Lemmon, an 8000-foot mountain northwest of Tucson, Arizona, where the setting sun is seen at a fairly large dip angle. O'Connell (1958) suggested that visibility depends on (spatially resolved) patches of air of higher density momentarily enhancing the refraction of the bluer portion of the spectral image of the Sun; with this explanation, because telescopes increase spatial resolution, even weak effects can be observed. The transient density enhancement theory is disputed, however, by Young and Kattawar (1998), who provide a more detailed explanation. See also §3.1.3 and Young et al. (1997) for a discussion of the green flash in the context of what these authors call a "mock mirage," an inverted overlying image, commonly seen by the naked eye in the setting Sun.

5.1.3. Rainbows and Mists

Rainbows are produced by the collective effect of the refractive properties of molecules of water vapor in the atmosphere. Sunlight entering a water vapor droplet is refracted by differing angles depending on the wavelength. Consequently, the refraction produces a dispersive effect within the droplet, and after an internal reflection, the light leaves the droplet in that dispersed state. In principal, any luminous white light source can produce a rainbow, but the brightness, contrast, and scale of the phenomenon limit the sources to the Sun and the Moon.[5] The center of the rainbow arc is opposite to the Sun in the sky and so, at any particular site, the effect is limited to particular ranges of the eastern or western horizon. The radius of the rainbow from the anti-solar point depends on wavelength. The violet has a radius of 40°; the red, 42°.

In addition to the primary rainbow, at a radius of 41° from the anti-solar point, a fainter secondary rainbow can sometimes be seen at a radius of 51° from this point. Whereas the primary rainbow is caused by light paths undergoing a single internal reflection inside a raindrop, the secondary bow is caused by paths undergoing two internal reflections. Figure 5.3 shows the light variation on either side of the rainbows. Note the reversal of the spectra in the secondary bow.

A much fainter tertiary rainbow, caused by three internal reflections, is located much closer to the Sun: 40°.33 centered on the Sun, but is unlikely to be observed with the naked eye because it is so dim.

The same phenomenon can be seen in the mists surrounding waterfalls; the association of the rainbow with life-giving water is absolute. To an ancient society grateful for rain, the rainbow must often have been looked upon as a sign of divine beneficence; it is referred to as a sign of a divine covenant in Genesis 9:9–17. Rainbow deities are found in many ancient cultures, and the presence of the rainbow in mountainous areas where orogenic clouds are

[5] Greenler (1980/1991) cites a photograph of a moonbow by William Sager who reported that it appeared white to him when he took the photograph, but appears as a colored bow in the photograph. Such a phenomenon can be understood in terms of the lower color sensitivity of the eye in low illumination conditions.

(a) (b)

FIGURE 5.3. Arcs of the same primary and secondary rainbows, seen from Calgary, summer 1997. Photos by E.F. Milone.

common provides an association with sacred places (see §5.1.5).

Among the Inuit in Igloolik, NWT, a rainbow complete to the horizon is the *kataujak* ("entrance to an igloo"). In traditional Inuit cosmology, the Sun and the Moon "rest" on the rainbow (Spencer 1959, p. 258; cited in MacDonald 1998, p. 159). A myth widespread among west coast Indians and Inuit involve a sister and brother or wife and husband who rise to the sky along the rainbow and become the Sun and Moon, respectively (see §13).

Other striking atmospheric phenomena involving fog or mists are the *Heiligenschein*[6] (Figure 5.4) and the "Spectre of the Brocken".[7] Both phenomena are clearly linked to the Sun. Ample illustrated discussions can be found in Minnaert (1954), Meinel and Meinel (1983), and Greenler (1980/1991).

5.1.4. Halos

In cold weather conditions, water droplets will usually freeze into ice crystals before rainbows can be observed (the

[6] A halo or aureole seen around shadows. It is due to total reflection in dew (best seen on certain types of grasses) or mist (Minnaert 1954, pp. 231–234). Figure 5.4 was obtained against a steaming fumarole in Yellowstone Park. The Heiligenschein is sometimes seen around balloon and even airplane shadows by passengers. The phenomenon must be viewed directly opposite the Sun for visibility.

[7] This phenomenon is the projected shadow of the viewer against a dense mist. Again, the Sun or other bright light must be directly behind the viewer (Minnaert 1954, p. 259). The shadow is greatly magnified, increasing with angle from the Sun-viewer line of sight. The resulting impression is that of a mountain, with the viewer's head as the peak! Black (1954) describes an example from the Grand Canyon in Arizona. The *Fo kuang*, "Buddha Light," reported in mountains in China (Franck 1925, p. 579, cited in Needham 1959, Vol. 3, p. 477; see also Needham, Figure 261 on p. 596), has been called an analogous phenomenon.

exception may be near waterfalls or unusual temperature gradient conditions). The presence of upper atmosphere ice crystals produces some interesting phenomena that are associated with the Sun or Moon. Halo phenomena are familiar sights at high latitudes. Among them are *parhelia* or *sundogs*, so called because they follow the Sun across the sky. If the crystals, found in high cirrus clouds, for example, are sufficiently widespread and randomly oriented, a complete circle can be seen around the Sun. The radius of the circle, caused by the prismatic effect of rays of sunlight passing through two sides of the hexagonal faces of elongated ice crystals, is ~22°. A fainter circle can be seen at 46°, caused by rays of sunlight passing through two faces 90° apart, at the ends of the elongated crystals or in flattened "plate" crystals (see Greenler 1980). The dispersive effects cause a rainbow-like effect, but with lower color contrast because of the proximity to the Sun. Because the phenomenon involves local atmospheric conditions, it affects primarily high-latitude, winter sites (see Figure 5.5). Similar effects can be seen around the Moon (*paraselenae*), especially the full Moon (Figure 5.6). Sometimes, convex and concave arcs may be seen adjoining or radiating from the parhelia circles, which depend on special orientations of the ice crystals. A related effect is the vertical ice column that is sometimes seen above lights viewed through ice fog (Figure 5.5 shows this line as well as other aspects of "sundog" phenomena).

FIGURE 5.4. "Heiligenschein" around the shadow of the photographer amidst steam from a fumarole, Yellowstone, Wyoming. Photo by E.F. Milone.

Inuit art sometimes depicts the phenomenon of multiple Suns, usually in a vertical line. The vertical column is

(a) (b)

FIGURE 5.5. (a) A vertical Sun column. Photo By T.A. Clark. (b) Sundog phenomena, including a vertical column of "multiple" Suns, due to the refractive effects of ice crystals in the air. Photo by E.F. Milone.

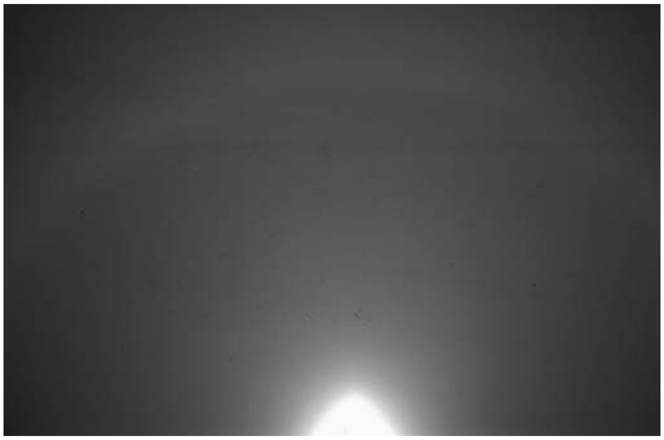


FIGURE 5.6. Lunar halo. Photographed in Calgary by E.F. Milone.

referred to as the "Sun's walking stick" among Inuit in Alaska (MacDonald 1998, p. 158), and a (horizontal) pair of mock Suns have been described as "crutches," to support the Sun when a gale is approaching (Jenness 1922, p. 179; cited in MacDonald). A ring around the Sun is called the "drum of the Sun" (such as is used in the "festival house" for ceremonies). There is a possible instance of the vertical Sun being used as a winter solstice marker in Mesoamerica at Teotihuacan (see §12.22).

In the manuscript "Essays on Astronomical and Meteorological Presages" (*Thien Yuan Ye Li Hsiang I Fu*) by the Ming emperor Chu Kao-Chih in 1425 A.D., solar halos are declared to signify important matters of state: the defeat of an army or a conspiracy of ministers (Needham and Ronan 1981, p. 229). Illustrations from the manuscript depict the "conspiring ministers" as sundogs.

In Polynesia, there is evidence for a conceptual linkage between the 22° and 46° halos and the maximum elongations of Mercury and Venus, respectively, although Mercury's elongation varies between 10 and ~28° (see §11.4).

Finally, Stephenson (1990) uses the irregular distribution of solar halo and other reports in Chinese and Korean records from 1 A.D. to 1649 A.D. to cast doubt on the reliability of auroral and sunspot reports to indicate solar and geomagnetic activity over this internal.

5.1.5. Precipitation

We end this section on atmospheric phenomena with some general comments about the connection between weather phenomena and ancient astronomical work.

The "rainy Pleiades" refers to a Greco-Roman way of deciding the proximity to the rainy season, marking an appropriate time for planting crops. An equatorial star chart with the ecliptic marked on it shows that the Pleiades set *cosmically* in the fall. This is the meaning of the phrase from Hesiod: "plough, when they go down," because rains are imminent. [*Works and Days*, Wender tr., 1973, p. 71]; but refer back to §2.3.1 for a *heliacal* setting case.

A connection between the annual flooding of the Nile and the heliacal rising of the star Sirius was made in ancient Egypt. A main concern of ancient astronomy was the establishment and use of calendrical indicators, such as the noon altitude or azimuth of the Sun on the horizon, and the cosmical or acronychal risings or settings of seasonal marker stars.

In some localities, the frequent occurence of clouds over high-altitude mountain peaks must have impressed the devisers of cultural myths profoundly. At places such as Mt. Olympus in Greece and, perhaps, Superstition Mountain in Arizona, the rush of a cool downdraft, the flash of lightning, and the following angry roll of the thunder became signs of the presence of the gods. Rudolf Otto (1958, p. 126) speaks of a "primal numinous awe" that mark "holy" sites as separate from many other sites, regardless of the animistic beliefs of the cultures concerned. In the Book of Exodus (19:12;16, King James ed.), Mt. Sinai seems to fulfil these conditions:

> And thou shalt set bounds unto the people round about, saying, Take heed to yourselves, that ye not go up into the mount, or touch the border of it: whosoever toucheth the mount shall be surely put to death. . . .
>
> And it came to pass on the third day in the morning, that there were thunders and lightnings, and a thick cloud upon the mount, and the voice of the trumpet exceeding loud; so that all the people that was in the camp trembled.

5.2. Solar and Lunar Eclipses

5.2.1. Eclipse Phenomena

Few heavenly sights are as spectacular as a total solar eclipse, and the awe in which it was held in antiquity provided both a powerful drive to study its predictability and a potent political instrument for those who knew something about it. Lunar eclipses too have inspired awe. Assyrian examples of both types will be given in §7; here, we present a few examples from ancient Greece.

Herodotus (b. Halicarnassos ~484 B.C.) mentions an event predicted by Thales in connection with a battle between the Medes and the Lydians (see §5.2.2 below) in which day was "changed into night."

Thucydides [Athens; ~460–~400 B.C.] cites a lunar eclipse in connection with the invasion of Syracuse by the Athenians in 413 B.C. and their subsequent disastrous defeat.

Prior to the fateful battle of Arbela (Gaugemela), in 331 B.C., between the armies of Alexander the Great and Darius, a lunar eclipse caused panic among the Macedonian troops. Quintus Curtius Rufus in *The History of Alexander* (Yardley tr. 1984, p. 73) wrote,

> First the moon lost its usual brightness, and then became suffused with a blood-red colour which caused a general dimness in the light it shed. Right on the brink of a decisive battle the men were already in a state of anxiety, and now this struck them with a deep religious awe which precipitated a kind of panic.

Alexander consulted Egyptian seers, whom he regarded as astronomical experts, about the meaning of the phenomenon. Curtius Rufus (Yardley tr. 1984, p. 73) says of them,

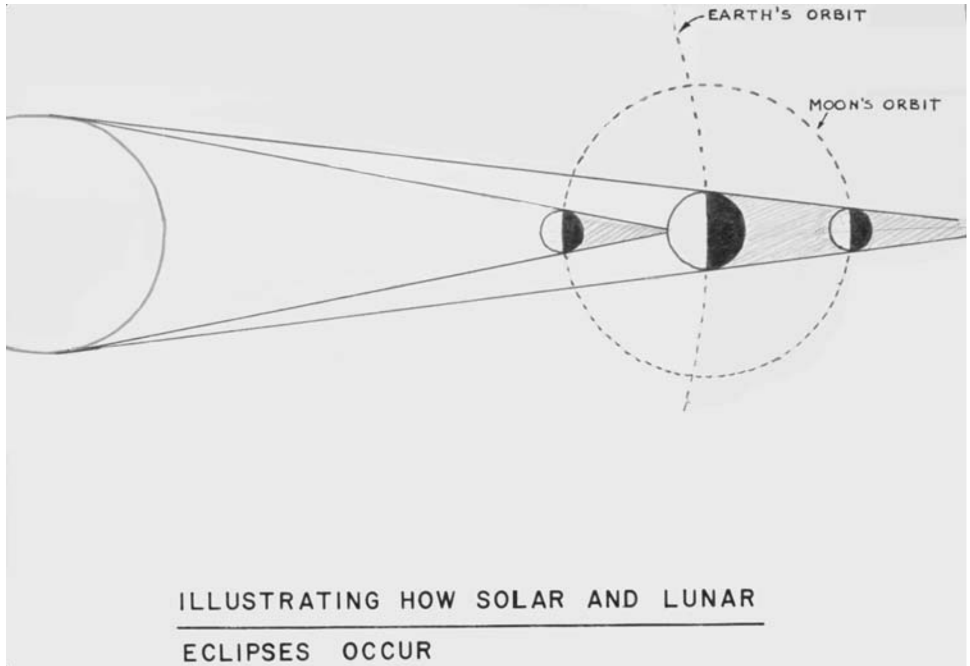


FIGURE 5.7. The basic geometry of solar and lunar eclipses: Eclipses are due to the incursion of the Moon into the cone defined by the cross-sectional outlines of the Sun and the Earth. Diagram and slide, courtesy Dr. D.J.I. Fry.

> They were well aware that the annual cycle follows a pattern of changes, that the moon is eclipsed when it passes behind the earth or is blocked by the sun (sic), but they did not give this explanation which they themselves knew, to the common soldiers. Instead they declared that the sun represented the Greeks and the moon the Persians, and that an eclipse of the moon predicted disaster and slaughter for those nations. They then listed examples from the history of Persian kings whom a lunar eclipse had demonstrated to have fought without divine approval.

Most lunar eclipses are not as impressive, especially when they are deprived of ascribed astrological significance, but no one can forget the sight of a total solar eclipse. It demonstrates the existence of powerful forces at work in the heavens.

In both lunar and solar eclipses, one body passes within the shadow cone of another (see Figure 5.7). Both for lunar and solar eclipses, also, the extent of the eclipse is called the *magnitude* of the eclipse. For lunar eclipses, it is the fraction of diameter of the Moon obscured by the shadow of the Earth. For solar eclipses, it is the fraction of the Sun obscured by the Moon. Because the geometries of the eclipses are slightly different, we describe them separately.

5.2.1.1. Solar Eclipses

Well before a solar eclipse reaches the stage of totality, the light at the horizon is noticeably different, as the distant shadow makes its way over the landscape. The Sun begins to disappear as a dark lune or crescent encroaches on it from the west: The dark lune waxes as the Sun's disk wanes. As the eclipse progresses, the air feels suddenly chilled, even on a warm day. The wind may come up, and clouds may form. As the sky darkens, birds stop singing and fly to their nests, dogs howl, and people in many cultures around the world make noise to frighten away whatever it is that menaces the Sun. As the solar crescent thins, a bright point on the limb may create the "Diamond Ring" effect. The last gleams of sunlight ("Bailey's Beads") appear to sparkle at the Moon's eastern limb, and the landscape seems to be filled with flickering shadows (the "shadow bands"). Suddenly, only a halo of light—the solar *corona*—can be seen surrounding a black disk. At this time, the stars, planets, and perhaps even one or more comets will be visible. Within minutes, the Sun's light emerges from the western limb, and the process is reversed. The solar crescent waxes as the dark disk wanes and the Sun returns to warm the world of the viewer. The reasons for the terror that a solar eclipse evokes involve not only the physical effects, which are evidently shared by other species, but also cultural cosmological frameworks. We will discuss these further on a culture by culture basis in Part II.

The outer atmosphere of the Sun is revealed during an eclipse. The visible disk of the uneclipsed Sun reveals the *photosphere*, a physically thin region of the solar atmosphere from which the bulk of the optical light is contributed. It is overlain by two other regions—the *chromosphere*, an even narrower, reddish region seen prominently during total solar eclipses and the appearance of which has been likened to that of a prairie fire, and the *corona*, a region extending to several photospheric radii. The corona is composed of very hot gases, ions, and dust; it provides the pearly white light and plumed extensions so familiar in eclipse pictures. See Figure 5.8.

The intensity of the remaining light is ~10^{-6} to 10^{-7} of the unobstructed Sun. When totality does not occur, so that the Moon does not cover the Sun completely, the chromosphere and the corona are not seen. A classic reference may provide a description of the appearance of these layers: Plutarch [46–120 A.D.] noted that "Even if the Moon . . . does sometime cover the Sun entirely, the eclipse does not have duration or extension; but a kind of light is visible about the rim which keeps the shadow from being profound and absolute" (*The Face on the Moon*, in *Moralia*, XII, tr. Cherniss, in Cherniss and Helmbold 1957, p. 121). Cherniss (p. 11) challenges the interpretation of this passage as a description of the upper solar atmosphere. He suggests instead that if Plutarch was describing an observed phenomenon at all, the passage is more likely to refer to an annular eclipse. If that is so, the choice of words in the phrase, "does sometime cover the Sun entirely," would seem to require some explanation.

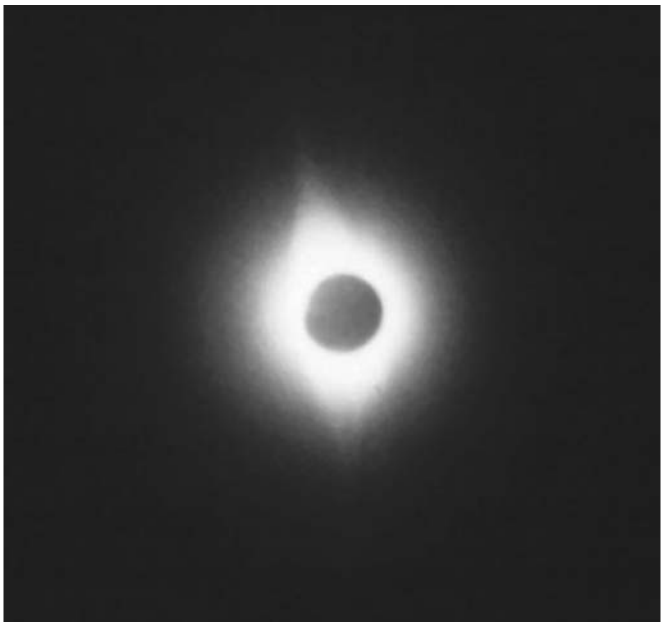


FIGURE 5.8. The solar eclipse of October 24, 1995, seen in Lopburi, Thailand, revealing the outer atmosphere of the Sun. A 70-mm lens photo by E.F. Milone.

Plutarch also discusses eclipses as portents in his *Lives*, usually arguing that the eclipses were nothing of the kind (Brenk 1977, pp. 28–48) and using such accounts to deprecate astrology and to extol astronomy. Plutarch may have witnessed an eclipse (*The Face on the Moon*, p. 117), identified by Ginzel (1899) as that of Mar. 20, 71 A.D., visible in Plutarch's town of Chaeronea. However, Sandbach (1929), assuming it to be in either Rome or Alexandria, identified the eclipse with that of Jan. 5, 75 A.D. or Dec. 28, 83 A.D., respectively. All fail the condition cited in this dialogue by Lucius, as starting "just after noonday." Stephenson and Fatoohi (1998), using ΔT values of Stephenson and Morrison (1995) and of Stephenson (1997), conclude that the 71 A.D. eclipse, with magnitude 99.5% at Athens, is the most likely.

Solar eclipses occur when sunlight is blocked out by the Moon: when the observer comes to be inside the Moon's shadow. Figure 5.9 illustrates the geometry and shows the distinction between total and partial phases as viewed at the same site but at different instances of time. A solar eclipse will be total where the disk of the Sun is completely covered by the Moon. Owing to the closeness in size of their apparent or angular diameters, at any instant, this can occur only over a narrow region on Earth, from zero to several hundred kilometers across. Partial eclipses are seen outside the umbral zone, and at all points along the path of totality as well except during the moments of totality. The penumbral zone or area of partial eclipse can be 3000 km or more on

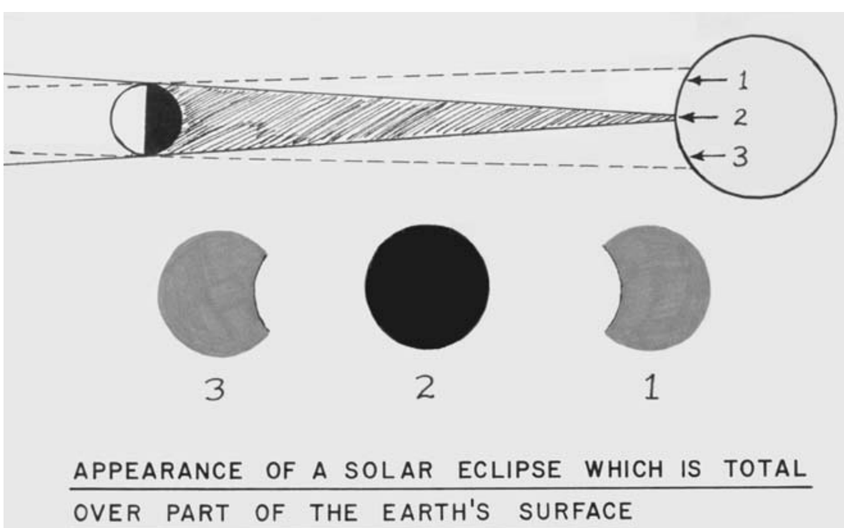


FIGURE 5.9. Solar eclipses occur only when the Moon is new and moves across the line joining the Sun and the Earth. Illustration courtesy Dr. D.J.I. Fry.

either side. The totally eclipsed area at any instant is oval, not circular, because of the projection of the shadow cone onto the curved surface of the Earth.

Seen from a particular site, a total eclipse begins with the instant of "first contact"—the onset of the eclipse, when the Moon starts to obscure the western limb of the Sun. The partial eclipse state that follows extends for as much as an hour or more. The instant of second contact is the onset of the total phase—when the Sun's disk is completely obscured. Third contact marks the end of the total phase; this is followed by a lengthy partial phase until fourth contact—the end of the eclipse, when the eastern limb of the Sun becomes fully visible. Around the moments of second and third contacts, a series of bright and dark shadows, the *shadow bands*,[8] sweep over the landscape at high speed.

The speed at which the shadow moves across the landscape is surprisingly large. The motion of the Moon in its orbit is more than 3000 km/hr eastward, the same direction in which the Earth is moving beneath it at up to 1500 km/hr.[9] The net motion of the shadow, with respect to a point on the ground, is eastward at more than 1500 km/hr. This means that the duration of the eclipse is short, less than 7½ minutes at most, and usually much less.[10]

The shadow cast by the Moon must, however, reach the Earth for the eclipse to be seen as total. If the Moon is too far away, the zone of totality (the *umbra*) does not reach Earth. In some cases, even on the central track, totality is not achieved because the Moon is far enough from the Earth that it has a smaller angular diameter than does the Sun. Such an eclipse is called an *annular* eclipse, because the result is to produce an annulus or ring at maximum obscuration. If the annular eclipse is central, there are four times of contact analogous to those for total eclipses.

Solar eclipses must occur when the Moon is new, but they do not occur every month because of the character of the lunar orbit. If the line joining the centers of the Sun and Moon does not intersect the Earth's surface at all, the eclipse can only be partial. If the line does intersect the Earth's surface but the Moon is far enough away so that the umbral shadow does not reach the Earth's surface, the eclipse will be annular. The partial eclipse zone or *penumbra* on the Earth's surface is always more extensive than is the umbra, which is confined to a narrow track, and may be absent altogether. Next, we discuss the determining conditions of an eclipse.

In §§3 and 4, we discussed the nature of the lunar orbit and the different periodicities of the Moon's motions. The inclination of the Moon's orbit to the ecliptic means that eclipses can occur only when the Sun and Moon are close to a node, or crossover point, where the Moon's orbit crosses the ecliptic (Figure 5.10).

An eclipse will be seen somewhere on Earth if the Sun is within a certain range of the node on the ecliptic, the *ecliptic limits*. The solar ecliptic limits are ~±17° for partial and ~±11° for total solar eclipses. These values vary because the angular sizes of the Sun and Moon vary with the distance to the Earth and because the inclination of the Moon's orbit varies slightly. See Figure 5.11 for illustrations of the eclipse limits and one source of their variations. The largest ("major") and smallest ("minor") values of the partial solar ecliptic limits are ±18°31′ and ±15°21′, whereas the major and minor total (or central) solar ecliptic limits are ±11°50′ and ±9°55′, respectively. The limits mean that a solar eclipse may occur within 18 days of the passage of the Sun through a node and must take place if the new moon occurs within 10 days of this solar node passage.

Many descriptions of solar eclipses can be found in historical records. A list of total or deep partial ancient solar eclipses of relatively high reliability is given in Table 5.1, taken primarily from Stephenson and Clark (1978). The location of the eclipse is not always explicitly known, but, in the case of Chinese eclipses, is usually assumed to be the capital, because this was also the site of the imperial observatory.

An additional eclipse, not included in Stephenson and Clark (1978), but well documented, is the Athenian eclipse of A.D. 484 Jan 14, in which the stars became visible (see Figure 4.13 for the conditions of the eclipse and the need for a ΔT correction). The event was associated with the death of the mathematician Proclos (or Proclus) in the following year. Stephenson (1997, pp. 367–368) has an extensive discussion of the circumstances of the eclipse, including the terrain to the east (Mt. Hymettus), which would have delayed the visibility of the eclipse in Athens.

5.2.1.2. *Lunar Eclipses*

Lunar eclipses arise when the Moon moves into the shadow of the Earth; Rufus was half right (cf. §5.2.1). They can occur only when the Moon is full, and a similar geometry to the solar eclipse prevails (see Figure 5.12).

There are differences in visibility and in duration, however. The lunar eclipse can be seen over a much larger geographic region than can solar ecl ipses—everywhere that the Moon is above the horizon during the times of eclipse. There

[8] To EFM, observing the solar eclipse of March 1970, the shadow bands seemed to coincide with the flickering of the "diamond ring" and "Bailey's Beads"—features on the Moon's limb caused by sunlight shining through lunar valleys. Unfortunately, on that occasion, the available film proved insufficiently sensitive to capture the rapidly varying but low-contrast shadow bands so that the degree of time-correlation with the flickering, which was captured on high-speed film, could not be determined. The experiment is worth repeating.

[9] The linear velocity of a point on the Earth varies with latitude: the circumference of a latitude circle/P_{rotn}, where P_{rotn} is the rotation period of the Earth, namely, $0^{d}.99727$ in units of the mean solar day. Because any arc on a small circle is equal to the corresponding large circle arc times the cosine of the latitude angle, $v = 2\pi R \cdot \cos\phi / P_{rotn}$.

[10] The totality phase of the eclipse of Feb. 26, 1979, which both authors viewed, lasted only $2^{m}15^{s}$ at Great Falls, Montana, the site of a joint gathering by eclipse observers from the University of Calgary and the College of Great Falls. The reason for the brevity is that the duration depends on the angular rate of motion of the Moon on the sky, and this depends on Moon's speed in its orbit (see §4.1.1.2) and on its distance from the Earth. During this eclipse, the Moon was near perigee; so the orbital motion (eastward) was greater, and its angular motion appeared large because of its proximity. These effects were more than enough to offset the larger angular size of the Moon (also due to its proximity), which by itself would tend to lengthen the eclipse.

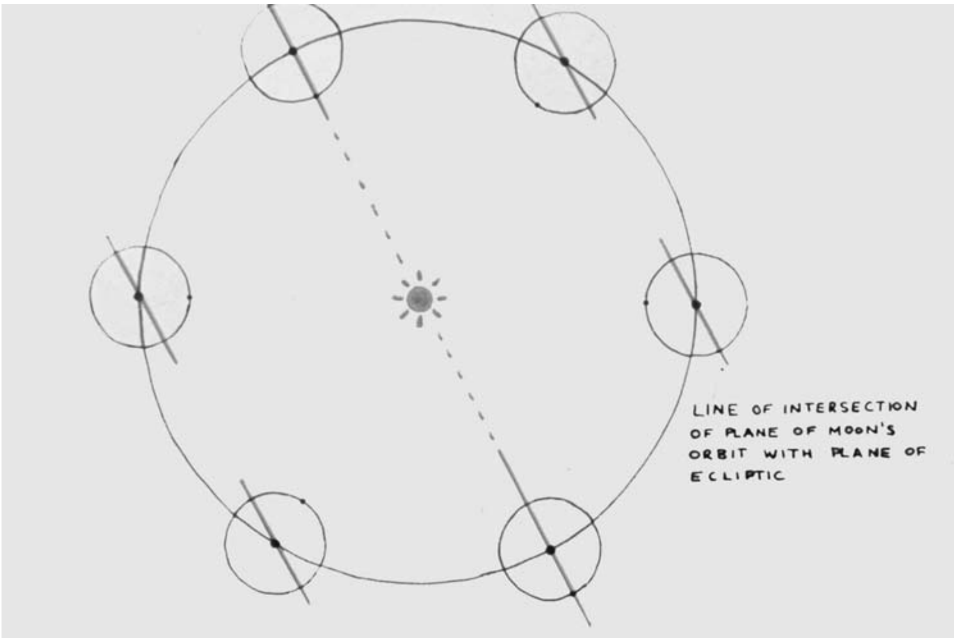


FIGURE 5.10. Nodes of the lunar orbit: Eclipses can occur only when both Moon and Sun are near a node. See Figure 5.11, which illustrates how near to a node the Sun must be. Illustration and slide, courtesy Dr. D.J.I. Fry.

TABLE 5.1. Selected records of ancient solar eclipses.

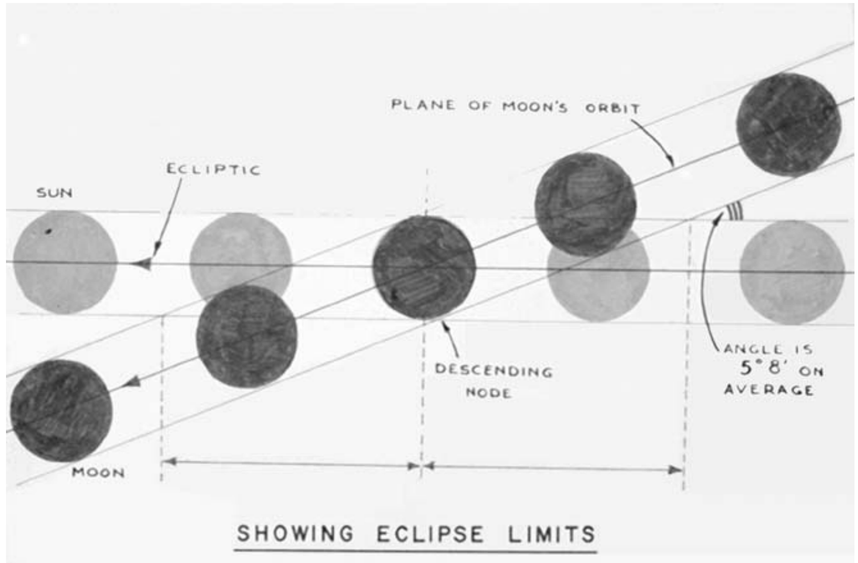
Date	Likely location	Modern circumstances	Description
B.C.			
709 July 17	Chü-fu	Total	*chi* ("complete")
601 Sept. 12	Ying:	Total	*chi*
549 June 19	Chü-fu	Total	*chi*
322 Sept. 26	Babylon	Total	
198 Aug. 7	Ch'ang-An	Annular (~95%)	*chi*
181 Mar. 4	Ch'ang-An	Total	"Dark in daytime"
136 Apr. 15	Babylon	Total	many stars; four planets seen
A.D.			
45 Aug. 1	North Africa	Total	Predicted for Claudius
65 Dec. 16	Kuang-ling:	Total	*chi*
120 Jan. 18[a]	Lo-Yang	deep partial	"Day became like evening"
516 Apr. 18	Chien-K'ang	Annular (~93%)	*chi*
522 June 10	Chien-K'ang	Total	*chi*
840 May 5	Bergamo:		"Sun hidden from world, then shown again"
912 June 17	Cordoba:	Total	"Darkness covered the Earth"
968 Dec. 22	Constantinople	Total	"Sun deprived of light"
975 Aug. 10	Kyoto	Total	*chi*; "Sun the color of ink"
1124 Aug. 11	Novgorod		"Sun perished completely"
1133 Aug. 2	Salzburg		"Sun suddenly disappeared"
1133 Aug. 2	Vysehrad	Partial	crescent at south limb
1176 Apr. 11	Antioch		Sun totally obscured
1178 Sept. 13	Vigeois	Partial	"Sun like a two- or three-day Old Moon"
1221 May 23[b]	Kerulen River	Total	*chi*
1239 June 3	Cerrato	Total	
1239 June 3	Toledo	Total	"Sun lost all its strength"
1239 June 3	Montpellier	Total	"Sun entirely covered by the Moon"
1239 June 3	Arezzo	Total	"Whole body of Sun covered for several minutes"
1239 June 3	Cesena	Total	"Sun covered with darkness; completely black"
1239 June 3	Siena	Total	"Sun completely obscured; No light"
1241 Oct. 6	Reichersberg	Total	"No part of the Sun could be seen"
1241 Oct. 6	Stade	Total	"Sun completely hidden from sight"
1267 May 25	Constantinople	Total	
1406 June 16	Braunschweig		"Sun stopped shining"
1415 June 7	Altaich		"Sun lost its light for several minutes"
1415 June 7	Prague		"Whole Sun eclipsed"
1485 Mar. 16	Melk		"Complete eclipse"
1560 Aug. 21	Coimbra		"Moon covered the whole Sun"
1567 Apr. 9	Rome	Annular	"Narrow circle of light surrounded whole Moon"[c]

[a] Stephenson and Houlden (1986, p. 208) show the predicted eclipse track, with $\Delta T = 2^h 19^m\!.5$, as going through Lo Yang, where the eclipse should have been total.

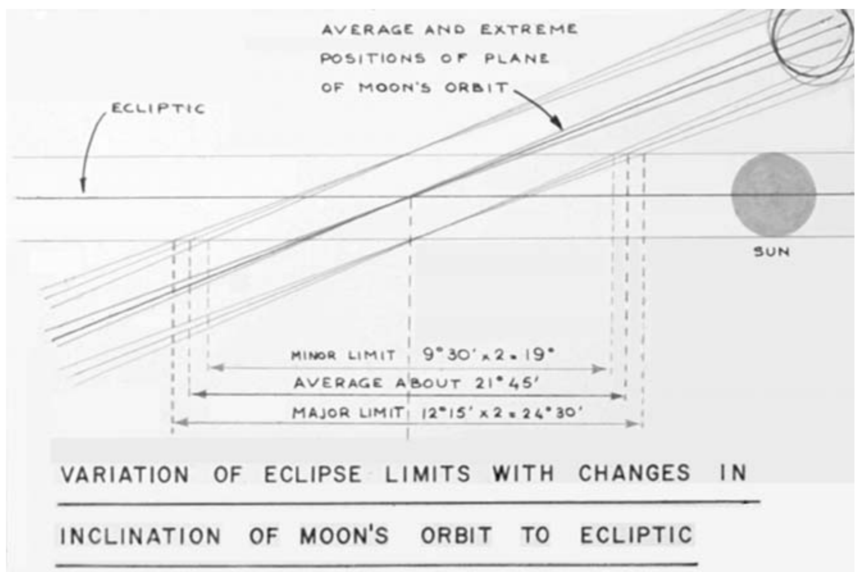
[b] This eclipse was observed by a Taoist Master Ch'ang-ch'un who was traveling to Samarkand from China, somewhere on the Kerulen River (extreme northwestern China to northeastern Mongolia).

[c] This eclipse, reported by Clavius, was total elsewhere along its track; such eclipses are known as "hybrid" eclipses.

Figure 5.11. The ecliptic limits, the angular distances of the Sun from a node of the Moon's orbit, over which distance an eclipse may be seen somewhere on Earth: (a) basic limits. (b) Variations in the ecliptic limits due to slight variations in the inclination of the moon's orbit. Illustration and slide, courtesy Dr. D.J.I. Fry.



(a)



(b)

are both umbral eclipses corresponding to total or partial conditions and penumbral eclipses, which are also called *appulses*.[11] In the latter case, the Moon enters only the penumbra of the Earth's shadow. The penumbra is a continuously shaded region, darkening gradually into the umbra. In most penumbral eclipses, there is only slight dimming, which could go unnoticed without photometric measurements. Umbral eclipses are far more spectacular, and they may be partial (see Figure 5.13) or total.

During totality, the moon may acquire a coppery, sometimes even crimson, color, especially if it is viewed close to the horizon. The color derives from the scattering of sunlight in the Earth's atmosphere. It is a similar phenomenon to that which produces a red sunset or moonset, but from a different vantage point. The explanation for the visibility of the Moon during lunar eclipses seems to have been advanced for the first time by Kepler (1604, pp. 267–284). Just as the redness and brightness of sunrise/set varies with atmospheric conditions, the brightness and redness of the Moon in the Earth's shadow vary with the atmospheric particle content and the cloud cover at the limbs of the Earth's disk as seen from the Moon. Matsushima et al. (1966) and

[11] Cf. the Explanatory Supplement to the Astronomical Ephemeris and Astronomical *Ephemeris & Nautical Almanac* (1961), p. 257.

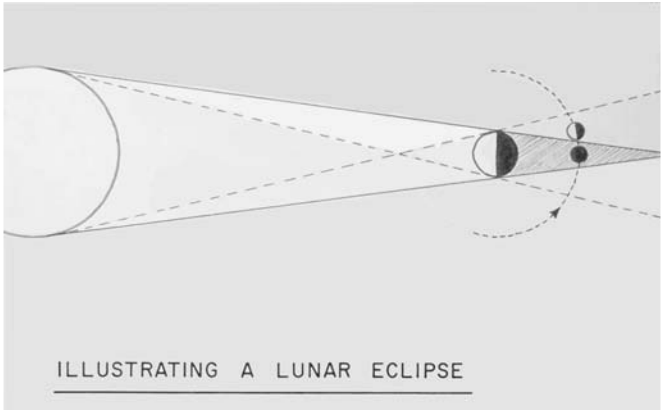


FIGURE 5.12. The basic geometry of a lunar eclipse: Lunar eclipses arise only when the Moon is full and can move into the shadow of the Earth. The geometry is similar to that of a solar eclipse. If the Moon enters the central region, where the Sun is completely blocked by the Earth, the eclipse is said to be umbral; outside this region, the eclipse is said to be penumbral. As is the case for solar eclipses, lunar eclipses may be either partial or total. Illustration and slide, courtesy Dr. D.J.I. Fry.

FIGURE 5.13. The Moon in partial umbral eclipse: RAO archives photo due to Dr. Rita Boreiko.

Matsushima (1967) derived the atmospheric aerosol content following the eruption of the Agung volcano in 1963. Keen (1983) suggested the generalization of this work and hinted that an unusually dark eclipse of 1100, recorded in the Anglo-Saxon Chronicle (Ingram 1912), as well as that of 1588, noted by Kepler, could have been due to such effects.

As is the case for solar eclipses, the Sun must be within the ecliptic limits of the node, when the Moon is opposite the Sun, for a lunar eclipse to occur. The lunar central ecliptic limit, which is the maximum separation in celestial longitude of the mid-shadow point of the Earth from the node, is ~±11°; the partial limit is ~±19°. Beyond these limits, there will be no umbral eclipse. As with the solar ecliptic limits, the actual range varies, so that the major and minor central eclipse limits are, respectively, ±12°15′ and ±9°30′. The duration of a lunar eclipse is much greater than that of solar eclipses; if it is central, the total umbral eclipse alone can last 100^m, the partial and penumbral immergent and emergent phases ~1^h each so that the entire eclipse may last nearly 6^h.

Examples of ancient lunar eclipse records, from Stephenson and Clark (1978) and Stephenson and Fatoohi (1997), are given in Table 5.2. The British Museum reference numbers of the tablets with Mesopotamian data are given in the Description column. The translations are by P.J. Huber (1973) and by H. Hunger (Sachs and Hunger 1988, 1989, 1996). The 424 B.C. eclipse record reads as follows:

> [Year 41 (Artaxerxes I)], month VI, day 14. 50 deg after sunset, beginning on the north-east side. After 22 deg, 2 fingers lacked to totality. 5 deg duration of maximal phase. In 23 deg toward [west it became bright] 50 deg total duration.

Note the use of "degrees" for time, angle, and angular separation, and "fingers" for small angle measures. This probably refers to the partial eclipse of September 28/29, with magnitude 0.931 (see §5.2.1.3) and umbral contact instants: $T_{beg.} = 18^h28^m$, $T_{max} = 20^h11^m$, and $T_{end} = 21^h53^m$, Universal Time (Liu and Fiala 1992, p. 75). Note that $T_{max} - T_{beg./end} = 1.72$ hour ⇒ ~51° total duration.

In ancient Greece, observations of lunar eclipses provided important data about the natural world. Aristotle argued that the roundness of the shadow of the Earth at every lunar eclipse implied that the Earth's shape had to be spherical. The relative sizes of the Earth's shadow and the Moon indicated to Aristarchos that the Earth was the larger of the two bodies. Their importance does not end there, however. Lunar eclipses have continued to fascinate and to instruct, down through the ages.

5.2.1.3. *Modern Uses of Ancient Eclipse Observations*

In addition to date and time and location from which the ancient eclipse was observed, the *magnitude* of the eclipse (§5.2.1) is another important parameter. This does not indicate the brightness of the Sun or Moon in magnitudes but the maximum extent of the eclipse. This *magnitude* of a solar eclipse is formally defined as the fraction of the Sun's apparent diameter covered by the Moon at the time of the greatest extent of the eclipse. Similarly, the magnitude of a lunar eclipse is the fraction of the Moon's apparent diameter covered by the Earth's shadow. The magnitude of a total solar eclipse, therefore, is ≥1, and for an annular or a partial eclipse, it is less than 1; for a total lunar eclipse, it may be greater than 1 because the Earth's shadow is larger than the Moon. The units used to express the magnitude of an eclipse have varied through history. In Chaucer's times, the appar-

TABLE 5.2. Selected records of ancient lunar eclipses.

Date			Viewing location	Modern circumstances[a]		Comments
B.C.						
424	Sept.	28–29	Babylon	Umbral	(0.931)	BM34787 (tr., Huber, pp. 32–33)
317	Dec.	13–14	Babylon	Total	(1.331)	BM32238 (tr., Huber, pp. 51–52)
215	Dec.	25	Babylon	Total	(1.376)	BM36402, 36865; astronomical diary entry (tr. Hunger, Sachs & Hunger 1989, **2**, pp. 32–33)
174	Apr.	30–May 1	Alexandria	Partial	(0.620)	From the *Almagest*
66	Dec.	28	Babylon	Umbral	(0.341)	"8 uš duration of greatest phase" (from BM34093, tr. Huber[b])
A.D.						
62	Mar.	13–14	Alexandria	Umbral	(0.722)	From Heron Alexandrinus (5th hour of the night; 10 days before Spring Equinox); see §7.1 for discussion
125	Apr.	5–6	Alexandria	Umbral	(0.150)	From Ptolemy
133	May	6–7	Alexandria	Total	(1.072)	From Ptolemy
134	Oct.	20–21	Alexandria	Umbral	(0.832)	From Ptolemy
136	Mar.	5–6	Alexandria	Umbral	(0.443)	From Ptolemy
927	Sept.	13–14	Baghdad	Umbral	(0.216)	From Ibn Iunis
1128	Nov.	8–9	Germany	Total	(1.714)	"The Moon was turned into blood" (from the Annales Sancti Blasii)
1504	Feb.	29–30	Jamaica	Total	(1.101)	Christopher Columbus "prediction"

[a] From Liu and Fiala (1992). Magnitudes are indicated in parentheses.
[b] Private communication to Stephenson and Clark (1978, pp. 30–31).

ent solar diameter was considered to have a width of 12 "points," each of which was divisible into 60 "minutes" and each "minute" again divisible into 60 "seconds." The "magnitude" in this context was the width of the eclipsed portion in these units (North 1988, p. 99); North notes that magnitudes were sometimes stipulated in area units as well). Modern techniques for computing times and eclipse magnitudes and for calculating eclipse maps are described in the Explanatory Supplement to the *Astronomical Ephemeris and the Astronomical Ephemeris and Nautical Almanac* (London: HMSO), 1961, among other sources. Link (1969) delineates the geometric details of lunar eclipses, both ancient and modern. Computer software is readily available to provide detailed images of the appearance of eclipses during various phases. *The Canon of Lunar Eclipses* of Liu and Fiala (1992) has companion software by Liu and Eagle that demonstrates both the appearance and the visibility of any of the lunar eclipses in the interval 1500 B.C. to 3000 A.D. anywhere on Earth.

Ancient eclipses have been and still are valuable to study for many reasons. First, the locations and times of ancient eclipses provided checks on theories of the motion of the Moon and Sun, in antiquity, for Hipparchos and Ptolemy (see the next section on lunar occultations); second, these data today provide information about the rate of change of the Earth's rotation (see §4.5 and Stephenson 1997 among other sources[12]); third, the size and shape of the solar corona provide an indication of solar activity (see §5.3.1, on sunspots and sunspot cycles), and fourth, the magnitude of the eclipse provides data on the size of the solar photosphere (see §5.8.1, on eclipsing variable stars). The use of lunar eclipses to study the averaged volcanic aerosol of the stratosphere was suggested by Keen (1983).

The earliest series of recordings of eclipse observations appear to be on oracle-bones from a site near An-Yang called the "Wastes of Yin" in China (Needham 1981, p. 197; Stephenson and Houlden 1986, p. xii). The records, from the Shang dynasty (~1550–1045 B.C.) include six lunar eclipses in an early series and six solar eclipses dated three generations later. The precise dates are dependent on general Shang dynasty chronology (see §10.1.2.2 and Tables 10.1, 10.5). A late Shang record bears the inscription "three flames ate up the sun, and a great star was visible." The "flames" may refer to the plume-like structure of the solar corona. As we discuss in §10, eclipses were important in China, but our records of Chinese observations of them are incomplete: Pang et al. (1988) note that the paucity of records from the Xia, Shang, and western Zhou dynasties must be due, at least in part, to the destruction of older records by the first emperor of China, Shi Huang Di (246–210 B.C.). Many eclipse records were made during the subsequent dynasties, and these are now proving invaluable in the determination of the rates of change of the Earth's rotation and the Moon's mean motion. A partial eclipse may be useful for this purpose too, if some special circumstance, such as visibility at sunrise or sunset, indicates the time of day. As recorded in *The History of the Northern Wei Kingdom* on a date in the first year of the reign of a King Chu, the Sun rose while in

[12] See also Newton 1974, p. 100; Muller and Stephenson 1975; Stephenson and Clark 1978; Stephenson and Morrison 1984; Stephenson and Houlden 1986.

eclipse. Pang et al. (1988) date this eclipse to Nov. 13, 532 A.D.

One of the most interesting as well as potentially useful records is that of the day with the "double dawn" (Pang et al. 1988). This record is from the time of the Eastern Zhou dynasty (771–221 B.C.) and is found in the reconstruction of the *Bamboo Annals* (*Zhu Shu Ji Nian*), the original of which ends in the 20th year of the reign of King Hsiang (~299 B.C.), with whom they were buried. The record states that the day dawned twice during the 1st year of the reign of a Western Zhou king named Yi at a place called *Zheng* (109°.8E, 34°.5N), in the present Shaanxi Province, 27 km west of the Hua mountain range (Chang 1981), which rises several degrees above the true eastern horizon from that site. Pang et al. analyzed all eclipses between the likely dates for the first year of King Yi's reign (which they place in the range 966–895 B.C.)[13] and concluded that an annular eclipse of April 21, 899 B.C., is the only one that fits the data. The description of the event is satisfied by the interruption of a normal dawn by the onset of 2nd contact, ~05:30 local time, when the Sun would have been less than 1° below the apparent (mountain) horizon, but already above the true horizon. At that time, the light would have decreased by thousands of times (the magnitude of the eclipse would have been 0.95) until 3rd contact, ~3 minutes later. Subsequently, a normal dawn would have appeared to return. Their analysis indicates that the accumulated clock error, ΔT, in the Earth's rotation over the nearly 2700^y interval (to Jan 1, 1800, taken as 0 by Pang et al.) is $5^h48^m \pm 500^s$, in order to have the eclipse begin just east of Zheng. The eclipse track presented by Pang et al. (1988, Figure 3, p. 845) seems to coincide with that of Oppolzer (1887/1962), whose work assumed empirical corrections for what we now call ΔT; Pang et al. conclude that $\Delta T = 5^h48^m$, but give few details of how they arrived at this value. Stephenson and Houlden (1986, p. 74) disagree on the track of the eclipse, however, and effectively disagree that the double dawn eclipse occurred on this date. They computed a value of ΔT of $6^h59^m\!.1$ for this particular eclipse; their track, if accurate, indicates that the eclipse would have been invisible over mainland China, commencing at dawn on the western side of the Korean peninsula and proceeding northeastward across the Sea of Japan, longitudinally bisecting the island of Honshu. The track shifts produced by Stephenson and Houlden (1986) are based on several telescopic timings of lunar occultations (see §5.3.3), Arab timings of lunar and solar eclipses, medieval observations of eclipses, and Babylonian timings of lunar eclipses. Finally, Stephenson (1997, p. 220) expresses doubt that the event refers to an eclipse at all, because the term *shih* is not used in the description (see §10).

The work of Pang et al. (1988) suggests a value for the Earth's rotational acceleration, $\tfrac{1}{2}\dot{e} \leq -37$ s/century^2 (refer to §4.5 for definitions of secular variation and the affect on the observed time of eclipses and other phenomena). This result is not inconsistent with the results of analysis by Huber (1986) of Babylonian (lunar) eclipse records, ~–34 s/century^2. Of course, a consistent value for the acceleration of the Moon's motion is necessary as well. Stephenson and Houlden (1986) used for their extensive Far East eclipse track calculations a value of $\dot{n} = -26$ arc × sec/century^2, and for ΔT the following expression[14] for years prior to 948 A.D.: $\Delta T = 1830 - 40.5 \times T + 46.5 \times T^2$. The coefficient of T^2 is the equivalent of $\dot{e} = -93$ s/century^2. Work by Stephenson and Morrison (1980) yielded a similar relation, whereas the simple fitting of the parabola $\Delta T = 32.5 \times T^2$ was derived from an analysis of Babylonian eclipse observations by Morrison and Stephenson (1982).

Ptolemy himself made use of ancient eclipse observations. For study of the motion of the Moon, he recognized the importance of lunar over solar eclipse records because the latter phenomenon is strongly dependent on the position of the observer, but the former is visible wherever the eclipsed Moon is above the horizon:

> Whereas in the case of lunar eclipses there is no such variation due to parallax, since the observer's position is not a contributory cause to what happens at lunar eclipse. For the moon's light is at all times caused by the illumination from the sun. Thus when it is diametrically opposite to the sun, it normally appears to us lighted over its whole surface, since the whole of its illuminated hemisphere is turned toward us as well at that time. However, when its position at opposition is such that it is immersed in the earth's shadow-cone (which revolves with the same speed of the sun but opposite it), then the moon loses the light over a part of its surface corresponding to the amount of its immersion, as the earth obstructs its illumination from the sun. Hence it appears to be eclipsed for all parts of the earth alike, both in size [of the eclipse] and the length of the intervals [of the various phases]. (Toomer 1984, p. 174)

This passage sounds remarkably modern in tone and is essentially correct in all details, if we allow that the sun "revolves" about the Earth as referring to apparent motion only. The important consequence is that the Moon's ecliptic longitude and latitude are known precisely at the time of a lunar eclipse. This is the case even though the circumstances of the eclipse do not vary across a broad range of terrestrial longitudes and the exact time of night is not usually recorded. There are historical lunar eclipses for which useful time information exists, nevertheless. The earliest lunar eclipse entry in Ptolemy's list was that seen in Alexandria in the year 546 of the Nabonassar era, on the 27/28 day of the Egyptian month Phamenoth, from the 8th to the 10th hour (reckoned from sunset). It reached greatest magnitude (~0.5) at $2\tfrac{1}{2}$ seasonal hours after midnight. Ptolemy provides the records of four lunar eclipses (see Table 5.2), and these are useful in providing information on the local dates that he used (year of the reign of Hadrian and months and days in the Egyptian calendar; see Schove 1984, p. 25; §7.3 for further details).

A series of lunar eclipses that is remarkable for detailed timing information is included in the eclipse records com-

[13] According to Tchang (1905/1967, p. 36), King Yi began his reign in 894 B.C. This is according to traditional chronology that assigns 53 years to the reign of King Yi and his son, who is known to have been removed from the throne in 841 B.C., the first fully agreed date of Chinese history. Therefore, Pang's dates appear unlikely.

[14] For years between 948 and 1600 A.D., they used $\Delta T = 22.5 \times T^2$; after 1600 A.D., ΔT was taken from tables of averages over five-year intervals by Stephenson and Morrison (1984).

piled by Ibn Iunis (d. 1009). For example, an eclipse was calculated and subsequently observed in Baghdad (44°24′E, 33°20′N) in 927 A.D. by Ali ibn Amajur and his son. The altitude of Sirius at the start (31°, "in the East"), and the rotation of the celestial sphere from sunset until onset of the eclipse (148⅓°) are specified. The latter is equivalent to 9^h52^m equal hours or 10 seasonal hours. According to Liu and Fiala (1992), the beginning of the partial (umbral) phase (T_2) should have been 01:11 UT on Sept. 14, maximum eclipse at 02:00 UT, and the end of partial phase (T_5) at 02:50 UT. We can reasonably ignore the penumbral start (T_1) and end (T_6) because these are difficult to discern with the eye alone. The longitude correction to local mean solar time is $+2\overset{h}{.}96 = +02^h\ 58^m$; adding this to T_2, 01:11, we obtain 04:09 local mean time (LMT), or ~10^h from the previous sunset. The position of Sirius (Table 3.1) can be precessed backward to get its position in 927 A.D. We compute the approximate equatorial coordinates: $\alpha = 05^h57\overset{m}{.}5$ and $\delta = -15\overset{\circ}{.}35$. From these, we compute the eastern hour angle of Sirius when it had an altitude of 31°: $H = -34\overset{\circ}{.}93 \approx -02^h20^m$, by means of (2.5). Thus, the local sidereal time is $H + \alpha \approx 03^h38^m$. With $\alpha_\odot \approx 12^h$, near the September equinox, $H_\odot \approx -08{:}22$. This is ~02:22 before sunrise. According to the software progam *Redshift*, sunrise is at 05:47 on Sept. 14, and the Sun's right ascension is about 11^h42^m. These values give a solar hour angle of –08:04, or 02:14 before sunrise. *Redshift* also gives a time of sunset of 18:06 at Baghdad on Sept. 13. From this moment to the onset of the umbral eclipse is 10:03, a reasonable approximation to the time recorded by Ali ibn Amajur. The same program indicates Sirius to be ~32° above the horizon at the onset of the umbral phase of the eclipse; so the reported data are consistent.

Because the observation of a solar eclipse is so dependent on the location of the observer—in longitude as well as in latitude—*all* records have implicit time information; but all historical records are subject to distortion and to copyist error, especially if they represent recollection long after the event. In a review of the degree of reliability[15] of ancient eclipse observations, Muller and Stephenson (1989) conclude that only four early solar eclipse records can be considered of the superior class "A" reliability:

- Total solar eclipse of 7 July 709 B.C., at Chu Fu, China
- Total solar eclipse of 26 Sept. 322 B.C., at Babylon
- Total solar eclipse of 4 March 181 B.C., at Ch'ang An, China
- Total solar eclipse of 15 April 136 B.C., at Babylon

The records of the eclipse of 136 B.C. were evaluated by Stephenson and Clark (1978) as the most accurate before the invention of the telescope. Two separate records were found among the clay tablets of the astronomical diaries of Babylon, and these provided precise locations of the Sun and several planets in the sky during totality. On the basis of planet positions and the date of nearby eclipses, Huber was able to determine the date of the eclipse. In addition, a "retrocalculation" by Mitchell (1989/90, p. 10) of the date of a lunar eclipse that occurred 14 days prior to the solar eclipse is also in agreement with the data recorded on one of the tablets.

Mitchell (1989–1990, p. 10) finds that values of the acceleration in the range 30–34 seconds/century², or, roughly, the value 32.5, fit the most reliable data from Chinese and Babylonian records over the interval ~700 B.C. to ~135 B.C.; however, the complete details of the process are not clear. As we noted in §4.5, Stephenson and Morrison's (1995) preferred solution is 31.0 (±0.9) for the coefficient of t^2, but make use of cubic splines to fit the data because they find evidence of additional terms (both periodic and secular) for the Earth's rotational acceleration.

A dramatic illustration of the effect of the accelerations on the timings of ancient eclipses was provided by Stephenson for Misner Thorne, and Wheeler (1973, p. 25), which shows that the uncorrected path of an eclipse predicted for 14 January 484 A.D., should begin at sunrise in the Atlantic ocean, just off the coast of Spain at a latitude ~40° (Figure 4.13). In fact, a record was made of the eclipse beginning in western Greece at about the same latitude but very close to 30° east of the predicted path of totality. This implies that the eclipse occurred two hours later than predicted. Because the Sun moves 30° in two hours = 7200 seconds, the difference in longitude implies a value:

$$c = \frac{7200}{(18.00 - 4.84)^2} = 41.57\text{s}/\text{century}^2.$$

Of course, this is only one case; as we have seen, different data, and different models of lunar motion and of terrestrial rotation can yield different values of $\dot{e}$.

5.2.2. Predictability and Eclipse Warnings

Eclipses can only occur when the Sun and Moon are near the nodes on the lunar orbit, so that eclipses begin to occur when the Sun is within the eclipse limits, and the Moon is new (for a solar eclipse) or full (for a lunar eclipse). Recall (from Table 2.5) that the Moon's nodal or draconic period is $27\overset{d}{.}2122$, compared with its sidereal period, $27\overset{d}{.}3217$. The difference is caused by the regression or westward movement of the line of nodes, which amounts to 360° in 18.6 years. The mean motion of the Sun is ≈ $(360°/365\overset{d}{.}2422)$ = 0.9856°/d, so that in $27\overset{d}{.}2122$ it travels $26\overset{\circ}{.}82$; because twice the minor solar ecliptic limit is $30\overset{\circ}{.}7$, at least one partial solar eclipse must occur whenever the Sun is near a node—a condition that occurs twice a year, ~173^d apart. But, suppose an eclipse were to occur near a node; would another eclipse then occur 173 days later? No! In 173^d, the Moon would complete 173/29.530589 = 5.86 synodic months (of mean length $29\overset{d}{.}530589$). The remaining part of the cycle,[16] 0.14^p, requires another four days to complete; i.e., for the Moon to catch up to the Sun. Therefore, even though the 173^d interval is known as an *eclipse season*, and twice this interval, $346\overset{d}{.}62$ is an *eclipse year*, neither is an eclipse interval!

[15] The reliability we mention here is for the purpose of acceleration determinations; for more general and historical purposes, eclipses other than those ranked "A" or even "B" may be useful.

[16] The superscript p indicates the decimal fraction of the period.

Table 5.3. Solar node passage and eclipse intervals.

Eclipse season	Lunations	Intervals	Difference
0^d	0	0^d	0^d
173.31	6	177.18	3.87
346.62	12	354.37	7.75
519.93	18	531.55	11.62
693.24	24	708.73	15.49
866.55	30	885.91	19.36
1039.86	36	1063.10	23.24
1213.17	42	1240.28	27.11
1386.48	48	1417.46	30.98
519.93	17	502.02	–17.91
693.24	23	679.20	–14.04
866.55	29	856.39	–10.16
1039.86	35	1033.57	–6.29
1213.17	41	1210.75	–2.42
1386.48	47	1387.94	1.49
1559.79	53	1565.12	5.31
1733.10	59	1742.30	9.20
1906.41	65	1919.49	13.08, etc.

They describe merely the interval of successive passages of the Sun (on average) through the Moon's orbital node. The 177^d interval, then, is an eclipse interval, and so after another eclipse season, 173^d later, or 346^d after the first solar node passage, an eclipse does not occur for a further 8^d interval. The progression, starting at a solar eclipse when the Sun is precisely at a node of the Moon's orbit, is given in Table 5.3. The differences between the first and third columns are given in the fourth, and tell us whether an eclipse will occur. For solar eclipses, an eclipse may occur if the difference is less than or equal to 18^d and must occur if it is less than or equal to 11^d. Note, therefore, that not all the intervals of column 3 in the upper section of the table are eclipse intervals, the intervals of 30–48 lunations overshoot the interval; by taking the previous lunation in these (and two earlier) cases, eclipse intervals are again found. The negative values indicate that the other side of the node is involved. The intervals in the latter part of the table are tabulated further, and their possible use in the Maya calendar is described by Spinden (1930, Table VI, pp. 52–53). For lunar eclipses, which are half lunations off from the solar cases, there may be an eclipse if the "Difference" in Table 5.3 is less than 15^d, and there must be an eclipse if the "Difference" is less than 10^d. These intervals follow from the eclipse limits. Note that at the 24th lunation, the difference between the eclipse season accumulation and the eclipse intervals accumulation is $15^{d}.49$, which is very close to half a lunation ($14^{d}.77$). Therefore, at full moon, just two weeks prior to the 24th new moon, a lunar eclipse must occur. Furthermore, after 48 lunations, the accumulated intervals are different by slightly more than one full lunation, ~31^d resulting in another solar eclipse, 47 lunations after the base eclipse.

There must be at least two solar eclipses in any given eclipse year. There may be three: two at the same eclipse season with the first starting at the western eclipse limit. It is also the case that the 177^d eclipse interval is not the shortest interval between successive solar eclipses in different seasons: From the end of one ecliptic limit to the beginning of the next is only about $173^d - 33^d$ or 140^d, although an eclipse cannot occur until slightly later[17] than this interval. The celestial longitude range for a total solar eclipse is only 19.8°–23.7° (twice the minor and major central ecliptic limits), and so it is possible for there to be no total (or annular) solar eclipses in any one calendar year.

The global frequency of lunar eclipses is less than solar eclipses (according to Oppolzer 1887/1962, there are 4000 solar eclipses in 1684 years and 4000 lunar eclipses in 2583 years), but because of their greater visibility, lunar eclipses can be seen more often at any single location on Earth. Smither (1986) calculated that viewed from a particular location (the Maya region), lunar eclipses were 4× as numerous as solar eclipses of any type. There cannot be two umbral lunar eclipses a month apart, but there can be two successive eclipses if at least one lunar eclipse is penumbral (which are more difficult to detect).

There can be no more than a total of seven eclipses—lunar and solar—in any one year. Total solar eclipses at a particular spot on Earth may not repeat for 300 years, although partial eclipses seen from that spot are more frequent.

The basic requirement for a repetition of a particular type of eclipse is that the interval between the two eclipses be an integer multiple of mean synodic months.[18] There are many possible eclipse intervals, but some are more interesting than are others. The following five conditions on the interval between eclipses will ensure repetition in several key ways:

(1) An integral number of years will give an eclipse at the same time of the year.
(2) An integral number of anomalistic periods will give an eclipse of the same duration.
(3) An integral number of nodical periods (with condition 1) will give an eclipse over the same latitude region and will also ensure a long series of repetitions.
(4) An integral number of solar days will give an eclipse at the same time of day and therefore over the same longitude region of Earth.

[17] The interval of 140^d is not a possible eclipse interval for the same reason that 173^d interval is not. Suppose an eclipse did occur at the end of the previous eclipse season, i.e., at the eclipse limit. After 140^d, the Moon will not be at the right phase for an eclipse to occur, because $140^d/29.53059^d = 4.74$ synodic months. Therefore, a new Moon will not occur again until ~8^d later or 148^d from the eclipse that occurred at the end of the previous eclipse season. Note further that the second eclipse (148^d later) could not occur if the first were at the beginning of the previous eclipse season.

[18] Recall that the synodic period varies slightly from month to month because the Moon moves on an eccentric (as well as a perturbed) orbit and therefore moves with varying velocity at different locations in its orbit. In the absence of perturbations, the cycle length of lunar velocity would be the anomalistic period (see Chapter 3), $P_a \approx 27^{d}.5546$, which is about 2^d or 7% shorter than the mean synodic period. The time taken to traverse the additional distance to catch the Sun will be smaller if the Moon is closer to perigee and longer if it is closer to apogee, than average.

(5) An integral number of sidereal months will result in eclipses occurring in the same region of the sky. This condition may have had astrological significance for some cultures.

The rules can be summarized as follows:

$$i \times S = n_y \times Y = j \times A = k \times N = n_d \times D = l \times \Theta, \quad (5.1)$$

where i, j, k, l, n_d, and n_y are integers and S, N, A, Θ, D, and Y are the lengths of the synodic, nodical (draconic), anomalistic, and sidereal months and the lengths of the mean solar day and year, respectively. The integers n_d and n_y are numbers of days and years, respectively. The conditions can be relaxed for any of the criteria, but the eclipses must take place very close to new or full Moon. A rigid application of all the criteria is virtually impossible in practice. An examination of a few examples (Table 5.4) shows, however, that the intervals can approximate at least some of the ideal conditions. Note that successive eclipses in cycle 1 will be visible at nearly the same place on Earth, but will have differing durations and will occur at different times of year. They will also occur in different regions of the sky. One of the better repetition intervals is sample cycle 3, the well-known *Saros*, encompassing an interval of $18^y\,11^d$. According to Neugebauer (1969, p. 141ff), there is no clear evidence that the Saros eclipse cycle was used in ancient Mesopotamia.[19] It does not succeed in meeting all the criteria in (5.1), but it does meet most of them: The eclipses occur at nearly the same time of year, will be seen from about the same latitudes,[20] and have similar durations; moreover, each succeeding eclipse will take place on the sky within half a zodiacal sign (<15°) of the previous eclipse in the series. There is one serious criticism of the idea that eclipses in this series were actually predicted by ancient cultures, however. Each successive eclipse takes place ~⅓ day later than the preceding, so that the Earth rotates ~120° in this extra interval. From such circumstances, only an *eclipse warning* table could be constructed—one that indicated the possibility, though not the certainty, that an eclipse would occur. This is a distinct possibility for a table of eclipses found in the "Dresden Codex" from Mesoamerica, used by the Maya (see §12.10).

[19] Neugebauer (1969, p. 116) states that a column found in linear zigzag functions of system A tables from the Seleucid era relates to the Saros cycle of 223 mean synodic months, but that its purpose was to compute the variable length of the synodic month. The term relates to an interval of 3600^y by Berossos (~290 B.C.), following a meaning of the Babylonian sign "sa'r," 3600. The application of the term "Saros" to an eclipse cycle (presumed known to the Babylonians) was due to a mistaken hypothesis about an 11th-century manuscript by Edmund Halley (1691 and 1692). Halley's view, which was strongly attacked by Le Gentil in 1766 cited in Neugebauer (1969, p. 142), nevertheless survived to propagate and repropagate through the literature. Kugler (1900) suggested that eclipses were computed during the Seleucid era from a study of the lunar latitudes relative to that when the Earth, Moon, and Sun were aligned (in *syzygy*). Neugebauer (1969, p. 142) does, however, suggest that some evidence points to a crude 18-year cycle as the means for a lunar eclipse repetition cycle prior to the Seleucid era.

[20] For solar eclipses, there is a slow northern shift from eclipse to eclipse in the Saros series, in which the eclipses occur at a descending node; there is a southern shift in successive Saros eclipses involving the ascending node.

TABLE 5.4. Eclipse repetitions table.

Cycle	Integral month	Interval in days	Interval in years
1	47 synodic	. 1387.94	3.80
	51 draconic	. 1387.82	
	50 anomalistic	. 1377.73	
	51 sidereal	. 1393.40	
	4.0 eclipse years	. 1386.48	
2	135 synodic	. 3986.63	10.87
(*Tritos*)	146.5 draconic	. 3986.59	
	145 anomalistic	. 3995.42	
	146 sidereal	. 3988.96	
	11.5 eclipse years	. 3986.13	
3	223 synodic	. 6585.32	18.03
(*saros*)	242 draconic	. 6585.36	
	239 anomalistic	. 6585.54	
	241 sidereal	. 6584.52	
	19.0 eclipse years	. 6585.78	
4	358 synodic	. 10571.95	28.95
(*Inex*)	388.5 draconic	. 10571.94	
	384 anomalistic	. 10580.97	
	337 sidereal	. 10573.48	
	30.5 eclipse years	. 10571.91	
5	669 synodic	. 19755.96	54.09
(*exeligmos*)	726 draconic	. 19756.03	
	717 anomalistic	. 19756.62	
	723 sidereal	. 19753.56	
	57.0 eclipse years	. 19757.34	

That the cycle ultimately works would be proved by sample cycle 5 of Table 5.4, which shows a triple Saros—after $54^y\,1^m\,4^d$, an eclipse will be seen in roughly the same longitudes, at the same time of day, as well as fulfilling the other conditions.[21] The triple Saros series is also known as the *Exeligmos*. It should be noted, though, that there are several *Saros* series occurring at any one time; thus, the predictability is considerably more complex than first meets the eye, and observations of eclipses alone are most unlikely to yield unambiguous predictions. On the other hand, it is certainly easy to spot when an eclipse is possible, merely by keeping track of the nodes of the Moon's orbit. The eclipses in a Saros series successively shift westward by about ⅓° with respect to the node, or, expressed in terms of time for the Moon to reach the node from the moment of syzygy, ~1/30 day. This and a slow latitude drift limit the length of any one Saros series to ~70 cycles, 15,610 lunations, or ~2100 years. In the case of solar eclipses, the descending-node series begins near the South Pole, and proceeds north; the ascending-node series begins near the North Pole, and proceeds South. In the case of lunar eclipses, the descending-node saros series begins with a penumbral eclipse of the Moon's northern limb; the ascending-node series begins with a penumbral eclipse of its southern limb.

Other historically important cycles include the *Inex*, the *Tritos*, the *Thix*, and the *Fox*. The periodicity of the *Inex* cycle was discovered in recent times by Simon Newcomb (although DHK thinks it probably was known in Mesoamerica). It involves 358 lunations (see cycle 4 in Table 5.4).

[21] The latitude drift in the successive Saros will cause the eclipse to be only a partial one at a certain place on Earth, if the previous eclipse was total at that place.

According to Sivin (1969, pp. 39–40), the magnitude of an eclipse in this cycle can vary greatly from one eclipse to the next. The *Inex* cycle series is a very long one ($23{,}000^{\mathrm{y}}$ or ~800 cycles), and unlike the Saros series, there is no gradual change in the longitude or latitude of the central track nor in the magnitude. It is especially difficult to track both very early and very late eclipses in the series.

The *Tritos* cycle (cycle 2 in Table 5.4) was used extensively in China. The term was coined by G. van den Bergh (1955); it is $\frac{1}{3}$ of a Mayan cycle of 405 lunations and is equal to the difference between the Inex and Saros cycles. The magnitudes of eclipses in a series of this cycle will be large only for the middle 25–30 eclipses, and the overall length of the series is about that of the Saros. The Chinese of the Han dynasty recognized the Tritos cycle in a sense. Chinese astronomers of the Han dynasty (206 B.C.–220 A.D.) believed that there were 23 eclipses per 135 lunations, an incorrect number by about 6, but usually sufficient to predict a warning. This matter will be discussed further in §10.1.2.2.

The *Thix* and *Fox* cycles were important for the Maya. The names of these cycles were suggested by Smiley (1973). The *Thix* is a cycle of $25^{\mathrm{y}}.630 = 9361^{\mathrm{d}}.20$, ~317 lunations, and ~36 Tzolkin (see §12.11). The *Fox* cycle is a triple Tritos cycle of $32^{\mathrm{y}}.745 = 11{,}959^{\mathrm{d}}.8$, ~405 lunations, and ~46 Tzolkin.

An early prediction of an eclipse has been claimed for the Ionian astronomer Thales. Herodotus (5th century, B.C., Book I, §74) describes an eclipse that took place during a battle between the Medes and the Lydians:

> In the sixth year of the war, which they had carried on with equal fortunes, an engagement took place in which it turned out that when the battle was in progress the day suddenly became night. This alteration of the day Thales the Milesian foretold to the Ionians, setting as its limit this year in which the change actually occurred. (Tr. G.S. Kirk in Kirk et al. 1983, pp. 81–82; cited in Panchenko 1994, p. 285)

The prediction would be meaningless if the event did not apply to an eclipse visible in the Mediterranean, because of the frequency of eclipses on a global scale. An eclipse was visible at the site of the battle on May 28, 585 B.C., but the vagueness of Herodotus's description and the lack of any other evidence for the existence of geographic predictability of eclipses among either Greeks or Babylonians at this time convinced Neugebauer (1969, p. 142) that the prediction was merely an unreliable story. Although earlier scholars had argued incorrectly that Thales could have used the *Saros* cycle to predict the eclipse, a more recent argument is that he might have had access to data from which the *Exeligmos* cycle could have been deduced. Dimitri Panchenko (1994) has made a case that the account of a prediction is probably accurate and that Thales was capable of making such a prediction, an argument made earlier by Hartner (1969) as well. First Panchenko notes that according to Diogenes Laërtios,[22] Thales's feat is mentioned by Heracleitos, Democritos, and Xenophon, so that it was widely attested and therefore deemed noteworthy in the ancient world. The source of Diogenes Laërtios's information was Eudemos of Rhodes, one of the earliest historians of science (see §7.3). Panchenko then argues that the text is usually misinterpreted. The phrase from Herodotus that Thales "set as its limit this year in which the change actually occurred"[23] is most often interpreted to mean that Thales predicted merely the year of the eclipse. Panchenko, however, suggests that the word "limit" implies "no later than" the current year—the year of the prediction or of a series of years. He also argues that a respected figure such as Thales, mentioned even by Plato, would not have risked failure by casually predicting an eclipse nor of stating it in so vague a manner as to render the prediction meaningless. He speculates that during Thales's lifetime, astronomers from some of the Assyrian cities that were destroyed by a resurgent Babylon could well have taken refuge in Egypt, Assyria's ally, where Thales could have learned of records of previous eclipses, and where sufficient data might have been available to discover the *exeligmos* or triple saros cycle (last series in Table 5.4). As we have noted, the *saros* cycle could not have been used to predict similar eclipses in the same longitude region, and from a geographically limited database, it is unlikely that such a series could have been recorded. The 54.09-year interval would have been recorded in a database, if it extended back far enough, and an apparent, though not reliable, 27/28 year series of eclipses may have also played a role.

A difficulty with the argument is that an eclipse on May 28, 585 B.C. could not have been predicted, according to Panchenko, by any method currently known. He is forced, therefore, to suppose that the eclipse prediction was made in 585 B.C., shortly after the 585 eclipse, perhaps at a Pan-Ionian festival, which would require the battle to have occurred either on Sept. 21, 582 B.C. or on March 16, 581 B.C., dates of total eclipses in the region. Panchenko favors the former because it was both earlier and of a larger magnitude than was the March eclipse. This in itself is an interesting prediction that present-day historians of science will need to attempt to verify. If Panchenko is correct, because the pan-Ionian festivals were held every four years, the prediction could have been made to assure the Ionians that such events were predictable, and the existence of eclipses in 582 and 581 B.C. could have been predicted from cycles deduced from Assyrian records.

Many atlases of eclipses are available with which ancient observations can be compared. For solar and lunar eclipses of the entire ancient world, only Oppolzer's *Canon of Eclipses* (1887/1962) has a nearly complete record. He lists 8000 solar and 5200 lunar eclipses. Schove (1984) states that the beginning and end points of Oppolzer's eclipses could have errors as large as 100 km on the polar plots provided. Oppolzer included a correction for the secular variation in the lunar longitude. It had been discovered by Laplace as early as 1786 that if the Earth's orbital eccentricity slowly decreased, the Moon would accelerate; subsequently, in 1853, J.C. Adams showed that the "acceleration" from this source would be ~6″ (the "acceleration in this context is the

[22] A noted 3rd-century B.C. historian of science, writing in *Lives of Eminent Philosophers* (tr. Hicks 1938).

[23] "οὖρον προθέμενος ἐνιαυτὸν τοῦτον, ἐν τῷ δὴ καὶ ἐγένετο ἡ μεταβολή."

coefficient of a term involving the square of the time, in Julian centuries). The slowing of the Earth's rotation and the magnitude of the tidal friction acceleration were not fully realized until the 20th century. The empirical corrections actually applied by Oppolzer and colleagues were described in his *Syzygientafeln* (1881), and are not provided in the *Canon*. P.V. Neugebauer (1931a,b) suggested that the error in timings amounted to only ~20 minutes in 700 B.C.

Other eclipse tables for selective purposes are:

(1) For Near East sites by P.V. Neugebauer and Hiller (1931) for the interval 4200 B.C. to 900 B.C. for solar and 3450 B.C. to 900 B.C. for lunar eclipses, and by Hudek and Mickler (1971) back to 3000 B.C.

(2) For the Mediterranean, by Ginzel (1899) for solar eclipses from 900 B.C. to 600 A.D.

(3) For the Far East, by Mucke and Meeus (1983) for the interval 2004 B.C. to 2526 A.D.; and by Newton (1977), whose lunar eclipse canon covers the years −1500 to −1000 of China, specifically. Also for the Far East, Stephenson and Houlden (1986) have solar eclipse maps—with modeled values of ΔT, for the interval 1500 B.C. to 1900 A.D., and Schove and Fletcher (1984) discuss sources of more localized maps. Liu and Fiala (1992) offer a modern and comprehensive canon of world lunar eclipses covering the interval −1500 to +3000 (with computer software to recreate the circumstances of eclipses on images of the Earth) with ΔT corrections. Their Table 3.3 contains corrections corresponding to the formulae of Stephenson and Morrison (1984) for the interval −1500 to +1500, but with a slightly different lunar tidal term ($-23.895''/\text{cy}^2$ from the value $-26''/\text{cy}^2$). This enables the user to subtract out the Stephenson and Morrison correction and to add other corrections, as improved values become available. Meeus and Mucke (1983) provide lunar eclipse tables for the interval 2003 B.C. to 2526 A.D.

5.2.3. Cultural Perceptions and Uses of Eclipses

The Indians of Mesoamerica (from southern Mexico through northern Honduras) still find eclipses very awe-inspiring. People make as much noise as possible, dogs are encouraged to bark, and pandemonium reigns as everyone tries to frighten away the monster (sometimes a dragon, sometimes a giant ant) who is trying to eat the Sun or Moon (as they believe in some areas) or to encourage the one attacked in a fight between Sun and Moon (as others believe).

Although a total solar eclipse, with the sudden onset of darkness and appearance of the stars is very frightening to many people, it only lasts a few minutes. A lunar eclipse, on the other hand, can last much longer and the Moon often turns a deep red (or sometimes a deep blue-black color) during the eclipse. The Quiche of Guatemala tell myths of *Xqiq*, "Blood Woman," apparently an eclipsed Moon goddess and of her twin sons (planetary gods), who go to the underworld to conquer the lords of death.

When planets and stars are too close to the Sun to be seen, it seems that the pre-Columbian Mesoamericans thought that they were in the underworld, and one of the most horrifying things about an eclipse must have been to see the land of the dead suddenly shining above in heaven, where the Sun god normally ruled.

One of the ways in which the planetary twins demonstrated their prowess to the lords of death was by dancing in flames, which left them unharmed. DHK suspects this refers to planetary conjunctions at the time of an eclipse, when the planet might be apparently engulfed by the corona yet appear unharmed a few days later as morning star.

Another way in which Mesoamericans conceptualized the movements of the heavenly bodies was as a gigantic ball game. Rubber balls were invented by American Indians, possibly in Brazil, Mesoamerica, or in one of the intermediate zones. With them, they invented a wide range of games. Our sources emphasize the cosmic nature of the ball game. In the major game played by the Aztecs, the players tried to knock the ball through a small ring, high above the court. They had to hit the ball with their head, shoulders, or body, and there were penalties for using arms or legs. Goals were so rare that the Spaniards said that when one occurred, the player was entitled to all the goods that the spectators had with them, even their clothes. Apparently, a goal was a signal for a mass rush to get away, while the winning player and his friends tried to catch as many of the spectators as possible. The goal had a cosmic analogue; a planet was thought of as a ball about to pass the goal at conjunction—that same planet, seen in a corona, was conceptualized as a Twin dancing in the flames. The kind of importance the Maya Indians put on the ball game is suggested by a series of stone sculptures at Yaxchilan, which show ball players and tell of an important game. The day of the game is counted from a base billions of years in the past—far earlier than the presently accepted geological age of the Earth.

In many parts of Mexico, a skull rack was near the ball court to contain the decapitated heads of enemies. Decapitation was one of the forms of human sacrifice practiced in the area, and losers in the ball game were apparently sometimes sacrificed in this way. One of the heroes who went to the underworld in an attempt to defeat the lords of death was identified as the Sun. After playing a ball game with the lords of the underworld, he was decapitated and his head hung in a gourd tree, where it changed into a gourd and eventually impregnated the maiden *Xqiq*, "Blood Woman," by spitting in her hand. He thereby became the father of the Twins, who did, ultimately, defeat the lords of death. This probably ancient story was, at some point, interpreted by the astronomers to mean that a solar eclipse was followed in the same month by a lunar eclipse and, shortly thereafter, by the "birth" of twins, perhaps, in this context, the appearance of Venus and Mercury as morning stars. Throughout Mesoamerica, decapitation of heroes or gods seems to refer either to solar or to lunar eclipses.

The religious fervor and intensity with which eclipses were regarded may have been a factor in the considerable knowledge of eclipse cycles that Mesoamerican astronomers developed. There is some evidence that they actually understood, at least partially, the physical mechanisms of eclipses.

Such understanding, however, was not possessed by the bulk of the people and does not seem to have been in conflict with their religious views.

5.3. Other Solar and Lunar Phenomena

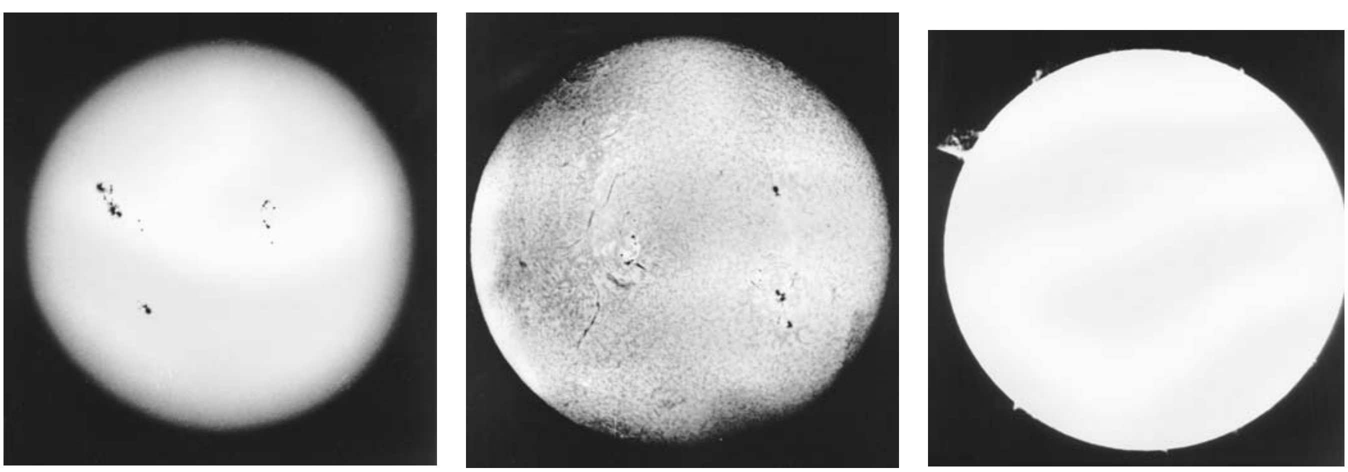
In addition to solar-related atmospheric phenomena and eclipses, other solar and lunar phenomena impact ancient astronomy. Solar flares and sunspots are among the more noticeable events, although they are best seen when the Sun is near the horizon. Lunar luminescence had at least the potential of being seen. Appulse and occultation events of a particular object are like eclipses in that they are repeatable and are directly affected by the lunar long-term $18\overset{\mathrm{y}}{.}6$ nodal regression. Finally, large meteoritic impacts on the Moon have the potential for being visible, and at least one is reported in medieval annals (see §5.3.2).

5.3.1. Sunspots and Related Phenomena

A sufficient number of sunspot phenomena have now been recovered from ancient chronicles, that the known sunspot records now extend back to at least 1 A.D. (Clark and Stephenson 1978) and possibly to 165 B.C. (Wittmann and Xu 1987). Mythical depictions of a crow in the Sun from Han dynasty tombs likely stem from observations of sunspots (Xu 1987), a suggestion supported by the circumstance that the word *wu*, often used in the annals prior to 28 B.C., means "crow" as well as "black" (Needham 1981, p. 211). A rubbing from a stone engraving of the family of the Han emperor Wu Ti shows an archer shooting crows that threaten drought by burning up the Earth. This is cited as an example of a "drought myth" by Fairbank, Reischauer, and Grieg (1989, p. 67). Between the 1st century B.C. and 1638 A.D., the annals, mainly the *Wên Hsien Thung Khao* from the 13th century and the *Thu Shu Chi Chhêng* imperial encyclopedia dating from 1726, list 112 descriptions. Wittmann and Xu (1987) provide 235 such descriptions from 165 B.C. to 1684 A.D. The crow-in-the-Sun image is part of the mythology deriving from the Chou and early Han dynasties.

The association of the crow and the Sun is found in other groups as well. The possible identification of the crow and the Sun in Celtic mythology is discussed in §6.2.8. The "bird of Apollo" in Hellenistic Greek belief was a crow. Stories told about Raven in myths of North American Indians contain motifs that seem to apply to the Sun. What is known about sunspots does not conflict with such associations.

Sunspots are regions of cooler temperatures in the photosphere of the Sun; they appear dark by contrast to the higher temperature of the surrounding solar atmosphere. They were telescopically discovered as true solar phenomena by Galileo (1613), who first traced their passage across the face of the Sun and thereby found the rotation of the Sun. Occasionally, very large spots appear on the Sun; sometimes they can be seen without optical aid. One of the largest seen in modern times occurred in April 1947 and was several arc-minutes across, clearly resolvable by the naked eye. There are many anecdotal accounts of such sightings when the solar disk is near or at the horizon (for example, A.J. Wesselink mentioned one such occasion to EFM). A systematic naked eye investigation correlated with telescopically determined sunspot numbers and areas would be useful to calibrate pretelescopic observations of sunspot numbers. The sunspots are basic indicators of solar activity; prominences and solar flares on the Sun and terrestrial aurorae are other indicators (see Figure 5.14).



(a) (b) (c)

FIGURE 5.14. Solar phenomena, August 31, 1988, observed with the RAO's heliostat: (a) A white light image of the Sun with sunspots. (b) The Sun in the red light of Hα, 6563 Å, showing prominences projected onto the disk. (c) Hα image from October, showing prominences on the limb. Photos courtesy Frederick M. Babott.

These phenomena wax and wane with an 11-year cyclicity (the sunspot cycle[24]). It has long been suspected that there is a connection between solar activity and weather patterns on Earth, but the complexity of Earth's weather patterns has precluded the determination of a reproducible relationship. Recently, some progress appears to have been made in decoupling other effects from those involving solar activity (cf. Kerr 1988). The connection, although difficult to understand in a cause-effect way, has attracted attention recently because of the Spörer-Maunder or Maunder minimum in solar activity during the period 1645–1715 (during the reign, ironically or perhaps appropriately enough, of the "Sun King," Louis XIV), when Europe suffered a "little ice age." This was a time when Europe underwent unusually severe winters. Supporting evidence that the spots were in fact few in number, and not merely unreported or under-reported, is to be found in the appearance of the solar corona observed during the solar eclipses of the period. It had little structure or extent—typical of coronae during solar minima. The records of auroral sightings also support the reality of the Maunder minimum. However, it would still be worthwhile to perform the calibrating experiment mentioned earlier.

In a typical 11-year cycle, the numbers of sunspots, flares, prominences, and so on, increase until reaching a maximum, typically, between two and five years after the preceding minimum. Although solar flares occur frequently, white-light flares, i.e., those that emit continuum radiation as opposed to those that emit light only in certain spectral lines (like the Balmer lines of hydrogen or the H and K lines of ionized calcium, for example), are rare. Such flares brighten a small portion of the solar disk and have limited lifetimes of half an hour or more; they are followed by auroral activity, changes in magnetic indications, and other effects, when the charged particles reach the Earth about 50 hours later.

In the chronicle, the "*Kai Yuan Zhan Jing*," descriptions of "flame-like gas" in, or "jumping in," the Sun are described (Xu 1987; 1990), which are considered to be the comments of diligent observers of solar phenomena (Wang and Siscoe 1980). These observations could describe solar prominences, which, when viewed through a telescope, give the appearance of dark, highly elongated regions when on the disk (cf. Figure 5.14c) but when seen off the limb, may appear as bright hoops or flame-like extensions off the disk. Only very large-scale features, viewed near sunrise/sunset, would be visible to the naked eye. Chromospheric and coronal features are best viewed, of course, during the total phase of a solar eclipse.

[24] Strictly speaking, the solar activity cycle is a 22-year one; after 11^y, the solar magnetic field polarity changes; this reversal causes leading spots in "bipolar groups" to have the polarity that following spots had in the previous 11^y cycle. The magnetic polarity of leading spots in the Northern Hemisphere is opposite to that in the Southern Hemisphere, and this too reverses in alternate 11^y cycles. From time to time longer cyclicities are suggested as being present in solar activity history. See §5.8 for further discussion of solar variability.

5.3.2. Transient Events on the Moon

In addition to eclipses, the Moon has occasionally produced other phenomena such as glowing or sudden flashes of light. But on these phenomena, there is less agreement as to the cause. The extensive cratering of the Moon indicates that the surface is constantly being bombarded by meteoroids, although at much lower frequency than that prevailing during the first billion years of the Moon's existence. The impact of the larger bodies must be accompanied by a flash of light as the material is vaporized during the explosion on impact. The source of energy for the explosion and creation of the crater is the kinetic energy of the body that encounters the Moon at or beyond the Moon's escape velocity (2375 m/s). The energy of impact would be at least 3×10^6 joules per kilogram of mass of the impacting body, but may be much larger.[25] The energies compare to the chemical energy in TNT: 4.2×10^6 J/kg. Such a collision has calculable effects.

For an object with a density of 1 g/cm^3, 10 m in radius, impacting the Moon with a velocity of 9 Km/s, the maximum energy to be dissipated would be $\sim 1.7 \times 10^{14}$ joules. If 10% of this energy were converted to visible light, and the radiated energy was released over a 1-second interval, the average power radiated would be $\sim 1.7 \times 10^{13}$ watts during that time (note, however, that a "luminous efficiency" of 10% may be too high; Bello Rubio, Ortiz, and Sada (2000) derive 0.2%, from observed impacts of Leonid meteoroids on the Moon in November, 1999, but with an uncertainty of a factor of 10). Viewed from Earth, the explosion would produce a radiant flux of $\sim 1 \times 10^{-5}$ W/m^2. The integrated light of the full moon over the V bandpass is about 5×10^{-3} $\text{Wm}^{-2}\mu^{-1}$ (C.W. Allen 1973, pp. 142ff); so there would be a negligible increase in the brightness of the Moon during the event. However, the surface brightness of the Moon decreases away from full Moon phase in dramatic fashion. As a function of phase angle on the Moon, α, the angle measured at the Moon between the Earth and the Sun, the V magnitude increases by ~0.25 magnitude[26] (becoming ~23% dimmer) for every 10° interval from full moon phase, where $\alpha = 0°$. The event would be still more apparent if it was to occur on the night side of the Moon, i.e., on the part unilluminated by the Sun. In fact, seen against the dark face of the Moon, the sample event would be about as bright as a 5th magnitude star, visible, but not spectacular. The energy dis-

[25] The kinetic energy is $\frac{1}{2} \times mv^2$. The Moon's mass is $M = 7.3483 \times 10^{22}$ kg, so that, using only the velocity of escape from the Moon's surface, $v_\infty = [2GM/R]^{1/2}$, with $G = 6.672 \times 10^{-11}$, and the Moon's radius, $R = 1.738 \times 10^6$ m, the energy of impact is 2.82×10^6 J/kg; adding the escape velocity of the Earth at the distance of the Moon, 1440 m/s, the energy becomes 7.28×10^6 J/kg; and finally, adding the speed relative to the Earth-Moon system of an object on a typical Earth-crossing asteroid orbit, ~5 km/s, the speed of impact becomes ~9000 m/s, and the impact energy becomes $\sim 4 \times 10^7$ J/kg. Thus, orbit details of the impacting body determine to a large extent the resulting energy of explosion. See Melosh (1989) for more detailed treatment.

[26] The full formula (C.W. Allen 1973, p. 144) is

$$V = +0.026 \times \alpha + 4.0 \cdot 10^{-9} \times \alpha^4.$$

sipated in the collision is proportional to the mass; in general, the mass is unknown, but $M = (4\pi\rho/3)R^3$, where M is the mass, ρ the density, and R the radius; so given the density and radius, the mass and thus the energy can be computed. If the object was denser, say, ~3 gm/cm^{-3}, typical of a rocky rather than an icy body, the collision energy would be proportionately greater. An object ten times the diameter of our test object would produce ~1000 times more energy; 100 times larger (~2 km across) would produce a million times more energy. The larger the object, however, the rarer it is. An object 20 km across is likely to impact only once in tens of millions of years. Strong and widespread evidence suggests that such events have punctuated the geological record, the most recent such major event occurring at the end of the Cretaceous period of the Mesozoic era, coinciding with the end of the age of dinosaurs.[27]

Observations of sudden brightenings on the Moon were recorded in the medieval annals of European monasteries (Newton 1972). They probably represent impacts of modest or intermediate size: a bright light within the lunar disk at "new moon" (Rampona, 1058); a light on the Moon's disk during a total eclipse (Cavenses, Aug. 6, 1096); and "the upper horn of the new moon seemed to split in two and a flame shot from it" (Gervaise, June 18, 1178). The phase "new moon" in these observations is probably a 1-day-old waxing crescent in modern astronomical terms. Such observations are consistent with the impact of an object ~200 m across that would appear to be a thousand times brighter, with a visual magnitude of at least –2.5, and would take on the appearance of a very bright star for a brief period of time. Recent investigations have denied an association with the crater Bruno as has sometimes been claimed, and it has been argued that atmospheric phenomena rather than a collisional event is what is being described. Whether or not the latter is the case, a verification of meteoritic transient events, albeit telescopic, was provided for the first time in 1999, by observers organized by David Dunham to look for Leonid meteor shower (see §5.6, especially, Table 5.8) impacts on the Moon.

A different sort of bombardment event could, in principle, be observed also. A luminescence mechanism has been demonstrated in the laboratory on meteoritic material, which was bombarded by high-velocity charged particles like those of the solar wind. The bombarding particles through ionizing interactions cause the material to emit a continuous light upon recombination. Observations of reddish glows on the Moon are reported in Kopal (1966, 388–402, 436–439), especially on the full Moon, when the Moon sweeps through the magnetic "tail"[28] of the Earth. Lunar luminescence has not been linked in any certain way with the recorded "transient lunar phenomena," however. Careful examination of lunar material gathered on the Apollo 11 expedition failed to show strong luminescence effects, but numerous data support the reality of the phenomena: Short (1975, p. 64) reports over 1200 citings of localized lunar brightenings, more than 300 of which have been associated with the Aristarchus crater. Link (1969, 88ff) summarizes and describes some of the evidence. The darkness of the moon during eclipse has been correlated with the solar cycle (see Link 1969, pp. 97–100). The astronomers Danjon (1920a,b) and de Vaucouleurs (1944) found that the brightness of the eclipsed Moon increases with phase of the 11-year cycle and drops sharply at the end of the cycle, so that the darkest Moon coincides with the beginning of the new cycle, when sunspots are few and are located at high solar latitudes. Matsushima (1966) found a correlation with the geomagnetic K_p index, which measures the strength of local geomagnetic effects of the solar activity cycle. As noted elsewhere, the reddening may be influenced also by the suspension of particles in the Earth's atmosphere, but Link (1947, 1969, p. 99) interprets the Danjon relation as evidence for luminescence excited by solar wind particles. Danjon's luminosity scale, created for prephotometric measurements, and therefore appropriate to apply to ancient eclipse descriptions, is indicated in Table 5.5.

TABLE 5.5. Danjon's eclipsed moon brightness scale.

Degree	Description
L = 0	Very dark; Moon barely visible at mid-totality
1	Dark gray-brown; disk details barely visible
2	Dark red-rust; edges of shadow somewhat brighter than center
3	Brick-red; edges of shadow brighter and yellow
4	Copper; bright with somewhat blue edge

Lunar volcanism is not considered a likely source of lunar events, although one observation of a possible volcanic event was reported by Kozyrev (1962), based on a spectroscopic observation of possible volcanic outgassing from the lunar crater Alphonsus. No further event has been seen, and so the existence of active volcanism on the Moon has not been confirmed. The current theory of the Moon's interior calls for a cold crust and upper mantle, with seismic disturbances limited to a region 700 to 1200 Km beneath the surface. This is not the kind of model for which surface volcanism is expected, and Öpik (1977) suggested that a more likely explanation for Kozyrev's observation was luminescence from a sunlit peak. Despite a body of anecdotal material from visual observers about such enhanced brightenings, convincing measurements seem to be lacking.

5.3.3. Lunar Occultations

Lunar occultations are easily observable phenomena explicit in some ancient observations and implicit in some myths. They are therefore of archaeoastronomical interest. The Moon can occasionally be observed to pass near (sometimes called an appulse—but see §2.1) or in front of (an occultation) a star or planet. All the bright planets, Uranus, and all the stars within the major standstill declination range

[27] The Chicxulub crater on the western edge of the Yucatan peninsula is widely held to be the impactor site for the K-T event.

[28] The tail is down-wind of the solar wind, which compresses the Earth's magnetosphere on the sunward side and causes its extension on the leeward side.

of the Moon, ±~28.5°, are regularly occulted by the Moon. The first magnitude stars Aldebaran (α Tau) at δ = +16°.5, Antares (α Sco) at δ = –26°.5, Regulus (α Leo) at δ = 12°.0, and Spica (α Vir) at δ = –11.0, (cf. Table 3.1) are occulted more than once every 18.6 years. Pederson (1987) points out the importance of such events for ancient astronomy. The Alexandrian astronomer Timocharis observed the occultation of Spica (α Vir) in 294 B.C. and a conjunction of Spica with the Moon in 283 B.C.; subsequently, Hipparchos established the position of Spica relative to the autumnal equinox during two lunar eclipses in 146 and 135 B.C. From Hipparchos's lunar theory, he would have been able to find the longitudes of Spica from the earlier observations and, with these data, find the shift in Spica's position relative to the equinoxes. In this way, he could have found the precession of the equinoxes; this is, in fact, the way Ptolemy claimed to have done it and demonstrated how it was done (cf. Toomer 1984, pp. 327ff). Aristotle (*de Caelo*, 2,12) recorded his own observation of the occultation of Mars—watching it disappear behind the east limb of the Moon and reappear beyond the west limb. His interest was purely cosmological (no times or dates are given): A demonstration that the Moon is closer than is Mars. Stephenson and Clark (1978) recovered this information: They state that the sole Mars occultation visible in Athens during the appropriate time interval occurred on May 4, 357 B.C. A RedShift simulation confirms that an occultation of Mars did occur on this date and could have been viewed in Athens.

5.4. Planetary Phenomena

The planets undergo changes in brightness as well as position and angular speed across the sky. The configurations of the planets, however, provide the phenomena in which ancient astronomers, especially in Mesopotamia, seemed most interested. The conjunctions of one planet with another, or the location of a planet in a particular zodiacal constellation, were interpreted in astrological ways as propitious or calamitous signs for kingdoms and sometimes for individuals (see §15.6).

Some configurations are of particular astronomical interest. These include the transits of Venus and Mercury across the face of the Sun. A transit requires an interior planet to be near a node of its orbit at the time of inferior conjunction, in other words, nearly in line with the Earth and the Sun. The transit limits—analogous to ecliptic limits—are only a few degrees. Those for Venus are narrower than are those for Mercury, and inferior conjunctions are fewer also, so that transits of Venus are more rare than are transits of Mercury, as Table 5.6 reveals. This table, based on Meeus (1989), is a continuous record of transit events but over a much different range of dates for each planet. Notice that Venus transits occur in pairs separated by eight years, and the pairs recur in alternate intervals of 121.5 years and 105.5 years, but the cyclicity is complicated and the intervals vary. The Venus transit seasons—roughly analogous to solar/lunar eclipse seasons—are currently in June and December. The Mercury transit seasons currently occur in May and November. Most seasons, however, are without a transit. There are 13 to 14 Mercury transits per century. The highly eccentric orbit of Mercury (cf. §2) makes the limits and transit conditions different for the two node crossings;[29] the ratio of the number of November to May events is 9 : 4. It is possible for such phenomena to have been observed in ancient times with optical aids in, for example, Mesoamerica.

In more recent times, the transits of Venus were studied in the 18th century to determine the astronomical unit. By observing the event from widely separated regions of the Earth, the times of contact could be compared. From them, the corresponding angle between the sites subtended at Venus could be computed. These angles, plus the knowledge of the distance between the sites permit the calculation of the distance from Venus in the same units, viz., miles or kilometers. Because the distance of Venus at the instant of transit is known in astronomical units (from orbital theory), the A.U. is determined in kilometers. Fernie (1976) describes the tribulations that were faced by astronomers attempting to carry out those observations.

5.5. Comets

Few astronomical phenomena have excited as much attention and awe as the appearance of a comet in the sky. Unlike the motions of the Sun, Moon, and planets that are complicated but predictable, comets appear without warning, occasionally become very bright, move quickly over the sky when they are most noticeable, and sometimes occupy a large fraction of the twilight or evening sky. The Bayeaux Tapestry and numerous woodcuts testify to the awesome, even ominous, apparition this must have provided. Aristotle argued that comets were atmospheric phenomena, but Tycho Brahe's careful positional work on the comet of 1577 demonstrated that this comet was at least three times farther than was the Moon. Comets were thought to be completely unpredictable until the work of Edmund Halley, who was the first to identify the repeated apparitions of ~76 years apart as reappearances of the same comet—the one that now bears his name (see Figure 5.15).

Most comets, indeed, are still unpredictable. Comets are members of the solar system[30] at very large average dis-

[29] Mercury's high eccentricity means that its distance from the Sun varies greatly; for a conjunction near aphelion, its high inclination means a smaller chance to transit the Sun.

[30] This is known from the fact that the eccentricities of newly seen comets are less than or equal to 1. An orbital eccentricity of 1 means the object is in a parabolic orbit—it has no more than the bare minimum energy to escape the Sun's gravity. This means that at very large distances from the Sun, they are essentially at rest with respect to the Sun. However, the Solar system is in orbit about the center of the Milky Way galaxy, and therefore, external objects encountering the solar system will have larger than parabolic velocities. Very few such velocities have been measured for comets, and these may be due to perturbations by the giant planets as the comets pass through that part of the solar system (no comet has been detected, thus far, beyond this region because they are still too faint).

TABLE 5.6. Selected transits of Venus and Mercury.

Venus			Mercury		
Nov. 22, 1035[a]	B.C.	Nov. 19, 1027	Nov. 01, 1605	A.D.	May 03, 1615
May 23, 921		May 21, 913	Nov. 04, 1618		May 05, 1628
Nov. 22, 792		Nov. 19, 783	Nov. 07, 1631[b]		—
	May 22, 670		Nov. 09, 1644		—
Nov. 22, 549		Nov. 19, 541	Nov. 03, 1651		May 03, 1661
	May 22, 427		Nov. 04, 1664		May 07, 1674
	Nov. 23, 306		Nov. 07, 1677		—
	May 23, 184		Nov. 10, 1690		—
	Nov. 23, 63		Nov. 03, 1697		May 05, 1707
A.D.	Nov. 23, 60		Nov. 06, 1710		—
	Nov. 23, 181		Nov. 09, 1723		—
	May 24, 303		Nov. 11, 1736		May 02, 1740
	Nov. 23, 424		Nov. 05, 1743		May 06, 1753
May 24, 546		May 22, 554	Nov. 07, 1756		—
	Nov. 23, 667		Nov. 09, 1769		—
May 24, 789		May 22, 797	Nov. 02, 1776		—
	Nov. 23, 910		Nov. 12, 1782		May 04, 1786
May 24, 1032		May 22, 1040	Nov. 05, 1789		May 07, 1799
	Nov. 23, 1153		Nov. 09, 1802		—
May 25, 1275		May 23, 1283	Nov. 12, 1815		—
	Nov. 23, 1396		Nov. 05, 1822		May 05, 1832
May 26, 1518		May 23, 1526	Nov. 07, 1835		May 08, 1845
Dec. 07, 1631[c]		Dec. 04, 1639[d]	Nov. 09, 1848		—
June 06, 1761		June 03, 1769	Nov. 12, 1861		—
Dec. 09, 1874		Dec. 06, 1882	Nov. 05, 1868		May 06, 1878
June 08, 2004		June 06, 2012	Nov. 08, 1881		May 10, 1891
Dec. 11, 2117		Dec. 08, 2125	Nov. 10, 1894		—
June 11, 2247		June 09, 2255	Nov. 14, 1907		—
Dec. 13, 2360		Dec. 10, 2368	Nov. 07, 1914		May 08, 1924
			Nov. 10, 1927		May 11, 1937
			Nov. 11, 1940		—
			Nov. 14, 1953		May 06, 1957
			Nov. 07, 1960		May 09, 1970
			Nov. 10, 1973		—
			Nov. 13, 1986		—
			Nov. 06, 1993		—
			Nov. 15, 1999		May 07, 2003

[a] Dates prior to 1583 A.D. are in the Julian calendar.
[b] First known observation (by the astronomer Pierre Gassendi); predicted by Kepler, who, however, had died in 1630.
[c] Predicted by Kepler (invisible in Paris, and so missed by Gassendi).
[d] First known observations (by Jeremiah Horrocks).

tances from the Sun (of order 50,000 A.U.s). The comets in Table 5.6, with periods less than ~200 years originally had much longer periods but were perturbed into much smaller (lower energy) orbits, with much smaller sidereal periods. The "short-period" comets with periods ~25 years or less have lost most of their volatile materials and are not currently visible to the naked eye. Comets with periods more than 25 years and less than 200 years are in an intermediate class, some members of which are bright enough to be seen on at least some passes. Thus, Comet Swift Tuttle has been visible on some, but not most, passes. A comet may be designated by year as well as by name. In column 1, the accepted name followed by the first and most recent year (to 1994) of appearance are given. As a rule, Roman numerals give the order of the perihelion passage within a year. The quantity q, the perihelion distance, is given in Table 5.7 instead of the semimajor axis, a, because most cometary orbits are highly elongated and the more important parameter, especially for visibility, is its closest approach to the Sun. The elements given are the most recent, and to the equinox 2000.0, but these elements, including the period, change over time thanks to planetary perturbations and even nongravitational forces. Such nongravitational forces may be due to interaction with the solar wind, the pressure of sunlight, and the effects of volcanic eruptions in the nucleus (which produce recoils of the comet). Thus, the computed orbital elements of Halley's comet based on the large numbers of observations of its apparitions show that the sidereal period, P_{sid}, has varied by more than 3^y, the eccentricity, e, by up to 0.001, the inclination, i, by more than 1°, the longitude of the ascending node, Ω, by 28°, and the argument of perihelion, ω, by nearly 24°. More details about

TABLE 5.7. Selected historically important comets.

Comet name (year) designations	E_0	P_{sid} (y)	q (au)	e	i (deg)	Ω (deg)	ω (deg)
Biela[a] (1772 = 1852 III)	1852.73	6.62	0.861	0.756	12.6	247	223
d'Arrest (1678 = 1982 VII)	1982.70	6.38	1.291	0.625	19.4	140	177
Encke[b] (1786 I = 1990 XXI)	1994.111	3.28	0.331	0.850	11.9	335	186
Giacobini-Zinner (1900 III = 1979 III)	1992.28	6.61	1.034	0.706	30.9	195	173
Halley[c] (–239 = 1986 III)	1986.110	76.0	0.587	0.967	162.2	59	112
Ikeya-Seki[d] (1965 VIII)	1965.80	879.88	0.008	1.000	141.9	346	69
Kohoutek[d,e] (1973 XII)	1973.99	≥1000	0.142	1.000	14.3	258	38
Olbers (1815 = 1956 IV)	1956.46	69.47	1.179	0.930	44.6	85	65
Pons-Brooks (1812 = 1954 VII)	1954.39	70.98	0.774	0.955	74.2	255	199
Schwassmann-Wachmann 1 (1908 IV = 1989 XV)	1957.36	16.10	5.538	0.132	9.5	322	356
Shoemaker-Levy 9[f] (1993e)	1994.244	17.69	5.380	0.207	5.8	221	355
Swift-Tuttle[g] (–68 = 1992t)	1862.64	120.0	0.963	0.960	113.6	139	153
Tempel-Tuttle (1366 = 1965 IV)	1965.33	32.9	0.982	0.904	162.7	235	173

[a] Discovered by M. Biela in 1826 (later identified with comets of 1772 and 1806), it was observed again in 1832. It was seen to split in two in 1846 by John Herschel (1792–1871); the two comets returned in 1852 but were never seen thereafter. A meteor stream now occupies the orbit.
[b] The first recorded observation was by Mechain in Jan. 1786. The comet was observed also by Caroline Herschel in Oct. 1805. The first computed elements and prediction of return were by Johann Encke (1791–1865) for 1822. To 1994, there were 57 recorded appearances, the largest number of known appearances of any comet. It is not visible to the naked eye.
[c] This is the oldest known extant periodic comet. Altogether, there have been 30 recorded appearances: 240, 164, 87 and 12 B.C., and A.D. 66, 141, 218, 295, 374, 451, 530, 607, 684, 760, 837, 912, 989, 1066, 1145, 1222, 1301, 1378, 1456, 1531, 1607, 1682, 1759, 1835, 1910, and 1986. This is probably the comet depicted in the Bayeaux tapestry and is the most likely model for the comet in Giotto's *Adoration of the Magi*.
[d] A long "short-period" comet. The eccentricity is listed as 1.000, but is actually slightly smaller than 1.
[e] A "virgin comet," its early brightness far from the Sun led some to predict that it would be one of the brightest comets ever seen. Its subsequent poor performance confirmed the reputation of comets as unpredictable in brightness.
[f] Independently discovered by three groups of observers on photographic images in 1993; it was captured by Jupiter after tidal interaction probably in July 1992 into a satellite orbit; the interaction broke up the comet into 21 major fragments that collided with Jupiter in July, 1994. This comet was not visible to the naked eye, but is historically important as an example of the explosive effects of such collisions.
[g] There have been five recorded appearances: 69 B.C., and A.D. 188, 1737, 1862, and 1992. The 1992t designation for the latest appearance.

FIGURE 5.15. Comet Halley as seen in March 1986 from Cancun, Mexico. Photo by E.F. Milone.

cometary orbits may be found in Marsden and Williams (1993), the source of most of the information in Table 5.7.

Today, we know comets to be icy bodies (water, methane, and ammonia ice) with some rocky material as well. The Sun heats these bodies as they approach, causing eruptions of gases through the icy crust. Ultraviolet solar radiation ionizes the gas vapors, and the charged particles of the solar wind drives them away. This gives rise to sharply defined structures called ion tails. The structure of the solar wind (it contains many regions of higher than normal plasma densities) creates in turn structure in the comet's ion tail. At the same time, the pressure exerted by the sunlight[31] on dust particles that are liberated during the heating and evaporation process are driven away from the Sun. The dust tail is diffuse in appearance and may be millions of kilometers long. The visibility of these structures in our sky depends on the comet's distance both from the Sun and from the Earth. Maximum tail development occurs when the comet is closest to the Sun; but in addition, the closer the comet to Earth, the larger and brighter its tail will appear. Occasionally, an "anti-tail" can be seen in the Sun-facing direction because of perspective (see Figure 5.16).

For record-dating purposes, it must be noted that the periodicity of comets is somewhat variable, due, it is currently believed, to a "rocket-effect," first proposed by the German astronomer F.W. Bessel (1784–1846). The eruption of gas

[31] To be more precise, by the particles of light, or *photons*, which Max Planck called *quanta* because they contain small bundles of energy that carry momentum as well as energy.

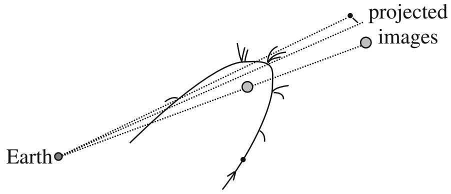


FIGURE 5.16. The origin of a comet's "sunward" tail. Drawing by E.F. Milone.

and dust by the action of solar radiation on the icy surface of the comet causes a recoil on the comet body that sometimes accelerates and sometimes decelerates the comet in its orbit, causing the period to increase or decrease, as the mean distance increases or decreases, respectively. This can make even the year of predicted appearance, especially for long period comets, open to uncertainty. Bright eruption sites on the nucleus of Halley's Comet were observed by spacecraft during its 1985/86 apparition.

According to Needham (1981, p. 208), the Chinese names for comet were "hui hsing" or "sao hsing," "brush-stars"; also, "long stars" and "candle-flame stars." The records of the "Wên Hsien Thung Khao," or "Historical Investigation of Public Affairs" by Ma Tuan-Lin and a supplement list 372 comets observed in the period 613 B.C.–1621 A.D. The list includes several observations of Halley's comet: 240 B.C., 87 B.C., 11 B.C., 66 A.D., and all subsequent returns to the end of the chronicle; records of 467 B.C. and 163 B.C. also may refer to this comet.

Several of the objects in the Chinese annals that are called "sweeping stars" are in fact comets; and it is possible that the large sizes (some are reported as being as "big" as the Sun, etc.), and blue colors attributed to some, refer to appearances of comets or at least of some phenomenon other than novae. The objects reported for 76 B.C. ("candle star"), 48 B.C. ("blue-white," "star as big as a melon") and 5 B.C. ("sweeping star") (cf. Table 5.10), fall into this category. However, the context of the comments regarding size in the Chinese annals sometimes makes it clear that brightness is being described and not a true angular size; for example, the Sung-shih and T'ung-k'ao annals report that from July 28 to August 6, 1203, a star with a blue-white color, "no flame or tail," as "big" as Saturn, stayed at Wei (Scorpius). The use of size to connote brightness is similar to western usage prior to the telescopic era (and in common usage, to the present day). A book that classifies comets by shape was discovered in 1973 in a Han tomb in Mawangdui, China, and dated to ~168 B.C. Each type is associated with a particular portent, which Yeomans (1991, p. 43ff) summarizes. One of the oldest reliable reports of a comet is given in the *Ch'un-ch'iu* ("Spring and Autumn") Chronicles of the state of *Lu* in the Eastern Chou Dynasty period of China (Stephenson and Yau 1992):

14th year [of *kung* ('Duke') Wên], autumn, 7th month, a comet (*hsing-po*) entered the Northern Dipper (*Pei-tou*).

The reference to the "7th month" places it between June 6 and July 5, 613 B.C., three years later than the best predicted date of Halley's Comet (Stephenson and Yau 1992; but see also Chang 1979). Several other comets are mentioned in the chronicle, or a commentary to it, the *Tso-chan* (which usually repeats entries, but sometimes has additional and later information), as appearing in 525, 482, or 481 B.C.

In Mesopotamia, the term for comet was *sallammu*. According to Sachs and Hunger (1988, p. 27), this is the term that appears in the Babylon astronomical diaries for the years 148 and 225 of the Seleucid era (~162 B.C. and ~87 B.C., respectively) when Halley's comet was visible. Chadwick (1989) discusses a record from a late Assyrian source of what is possibly a comet with a "beak" in front, perhaps an "anti-tail." He also cites a reference to a 7th century B.C. diviners' manual from Babylon (Oppenheim 1974), which refers to a star with a tail in back and a beak in front that can light up the sky.

In classical Greece, in the Hellenistic and later in the Roman world, comets were commented on widely, and not particularly by astronomers. Hippocrates of Cos [~440 B.C.] suggested that comets were planets that appeared infrequently. Ephorus of Cyme [405–330 B.C.] noted that the comet of 371 B.C. split into two "stars." This may be the first observation of the breakup of a comet.[32] The philosopher Seneca [4 B.C.–65 A.D.] in *Questiones Naturales* asserted that the tails of comets "fly from the sun's rays," that a comet was "among nature's permanent creations," not a "sudden fire," and that planets (which he considered comets to be) need not be found only in the ecliptic. He noted that Posidonius had observed a comet during a solar eclipse. On the other hand, he also discussed using comets to forecast the weather. Pliny the Elder in *Natural History* (~77 A.D.) provided a classification scheme for comets. Some of history's most distinguished figures held that comets were indeed portents of change or disaster. Among them have been Ptolemy [~100–175]; Venerable Bede, a Benedictine monk from Jarrow, England [~673–735]; Albertus Magnus [1193–1280]; Thomas Aquinas [~1225–1274]; Roger Bacon [1214–1294]; and Martin Luther [1483–1546]. Origen, writing in the 3rd century (*Contra Celsum*, Chap. LIX; tr. Roberts and Donaldson/Coxe, repr. 1994, p. 422) on the Christmas star, summarizes the general view as filtered through his optimistic frame of mind:

It has been observed that, on the occurrence of great events, and of mighty changes in terrestrial things, such stars are wont to appear, indicating either the removal of dynasties or the breaking out of wars, or the happening of such circumstances as may cause commotions upon the earth. But we have read in the *Treatise on Comets* by Chaeremon the Stoic, that on some occasions also, when *good* was to happen, made their appearance; and he gives an account of such instances.

See §15.2.2 for further discussion of the Star of Bethlehem and Origen's interpretation of it. The influence of Aristotle on later notions of comets is unmistakable; even

[32] As noted earlier, a recent dramatic example of such a phenomenon is the breakup of Comet Levy-Shoemaker 9 (1993e) into ~20 fragments, prior to their fiery demise in the Jovian atmosphere. The breakup was due not to tidal effects of the Sun, but to the tides raised by Jupiter, of which the comet had become a satellite.

Copernicus believed that they were terrestrial phenomena. Galileo did not accept the conclusion of contemporary astronomers that comets were necessarily farther than the Moon and argued for a vertical ascent from the Earth.

Scientific measurements of comets were attempted at least as early as 1299, when Peter Limoges [fl. ~1300] measured the celestial longitude and latitude of a comet with a torquetum (Yeomans 1991, p. 24; see §3.3 for a description of this instrument). Georg von Peurbach [1423–1461] is said to have attempted the first parallax measurements of the comet of 1456 (later to be known as Comet Halley), at Vienna; unfortunately, his relatively inaccurate measurements indicated a distance of only one Earth radius above the surface. Similar attempts were made by Peter Apian, at Ingolstadt [1495–1552], and Johannes Vögelin (also with incorrect results). Tycho Brahe's careful measurements of the Comet of 1577 with new instruments marked a turning point. His parallax measurements relative to 12 reference stars were the most accurate of its kind, and taking into account the mean motion of the comet, he found a distance six times that of the Moon. He also compared measurements of cometary positions made at the same instant by others (Yeomans 1991, p. 40), notably, William IV, Landgraf of Hesse Kassel [1532–1592] and Thaddaeus Hagecius at Prague [fl. ~1580] and obtained similar results. Despite Galileo's misgivings, this marked the beginning of the end of Aristotelian dominance in astronomy.

5.6. Meteors and Meteorites

A meteor (from μετεορα—"things in the air") is an atmospheric phenomenon, and most generally refers to such phenomena as halos, rainbows, hail, whirlwinds, and so on. Here, we will use the astronomical definition and apply the term only to what has classically been called a "shooting star": a streak or sometimes a point of light due to the incandescence of a celestial object (called a meteoroid) that enters the Earth's atmosphere at high speed (typically in the range 10–20 Km/s). The process of frictional heating ablates the meteoroid and causes a large volume of excited and ionized atoms in its wake. It is the glow from the subsequent deionization and deexcitation that we see in the meteorite trail. Most meteors are dust motes or small fragments, including most of those that are seen in meteor "showers."

When the Earth crosses the orbital debris of a comet, a meteor shower may be observed. The frequency of meteors seen during a meteor shower may vary from a few per hour to hundreds or thousands per hour but the latter are rare. A number of the showers are periodic. A list of the more prominent known showers appears in Table 5.8, which gives the approximate date of the onset of the shower (± ~2 days), the typical shower range of dates over which it is visible, the radiant, or point in the sky from which the meteors appear to diverge, and, if it is known, the comet associated with the shower. The names of the showers derive from the constellation or star within the constellation closest to the radiant. Both the date and the duration are approximate and may fluctuate from year to year. The dates of the shower mark the ascending or descending nodes of the nearly identical paths of the particles in the shower. Like the comets from which they most likely derive, the orbits are subject to perturbation, and the particles' orbits increasingly diverge, broadening the stream, and spreading the particles along the orbit with time. From year to year, any particular shower will vary in brilliance and duration, depending on the local time of transit of the radiant. It is to be expected that the ancient records might show showers that no longer occur as the result of planetary perturbations, or very long-term encounters as a result of limited dispersion in a long-period cometary orbit. A list by Imoto and Hasegawa (1958) contains at least three radiants that may fall into one or the other of these categories. Records of European observations of meteors between the 5th and 15th centuries by Dall'olmo (1978) indicate many cyclical shower events. Forty-seven of the observations are of certain or suspected showers, and although precise dates are not always stipulated, it is clear that April 4/5 (Julian) marked the date of a recurrent shower. Major showers were observed on these dates in the years 1040, 1094, 1095, 1096, 1122, and 1123. Stephenson and Clark (1978, pp. 11–12) suggest that the 1095 and 1122 events may be the April Lyrids. Probably, all these events are Lyrids. At least one of these occurrences had historical significance. In his book on the crusades, Treece (1962, p. 84) noted that the April 1095 shower was so impressive that Gislebert, Bishop of Lisieux, interpreted it as a sign of heavenly approval for a crusade. In November of that year, Pope Urban II convened the Council of Clermont, and, declaring that the end of the world was near, launched the "holy war" known later as the First Crusade.

Meteors in meteor showers are typically neither very bright nor very massive, but records of bright meteors and even meteorite falls observed in connection with showers are not unknown (see the Dall'olmo 1978 list), recent examples of which are the videotaped meteor impacts on the Moon during the 1999 Leonid meteor shower. Meteors that are not in showers are called sporadic meteors. Occasionally, they are bright enough to be seen even in the daytime. Such a meteor is called a "fireball" or bolide. Some have been observed (and even heard!) to explode during transit. Babylonian diaries recorded the phenomenon, referred to as *kakkabu rabû*, "big star," as this excerpt from the diaries of the year 419 B.C. (Sachs and Hunger 1988, p. 65) illustrates:

> Year 5 of Umakus, . . . Month II, . . . The 22nd, Venus' last appearance in the West behind the chariot. In the middle part of the day, a big star which was like a torch flashed from south to north, and the land heard the noise of the sky.

Chadwick (1989) suggests that the term *kisri* ("lump," "knot") was sometimes used to refer to meteors as far back as 2000–1600 B.C., in the old Babylonian period.

Stephenson and Yau (1992) find a reference to what may be the earliest reliably recorded meteor shower in the *Ch'un-ch'iu* ("Spring and Autumn") Annals, records of the feudal state of *Lu* for the years 722–481 B.C., during the Eastern Chou dynasty (770–256 B.C.) of China:

> 7th year [of the *kung* (Duke) of Lu], summer, 4th month, day *hsin-mao*. At night the regular stars are not seen. At midnight the stars fell like rain.

TABLE 5.8. Selected meteor showers.[a]

Name	Date	Duration	Radiant	Associated comet
Quadrantids[b]	Jan. 3	1^d	15^h28^m +50°	
Lyrids[c]	Apr. 23	3	18 16 +34	1861 I
η Aquarids[d]	May 4	10	22 24 +00	Halley:
S δ Aquarids	July 28	24	22 36 –17	
N δ Aquarids	Aug. 12	5	21 24 –05	
Perseids[e]	Aug. 12	20	03 04 +58	1962 III, (Tuttle)
Draconids	Oct. 10	1	17 40 +54	1933 III, Giacobini-Zinner
Orionids[f]	Oct. 21	7	06 20 +15	Halley:
Taurids	Nov. 3	30	03 32 +14	Encke
Leonids[g]	Nov. 16	6	10 08 +22	1866 I (Tempel-Tuttle)
Andromedids[h]	Nov. 20	21	00 52 +55	1852 III (Biela)
Geminids[i]	Dec. 13	8	07 32 +32	Phaeton
Ursids	Dec. 22	5	14 28 +76	Tuttle

[a] Taken largely from Imoto and Hasegawa (1958), especially for Asian material.

[b] From an archaic and now disused constellation named Quadrans muralis; the radiant is in Bootes. Typical modern rate: ~80/h.

[c] The last major shower was in 1803; Chinese records list showers on March 23, 687 B.C. (~10 "stars flew"), and March 26, 15 B.C. ("Stars fell like a shower"); a similar description applies to a Korean record of an April 3, 1136 shower. Typical modern rate: 15/h.

[d] Five meteor showers recorded in Chinese annals are ascribed to the Aquarids. The earliest recorded shower occurred on April 8, 401. Typical modern rate: 60/h.

[e] Many records of Perseids are found among Chinese, Japanese, and Korean sources. The earliest firm identification is that of the shower ("more than 100 small stars flew") of the first year of the Chien Wu era, 12th moon, on the Wu-hsü (5th) day or July 17, 36 A.D. Typical modern rate: 95/h.

[f] Widely variable (~4×) in rates of meteors from year to year. Major displays are recorded in Chinese records for September 23, 585 A.D. ("many stars chased each other"), September 25, 930, several dates in the 15th, and one in the 17th century. Typical modern rate: 30/h.

[g] The period of comet 1866 I = Tempel-Tuttle was $33^y.176$. Every 33 years (with some gaps, e.g., 1933 was disappointing), the Leonids have given spectacular displays; 1966 was an exceptionally strong meteor "storm." Chinese, Korean, and Japanese annals record many such displays starting on October 15 and 16, 931 A.D.

[h] Also called the Bielids. Meteor "storms" were seen in 1872 and 1885 with rates ~75,000 meteors/hour. Little activity has been seen since, but the nodes of the orbit undergo rapid regression.

[i] Phaeton is, at least at present, an asteroid. Typical modern rate: ~90/h.

The reference has been dated to March 23, 687 B.C. A second record deals with a meteorite fall. In a famous historical context, Plutarch (~120 A.D.) comments that on the night before their fateful battle at Pharsalus in 48 B.C., a "bright flaming light" was seen to pass over Julius Caesar's camp and fall into Pompey's.

Details about Chinese, Korean, and Japanese records and comments on and dates of those records are found in Imoto and Hasegawa (1958), a principal source for Table 5.8.

Whether they are observed as meteors, many meteoroids survive the passage through the atmosphere and land, at which point they are known as meteorites. In the past, there were considered three principal categories of meteorites: "stony meteorites," "stones," or *aerolites*; "irons" or *siderites*; and "stony-irons" or *siderolites*. These categories are still broadly useful, but meterorite taxonomy has progressed so far in recent decades and so many more categories (based on mineralogy, isotopic composition, crystal structure, and dated ages of various kinds) are recognized now, that the old categories are falling into disuse. The new categories help to identify the separate places of origin, and subsequent physical modification of the meteorites and parent bodies. Modern categories distinguish between various differentiated[33] types of meteorites and nondifferentiated ones. But because many references used the old categories, we will use them also, except where the physical nature of the meteorite bears on the historical context. The "stony" meteorites look much like terrestrial rocks, and after the fusion coating, produced during the frictional ablation process in the atmosphere, is eroded, may be difficult to identify and so go undetected. The irons are distinctive in appearance, often showing a dimpled appearance. In the past, although stony *falls* are far more numerous, iron *finds* were more common.

Records of meteorite falls are common and worldwide. Chinese records date back to the 7th century B.C. The *Ch'un-*

[33] The (asteroidal) meteorite parent bodies, if sufficiently large so that they retained sufficient heat at formation to completely melt, were subject to a fractionation process whereby the denser material sank to the center, while the less dense material rose to the surface to form, respectively, a metallic core and surface crust. As collisions (particularly frequent in the early solar system) broke apart many of these parent bodies, those with an abundance of nickel and iron (the "irons"), and *differentiated silicon-rich meteorites* ("stony irons" and some "stony meteorites" known as *achondrites*) were produced from the core and nearer the surface, respectively. The largest group of meteorites, the *chondrites,* bear glass beads called *chondrules*, from the Greek *chondros*, granule, are undifferentiated, and although modified through subsequent collisions and radiation over the eons, represent an ancient form of matter dating back to the original disk from which the planets formed nearly five billion years ago. The *chondrites* form the bulk of the "stony" meteorites; a subset, the *carbonaceous chondrites,* contain water and carbon.

ch'iu ("Spring and Autumn") Chronicle, previously cited, describes an apparent meteorite fall very briefly:

16th year [of *kung* ('Duke') Hsi], spring, in the king's first month, day *wu-shen*, the first day of the month, stones fell in Sung; there were five.

The entry has been dated Dec. 24, 645 B.C. (Stephenson and Yau 1992).

The fall of a large iron meteorite was observed in China in 1064 and recorded in the "Mêng Chhi Pi Than," "Dream Pool Essays" by Shen Kua in 1086 (Needham 1981, pp. 210–211):

In the first year of the Chih-Phing reign period, there was a tremendous noise like thunder at Chhang-chou about noon. A fiery star as big as the moon appeared in the South-east. In a moment there was a further thunderclap while the star moved to the south-west, and then with more thunder it fell in the garden of the Hsu family in the I-Hsing district. Fire was seen reflected in the sky far and near, and fences in the garden roundabout were all burned. When they had been extinguished, a bowl-shaped hole was seen in the ground, with the meteorite glowing within it for a long time. Even when the glow ceased it was too hot to be approached. Finally the earth was dug up, and a round stone, as big as a fist, still hot, was found, with one side elongated (i.e. pear-shaped). Its color and weight were just like iron.

Chadwick (1989) cites a passage from the Gilgamesh epic dating to the beginning of the first millennium B.C. translated by Tigay (1982, p. 270), which suggests a meteor falling to earth.

The Ionian philosopher Anaxagoras (b. ~500 B.C.) of Clazomenae, on the west coast of what is now Turkey, reported that during his 33rd year, a meteorite, which he regarded as a piece of the Sun, fell in broad daylight near the small town of Aegospotami. It was large enough to fill a wagon. He regarded both the stars and the Sun as incandescent stones, with the latter being larger than the Peloponnese.

Momentous events such as eclipses and fireballs have always impressed and awed people through history. To a religious person, all events are signs, a disposition that has resulted in pious and ethical behavior as well as astrological practice, as we note in §15. Meteorite falls as events that were taken as religious signs.

In the New Testament book of Acts, Paul arouses the passions of the artisans and merchants of Ephesus, who recognized the threat that Christianity posed to the worship of Artemis, and the business activity associated with it; the city is described as being the "temple keeper" of the goddess and of "the great stone that fell from the sky" (Acts 19:35).[34] Artemis was often depicted as a many-breasted goddess, a possible, if mythic, reference to the appearance of a large iron meteorite (see also comments by Wood 1968 or Wasson 1985).

The "image" of the Syro-Phoenician Sun-god, a black meteorite set among precious gems, was carried in a procession in Rome, when its priest, Heliogabalus, was named Emperor of Rome in 218 A.D.

The black stone of the Kaaba in Mecca, sacred to Muslims, has been suggested to be a meteorite also (Wood 1968, p. 2).

Dall'olmo (1978) notes many records of meteorites from medieval Europe: ~453 (Thrace); 874 ("very big stones"); 921 (Italy, "many stones"); 950/952 (Augsburg, "falling mass of iron"—"followed by noise"); 998 (~Magdeburg, "two inflamed stones"); 1094 or 1095 (Gallia, a meteor seen during a meteor shower fell into a marshy area and sizzled); 1135 (Duringia in Germany, a stone as big as a house half-buried itself and burned for three days, but, mysteriously, a "terrible" noise lasted three days before it fell); 1136 (Altesleibon in Germany, a stone the size of a man's head); 1143, June 15 (Mt. Brisach, fell from a clear sky in front of the church doors); 1481 (reported in Genoa that a stone of weight "1000" fell). An existing woodcut depicts a "thunderstone" observed to fall on the town of Ensisheim, Alsace, on November 7, 1492 (Wasson 1985, p. 3).

Dall'olmo's (1978) records include a number of references to meteors as dragons, as a result of sparks, flames, or smoke. The first such reference is to the Augsburg meteor of 950 or 952; others are recorded in the years 956 ("dragon without a head"); 1130 Oct. 15 ("*signum draconis*"; "*quoddam monstrum*" in two sources); 1202 Sept. 6 ("almost like a dragon"); 1239 July 24 (a bright star like Venus appeared at sunset, with fire and smoke left behind; also considered a comet and a dragon); 1241 July 11 (dragon with thin, red tail); 1280 Mar. 18 (a flying dragon with long tail, seen after a lunar eclipse). In addition, there are many references to writhing, snake-like tails, as the debris train encounters upper atmospheric winds. An astronomical source for the myth of the dragon is strongly suggested, but Oriental references are required to make the claim universal.

Despite overwhelming historical evidence, the notion that objects from space could actually fall to Earth was not readily accepted by the rational 18th century. After a report by Professors Siliman and Kingley, both at Yale, that a meteorite had been recovered at Weston, Connecticut, on Dec. 14, 1807, Thomas Jefferson is reputed to have commented acerbically that "it is easier to believe that two Yankee professors would lie than that stones would fall from heaven" (Wood 1968, p. 4). Although the comment has never been verified, a letter written by Jefferson two months after the sighting does discuss the matter, albeit expressing a more open view of the truth or falsity of the event (Wasson 1985, p. 4).

Many meteor craters are now known, and the meteors associated with several of these must have fallen during the past 50,000 years. Two small meteor craters (~100 m across, 12 m deep, and ~50 m wide, 9 m deep), amid smaller ones buried by sand dunes, were found in the *Rub' al Khali*, the "Empty Quarter," of Saudi Arabia during H. St. J. Philby's 1932 search for the "lost city" of Wabar, which was alleged to have been "destroyed by fire from heaven" (Baldwin 1963, p. 35) in Arabic traditions. Extensive iron meteorite fragments have been found in the area. More than a dozen craters have been found near Henbury, Australia; iron meteorites have been recovered, and the presence of extensive oxidation of the meteorites, and their C^{14} content, suggest ages of at least several thousands of years. The aboriginal

[34] The phrase "Αρτέμιδος και τοῦ διοπετους" (Nestle 1858/1953) is interpreted as "the image of Artemis fallen from Heaven" (Arndt and Gingrich 1952/1957, p. 198).

name for the place is *chindu chinna waru chingi yabu*, "Sun walk fire devil rock," and natives would not camp within miles of the craters (Baldwin 1963, pp. 28–29). In the beginning of the 18th century, nomads near Murgab in what is now Tazhikistan, witnessed the impact of two large meteorites. The craters are 80 and 16 m across, and the larger is 15 m deep. The area is called *Chaglan Toushtou*, "place where lightning fell." Odessa, Texas, and Haviland, Kansas, are sites of other craters of relatively recent age. Two major impacts were witnessed in Siberia in this century: in Tunguska, an explosion rated at $9 \cdot 10^{16}$ J, equivalent to a 22 Megaton bomb, occurred in 1908, and another observed on February 12, 1947, was rated at $\sim 7 \times 10^{13}$ J (Baldwin 1963), equivalent to 17 KT. A smaller such event may have taken place around the Peruvian-Brazilian frontier on the morning of August 13, 1930 (Bailey 1995). A delightful account and update is given by Huyghe (1996). These events do not appear to involve meteoroids (no major bodies have been discovered from the Siberian event despite extensive searches; the South American has been less well studied, but thus far nothing has been found). Small comets, loose aggregations of dust and ices with densities less than 1 g/cm^3, (1000 kg/m^3), would not easily survive impact intact and are likely candidates for the colliding bodies in these two cases.

With the widespread publicity received by the Levy-Shoemaker 9 cometary impacts on Jupiter, with more and more frequent reports of near-Earth trajectories by meteoroids, and with accumulating evidence for the impact theory of extinctions recorded in the geological record of the Earth's crust, the *catastrophism* theory of evolution (as opposed to *uniformitarianism*) has been resurrected, more than a century and a half after it was disdainfully dismissed by Charles Lyell (~1830) in his *Principles of Geology.* Impacts by asteroids or comets are now thought to have played a major role in the punctuation, so to speak, of the geological record. Further details on meteorite craters can be found in Hodge (1994).

5.7. Zodiacal Light

Dust is a common feature of the solar system. It is found even in the very high temperature (~2,000,000 K) solar corona, where its presence is revealed through the reflection of the spectrum of the solar photosphere. The dust is located predominantly in the ecliptic plane. Sunlight reflected from this dust is visible just after sunset or before sunrise along a tapered cone pointing upward from the horizon, along the ecliptic. It is called zodiacal light. It is best seen at the times of year when the ecliptic rises most steeply from the horizon. This means early evening in spring, and before dawn in the fall. Figure 5.17 illustrates the angle of visibility. It usually is not well seen from high-latitude sites, because of the angle of the ecliptic in autumn, and the lack of night sky in the summer. At high latitudes, it also competes with aurorae and air glow, a faint, diffuse emission from excited high-altitude atoms and ions.

A related phenomenon is the gegenschein or "counterglow." This phenomenon, which is usually difficult to see except at exceptionally dark and high-altitude sites, is a faint patch of light, opposite the Sun in the sky. It is believed that the gegenschein too has its origin in solar system dust, but here we see the dust at "full" phase, scattering sunlight directly back from the Sun. Its angular size is ~6° × 9°, and it varies in size by ~10%. It has been suggested that the Mesomerican "spider path to heaven" refers either to the zodiacal light or to the gegenschein (see §12.15).

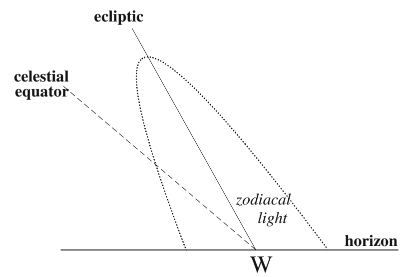


FIGURE 5.17. The springtime visibility (in the Northern Hemisphere) of zodiacal light. Drawing by E.F. Milone.

5.8. Variable Stars

A number of naked eye stars vary perceptibly because of a variety of causes. The most spectacular variables, which may brighten to hundreds of thousands of times the Sun's luminosity (in the case of novae) to billions of times brighter (in the case of supernovae), but are rare, we save for later. Here, we describe stars that vary because of geometry (eclipsing double stars, or rotating spotted stars), pulsations (causing more or less periodic variations due to changing temperature and size), eruptions (where material is ejected causing dimming or brightening), or some combination of these events causing irregular light variation. Table 5.9 lists the brightest of these variables that vary more than 0.2 magnitude (roughly, 20% light variation; see (5.2) below). An exception is Polaris, included because of its prominent place in the sky even though its variation is only ~15%. For completeness, other bright or short-period variable stars, with amplitudes too low to be included in Table 5.9, are listed below in alphabetic order of constellation name; the amplitude in visual magnitude and period in days (if known) are given in parentheses:

β Aur ($0.^{m}09$, 4d); β CMa ($0.^{m}07$, $0.^{d}25$); σ CMa ($0.^{m}06$); p Car = PP Car ($0.^{m}10$); q Car = V337 Car ($0.^{m}06$); β Cas ($0.^{m}05$, P = $0.^{d}10$); δ Cas ($0.^{m}08$, 759d); β Cen ($0.^{m}07$); δ Cen ($0.^{m}14$); β Cep ($0.^{m}11$, $0.^{d}2$); α CrB ($.^{m}11$, $17.^{d}4$); γ Cru A ($0.^{m}07$); β Cru ($0.^{m}08$, $0.^{d}7$:); δ Cru ($0.^{m}06$, 015); σ Lib ($0.^{m}16$); α Lup ($0.^{m}03$, $0.^{d}26$); α Mus ($0.^{m}07$,$0.^{d}1$); θ Oph ($0.^{m}04$, $0.^{m}14$); γ Peg ($0.^{m}07$, $0.^{d}15$); γ Phe ($0.^{m}10$); ρ Pup ($0.^{m}10$, $0.^{d}14$); η Sgr A ($0.^{m}04$); λ Sco ($0.^{m}06$, $0.^{d}21$); κ Sco ($0.^{m}03$, $0.^{d}2$); σ Sco A ($0.^{m}12$, $0.^{d}25$); ζ Tau ($0.^{m}13$); ε UMa ($0.^{m}03$, $5.^{d}1$); υ UMa ($0.^{m}18$, $0.^{d}13$); λ Vel ($0.^{m}08$); α Vir ($0.^{m}07$, multiple: $3.^{d}1$, $4.^{d}5$, $7.^{d}5$).

The name designations follow variable star usage when no naked-eye designation is used. Variable star names are determined by order of discovery within the constellation and, like the Bayer (Greek), Flamsteed (numbers), and Lacaille (Roman letters) designations, are followed by the Latin genitive name of the constellation. They start with the

TABLE 5.9. Bright, large-amplitude periodic variable stars.

Variable star	Class	(2000) α	δ	Sp	V_{max}	V_{min}	P
TV Psc (47 Psc)	semi-reg.	00 28	+17.9	M3 – 4	4.7	5.4	49[d]:
γ Cas	γ Cas	00 57	+60.7	B0	1.6	3.0	—
ζ Phe	ecl. bin.	01 08	–55.2	B6 + B9	3.9	4.4	2
ψ Phe	semi-reg.	01 54	–46.3	M4	4.3	4.5	30
o Cet (Mira)	Mira	02 19	–03.0	M5 – 9	2.0	10.1	332
α UMi A (Polaris)	Cepheid[a]	02 32	+89.3	F5 – 8	1.9	2.1	4
R Tri	Mira	02 37	+34.3	M4	5.4	12.6	267v
R Hor	Mira	02 54	–49.9	M7	4.7	14.3	404
ρ Per	semi-reg.	03 05	+38.8	M4	3.3	4.0	50:
β Per A (Algol)	ecl. bin.	03 08	+41.0	B8 + G5	2.1	3.4	3
BU Tau (Pleione)	γ Cas	03 49	+24.1	B8	4.8	5.5	—
λ Tau A	ecl. bin.	04 01	+12.5	B3 + A4	3.3	3.8	4
α Tau A (Aldebaran)	LPV:	04 36	+16.5	K5	0.75	0.95	—
R Dor A	semi-reg.	04 37	–62.1	M8	4.8	6.6	338:
ζ Aur	ecl. bin.	05 02	+41.1	B7 + K5	3.7	3.9	972
ε Aur[c] A	ecl. bin.	05 02	+43.8	A9 + (B)	2.9	3.8	9892
μ Lep	α CVn	05 01	–16.2	B9	3.0	3.4	2:
η Ori[d] Aab	ecl. bin.	05 24	–02.4	B1 + B	3.1	3.3	8
δ Ori A	ecl. bin.	05 32	–00.8	O9.5	1.9	2.1	6
β Dor	Cepheid	05 34	–62.5	F7 – G2	3.5	4.1	10v
α Ori[e]A	semi-reg.	05 55	+07.4	M1 – M2	0.4	1.3	2110
U Ori	Mira	05 56	+20.2	M6.5	4.8	12.6	372v
δ Pic	ecl. bin.	06 10	–55.0	B0	4.6	4.9	2
η Gem A	semi-reg.	06 15	+22.5	M3	3.2	3.9	233
ψ1 Aur	LPV	06 25	+49.3	K5 – M0	4.8	5.7	?
μ Gem A	LPV	06 23	+22.5	M3	2.8	3.0	—
ζ Gem	Cepheid	07 04	+20.6	F7 – G3	3.7	4.2	10
L2 Pup A	LPV	07 14	–44.6	M5	2.6	6.2	140
EW CMa[f] (27 CMa)	γ Cas	07 14	–26.4	B3	4.4	4.8	—
V Pup A	ecl. bin.	07 58	–49.2	B1 + B3	4.7	5.2	1.5
γ2 Vel A	WR	08 10	–47.3	WC + O9	1.6	1.8	154s
a Car	ecl. bin.	09 11	–59.0	B2	3.2	3.6	7
R Car A	Mira	09 32	–62.8	M4 – M8	3.9	10.5	309
ℓ Car	Cepheid	09 45	–62.5	F9 – G5	3.3	4.2	35
R Leo	Mira	09 48	+11.4	M8	4.4	11.3	312v
S Car	Mira	10 09	–61.5	K5 – M6	4.5	9.9	150
U Hya	semi-reg.	10 38	–13.4	N2	4.3	6.5	450:
η Car[g]	S Dor	10 45	–59.7	pec	–0.8	7.9	—
R Hya A	Mira	13 30	–23.3	M7	4.5	9.5	390
μ Cen A	γ Cas	13 50	–42.5	B2	2.9	3.4	—
ET Vir	semi-reg.	14 11	–16.3	M3	4.8	5.0	80
W Boo[h]	semi-reg.	14 43	+26.5	M	4.7	5.4	450
δ Lib	ecl. bin.	15 01	–08.5	B9.5	4.9	5.9	2
44 = i Boo B	ecl. bin.	15 04	+47.7	G2 + G2	6.5	7.1	0.3v
GG Lup	ecl. bin.	15 19	–40.8	B5 + A0	5.4	6.0	2
R CrB	R CrB[b]	15 49	+28.2	C0,0	5.8	14.8	—
χ Oph	γ Cas	16 27	–18.5	B2	4.4	5.2	—
α Sco A (Antares)	semi-reg.	16 29	–26.4	M1 – B4	0.9	1.8	1733
μ^1 Sco	ecl. bin.	16 52	–38.0	B2 + B7	2.8	3.1	1.4
κ Oph	LPV:	16 58	+09.4	K2	2.8	3.6	?
α Her A	semi-reg.	17 15	+14.4	M5	3.1	4.0	6y:
68 or u Her A	ecl. bin.	17 17	+33.1	B1 + B5	4.6	5.3	2d
V862 Sco[i]	γ Cas:	17 40	–32.2	B1 – 8	2.0	8.5	—
X Sgr	Cepheid	17 48	–27.8	F7	4.2	4.8	7v
W Sgr A	Cepheid	18 05	–29.6	F4 – G1	4.3	5.1	8v
δ Sct A	δ Scuti	18 42	–09.1	F3	4.9	5.2	0.2
R Sct	RV Tauri	18 47	–05.7	G0 – K0	4.6	8.2	144v
β Lyr A	ecl. bin.	18 50	+33.4	B7 + A8	3.5	4.3	13
λ Pav A	γ Cas	18 52	–62.2	B2	4.0	4.9	—
R Lyr	semi-reg.	18 55	+43.9	M5	3.9	5.0	46
κ Pav	Cepheid	18 57	–67.2	F5	3.9	4.8	9v
ε CrA	ecl. bin.	18 59	–37.1	F0	4.7	5.0	0.6
χ Cyg	Mira	19 51	+32.9	S6 – S10	3.3	14.2	407

Table 5.9. *Continued.*

Variable star	Class	(2000) α	δ	Sp	V_{max}	V_{min}	*P*
η Aql	Cepheid	19 52	+01.0	F6 – G1	3.5	4.4	7v
V695 Cyg (o1)	ecl. bin	20 14	+46.7	B4 + K4	3.8	—	3784
P Cyg[j]	S Doradus	20 18	+38.0	B2	3.0	6.0	—
T Cyg A	irreg.	20 47	+34.4	K3	5.0	5.5	—
V832 Cyg (59)	γ Cas	21 00	+47.5	B2	4.5	4.9	—
μ Cep A	semi-reg.	21 44	+58.8	M2	3.4	5.1	730
ε Peg[k]	irreg.	21 44	+09.9	K2	0.7	3.5	—
δ Cap A	ecl. bin.	21 47	–16.1	Am(F2)	2.8	3.1	1
VV Cep	ecl. bin.	21 57	+63.6	M2 + B8	4.8	5.4	7430
ε Oct	semi-reg.	22 20	–80.4	M6	5.0	5.4	956
δ Cep A	Cepheid	22 29	+58.4	F5 – G2	3.5	4.4	5v
β Gru	LPV:	22 43	–46.9	M3	2.0	2.3	?
β Peg A	LPV	23 04	+28.1	M2	2.3	2.7	?
λ And[l]	semi-reg.:	23 38	+46.5	G8	3.8	4.2	54

[a] A regularly pulsating variable star whose prototype is δ Cephei.
[b] An irregular variable characterized by sudden decreases in light caused by ejection of an obscuring, carbon-rich shell.
[c] Superimposed on the longer cycle is a $0\overset{\mathrm{m}}{.}24$-amplitude variation over a period of 110 days; eclipse appears to be due to a disk surrounding a hot, unseen companion.
[d] Multiple star system; "Aab" refers to double-lined spectroscopic binary making up visual component A; there may be additional variations due to sporadic episodes of pulsation of component b (amplitude $0\overset{\mathrm{m}}{.}05$; $P = 0\overset{\mathrm{d}}{.}3$).
[e] Betelgeuse's cyclicity varies from epoch to epoch; longer cyclicities are noted.
[f] Spectroscopic binary of $P = 0\overset{\mathrm{d}}{.}26$; variations due to one or more shells. There is a close visual companion also.
[g] In an emission nebula and near an open cluster, this massive, young star has an expanding dust shell. Maximum light was seen in 1843; since 1880, the visual brightness has been in the range $5\overset{\mathrm{m}}{.}9$–$7\overset{\mathrm{m}}{.}9$.
[h] A cycle of 30-day length is also reported.
[i] Flared for 40 minutes in 1965; usual range: $6\overset{\mathrm{m}}{.}67$–$6\overset{\mathrm{m}}{.}76$; in an open cluster.
[j] Brightest in 1600; since 18th century, range has been $4\overset{\mathrm{m}}{.}6$–$5\overset{\mathrm{m}}{.}6$.
[k] Flared for ~10 minutes in 1972; dimmed to $3\overset{\mathrm{m}}{.}5$ in 1847; usual range: $2\overset{\mathrm{m}}{.}29$–$2\overset{\mathrm{m}}{.}44$.
[l] Variation possibly due to starspot modulation. Spectroscopic binary with $P = 20\overset{\mathrm{d}}{.}6$.

letter R and proceed to Z; then they begin again with RR, RS, . . . , R Z; then, SS, ST, . . . , S Z; and so on until ZZ; when they start again with AA, AB, . . . , AZ, then, BB, . . . , BZ, etc., but avoiding combinations involving J, until QZ. Thereafter, the designations proceed in an uninterrupted numerical order: V335, V336, and so on. The nomenclature is thus a series of compounded mistakes based on inadequate appreciation of the number of variable stars in the sky—possibly a carryover from Greek notions of immutability in the skies by people unaware of their implicit assumptions. The suffix A or B after the name indicates the brightest or second brightest member of a visual double star, respectively. Such visual doubles need not be physical binaries, but simply lie along the same line of sight. For low-amplitude variability, as seen in these cases, the relationship between amplitude in magnitudes, Δm, and the proportional light variation, $\Delta\ell/\ell$, is

$$\Delta m = -2.5\Delta\log(\ell) = -2.5\log e\cdot\Delta\ln(\ell) \approx \frac{1.086\Delta\ell}{\ell}. \quad (5.2)$$

Because some variable stars are recorded in ancient literature, we are obliged to describe the classes of variables. First, we distinguish between stars with periodic and nonperiodic variations.

The two major types of periodic variable stars are eclipsing binaries and pulsating variables.

5.8.1. Eclipsing and Pulsating Stars

Eclipsing variables are binary star systems whose orbital plane just happens to lie perpendicular to the plane of the sky. The stars alternately eclipse each other, thereby cutting off each other's light. The amount of light lost at each eclipse depends on the surface brightnesses of the two stars; the eclipse of the star with the greater surface brightness[35] undergoes the deeper eclipse so that the system light is lowest at this phase. In European literature, the first report that the star β Persei or Algol varied in brightness was made by G. Montanari in 1669, but this bright star must have had multiple prior discoveries. That its popular name comes from the Arabic, *al ghul*, the demon, would seem to support this idea. The first known explanation for its variation in terms of a geometric effect—either a rotating spot on a star or an eclipse of one star by a companion—was given by J. Goodricke, in 1783, when he was about 18 years old. In 1784, he discovered the variation of β Lyrae and of the pulsating star δ Cephei. It is astronomy's loss that Goodricke

[35] Formally defined as the *radiance*, or the amount of energy radiated each second by a square meter of surface area into a unit solid angle at the source. See §3.1.2.1 for a discussion of the terms used to describe stellar brightness.

died only two years after these discoveries. One fainter eclipsing binary is included in Table 5.9: 44(i) Bootis, the brightest of the W Ursae Majoris system of binaries, more commonly called "contact systems." because their atmospheres are literally in contact. It is included because of its very short period (~6 hours). Eclipsing binary systems represent only a fraction of all binary star systems; many binaries are detected only because of traces of a second star in the spectrum or because changes in the Doppler shift of one or both stars' spectral lines can be seen, showing that the system is a single-lined or double-lined spectroscopic binary.

The earliest report of the periodic variability of a star is that of D. Fabricius in 1596, but essentially this was forgotten until in 1639 P. Holwarda rediscovered the variability of o Ceti, or Mira (or stella mira—star of wonder). Subclasses of pulsating stars include the Cepheids, the Mira or long-period variables (LPVs), the semiregular variables (whose periodicities are cyclic but not strictly periodic), and the RV Tauri variables that are pulsating stars with more complicated waveforms (many have alternating high and low maxima, for example). Pulsating stars with maximum brighter than 5th magnitude are included in Table 5.9. Pulsating variables are intrinsically variable. They undergo changes both in surface temperature and in size so that both surface brightness and surface area vary with time. A change in either causes a change in brightness. In the case of Mira, the temperature change leads to a change in the wavelength at which the star radiates the peak of its spectral radiation. As it expands and the outer layers cool, it radiates a greater percentage of its energy in the infrared, causing it to look much fainter than it actually is (the bolometric magnitude variation is much smaller than is the optical or visual light variation). In visual light, it is invisible to the naked eye long before it reaches the minimum of its light curve. It is difficult to believe that a star that varies so greatly in magnitude was not observed repeatedly by the careful watchers of the skies in ancient Babylon, China, India, and elsewhere.

Some pulsating stars are multiperiodic so that the light curve is a complicated combination of several superimposed waves, making periodicities more difficult to detect. The class of pulsating stars also includes stars that are referred to as "semiregular" (SR) and those whose light curves are merely cyclic rather than strictly periodic, so that the level of brightness may not be precisely predicted from cycle to cycle. The SR stars and at least some RV Tauri stars are among the latter. There are also periodic stars that vary in light because of their distorted shapes, for example, the ellipsoidal variables, which are thought to be tidally distorted close binary systems but that are not eclipsing systems (Morris 1985); others may vary because of the presence of variable dark or bright areas on their disks due to strong magnetic field effects modulated by rotation or, in binary systems, by the orbital period. The Sun could be considered a variable star on this basis, because it undergoes changes in brightness due to the effects of varying dark sunspots, as well as bright gaseous areas called plages and faculae. Earlier, we discussed the solar cycle briefly, but much longer term variation is possible too.

5.8.2. Irregular Variables

Table 5.9 includes the brightest of the irregular variables, whose sudden brightenings, or decreases in brightness, are unpredictable. They include the R CrB (for R Coronae Borealis) and S Dor (for S Doradus) classes. R CrB stars are known for sudden dips in brightness followed by slower recovery to normal levels; there is evidence for ejected clouds of carbon during such episodes. S Dor stars are supergiants that undergo shell ejection. The prototype for this class is S Doradus, among the most intrinsically luminous stars (Hoffmeister et al. 1985, p. 176); it is located in the Large Magellanic Cloud. Related to S Dor stars are stars that, although much closer to the main sequence in the Herzsprung-Russell diagram, also undergo shell ejection episodes. One of the better known stars of this subclass is the "shell star" P Cygni, discovered by W. Blaeuw in 1600. P Cygni underwent a visual brightness change of three magnitudes between 1597 and 1602. These variable stars are very luminous and blue, with large light amplitude and long time scales of variation. Spectra show evidence of past ejections of massive shells of gas. As is sometimes the case within classes of variable stars, the amplitude, time scale of variation, luminosity class, and spectral type of S Dor variables differ from object to object.

Another type of star shedding its atmosphere is the very hot Wolf-Rayet (WR) class; this kind of object too is observed to undergo irregular light variations.

The star γ Cass has an amplitude of 1.4 magnitudes (Hoffmeister et al. 1985, p. 178); its spectrum shows evidence of a rapidly rotating disk or shell. One of the Pleiades stars, BU Tau, better known as Pleione, undergoes shell ejection with a small light variation. Other stars in the Pleiades may also be shell stars, and some of the speculation about the "lost Pleiad" has involved this type of variability.

5.8.3. The Lost Pleiad

As Aratos of Soli (~3rd century B.C.) described the mystery,

> Seven in number are placed in record, but to our sight only six appear. It is not known for certain when the missing star disappeared. Nevertheless they each have their respective names. Alcyone, Merope, Celaeno, Electra, Sterope, Taygeta, and the queenly Maia. (cited in Payne-Gaposchkin and Haramundanis 1954/1970, p. 18)

The Aratus list has been used by medieval scholars to assign names to the individual stars of the Pleiades group that are still used today; it is far from certain, however, that they made the same identifications as were done in antiquity. The present naked-eye stars of the Pleiades are depicted in Figure 5.18.

In order of present-era brightness, they are as follows:

(1) Alcyone (otherwise called η Tau or HR1165, V = 2.87)
(2) Atlas (27 Tau = HR1178, 3.64)
(3) Electra (17 Tau = HR1142, 3.71)
(4) Maia (20 Tau = HR1149, 3.88)
(5) Merope (23 Tau = HR1156, 4.18)

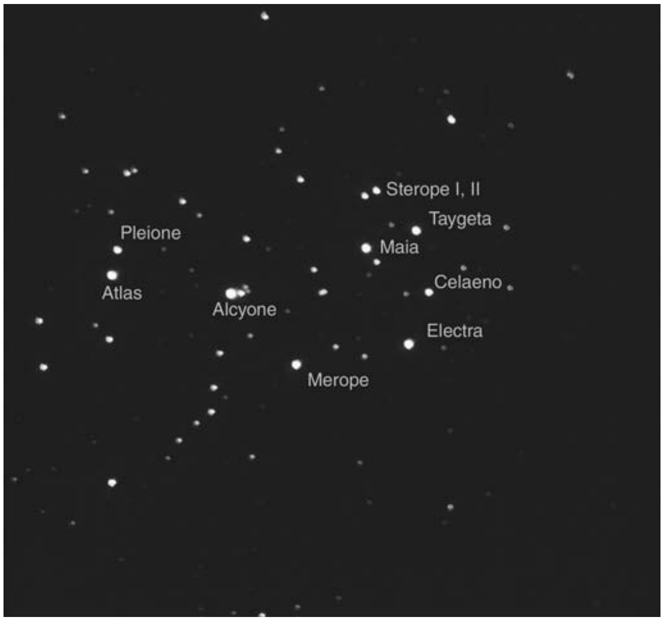


Figure 5.18. A telescopic photo of the Pleiades, from the RAO archives, courtesy of James T. Himer of Calgary. Labeling provided by E.F. Milone.

(6)	Taygete	(19 Tau = HR1145, 4.31)
(7)	Pleione	(28 Tau = HR1180, 5.09)
(8)	Celaeno	(16 Tau = HR1140, 5.46)
(9)	Asterope	(or Sterope = HR1151, 5.76)
(10)	Sterope II	(22 Tau = HR1152, 6.43)

Therefore, Aratos's list is not in order of brightness if the ancient names correspond to the modern names. Atlas (the father of the seven sisters) and Pleione are slightly to the east of the others and were clearly not in the original asterism. Aratos's list appears to be the order of the western group counted CCW, but Celaeno (16 Tau = HR1140, V = 5.46) and Electra are reversed, if current assignments are correct. If they are not, then following Aratos's list, Celaeno could be somewhere between, and possibly south of, 23 and 17 Tau, while 16 Tau, between (but not in line with) 17 and 19 Tau, could be a candidate for Sterope. There are other interpretations. E.C. Pickering [1846–1919], then director of the Harvard College Observatory, suggested that Pleione, a rapidly rotating B subgiant with a P Cygni spectrum, was the missing Pleiad,[36] having faded since earlier times. The idea is not implausible that shell stars, or as they are usually called, B_e stars (the "e" subscript signifies emission features in the spectra), are variable in large amplitude on very long timescales. McNamara (1987) found Atlas, Pleione, and Merope to be variable. Curiously, in Greek myth, Pleione was the wife of Atlas and the mother of the seven Pleiades and thus hardly qualified to be the missing Pleiad. Hertzog (1984, 1986) discovered a Hipparchos observation of the variable star V344 Car, indicating a previously unknown period of variability of greater than ~100 years. Hertzog (1987) argues, that Celaeno (16 Tau) is the lost Pleiad; he cites Asian depictions from the 7th to 13th centuries A.D., which show a seventh star as one of three south of the 19–20-η Tau line. This suggestion follows Needham (1959, p. 3, Figs. 93, 104, 106, 107). The three stars are presumably 16, 17, and 23 Tau (Celaeno, Electra, and Merope, respectively).

It is also interesting to note that the non-Pleiad, currently visible, B_e star, σ Tau, is missing from the Almagest list of bright stars and from the oldest Chinese records.

The bright star Electra has been a candidate solely on the basis of legend. As the mother of Dardanos, the founder of Troy, Ovid (in the *Fasti)* wrote of her that she hid her light in sorrow at the city's destruction; Hyginus [d. 10 A.D.] suggested that she left her place to wander off as a comet or to be a companion to Mizar (namely, Alcor = 80 UMa). Hyginus's suggestions are interesting. The first is reminiscent of the passage of Halley's Comet near the Pleiades during its 1985–1986 apparition, and one wonders if the suggestion came about as the result of a similar phenomenon in Hyginus's time. The latter is curious, because 80 UMa is not especially bright ($V = 4.01$), certainly fainter than Electra is at present. Among the Bugis mariners of Indonesia, the "lost Pleiad" is Antares (α Tau), but here the myth has navigational utility (see §11.3). Sterope I and Sterope II have also been suggested as the missing Pleiad, mainly on the basis of a 5th-magnitude assessment of the combined light of the pair by the Persian astronomer al Sufi [903–986] and through the circumstance that Ovid referred to the Pleiades as a whole as *Steropes sidus* (cf. Allen 1899/1963, p. 407). On the other hand, the Roman poet Valerius Flaccus is said to have used the name *Pleione* to refer to the Pleiades as a whole (Allen 1899/1963, p. 408); so these may be but instances of poetic license.

The star cluster is partially screened by nebulosity, which can be seen in time exposures, scattering, and obscuring some of its stars. The collective appearance of the many faint stars of a star cluster to the naked eye can convey the impression of fuzziness even in the absence of nebulosity. This may account for the comment by Ovid (in his Latin translation of Aratus's poem, the *Phainomena*):

> Six only are visible, but the seventh is beneath the cloud.

Supporting this view is a tale from the Nez Perce of the North American Plateau about the Seven Sisters, among whom the next to youngest sister was known as "Eyes-in-Different-Colors" (Miller 1997, p. 117). She loved a mortal, but at his death, she hid herself so that we now see only six of the sisters. (Note that if she represented the second faintest of the seven in order of current brightness, and Atlas and Pleione are excluded, Celaeno is suggested.)

However, even in antiquity, Hipparchos criticized Aratus for suggesting that

> Yet six alone are viewed by mortal eyes.

Hipparchos's comment is that

[36] Payne-Gaposchkin and Harmundanis (1970, p. 498) suggested the possibility also, because Pleione was already known to be a low-amplitude variable.

One star escaped his attention, for when the eye is attentively fixed on this constellation, on a serene and moonless night, seven stars are visible. (Allen 1899/1963, p. 408).

This comment, and the circumstance that the 7th Pleiad in our list of ranking according to brightness (including this time Atlas and Pleione) is of magnitude 5.09, suggests a visibility and perhaps acuity problem for some observers, but intrinsic long-term variation by one or more stars cannot be ruled out. The matter is further confused when one considers that to a sharp eye, the current brightnesses of stars may permit 12 or more to be seen. Allen (1899/1963, p. 410) cites claims of 9 to as many as 16 (Johannes Kepler reported that his student, Michel Möstlin, could see 14), and one of us (DHK) claims to have been able to see 11 on dark, clear nights in his youth. Presumably, the relative contrast plays a role in judging the visibility of the 7th star because most modern observers can see only six Pleiads. It is possible that light pollution at observing sites was worse than we might wish to imagine (see comments in §3.1 about effects of cooking fires even outside urban centers), and that six or maybe seven stars were as many as could be discerned under most circumstances. This would suggest that an additional star was (usually) somewhat more prominent in Aratus's day than are the fainter alternatives today, and perhaps fainter than Hipparchos found in his day.

5.8.4. Variation Due to Evolution and a Sirius Mystery

There is sufficient spread in the brightness of stars of approximately the same mass and stage of evolution as the Sun to suggest that much longer term changes in the brightness and energy output of stars, including those like the Sun, are likely. At present, a former major problem in astrophysics, the solar neutrino question has just been solved. Techniques for detecting the elusive neutrino, which is produced during the thermonuclear reactions that are thought to be the Sun's present energy source, have yielded significantly lower detection rates than have been predicted (~1/3), although recent studies in Japan and Canada using pure and heavy water chambers that detect different types of neutrinos indicate that the deficit no longer exists. Had the deficit been real and the condition were to persist for a long enough time, the Sun would begin to collapse under its own weight as the interior radiation and gas pressure began to wane; this slow collapse would initiate increases in the heat energy of the interior that would lead to expansion of the outer layers, changing both color and brightness of the Sun. Increased heating in the interior would cause nuclear burning to increase as temperatures and pressures became sufficiently high. Five billion years from now, when the Sun has thoroughly exhausted the reserves of hydrogen in its deep interior, it will, according to well-accepted theory, become a red giant. Red giants eventually lose their outer envelopes, leaving the core of the star visible. The process requires of order 10^7 to 10^8 years or so for most stars, depending on of stellar mass, from the shell ejection, and the creation of a "planetary nebula," to the white dwarf state. At that point, it will be a white dwarf.

Are there any instances in which stars have undergone shorter time scale changes than evolutionary time scales would require? Here is a case in which historical astronomy may provide an answer. There is the interesting case of Sirius, a white star now, but often described as red in ancient times. This is interesting because Sirius is a binary star system, with one white main sequence star, Sirius A, which is also the brightest star in the sky (after the Sun), and a white dwarf companion, Sirius B. The white dwarf companion has a surface temperature of 27,000 K but is about 10 magnitudes or 10,000 times fainter than is Sirius A. This huge luminosity difference requires that it have very little surface area: only about that of the planet Earth. Yet, Sirius B has a mass about equal to that of the Sun, so that it must be a very dense object. Its progenitor was likely the more massive of the two components, originally. More massive stars evolve more quickly than do less massive ones, and so Sirius B had to undergo the transformation to the red giant stage, lose its envelope, and go through what is called the planetary nebula stage, before arriving at its current state. But the process requires of order 10^7 to 10^8 years from the shell ejection to the white dwarf state for stars of mass typical of the Sirius B progenitor. How then could it have been a red giant only 2000 years ago? We will return to this question again, but first we ask two reasonable questions: "How reliable are the reports of a color change?" and "Are we interpreting the reports correctly?"

Although the Chinese references in connection with this star use the word "white," the term may actually apply to a direction, because each cardinal direction was associated with a color (white for west, red for south). In ancient China, colors were also associated with planets (see §§10.1.4 and 10.1.5, especially, Tables 10.4 and 10.8), however, and it is instructive to see the association: Mercury-Black, Jupiter-blue, Venus-white, Mars-red, and Saturn-yellow. One can speculate about the origin of the correspondence, but it may have some basis in observation—at least for the last three planets. The color of Jupiter has been described as white (for example, in Mesopotamia), so perhaps blue is not too wide a stretch, but Mercury-black would seem to be a problem, unless an optical aid had been used to observe the transit of Mercury across the face of the Sun (see §3.4). By contrast to the Sun's surface, it certainly looks black. However, because the Chinese were associating five categories of many different phenomena, no direct association between the colors and the planets may be intended. In the Astrological Treatise of *Sima Qian* (cited in Walters 1992, p. 191), there is a suggestive phrase, "When the Wolf changes colour, there will be much piracy and theft." The "Wolf" is a "large star in the East," identified as Sirius, and a color change in this context could easily refer to low-altitude seeing effects and other atmospheric phenomena. In any case, if China were the only source of color information about Sirius, there would be little else to say. It is not. For example, a Babylonian source from 800 to 700 B.C., describes the object as *kak-si-di*, or "shines like copper."

Classical references are abundant. A host of classical writers, among them Homer, Hesiod, Aratus, Virgil, Horace, Seneca, Pliny, Geminus, Ptolemy, Theon, and Cicero, refer to the star as being red, the color of angry Gods. The comments of the astronomer Geminus are particularly telling, for he criticizes the idea that a red star like Sirius should have any more influence than one of any other type. Ptolemy describes this star in Canis Major as "The star in the mouth, the brightest, which is called 'the Dog' and is reddish" (Toomer 1984, p. 387). The word translated as "reddish" may mean "red" or possibly "yellow," but it certainly does not mean white.[37] On the other hand, there are corruptions in the texts that were recopied several times before reaching Europe, and some of the manuscripts refer to only five red stars. Hertzog (1987) argues that the red Sirius description "should not be taken seriously" (no pun intended here!) because of the many mistakes in Ptolemy's catalog and the fact that the data were not from Ptolemy's observations (see §7.2 for further discussion of Ptolemy and the Almagest). Even if all of this were correct, any copyist insertion of the color of Sirius raises questions of motive, and anyway, Ptolemy is hardly the only source of such information. The comments of the classical writers seem to put Sirius in the same category as Mars and Antares (see Tables 3.1 and 3.2 for their colors). Seneca (cited in Brecher 1979, p. 97) noted that the Dog Star was redder than Mars, and that compared with these two, Jupiter was not red at all.

To add to the difficulties, Schlosser and Bergmann (1985) cite an 8th-century manuscript of Gregory of Tours that describes an object assumed to be Sirius as "Rubeola" and "stella splendida" (although it has been suggested that the star that was described was not Sirius but Arcturus, because of its times of visibility). It is important to clarify the identification because the first unambiguous reference (known to us) to Sirius as a white star is by Al Sufi (fl. ~980 A.D.),[38] who describes the other five red stars in Ptolemy's catalog as indeed being red.

Moreover, there are several other cultures in which Sirius seems to have been described as red: Among the African Dogon, the Polynesians, and the North American Pawnee, a star that is probably Sirius is traditionally described as "red."

In our summary of historical evidence, we are also permitted to bring in our experience concerning color extinction and seeing effects. A color photograph of Sirius setting in the Southern sky of Alberta, at latitude 51° shows that atmospheric color extinction (see §3.1.2.2) is probably not the answer, because Sirius is clearly seen to look white compared with Betelgeuse, which is much higher in the sky (Figure 5.19). To this we can add other blue or white stars, such as Rigel (β Ori), which ought to undergo similar reddening effects in the same season of the year, but no source ever describes it as red. Finally, as Brecher (1979, pp. 98–99) notes, α Centauri, which was only a few degrees above the horizon at Alexandria, and therefore most susceptible to such reddening, is not described as red in the Almagest.

We conclude that the bulk of the evidence supports a literal red Sirius interpretation, but the discussion of the subject indicates that some degree of doubt still lingers. We now return to the question of the time scale of stellar evolution and an astrophysical explanation for such a rapid metamorphosis.

Astrophysical attempts to model the evolutionary behavior of the system indeed may be able to provide a solution (Bruhweiler et al. 1986). Stellar structure and evolution models reveal that the structure of the core of a well-evolved star is a bit like an onion, with a raw hydrogen layer on top and layers of helium and carbon beneath. If the hydrogen is able to diffuse down into the hotter carbon region, a thermonuclear runaway could be generated that would lead to a retracing of the star's evolution back through the red giant branch, and making the star that became Sirius B to appear as much as 100 times more luminous than Sirius A. This would suffice to make the combination appear red and not white. The length of time for it to remain in such a state would depend on the extent of the hydrogen overlay region; hundreds of years would be possible for an envelope mass of only $10^{-4}\,M_\odot$ before it reverted to the white dwarf state. The diffusion-induced nuclear burning in this scenario is most likely in a white dwarf with surface temperature near 30,000 K, which is the case for Sirius B, one of the hottest white dwarfs known.

The scenario has at least one major impediment, however: a 100 : 1 brightness ratio of a red giant to Sirius A. The combination would have a combined magnitude of $V \approx -6.5$. Such brilliance would make it brighter than Venus at that planet's impressive maximum, but its brightness is recorded by Ptolemy, and there is no evidence for any great change in the overall brightness of the Sirius system. Thus, theory may have provided part of the solution, but the final resolution requires sufficient fine-tuning of the models to demonstrate a reddening without much brightening. At present, a final solution to the problem has not yet been found.

Regardless of the short-term evolution of Sirius B, there was still ample evidence of the mutability of the heavens to all who were attentive to it: the novae and supernovae.

5.8.5. Novae and Supernovae

A *nova* is a "new star" only in that it may have suddenly become visible in the sky; in actuality, it is in the late stages of stellar evolution. The name indicates that this fact has been recognized only in modern times. A nova candidate is typically a white dwarf component in a binary star system; its destiny is to violently expel material thrust on it by its companion star. The evolution of the companion of the

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[37] The same word, υποκιρρος, was used to describe Aldebaran (α Tau), Antares (α Sco), Arcturus (α Boo), Betelgeuse (α Ori), and Pollux (β Gem), all orange or red stars (see Table 3.1).

[38] Roger Ceragioli (1992) contends that the red color referred to so often in classical writings refers to a purely astrological association with Sirius, and that two classical writers, Manilius and Avienus, refer to Sirius as "sea-blue." The astrological associations among Sirius, dogs, wolves, fevers, the Sun, and excessive heat (the heliacal rising of Sirius was in July, the hottest and driest time of year in Greece and Rome), have only one counterpart in reality, according to this interpretation: varicolored twinkling near the horizon. Ceragioli cites the words of the Hellenistic Theban astrologer Hepahaestion interpreting Egyptian beliefs that if Sirius "*rises bright and white and its appearance shines through, then the Nile will rise high and there will be abundance, but if it rises fiery and reddish there will be war*," which could suggest both that Sirius was basically white, and that atmospheric effects alone made it appear red.

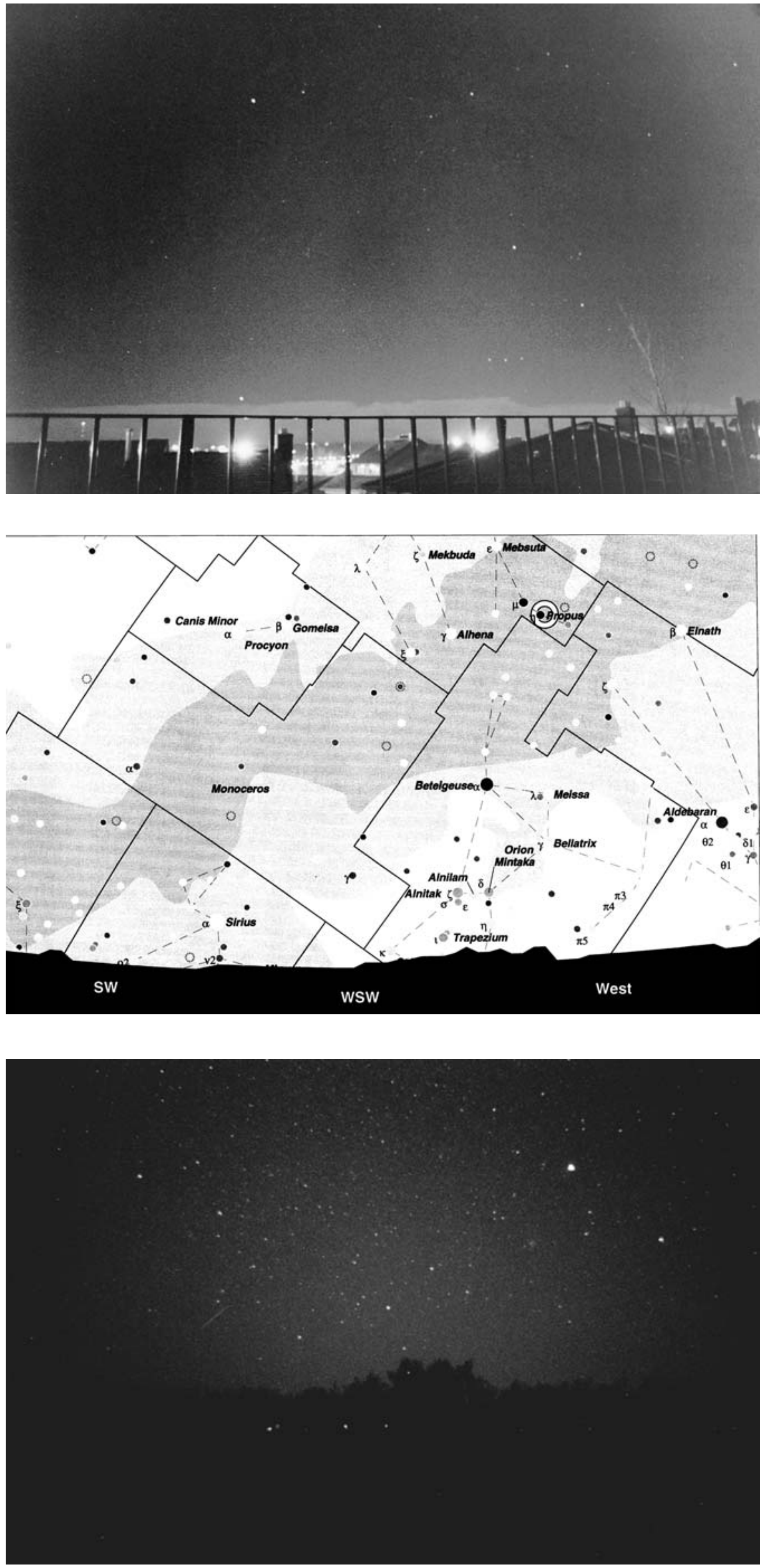


FIGURE 5.19. The winter sky showing Sirius and Betelgeuse near the horizon: (a) Short exposure, Calgary, December 25, 1987, at ~5 A.M. Photo by E.F. Milone. (b) Simulation with TheSky software; red stars appear dark. (c) A deeper exposure, showing many fainter (and redder) stars, but at higher altitude. Photo courtesy of Tammy Dugan of Calgary.

Table 5.10. A sample of the brighter novae.

Name	Type[a]	α (2000) δ	Max	Min	P_{orb}	Outburst(s)
GK Per	Nova	03^h31^m +43.9°	+0.2	14.0		1901
SS Lep	Z And	06 05 −16.5	+4.8	5.1	258d	
CP Pup	Nova	08 12 −35.3	+0.5	>17		1942
T Pyx	Rec.	09 05 −32.4	+6.3	14.0		1890, 1902, 1920, 1944, 1966
T CrB	Rec.	16 00 +26.0	+2.0	10.8	$227^d.6$	1866, 1946
V841 Oph	Nova	16 40 −12.9	+4.3	13.5		1848
RS Oph	Rec.	17 50 −06.7	+4.3	12.3		1898, 1933, 1958, 1967, 1985
V603 Aql	Nova	18 49 +00.1	−1.4	12.0		1918
V1500 Cyg	Nova	21 12 +48.2	+1.7	20.8	$0^d.141$	1975
AG Peg	Nova	21 51 +12.6	+6.0	9.4	800d	1870

[a] rec. designates a recurrent nova; Z And is a type of symbiotic variable star—a complex interacting binary star system probably involving a hot dwarf star encircled by a disk fed by a gas stream produced by the companion red giant star.

white dwarf is slower because of a mass difference between the pair. The more massive the object, the faster the evolution. As we have mentioned already, the process of stellar evolution causes a star, sooner or later, depending on its mass, to expand into a red giant. When it does so in a binary star system, the red giant envelope material facing the other star may be as equally attracted to that other star as to its own, and with the outward pressure, it begins to stream or spiral down onto the other star. The star that is currently the white dwarf would have had to undergo this process, losing mass both to its companion and to the outside universe. The mass gained by the companion helped it to evolve faster, and eventually, to return mass to the (now) white dwarf. There is a big difference, however, in the way this mass is received by the white dwarf, and how the receiver deals with it. As the material, mostly in the form of hydrogen gas, spirals downward in the gravitational field of the white dwarf, it heats up and overlays the surface matter of the white dwarf. Mixing with still hotter material in the interior of the white dwarf ignites a runaway thermonuclear explosion, burning the fresh hydrogen. The resulting fireball greatly exceeds the size of the area of the white dwarf and may increase the brightness of the system by 10,000 times or more. It is likely that all novae are members of binary star systems. If it is always the case, then all novae are recurrent to some extent, but the interval cannot be predicted with much precision, because it depends strongly on the transfer rate. The rate of mass transfer varies from system to system, and material may be "stored" in an accretion disk around the white dwarf component for some time before a cataclysmic eruption again takes place. It may take years or centuries or even longer, with some systems erupting much more frequently than others. Novae reach peak brightness in a few days or less and may slowly decline for hundreds of days or so before reaching the former level of faintness. One of the brightest recent novae was V1500 Cygni (Nova Cygni 1975) that, at peak brightness was visible in the twilight sky along with the stars of the summer triangle.[39] It declined below the naked-eye limit (~6th magnitude) within about three months. The rates of decline of novae are tied to their brightness—the greater the peak brightness, the quicker the initial decline. As a consequence, novae are often classified as "fast" or "slow." About 10 novae per year are estimated to occur in the galaxy.

[39] Altair, Deneb, and Vega.

Table 5.10 lists some of the brighter novae and novae-like objects of recent times. The positions are to the equinox 2000. Note the frequencies of recurrence documented for T Pyxidis and RS Ophiuchi. Recurrence is also suspected among the eruptive variables classified as "novae," which were recorded by ancient astronomers as well.

A selected sample of the historic eruptive variables is provided in Table 5.11, where "rec." means the star has been observed to be a recurrent nova, and Z And is a type of symbiotic star—a system in which there is evidence of a hot blue object and a cool giant star that interact.

In the Chinese chronicles from the middle of the Han dynasty onward, novae are listed as *kho hsing*, "guest stars," presumably because they are not seen to have taken up permanent residence in the sky once they appear. These stars are distributed on the sky in the same way as modern novae, verifying that in the main, these records do in fact refer to galactic objects and are not astrological inventions. The oldest record of a nova may be the inscription on an oracle bone (from an ox), dating from 1300 B.C. According to the translation provided by Needham/Ronan (1981, pp. 205–206), the inscription states, in part, that "On the 7th day of the month a *chi-ssu* day, a great new star appeared in company with Antares." Another inscription from the same period reads that "On a *hsin-wei* day, the new star dwindled" (or "disappeared"). The day referred to, *hsin-wei*, is two days after the day, *chi-ssu*, but the names repeat at 60-day intervals (see §10.1.2.1 for a discussion of the Chinese sexagenary cycles), and we do not know if the inscriptions refer to the same event. Among the many other guest-stars recorded are four we today would consider supernovae.

Most spectacular of all the eruptive variables are the supernovae. A true cosmic catastrophe, a supernova explosion means the destruction of a star. The increase in brightness may be up to hundreds of millions of times. From the

TABLE 5.11. A sample of ancient novae.

Year	α (2000) δ	Source	Comments
532 B.C. (Spring)	20^h50^m −10°	Bamboo Annals; Tso-chuan; Shih-chi	Oldest firm observation
204 B.C. (Aug.–Sept.)	14 20 +20	Han History; Wên-hsien t'ung-k'ao	Near α Boo. Poss. recurrence on Apr. 27, 575 A.D.
134 B.C. (June–July)	16 00 −25	Han-shu (Han History)	Guest star (k'o hsing)
77 B.C. (Oct.–Nov.)	11 10 +75	Han-shu	Guest star
48 B.C. (May)	18 40 −25	Han-shu	"Blue-white"
5 B.C. (Mar.–Apr.)	20 20 −15	Han-shu	"Star as large as a melon" "Sweeping star" (hui-hsing) visible more than 70 days
29 A.D.	17 15 +15	Biography of Yen Kuang in Hou Han-shu (History of later Han dynasty)	Near α Her; guest star. Pos. recurrent nova (June, 911 A.D.)
70 (Dec.–Jan.)	9 40 +25	Hou Han-shu	Guest star in Leo; visible 48 days
101 Dec. 30	9 35 +35	Tung-han hui-yao; Hou Han-shu; T'ung-k'ao	"Small guest star" near 40 Lyn, "blue-yellow"
304 (June–July)	4 20 +15	Chin-shu; T'ung-Chih; T'ung-k'ao	"Guest star" staying at Pi (Hyades)
305 (Sept.)	~4h ~+20	T'ung-chih	"Star sparkling at Mao and Pi" (Mao = Pleiades)
722 (Aug. 19)	1 00 +60	Japanese sources	"Guest star" near Kaku-do (δ, ∊ Cas), visible 5 days
827	~17h ~−30	Arabic sources	Possible supernova

light curves, there are at least two types of supernovae, with differing initial chemical compositions. Type II have the somewhat greater abundance of metals.[40] They are the end points of evolution of very massive stars whose inevitable internal collapse is brought about by the exhaustion of exothermic nuclear fuel. With sudden collapse, the fresh fuel in the outer layers falls into much higher temperature regions, resulting in a catastrophic explosion that can either shatter the entire star, leave only a very high density core remnant,[41] or compress the inner core into a black hole.[42] Supernovae are rare events—occurring at a typical frequency of a few per galaxy per century. The Milky Way galaxy is overdue for another occurrence—the last recorded supernova was that described by Kepler (and other astronomers around the world) in the constellation of Ophiuchus in October 1604. Table 5.12 lists the known and strongly suspected cases of supernovae in our galaxy (and in the Magellanic Clouds). The latter are separate galaxies but are close enough for the supernova discovered by Ian Shelton in 1987 to be visible to the naked eye.

Ancient observations of supernovae can aid modern astrophysics! First, the identification of the moment of explosion helps to determine the distance as well as the age of the object. We can make use of the basic relationship between arcs and angles (§2.2.4): The angular size (α) of the object in the sky depends on both the physical size, (say, diameter, D) and the distance (r), $D = \alpha \times r$. Second, the rate of expansion as measured by Doppler shifts of spectral lines can be compared with the rate of nebular expansion to reveal the rate of deceleration of the nebulosity (the rate at which it slows as it leaves the star due to the gravitational pull of the remnant). This provides information about the environment of the supernova and the mass of the remnant core, if any. Finally, estimates of the observed brightness of the supernova and the rate at which it fades provide its luminosity. At present, there are long-standing questions about the reliability of supernovae as standard candles; therefore, each one that can be calibrated provides more evidence for the potentially brightest of all standard candles. The distance scale of the universe is at stake in the correct resolution of this question.

Table 5.12 lists candidates for supernovae that are recorded in ancient records. Most of the data in Table 5.12 are taken from Hsi Tsê-Tsung (1958), Clark and Stephenson (1977), or Stephenson and Clark (1978). These include the date and location in the sky with western identification and modern right ascension and declination, the maximum brightness in visual magnitudes, and the historical sources of the data. The peak brightness was determined by Stephenson and Clark from the records or on the basis of the duration, to which the peak brightness is related. The brightest supernova ever recorded (as far as we know) was that of 1006, which was visible in broad daylight. See §15.2.2 for a discussion of possible supernova sightings in connection with the Star of Bethlehem.

Tycho's "Star" of 1572 in Cassiopeia was discovered just prior to Kepler's "Nova." This was an important observation because Tycho demonstrated that the lack of parallax implied a distance greater than that of the Moon. This was indeed a sign of the mutability of the heavens, and a blow

[40] Astrophysically, in this context, the term 'metals' refers to all elements heavier than Helium. Types I and II supernovae belong to star populations II and I, respectively. Population II stars are older, less confined to the galactic plane, and have less metal content than do Population I stars.

[41] A "neutron star" is so-called because its density is like that of the nuclear component itself—electrons and protons so closely packed together that they are forced into neutron mergers! The mass of such a star (≈1 solar mass) is compressed into a sphere only a few 10's of kilometers in diameter. A spinning neutron star can be detected as a radio (and sometimes also an optical or x-ray) pulsar. A pulsar at the location of SN1987a was detected in February 1989.

[42] This refers to an object with so strong a gravitational field that light cannot escape from it. First described by Laplace as a "corps obscure," several candidates are contained in binary star systems, where their masses, although not directly seen, exert gravitational force on their visible companions. There is strong evidence for very massive black holes at the centers of at least some galaxies, and for a modest-sized black hole at the center of the Milky Way galaxy.

TABLE 5.12. Possible supernovae in ancient records.

Dates	Name/location	Max	Source/remnant evidence
185/6 (Dec. 7–July)	Nanmên, between α & β Cen (14h29m, −60°)	−8	Chinese (*Hou Han-shu*, *T'ung-k'ao*) Optical; radio
386 (Apr.–Aug.)	Nantou (Sag.) (18 30, −25)	?	Chinese (*T'ung-chih*, *T'ung-k'ao*). Radio, x-ray; pulsar
393 (Mar.–Aug.)	Wei (Sco) (17 10, −40)	−1:	Chinese (*Chin-shu*, *T'ung-chih*, *T'ung-k'ao*). Possible radio
1006/8 (Apr. 3)	Tienti or Ti ~ Lupus (15 10, −40)	−9.5	Chinese (*Yü-hu ch'ing-hua*, *T'ung-k'ao*, *Sung-shih*); Japanese (*Meigetsu-ki*); European (Hepidanus; Barhebraeus). Optical, x-ray, radio
1054/5 (June 10)	T'ien-kuan, S.E.; Crab Nebula/Tau (05 40, +20)	−5	Chinese (*Sung-shih*); Japanese (*Meigetsu-ki*); North America? (Fern Cave; Chaco Canyon)—see text. Optical, x-ray, radio; pulsar
1181/2 (Aug. 6–Feb. 6)	K'uei (And, Psc) (01 40, +70)	0	Chinese (*Sung-shih*, *T'ung-k'ao*, *Chin-shih*); Japanese (*Azumakagani*, *Gyokuyo*, *Meigetsu-ki*, *Hyakuren-sho*). Optical, radio
1572/4 (Nov. 8–May)	Tycho's Star/Cas (00 20, +65)	−4	Chinese (biography of Shên-tsung from *Ming-shih*, preface of Ming Ting-wen) European (Tycho Brahe); Korean. Optical, x-ray, radio
1604/5 (Oct. 10–Oct. 7)	Kepler's Nova/Oph (17 30, −20)	−2.5	Chinese (*Ming-shih*, *T'ung-k'ao*) European (J. Kepler). Korean (*Sŏnjo Sillok*). Optical, radio
1885	S And (M31)	+5	Modern
1987	SN1987A (LMC)	+4	Modern

against the Aristotelian view of the heavens as changeless and perfect. It was not, however, the first such event to be witnessed and recorded in human history.

The best-known supernova remnant is the Crab Nebula—a product of the supernova of July 1054. This particular supernova will be discussed further in §13.1 under North American astronomical representations, because there is evidence for its depiction on the roof of a rock shelter in Chaco Canyon, New Mexico (see Figure 13.1), and at least one other site, Fern Cave, California. A Mimbres pot from New Mexico may bear another representation (§13.1). Among the known extant records of supernovae in far Eastern annals are those of 1006, 1054, 1572, and 1604. All but the 1054 SN were noted in Western Europe; of the 1054 SN, however, there is no obvious trace (see §5.8.6 below, however, for a reevaluation). The identification of the 1054 SN in Chinese records indicate that it was as bright as Venus (Needham/Ronan 1981, p. 205). The expanding gas cloud that was the star's envelope—the Crab Nebula—is still visible, and from its angular size and rate of expansion, its age can be determined, assuming that the expansion velocity has been constant. This assumption is not exactly right, but the resulting age is in reasonable agreement with the date of the records (there are actually five records of it). The guest star was reported as having disappeared in April 1056. This "guest star" appears on the Su Chow (*or Suzhou*) star chart (Figure 10.7) from Sung Dynasty, China, ~1193 A.D. (see §10.1.2.3, and §10.1.7 for context). The text from the *Sung Hui Yao*, "History of the Administrative Statutes of the Sung Dynasty," is interesting for at least two reason: It mentions the color of the star, and it throws light on the motivation for performing this kind of work:

> In the fifth month of the first year of the Chih-Ho reign period, Yang Wei-Tê (Chief Calendar Computer) said, 'Prostrating myself, I have observed the appearance of a guest star; on the star there was a slightly iridescent yellow color. Respectfully, according to the disposition for emperors, I have prognosticated, and the result said, 'The Guest star does not infringe upon Aldebaran; this shows that a Plentiful One is Lord, and that the country has a Great Worthy.' I request that this prognostication be given to the Bureau of Historiography to be preserved. (Needham/Ronan 1981, p. 207)

The yellowish color mentioned in the text is the eye's response to a star that has a strong red component to its color; as observational astronomers can attest, "yellowish" is an appropriate color description of even M spectral class red stars as viewed from dark, mountain-top sites. In the case of the nova, an important source of the red component is the very strong emission line radiation at 656.3 nm (the principal line of the Balmer series, Hα, of atomic hydrogen).

5.8.6. Mutability of the Heavens and the 1054 Supernova

We referred earlier to the absence of any Western European records for the Crab supernova event. Needham/Ronan (1981, p. 107) and others suggest that this was due to a predisposition in medieval Europe to deny changes in the heavens. Indeed, studies of medieval European chronicles, kept principally by monasteries, have revealed a paucity of observations of such phenomena as novae, sunspots, planetary conjunctions, occultations, and appulses (Stephenson and Clark 1978, p. 7). Because the few cases that are mentioned provide few details, it can be argued that the chroniclers may simply reflect the lack of interest of their times in such phenomena.

However, there is evidence of interest in the behavior of objects in the sky. First, the monasteries of Europe had cause to observe the heavens in order to keep the hours, for purposes of prayer, fasting, and the order of the day. During the night, an elaborate series of decanal-like asterisms was employed. A manual describing the stars and the process was created by Gregory of Tours for his monastic order (see McCluskey 1990), and there were undoubtedly others.

Second, natural phenomena are frequently, if sporadically, mentioned. Although the monastery chronicles of the British Isles tend to emphasize the deaths of nobles and military action, natural events are also often recorded. Thus, in 1008, the Ulster Annals note that there was severe frost and snow from 6th of the Ides [8th] of January to Easter [Mar 28]; and in 1021, "a shower of wheat" is reputed to have fallen in Osraigi; in 1037, "very wet stormy weather this year" is recorded; in 1047, a great snowfall lasting from the Feast of Mary (in the winter) [Dec. 8] to the Feast of Patrick [Mar. 17], "the like of which was never experienced before and it caused the death of many people and cattle and sea-beasts and birds"; and in 1056, lightning killed three people at one locale and a student at another and broke down "the ancient tree."

Third, there are astronomical records from the 11th century. The age of the Moon is frequently mentioned at the start of the year, for example, the first entry in the *Annals of Inisfallen* (AI) for the year 1054 reads

> The Kalends of January on Saturday, and the eighteenth day of the moon thereon. The one thousandth and fifty-fourth year from the incarnation of Christ. The second year after the bissextile.

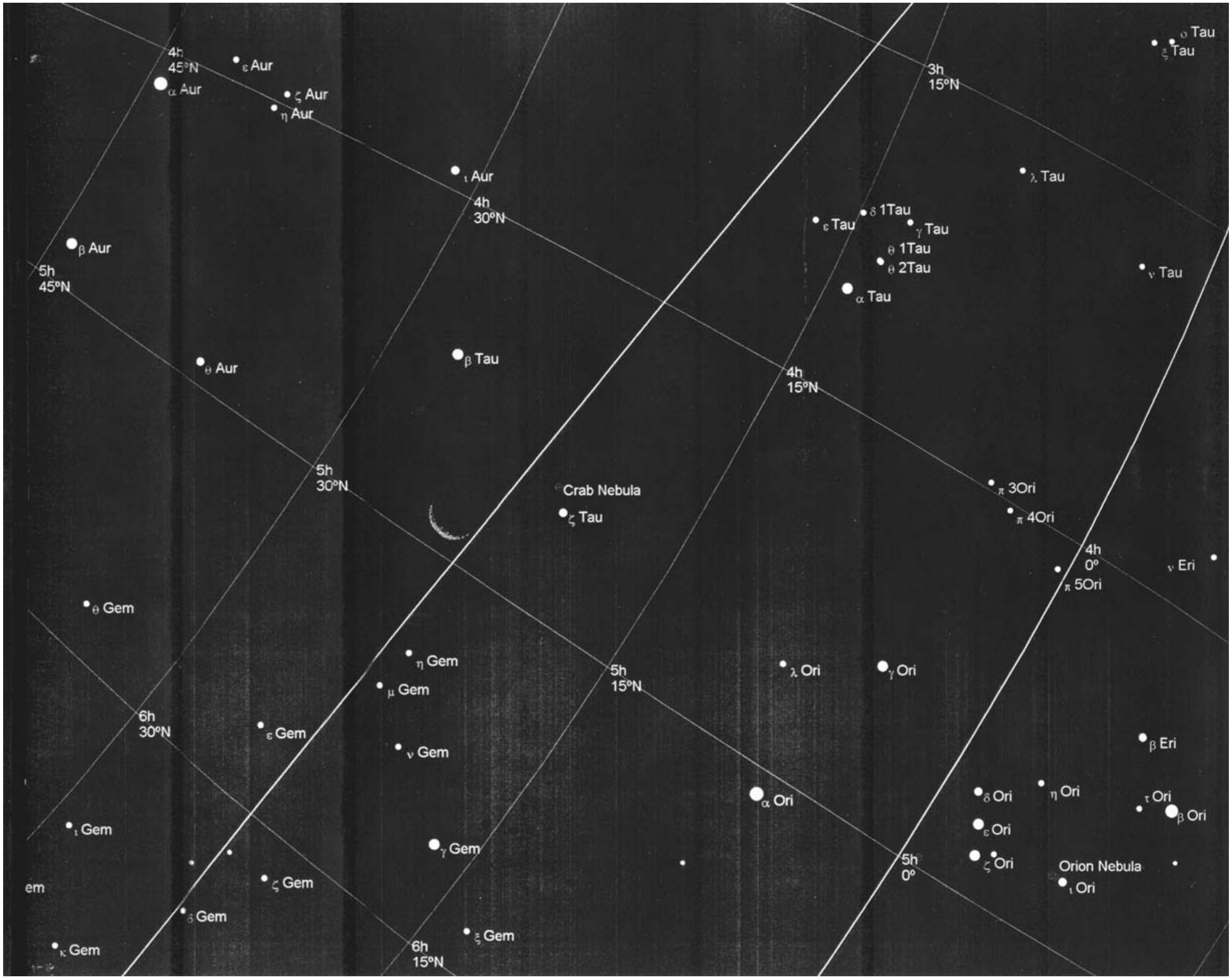
Eclipses are recorded in the annals twice during this century, in 1023. In AI, "A solar eclipse this year, i.e., the spring of the black cloud"; and in *The Annals of Ulster* (AU),

> A lunar eclipse on the fourteenth day of the January moon, that is, on Thursday the fourth of the Ides [10] of January. A solar eclipse, moreover, a fortnight afterwards on the twenty-seventh of the same moon.

Comets are reported several times. AU records a comet visible for a fortnight in the autumn season. Comet Halley's 1066 apparition is recorded in European records, as is the 1006 SN, perhaps the most spectacular historical supernova event. These, together with medieval records of meteoritic phenomena, both terrestrial, and, more tellingly, lunar (§5.3.2), give strong evidence of at least some interest in occurrences in the heavens. Moreover, in light of the absence in the Christian world, at this time, of widespread acceptance of Aristotelian ideas, an explanation based on philosophical prejudice appears to us to be inadequate.

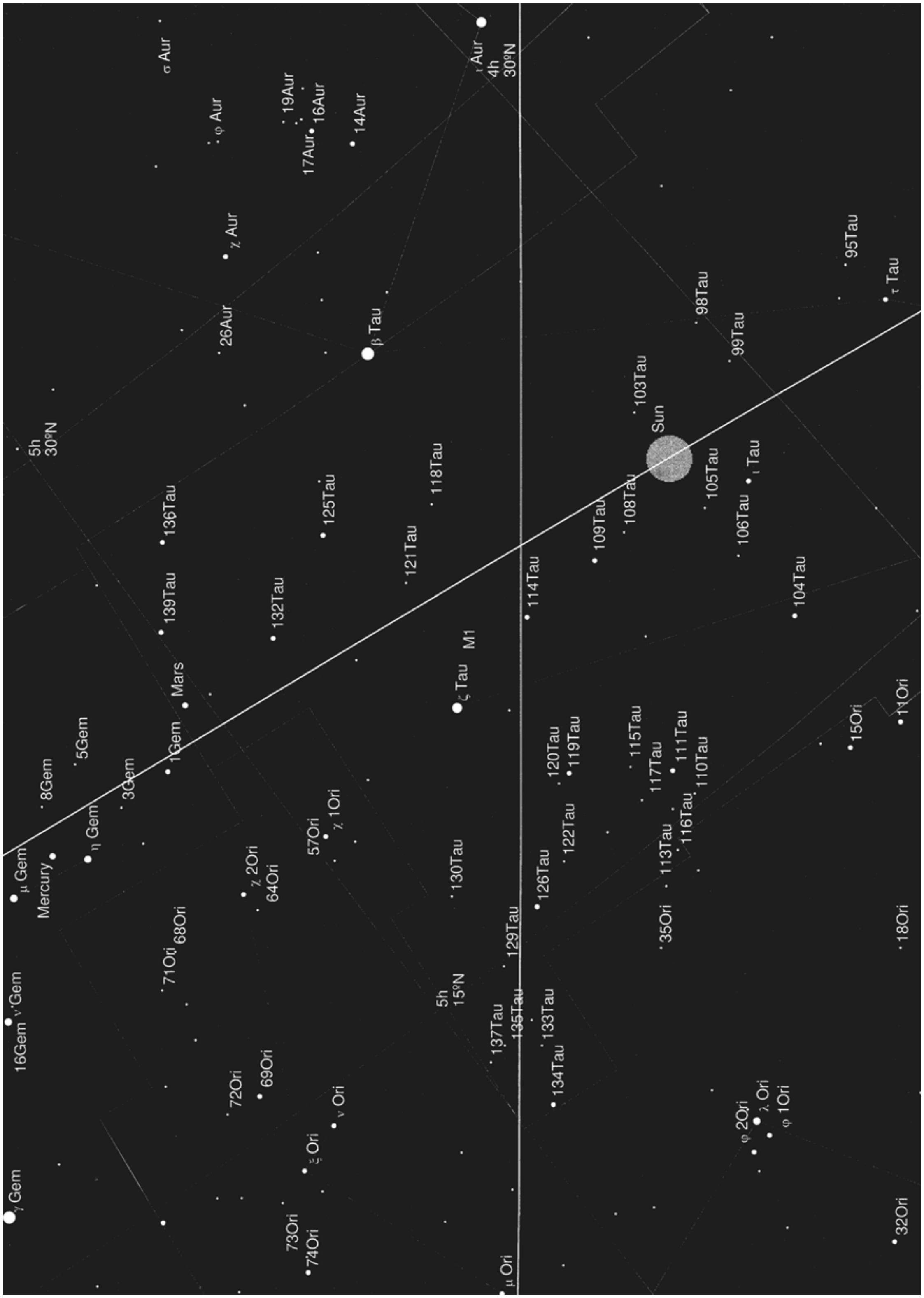
As to why records in Europe are so sparse, meterological and geomagnetic records ought to be able to provide some evidence for or against weather conditions as an explanation. A summer of largely cloudy skies at relatively high-latitude locations is entirely believable. Williams (1981) reaches just such a conclusion about Europe and the visibility of SN 1054.

More recently, another explanation has been offered, challenging the July 4 date for the event. Collins, Claspey and Martin (1999) suggest that the date of the supernova occurrence has been misinterpreted in the eastern records, and that the true date was some time in April or early May, based on simulations performed with the Red Shift PC planetarium software. They argue that a number of overlooked sources (some of which were overlooked because of the widely accepted July 4 date) and otherwise puzzling comments in historical records (mostly regarding the death of Pope Leo IX on April 19, 1054), are all consistent with the 1054 event if the supernova was already in the sky. The *Rampona Chronicle* (Sorbelli 1905), a derivative of earlier and now apparently lost sources, by Muratori (15th century) lists a bright star ("*stella clarissima*") occurring during the time of Henry III, i.e., in or after 1055. A date is indicated: "*in circuitu prime lune est, 13 Kalendas in nocto inito*," (in the orbit/vicinity [our reading] of the (new) Moon early in the night of 13th of the calends), Williams (1981), reproduced in Collins et al. (1999); the original reference was uncovered by Newton (1972, p. 690). Collins et al. argue that this date is 13 *kalendas Iuni*, or May 20, when the location of the supernova would have been 7° east of the Sun and, thus, near the position occupied by a "new" Moon, i.e., a thin waxing crescent, if the Moon were at this phase. They conclude that the supernova would have been visible against the twilight sky. Collins et al. also cite and discuss one of the Armenian Chronicles (that of Etum Patmich—see Astapovich 1974), and a reinterpretation of the date of a near eastern source (see Brecher et al. 1978; Guidoboni et al. 1972) to place the dates of observation of a bright star phenomenon by these sources on May 14 and April 11, 1054, respectively. Two other references cited by Collins, et al., and discussed by Guidoboni et al. (1972) and by Breen and McCarthy (1995) concern the death of Pope Leo IX on April 19, 1054. One reference, the *Tractus de ecclesia S. Petri Aldenburgensi* (Holder-Egger 1888), refers to a "an orb of extraordinary brilliance" that briefly appeared at the "very hour" of death (Collins et al. 1999, p. 872). Their examination of the oriental sources are equally thorough, and they discuss the visibility issues (see §3.1.2.5) to conclude that a nearby star mentioned in the Chinese chronicles as being seen in the dawn sky on July 4, 1054, could not have been ζ Tau, the position of which is on the wrong side in the sources ("several inches southeast of ζ Tau," Ho et al. 1972; cited in Collins et al. 1999, p. 874), but more likely β Tau, a slightly brighter star to the north and slightly to the west of ζ Tau (see Table 3.1). They also note that the Chief of the Astronomical Bureau (whom Collins et al. refer to as the "chief astrologer"), did not prognosticate about this event until Aug. 27, by which it had faded sufficently to be invisible in the daytime sky. The implication is that the astrological concerns of the bureau outweighed any strictly accurate historical record, and consequently, they do not regard the July 4 date as of any great significance; they admit that the association of the death of Leo IX with the bright star could have been stretched somewhat ("with only minimal poetical license") in the interest of ecclesiastical politics, thus, allowing for a May date for the outburst. Note, however, that there continue to be disagreements among the sources. Collins et al. also reexamine the date question of these sources and argue for a late May date for the Japanese observations. If further investigation (especially of the eastern records) supports these conclusions, the mystery of the absence in the West of records of the 1054 supernova will have been solved. But, if their conjecture is correct, we must ask why it took so long for the Chinese astronomers to see



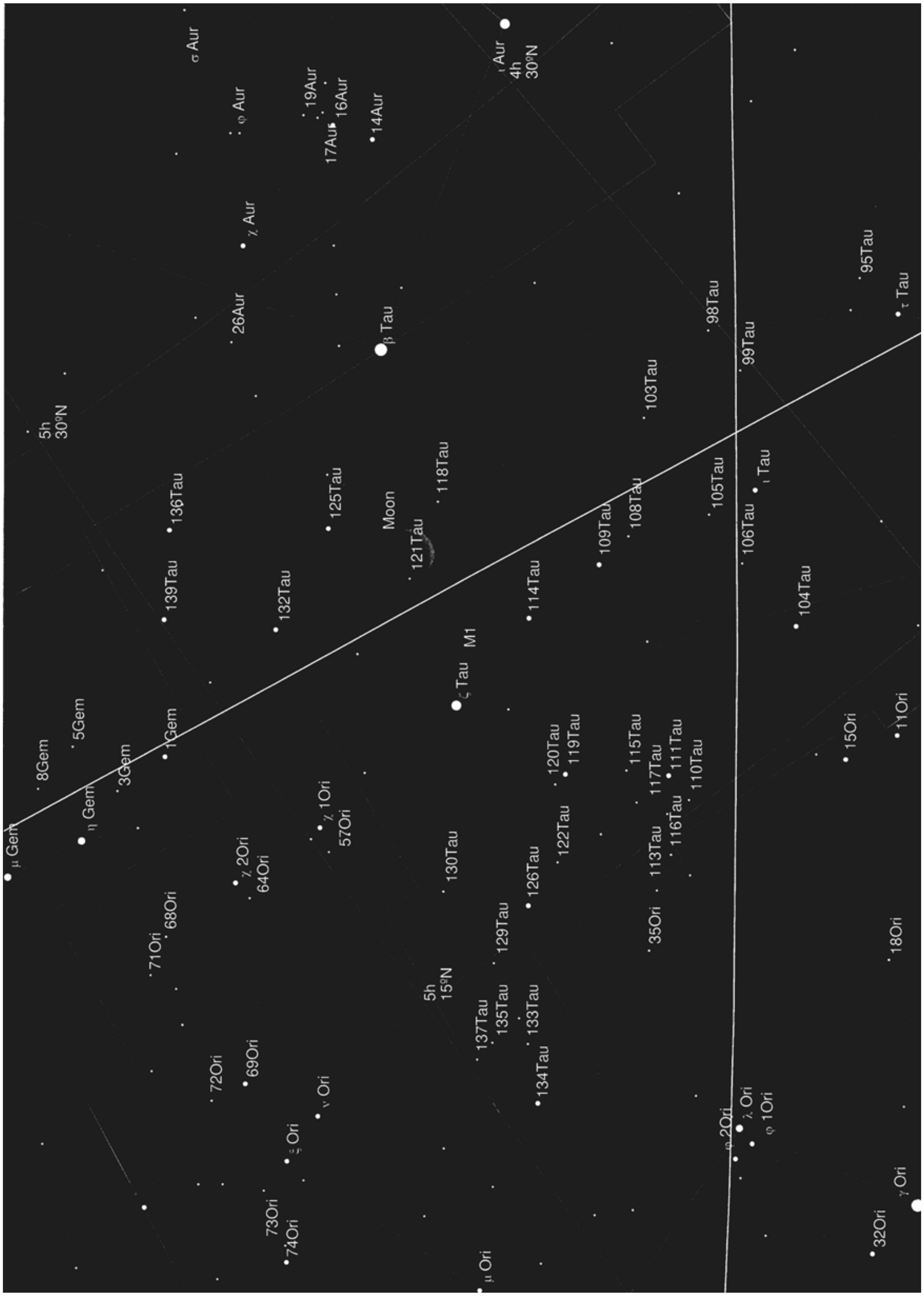
(a)

FIGURE 5.20. The sky of the supernova explosion that produced the Crab Nebula, possibly, on (a) the morning sky of July 5, 1054; (b) the evening sky of May 20, 1054; and (c) the evening sky of April 13, 1054. The Crab nebula (M1 in the Messier Catalogue) is near ζ Tau. Compare these simulations with Figure 13.1. Simulations by E.F. Milone with RedShift software.



(b)

FIGURE 5.20. *Continued.*



(c)

FIGURE 5.20. *Continued.*

the supernova, if at all, astrological implications notwithstanding, because it would have been easily visible in the evening sky in April or May. Figure 5.20 shows our simulations of the events. Compare the photograph of the Chaco Canyon markings (Figure 13.1) with the positions of the Sun, Moon, and the Crab Nebula, near the star ζ Tau. On Apr. 13. 1054, there is a waxing crescent moon in the vicinity of ζ Tau. Of course, as we have noted, the pictographic material may have had nothing to do with the supernova, but, as in many archaeoastronomy contexts, the near coincidences are striking.

The records of observations of transient phenomena and the attempts of groups to understand them contribute in basic ways to our understanding of those cultures. Now, we will begin examining archaeoastronomy anew, from a cultural perspective, beginning with Palaeolithic and Megalithic peoples, and proceeding through specific geographic regions culture by culture.

Part II
Astronomy in Cultures

In Chapters 6 to 14, we discuss the cultural contexts in which premodern astronomy was practiced. We begin each chapter with brief descriptions of the region and of the history, activities, and practices of the people or peoples dwelling there. Three broad sources can be recommended to place the cultures and their monuments in a fuller context of world archeology than we can attempt here. The *Times Atlas of Archeology* (*Past Worlds* by Hammond Inc., 1988) provides summary maps and cultural descriptions for archeological remains from the earliest period to the present. A more technical atlas by Whitehouse and Whitehouse (1975) locates the major sites throughout the world, and Jacquetta Hawkes (1974) has done a summary of the archeologically known cultures of the world. The latter work is described as an atlas also but has substantially less cartography and much more archeological content than do the other two. For North and South America, Willey (1966, 1971), although out of date, still provides the most comprehensive archeological overview. For nonprofessional readers, Ingpen and Wilkinson (1990) gives carefully done reconstructions of many sites discussed in this book, with competent descriptions. We begin by reviewing the evidence of astronomical interest in the earliest of cultures—those of the Paleolithic.

6
Paleolithic and Neolithic Cultures

6.1. Paleolithic Cultures

For most of the Paleolithic period [or *Old Stone Age*, beginning more than ~2½ million years before present (b.p.)], there are few materials that could be interpreted as relevant to human understanding of astronomy, even in the vaguest terms. Evidence for interest in the heavenly bodies has been suggested only for Australia (see §11) and for Western Europe during the Upper Paleolithic (70,000 to ~10,000 years b.p.). A critical summary of the European Upper Paleolithic is provided by Hadingham (1979) in *Secrets of the Ice Age*. Despite its provocative title and popular nature, this work reviews the results of modern scholarship about the hunters and gatherers of the last 70,000 years or so, mostly from Italy, France, and Spain. He emphasizes the difference of the environment of that time from any existing today: colder, wetter, but in some ways richer, with vastly different fauna. He discusses both continuities and changes among human populations, their tool kits, and other aspects of the culture. The people were Neanderthals (*Homo sapiens neanderthalensis*) or Cro-Magnon (*Homo sapiens sapiens*)—both much like ourselves in physical type and inherent capabilities. They were skilled in making stone tools and had some crude housing, at least in some areas. They depended heavily on game, and some became skilled (and perhaps overspecialized) reindeer hunters. Others depended on wild cattle, and most groups probably killed a wide range of animals. Gathering of vegetable foods was surely of great importance, although usually this must be inferred from sketchy evidence. Fishing was probably of some importance, with more lakes and streams than today. Most sites that were then along the coast, where we might expect some evidence of fishing and indications of whether it was based on use of good watercraft, are now sunk deep beneath coastal waters, which have risen many meters since the melting of so much glacial ice. It has been suggested that in some areas there were substantial attempts to control the animal populations and that some of the reindeer could be considered as having been at least semidomesticated. Similar suggestions have been made for horses. Possible halters or bridles are shown on carved designs of horses, which appear very convincing in isolation; comparable depictions of bison make the interpretation seem less likely. Despite fanciful popular accounts, we know nothing directly or by firm inference about the social structure of these peoples except for clear evidence of the existence of nuclear families of parents and children, and some evidence for care of partially disabled individuals. The great cave paintings of Altamira and elsewhere are majestic and inspiring art, but the motivations behind them remain obscure. Some degree of religious or magical inspiration seems likely in at least some cases, and few archeologists would regard sheer esthetic pleasure as an adequate explanation. Some sort of symbolic interpretation seems likely. Leroi-Gourhan, cited in Campbell (1988b, Pt. 2, p. viii), notes that only certain species of animal known to exist in the Paleolithic are depicted, and these in discrete pairings, architecturally arranged both geographically and historically in such a way as to convey the sense of a polished system of religious belief.

A series of carved markings have been uncovered on antler and bone that look like tallies. Alexander Marshack has published several articles and a popular book (Marshack 1972b) arguing his case that these apparent tallies were designed to mark lunations and therefore represent mathematical notations, which, for him, form an ultimate basis for all science, a necessary, and before this, a missing, prototype. The marks were regarded in the 19th century as perhaps hunting tallies. Marshack has demonstrated by microscopic analysis that the marks were usually made by different tools, hence, presumably marking a succession of different events, thus confirming the tally hypothesis, but were made over extended time. Marshack's analysis of three faces of an eagle bone from Le Placard, France, suggested that the "feet" were added after the vertical lines and constituted a reuse of each vertical symbol. Marshack further argued that the doubling of the "foot" and vertical components indicates "waiting" periods perhaps created by bad weather; the true observation of the phase then being made on the following day. The notch indicates that whatever calendrical purpose the bone may have had, it was used as a whistle. Marshack's claim that they represent a lunar calendar is more controversial, and his view that all the carvings represent a single tradition is in no way demonstrated. Hadingham (1979, p. 253) cites M.A. Littauer, who suggests that the material shows that humans were capable of "cumulative symbolic recording" and that there were "varied and idiosyncratic" ways in which that was done.

Even if no more than this was demonstrated by Marshack, it represents an important advance in our knowledge. This "cumulative symbolic recording" is a necessary base for determining all but the most basic astronomical periodicities. The objects of Marshack's study include a small engraved bone from the Blanchard site of the Aurignacian period (Marshack 1972b, pp. 40–49) and a ritual "baton" from Le Placard of the Magdalenian III period (Marshack 1972b, pp. 88–89). It is worth emphasizing that the Magdalenian III period is separated from the Aurignacian by a longer interval than separates us from the Magdalenian. The Blanchard bone of the Aurignacian period had 69 marks in 24 groups that had been made at different times, sometimes with different inplements. There were 1 to 8 marks in each single group, and the shape of the marks varies from near ovals through broad crescents to thin crescents. They do indeed appear to be some sort of tally, and the shapes are suggestive of a lunar notation. Marshack thinks that the notations may cover two and a quarter months.

Hadingham (1979, pp. 250–251) concluded that by accepting the notches as marking whole lunations, half lunations, and quarter lunations as divisions that were used, allowing for weather-biased counts, and even for noncontinuous record-keeping, "the potential of proving any string of numbers to be lunar is considerable."

Marshack (1972b, pp. 141–143) gives two examples of wooden calendar sticks from the Nicobar Islands, Bay of Bengal, which are visually and structurally similar to many of the Upper Paleolithic examples. One of these is shown with a Magdalenian-period baton from Le Placard, France (Marshack 1972b, pp. 88–89). Marshack analyzed the sequence of markings and groupings on the baton and suggested lunar interpretations. Both sets keep a tally by different lengths and different angles of lines and different groupings. Neither tally would necessarily lead an uninformed observer to think that it dealt with lunations. The Nicobarese sequence

3–5–5–10–11–(13)–11–10–10–10–11–10

does not obviously seem to be lunar. The difference between the Le Placard baton and the Nicobarese calendar stick is simply that we know from Nicobarese informants that their calendar sticks were indeed being used for lunar tallies. Despite the obvious differentiation of subgroups on the Magdalenian baton, it is by no means certain that Marshack's grouping coincides entirely with those of the Magdalenian engraver, particularly for longer intervals than for any short grouping. It is these longer intervals that coincide with lunations (or can be made to do so).

We concur with Hadingham's (1979) summary:

> Marshack has never published analyses of a large number of objects which would allow anyone to repeat the statistical tests which he claims back up his theory. Instead, his most detailed study is of only six objects with notches that *do* fit the lunar phases to varying degrees, which is not to say that another explanation might not fit them better. No one would deny the attractiveness of the theory of a Palaeolithic lunar calendar, its convenience as a rational explanation of the 'hunting marks', and its widespread use by peoples at a comparable level of technology. Common sense seems to tell us that Marshack is right, but as yet the proofs are lacking.

More pointed criticism has been made by d'Errico (1989, 1992). In any case, Marshack's detailed presentation should be consulted by anyone wishing to form an independent judgment on this important issue. There is another parallel in a North American calendar stick, published by Merrill (1945).

It has been claimed that certain Paleolithic paintings represent asterisms (Huffer Trinklein and Bunge 1967, p. 95). If verified, these would be the earliest such representations known and therefore would be of great importance. More recently, Michael Rappenglück (1997, 1999, 2000) has compared Guide 7 software package sky simulations with star-like representations at several Paleolithic sites. He attempts to match the dates of the asterisms as affected by proper motions (see §3.1.7) to the best estimates of the dates of the paintings, and he considers the contexts of the images within their tableaux. Among the asterisms that he thinks may be represented are Corona Borealis (Cueva del Castillo), the Pleiades and Leo, interpreted as a horse (both at Lascaux). He draws many parallels with later work, as for example, grotto art done for Tiberias, and with Celtic myths and images. Although we cannot comment on the results at this juncture, the broad range of scholarship brought to bear on the work is to be commended.

6.2. Megalithic Cultures

6.2.1. The Megalithic World: Cultural Description

Human endeavors of the post-Paleolithic world of Europe were dominated by two factors: increasing reliance on the sea, from molluscs to large fish, and the development of farming techniques, including the use of domestic animals and a wide range of plants, especially grains. Although we know little about the watercraft involved, people had reached Ireland by about 6500 B.C. and they must have been skilled sailors to get there. The spread of farming techniques occurred later. The invention and spread of the polished stone axe, the hallmark of the Neolithic or "new stone age," was an important factor in clearing forests to create fields for grain. Pottery was another important innovation that allowed storage of foods and liquids and changed cooking techniques, especially of meat. Stews allow adequate nutrition from a much smaller amount of meat than do other cooking techniques, while reducing the danger of disease. Techniques of building with wood, probably largely devel-

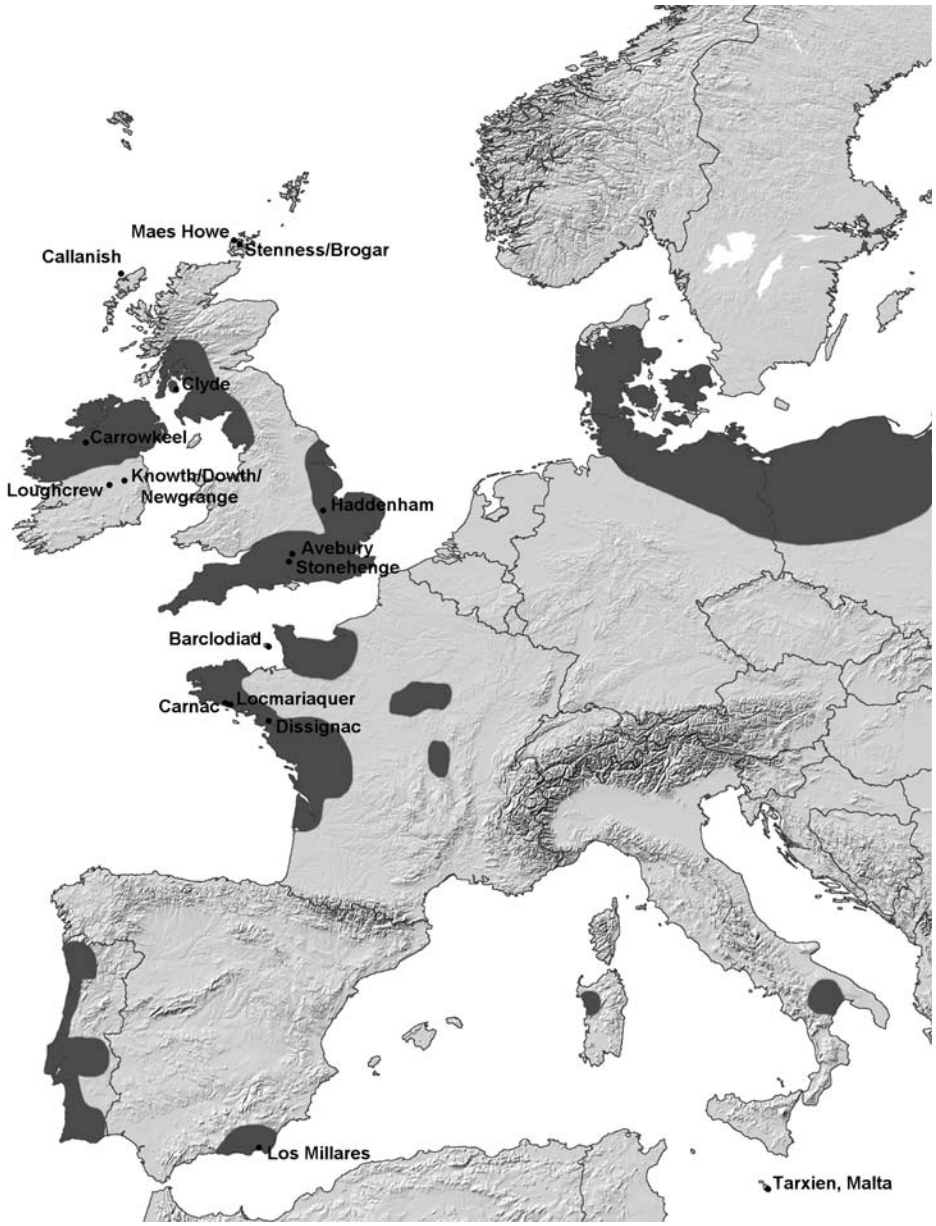


FIGURE 6.1. Some important megalithic monuments of Europe: Note that many are near coasts. Shading indicates the principle areas where structures are found. For fuller maps, see Mohen (1990). Drawing by Sharon Hanna.

oped for housing, may also have been used in building more developed watercraft. The movement of cattle, sheep, goats, and pigs by water involves different craft than do those that are adequate for fishing, even deep-sea fishing.

In the 5th millennium B.C., in coastal areas from the Mediterranean to Ireland and the North Sea, Neolithic people began making monumental structures incorporating massive blocks of stone. These were usually either large collective tombs or temples. The term "megalithic" has been applied to such structures. The distribution of such early structures is shown in Figure 6.1.

The principal classes of monuments relating megalithic cultures to astronomy are as follows:

(1) *Mounds*, especially those with so-called passage graves, each of which consisted of a central burial chamber and a long entrance passage
(2) *Menhirs*, from the Breton word for large pillars, often isolated or in groups of 2 or 3
(3) *Rows* or *fans* of pillars in alignments
(4) *Geometric figures*—rings (circles, flattened circles, combinations of arcs of different radii), rectangles, or other shaped figures

Our knowledge of the archeological context of such monuments is increasing rapidly, but many of them are very hard to date. The most sophisticated attempts to date

Table 6.1. Chronology of selected megalithic sites.

Date	Site		
4600 B.C.	Dissignac: Tomb oriented to midwinter solstice light play		
4200 B.C.			
3800 B.C.			
	Le Grand Menhir Brisé		Malta: Temples aligned on asterisms—Numeracy and notation
3400 B.C.	Gavr'inis: Tropical year Castle Rigg Long Meg and her Daughters		Maes Howe: Midwinter sunset light play
3000 B.C.			
	Los Millares: Tombs usually oriented to SE quad Stonehenge Ia: Solar and lunar standstills	Brugh-na-Boinne: Complex tropical year alignments sundial?	
2600 B.C.	Crucuno: Pythagorean triangles, megalithic "yard," tropical year alignments	Stonehenge Ib suggested eclipse prediction	
2200 B.C.	Mzorah: Cardinal directions	(Hill o' Stanes, Mid-Clyth)	Callanish: True N-S alignment, lunar movements
1800 B.C.	Mull and Argyll: Extremes of sun and moon		Hunnenbette: Solar (and lunar?) alignments
	Temple Wood: Extreme N. decl. of Moon	Ballochroy: Midwinter and midsummer alignments at right angles	
1400 B.C.			

large groups of monuments are those of Aubrey Burl (especially, 1976, 1993). We summarize the chronological data for a selection of the most important sites in Table 6.1.

6.2.2. Engineering and Astronomy

Most of the important problems in the astronomical interpretation of megalithic architecture have been raised by Alexander Thom, who also suggested answers to many of them in a voluminous body of writings. Archibald S. Thom (1988) lists 129 articles and books that his father wrote or coauthored. The elder Thom was already reading about archaeoastronomy in 1912 and by the 1930s began mapping sites and studying their geometries. His work as an engineering professor, and his avocation, sailing, helped him in the endeavor. In the Thomistic spirit, we again raise questions he raised and explore, with the help of his field work and subsequent work, the evidence for alignments. The main questions are as follows:

(1) How were the megalithic sites laid out?
(2) Were they observational sites?
(3) Do they incorporate astronomical information?
(4) If they do incorporate astronomical information, how was this information transmitted within the culture?

First, how were the sites laid out? Thom suggested a range of well-understood geometrical patterns, incorporating Pythagorean triangles and use of a regular unit of measurement, which he called the *megalithic yard*. It is logically possible to separate the problem of geometric layout from the problem of mensuration, but here the two seem intimately related and the evidence for one is closely tied to the evidence for the other.

Were they used observationally to determine or check astronomical data?

Do the sites incorporate astronomical information? The possibilities include solar, lunar, stellar, and planetary alignments, and Thom has at various times suggested that particular sites included information about the Sun, the Moon and, rarely, the stars. To our knowledge, planetary alignments have not been suggested in the megalithic material. Thom also maintained that many sites included alignments on distant natural features, such as notches on the horizon, or on very large man-made features, such as *Le Grand Menhir Brisé* in Brittany, which was visible for many miles around. If such features were used, they would have increased the precision with which astronomical phenomena could have been measured.

How was the information transmitted? If data were actually gathered, how could they be stored and subsequently used to determine periodicities or cyclicities of such phenomena as lunar motions and eclipses? Some scholars consider that the lack of clear written records provides an insuperable objection to the argument that astronomical alignments in megalithic structures were intentional. On the other hand, many archaeoastronomers accept the view that the monuments are, as the festschrift to Thom puts it, "records in stone." Thom believed that the "cup and ring" markings, which we discuss later, were some sort of notational record, not a record of the language of scribes, but nonetheless a minimal written record. With respect to the Irish monuments, Brennan (1983) has attempted to interpret some iconographic motifs in megalithic art as notations of astronomical information. Finally, O'Kelly's (1982) discussion of pagan Irish mythology in connection with his studies of Newgrange shows that mythology may have been one of the vehicles for the transmission of astronomical knowledge, although this is not how he phrases it.

The answers to these questions are tied to a priori conceptions about the cultures involved and about how such problems should be studied. This is to some extent true for all investigations involving cultures. Here, the conceptions affect and are affected by our understanding of the overall functions of the monuments. A statistical study of various Scottish sites led Norris (1988, p. 273) to write, "These results constitute the first definitive evidence that megalithic man was interested in marking the southern limits of the Sun and Moon." A more cautious statement is that there is a low statistical probability that the alignments are random, which suggests interest in particular alignments that coincide with lunar and solar alignments (and that we might regard as significant). One approach, taken by Ruggles (1988) and his associates, is to remove the problem as far from the context as possible in order to achieve "fair" conditions, unbiased by expectations, in order to make objective determinations. But this approach too is not without its biases; for example, is it truly scientific to ignore possible compensations provided by human ingenuity in dealing with observing alignments involving large and often irregular stones? Scholars from ethnology, anthropology, or archaeology tend to see astronomers as useful technicians who can supply important data, but who are unskilled amateurs in the study of human behavior and artifacts and who are unable to integrate the data into the contexts that alone can give them meaning. Ruggles (1989, p. 24) has expressed the view that both approaches are necessary:

> British archaeoastronomers have often been accused by their American colleagues of lavishing too much attention on statistical rigour at the expense of cultural context; it may soon be the turn of the British to persuade their colleagues that statistical rigour has a crucial rôle for a great many archaeoastronomers, and to teach them how it can be integrated into an approach which quite properly considers the great diversity of cultural evidence which may be available.

Thom has been attacked on statistical grounds by those who cite unconscious bias in selection of evidence favorable to the expected alignments, and Thom's attention to the geographical context in attempting to determine if particular alignments are meaningful. Attacks on Thom's work have come also from the archaeologists (e.g., Burl 1988). Anthropologists and archaeologists tend to regard Thom's selections on the basis of geographic context as admirable, but criticize his inadequate use of cultural context. Which methodology is appropriate requires examination of the contextual features. Ruggles (1988) has argued that "megalithic culture" is, archaeologically, many definably distinct cultures. This is true, but can we, nevertheless, speak of a single megalithic tradition that may extend for millennia and over much of Europe, especially in coastal zones? Put another way, to what extent can conclusions validated for one area be extended to other areas? To answer these questions, we consider the common cultural contexts.

We know from historical and ethnographic records that farmers in most parts of the world believe that all activities of farming, from clearing the fields to harvesting, are affected by the movements of the Moon. Is it reasonable or not to suppose that the Moon was equally important in the beliefs of European Neolithic farmers? We also know from the distribution of monuments (see Figure 6.1) that at least some members of these groups were able sailors. Navigation plays a crucial role in sailing, and coastal navigation has traditionally relied on real or artificial landmarks, with sailing directions tied to successive alignments of such features. Useful landmarks need not be the most prominent features of the landscape, and they may be as diverse as the trees, rocks, spits, sand bars, and other features of variegated shores. Moreover, navigation, in all cases in which we have adequate records, has been tied to stellar observations and stellar alignments for craft out of sight of land. If builders of megalithic monuments were drawing on experience as navigators, we would expect to find natural landmarks as distant foresights or backsights and we would expect to find stellar alignments. Moreover, important alignments are determined from the information they give about sailing geometry, not whether they are bright stars or dim ones. This should be borne in mind when assessing claims for particular sites in which no stellar alignments were found, when only the brightest stars were examined.

As we have noted already, the Moon has two properties that impact ancient cultures: its light and its gravity. The light of the Moon is especially important on a non-summer night and at high latitudes; given the limited range of illumination of torches, nocturnal travels on the sea or on land require the Moon, and the fuller the phase, the better. Moreover, for seafarers, the Moon is important for more than its night light. The tides arise from the different effects of the Moon's (and, to a less extent, the Sun's) gravitational attraction on different portions of the Earth (see §4.5.2, for a discussion of the origin of the tides). The Moon's association with tides is readily discernible: The time difference between the meridian passage of the Moon and high tide is a fixed quantity for a given site (*the establishment of the port*), even though it varies from site to site because of the effects of local geography. Because the tide-raising effects of the Moon and Sun add together vectorially, the strongest tides will occur around new and full moon (*spring tides*), and least at first and third quarter (*neap tides*). Thus, the strengths of the tides are correlated with lunar phase. Moreover, the strongest tides occur when the Sun and Moon are in syzygy, and in such circumstances, eclipses can occur, some of which may be visible locally. The Moon contributes roughly 2/3 of the tide raising forces, and the Sun, ~1/3. According to Harris (1937, p. 611), the range of lunar tides is ~10% greater at a node crossing and ~10% less when the Moon is 90° away from it. Finally, the tide-raising force varies with the inverse *cube* (not the *square*) of the distance, so that the lunar tides depend on the location of the Moon in its eccentric orbit (see §2.3.5). Consequently, the range of the tides is ~17% greater when the Moon is near perigee and about the same amount less when it is at apogee. In waters with dangerous rip tides, these phenomena provide an adequate reason for attempts to determine lunar movements with precision. The importance of stellar horizon marking might easily have been extended to the Moon. These facts provide strong motivation for the study of the movements of the Moon and stars, and they may provide the basis for a broad and lengthy tradition, as ethnological studies of indigenous cultures have shown (see §8 and 11).

Given the evident motivation for and likely continuing tradition of megalithic observations, what makes claims of astronomical alignments controversial?

There are several problems. First, there is the problem of relating the current position of a monument to its placement at the time of its erection and use. Historical records indicate that many of the boulders that are allegedly part of alignments in Brittany and Britain have been reerected. The establishment of the existence of a present alignment is relatively trivial compared with doing so for the remote past. Even if historical records do not indicate the reerection of a standing stone, movement of the stones is highly likely from a number of factors: natural forces (trees, frost heaves, earth tremors, etc.) or by people (because of agricultural activity, subsequent religious usage or the discouragement of it, or mere vandalism).

Second, the precision with which observations could have been made with a particular alignment configuration is not known. There are also questions involving the visibility of distant foresites. The vegetation cover between the alleged foresights and backsights at the time of their presumed use is largely unknown for many sites, especially those in agricultural and village areas. In our highly agriculturalized time, open farm land is far more common than it ever was in megalithic times. The atmospheric conditions that prevailed can be plumbed to a certain extent, as we discussed in §3.1.1, but this is scarcely sufficient to provide an appropriate atmospheric pressure and temperature on a day-by-day basis. Therefore, the range of the refraction variation (see §3.1.3) in any given period is only loosely constrained.

Third, given the large number of menhirs, boulders, or tumuli in many sites, and a plethora of distant foresites, there is the problem of selection of relevant sightlines. The arbitrariness of some of the directions selected (and none other) for the observation ascribed to particular sites by current day archaeoastronomers is a principal ground of criticism.

Implicit in all the criticisms is the fundamental problem of the intended usage of the site. In no case do we have direct evidence how or even if any megalithic monument was used; we know only what *could have been done with it*.[1]

[1] The same criticism applies to the use of certain features of a site, for example, the Aubrey holes at Stonehenge, which are to some a stone age computer (or perhaps abacus?), and to others a collection of 56 chalk-filled holes arranged (more or less) around a circle.

One possible direction to take is to consider an inverse problem: If an alleged foresight-backsight line were blocked by elevation, vegetation, or construction at the time of its erection, could we not say that that particular astronomical association would be disproven? Unfortunately, it appears that we cannot be sure even of this. At Newgrange, we shall see that some of the kerbstones have decoration facing the mound and, hence, would have been invisible after the mound was completed, and until reexposed by excavation. Yet the symbolism of the site is such that they could be considered to have been so placed by intent.

Many of Thom's astronomical interpretations rest on his ideas that high precision was sought in the observations of the ancient Britons, and that they possessed considerable understanding of geometry. His ideas about how the figures of large stones were laid out bear some scrutiny because they involve Pythagorean triangles.

6.2.3. Megalithic Mensuration

From a study of the dimensions of megalithic monuments throughout the British Isles, Alexander Thom (1967/1971/1973/1978) concluded that standard units of scale were employed. Some practitioners call this the "quantum hypothesis." Among the units were what Thom called the Megalithic Inch (MI) equal to 0.82 in or 21 mm, and the Megalithic Yard (MY) equal to 2.720 ± 0.003 ft or 0.829 m (the precision cited is Thom's). The data, methods, and results have all come under careful scrutiny with the result that most investigators subsequent to the Thoms have concluded that marginal evidence exists for the Megalithic Yard, but not as uniform a measure as Thom's estimates would imply. It is important to reexamine the evidence to see how this conclusion was reached and, regardless of established opinion, to see if the quantum hypothesis may, nevertheless, be true regardless of rigid tests of significance.

The *quantum*, or the smallest basic unit of any quantity, can be determined from two basic conditions: It can be no larger than the smallest measured quantity and all larger quantities must be integral multiples of it. This can be considered the case if and only if no more than one such similar-scale unit was being used by different groups in the area. One can indeed question whether it is reasonable to expect a culture that has left no accepted evidence of writing ("cup and rings" notwithstanding) to be able to systematize their units of scale so that the same value is derived for each site. Leaving that question aside, what are the bases for the claims that these units were in use among the megalith builders?

They are the scale of markings on the stones in the case of the MI and the scales of the geometric figures created by the placements of the stones in the cases of larger units. Thom identified the Megalithic Inch to be about 1/40 MY on the basis of a histogram of frequencies of occurence of diameters of markings under 12 inches; the histogram shows that there is an apparent clumpiness of diameters near integral units of the Megalithic Inch. The case for the Megalithic Inch was subjected to Broadbent's *lumped variance test*[2] by Thom and found to be significant. Heggie (1981b, p. 48) subjected the data to more stringent testing, which did not show significant clumping. On the latter basis, there does not seem to be a *unique* unit that provides a clearly better histogram than any other. Basically, the situation is this: If one assumes a value of the MI (e.g., 1/40 MY), one gets an indication of significance, but this does not prove that that unit alone was significant. Similar arguments have cropped up for the larger units.

With respect to the Megalithic Yard, the studies have been more positive, but the strictest tests suggest marginal significance only. Again, the evidence is for that unit in the form of a histogram of the frequencies of the diameters of stone "circles" (these are often not circular, as we discuss below). The diameters yield significant results for the existence of the MY once a unit is suggested. The same is true for a number of subsets investigated by Thom and others. There is somewhat greater significance for the more flattened variety of circles and for the Scottish circles than for the more nearly circular configurations and for the English and Welsh circles. Supporting evidence for the quantum hypothesis comes from other measurements [(such as the separations of individual stones, cf. Thom (1964/1971/1973/1978)] and from different types of structures, such as stone "fans." The separation of stones yields a common unit of 0.5 MY to a significance level of 0.97, meaning that the probability of the clumping being produced randomly is only 3%. An example of a stone fan is seen at Mid Clyth, where the convergent rows of stones march up (or down) a hillside (Figure 6.2).

The quantum found here, however, was not the Megalithic Yard, but a value 7.743 ft. = 2.360 m (2.843 ≈ 20/7 MY). Work on sites at Carnac and elsewhere has shown marginally significant results. There are notable examples of a failure to confirm the existence of the MY: In the Irish stone circles examined by Barber (1972) and in rings of the "Sanctuary" near Avebury in Wiltshire (Heggie 1981b, p. 42, based on Burl 1979), there does not seem to be evidence for the Megalithic Yard. This has led to suggestions that the integral values of diameters may be suggesting merely "popular" values, or that units were used in some cases and were randomly selected in others.

Supposing the existence of the MY, the measures of accuracy with which it can be obtained have been studied by Heggie (1981b, 56ff). The diameter of the highly circular Ring of Brogar at Orkney (cf. Figure 6.3, which shows also a portion of a comparably large site, Avebury) was determined by Thom and Thom (1973, p. 171) to be 340.02 ± 0.60 ft or 103.64 ± 0.18 m.

This is close to 125 MY. If that were the intended value, the error in the MY would be ≈0.005 ft. The uncertainty is small enough in whatever unit was intended. And it was most probably the Megalithic Yard as suggested by Thom. The variations from site to site suggest that it may have been some aspect of human dimensions—such as foot pacing—which can be done with high precision yet the resulting structure will vary slightly in dimensions from site to site with the builders.[3] This was the hypothesis of Kendall (1974, p. 258), although it was challenged by Thom (1974, p. 179).

Thom's metrical and geometrical hypotheses were supported by subsequent analysis of the Breton site of Crucuno. Although the site is composed of moderately large standing stones, it is a simple rectangle and not impressive compared with many other sites in the region. This Megalithic site is, nevertheless, one of the most important, as a glance at Figure 6.4 reveals.

A considerable number of the stones of the site are known to have been reset. This led Hadingham (1976, p. 162) to declare, "Unfortunately, the enclosure was restored in the last century, so that no reliance can be placed on these remarkable facts." Such a statement ignores the fact that the rectangle is one of the easiest shapes to restore with substantial accuracy. Moreover, the stones are large enough to make a great deal of natural movement unlikely. In 1882, only 9 of the 22 stones were standing but a plan of 1867 offers strong support for the view that the reconstruction was done very carefully (Burl 1985, p. 133). If the alignments of the stones are even roughly authentic, displacements along the lines would not greatly affect the remarkable properties of this rectangle. The short sides of the rectangle measure 30 MY, the long sides, 40 MY, and thus the diagonals, 50 MY. These are the proportions of the classic "Pythagorean triangle," which, Thom has maintained, is basic to the construction of most megalithic structures. The absolute values conform with the unit of the Megalithic Yard as worked out by Thom from data of more complicated sites in Britain. The simple rectangle (the existence of the triangle is hypothetical but the rectangular is a manifest description) is in a way the best support yet published for the existence of that unit with a value very close to that given by Thom. The rectangle also possesses astronomical alignments, as it defines solar alignments at both solstices and equinoxes. The long sides are aligned east-west, and the short sides, north-south. Thus, the long sides point to both rising and setting Sun at both equinoxes. At this latitude (~47.5°), the diagonal line from the northwest points to the rising of the midwinter Sun, and the diagonal from the northeast points to the setting Sun on the same date. The diagonal from the southwest points to the rising of the midsummer Sun, and the diagonal from the southeast points to the setting of the midsummer Sun. The dimensions of the features of the Crucuno monument are matched to its latitude if its purpose was to provide solar alignments. Hence, the Crucuno monument furnishes simple but strong evidence of a deep megalithic involvement in astronomy. In terms of our understanding, this interpretation is both straightforward and complex. It suggests complete understanding of the regularities in the correspondence of the figure with the apparent movements of the Sun. It seems

[2] See Broadbent (1955). The test involves the average of the squares of deviations.

[3] The modern inch, span, fathom, and foot all have such anthropological origins.

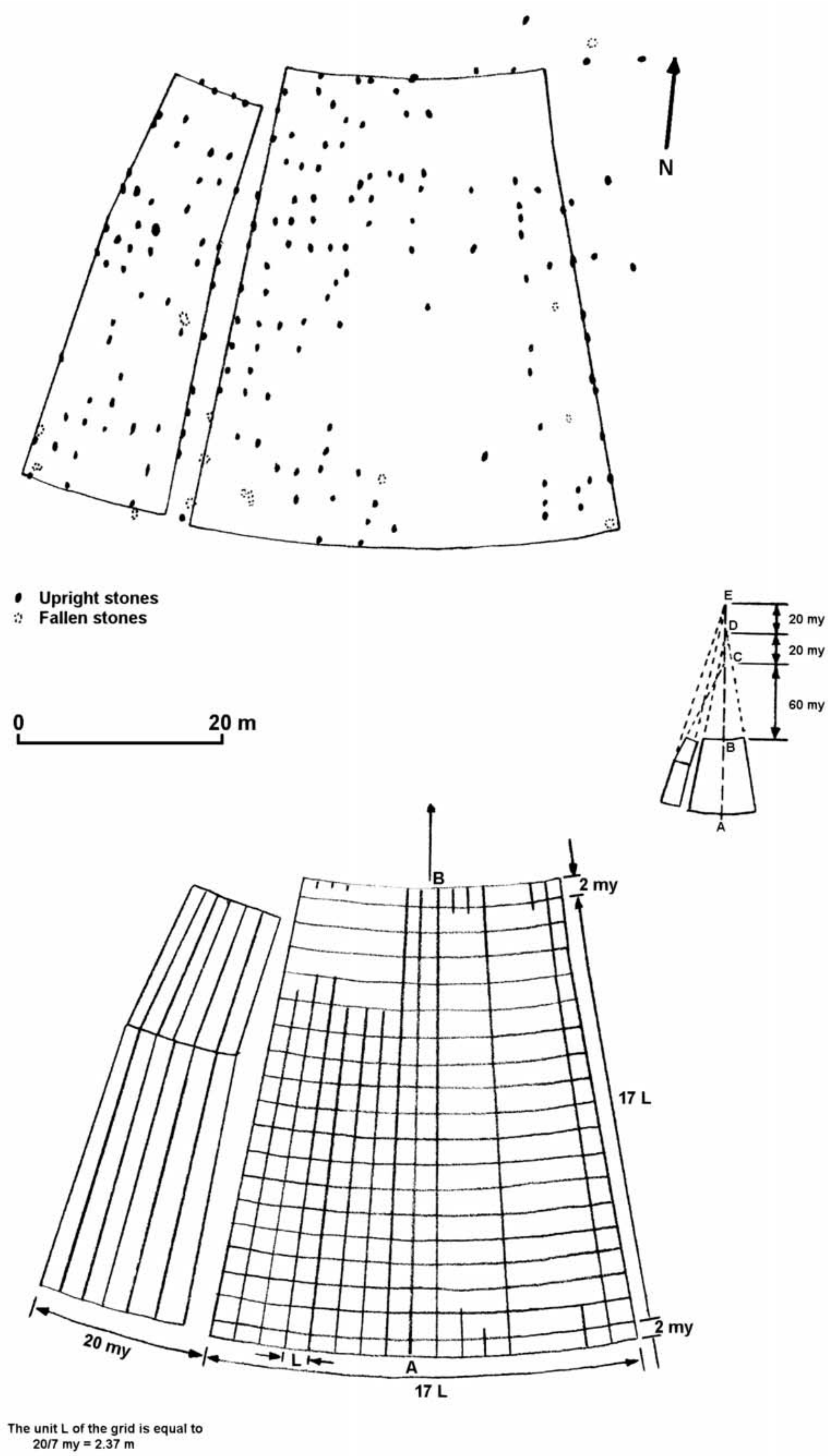


FIGURE 6.2. A sketch of the megalithic fan-shaped configuration of stones at Mid Clyth in Caithness, in northern Scotland: From Thom (1964), who finds in such constructs evidence of stone grids used for lunar calculations. For discussion of the functioning of the site, see §6.2.15. Drawing by Sharon Hanna.

(a)

(b)

FIGURE 6.3. (a) The Ring of Brogar, Orkney, northern Scotland: The monument has a diameter of 103.6 m, surrounded by a circular ditch with diameter of 142 m. These dimensions make it one of the largest of the stone rings, comparable to Avebury. Photo courtesy of Sharon Hanna. (b) Avebury in the SW, looking SE: Large entrance stones marking the South entrance are on the right. Photo by David H. Kelley.

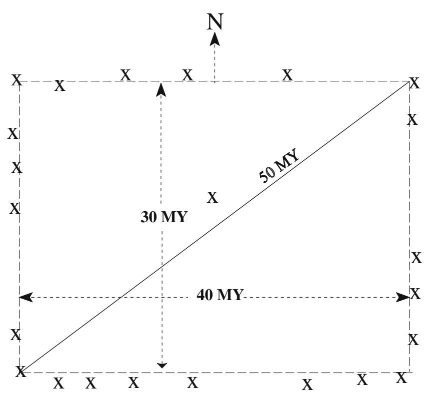


FIGURE 6.4. The construct features at Crucuno: The Xs mark the approximate positions of the stones. Drawing by E.F. Milone, after Thom et al. (1973).

highly unlikely that a rectangle with these geometrical and astronomical properties would be set by chance on the line of latitude where they could work. The site is about 9 miles from le Grand Menhir Brisé, which should have been visible at Crucuno. However, we know of no suggestion of an astronomical relationship between the two, and they may not have been contemporary. There was once a somewhat similar rectangle, oriented E-W, at Lanvéoc on the the Crozon peninsula in Finistère. Unfortunately, the surviving drawing of the site is not adequate for determining its geometric or astronomical characteristics with precision (Burl 1993, p. 54).

The principal factor in determining the possible astronomical or calendrical features of a site is the presence of specified types of geometric or astronomical alignments supported or at least not contradicted by the geographical and archeological contexts. For example, if several stones point to a distant artificial foresight, and a standstill Sun/Moon set in a knoll as indicated by the foresight in the epoch (independently determined by archaeological data) when the declination permitted this to happen, and if the probability of a random physical alignment of the stones in this direction were vanishingly small, a moderately convincing case for an astronomical alignment will have been made.

6.2.4. Horizon Astronomy

The basic astronomical formulae are (2.1) to (2.4). Solving these equations for the case in which the altitude, $h = 0$, when an object of declination δ is on the horizon, we have approximate expressions for azimuths and hour angles of rise and set:

$$\cos A = \frac{\sin \delta}{\cos \phi}, \tag{6.1}$$

$$\sin A = -\cos \delta \times \sin H, \tag{6.2}$$

$$\sin \mathrm{H} = \frac{-\sin A}{\cos \delta}, \tag{6.3}$$

$$\cos \mathrm{H} = -\tan \phi \times \tan \delta. \tag{6.4}$$

Recall that observations are made through Earth's atmosphere, which both refracts and scatters light. Therefore, for accurate results, corrections to the altitude for elevation, dip, and refraction must be made to determine the true azimuth and hour angle of the object. Consult §3.1.3 for details.

Twice the hour angle of rise or set is the time spent by the object above the horizon; as far as we know, there is no direct evidence that this type of information was recorded in any way in megalithic times. The azimuth of rise or set, on the other hand, can be and probably was marked by sightlines directed to points on the horizon.

It is the reality and the purpose of the layouts of these sightlines that constitute the main subjects of debate in megalithic astronomy. In *Megalithic Sites in Britain*, Thom (1967) described 145 stone circles and other monuments, and the solar and lunar alignments. With subsequent works (Thom 1971, 1974, A.S. Thom 1984, among others), the claims were sharpened and better substantiated. But criticisms abound (many are summarized by Hicks 1984a). To see why, we first describe how alignments are measured, and then we discuss the types and results of such measurements.

Sightlines are best measured with a theodolite, a survey device capable of high-precision measurements of altitude and azimuth. A measurement of the altitude and azimuth of the Sun in the daytime, or of a star at night, made at a precisely recorded instant of time (necessitating a precision chronometer), permits both longitude and latitude to be obtained (see §3.2.1). The determination of azimuth for surveying purposes requires that the direction of north (or some other direction) be known precisely, but measurements relative to some given direction can be made and later corrected. North can be established in several ways: by magnetic compass and application of the correction to true north; by measurements of the apparent azimuth and altitude of Polaris (or other appropriate stellar marker for previous epochs); by solar gnomon; or by bisection of the angle relating sunrise to sunset azimuths. Tables giving the differences in A and h between Polaris and the NCP at a given instant on a given date are provided in astronomical almanacs. To save time, the positions of landmarks that are included on accurate survey maps can be measured, and the true azimuth and altitude readings corresponding to all relative measures can be found later. The reduction requires tables of the right ascension and declination of the Sun for the dates of observation, and the star positions, corrected for precession. Corrections must be made for refraction and dip. Recall from §3.1.3 that refraction lifts the image of the rising or setting Sun (or Moon) above the horizon by an amount that is approximately equal to half a degree, but which varies with atmospheric temperature and air pressure, especially within the last few kilometers of the observer. The effect of refraction is to cause objects to rise sooner at smaller azimuths and set later at larger azimuths[4] than they would without refraction. Similar corrections must be applied for measurements of the objects on the horizon (distant foresights) or closer objects. Dip causes the horizon to be depressed with effects similar to those of refraction, in the sense that lower altitudes are visible than with a flat horizon. Finally, there may be instrument corrections (scale and zero-point adjustments).

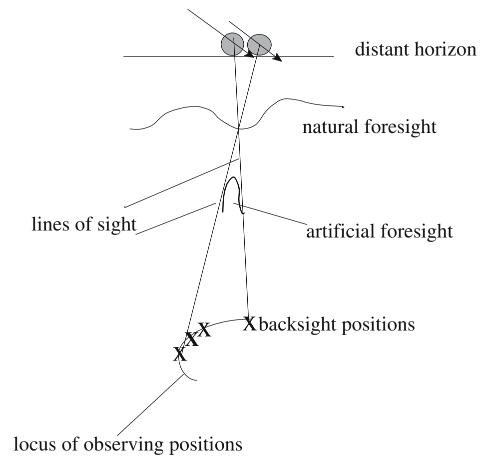


FIGURE 6.5. An example of an astronomical alignment involving distant foresights and backsights, and observations of a setting Moon near maximum standstill. Drawing by E.F. Milone.

The kinds of alignment-checking measurements that can be made depend on the type and layout of structure being studied. In the relatively straightforward case of a shaft through a building (or tomb), its bearing can be measured by sighting along its length. In the case of two or more standing stones, the measurement of the bearing can be made by aligning the instrument along the stones. On the other hand, a ring of stones presents many more possible alignments and an accurate survey of the site may take considerable time. In some cases, mountains on a distant horizon may align a rising or setting object with a backsight (an object closer to the observer). In principle, such an alignment is purely arbitrary unless features of the local terrain, such as the side of a hill, greatly restrict the field of view, or unless the backsight is a suitable distance away from the observer. Both types of conditions serve to improve the probability that the alignment is intentional. Such an arrangement seems to have been found at Kintraw (Thom 1971/1973/1978, pp. 36–40; MacKie 1974), in the British Isles, for example, but even this site is not without controversy. The measurements, although sometimes inconvenient to make, are straightforward. Surveying is only the beginning, however. The interpretation is more difficult. Figure 6.5 illustrates an astronomical alignment involving distant foresights, backsights, and an observation of a setting Moon at maximum standstill. The more distant the foresights, the more potentially precise the observation, to the limits set by visual acuity and atmospheric conditions. Note that the "artificial foresight" could function as a backsight.

Once the measurement of azimuth of a distant foresight has been made and the corrections determined, the declination of an astronomical object conforming to the direction of the alignment can be obtained by the equations of §2.2.4.

[4] Recall that we have defined azimuth to be measured from the North Point (in the Northern Hemisphere) positive eastward. With a similar convention for treating azimuths at Southern Hemisphere sites, measured from the South Point eastward, the same comment holds for the Southern Hemisphere.

This result can be compared with stellar positions that have been precessed back to the expected epoch, to the Sun at specified times of the year, or to the Moon sometime within the nodal regression cycle.

As we described previously, Ruggles (1981/1982a,c/1983) reviewed the evidence provided so carefully by Thom and associates and strongly criticized Thom's conclusions concerning the high precision of megalithic astronomical alignments. Nevertheless, Ruggles (1988a) concluded that alignments exist to three levels of precision:

(1) At the highest precision, there is some evidence, although marginal, indicating a preference for six specific values of declination, δ, viz., −30°, −25°, −22.5°, +18°, +27+, and +33°.
(2) At an intermediate level, there is a strong preference for alignments indicating $-31° \leq \delta \leq -19°$.
(3) At the lowest precision, alignments indicating the range $-15° \leq \delta \leq +15°$ are present but rare, perhaps avoided.

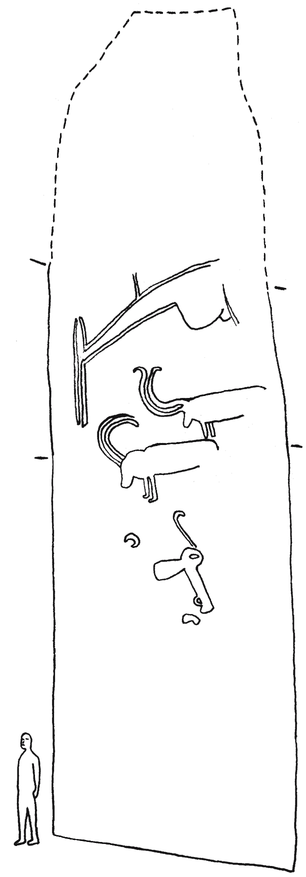
We now turn from general propositions to particular cases.

6.2.5. Brittany

In Brittany, we find early passage graves made from gigantic rocks and covered with earth. Most of these show a clear preference for an orientation of the passage to the southeast. A few show a precise alignment to a position that we can regard as astronomically significant. Burl (1985, pp. 23–24) suggests that only the general orientation to the southeast was important and that within that range, the precision of an alignment, for example, to the winter solstice, was purely accidental. This is a solution that has found substantial favor with many archaeologists, not least because it relieves them both of the necessity to understand the astronomical evidence, and of the tedious labor of checking alignments, horizons, and the possible astronomical-geometrical relationships of the site being studied. But there would seem to be at least two other possibilities. One is that the bulk of the population being buried in these great tombs was only interested in a general orientation, but that a small minority was deeply interested in great precision and that these are the people responsible for such alignments as that of Dissignac, Brittany (to be discussed later in this section), to the winter solstice rising Sun. The second possibility is that most or all of the population was interested in a variety of different precise alignments that were important to them but lack significance for us. At the moment, we know of no objective external criteria that would allow us to choose between these alternatives.

The earliest case that involves a precise alignment is found in one of two passage graves at Dissignac in Brittany. This burial monument has a corridor so oriented that the rising winter solstice Sun illuminates the burial chamber. Both graves are in a common mound that was built in several stages, and the graves may be of slightly different dates. Mohen (1990, p. 304) assigns the initial construction to about 4500 B.C. The tomb having the alignment lies to the south-

FIGURE 6.6. The large menhir, broken pieces of which have been incorporated into the lintel of the passage grave at Gavr'inis and in the tomb of the Table des Marchands at Loc Mariaquer: Note the enormous scale of the complete menhir and its elaborate decoration. Drawing by Sharon Hanna.



west, with a 7-m long passage leading to a rectangular chamber, which contained many pieces of broken, extensively decorated pottery, beads, and a range of stone artifacts (Burl 1985, pp. 98–99). The entrance capstone has representations of shepherds' crooks and axes, appropriate for a small farming community. The northeast tomb has a similar passage, but with different orientation and with a bend that prevents light from entering the inner chamber. At this writing, early in the 21st century, this site appears to mark the beginning of the archaeoastronomy record.

One of the more interesting Breton sites investigated thus far is the passage grave at Gavr'inis. One of the lintels of this monument is a broken piece of a giant menhir, which once stood 14 m high (see Figure 6.6). Another piece of the same menhir is built into the *Table des Marchands* tomb at Loc Mariaquer.

The latter site is also the location of another menhir, the tallest one known, *Le Grand Menhir Brisé*, which would have stood 20.3 m high when erected. It has been argued that this monument was so large that the people who tried to erect it were unable to do so and that it fell and broke. The discovery of another broken menhir of the same class and similar material at the same site suggests that both were broken in the same way, which is much less likely to be due to technical incompetence in both cases. Both Burl and Mohen have separately suggested that both monuments were deliberately torn down. However, the differing positions of the broken parts of Le Grand Menhir Brisé constitute a good argument for the view that the monument was toppled by earthquake (Thom and Thom 1978a, p. 98ff). Interestingly, Burl and Mohen draw opposite conclusions about the incorporation of part of a broken menhir into a passage grave. Burl (1985, p. 109) suggests that this "is evidence of the indifference prehistoric people could have for the handiwork of earlier societies," whereas Mohen (1990, p. 172) writes, "Using blocks again in other monuments symbolizes the endurance of a cult whose rites would suffer complete destruction of some of its sites." In any case, the presence of two broken giant menhirs in the same area is strongly suggestive that the same event was responsible for breaking both, whether due to deliberate human action, as Burl and Mohen suppose, or by natural events, as others have thought.

Thom and Thom (1978a, pp. 100–102) had presented the hypothesis that Le Grand Menhir Brisé acted as a foresight for megalithic astronomers gathering information on the movements of the Moon and suggested the identification of a number of sites that could have functioned as observing points for making these observations. From an archaeological viewpoint, the best support for such a view would have been some identification that the sites involved formed a complex. If they were all the same kind of monuments and all derived from about the same period, the hypothesis would have been supported. However, Burl (1985, p. 136) argues that three of the postulated backsights were probably not Neolithic monuments at all. He further argues that an alignment to a mound at Tumiac was inaccurately determined by Thom (if true this would be a rarity), and that the remaining monuments, menhirs, mounds, and passage grave are dissimilar in both architecture and date. Thom's postulated astronomical date of 1700 B.C. is later than some of the monuments. The most damaging case against the universal foresight hypothesis is that Le Grand Menhir Brisé was probably toppled before some of the other monuments were constructed and long before 1700 B.C. On the basis of ^{14}C dating (see §4.3), Burl (1985, p. 108) suggests that Gavr'inis was built "in the centuries around 3500 B.C." The hypothesis demonstrates that it is easy to be misled when there is a plethora of monuments. A straight line, after all, requires only two points, and there is a high probability that any line drawn through the monument laden region will pass over some monument. A line from a particular monument to a specifed point on the horizon can almost certainly be extended backward to pass over some monument from which the foresight could have been seen.

The Gavr'inis site, however, has considerable importance beyond its role in the story of the great menhirs. As at Dissignac, the passage grave at Gavr'inis is illuminated by the winter solstice Sun. Burl (1985, pp. 110–111) notes an added interesting difference between this site and Newgrange (described in §6.2.6):

> Looking from Stone 19, at the left-hand entrance of the chamber, toward Stone 1, the bearing is 128°, almost perfectly in line with the midwinter sunrise. The main axis of the passage is 134° towards the low-lying Arzon peninsula and the orientation is close to that of the major southern moonrise. It has been calculated that the two alignments, one solar, the other lunar, intersect halfway down the passage level with Stone 7, the white quartz slab whose undecorated surface may have been illuminated by the light of the rising Sun and Moon.

Gavr'inis is among the most lavishly decorated of the Breton tombs. Representations of long-horned cattle abound on the earliest Breton monuments, and the menhir that became the Gavr'inis capstone shows representations of such cattle. These have often been called oxen or bulls, but if the Breton cattle were similar to the contemporaneous Egyptian breed, the exceptional length of the horns would signify cows rather than bulls.

There is also extensive decoration on the companion passage grave at Le Table des Merchands. Here, however, it may be notational. Müller (1970, pp. 107–108) has drawn attention to the 56 shepherd's crooks, divided into 29 on the left and 27 on the right, and 19 accompanying curved elements, suggestive of the nearest whole number of days of synodic and sidereal months and of the Metonic cycle. At present, however, there is otherwise little evidence to connect the symbols with the cycles. Moreover, scholars disagree on what is being depicted. Burl (1985, p. 136) sees 53 crooks and an "anthropomorphic figurine," and Twohig (1981, p. 97) sketches the decoration differently. Whatever the outcome of this dispute, the motifs and style of the Breton passage grave decoration are closely paralleled at Newgrange and Knowth in the Boyne Valley of Ireland, and it is generally accepted that there is a close historical connection. The orientation to a winter solstice sunrise is common to Gavr'inis and Newgrange and suggests that both alignments are indeed intentional and arise from convergent or parallel traditions[5] that stem from an earlier passage grave tradition in both areas.

6.2.6. Brugh na Boinne

The remarkable complex at Brugh na Boinne (Figure 6.7) provides the best evidence of a contextual (rather than a statistical) nature for extensive and precise interest in astronomy. The three great mounds of Newgrange, Knowth, and Dowth and associated monuments are for the most part intervisible, and together, they form a kind of massive record, which we may only now be starting to understand. Eogan's (1986) work at Knowth has revealed two massive passage graves, one aligned to the east (and so to the rising equinox Sun), in which the sunlight directly penetrates the main burial chamber, the other aligned to the west (and the equinox setting Sun), with sunlight penetrating far down the passage but prevented from actually entering the burial chamber by a bend. The bent shaft is a feature reminiscent

[5] *Tradition* implies a common background. A *convergent tradition* involves groups becoming more alike, usually because of common external factors. A *parallel tradition* merely preserves common, older features, but that may not have been originally explicit.

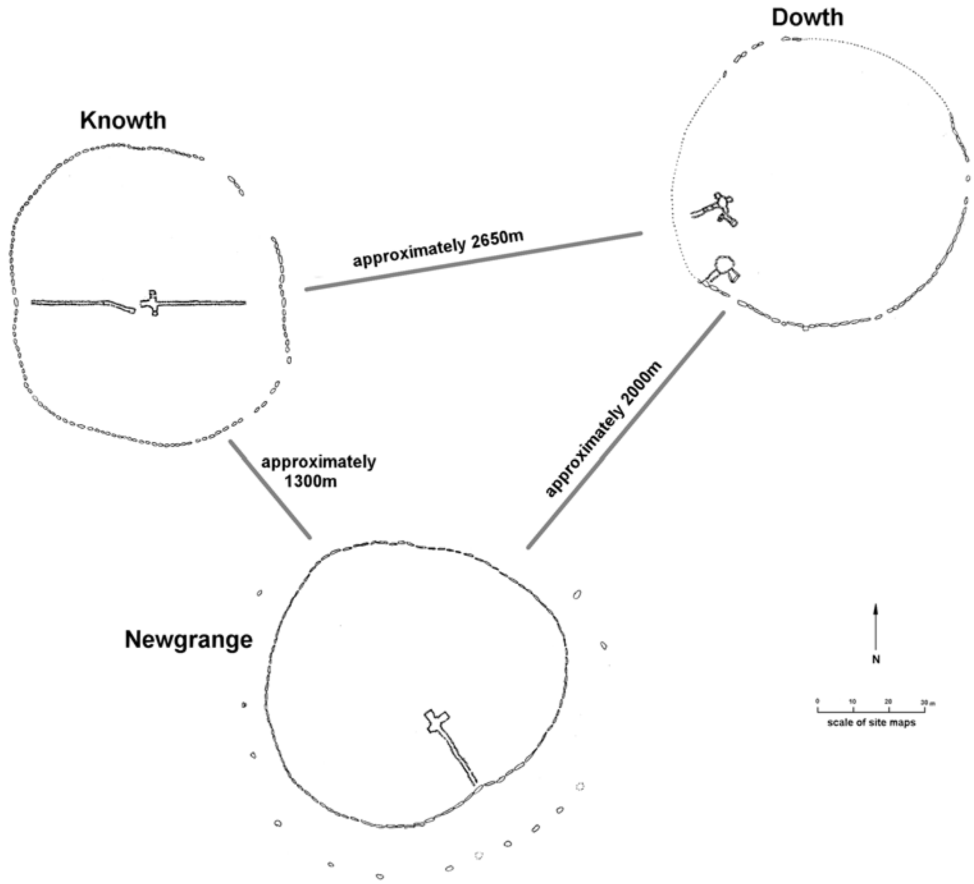


FIGURE 6.7. The funerary complex in the Boinne Valley, Ireland: It consists of three great mounds—Newgrange, Knowth, and Dowth—and associated monuments. Drawing by Sharon Hanna.

of the second passage grave at Gavr'inis. The kerbstones around the monument and many interior decorated stones provide the most extensive collection of megalithic art yet known, thanks to Eogan's work. At Newgrange, Michael O'Kelly (1982/1989) meticulously reset stones and cleaned and reconstructed the mound, while carefully recording information on the building sequence, construction techniques, and chronology of the mound, which stands more than 45 ft high and 300 ft across. Its quartz crystal facing glistens again in the Sun, making Newgrange one of the most visually impressive of all the megalithic monuments (Figure 6.8). He discovered a "roof box," a 62-ft long window shaft over the top of the entrance passage that still lets the rays of the rising winter solstice Sun illuminate the great corbel-vaulted chamber almost[6] as it did 5000 years ago. The discovery has helped to convince archeologists of the deliberate and accurate nature of the astronomical alignment of this passage, which was first demonstrated by Patrick

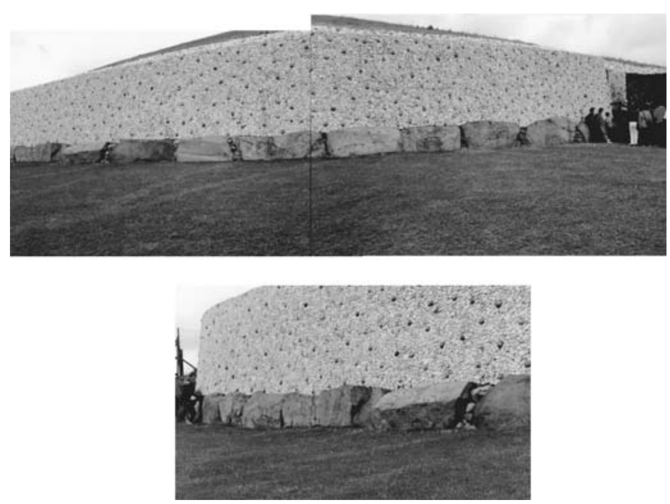


FIGURE 6.8. A photographic mosaic of the front of the quartz crystal facing of the passage grave monument at Newgrange, one of the most visually impressive of all the megalithic monuments. Photos by E.F. Milone.

[6] We say "almost" because the obliquity of the ecliptic has decreased by about 0.5° over that interval, decreasing the azimuth of rise of the midwinter Sun by about 1°.

Figure 6.9. Views and close-ups of the spirals on kerbstone 1 and on the opposite side kerbstone of the Newgrange passage grave. Photos by E.F. Milone.

(1974a,b) and refined by Rea (1988), who showed that in neolithic times, the sunrise rays could have penetrated far into the interior, illuminating a three-leafed spiral on the back wall.

Although the carbon-fourteen data from Newgrange suggest a date about 3100 B.C. for the construction of the mound (O'Kelly 1989, p. 351), a similar date from Knowth antedates the construction of the main mound there, suggesting that Knowth may be slightly later than Newgrange (O'Kelly 1989, pp. 109–110). Interpretations by Brennan (1983), whose activities and lack of meticulous surveying and incomplete documentation of his work have led to strong personal differences with archaeologists who have worked in this area, nevertheless provide some important insights. Three passage graves show alignments related to the winter solstice: the sunrise of Newgrange, the sunset at Dowth, and a possible noon alignment at Mound K—a badly damaged structure that nonetheless still indicates that the passage must have had a very low roof, which would have allowed sunlight to enter the chamber only at midday, when the Sun crosses the celestial meridian. At such a time, it will be remembered from earlier chapters, see, especially, Figure 3.17, the Sun is due South, and at the highest point of its diurnal arc, at an altitude given approximately by

$$h = (90 - \phi) + \delta. \tag{6.5}$$

At midwinter, the solar declination is equal to the negative of the obliquity of the ecliptic, $\delta = -\varepsilon \approx -24°$; the latitude at Dowth is $\phi = 53°41'$, so we find $h \approx {\sim}12°$. At the main mound of Knowth, a cruciform chamber is lighted by the rising equinox Sun and an angled passage grave is illuminated by the equinox setting Sun, to the point of the bend. The unique property of these passage graves is the unambiguous direction of the alignments. The shaft subtends a small solid angle on the horizon, and that angle is small due to the lengths of the shafts providing the alignments. Slight changes in the direction of the Sun cause different portions of the passageways and the burial chambers to be illuminated, giving high precision to the astronomical alignment. These passage graves provide strong evidence that precision in alignment direction was of direct concern to the people who built these structures, and so make at least plausible some of the arguments by Thom that distant foresights were used to accomplish similar precise alignments of other structures.

At Newgrange, 31 of the 97 kerbstones are known to be decorated, but only about 1/3 of the stones have been completely exposed (M.J. O'Kelly 1982, p. 15; C. O'Kelly 1973/1978/1982/1984, p. 152). Some are decorated not only on the exterior, but also on the side facing the mound, which would have been invisible at any time since the mound was constructed. The alignment of the passage grave is marked by kerbstone 1 (K1) at the entrance and by kerbstone 52 directly opposite. Both of these are bilaterally divided down the middle. K1 has a group of clockwise spirals on the left of the dividing line and a group of counterclockwise spirals on the right (see Figure 6.9).

Brennan suggests that the spiral marks the passage of the rising Sun on successive days northward along the horizon. The horizon movement, as we have described extensively (§2.3.1), continues northward from winter solstice until summer solstice, when the movement comes to a stop (the "solstice") and then reverses. We will return to this spiral motif again and again; it is a motif shared by many cultures.[7] Brennan suggests that the CCW spiral describes

[7] In her book on Polynesia, Makemson (1941, p. 22) refers to "the spiraling path of the Sun."

the northward movement, and the CW spiral describes the southern. Other stones, some not in alignment with extreme or equinox positions, are also marked with spirals, making the interpretation less convincing.

Surrounding the mound is another interesting feature, a ring of standing stones. Figure 6.10 shows the stones in a counterclockwise pacing around the northeast arc of these stones.

MacKie (1977a, pp. 72–73) regards the ring of stones as half ellipse and half circular arcs, with "the arcs of circles centered on the corners of two opposed right-angled Pythagorean triangles." However that may be, in ~2015 B.C. [Sweetman's (1984) date for the stone ring], Stone 1 of the ring cast a shadow onto the three-leafed spiral on the kerbstone in front of the entrance, K1, at the winter solstice. Prendergast (1991a,b) confirmed this circumstance (with the standing stone most directly in front of the entrance, GC1 in his designation,[8] casting a shadow, for a 20-minute interval after dawn, to K1's three-leafed spiral only for $-23°56' \leq \delta \leq -23°22'$, and found solar declination ranges for the shadows of other stones on the spiral as well: that of GC-2 for $-01°14' \leq \delta \leq +01°26'$, and that of GC-1 for $-12°53' \leq \delta \leq -09°51'$, corresponding to equinox and midseason declinations. Other determinations were: CG11 to GC7 aligned to $\delta = -23°49'$; GC5 to GC3 to a midseason $\delta = +11°33'$; and GC1 to GC-2 aligned to $+23°15'$, a possible summer solstice alignment). Figure 6.11, from Prendergast (1991, Fig. 5), shows the shadow play on K1.

Claire O'Kelly (1982/1984, p. 149) argues that K1 and K52 were in position before the neighboring stones were placed—possibly before the bulk of the monument was constructed. This raises the possibility that the ring predates the mound, and that stones of the ring bearing known alignments were used in laying out the passage grave. In fact, the size of the mound would have precluded any use of the ring in terms of alignments. If some of the kerbstones were used in conjunction with shadows of the ring stones in laying out the passage grave, the symbols on the interior faces of the kerbstones may become explicable. K13, possibly used in summer solstice sunrise-winter solstice sunset alignments, is extensively decorated on both faces, so that it is possible that it was intended to be used in connection with the construction of the mound and the correct placement of its reciprocal, K67. Later stratigraphic work by Sweetman (1984) suggested that the standing stones were erected a millennium after the positioning of K1. Even if true, and the alignments with K1 are somehow fortuitous, the internal alignments among the standing stones remain. Prendergast (1991) also estimates the probability that the apparent solar alignments are due to chance placements of the standing stones and K1. He uses the uncertainty in azimuth, σ_A, to produce a probablility of a random alignment in the sector of interest of $p = \Sigma\, 2\sigma_A/180°$, that is, the

FIGURE 6.10. Portions of the ring of standing stones around the passage grave monument at Newgrange: Three successive views proceeding CCW around the entrance. Photos by E.F. Milone.

[8] The designations of the standing stones are those of M.J. O'Kelly: proceeding clockwise from the tomb entrance, but allowing for gaps, as GC1, GC3, and so on; and the stones proceeding in a counterclockwise direction just to the northeast of GC1 are labeled GC-1, GC-2, and so on.

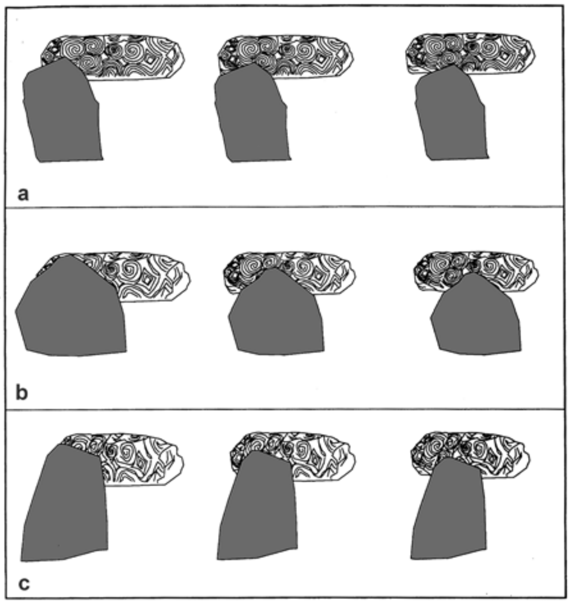


Figure 6.11. Simulation of shadow effects on kerbstone 1 by standing stones in the ring at Newgrange (Prendergast 1991, Fig. 5, modified by Sharon Hanna): (a) Shadows cast by standing stone GC1 at winter solstice over a 20-minute interval starting at sunrise with a solar declination –23°56′, appropriate for 2015 B.C. (b) Shadows cast by stone GC-1 when the Sun had a mid-declination of –11°53′. (c) Shadows cast by stone GC-2 at equinoxes (declination 00°31′).

sum of all ranges of angle $\pm\sigma_A$ centered on particular azimuths. He follows Schaefer (1986) to obtain an overall probablility that the apparent astronomical alignments are significant.[9] If $\mathcal{N}$ represents the number of such apparent astronomical alignments, and N is the total number of lines between the stones at the site, then the probability that the alignments are due solely to chance is

$$P(\mathcal{N}) = \frac{N! \times p^{\mathcal{N}}(1-p)^{N-\mathcal{N}}}{\mathcal{N}! \times (N-\mathcal{N})!}. \quad (6.6)$$

He concludes that the probability that the Newgrange alignments among the stones are due to chance is ~0.01. Note, however, that this approach is hardly foolproof in general; as the errors in the alignments, σ_A, become very large, so does p, and as p approaches 1, $P(\mathcal{N})$ approaches 0. Here, however, σ can be assumed to be at most tens of arcminutes.

[9] Generally, the chance probability in achieving $\mathcal{N}$ successes out of N trials in any situation in which the probability of a "success" is p can be written: ${}^{N}C_{\mathcal{N}}\, p^{\mathcal{N}}(1-p)^{N-\mathcal{N}}$, where ${}^{N}C_{\mathcal{N}}$ is the number of ways (combinations) to achieve these successes: ${}^{N}C_{\mathcal{N}} \equiv N!/[\mathcal{N}! \times (N-\mathcal{N})!] = [N \times (N-1) \times (N-2) \times \ldots (N-\mathcal{N}+1)]/[1 \times 2 \times \ldots \times \mathcal{N}]$.

The second of the great funerary centers in the Boinne complex is Knowth. At Knowth, 90 of the surviving 123 kerbstones are decorated externally and 11 are decorated on the interior side (Eogan 1986, p. 150). The structure of the principal mound, the placement of its kerbstone elements, and their ornamentation can be seen in Figure 6.12.

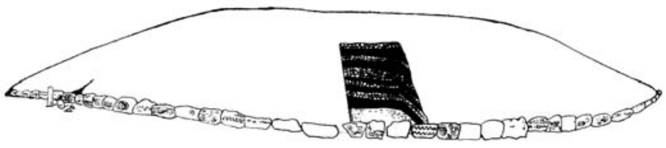
Calendrical concerns are suggested in the spirals and perhaps temporal concerns in what appears to be the face of a vertical sundial at the top of the fifth kerbstone to the south from the eastern entrance (Figure 6.13).

The radiating lines and the two depressions (albeit very shallow depressions) resemble those seen on a flat Egyptian sundial found at Luxor and now in the Ägyptische Museum, Berlin (Clagett 1995, Fig. III.56; see Figure 4.5). The Luxor sundial supported a weighted string that indicated the vertical and presumably a horizontal stylus to provide a shadow. If the Knowth kerbstone is indeed a sundial, it may be the earliest known example. A gnomon for such a device could have been horizontal with solid footing on the ground and two fingers to steady it in the two depressions. Because the length of a gnomon's shadow at any measured instant can give seasonal information, such a sundial might have been useful in the placements of some of the other kerbstones. The markings on the northern half of the Knowth dial include eight major points and eight minor points. This is exactly the sort of division one would expect if the 16 calendar divisions postulated by Thom (1967/1972, pp. 109ff) have validity, but if this were a sundial, it would antedate by more than a thousand years the alignments that led Thom to postulate such a calendar.

It is noteworthy that the kerbstones at the entrances to the two passage graves are also divided down the middle, like those at Newgrange. A bisecting shadow is cast onto the exterior face of the kerbstone at the west entrance at the equinoxes. Brennan has written at length about the possible interpretations of many of these kerbstones, but other than calling attention to the markers, he has not made any explicit attempt to determine the relationship between the "decorations" (or possibly notations) and associated alignments. The concept of a notational system, intermediate between iconographic symbolism and true writing is not one that most megalithic scholars have had occasion to consider prior to Brennan's work, and Brennan does not phrase his studies in these terms. The nature and implications of such a system are treated most fully, to our knowledge, in a work by Langley (1986) relating to repeated symbols in similar contexts in the art of Teotihuacan. Many of his general remarks are probably applicable here.

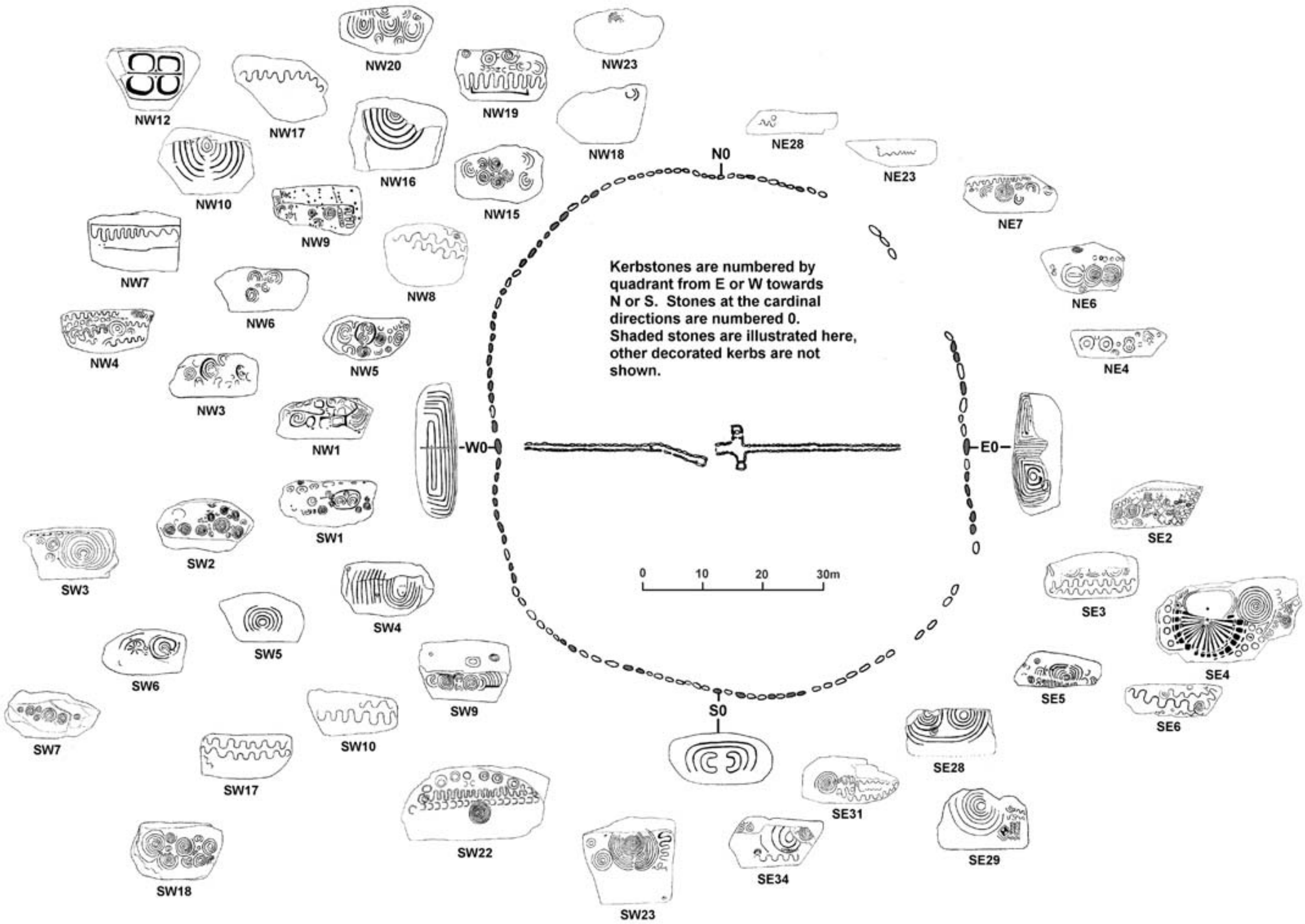
Of all Brennan's interpretations other than for the previously mentioned spiral, DHK finds that K52 (in Eogan's numbering; SW22 in Brennan) is the most convincing (Figure 6.14).

It displays a series of 22 crescents and 7 circles, features that could be stylized representations of the Moon over a synodic month. A spiral (representing the moving Sun?) cuts through three crescents and appears ten times on the right and nine on the left. Brennan also discusses possible



(a)

Figure 6.12. The grave monument at Knowth: (a) Diagram of the structure shows the kerbstone placements. Drawing by Rea Postolowski and Sharon Hanna. (b) Examples of ornamentation on the kerbstones related to their orientation at Knowth. The frequent use of spirals in funerary monuments probably implies a profound and widespread association between the human life cycle and the cyclical movements of the Sun and Moon. Drawing by Sharon Hanna.



(b)

meaning for other features on the kerbstones, such as wavy lines. Although seemingly ad hoc, these ideas merit consideration because they are applied in a context in which alignment and shadow effect appear to be genuine. One possible alternative has been suggested. Stooke (1994) maintains that the "crescents" are actually fairly realistic images of the maria of the Moon rather than stylistic images of a crescent Moon. We find this unconvincing.

Dowth is the third great funerary site in the Boinne valley complex. The layout is seen in Figure 6.7. Examples of ornamentation at the exterior and interior of this site can be seen in Figure 6.15. Note the spirals on the entrance kerbstone and circle and starburst symbols in the interior.

Differences of motifs have been magnified into separate "styles" in megalithic art to an extent that seems baffling to an outsider. DHK does not think that the decorative

FIGURE 6.13. Ornamentation on a kerbstone at Knowth, as it appeared on a visit to the site in August 1990: Spiral structures strongly suggest solar and calendrical concerns, and the radiating lines from the central shallow depression invoke the features of a vertical sundial. If it was indeed used as such, it would be the earliest known sundial. Photos by E.F. Milone.

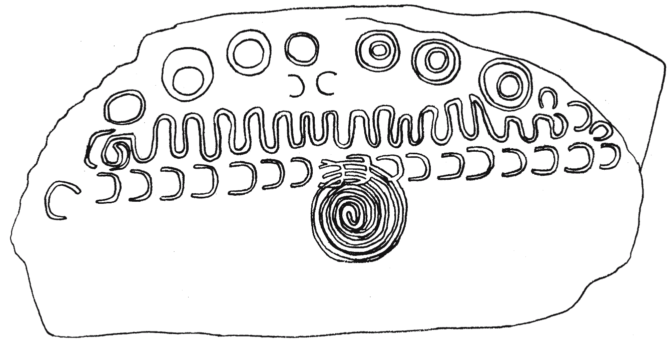


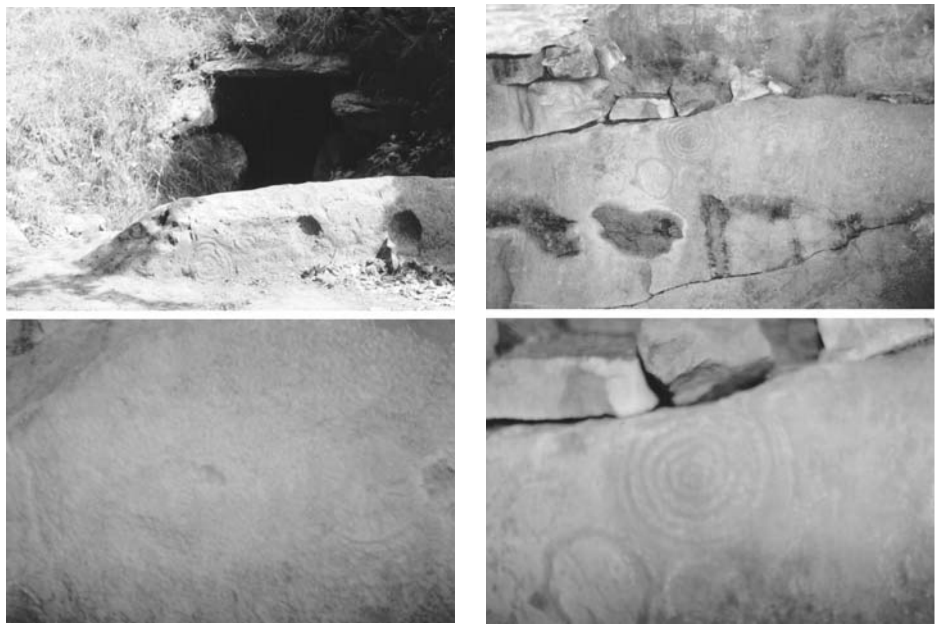
FIGURE 6.14. Ornamentation on kerbstone 52 shows possible lunar representations. Drawing by Sharon Hanna.

symbols should be classified into separate styles unless there is objective external evidence of differences of distribution that can be linked clearly either with specifiable geographic areas, time periods, or both.

The monuments in the bend of the Boinne have been referred to as a complex. This might be taken to imply that all were built at about the same time, or that a major and continuing plan was in effect. In a more limited sense, it must at least imply that similar or identical governing concepts determined the placement of newer features in ways that were congruent with those already there. We think that even a cursory examination of the layout of the area supports the view that it is, indeed, a complex in at least the latter sense. The east-west line through mound U to the great Newgrange mound, to mound L (off-center) and mound K, may be such an indication because it is parallel (as any east-west alignment must be) to the equinoctial alignment of Knowth. Another may be the north-south line through the Newgrange mound and the earthen ring or henge to the south, paralleling an alignment involving mound K. Although one is disposed to give weight to the argument that astronomical alignments were being replicated, somewhat higher weight could be given to less obvious geometric factors that influence the placement of monuments. For example, the alignments through the Dowth mound to the NE and through the Knowth mound to the NW are both at angles between 31° and 34° north of the east-west line through Newgrange. Each is on top of a separate ridge, and this purely topographic feature seems to be of central importance in determining the relative distances. More details can be found in Brennan (1983, pp. 70–71) and O'Kelly (1982/1984, pp. 83–84), where reference is made also to work by J. Patrick.

Not only is the *Brugh na Boinne* complex well marked in astronomical and artistic contexts, but it is also the only set of megalithic monuments in Europe that is directly relatable to pre-Christian myths and clearly incorporate astronomical motifs. However, words of warning are in order. We know of no one who would maintain that Celtic mythology is an unmodified representation of the views of megalithic farmers.

Even if existing stories and scraps of information allow us to glean some aspects of belief in the late centuries B.C., it must be remembered that Celtic warriors in their chariots at that time were as far removed temporally from the builders of Newgrange as we are from those Celts. Nonetheless, *Brugh na Boinne* plays a role in several Irish myths, which may well retain in modified form older beliefs. They should be considered in any attempt to determine the meaning of the site. In Irish, the common name for a mound is *brugh*, "mansion" and the different mounds are assigned to different gods. The mound of Newgrange is assigned to *Oengus Mac nOg*, spelled and interpreted in various ways. O'Rahilly (1946/1957, pp. 516–517) argues convincingly that *Mac nOg* is the Gaelic equivalent of the god known from British inscriptions as *Maponos*, and there identified as Apollo, although one need not accept all the linguistic details of O'Rahilly's argument. The name *Maponos* means "youth," whereas *Mac nOg* seems to incorporate the words for "boy, son" and for "young." Such names are typical for sun-gods,



(a) (b)

Figure 6.15. (a) Exterior and (b) interior views of a tomb at Dowth, Ireland: Note the spiral on the kerbstone and the circle and starburst symbols within. Photos by E.F. Milone.

born again each morning, so that the aforementioned equation with Apollo may be unnecessary. The sun god is also normally thought of as lord of the year, in which role he is to be born at the winter solstice [cf. Fraser (ed., T.H. Gaster) 1959, p. 633]. The appropriate nature of the association of Oengus Mac nOg with Newgrange is clear. The father of Oengus was *Dagda* or "good god" who seduced Oengus's mother, *Boand*, away from her husband, who was variously called *Elcmar*, *Nechtan*, or *Nuadu of the Silver Hand*. *Boand* is the later version of the name of the river goddess *Buvinda*, "White Cow"—the name of the presumed moon goddess whose name was given to the river Boyne.

O'Rahilly thinks that *Necthan* is a Gaelic name cognate with the Latin *Neptune* and is a byname of *Nuadu*; the latter name appears in Britain as *Nodons* (O'Rahilly 1946/1957, p. 321) and is surprisingly equated with Mars in one inscription (O'Rahilly 1946/1957, p. 527), although O'Rahilly equates him with the sun god and the "Otherworld-god of the Celts." The "silver-hand" suggests a linkage with *Tsiw*, the Germanic war god, whose hand was bitten off by the Fenris Wolf. Tsiw's name is incorporated in our Tuesday, the day of Mars in the planetary week. Elcmar or Elcmaire is supposed to have possessed the *Brugh na Boinne* before Oengus. An Irish tale tells how Cuchulainn, the "Hound of Cuala," "speared a salmon in the Boyne and then mutilated Elcmaire, who had entered the river to oppose him." (O'Rahilly 1946/1957, p. 320). The salmon that Elcmaire attempted to protect may have been the "Salmon of Wisdom," supposed to have resided in a pool at the head of the Boyne, but the complexities of identification are not adequately treated by O'Rahilly. Celtic lore also knows sun goddesses, of whom the greatest is *Grian*, "sun," and another is probably *Etain* who lives in a crystal *grianan* or sun-house (O'Rahilly 1946/1957, pp. 287–293)—a description that once would have fitted Newgrange well.

Eogan (1986, p. 20) reproduces from the *Seanchas na Relec* (the History of the Cemeteries) a list of burials of the *Tuatha de Danann*,[10] the people of the goddess *Danu*. One of the burials is the "Caisel" (castle) of Aengus, probably Newgrange. Another is the grave of Boinn, the goddess herself; it would be interesting to know which (if any) of the mounds was particularly associated with her name. Features of the area included the "paps of Morrigan," the war goddess; the mound of Tresc; the mound of the Bones; the cave of Buailcc Bec; and the items associated with Esclam, Aedh Luirgnech, Cirr, Cuirell, Cellach, Cineadh, and "the pillar stone of Buidi, 'where his head is interred'". The names are more or less obscure, and there is no direct evidence for tying most of them to particular mounds, but the list may yet become important in suggesting interpretations of astronomy. At the moment, the most that can be said is that the gods were associated with the mounds and that at least some of the associated gods are planetary, but we have no evidence for planetary alignments at these sites, nor perhaps could one readily expect them. Planetary movements are much more complex than are those of the Sun or even the Moon due to the effects of the relative motions of planet and Earth, causing variations between synodic period intervals.

[10] Celtic deities, later euhemerized to become early rulers of Ireland.

(a)

(b)

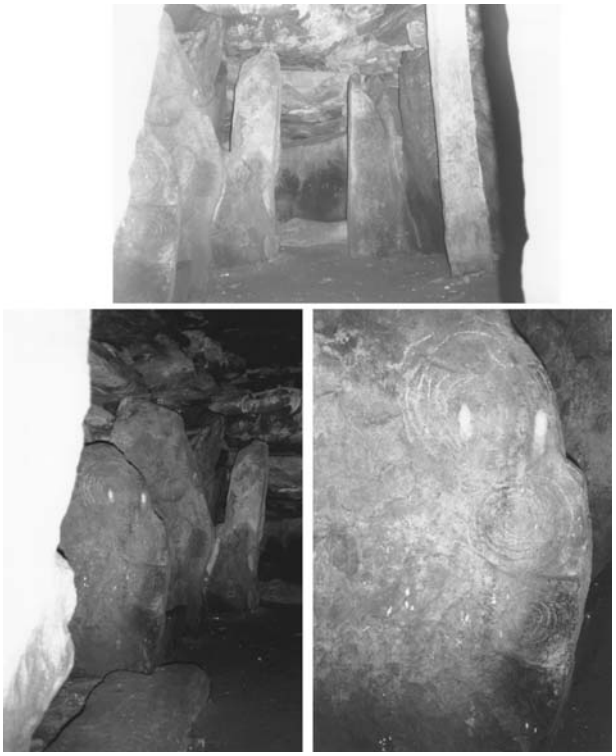
FIGURE 6.16. Sectional panoramas of the Loughcrew (*Sliabh na Caillaighe*) burial complex, Ireland, as seen from Cairn L, on the westernmost hill of the four-hill complex: (a) Montage of views to the west through south, with a close-up of the southwest horizon. Note the menhir, a potential foresight for midwinter sunset. (b) Further views from L show cairns in various conditions of preservation. Photos by E.F. Milone.

Nowhere else do we seem to have the degree of mythic relevance that appears with Newgrange and the Boyne complex, although a considerable amount of lore is known that associates mounds with Irish gods, kings, and heroes. Certain other sites reveal more direct information about alignments and associations with possible notational art.

The Loughcrew complex (*Sliabh na Caillaighe* or *Sliabh na Caillighe* (Ríordan 1979), *Slieve na Calliagh* (Harbison 1970/1992), "Hill of the Witch") is located in the same county (Meath) on high ground 40 km west of the Boinne complex with magnificent and commanding views of the surrounding lush green hills. The burials are centered on four hills more than 200 m in height. Loughcrew had as many as 30 mounds in the last century but only a few are relatively well preserved (see Figure 6.16).

As at Brugh na Boinne, the mounds contain a considerable amount of art, but it is freer and cruder than is the Boyne complex. It has been suggested that it is either a prototype or a provincial copy. Because we have no external evidence about the chronology, this problem cannot be resolved at present. There are some very revealing items at Loughcrew even now. The most important of the mounds is Cairn L (Figure 6.17). This is aligned 9° south of east, according to Brennan, but the Sun shines in at the equinoxes at a time when it is substantially above the horizon. However, the declination of the rising Sun can be slightly different at the sunrise closest to the equinox from year to year and from spring to fall,[11] and therefore, the shape of the light beam that actually reaches the chamber can be subtly different. Brennan's information is that as the Sun rises higher and higher, it successively illuminates different parts of the stone, framing first one, and then the other. If the evidence is accurately presented there would seem to be a relationship between the light beam and the design elements delineating the equinox.

[11] The rising line of the ecliptic is tilted toward the south in the spring and north in the fall (see Figure 2.20). Thus, the diurnal path of the Sun continuously varies in a small but discernible way and with it the azimuth and altitude that together determine shadowing effects. Here, the effect may be enhanced by altitude variation along the eastern horizon.



(a)

(b)

As in the Boinne complex, one small mound faces due south and hence marks mid-day, but whereas the low roof of the Boinne monument would have stopped the light beam from entering except near the winter solstice, here a floor cut below ground level apparently allows light to enter even when the Sun is at its highest, near the summer solstice. It is interesting to note that at summer solstice, a shadow bisects the symmetrical design of Stone 8 of Cairn U (Brennan 1983, p. 87), made possible by the destruction of the roof of the cairn. As at Newgrange, the summer solstice marker would have been visible only at an early stage of the construction of the mound and invisible thereafter.

Two further points can be derived from this material. One is that many of the mounds present unexpected or unexplained alignments. There seem to be alignments to the cross-quarter points of the horizon. A set of four mounds have successively changing alignments. Although some may mark solar calendar divisions, some do not seem to fit any scheme that we can recognize. The second point is that one important series of mounds is apparently aligned on the summer solstice rising Sun, although the individual passages have different alignments. The situation is like that of the east-west alignment at the Boyne complex, and it supports the inferences drawn from that complex.

Other Irish sites described by Brennan have passage grave alignments to solstices and both astronomical-calendrical investigations, and examination of design motifs should be considerably extended beyond what has been done already. Because of the paucity of human skeletons at these sites, and the alleged use of chambers to determine when phenomena would take place, Brennan called them "observatories." In no normal sense does the use of this term appear appropriate. The passage graves are oriented to already known phenomena, appearing once or twice a year or, perhaps, less. They could serve as calendrical markers, and they may well have served to indicate when particular festivals or rituals should occur, but this hardly requires the use of an observatory. Burl has suggested that the importance of ritual was beginning to outweigh that of burial. However, we cannot accept the view that the burials in these structures were of secondary importance to the astronomical alignments. They are, rather, inseparably linked. Although it is clear that intrusive burials continued to be made in some of the graves at least until Christianity became the dominant religion, the archaeological evidence both in terms of stratigraphy and of associated grave deposits is equally clear that many of the burials are primary deposits made at the time of construction of the monument. The use of the technical term "secondary burials" to indicate that the burials were not made immediately at the time of death may give nonarchaeological readers a mistaken impression. These were mass burials,

Figure 6.17. Cairn L of the Loughcrew complex (Sliabh na Caillaighe): (a) Interior views. (b) Exterior view from the entrance (upper), and view from inside toward the entrance. Photos by E.F. Milone.

and in Ireland, the bodies were normally cremated before burial. Thus, they may represent an accumulation built over several years. There is in fact every reason to think that the primary purpose of the monuments was to be graves. The astronomical associations of the winter solstice with the death and rebirth of the Sun, found in so many other cultures, may have been held by the builders of passage graves also. Similar relationships of gods and humans could be postulated for other alignments.

There are, of course, monuments other than passage graves for which it would be difficult even to postulate as much about the ritual activity and beliefs as has been suggested from passage graves. The burial mound of Newgrange may have been built inside an already erected stone circle, but there are contrary opinions. If it were erected earlier than the mound, however, it could have been laid out with a peg and a rope. This in turn could help explain why its diameter, 103.6 m or 125 MY, is the same as at Brogar and the inner rings of Avebury (Burl 1976, p. 71). At about the same time that the Newgrange burial mound was being built, a major set of stone circles was being built in Cumbria.

6.2.7. The Cumbrian Circles

Cumbria (formerly the counties of Cumberland and Westmorland) is in the extreme northwest of England, roughly bounded on the east by the Pennine Mountains, and the dominant type of circle and henge found here is known as the Cumbrian style, after the ancient district name. Over 50 stone circles are known in the Cumbrian region, but nine extremely large ones are known from the Lake District, "a part of Cumbria where virtually no other Neolithic site exists." There are also two in the same style in Scotland and one in Ireland. Table 6.2, adapted from Burl (1988, pp. 188, 203–205) lists the sites. These may be the earliest megalithic monuments known from England (perhaps as early as 3400 B.C., Burl 1988, p. 184), and they seem to be associated with the manufacture and distribution of polished stone axes (Burl 1988, pp. 183–184); Cumbrian axe factories were apparently also flourishing by 3400 B.C. Burl (1988, pp. 183–186) suggests that one of the purposes of these great stone circles was as a meeting place where people could trade for axes, a sort of market on neutral ground to which outsiders were allowed access at specific times. This may have been particularly important because this seems to have been a time of deteriorating climate caused by volcanic eruptions (3250 B.C. ±80; tree ring date ~3190 B.C.: Burl 1993, p. 30). The association of axes with megalithic monuments is even more striking in Brittany, where axes seem to play a ritual role, and it is widespread in Europe. This accompanies the even more widespread idea that stone axes are thunderbolts. There is also an association (possibly resultant) of stone axes with gods of thunder and lightning. It does not seem implausible to suppose that this association may have been already present at this time, as Burl (1976, pp. 81–182) thought. The further alleged association of thunder-axes with the Sun seems forced and unlikely unless solar phenomena were being correlated with planetary movements. If there was an astronomical connection of the axe cult, it is more likely to have been with the planet Jupiter, as known from the Mediterranean (cf. the Roman god *Jupiter Tonans*, "Thundering Jupiter") and arguable for Scandinavia.[12] Such an association, however, is not demonstrable for the megalithic sites.

TABLE 6.2. Cumbrian circles.[a]

Name or location	Phase[b]	Source of dating information
Castlerigg, Keswick	1	Stone axe
Long Meg, Eden River east	1	
Swinside	1	
Grey Yauds	1	
Brat's Hill	2	Antlers
Elva Plain	2	
Shap Centre	2	
Shap South	2	
Grey Croft	2	Stone axe
Gamelands	2	
Ash-House Wood	2	
Broomigg A	2	
Studfold	3	
Oddendale	3	
Casterton	3	Burial
Kirk, Kirkby Moor	3	
Blakely Raise	3	
The Beacon	3	
Shap North	3	
Lacra B	3	Flint
Kopstone	3	
Birkrigg	3	Urn
White Moss NE	4	
White Moss SW	4	
Gretigate NW (B)	4	
Gretigate NE (C)	4	Hematite
Low Longrigg SW	4	
Low Longrigg NE	4	
Moor Divock 4	4	Food vessel
The Cockpit	4	
Lacra D	4	Urn
Bleaberry Haws	4	Flints

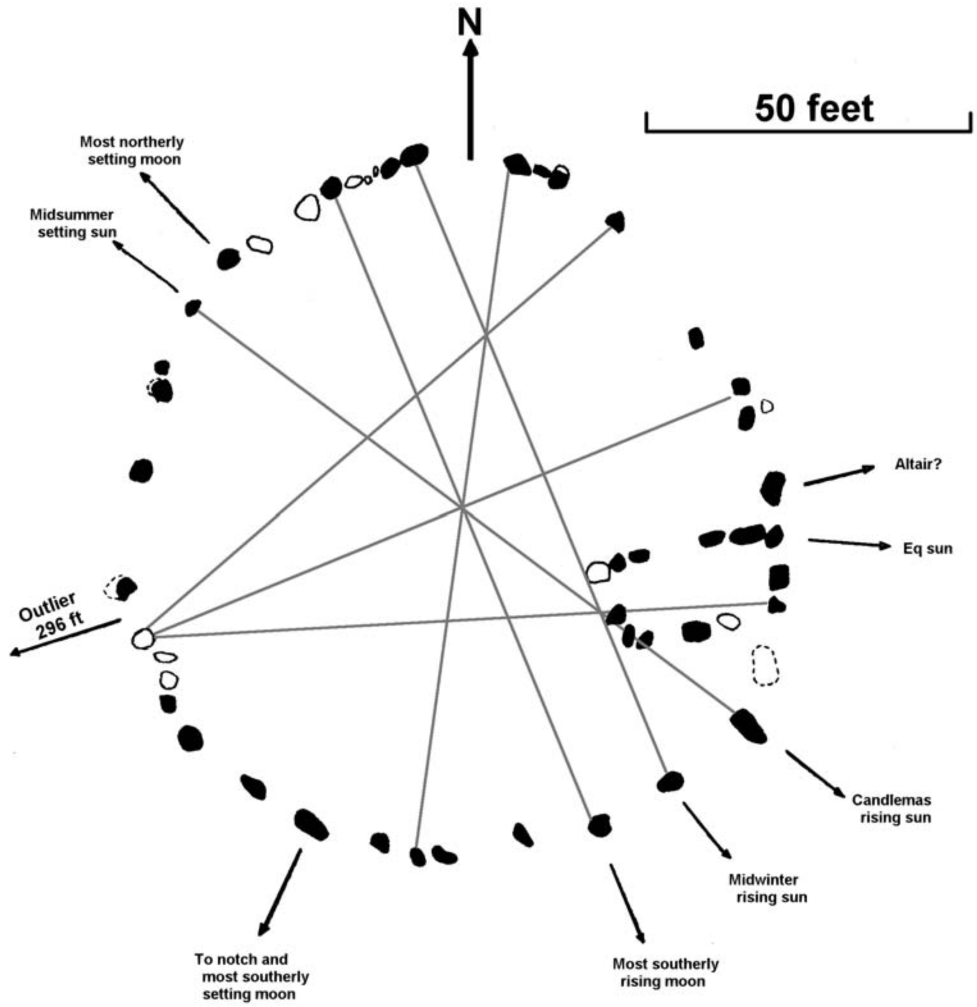
[a] Adapted from Burl (1976, Table 2).
[b] Burl's chronological ordering, based largely on early and late traits.

Cumbrian monuments include a predominance of flattened circles (as opposed to circles, egg-shaped ovals, or ellipses), suggesting a consistent style. The best known monuments of this region are Castlerigg (or Castle Rigg) near Keswick (Figures 6.18 and 6.19), and Long Meg and her Daughters, East of the Eden River, near Penrith (Figure 6.20).

Castlerigg is a flattened circle where the geometry and astronomy seem especially well blended (Thom 1966, 1967).

[12] Thor, the northern axe and thunder god, became the ruler of our day Thursday, the day of Jupiter in the planetary week.

FIGURE 6.18. The layout of the Cumbrian circle of Castlerigg, near Keswick, England. Drawing by Sharon Hanna.



Modest in scale, the diameter of the ring is ~97 ft (29.6 m), and the height of the tallest stone is ~7.4 ft (2 1/4 m). The horizon is very uneven.

Long Meg is located on the track to the Tyne Gap in the Pennine Mountains that provides access to northeastern England. The ring is a flattened circle, roughly 361 × 305 ft (109 × 93 m), the largest of the Cumbrian sites. It has a partial henge associated with it. A double-stone entrance is at the southwest, and 18 m beyond in the same direction stands the outlier stone, Long Meg (Figure 6.21), 3.4 m high, weighing ~28 tons (Burl 1976, p. 89).

According to Burl (1976, p. 92), the bearing of Long Meg from the circle's center is 223.4°. At a latitude of 54.7°, the azimuth of sunset with the Sun at $\delta = -24°$ is actually 227.8° for a level horizon, but Long Meg is the tallest of the stones, 3.7 m high and is moreover set at the top of a ridge. These circumstances mean that the Sun will disappear over the stone at a smaller azimuth by an amount that depends on the relative heights of the observer and the stone. The association with an observational solar function goes beyond the bearing, however. On the face toward the ring, Long Meg bears three markings: cup and ring, spiral, and a series of concentric circles, of which the outer two are incomplete (see Figure 6.22). The spiral is counterclockwise, a feature that has been associated with the winter solstice. From the center of the circle, the outlier, Long Meg, stands in line with the midwinter sunset (Burl 1988, pp. 196–197).

There was once a great circle of this group at Lochmaben, Dumfries, near the coast; now only two stones remain. Charcoal associated with one of the remaining stones gave a date of 3275 B.C. ±80. The site is mentioned by the Ravenna Geographer of late Roman times as *Locus Maponi* (from which the present name derives), and the Roman name derives from *Maponos*, the British-Celtic form of the name of the god known in Ireland as *Mac nOg* and associated with Newgrange (approximately contemporary in construction with Lochmaben) (Burl 1976, p. 205; O'Rahilly 1946/1957, pp. 292–293). One of the mythical figures associated with King

FIGURE 6.19. Sectional panoramas of the Cumbrian circle of Castlerigg, England: (a) View toward the entrance from the North. (b) Looking ENE across a rectangular enclosure—the largest hill on the right is the Threlkeld Knotts, over which the Sun appears at the equinoxes. (c) Three views of the rightmost of the stones in (b), and the largest in the circle. Photos by E.F. Milone.

Arthur is Mabon, son of Mellt, i.e., *Maponos,[13] son of *Meldos. Here we begin to see a relationship of the Sun god with the god of thunder and lightning, for *Meldos meant "lightning." The Irish *Mac nOg* is said to have been a son of the *Dagda* or "Good God." *Mac nOg* tricked his father out of his rightful possession, the *Brugh na boinne* (O'Rahilly 1957, pp. 52, 516–517). This association of Sun god and lightning god is definitely not an identity. Burl (1976, p. 205) thought that the name of *Maponos in this connection confirmed "the long use of some stone circles and the continuity of tradition whereby customs were perpetuated even by later comers to the district." The continuity may have been even fuller than Burl realized.

At Penrith, 10 km SSE of Long Meg, is a henge known as "King Arthur's Round Table." The central area is 50 m in diameter, and it is surrounded by a circular ditch that in turn is encircled by a bank. The full diameter of the structure is ~90 m, comparable to that of the flattened ring of Long Meg's Daughters, and probably had a similar function, to gather large numbers of people, possibly for axe trading (Burl 1976, p. 25). Large numbers of axes have been found at Windmill Hill and at Avebury. The stone circle construction, he notes, took a comparable amount of time to construct (he estimates 70 stones × 60 people × 10 hours/day = 42,000 man-hours) compared with estimates by Atkinson (1961) and Coles (1973, p. 73) of 55,000 man-hours for the Penrith henge (cited in Burl 1976/1989, p. 64). Burl also discusses the distributions of these forms. The stone circles and henges have a somewhat different distribution, with larger (over 200 ft, or 61 m diameter) henges distributed more evenly but with larger numbers in the central regions, whereas stone circles are much more strongly concentrated in the central and western regions. It is instructive that the stone circles in the central region tend to be accompanied by henges, but far less so in the western region (Burl 1976, p. 28). Was there competition for local populations in the central regions? If these great enclosures were used primarily as trade centers, the great number of them become somewhat more explicable, and so does the willingness on

[13] Linguists use an asterisk to mark recontructed forms. See §11.4, footnote 10.

FIGURE 6.20. Sectional panoramas of the Cumbrian circle of Long Meg and Her Daughters, near Penrith, England: (a) to (c) As viewed from the center, proceeding clockwise from the South. (d) As viewed from outside the eastern arc of the circle. Long Meg lies along a line to winter solstice sunset. Photos by E.F. Milone.

(a)

(b)

(c)

(d)

the part of the stone circle builders to adopt the henge in the most heavily henged regions. This does not explain if or why astronomy or burials would be involved, but it is clear that some of the most elaborate ones (Avebury and Stonehenge, for instance) apparently served more than one purpose (social functions, trade, funerary, calendric, and maybe other kinds of astronomy functions). Does similarity in style of a center accompany similarity of purposes?

Burl (1988, pp. 187–190, 195) maintains that there is little evidence of numeracy at this period, although he points out (following Thom) the remarkable similarity in design and size between Castle Rigg and Brats Hill on Burn Moor. There is also a similarity between Swinside and Ballynoe in (Northern) Ireland, that is so great that Burl thinks Ballynoe was actually built by Cumbrians. At Swinside (60 stones in a circle 90 ft in diameter), there is a portal entrance to the SE. The two northern stones of the portal coincide with alignment with sunrise on Samain (a cross-quarter day; modern Halloween) (Burl 1993, p. 38). At Ballynoe, a circle of 72 stones with a diameter of 108 ft, has a large portal with the northern stones of the portal aligned on the equinox sunset (Burl 1993, p. 38).

Figure 6.21. In this view, Long Meg presents the image of a leader addressing a gathering, or perhaps a teacher and her class or a matriarch and her family. Photo by Sharon Hanna.

Burl (1988, p. 189) thinks that the diameter of the circles may be a guide to the size of the populations that created them and gathered in them. He guesses supporting populations of ~400 people at Castle Rigg and ~4000 at Long Meg and Her Daughters; of these numbers, 1/10 would have been present at any one time. The circles normally had an entrance or portal marked by two larger stones, with a bigger than usual distance between them, and another pair outside the circle aligned on the entrance pair. The entrances were roughly on the cardinal points. Burl (1988, p. 200) writes

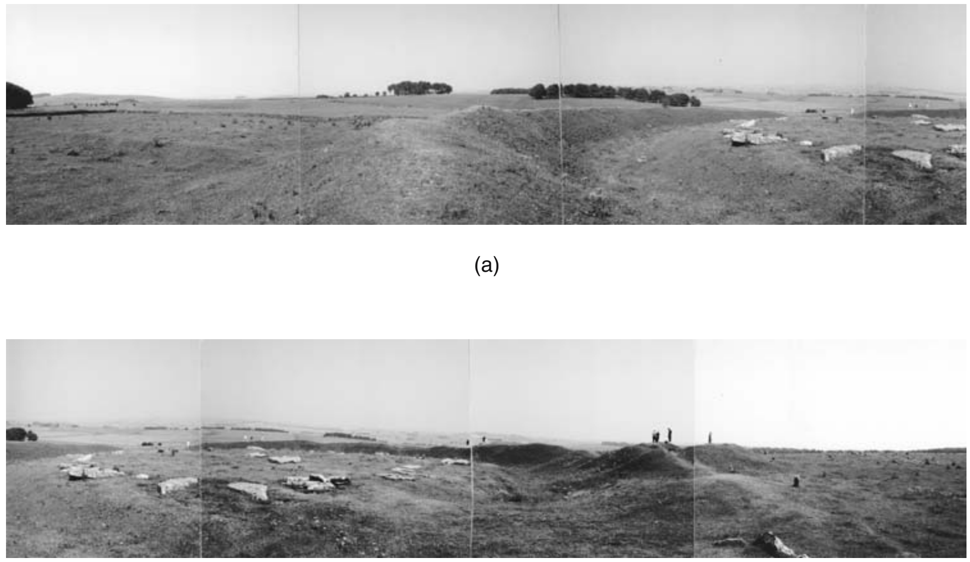
> there is hardly a precise alignment in the Cumbrian rings and if any one site were taken on its own, one would be justified in thinking that a supposed calendrical or cardinal orientation was accidental, even imaginary. Single sites can be misleading. Instead, it is the repetition, in ring after ring of comparable alignments that reinforces the belief that the lines were intended and needed by prehistoric people. General patterns, rather than individual site-lines, buttress the argument in favour of archaeoastronomy.

Burl's final summary of his views on the Cumbrian circles is much more broadly applicable (Burl 1988, p. 202):

> This may have been what a stone circle was to its people, a place where axes and gifts were exchanged, a place where annual gatherings were held, a place to which the bodies of the dead were brought before burial, but, above all, a place that was the symbol of the cosmos, the living world made everlasting in stone, its circle the circle of the skyline, its North point the token of the unchangingness of life, a microcosm of the world in stone, the most sacred of places to its men and women.

South of the Cumbrian circles in the British Midlands are a number of old, flattened circles, one of the best preserved of which is that at Arbor Low (Figure 6.23), although the stones are nearly all fallen over. At the center of its henge

Figure 6.22. Rain-darkened markings on Long Meg. There are three markings on this monument. (a) The entire stone; (b) cup and ring, and spiral; and (c) concentric rings. The spiral is poorly visible in (b) at the lower right. Photo by E.F. Milone.



(a)

(b)

FIGURE 6.23. Panoramic view of Arbor Low at Derbyshire, in the English midlands, a large henge and ring structure comparable in scale to Long Meg and Her Daughters: Note the combination of mound, ditch, and stone circle, characteristic of midland sites. Photos and Montage, courtesy Dr. T.A. Clark.

and ring is one of only four "coves"—three-sided structures composed of three large stones—to be located at such sites in the British Isles.[14] It faces SSW but is now fallen. Arbor Low shares many similarities with Cairnpapple (in scale and shape, of both henge and circle), where the funerary tradition spans millennia (Burl 1976, pp. 279–282).

6.2.8. Callanish: The White Cow

On the Isle of Lewis in the Outer Hebrides, in the Northwest of Scotland, there are a number of stone circles, all located near Loch Roag. The best known is at Callanish (Figure 6.24).

It consists of a ring of stones from which an avenue, defined by flanking stones, extends 82 m to the NNE. The stones are angular with their wider sides facing the avenue, except for the outer two, which face the visitor as if they were guard stones. The features of the site are shown in Figure 6.25.

Shorter lines of stones emerge to the east and (in the same line) to the west, as well as to the south. The avenue stones are along bearings 190.6° and 189.2° on the west and east sides, respectively (Thom 1971/1973/1978, p. 68). Burl (1993, pp. 61, 57) points out that the stones on the east side of the avenue are consistently about 3/4 as high as are the stones on the west side. This feature is characteristic of northern Irish avenues and double rows and of those on the Crozon peninsula in far western Brittany. Sometimes, the kinds of stones used were different as well. If there is any historical connection among these locations, it is probably due to their mutual accessibility by water. The cruciform shape of the Callanish complex is striking, and its location on a hill on a promontory makes it prominently visible at sea. Within the circle and in contact with its east wall is a smaller circle of predominantly smaller stones about a mound in which there is a passage grave with opening to the east. The tomb post-dates the circle, and its kerbstones are still later additions. The astronomical implications of the site have been examined by Somerville (1912b, p. 83), Hawkins (1966, p. 186), Thom (1967, p. 122; 1971/1973/1978, pp. 68–69), Hadingham (1976, especially pp. 101–106), Gerald and Margaret Ponting (1982, 1984a,b), M. Ponting (1988), and Burl (1976, pp. 148–155; 1993, pp. 14–16, 59–61, 63–65, 178–180). Thom's

FIGURE 6.24. View from the NNE avenue of the cruciform monument of Callanish on the Isle of Lewis in the Outer Hebrides. Photo by Sharan Hanna.

[14] The other coves are located at Stanton Drew in Somerset (where it lies WSW of the main circle) and faces roughly south, at Cairnpapple in West Lothian and faces east, and at Avebury, where it faces NE.

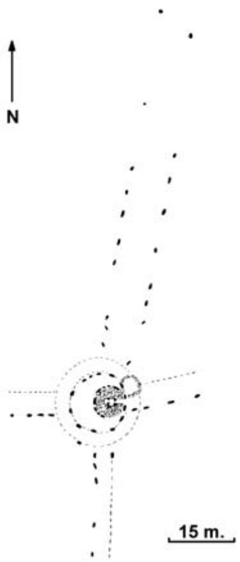


FIGURE 6.25. Features of the Callanish site. Drawing by Sharon Hanna.

analysis of the Ordnance Survey data suggest that the extreme Southern setting position of the major standstill Moon could have been observed at this site. The 173^{d} periodicity in the variation of the lunar inclination could have been noted through the interaction between the setting Moon and the terrain near Mt. Clisham in the Harris region of the island because at the range of declinations (−29°11.3′ to −29°26.8′), the Moon would alternate between skirting the top and the bottom of the undulating horizon. Ponting and Ponting strongly challenge this observation and state that an intervening hillock would have prevented this observation from this site, although not from sites in the vicinity. Thom also noted that the limits of the short-term perturbation in *i* could have been determined more easily at another nearby site, at moonrise, against a foresight with more variation. Stellar alignments claimed for Callanish are more problematical. The avenue was said to have been aligned on Capella, for example, by Lockyer (1906/1909, p. 377), Somerville (1912), and Thom (1967, p. 98), but for dates between 1800 and 1790 B.C., in the Middle-Bronze Age, most likely well after the monument was constructed and when the tradition of standing stones was into decline. The history is discussed by Burl (1982, p. 144).

Callanish illustrates the difficulties of reconciling archaeological and astronomical evidence. Hawkins (1965b) determined 12 alignments based on Somerville's map. Unfortunately, five of these depend on stone 35, which was reerected ~1860, almost certainly not at the original location (Ponting and Ponting 1984, p. 47). On the other hand, Thom thought that a number of other stones had been reerected, based on early descriptions of some of them as "fallen." In fact, they were all in position, buried in 5 ft or more of peat in early photographs, with only the upper part showing, sometimes mistakenly giving the impression of much smaller fallen stones. At that time, the cairn was completely covered. The peat began forming about 1000 B.C., with changing weather conditions, and thus establishes a minimum age for the site (Ponting and Ponting 1984a, p. 7). Archaeological materials that were recovered in excavations in 1980 and 1981 indicate that the circle was built ~2200 B.C. The Pontings think that the tall standing stone now at the circle's center was put up still earlier. Stone 33A was visible in 1857 but then covered; it was rediscovered by the Pontings in 1977, by probing, then excavated in 1980, and reerected in its original hole in 1982. A Glasgow University survey in 1974 determined that the azimuth of the east row was 76°5′ rather than 77°8′ as recorded by Somerville and used in all studies prior to the survey. According to Burl (1993, p. 180), the east row would have been aligned on the rising of the Pleiades ~1550 B.C.

There is a suggestive similarity between what has been determined about Callanish and a famous description of a Hyperborean temple by Diodorus Siculus (1st century B.C.) derived from Hecataeus of Abdera (~500 B.C.). The description has frequently been applied to Stonehenge, but Burl (1993, pp. 64–65, 179–180) shows that interpretation to be highly unlikely. Diodorus wrote

> Of those who have written about the ancient myths, Hecataeus and certain others say that in the regions beyond the land of the Celts there lies in the ocean an island no smaller than Sicily. This island, the account continues, is situated in the north and is inhabited by the Hyperboreans, who are called by that name because their home is beyond the point whence the north wind (Boreas) blows; and the island is both fertile and productive of every crop, and since it has an unusually temperate climate it produces two harvests each year. Moreover, the following legend is told concerning it: Leto [mother of Apollo] was born on this island, and for that reason Apollo is honored among them above all other gods; and the inhabitants are looked upon as priests of Apollo, after a manner, since daily they praise this god continuously in song and honor him exceedingly. And there is also on the island both a magnificant sacred precinct of Apollo and a notable temple which is adorned with many votive offerings and is spherical[15] in shape. Furthermore, a city[16] is there which is sacred to this god, and the majority of its inhabitants are players on the cithara; and these continually play on this instrument in the temple and sing hymns of praise to the god, glorifying his deeds.
>
> The Hyperboreans also have a language, we are informed, which is peculiar to them, and are most friendly disposed towards the Greeks, and especially towards the Athenians and the Delians, who have inherited this good-will from most ancient times. The myth also relates that certain Greeks visited the Hyperboreans and left behind them there costly votive offerings bearing inscriptions in Greek letters. And in the same way Abaris, a Hyperborean, came to Greece in ancient times and renewed the good-will and kinship of his people to the Delians. They say also that the moon, as viewed from this island, appears to be but a little distance from the earth and to have upon it prominences, like those of the earth, which are visible to the eye. The account is also given that the god visits the island every nineteen years, the period in which the return of the stars to the same place in the heavens is accomplished; and for this reason the nineteen-year period is called by the Greeks the "year of Meton." At the time of this appearance of the god he both plays

[15] In Greek, σφαιροειδῆ.

[16] "Community" may be a better rendering of the Greek πόλιν in this case.

on the cithara and dances continuously the night through from the vernal equinox until the rising of the Pleiades, expressing in this manner his delight in his successes. And the kings of this city and the supervisors of the sacred precinct are called Boreadae, since they are descendants of Boreas, and the succession to these positions is always kept in their family (Loeb Library, Book II, §47). [Bracketed material added by present authors.]

Burl, with the Pontings, supposes that the "Moon being nearer the Earth" refers to the appearance of the major standstill Moon above the Callanish horizon. At its southern maximum ($\delta \approx -29°$), the Moon never rises more than ~3° above the horizon and the "big moon" effect (see §3.1.3) would enhance the illusion that the Moon appears closer to the Earth at that time. This is a result of the high latitude of the Callanish site ($\phi \approx 58°10'$) and the circumstance that the altitude of an object transiting the celestial meridian is equal to the sum of its declination and the site's colatitude: $\delta + (90 - \phi)$. The effect is far less striking at Stonehenge ($\phi = 51°11'$), where the altitude of the Moon would be greater. The seemingly sharper details are more difficult to explain, because the greater air mass of the lower altitude Moon at Callanish would tend to obscure details rather than enhance them. Perhaps, in this case, the local observer's visual acuity played an important role. It is interesting that the Greeks adopted the cult of "Hyperborean Apollo" in about 470 B.C. and that Abaris, possibly a mythical figure, is alleged to have taught Pythagoras (Burkert 1972, pp. 149–150).

Another different line of evidence for Callanish as the island of the Hyperboreans involves the reference to the birth of Leto, mother of Apollo, on the island. If we transfer this into Celtic terms, Mac nOg, the equivalent of Apollo, was a son of *Bu-vinda, "White Cow," the goddess who gave her name to the Boyne River. Ponting and Ponting (1984, p. 30) relate a legend about the arrival of a Gaelic-speaking white cow, which emerged from the sea during a famine. The cow told the people to come to the Callanish stones and she would give them each a bucket of milk. However, a witch brought a bottomless bucket and milked her dry. DHK thinks this is a version of the cornucopia myth, the horn taken from Amaltheia by Zeus and given to the nymphs Io and (her sister) Adrasteia. Io was a name of the moon goddess in Argos and the name given to a woman beloved of Zeus, who turned her into a white cow to evade Hera's jealousy. The various motifs linked by the story from Callanish look more like scraps of ancient mythology than most such stories.

Another legend given by the Pontings (1984a, p. 27) says that the Stones were brought to Callanish in ships and erected by black men under the direction of a priest-king, who was always accompanied by wrens. He and other priests wore feather cloaks (which was true of some Gaels in the pre-Christian period). The reference to wrens suggests the golden-crested wren, king of the birds. As sacred birds, wrens could be killed only once a year by the "wren-boys" on St. Stephen's day (Dec. 26) just after winter solstice (Frazer 1912, Part V, Vol. 2, pp. 317–320).[17] Sometimes the killing was done by piercing the bird with sticks, fastened to make a kind of armillary sphere[18] (see Figure 6.26). It has always been assumed that Diodorus's "spherical temple" was merely some curious error for "circular temple," but the association of Callanish with wrens and the winter solstice raises the possibility of a different meaning, involving an actual spherical structure such as an armilla; certainly one would expect educated Greeks of the 1st century B.C. to be able to distinguish a sphere from a circle.

The wren king is known in Devonshire as "the cuddy vran," "Bran's sparrow," and Bran is another important bird, "crow, raven" as well as a figure of Welsh traditional legend, King Bran. In the *Romance of Branwen* (named for Branwen, "white crow," sister of Bran), it is said that Bran's decapitated head was buried at Tower Hill in London to guard the city from invasion. Decapitation is associated with eclipses in other culture areas. The decapitation and other associated motifs suggest a solar identity for Bran. Apollo's bird was the crow, and the traditional phrase "as the crow flies" implies a recognized analogy between the crow's flight and the movement of the Sun along the ecliptic.

It is reasonable to suppose that the Greeks had already defined the "four winds" as direction markers at an early date; two sons of Boreas are included among the crew of the Argonauts. We may say, therefore, that the line south of the circle, which has a true north-south alignment,[19] was, in Greek terms, a line to Boreas. The movement of the Moon in the sky and in the 19-year Metonic cycle, the winter solstice alignment, the "north pointer," the equinox alignment, the possible Pleiades alignment, the size of the island group (the Hebrides), and even the reference to the sphere all seem to fit Callanish far better than Stonehenge.

Burl has repeatedly emphasized that groups of sites that show similar alignments provide much better evidence of intent than any single site can, however great the apparent precision at a single site. On the Isle of Lewis in the near vicinity of Callanish, three stone circles are also oriented to the southernmost setting of the major standstill Moon, and other monuments suggest the same orientation. Ruggles (1984, 1985) demonstrated that north-south lines were common in SW Scotland. There is also a rarer alignment at Callanish that is seldom mentioned.

Looking from the main site (Callanish I) to the east, Callanish XIV, a single standing stone, becomes a remarkably good marker for the equinoctial sunrise (Ponting and Ponting 1985b, p. 37).

6.2.9. Brogar, Stenness, and Maes Howe

These three monuments date from about the same period, 3000–2800 B.C. according to Mohen 1990, p. 132; Burl (1976, p. 101) suggests that Stenness and Maes Howe are slightly

[17] The wren appears as Βασιλισκος or "little king" in classical Greek, as Regulus and rex avium in Latin, and similarly in Italian, Spanish, French, German, Dutch, Danish, Swedish, English, and Welsh.

[18] In 18th-century Ireland and on the Isle of Man, the wren was killed on Christmas Day and was hung by a leg from two hoops crossed at right angles.

[19] It was this feature that so impressed Thom and was so critical in the development of modern archaeoastronomy.

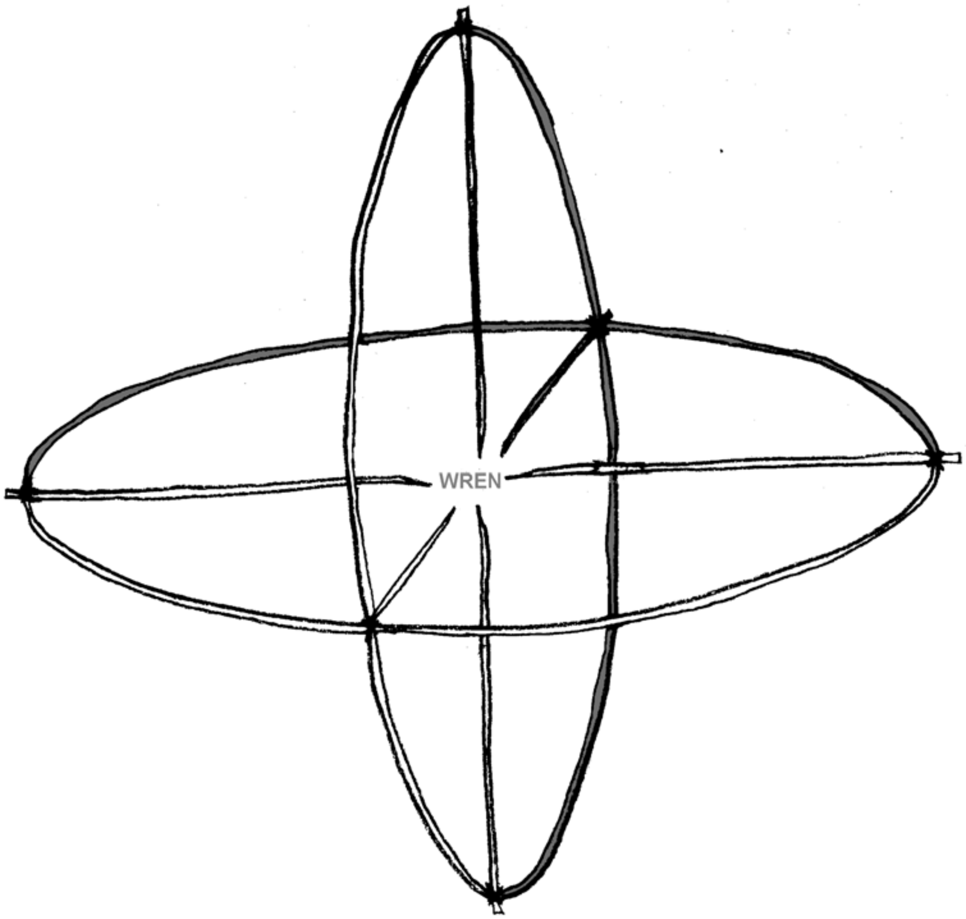


FIGURE 6.26. The (symbolic) killing of the sacred wren on Saint Stephen's Day, just after the winter solstice: It was sometimes depicted as the piercing of the bird with sticks, fastened to make a kind of armillary sphere. Drawing by Sharon Hanna.

older than Brogar. The Brogar (sometimes, *Brodgar*) and Stenness monuments are rings of standing stones; Maes Howe is a tumulus or burial mound. All are located on the main island ("Mainland") of the Orkneys in the extreme north of Scotland. The latitude of these sites is ~59.0°. Stenness and Brogar are about a mile apart on an isthmus separating the Loch of Stenness from the Loch of Harray.

The Brogar stone circle monument (Figure 6.2) has a diameter of 103.6m (125MY), the same diameter as at Avebury (A. and A.S. Thom 1973, p. 122) and of the standing stone circle surrounding the great tumulus at Newgrange in Ireland. These dimensions make it one of the largest of the stone rings. The stone circle at Brogar is surrounded by a circular ditch with a diameter of 142m. Thom and Thom (1973) argued that the site was used for lunar observations, although the dates assigned to this relatively high-precision activity, ~1560 B.C., suggest a very late refinement of use of an ancient site. The use of natural foresights on the horizon provides much greater accuracy as well as measurement precision, as we have noted (§§3.2.1, 6.2.4).

The "Standing Stones of Stenness" (Figure 6.27) are on a circle 31.1m in diameter, surrounded by a circular bank 61m in diameter. It has an entrance avenue to the NNW, thus, to the setting direction of the midsummer Sun. It originally had 12 stones.

FIGURE 6.27. A few of the Standing Stones of Stenness on the Mainland island of Orkney: The central rectangle is just visible. Photo by Sharon Hanna.

Burl identifies the Stenness henged ring as older than the other two sites on the basis both of stylistic considerations—he classifies Stenness as a class I henge and Brogar as class II—and ^{14}C dates (timber and uncremated bone gave uncorrected ^{14}C dates of 1730 ± 270 bc and 2238 ± 70 bc, respectively, and 2356 ± 65 bc was found for an animal bone found in the ditch). Many broken axe heads were found at Stenness.

Seventeenth-century tales (recounted by Burl 1976, p. 15) tell of Sun worship being carried out at Brogar and moon worship at Stenness. Less than a mile east of Stenness is Maes Howe.

Maes Howe is on a raised platform surrounded by an incomplete ditch. It contains a passage grave with a passage 24 m long and lined with flat slab walls and corbelled roof. It terminates in a square chamber adjoined by three square cellular chambers. The tomb is carefully constructed with fine stone workmanship, and it has been cited among Europe's finest megalithic constructs. A door into the chamber was deliberately cut lower so that it did not completely block the entrance, allowing light from the midwinter sunset to enter the tomb (Burl 1993, p. 63). This has an analog in the midwinter sunrise phenomenon at Newgrange, which is roughly contemporary. The Orkneys, formerly the Orcades, were named for the "Pig People." See §6.2.18.3 for a discussion of similar megalithic alignments on the "Big Pig" and "Little Pig" islands.

In addition to these sites is another, lesser known monument, the Ring of Bookan on a platform surrounded by a ditch about one mile NW of Brogar, which contains a passage grave. Also near Brogar is the Stones of Via passage grave, and a long mound and ~20 cairns. There are also four other passage graves within ~10 km of Stenness. A village of stone houses at Skara Brae on the west coast of Mainland, Orkney, was recovered in the mid-19th century. From carbon 14 dating, its true dates of occupation were between 2400 to 1800 B.C. (Mohen 1990, p. 315).

6.2.10. Stonehenge

This is the best known of all the megalithic constructs. Figure 6.28 gives the modern appearance of the monument, and the layout of the site is given in Figure 6.29.

Stonehenge has been speculated about since the 12th century,[20] and carries back in legend further than this. The comments of the Sicilian writer Diodorus, discussed in the context of Callanish, are often thought to refer to Stonehenge, but they are not Stonehenge-specific. Moreover, the historicity of Diodorus's source, the 6th-century B.C. writer Hecataeus, is not regarded with any great confidence. Ptolemy refers to both the 19th parallel (51½°N, longest day of 16½ equinoctial hours) through southernmost "Brittania" and the 28th (62°N, 19½ equinoctial hours) through "Eboudae," by which he means the Hebrides (Toomer 1984, pp. 87–89, fn. 65). Roman references to the island are common; in particular, many historical references can be found to the Druids and their worship of trees, stones, and sky deities. However, the Druids were not the builders of this or of the other megalithic sites, although they may have used and maintained them. The origins are in the Neolithic. The history of speculation about Stonehenge is entertainingly conveyed by Hawkins (1965). The chronology (based on Atkinson 1956/1979 but revised with other data) is given in Table 6.3.

Archeologists agree that Stonehenge appears to have been built in three stages. The ^{14}C age for Stonehenge I is ~3000–2500 B.C. (see Hoyle 1977a, pp. 32–34 for the details of the process and further comments), whereas the last phase, Stonehenge III, was constructed about 1000 years later. We begin our discussion with Stonehenge I.

The earliest stage involved the construction of a 409-ft. (125-m) diameter ditch that defines the outer part of the monument, a large earth bank, 56 chalk-filled holes (the Aubrey Holes[21]) arranged in a circle within the banked enclosure, mounds located within the bank, an entrance "causeway" created by a 35-ft (10.7-m) break in the bank and ditch to the northeast, a large standing stone (No. 96) known as the "Heel Stone" (also written "Heelstone" or "Hele stone"), post holes near the causeway and near the Heel Stone, and stone holes in the entrance (Figure 6.30).

The Heel Stone is of a kind of sandstone, called a "sarsen" stone (derivation uncertain). It rises 16 ft (8.5 m) above ground (another 4 ft is estimated to lie below the surface) and has a thickness never less than 8 ft (2.4-m) across its length. The Causeway and postholes preceded the erection of the Heel Stone, which otherwise would have obscured the posts on the right-hand side of the Causeway. Wood (1978, pp. 162–164) argues persuasively that the Causeway, originally oriented a few degrees north of midwinter sunrise, and the posts in the Causeway were intended for observation of the northern risings of the Moon. Brinckerhoff (1976) noted that between the Causeway posts the Moon could be observed to rise at 1/4, 1/3, and 1/2 of the length of time between the midpoint and major standstill of the lunar cycle. The Heel Stone would have marked a lunar midpoint rise more permanently than any wooden post. Another group of features seems to involve alignments from a slightly later stage of construction (late in Stonehenge I or in Stonehenge II), and so we discuss these before the Aubrey Holes themselves. Within the Aubrey Hole ring perimeter are four "Stations," 91, 92, 93, and 94 (indicated on Figure 6.29), which form a rectangle of important solar alignments. Stations 91 and 93 are stones (Station stone 91 is a fallen menhir, 3.66 m long). Stations 92 and 94 are on opposing mounds (covering Aubrey holes and thus indicating that they are newer), with 92 being the site of a filled hole that may have held a stone or post. At the latitude of Stonehenge, 51°11′, this rectangle describes the approximate alignment of extreme aspects of the horizon solar calendar, i.e., the amplitude of

[20] Geoffrey of Monmouth's *History of the Kings of England* contains a summary of legends regarding the site.

[21] Named after John Aubrey. Aubrey inspected and reported on the site for Charles II, beginning in 1663. His description of the chalk-filled holes is contained in his unpublished manuscript entitled *Monumenta Brittanica* now in the Bodleian Library, Oxford.

(a)

(b)

(c)

Figure 6.28. Stonehenge on Salisbury Plain in southern England as seen from (a) the East, (b) the ENE, and (c) the NNE permits the intact portions of the trilithons to be identified. Photos by Marie C. Jack.

Table 6.3. The chronology of Stonehenge.

Dates B.C.	Raw C^{14} date[a] (corrected date)	Source of C^{14} date	Features
Stonehenge Ia			
3200–2700	2180 ± 105 (2810)	Antlers at ditch bottom	Bank, Ditch; possible hut in center; Causeway postholes.
	[*2450 ± 60 (3080)*]	Mean of two antlers	
Stonehenge Ib			
2700–2200	1848 ± 275 (2305)	Charcoal in Aubrey Hole	Aubrey Holes; Heel Stone in place.
Stonehenge II			
2200–2000	1728 ± 68 (2130)	Antler from avenue ditch	Four Station stones (91–94).
	1765 ± 70 (2180)	Skeleton from ditch	Erection of bluestones in two (later abandoned) circles ("Q and 'R' Holes); first part of avenue.
	1720 ± 150 (2120)	Antler near sarsen trilithon	
	1620 ± 110 (2000)	Antler in "R" Hole	
Stonehenge IIIa–b			
2000–1550	1720 ± 150 (2120)	Antler in erection ramp of Sarsen Stone 56	Transport of Sarsen Stones to site; Dismantling of Q and R bluestone circles; Sarsen circle, trilithons, Slaughter & other Portal Stones in place.
	1240 ± 105 (1550)	Antler from bottom of Y hole	Dressed bluestones tooled and erected; Digging and then abandonment of the Y and Z Holes.
Stonehenge IIIc			
1550–1100			Dismantling of dressed bluestones; Bluestones reerected in circle and horseshoe, within corresponding Sarsen constructs.
Stonehenge IV			
1100	800 ± 100 (975 ± 115)	Bone and antler from ditches	Extension of Avenue to West Amesbury.
	1070 ± 180 (1345 ± 190)	Antler from ditch at W. Amesbury	

[a] See §4.4 for a discussion of this dating technique and the corrections that need to be applied. The phase divisions are due to Atkinson (1960/1979). Data are from several sources, especially Burl (1987) for most carbon 14 dates. "Raw" dates are often denoted "bc"; corrected dates, "B.C."

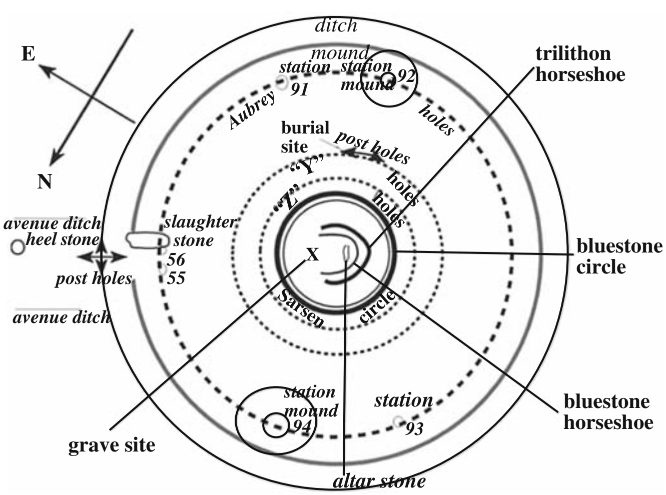


Figure 6.29. The general layout of Stonehenge: Several prominent features are noted, among them Aubrey holes 55 and 56, the Avenue, and the four stations. Drawing by E.F. Milone.

Table 6.4. Alignments at Stonehenge.

Stations	Azimuth	Declination	Event	Calendar mark
93–94	51.5°	+23.9°	Sunrise	Summer Solstice
91–92	229.1	–23.9	Sunset	Winter solstice
91–94	319.6	+29.0	Moonset	Major standstill
91–93	297.4	+18.7	Moonset	Minor standstill
93–92	140.7	–29.0	Moonrise	Major standstill
93–91	117.4	–18.7	Moonrise	Minor standstill

the Sun's motion and those of the Moon for both major and minor standstills (see §2.3.1 for the tie-in between the Sun's annual variation in declination and the effect of this variation on the azimuth amplitude of sunrise and sunset; see §2.3.5 for the discussion of the Moon motions and of the phenomena of major and minor standstills in the $18^{y}.6$ cycle). Figure 6.31 demonstrates the amplitudes of the Sun and Moon at the latitude of Stonehenge in this plan view of the astronomical horizon (for an "elevation" view, see Figure 2.17a) for a late epoch.

The declinations indicated by alignments among pairs of the four stations are given in Table 6.4, the data of which are taken from Hawkins (1965). Dibble (1976) noted that the rectangle made by the four Stations is composed of two triangles very nearly matching 5 × 12 × 13 Pythagorean triangles. Among themselves, the stations could not have provided high-precision alignments. In 1966, however, three postholes were discovered in a car-park to the northwest.

(a)

(b)

FIGURE 6.30. One of the two main outliers at Stonehenge: The Heelstone. (a) Distance view, photo by Marie C. Jack. (b) In closeup, revealing the cup markings. Photo courtesy of Sharon Hanna.

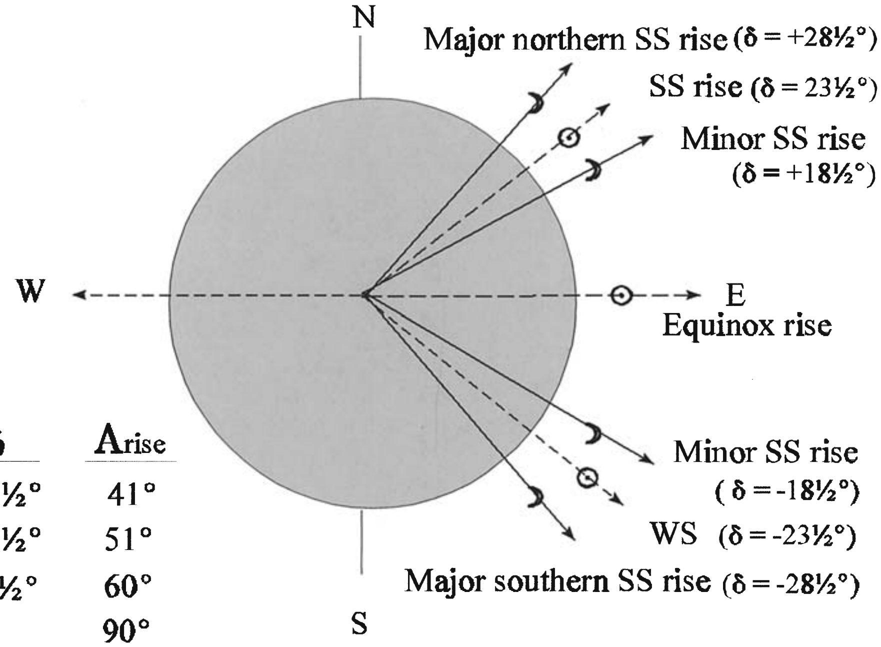
Their locations are marked in concrete on the road surface. Newham (1972) suggests that in combination with stations 91, 92, and 94, and the Heelstone, both solar (setting, summer solstice) and lunar (setting, northern major standstill; setting, northern minor standstill; and setting, midway between the standstills) alignments were achievable with posts set into these holes. They may have been erected in order to help in the layout of the Stations (Newall 1953/1959/1981, p. 23).

If, and only if, the full moon is considered, the directions 91–94 and 91–93 refer to winter solstice moonsets (that is, a moonset when the Sun is at the winter solstice) at the times of major and minor lunar standstills, respectively. Similarly, if only the full moon is considered, 93–92 and 93–91 refer to summer solstice moonrises at the time of major and minor lunar standstills, respectively. When Hawkins (1965) refers to "Midwinter Moonrise," for example, in connection with these alignments, he is referring to this phenomenon. It must be remembered that the Moon goes through its entire amplitude in a mere month, but that the amplitude varies in size from lunation to lunation, continuously changing over the period of 18.6 years of the nodal regression cycle. Thus, from night to night, the Moon will rise, and set, at a sequence of intermediate azimuths within its rising and setting amplitude.

It is this circumstance that suggests the use of the Aubrey Holes as an eclipse predictor. The ring of Aubrey Holes is ~250 ft (86.87 m) in diameter (Wood 1978, p. 163, gives the circumference as 271.6 m and the radius as 43.2 m). The holes are about 3.5 ft (1.07 m) in diameter and ~2.5 ft (0.76 m) deep with flat bottoms and were dug out of the chalk that underlies much of the region. They are filled with rubble, crematorial remains, charcoal, and chalky debris. The organic material was used in the ^{14}C dating of Stonehenge I and may well be later than the actual construction date. The works by Hawkins (1965) and later by Hoyle (1977) emphasize the importance of the number of Aubrey holes: 56. The mean of three intervals of 19, 19, and 18 years is $18^{\mathrm{y}}.67$, an approximation to the nodal regression cycle, and the sum of these numbers is 56. There are three other potential tie-ins of this number to astronomical phenomena.

The number of the Aubrey holes, which, it must be remembered, were a prominent component of the earliest stage of Stonehenge, in a way already nearly encapsulate the motion of the Moon. Other possible tie-ins that have been suggested are the nearly 55 ($54\frac{2}{3}$) nights in which the Moon has completed its motion among the stars twice ($P_{\mathrm{sid}} \approx 27^{\mathrm{d}}.3$), and the period of the triple Saros cycle, $54^{\mathrm{y}}\ 33^{\mathrm{d}}$, over which nearly identical conditions for an eclipse will recur. Thus, an earlier eclipse will be followed by another of similar duration, and seen at a similar range of longitudes on Earth. Finally, this number is serendipitously close to a triple Metonic cycle ($19 \times 3 = 57$), which reconciles the lunar and solar calendars.

Hawkins's (1965) scheme for the use of Stonehenge as a "computer" (Schlosser et al. 1991/1994 suggest an "abacus" to be a better analogy), at its simplest, involved the use of six stones of alternate kinds (say, black and white stones), placed in Aubrey holes at intervals of 10, 9, 9, 10, 9, and 9 holes. Figure 6.32 demonstrates the arrangement. Each year,



δ	Arise
+28½°	41°
+23½°	51°
+18½°	60°
0	90°
-18½°	120°
-23½°	129°
-28½°	139°

FIGURE 6.31. A plan view of the horizon shows the northern and southern extreme rise points for the Sun and Moon for a flat horizon at latitude 51°N and, thus, the amplitudes of the major and minor standstills of the Moon and the solstices for those conditions. The set points are symmetrical. Drawing by E.F. Milone.

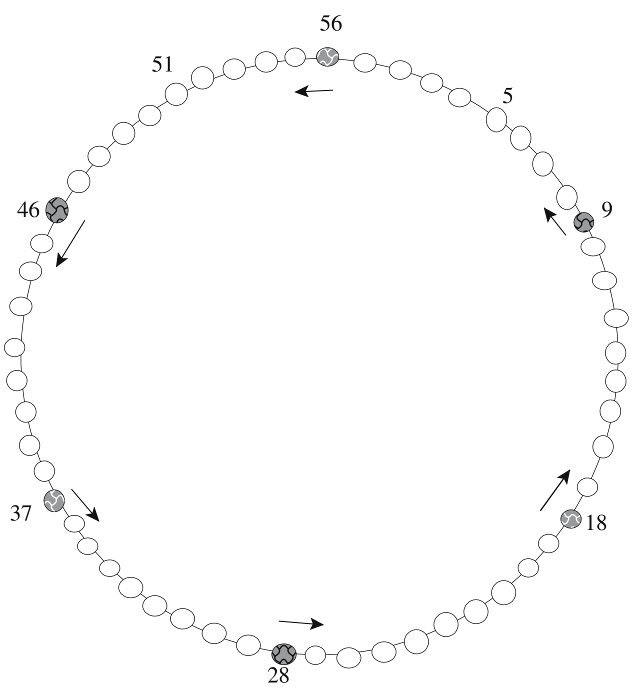


FIGURE 6.32. Use of the Aubrey holes Stonehenge as a stone age "abacus": It may have involved the use of six stones of alternate kinds (say, black and white, as indicated here by black and gray circles, respectively). Each year, each of the stones would be advanced one hole; the direction of advancement shown here is counterclockwise, but this is not critical if the stones are separated by 10, 9, 9, 10, 9, and 9 holes in the direction of rotation. Drawing by E.F. Milone.

each of the six stones would be advanced one hole; the direction of advancement adopted here is counterclockwise (as in Hawkins 1965, p. 142), but this is not critical, as he pointed out, as long as the hole intervals between the stones are maintained.

At least three holes have special meaning, because an eclipse danger occurs when a particular type of stone falls in one of these three holes: 51, 56, and 5. The eclipse phenomena would be accompanied by the rise of the full moon over one of three standing stones in the Avenue: the northernmost rise of the major standstill full moon (at $\delta \approx +29°$) over Stone D, the northernmost rise of the full moon at mid-cycle ($\delta \approx +24°$) over the Heel Stone, and the northernmost rise of the full moon at minor standstill ($\delta \approx +19°$) over Stone F. The example provided by Hawkins (1965, pp. 141ff) starts with a white stone in hole 56, in the Avenue, during a year when the Moon rose over the Heel Stone at its northernmost rising (with $\delta \approx +24°$) and when solsticial eclipses of Sun and Moon could be seen. A white stone in holes 56, 51, or 5 becomes a marker of an eclipse danger. A black stone in hole 56 will produce the same result. A white stone in holes 5 or 51, however, will mark a danger of equinoctial eclipses. The success of the proposed scheme can be assessed in Table 6.5, which lists the eclipse phenomena for selected dates in the mid-16th century B.C. from data provided by Hawkins (1965, pp. 178–180). Although the dates refer to a time 1000 years after the construction of Stonehenge I, the table may illustrate the continuing predictive power of the site. Alternative schemes are provided by Hoyle (1977) and by Schlosser et al. (1991/1993, p. 15), with various degrees of success. Schemes occasionally break down, and eclipse cycles come to an end (see Robinson 1983). Such failures

TABLE 6.5. An example of sequential eclipse dates[a] at Stonehenge.

Eclipse type	Moonrise Heel Stone	Moonrise Stone D	Moonrise Stone F	Lunar eclipses	Solar eclipses
Solsticial	1554				1554 Jan. 4
Equinoctial		1549		1549 Mar. 23	
Solsticial	1545			1545 Jan. 10	
Equinoctial			1540		1541 Apr. 9
					1541 Oct. 2
Solsticial	1536				1536 Jan. 14
Equinoctial		1531		1531 Apr. 3	
				1531 Sept. 28	
Solsticial	1527			1527 July 16	1526 June 21
Equinoctial			1522		1522 Apr. 9
					1522 Oct. 3
Solsticial	1517			1518 Dec. 31	

[a] Based on Hawkins (1965, Tables 2, 3, and 4). All dates are B.C., Julian Calender; these dates post date the actual time of building probably by more than a millennium. The sequence, however, illustrates the possible predictive value of the site.

may account for the temporary abandonment of the site at various times in its history. The terminations of such series (here, 2039 or 2104 B.C.; cf., Robinson 1983, p. 128) may provide an important way of dating archeological monuments.

Of course, there is no direct evidence that the Aubrey holes were actually used for eclipse prediction, nor is their use strictly necessary, because the rise azimuths of the Moon provide the principal clues. The argument is one of plausibility only. The alignments are evidence of interest in lunar and solar phenomena. By association, the placement of particular stones in particular holes with the moonrise over various foresights in what later became the Avenue could have served as an early-warning device for that terrifying phenomenon of the ancient world, the eclipse. Such a warning device could serve well in periods of bad weather when close observations of the Moon's behavior were not possible.

The recognition by the builders of the astronomical significance of the number 56 is critical for the hypothesis that the Aubrey Holes were used to determine eclipses. Against the idea of the Aubrey Holes as an abacus or computer is the circumstance that while 10 other sites in Britain have chalk circles associated with henges, none has 56 of them (Burl 1987, pp. 86–88). Their numbers range from 5 for Llandegal in Gwynedd (Wales) to 44 or 45 for Maumbury Rings in Dorset, but all the others number between 7 and 14. Moreover, Burl (1987, pp. 89–90) argues that the number 56 may be an artifact of the layout of the Aubrey Holes (investigated by Thom and Thom 1974): At each of the cardinal points, two stones nearly (within 1/2 degree) flank the cardinal directions. If 12 other stones are placed between these pairs, the number 56 falls out immediately. The 12 is somewhat arbitrary but does give approximately even spacing. Burl (1987, p. 90) also points out that both the radius of the Aubrey Hole ring (which he gives as 141.4 ft = 43.7 m) and the separation between stones (16.3 ft = 5.0 m) are not even multiples of the "Megalithic Rod" (6.8 ft = 2.1 m), at 20.8 and 2.4 MR, respectively); Thom and Thom (1973) had found, however, that the length of the circumference amounted to an even 131 MR. Whatever the purpose, Newham (1972) noticed that the length of the chord joining every other Aubrey Hole was about 1/3 that of the radius of the Aubrey circle. Once the circle had been established by means of a rope anchored at the center, and marked, the rope could have been folded in thirds and this length laid out as chords across the perimeter. In three turns around the circle, 56 holes could have been marked.

In the next major phase of construction, "Stonehenge II," a double ring of 82 "bluestones" (principally dolerite and rhyolite rocks and modified volcanic ash, but other types are also present) was erected in features called *Q* and *R* Holes. These stones all seem to come from a localized region in the Prescelly Mountains in Pembrokeshire in Wales (Atkinson 1979, pp. 49, 51). Because bluestone chips are not found below the (current) middle layer of the ditch, and there only sparsely at a level consistent with mere transport to the site (Atkinson 1979, p. 72), it is clear that they were erected later than were the features ascribed to Stonehenge I. The Q and R Hole circles have diameters of 86 ft (26 m), and 75 ft (23 m), respectively. Finally, during Stonehenge II , the ditch was further filled in on the eastern side and the "causeway" was extended into an "Avenue" beyond the monument, toward the River Avon, with a new net orientation: to the midsummer sunrise.

Stonehenge III is usually considered to have developed in three substages. The first, Stonehenge IIIA, saw massive reconstruction activity, which involved the transporting of the huge sarsen stones from Marlborough Downs, near Avebury, some 20 miles away. This period involved the dismantling of the double bluestone circle, and the subsequent erection of five massive sarsen trilithons (three-stone combinations with mortice and tenon anchoring the top stone slab) in a horseshoe pattern open to the northeast. The horseshoe is encircled by sarsen stones, also possessing lintels, some of which are still in place. The upright components of the horseshoe trilithons weigh as much as 30 tons and the transport of these 80 sarsens represents a considerable engineering feat, involving as many as a thousand laborers over several years. See Atkinson (1956/1979) or Hawkins (1965) for informed speculation about how this could have been done.

Carvings of thirty axe-heads and a hilted dagger have been found on the sarsen stones. The dagger shape most resembles that of daggers found in Shaft Graves at Mycenae in Greece, with dates prior to ~1500 B.C. (Atkinson 1979, p. 92). Atkinson (1979, p. 93) states that grave goods of Wessex Culture burials "provide clear evidence" for trade with Greece in this period. Moreover, axe cults are known to have been widespread (as in Minoan Crete) in this period, but axes are also carved in tombs in Brittany and elsewhere in England. The Stonehenge axe carvings closely resemble bronze axes manufactured in Ireland and brought to England between 1650 and 1500 B.C. We recall our earlier discussion of axeheads, and note that associations with lightning or with the Sun are possible here also.

In Stonehenge IIIB, the bluestones that formally occupied the Q and R Holes were prepared and perhaps temporarily set aside, whereas a new set of holes (the *Y* and *Z* Holes) were created in concentric circles outside of the sarsen stone circle. There were 60 (or 59) of these holes, with the Z holes lying closer to the sarsen circle. However, it does not appear that the bluestones were ever set into these holes.

In Stonehenge IIIC, the remaining 22 bluestones were reset into a ring just inside the sarsen ring, and into a smaller horseshoe of trilithons within the sarsen trilithons.

Other features of the site include the fallen "Altar Stone," a 16-ft long, relatively narrow ($3\frac{1}{2}$ ft × $1\frac{1}{2}$ ft) block of green sandstone, speckled with mica, from a site near Milford Haven in SW Wales (not from the slightly more distant Prescelly Mountains) near the central sarsen trilithon. Its exact intended placement in the monument is not known. A four-stone "portal" of very large stones commanded the entrance to the site from Stonehenge IIIA until at least the mid-17th century (Burl 1993, p. 39). Of these, only the so-called "Slaughter Stone" is still in place. This portal constitutes a striking similarity to portals found in the great circles of the Lake District, although Burl (1993) is unwilling to suggest that the Cumbrian circles were prototypes of Stonehenge III. However, the Lake District circles were standing even more impressively then than now, and the influence could have been transmitted by an individual of the Stonehenge community who had seen one and liked the idea.

It seems impossible that precision alignments could have been made with the massive, irregular stones of the monument as either backsights or not-so-distant foresights, although rough approximations to the solar and lunar standstills could certainly have been made. Atkinson (1979, pp. 94–96) in discussing and refuting Lockyer's (1909) theory that the midsummer sunrise alignment along the Avenue matched precisely in 1680 B.C. argues that the alignment if determined by observing through spaces of several feet between the sarsens could not possibly give a precise date for the obliquity, because a movement of 1 in would change the date by 200 years, and that by using, say, the right eye instead of the left would shift it by 500 years! It seems likely, however, that the postholes of the earliest phase of Stonehenge could have held smaller and therefore more useful foresights in combination with smaller backsights, or the posts of the entrance way could have been used as backsites by observers near the center of monument in connection with distant foresights. Brinckerhoff (1976) has suggested that pits on the lintels of the great stones in the Sarsen Circle facing the Avenue could have held small wands to be used as foresights, in a manner suggested for the posts of the Causeway during Stonehenge I. The hypothesis requires a backsight across the Sarsen Circle from a now missing lintel. Alignments to northern, major standstill moonrise and to the summer solstice sunrise both at ~2000 B.C. could have been established in this way. Systematic departures of ~$0.^\circ 2$ from alignments with the Causeway postholes were attributed to a change in the obliquity of the ecliptic (see §2.3.3) over the approximate thousand-year interval between Stonehenge I and IIIA. More distant foresights have been proposed also. Alexander Thom (1971/1973/1978) argued that at many sites, especially in Scotland, a relatively high order of precision was achievable, and apparently achieved, by the use of backsights far removed from the observing platform and foresights on a distant horizon. Thom designed a method by which the builders or users of the sites could have sufficiently high-precision measurements of the position of the Moon to detect the 9 minutes of arc variation in the Moon's inclination. The Thoms suggested several places in the vicinity of Stonehenge from which distant foresights could have been set up (Peter's Mound, summer solstice sunrise; Coneybury Barrow, southern minor standstill moonrise; Figbury Rings, southern major standstill moonrise; Chain Hill, southern major standstill moonset; Hanging Langford Camp, southern minor standstill moonset; Gibbet Knoll), but some of these places would have been obscured by an intervening ridge and would have required artificial foresights to have been placed on them. See Wood (1978, pp. 178–181) for a thorough discussion. We review the method in a later section (§6.2.15); at present, we discuss the evidence from some carefully studied sites.

6.2.11. Mull and Argyll: A Test of Precision

Ruggles (1984a, 1988a,b) and Norris (1988) discuss at length a series of sites selected to test Thom's ideas about lunar and solar alignments. Ruggles used predefined criteria for site selection and examined 300 western Scottish sites that had not previously been examined by Thom. Ruggles (1988, p. 275) argues that his criteria are necessary to avoid bias in selection of the sites and measurement points, and he roundly criticizes the work of the Thoms as suffering from just these kinds of bias. All Ruggles's data were collected before any analysis was undertaken to preclude preliminary analyses from biasing later data recording. This was designed to be a test of Thom's ideas, in the sense that the data were comparably rigorous but constituted an entirely independent sample. In the first stage of the study, Ruggles (1988, p. 234) concluded that

(1) There were indications of preferred declinations, but at three levels of precision:
    (a) At the lowest level, $\delta = \pm 15^\circ$ were "strongly avoided"
    (b) At the midlevel, there was "marked preference" for $\delta > 27^\circ$, and for $-31^\circ < \delta < -19^\circ$

   (c) At the highest precision level (1° to 2°), there was marginal precision for six declinations: –30°, –25°, –22.5°, +18°, +27°, and +33°
(2) Sites in Mull and Argyll, especially those with 3-, 4-, and 5-stone rows, showed specific declination preferences
(3) The declination trends became more marked for stone rows, pairs, and single flat slabs in the majority of Mull and Argyll sites, especially for the range, $-31° < \delta < -19°$

A second derivative study concentrated on 92 linear arrangements in Argyle and Mull that included new horizon data. This showed a primary grouping of declinations within a degree or two of –30° and a secondary grouping centered on –23° with somewhat more variation. Of these, a statistically defined group of 15 emerged, somewhat modified by later study. The data indicated "secondary" alignments (in terms of the way the menhirs are arranged) toward –24° at sites that also contained "primary" alignments near –30°. The archeologically defined "primary" and "secondary" alignments were reversed at Duncracaig and at Ardmacross, where only declinations near –24° were found. "The primary orientations appear to present particularly strong evidence of deliberate orientation upon the southern major standstill of the moon" (Ruggles 1988, p. 245). The secondary orientations were interpreted as marking either another point in the lunar cycle (although with no declinations higher than –21°) or the midwinter Sun (statistically indistinguishable). Ruggles's more general conclusions are that the high-precision results of the Thoms are spurious, but that the Megalith builders were indeed interested in marking the extreme solar and lunar positions. These conclusions, however, say nothing about the precision that may have been achieved at particular sites, where a combination of natural features on the horizon, as well as care, intelligence, and good luck on the part of the builders may well have led to at least some of the precise alignments deduced by Thom. The alternative, skeptical view of the apparent successes of the Thom hypothesis at these sites is that they are merely fortuitous. We discuss some of these sites in the next few subsections.

6.2.12. Ballochroy and Kintraw: Controversial Sites

The site of Ballochroy in Argyll (western Scotland) now consists of a row of three stones with the flat faces, most unusually, across the row. A small cist is the only surviving remnant of a former large cairn or burial mound. There were once two small cairns and another standing stone in the same alignment (Burl 1993, p. 176). The alignment to the southeast ($A \approx 226°$) passes over the islet of Cara and would have marked the sunset at the winter solstice [$\delta = -23.06°$; Ruggles (1984, p. 279) finds declination limits –25.5 to –24.5°]. Looking across the *flat* sides of the stones, one would have seen the Paps of Jura across the sea in the distance, with Corra Bheinn mountain marking the summer solstice sunset. To the northeast, along an elevated horizon, the line marks the extreme northerly position of the Moon (moonrise at major standstill). Burl (1993, p. 177) wrote

> The sightline towards Jura and the midsummer sunset was uninterrupted, and knowing that the wide faces of the slabs were atypically angled across the row it is likely that the builders of the row quite deliberately set them transversely to establish the alignment, unaware of the lucky coincidence that theirs was the lone latitude in Britain where the midwinter and midsummer solstices occurred at right angles to each other. A few degrees to the north or south would have rendered a comparable design unworkable.

The view would seem to be only slightly exaggerated. At an epoch such as 1750 B.C., when $\delta = 23.90°$ (Thom 1971/1978, p. 42), one finds that the site where twice the amplitude on a flat horizon is 90° has a latitude of 55.0°. For the given latitude of the Ballochroy site, 55°42′44″ (Thom 1971/1978, p. 37), summer and winter solstice azimuths of sunset, are, respectively, $A_{SS} = 315.99$, $A_{WS} = 224.01$, so that their difference is $A_{SS} - A_{WS} = 91.97°$, again for a flat horizon. However, the horizon is not flat. Thom (1971/1978, p. 42) assumed that the alignment of the Ballochroy cist to the rolling slope of Corra Bheinn was the intended alignment to midsummer sunset and that the alignment from Ballochroy to the Isle of Cara was intended to mark midwinter sunset. The differences between these two measured azimuths, 316°05′ – 226°16′, is 89°49′. Thom's analysis of this (and related sites) considers the effect of the elevation of the horizon and refraction and with a corrected true altitude of setting. From Ballochroy, he derived a value for the obliquity: 23°54′.2 ± 0′.7, and from this a date: 1750 ± 100 B.C. Burl's "coincidence" statement requires a range of dates to be meaningful, but if Thom's analysis is correct, and if the site were in fact erected ~1750 B.C., it seems to us extremely unlikely that the builders who followed this atypical procedure would not know that they were at a place where it would work.

To the North, at Kintraw, there is a site that has been the subject of a major controversy. In a field, there is a cairn with a posthole in it and a very tilted standing stone. Most unusually, the cairn is not a burial mound. The stone does not seem to be aligned on anything that would have been visible at the site from ground level. However, Thom suggested that it was aligned to a notch created by the profiles of two mountains, one of which was Corra Bheinn in the Paps of Jura (the same one aligned from Ballochroy, nearly 30 miles to the SW). The midwinter setting Sun might have been visible for a moment or two from the top of the cairn (at $A = 224°$), but the cairn would need to have been higher than it is at present, or the observer would need to have been tall. In fact, the placement of the cairn could have been made without seeing the Sun from this site, if the site line were established with other markers.

On examining the site, Thom found a ledge on a slope from which the Sun could have been seen, and the location of the cairn established. Euan MacKie (1976) realized that the archaeoastronomical usage of the ledge was a hypothesis that could be tested archaeologically, and he tried to do so. He found that there were two boulders placed so that an observer looking between them would see the notch and a line to the notch would pass directly over the cairn. He then excavated the ledge on which the boulders rested, but found only indirect evidence that the site was artificial.[22] Contro-

[22] A stone layer that extended upstream from the boulders appeared to be artificial in terms of location and in the orientation and dip of the stones themselves.

versy developed concerning the visibility of the notch on Jura and the necessary height of an observer to see the notch from the platform (MacKie 1976, 1981; Patrick 1981; McCreery, Hastie, and Moulds 1982). The conclusion of McCreery et al. (1982) was that an observer would always have had to be taller than 5′ and that the amount of foliage on intervening trees could have obscured the view for an observer under 5′7″. Refraction variations, inherently unpredictable, would have contributed to the visibility problem. Whatever the validity of these criticisms for the epoch when the site was in use, the notch is plainly visible in a photograph published by MacKie (1976).

Another aspect of controversy involved the width of the ledge. MacKie (1976) claimed that the ledge was wide enough to observe the Sun for some days before and after the solstice. According to McCreery et al. (1982, pp. 187–198), the ledge is not wide enough. They attribute the MacKie claim to a confusion between the azimuth change caused by a declination change and that of the declination. We will discuss the use of a platform at Kintraw for precise observations of the Sun near the end of §6.2.15, after we describe Thom's proposed observing method, and compute the necessary distance that would have been stepped by an observer to see the shifted azimuth caused by the changing declination of the Sun and Moon.

From the cairn, the lunar 9′ perturbation (see §3.4.5) could have been detected as the Moon set at minor standstill among the complex silhouette of the hills of Jura (Thom 1971/1973/1978, p. 39). The possibility that such precision could be obtainable in the megalithic is, well, incredible, and it is not surprising that many investigators have refused to believe it. In the next few sections, however, megalithic constructs are described that make it at least possible that the necessary information was indeed encoded in the monuments.

6.2.13. Merrivale Stone Rows

On Dartmoor in Devonshire, England, there are ~60 single, double, and triple rows of stones. One of these sites is at Merrivale, about 4 km west of Princetown. The site consists of two rows of stones with a cairn midway along the southern of the two rows, five other cairns, two cists, four stone circles, and isolated menhirs and stone slabs. The two rows are not quite parallel to each other, and extending to the SW from a point ~1/3 of the way from the west end of the southern row is a shorter row leading from a cairn just off the southern row to a pair of stones. The northern row has a bearing of 83.7°, and it is ~182 m long; the second has a bearing of 81.7° and a length of ~264 m. Both rows are actually two parallel sets of stones. The third row is single, with a bearing of 23°, and a length of 42 m. Wood (1978, pp. 130–139) suggests that there are several alignments, including some to the major standstill moonset, at this site, and that various features of the site provide triangles to compute means of extrapolation to be described in §6.2.15. As intriguing as this site is, there are others where the cases for alignments have been made, and where stone grids, touted by Thom as possible computational devices, exist.

6.2.14. Temple Wood: Clear Evidence of High-Precision Measurements?

The site of Temple Wood in Argylle has been called a lunar observatory by Thom (1971/1973/1978). The site consists of two major sections: the main site, a small circles of stones in which there is a smaller ring and a kist; and a secondary site consisting of a linear arrangement of groups of menhirs. The extremities of the secondary site are marked by pairs of menhirs. The southernmost pair (S_4 and S_5) is oriented approximately toward a notch in a distant hill at azimuth 317.9°. The bearing of the northernmost pair (S_2 and S_3) is toward another stone, S_6, 110 m distant, at 316.0°. Between these two extremes are two clusters of stones. The southern cluster ("Group Q"), which in a 1939 survey consisted of four stones, three upright and one fallen, had, at the time of Thom's study, only three—the fallen stone having disappeared in the interim. The bearing of the notch from these stones is 317.2°. Finally, the northern group of stones consists of the largest menhir in the complex, S_1, surrounded by four smaller, upright stone slabs. Stone S_1 bears cup markings. About 310 m toward an azimuth of 315° stands the circle of the main site of Temple Wood, and 2 km away at an azimuth of 317.0° is the foresight notch, to which the southern pair of menhirs already appears to point. The relationships between these bearings and the declinations of the setting major standstill Moon are shown in Table 6.6, based on Thom's (1971/1973/1978) Table 5.1. Thom assumes an obliquity $\varepsilon = 23°54'.3$, a height of 1.68 m (5.5 ft) for the observer, a lunar inclination $i = 5°8'.7$, an apparent lunar

Table 6.6. Observations and analysis of Temple Wood.

Backsight	Foresight	Azimuth	Altitude	Obs. Dec.		Calc. Dec.
Group Q	Notch over Circle	317°12′.6	4°37′.7	+29°02′.5	ε + i	= +29°03′.0
$S_4 - S_5$	Notch over Circle	317°52′.5	4°37′.2	+29°19′.1	ε + i + s	= +29°18′.5
S_1	Notch over Circle	316°59′.0	4°37′.7	+28°56′.5	ε + i − s + Δ	= +29°56′.5
S_6	Notch over Circle	315°19′.	4°54′.	+28°28′.		+29°29′.
$S_2 - S_3$	Notch over Circle	316°01′.6	4°38′.7	+28°326		+29°34′.
Mean (ε + i)	Notch over Circle			+29°03′.0		
S_1	Notch B, Bellanoch Hill	203°46′.	0°52′.	−29°20′.	−(ε + i + s)	= −29°18′.5
S_2	Notch A_2, Bellanoch Hill	207°56′.	0°18′.	−28°48′.	−(ε + i − s)	= −28°47′.5
Mean [−(ε + i)]	Bellanoch Hill			−29°04′.		

radius ("semidiameter") $s = 15'.5$ and a "declination" perturbation amplitude,[23] $\Delta = 9'.0$ (see §2.3.5). The mean declination of all the northernmost moonset azimuth alignment indicators is 29°3′.0, a respectable enough approximation to the extreme northern declination of the Moon. However, Thom's conclusion of this analysis was that the various alignment indicators were intended to obtain highly precise refinements of the declination, as noted in the last two columns of Table 6.6. For instance, the azimuth alignment over Group Q to the notch was to the Moon's center, with declination $\delta = \varepsilon + i$; that of $S_4 - S_5$ to the notch indicates an azimuth alignment corresponding to $\delta = \varepsilon + i + s$, while the alignment from S_1 over the main site to the notch indicates a declination, $\delta = \varepsilon + i - s + \Delta$. Thom (1971/1973/1978, p. 48) suggests that the bearing differences of the smaller stones around S_1 indicate the variation in Δ, about 1 arc-minute! Unfortunately for Thom's hypothesis that megalithic exploration of the small variables was attempted, the necessary backsights to obtain high-precision alignments for $\delta = \varepsilon + i - s$ and for $\delta = \varepsilon + i - s - \Delta$ are not present. Whether the higher precisions implied by the analysis were actually attained or not, the case for intentional alignments to mark the extreme setting points of the major standstill Moon would appear to be strong enough. But there is more evidence yet.

Thom also discovered an alignment to the southernmost setting direction of the Moon from stones S_1 and S_2 to separate notches in the rolling profile of Ballanoch Hill, 6.3 km away at bearings of 203.8° and 207.9°, respectively, which imply a mean declination of −29.1°, but separate declinations $\delta = -(\varepsilon + i + s) \approx -29.3$ and $\delta = -(\varepsilon + i - s) \approx -28.8°$, respectively. The SW alignment from S_1 is currently impossible due to groups of trees, but that certainly need not have been the case in the Neolithic.

Thom (1971/1973/1978, pp. 50–51) also suggested that alignments involving stones S_3 and S_6 could have been used to provide warning of the approach of the Moon to the maximum. If the perturbation in declination (the amplitude or maximum value of which, 9′, has been designated Δ) were to achieve a maximum at the same time that the major standstill did, the lower limb of the Moon (at $\delta = 28°29'$) would have coincided with the notch as seen from S_6 one and a half cycles or 260 days prior to the true moment of maximum standstill. If, on the other hand, the minimum were to occur at a major standstill, the lower limb of the Moon would have coincided with the notch as seen from S_3 only 1 cycle or 173 days prior to major standstill. Finally, he suggested that the alignment involving the center of Group Q would have achieved the alignment to the Moon at declination $\delta = \varepsilon + i = 29°2'.5$, to an uncertainty of 1′ only at the epoch B.C. 1700 ± 100, assuming the Moon's inclination to be $i = 5°8'43''$. This is because of the slow variation of ε with time (see §4.4).

We are left wondering if high precision at particular sites, using particular combinations of stones and sightlines, was not being achieved afterall. Statistical arguments do not really touch this issue if there is clear evidence of distant enough foresights, or reasonably precise backsights and space for standing platforms at which to record the measurements in some way.

Thom, of course, carried out his own statistical analyses. In one of them (Thom 1971/1973/1978, pp. 75–79), he selected 40 sightlines at 23 sites and from them deduced four values: the obliquity, $\varepsilon = 23°53'26''$; the inclination of the Moon's orbit, $i = 5°8'52''$; the major perturbation of the Moon's inclination (seen in the effect of the declination on the azimuth), $\Delta = 9'23''$; and a mean semidiameter of the Moon's disk, $s = 15'55''$ (allowing for the upper limb, lower limb, or mid-disk to be the point of alignment on a distant foresight). Of course by preselecting these sightlines as being astronomically relevant, Thom's argument can be construed as circular, but the results are impressive in any case. Now, we will explore possible procedures for observing and recording such observations.

6.2.15. Caithness Sites and a Potential Observing Method

At Mid-Clyth in Caithness in northeastern Scotland, there is a grid that perhaps once held as many as ~250 stones on a gently sloping hillside: "the Hill o' Many Stanes." Thom (1971/1973/1978, pp. 23–25; 86–90) saw the establishment of the extreme azimuths of the rising and setting Moon as a principal goal of megalithic astronomy, perhaps for eclipse purposes, or because of interest in the Moon for its sacredotal, luminary, or tidal effects. In §3.2.1, we mentioned Thom's hypothesis that three components of the Moon's motion could be measured from at least some selected megalithic sites. Thom believed he had found evidence that the requisite information was obtained by virtue of the alignments; he also believed that the information was stored in the geometric grids at Mid-Clyth and perhaps elsewhere and, moreover, that the grids provided computational assistance to determine those components.

The method of encoding the observational information allegedly began with a distance stepped off nightly on either side of the date of extreme azimuth of moonrise/set. The careful marking of where the observer stood to observe a given phenomenon would provide data to determine the moment of extreme azimuth (and therefore declination). We now discuss how this could be accomplished for particular sites (see Chapters 2 and 3 and references cited therein for the geometry and spherical trigonometry background).

For any particular alignment, the azimuth of a rising (or setting) object depends on the declination of the object, δ, the zenith distance, z, and on the observer's latitude, ϕ. In general, the relationship (2.1) can be expressed as

$$\sin\delta = \cos z \times \sin\varphi + \sin z \times \cos\varphi \times \cos A. \qquad (6.7)$$

The basic idea is this: The declination of the moon rises to a maximum sometime around its extreme rise (or set) azimuth during the month. The variation of the declination over a couple of days on either side of the maximum is assumed to be representable by a parabola of the form

$$\Delta\delta = k(\Delta t)^2, \qquad (6.8)$$

[23] The perturbation is actually on the inclination; at a major/minor standstill, however, the perturbation adds directly to the declination; see Figure 2.17b.

where Δt is the time interval from the moment of extreme declination, $\Delta\delta$ is the change in declination over that interval, and k is a constant.[24] For the solstitial Sun, at $\delta = 24°$, $k \approx 13$ arc secs/day^2. For the Moon, at major standstill, with $\delta = 29°$, $P = 27^{\mathrm{d}}.32$, $k \approx 46$ arc mins/day^2, and at minor standstill, with $\delta = 19°$, $k \approx 30$ arc mins/day^2. The interval between successive transits of the meridian by the Moon is given by the angular rate formula in terms of the mean solar day (Table 2.6):

$$\omega = 1 - \frac{1}{29.53}. \tag{6.9}$$

The inverse of ω could be called a "lunar day" and is equal to ~1.0350 mean solar days (MSD). In half of such a lunar day, the declination can be expected to change by approximately

$$\Delta\delta \approx k(\Delta t)^2 = 46.0(\tfrac{1}{2} \times 1.035)^2$$
$$= 12.3 \text{ arc minutes at major standstill,}$$

and

$$\Delta\delta \approx 30.2(\tfrac{1}{2} \times 1.035)^2 = 8.1 \text{ arc minutes at minor standstill.}$$

For the Sun, the relations are simpler:

$$\Delta\delta \approx k(\Delta t)^2 = 13(\tfrac{1}{2})^2$$
$$\cong 3 \text{ arc arc seconds over a half-day interval.}$$

The change in azimuth arising from a such a change in declination is obtainable through differencing (6.7), keeping the latitude and zenith distance (the complement of the altitude, h) constant:

$$\cos\delta \cdot \Delta\delta = -\sin z \times \cos\varphi \times \sin A \times \Delta A. \tag{6.10}$$

Therefore, solving for the change in A due to the change in δ alone, we get

$$\frac{\Delta A}{\Delta\delta} = -\frac{\cos\delta}{\sin z \times \cos\phi \times \sin A} \tag{6.11}$$

so that we may write the change in azimuth as

$$\Delta A \approx k(\Delta t)^2 \times \frac{\Delta A}{\Delta\delta} = k(\Delta t)^2 \times \frac{-\cos\delta}{\sin z \times \cos\phi \times \sin A}. \tag{6.12}$$

Any change in azimuth can be matched by stepping a number of paces perpendicular to the direction of the distant foresight. If we call the distance to be stepped off in, say, feet, ΔS, then the relation between ΔS and ΔA is

$$\Delta S = d \times \Delta A, \tag{6.13}$$

where d is the distance to the foresight, and in the same unit as ΔS, and ΔA is in radian measure.

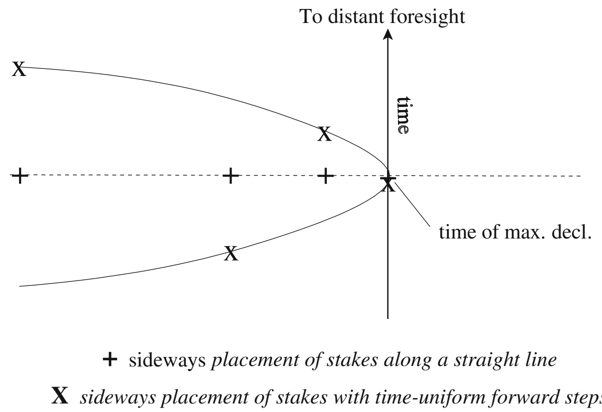


FIGURE 6.33. The geometry of the "step" analysis shows the parallactic shift in azimuth needed to observe a given shift in declination. The foresight is in the direction of time's arrow. Drawing by E.F. Milone.

We may then write for the size of step to observe the Moon's rising or setting at the same distant feature of the horizon:

$$\Delta S = d \times \Delta A \approx d \times k(\Delta t)^2 \times \frac{\Delta A}{\Delta\delta}$$
$$= 12.3 \times d \times \frac{\Delta A}{\Delta\delta} \tag{6.14}$$

at major standstill of the Moon. This is an application of the principle of parallax discussed in §3.1.3: The larger the distance to the foresight, d, the larger the "baseline" shift, ΔS, required to follow a given shift in angle, ΔA.

Thom's (1971/1973/1978, Fig. 1.1, p. 14) (see our Figure 6.33 for a similar idea) illustrates clearly that if the observer stepped step back on successive evenings a fixed number of paces, before moving laterally to determine the view to the Moon's set point against the distant foresight and to set a stake or stone, then the Moon's change in declination, scaled by some factor, would be illustrated by the curve on the ground created by the placements of the stakes or stones. Indeed, extending the arc between the two markers closest to the moment of extreme declination would give the precise declination (if the scaling factor were known) as well as the moment when this extreme declination occurred.

Whether this purely geometric determination was ever carried out is completely unknown; that is, at present, no one has come forth with evidence of stones so placed at any relevant site, but the process is transparently clear, at least to us, millennia later! What is not so clear is whether the geometric interests of megalithic circle builders extended to the determination of the arcane motions of the Moon, and whether any class of them living in precarious times (see Burl 1987 for vivid accounts of life at Stonehenge!) really had the leisure to study a practical form of analytical geometry, contemplate the meaning and consequences of these motions, and engage in the painstaking work of making both the observations and the determinations. For the time being, we skip over these questions to explore with Thom further methods of determinations—at least how scientists of today

[24] The apparent variation in declination of the Moon, whether in the $18^{\mathrm{y}}.61$, the $27^{\mathrm{d}}.32$ or $173^{\mathrm{d}}.3$ cycles, or that of the Sun in the $365^{\mathrm{d}}.2422$ cycle, is sinusoidal and at the peak of the cycle can be approximated by an expression such as $\Delta\delta = \delta_{max} - \delta_{max} \times \cos(2\pi \times \Delta t/P)$, where Δt is the time interval from the maximum value of the declination, δ. From this, $\Delta\delta = \delta_{max} \times [1 - \cos(2\pi \times t/P)] = \delta_{max} \times [2\sin^2(\pi \times \Delta t/P)]$, which for short intervals from the moment of maximum (i.e., for $\Delta t \ll P$), becomes $\Delta\delta = 2\delta_{max} \times (\pi \times \Delta t/P)^2 = k(\Delta t)^2$.

transported back to ancient Britain in a Connecticut Yankee sort-of-way could have done so.

Thom (1971/1973/1978, pp. 86–90) related the lateral distances required to observe the shifts in azimuth to the geometric grids found at Merrivale, Mid-Clyth, and elsewhere. He defined a quantity G as that value of ΔS corresponding to the change in the extreme declination exactly half of a lunar day before or after the extreme. Because the Moon is not likely to be setting at exactly the same moment that it reached its extreme declination, G is not directly measurable. Yet Thom claimed that the value of G was nevertheless recorded at some megalithic sites. Here is how he thought this could happen: If ΔA is expressed in arc-minutes and d is given in kms (1000 m), then because there are 3438 arc-minutes/radian, the expression

$$G \approx \frac{12{,}300}{3438} \times d \times \frac{\Delta A}{\Delta\delta} = 3.58 \times d \times \frac{\Delta A}{\Delta\delta} \tag{6.15}$$

describes the change in position, in meters, in half a day at major standstill. The corresponding shift at minor standstill is

$$G \approx \frac{8100}{3438} \times d \times \frac{\Delta A}{\Delta\delta} = 2.36 \times d \times \frac{\Delta A}{\Delta\delta}. \tag{6.16}$$

The difference ratio, $\Delta A/\Delta\delta$, is evaluated from (6.11). Recall that G represents the theoretical baseline shift of the observer in half a lunar day before or after the peak in order to preserve the aspect of the Moon over the same distant foresight. If the stakes are at the same spot, the distance to the peak position would be close to a distance G from the stakes.[25] From (6.12), over a whole lunar day, the change in declination will vary by a factor of 4 over the 1/2 day change (12.3′ or 8.1′ at major or minor standstill, respectively) given above. The corresponding motion of the observer would be $4G$, which may be a large distance.[26] Thom's suggested method of using this quantity was for the megalithic observer to place a stake each night at the location from which the alignment was seen against the selected and presumably distinctive foresight on the distant horizon. If two stakes were separated by a distance $4G$, the position at the peak must lie close to one of the two stakes (stake positions on subsequent days will easily indicate which—if there is enough pacing distance at the observing site). A method of graphical extrapolation in position (corresponding to an interpolation in time) could have been used to obtain the position of maximum declination. Thom (1971/1973/1978, pp. 86–90; Fig. 8.2 illustrates the process). He describes two methods and Wood (1978, pp. 114ff) elaborates on them. The methods involve the use of triangles and sectors, such as those found at Mid Clyth and Merrivale.

Thom (1971/1973/1978, p. 87) shows that if observations of the lunar maximum were made exactly one lunar day apart, and if the alignment-giving backsight locations were marked by stakes or some other means, then the distance between the midpoint of the stakes and the point from which the maximum-declination Moon would have set, would be given by

$$\eta = \frac{p^2}{4G}, \tag{6.17}$$

where $2p$ is the separation of the stakes. By dividing both sides of (6.17) by p, we get $\eta/p = p/4G$, from which η can be found by setting up a right triangle of adjacent side $4G$ and opposite side p, and laying off a distance p along the adjacent side (see Figure 6.34).

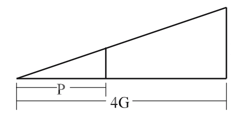


FIGURE 6.34. The triangle method of determining the time correction to the extreme declination of the Moon, showing relationships among the quantities G, p, and η: See text for details. Drawing by E.F. Milone.

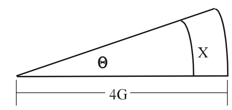


FIGURE 6.35. The sector method of determining the time correction to the extreme declination of the Moon, showing relationships among the quantities G, p, and η: See text for details. Drawing by E.F. Milone.

The length of a perpendicular from this point to the hypotenuse then defines a similar right triangle, and the opposite side of this small triangle is η. Because the ratios of like sides of similar triangles are equal, the ratio $\eta/p = p/4G$ follows. If the leftmost stake represents the Moon's position prior to the maximum, and the rightmost a lunar day later, after the maximum, then by moving the distance $G + \eta$ to the right, the position of the Moon at true maximum would be determined. Thom (1971/1973/1978, p. 88) suggests that this is the method that was used in Argyllshire.

In a second analytic method, p is the arc of a sector of radius $4G$ (see Figure 6.35); if one moves in, along the radius, a distance p, and defines a second arc of length, say, x, at the radius $(4G - p)$, then the difference between p and this arc length, $p - x$, is η.

We demonstrate this as follows: If θ is the angle subtended by the arcs, then the relation between θ, p, and $4G$ is $(4G)\theta = p$, so that $\theta = p/4G$ (expressed in radian measure). Then, because $x = (4G - p)\theta$, $x = p - p^2/4G$, and $\eta = p - x$ follows. Thom suggests that a variety of this method was used at Caithness.

When $p > G$, that is, when the stake separation $(2p)$ is greater than $2G$, so that one of the stakes lies fairly close to the maximum, one can define a quantity $m = 2G - p$. Then, setting $m^2/4G = G - p + p^2/4G = G - p + \eta = y_L$, so that

$$\frac{y_L}{m} = \frac{m}{4G}, \tag{6.18}$$

[25] The quantity G can also be understood geometrically as a *sagitta*. Given the stepping technique, and the tracing of a parabolic arc on the ground, it is the line between a point on the arc midway between the two stakes and the center of the straight line between the two stakes.

[26] One of the questions raised about the site of Kintraw, discussed above, was whether the ledge provided sufficient space to recreate the alignment within a day.

where y_L is the distance from the closest stake (the rightmost stake in this example) to the place where the maximum declination would have been seen if it occurred at the moment of setting or rising.

A similar procedure was used, arguably, to find the maximum date from observations at several lunations (Thom 1971/1973/1978, pp. 89–90). The same equations are still applicable, but the time interval is a lunar month instead of a lunar day, and the specific values of the variables, such as G will be different.

In Thom's view, the relating of the position of stakes to the location of the Moon requires only empirical ideas based on observation. Whether these ideas were in fact carried out is moot; if they were not, however, some alternative explanation for the sectored stone rows is required. This has not yet been provided.

Again, in Thom's view, the value of the site at Mid-Clyth was that it provided a grid for interpolation, from which the foresight direction at the peak of the Moon's extreme declination could be determined. The stones are arranged in grids of convergent sectors. The base and height of the main sector are 132 ft or $17L$, where $L = 20/7$ MY, the grid element at Mid Clyth. Although Thom asserts that this is exactly equal to G (Thom 1971/1973/1978, p. 89), the calculated value of G is actually equal to 126 ft [38.36 m from (6.15)], within 5% of the correct value, if one uses the closest of the foresights discussed by Thom. More problematic is the quantity $4G$, which should be the radius of the sector, if Thom's proposed extrapolation scheme was used. The radius of the main sector is 360 ft and that of the SW sector, 413 ft, far from the calculated value, ~503 ft (Thom 1971/1973/1978, p. 104).

The evidence for alignments at the site is also provided by Thom (1971/1973/1978, pp. 93–95). There is a small notch only 1.8 miles (2.9 km) distant in an otherwise featureless western horizon to which a line of stones at the top of the hill seems to point. According to Thom, the directions to the notch from various backsight positions along the "Hill o' Stanes" ridge mark the direction of rise of the Moon in a full range of variables: perhaps $\varepsilon + i - s$, $\varepsilon + i - s + \Delta$, $\varepsilon + i$, $\varepsilon + i + s - \Delta$, $\varepsilon + i + s$, and $\varepsilon + i + s + \Delta$ in the direction toward $A \approx 24°$, and $-(\varepsilon + i)$ with similar variations, to the southeast. However, the distance to the southeastern foresight is ~50 miles (~80 kms) and a value of G calculated for such a foresight greatly exceeds the scale of the known grid.

Three similar sites of stone sectors are found within 20 km of Mid Clyth: at Camster, Dirlot, and Loch of Yarrows (Wood 1978, p. 124). At Dirlot, a similar sectored grid of 70 to 80 stones is found, and as at the Hill o' Stanes, the narrow end of the sector is uphill. Thom asserts that the radius of the base is 145 MY and that the grid elements are 3 MY apart. Here, there is evidence for alignment to the minor standstill moonrise but not with a distant, natural foresight. There is also evidence for the quantity $4G$, here computed to be 398 ft, compared with the radius of the sector, 394 ft. The base of the sector, however, is 147 ft, not a calculated $G = 100$ ft. The azimuth of a direction of three menhirs of which only one is standing currently is 52.°3, corresponding to a declination of +19°11′, the extreme northern limit of a minor standstill moonrise ($\delta = \varepsilon - i + s + \Delta$). There is also an (as yet) unexplained precisely laid-out zigzag of stones with bearings 59°28′ ± 2′, 337°59′ ± 1′, and 61°33′ ± 1′.

The Loch of Yarrows is 8 km south of Wick and has a nonorthogonal grid. Several distant menhirs and a cairn could have provided artificial foresights, and Thom (1971/1973/1978, p. 99) suggests that a very small break in the contours of Tannoch Hill, about 1 km away, now filled with peat, could have been greater in the past. Alignments to $\delta = -(\varepsilon + i - s - \Delta)$ for the artificial foresights and to $\delta = (\varepsilon + i)$ for the natural one are proposed. The measured length of the radii of the rows is 800 ft, compared with computed values of 756, 765, and 826 ft. Thom (1971/1973/1978, p. 98) indicates the lozenge-shaped grid element size to be 2.5 × 2.75 MY.

At Camster, there are two cairns north of a series of stone rows. Here, only about 33 stones are currently known in place, about half of those at the Loch of Yarrows. An alignment is noted to $\delta = -(\varepsilon + i - s - \Delta)$, but Thom (1971/1973/1978, p. 100) indicates that excavations are needed to establish the radii of the sparsely filled grid rows with greater precision. From what is extrapolated, it appears that the radius is ~544 ft, against $4G = 606$ ft sufficient, Thom felt.

Finally, we discuss the situation at Kintraw. From the platform above the gorge, the midwinter Sun's upper limb may briefly twinkle when it is seen at a coll between Beinn Shiantaidh (43.7 km distance) and Beinn a' Chaolais (46.5 km). Thom (1971/1973/1978, p. 38) suggested that a *green flash* might have been visible at this instant in what he regarded as the clearer skies of the Megalithic. For the Sun, (6.12) is still valid:

$$\Delta S = d \times \Delta A \approx d \times k(\Delta t)^2 \times \frac{\Delta A}{\Delta \delta}, \qquad (6.19)$$

but the constant k for the Sun is ~13 arc-seconds per mean solar day. With $\delta = -23.90°$, $A = 224°$, $z = 89.4333°$, and $\phi = 56.18833°$, $\Delta A/\Delta\delta = 2.365$. Therefore, 13 arc-seconds of declination, the change in the declination of the Sun 24 hours from the summer solstice, causes a shift of only ~30 arc-seconds of azimuth in this interval. For the Sun,

$$G_\odot \approx \frac{13{,}000}{206{,}265} \times d \times \frac{\Delta A}{\Delta \delta} = 0.063 \times d \times \frac{\Delta A}{\Delta \delta} m \qquad (6.20)$$

so that here, $G_\odot = 0.063 \times 43.7 \times 2.365 = 6.5$ m (~21 ft), compared with Thom's (1971/1973/1978, p. 38) value of 19 ft. From the description of the platform and contour chart given by MacKie (1974, especially, pp. 178–181), which shows at least 50 m (±4G) of a path length normal to the direction of the col, there should be ample room to establish the correct vantage point for the Sun and, therefore, to establish the location of the cairn and menhir in the intervening valley. However, McCreery et al. (1982) suggest that the col was not visible over this range. Thus, the controversy continues, but the *feasibility* of high-precision determination at this site seems clear. We conclude our comments on Kintraw by noting that it is interesting that a boulder is found on the platform in line with the col and the menhir, and that a petrofabric analysis by J.S. Bibby, appended to MacKie's paper, supports a conclusion that the platform was deliberately created rather than a natural feature of the landscape.

6.2.16. Stone Rows at Carnac: Accidental Alignments?

The largest concentration of megaliths in the world is in Carnac in Brittany. As a site to be studied, however, it has problems. Thom and Thom (1971), who surveyed the site, had great difficulty in finding a stone that had not been moved, with any degree of certainty. Nevertheless, DHK, who has visited the site, notes that the stones are not readily moved, and unless there have been organized efforts by pranksters, farmers, or builders, large-scale systematic movement is not likely to have taken place, although cromlechs (mounds enclosed by stones) have been destroyed.

The dates of the stone rows at Carnac and elsewhere in Brittany are unclear. The cromlechs seem to have been the primary focus of interest to which the rows led. At least some of these cromlechs were in existence by about 3000 B.C. However, many of the rows appear to have been built by a process of accumulation over an interval of many centuries. Burl (1993, p. 146) writes, "It is interesting that the short axis of the Ménec West cromlech, an inverted egg, is in line with midwinter sunrise and that the long axis of its eastern counterpart points in the direction of the midsummer sunset as though the two rings were complementary, each for celebrations at the year's ends." He goes on to suggest festivals at the cross-quarter days of *Beltane* (early May) and *Samain* (early November). Burl points out that there is clear evidence of ceremonial fires associated with some of the cromlechs and that such fires were frequently built in association with equinoxes and solstices. A summer solstice bonfire was built on a burial mound overlooking the rows of Carnac as late as the 19th century.

We have already mentioned the very early erection of the menhirs and one of the most spectacular features of the Carnac area, *Le Grand Menhir Brisé*, or *Er Grah*, the largest known menhir. The broken fragments of this monument now lie on the ground at Lacmariaquer. If erect, they would have had a combined height of ~22.5 m (67 ft) and weighed ~340 tons. It was proposed by Thom and Thom (1971) that this was a universal foresight for several backsights in the Carnac region. From these various proposed backsights (the italicized names are currently existing backsights), the orientation to *Er Grah* reveals the following alignments:

(1) *Quiberon*: $+(\varepsilon + i)$ rise
(2) St. Pierre: $+(\varepsilon - i)$ rise
(3) *Le Moustoir*: $-(\varepsilon - i)$ rise
(4) *Kervilor*: $-(\varepsilon - i)$ rise
(5) *Kerran*: $-(\varepsilon + i)$ rise
(6) Trevas: $-(\varepsilon + i)$ set, and toward Quiberon
(7) Tumiac: $-(\varepsilon - i)$ set, and toward Kervilor and Le Moustoir
(8) Petit Mont: $+(\varepsilon + i)$ set, and toward Kerran

There is what Thom and Thom describe as an "extrapolating sector" near St. Pierre, and there are tumuli at Le Moustoir and at sites very close to Petit Mont and Tumiac. Thom and Thom find values of G of 114 ft for Le Moustoir and 94 ft for Kervilor. These sites could have provided extrapolation sites for the southernmost major standstill moonrise. From the proposed site of the northernmost major standstill moonrise alignment, ~1 km south of St. Pierre, there is no record of stones or other indications of a backsight, but the radius of the sector at St. Pierre is ~700 ft, which compares with the computed value of $4G$ for the site, 720 ft. Although Thom and Thom do not seem to have been aware of it, reports from the last century make it certain that the rows were once much longer and have been partially submerged by the sea (Burl 1993).

Thom and Thom deduced a value for the obliquity that indicated a date near 1580 B.C., but the uncertainties in measurement permitted an even later date. At the date of their work, the hypothesis that the Grand Menhir had been a major lunar foresight at 1580 B.C. or later seemed reasonable. DHK, however, agrees with Burl (1993) that the archaeological evidence now makes the proposal utterly unlikely and that the Brittany study provides a very good example of the dangers of accidental alignments when the monuments being examined are not part of a single complex.

In addition to these interesting features, there are several local sites of stone rows in the area, which can be examined separately:

(1) *Le Menec* stone rows
(2) *Kermario* stone rows
(3) *Petit menec* stone sectored grid
(4) *St. Pierre* sector
(5) *Champ de menhirs*

The Le Menec row and Kermario rows are in the north of the Carnac region proper. The Le Menec rows show a distinct direction shift about midway of its overall length, ~3000 ft or ~1 km. The Kermario rows, of similar overall length, to the northeast, show three such areas, but the westernmost is short, ~100 m. The width of both of these sets of rows is also ~100 m. Further to the northeast, near Kerlescan, there is another, much shorter sector oriented roughly eastward, toward Petit Menec. The sector at Petit Menec is shorter still; Thom and Thom (1971, Fig. 5) give its overall length ~93.6 m or 112 MY, and compute its radius as 225 MY, and its broad base consisting of 14 squares with sides of length 4 MY is 56 MY on the arc. The previously mentioned St. Pierre sector (Thom and Thom 1971, Fig. 6) seems to have squares of 10 MY sides at the base, 40 MY on the arc.

6.2.17. Megalithic Sites in Central Europe

In Oldenburg, near the city Wildeshausen, are seven pairs of long parallel stone rows known locally as Hünenbetten ("Beds of the Huns"). These are discussed by Müller (1970, pp. 75–81). Müller points out that in 1934, at a time when scholarly work on archaeoastronomy was virtually nonexistent, D. Wattenberg noted that the major alignment of the Hünenbett at *Visbeker Braut* ("bride") pointed at the midsummer Moon's major standstill position in the South (–29°). The row is closed at the end by four large stone pillars that act as a foresight in similar fashion to natural foresights suggested by Thom at numerous sites. It should be noted that the two outside pillars have pointed tops, whereas the two interior pillars have flattened tops, paralleling the situation described by Burl (1993) for British sites. At *Visbeker Bräutigam* ("bridegroom"), the Hünenbett is aligned nearly on the equinox (90.8° W of N). The other alignments are not as obviously meaningful. The archeological context seems to be in the Neolithic, ~2200–1700 B.C. The *Hohe Steine* ("tall stones") site has four large boulders set in the middle of an oval ring of much smaller stones.

At *Boitin*, in Mecklenburg, are four stone circles referred to as *Steintanze* ("stone dances") (Müller 1970, pp. 54–50, 81–84). Lines between the centers of three of these circles form an isosceles triangle, one side of which is only 1/2° off a line to true north, and the base of which aligns to the extreme southern moonrise (–29°) in 1800 B.C.

At Klopzow, another site in Mecklenburg, there is a double ellipse or circle, with an entrance and small stones to the southeast and large ones to the northwest. A line drawn from the entrance across the largest stones gives an azimuth of 315°. The horizon is flat at this site, which has a latitiude of 53.5°. This implies a declination of ~24°, summer solstice sunset (Müller 1970, pp. 84–85).

According to Müller (1970, pp. 85–88), a group of stone circles in Odry, in West Prussia, seem to be strongly interrelated, with alignments marking the equinoxes and the rise and set points of the Sun at both solstices and the major standstill southern moonrise and the northern moonset. There is also an alignment to a setting at $\delta = 33°$ (for the equinox –1760), said to be for Capella. All alignments are said to work best at about 1800 B.C. It is of importance that the lunar and solar interests recognized for the builders of the British megalithic monuments have also been deduced for these similar continental monuments of about the same date.

6.2.18. Mediterranean and North African Megalithic Sites

Our knowledge of the megalithic archaeoastronomy of the Mediterranean is due particularly to Michael Hoskin and his associates, Allen, Gralewski, Ventura, Serio, Tusa, Morales, Papathanassiou, Papadopoulou, Hochsiedel, Knösel. Many of the monuments of Spain and the Mediterranean islands, especially the burial monuments are decidedly similar to those of the megalithic tradition in Brittany and the British Isles, but no one has yet suggested the presence of the complex astronomy that has been postulated for some of the British sites.

6.2.18.1. Malta

The megalithic temples of Malta (Serio et al. 1992; Agius and Ventura 1981) began to be built about 3600 B.C., and construction continued for about a thousand years. Although the date and the tremendous stones used in the temples justify the term "megalithic," these sites are markedly distinct from other megalithic sites. The first major difference is implicit in the word "temple." To our knowledge, no one has challenged the appropriateness of this term in Malta and no one has demonstrated that it is really appropriate in most of the megalithic world. There are some generic parallels of later date in Sardinia and Menorca. Great circles, standing stones, and elaborate graves, usually with an opening to the southeast, are absent. The orientations of the temples show completely different astronomical interests. Shifting alignments through time suggest that asterisms (including single stars) were of primary importance in this culture, in contrast to anything that can be clearly demonstrated in other megalithic sites. Art carved on Maltese monuments included geometric figures, animals, and watercraft. Finally, and perhaps most significantly, there are indications of numeracy, astronomical interest, and astronomical record-keeping at a different level than that found elsewhere in megalithic cultures. The most striking example may be seen in the Tal Qadi stone (Figure 6.36). The carving shows dividing lines between apparently sectored groups of star symbols and one marked-off segment containing a possible lunar symbol. This suggests the possibility that the sky was formally divided into nearly equal areas, perhaps marked by asterisms. There are reported to be five segments in the stone fragment and may have been as many as 14–18 on the entire stone face.

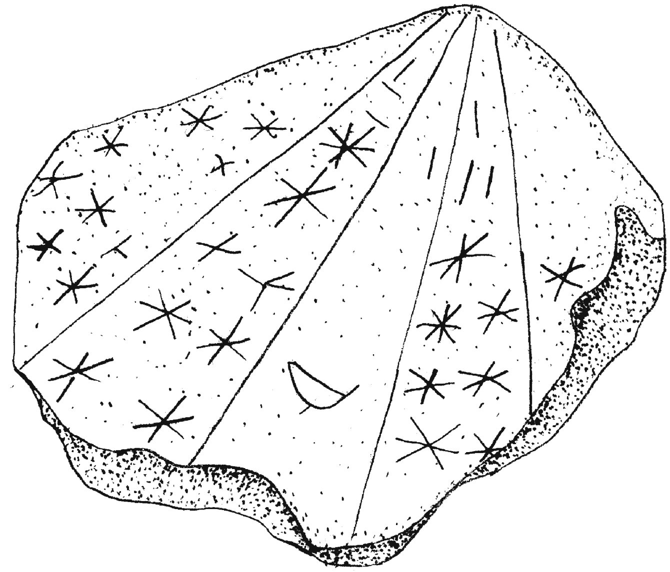


FIGURE 6.36. The Tal Qadi stone: The carving shows dividing lines between apparently sectored groups of star symbols and one marked-off segment containing a possible lunar symbol. Drawing by Sharon Hanna.

The work of Serio et al. (1992) shows that the 14 alignments of the temples of Malta (with the exception of the Mnajdra Temple I) are too far south ever to face a rising or setting Sun and at least 12 are too far south ever to face a rising or setting Moon. If the strongly clustered alignments are astronomically based, it is probable that they are associated with stellar risings, settings, or southern transits. They opt for the latter possibility with emphasis on α and β Cen and the stars of the Southern Cross. They think that the dif-

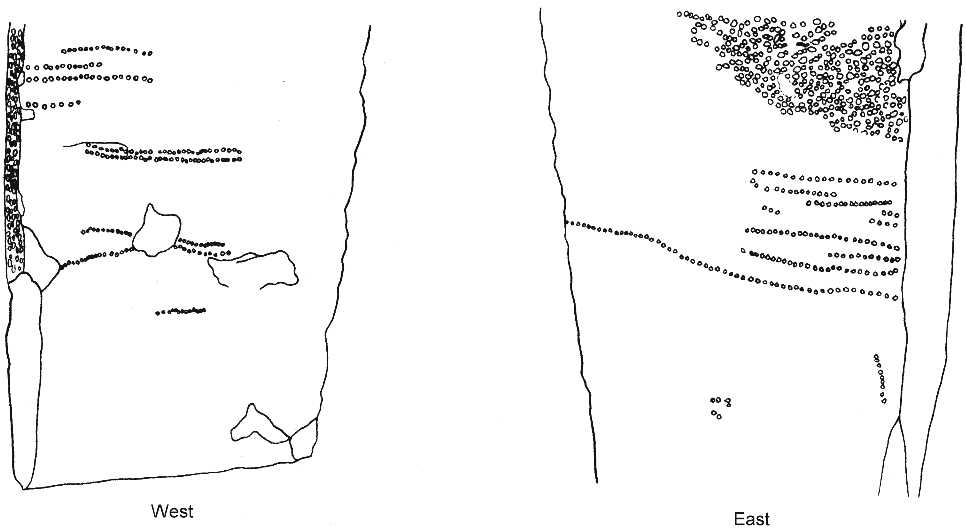


FIGURE 6.37. Pillar markings at Mnajdra Temple III on Malta. Drawing by Sharon Hanna.

TABLE 6.7. Structure in pillar markings at Mnajdra Temple III.

West Pillar		East Pillar			
Line count	Sum	Line count	Sum	Postulated dates[a]	Associated asterism
0		0		Apr. 6	Pleiades
16	16	19	19	Apr. 25	α Tau
12	28	13	32	May 8	Hyades
19	47	16	48	May 24	α Ori
7	54	3 + 3	54	May 27, 30	γ Ori
		4	58	June 3	β Ori
30/31	84/85	24/25	82/83	June 27	α CMa
31/32	115/117	11	93/94	July 8	β CMa
35:	150/152:	25	118/119	Aug. 2	α Boo
37:	187/189:	53	171/173	Sep. 24	γ Cru
12/13	199/202:	(8/9	180/182)[b]	Oct. 2/3	β Cen
		(6	186/188)[c]	—	

[a] Assuming each dot on East Pillar marks 1 day counted from the heliacal rising of the Pleiades.
[b] Nearly vertical line of dots and separated from the above sequences.
[c] Three pairs of dots forming a roughly triangular grouping, separated from the sequences.

ference of alignments between Ggantija I at $\delta = -27.3$ (corresponding to $A = 125.5$) and the somewhat later Ggantija II with $\delta = -33.8$ ($A = 134.5$) may best be explained by the precessional shift.

At Mnajdra Temple III, the earliest of the three temples at this site, there are two pillars into which rows of dots have been drilled (Ventura, Serio, and Hoskin 1993). The features of the pillar are sketched in Figure 6.37.

The holes apparently represent a tally count because of structural similarity between the counts on the two pillars, summarized in Table 6.7, in which the counts are summed in the same way, from top to bottom. The rows are not similar in position on the two pillars, and all but the last two groupings on the East Pillar are horizontal. The upper half of the structure, at least, seems to reflect a common interest on both pillars, but exactly what that interest is remains obscure. Ventura et al. (1993) think that the tally refers to days and that the total of sequenced holes on the East Pillar may represent a half-year. However, the fact that Mnajdra I is aligned closely on equinox sunrise, which is also the direction of the heliacally rising Pleiades, eventually led them to an interpretation of the tally numbers as marking intervals between the heliacal risings of a series of bright stars or asterisms (last column of Table 6.7). They start the tally with April 6 (Day 96 of the current calendar) as the date of the heliacal rising of the Pleiades. The stars were presumably selected because of the proximity of their heliacal rises to the postulated dates at the ends of the sequences; the calculation of heliacal rise dates depends to some extent on the visual extinction coefficients (see §3.1.2.2) reasonably assumed to be between 0.20 and 0.25 (said to be based on unpublished calculations by Bradley Schaefer). With these assumptions, the dates of agreement are less than about 4 days apart at most; the authors argue that this degree of congruence is unlikely to be due to chance.

6.2.18.2. *Iberia*

One of the major megalithic sites of Spain is Los Millares (Mohen 1990, pp. 124–126, 153; Sieveking 1963, pp. 300–304, 313–315). The site was once regarded as an intermediary one, transmitting ideas from the Fertile Crescent and the eastern Mediterranean to the megalithic world of northern Europe. It is now recognized as a southern manifestation of a more general and ancient megalithic tradition. The Los Millares culture has been dated to ~3000–2500 B.C. One impressive monument is a large burial mound surrounded by three concentric rings of menhirs.

The "tholos" tombs of Los Millares were so named because of similarity to the architectural style of Cretan and Mycenean tombs, which are elaborate corbelled domes within burial mounds with large stone-faced entrances. The latter, however, are now known to be of much later date. The tholos tombs frequently have "porthole" entrances. Hoskin, Allen, and Gralewski (1995) report that of 48 tombs with measurable orientations at Los Millares, two were to the southwest, four were somewhat to the south of the midwinter sunrise point, and the rest were oriented to points between midwinter sunrise and midsummer sunrise. The 11 tholos tombs at Barranquete, southeast of Los Millares, were oriented entirely to points between the east and south. The orientations of the tholos tombs have a range similar to those of the tombs of the Montefrio area (Hoskin et al. 1995, p. S69). Azimuths of 41 tomb entrances were measured. Of these, 30 lie in a range from due east to the azimuth of midwinter sunrise, with one alignment at each extreme. Seven fell somewhat north of east and four were south of midwinter sunrise.

Elsewhere in Andalucia, there are several different kinds of burial mounds with a general resemblance to those of Brittany and the British Isles (Hoskin et al. 1995). The passage leading to the burial chamber usually has its entrance in the southeast quadrant. Many more southerly orientations are found here than at Los Millares and Montefrio. Of 198 tombs, the azimuth of which could be determined with assurance, 164 were to the southeast quadrant, 3 (of which one is doubtful) to the southwest quadrant, 1 pointed due south, and 20 to the northeast quadrant. Individually, the most remarkable single monument is the gigantic *Dolmen de Menga* at Antequera (Hoskin et al. 1994a, pp. S79–S80), which faces northeast. The burial chamber is 18.5 m long and 6 m wide, narrowing to a passage 5 m long and 3.5 m wide. The entire structure is roofed by only five slabs, the largest of which has a volume of 120 m^3.

Hoskin et al. (1994b) think that there is no evidence in Iberian tombs of alignments to stars or to the Moon. They suggest that many tombs were aligned on the rising points of the Sun at various times of the year and that the others were aligned so that the passage of the Sun across the sky would illuminate the tomb interior. The pattern is suggestive of the alignments of medieval churches, many of which were set so that the Sun illuminated the high altar on the Saint's Day of the church (see Heilbron 1999).

6.2.18.3. *Balearic Islands, Sardinia, and Pantelleria*

The Island of Menorca contains four megalithic sepulchres; neighboring Mallorca and Formentera each contains one. They apparently date from early in the 2nd millennium B.C. (Hoskin and Morales 1991). All are oriented in western and southwestern directions, with azimuths from 220° to 278°. There are also somewhat later communal burial tombs of large stone blocks. The tombs are called *navetas*, from a resemblance to overturned boats, and may derive from the earlier tradition. Hoskin and Morales divide the navetas into three groups: oval navetas restricted to the east, and eastern and western elongated navetas. The orientations of the six western elongated navetas all fall within the limits of the orientations of the Balearic megalithic sepulchres. The orientation of the six oval navetas and the six eastern elongated navetas center on the south. Only one in each of the latter groups is within the range of the western navetas. Thus, all of these alignments are substantially different from those that are common elsewhere, but there are also markedly distinct subgroups.

Hoskin (1985, 1989, 1991) also discussed Menorca towers, called *talayots*, which were constructed between 1400 B.C. and the Roman conquest, and they may represent the last remnants of a megalithic tradition. The towers tend to dominate villages that often also contain a physically bounded area or "precinct" with a *taula* ("table"). These are massive monuments composed of two limestone slabs, one upright and the other horizontal forming a large tau-shaped object. Whether the towers and precincts were sacred or secular is disputed, but Hoskin has come to think that the precincts were sacred areas or sanctuaries. The precinct entrance is usually southward, and Hoskin has suggested that they were aligned to face the passage of the constellation of the Centaur, Chiron (an attested name for this constellation). One of the taula-precincts contained a statue of the Egyptian architect, Imhotep, later deified and associated with medicine. He was equated by the Greeks with their god Asklepios (or Aesculapius). Asklepios was said to be a pupil of Chiron, who was renowned for his healing powers. One of the taula precincts had an alignment coinciding with the heliacal rising of Sirius. Hoskin (1991) points out that there was a ritual on Mount Pelion at the time of the heliacal rising of Sirius. Mount Pelion was said to be disputed territory between Centaurs and Lapiths, whose royal lines had a common origin (Graves 1955–1957 I, pp. 360–362). The mother of Asklepios was said to be a Lapith princess. Aristaeus, a grandson of the Lapith king Hypsaeus, learned Mysteries in Chiron's cave and was taught healing by the Muses. He is credited with ending a plague sent to the island of Cos by the Dog Star, Sirius (Graves 1955–1957, I, pp. 277–278). These details offer some support for Hoskin's views. Hypsaeus was the son of one Naiad and the husband of another (Graves 1955–1957, I, pp. 276–277). Naiads were daughters of Phorcys (Boar). The Latin equivalent of Phorcys was Orcus (Graves 1955–1957, p. 129, II, p. 107), whose name is probably incorporated in the names Menorca and Mallorca.

The towers of Sardinia (Hoskin et al. 1993) resemble the talayots of Menorca, which are simpler, and the so-called "Tombs of the Giants" resemble the Menorcan navetas. They seem to be approximately contemporary. Many scholars have supposed a close cultural relationship between them. Hoskin et al. (1993, p. S24) thinks that the similarites

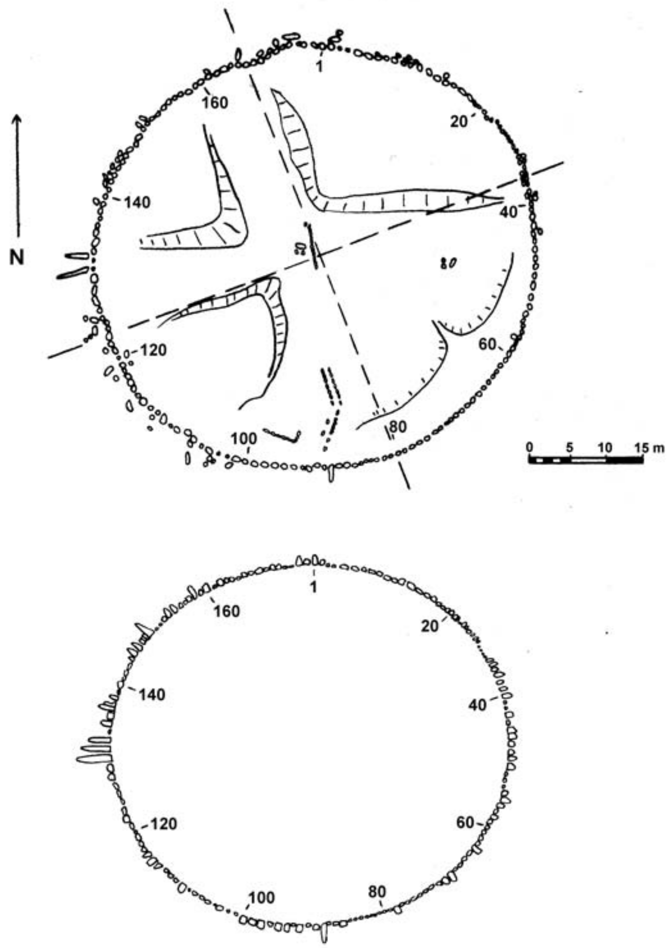


FIGURE 6.38. The tumulus and menhirs of Mzorah, North Africa. Drawing by Sharon Hanna.

are more likely to be due to limitations imposed by the building materials and techniques. In any case, alignments in the two areas are decidely distinct. The Sardinian monuments share the generalized southeast orientation that is so widespread in megalithic monuments.

On Pantelleria, there is a group of communal tombs, called *sesi*, dating from ~1800 to 1600 B.C. The largest is a mound with 11 entrances and 12 passageways leading to separate chambers inside the mound. There is no discernible clustering of orientations in or among the 42 monuments examined (Tusa, Serio, and Hoskin 1992).

6.2.18.4. Northern Africa

Somewhat south of Tangiers in North Africa, at the site of Mzorah (5°56′.73W, 35°24′.59N; 118 m above sea level), there is a major megalithic monument, a great ellipse of menhirs surrounding a tumulus (Mavor 1977). Mzorah means "Holy Place." As can be seen in Figure 6.38, the menhirs are closely spaced.

There are 168 menhirs or their broken stumps still in place, but only ~1/3 are erect and unbroken. Mavor's careful mapping led him to conclude that there were originally 175 present. Mavor suggested that the ellipse appeared to have been laid out on the basis of a 37-35-12 Pythagorean triangle, a type of structure that Thom claimed as the second most common pattern found in the British Isles. Mavor gives a full list of the distances and azimuths of all the menhirs, as measured from the center. Three tall stones (Nos. 130, 131, 132) mark the west point. The south point is marked approximately by a single stone (no. 90). Mavor notes a substantial number of other possibly intentional alignments, including all solar solsticial and equinoctial alignments and lunar major and minor standstill rising alignments and at least one setting alignment. He assumed that the ellipse had been used for observing for a substantial length of time before the tumulus was built, arguing that somewhat similar tumuli were being built in Morocco in the first millennium B.C. and that the menhir circle had affinities with British megalithic monuments dated by Thom in the early 2nd millennium B.C. on the basis of stellar alignments, which the Mzorah monument shares. However, Thom's stellar alignments are not generally accepted because archeological evidence makes it unlikely that the British monuments are as late as Thom thought, and, with 175 possible targets, and a center point defined only by assumed geometry of the ellipse, it is difficult to ascertain which of the alignments was indeed intended. The coincidence of the eastward thrust of the major axis with the direction of rise of the Moon at minor standstill (between stones 35 and 36) is suggestive, however. This direction is also toward the summit of the mountain Jbel Si Habib.

Mavor makes the point that the ellipse must have been there before the tumulus because it would have been impossible to lay out if the tumulus had been in place. It seems likely to be in the same megalithic tradition as the stone circles of northern Europe, and Mavor cites anthropological and archeological evidence to connect the cultures of neolithic and early Bronze age Europe to those of Morocco.

The monument is unusual because it is mentioned in the writings of Pindar [518–438 B.C.], a poet from Akragas (Agrigento) in present day Sicily, as the burial place of the giant Antaeus, King of Libya (a former generic name for Northern Africa), said to have been a son of Poseidon and Mother Earth, and killed by Heracles. The name *Libya* is taken from the name of the daughter or granddaughter of Io (who was transformed into a white cow by Zeus) and of a woodpecker (or Zeus in the form of a woodpecker), apparently regarded in the story as the king of birds (Graves 1955–1957).

6.2.19. Megalithic Summary

At present, megalithic material from areas outside Brittany and the British Isles is still too sporadically recorded to be included effectively in a general summary. Extremely large stones were used in building monuments in many parts of the world (Mohen 1989, pp. 42–67). In a purely descriptive sense, such architecture may properly be called megalithic. Many scholars at the beginning of the 20th century assumed that all such monuments belonged to a single historical tradition, ultimately derived from Europe. We know of no attempt by any archaeologically competent scholar to defend such a view in the last 50 years. Certainly, some combinations of earth mounds as burial places with large stone monuments seem strikingly similar in widely separated areas, but independent origins seem likely for most of them. For example, the "megalithic" of India (*ca.* 800–100 B.C.) is now known to follow the Early Iron Age and seems to be associated with Dravidian languages (Parpola 1994, pp. 172–173). In some cases, approximate alignments are suggested by plans and descriptions although astronomical associations of most of these monuments are still undemonstrated at the present time.

For Brittany and the British Isles, we can provide some rough conclusions about the state of present scholarship. The earliest evidence for astronomical interests appears in connection with large burial mounds in Brittany and western Ireland. Entrance passages to these tombs usually had an orientation to the southeast, sometimes specifically to the winter solstice. Early megalithic cultures probably spread largely by sea, and astronomical observations would have been important in navigation as well as religion. Artistic motifs may have been used as notations of astronomical phenomena. Gigantic single pillars of stone were sometimes erected during this period, but clear indications that they were used astronomically are lacking. Somewhat before 3000 B.C., large stone circles were built. These were apparently used as meeting places and incorporated community beliefs about cosmic order, which embodied astronomical orientations and therefore the timing of ritual events. There is very good evidence at this period for alignments to sunrise at winter solstice and good evidence for equinoctial horizon alignments. There are also possibly deliberate alignments on the cross-quarter days, intermediate between solstices and equinoxes. Evidence for interest in smaller divisions of the year or for alignments on stellar rising points is very weak, as is evidence for lunar alignments, at this period. This situation began to change at about the time of the appearance of avenues in the form of long rows of paired stones in the mid-3rd millennium B.C. An interest in the major and minor lunar standstills, and perhaps in eclipses, probably antedates 2000 B.C. Clear data about such interests seem to be associated with shorter rows of stones. Fans of stone rows seem usually to align on associated cists and to date well after 2000 B.C. The suggested function of the fans for measuring the lunar wobble (the 9′ of inclination variation) is still strongly disputed. However, by about 1500 B.C., short rows of stones seemed to be used for making and recording sophisticated lunar and solar observations. Near the end of the Megalithic tradition, pairs of disparate stones (tall and pointed vs. squat and rounded) appear, but have no clear astronomical significance.

6.3. New World Medicine Wheels

At about the time that megalithic astronomy was at its height and Egyptian astronomy was just beginning, a parallel tradition arose in North America. Similar to the megalithic monuments of Europe in structure and perhaps in function, the medicine wheels of North America span the millennia. The term "medicine" is here used in the American Indian sense of sacred power, including the possibility of healing. This tradition shows marked internal continuity but with a poorly defined relationship to later American archaeoastronomical data. It is, therefore, treated separately.

The medicine wheels are found predominantly in Alberta, but are found also in Saskatchewan, Montana, and Wyoming, with others reported as far south as New Mexico and Arizona. More are being reported every year. Brumley (1986) and Brace (1987) have summarized materials on medicine wheels and classified them into descriptive groupings. They reflect the views of "dirt archeologists," who have first-hand familiarity with many of the sites but who did not attempt detailed appraisals of the archaeoastronomy. Vogt (1993) has provided a comprehensive and critical study of known medicine wheels. Vogt cites references to 134 medicine wheels, of which 94 had adequate information for purposes of his statistical analyses. These analyses were the first attempt to establish groupings based on statistical clusterings of traits. The "important" characteristics for this purpose are those that permit clustering. This creates a degree of circularity in the reasoning and does not allow for the very real possibility that the important characteristics to the builders were those that distinguished one wheel from another.

The layout of medicine wheels is suggestive of megalithic circles, but the use of piled up rocks and boulders rather than standing stones decreases the precision obtainable relative to the megalithic circles of Europe. It has been suggested that poles may have been stuck into the tops of cairns; that could have substantially increased precision. There is some direct evidence that that occasionally occurred. The use of alignments to horizon markers has also been suggested in some cases. The sizes of medicine wheels vary greatly, ranging from less than 10 to more than 100 m. Ideally, there is a central stone cairn, a surrounding circle or oval, a series of spokes, and some outlying cairns. Some of the medicine wheels have a shape approximating that of a turtle rather than a circle, and they may belong in the general category of boulder effigy figures (also called geoglyphs). Modern Indians claim that many of the medicine wheels are burials or memorials to dead chiefs, but only two are known to have burials in the central cairn.

Vogt (1993) makes a number of generalizations about medicine wheels based on his survey of the literature. They are normally on top of the highest local hill, usually with a good view in all directions. They are often regarded by local groups as sacred places. Many sites have associated caches and offerings, extending, at least at Majorville, over several thousand years. There are patterned repetitions of statistically defined types of medicine wheels. These include clusters of directional alignments. Fifteen sites show markers for true north, to the extent that the basic data are trustworthy. Vogt has demonstrated that previously proposed adaptations to local features of topography are inadequate to explain these clusters. He maintains that astronomical targets are the only adequate explanation for the alignments. Moreover, not all can be explained by solar, lunar, or planetary data. Some targets must have been either individual stars or asterisms. Precision may not have been an important factor in alignments. He maintains that these alignments were "scientific elements of what probably were largely religious knowledge systems." Vogt (1993) argues that the types of horizon-based observations earlier suggested by Eddy and others would often have been obscured by tents if the tipi rings, which are frequently found at such sites, are a good indicator. This throws doubt on the use but not necessarily the purpose because the layout could have been done in accordance with horizon observations and the tipis may not have been erected until the appropriate observations had been made.

Vogt (1990, pp. 48–49) discusses the way in which Plains Indians symbolize the cosmos in their dwelling places and ceremonies. He emphasizes the importance of the central pole of the Sun Dance lodge as representing both the "World Pole" and the center. The World Pole is the conceptual axis around which the sky revolves, associated in modern times with Polaris. The Sun Dance was particularly associated with the full moon following the summer solstice (Vogt 1993). Each family group had its assigned position in a circle of tents surrounding the Sun Lodge and in more permanent camps as well (Brace 1987, pp. 122–124). Among more southerly Siouan groups, it is attested that each clan was associated with a particular star or asterism. Hence, any alignment would indicate a particular clan (as Brace suggests) and a particular asterism. Given the view that the cosmos is reflected in the encampments, it seems likely that the association of clans and asterisms frequently held, even in groups for which the association is not attested. Such an association might have involved strict alignments from the center point toward the horizon rising point of "their" asterism among some groups during some periods and a much looser and astronomically imprecise alignment for other groups or during other periods.

6.3.1. Majorville, Moose Mountain, and Big Horn

There are three sites that are of particular interest for archaeoastronomy because of striking similarities in their structural layout and because of their wide separation in space and time. These are the Majorville site in Alberta, the Moose Mountain site in Saskatchewan, and the Big Horn site in Wyoming (Figure 6.39). The Majorville site is archeologically the most important, but its archaeoastronomy is the least well known.

6.3.1.1. Majorville

Probably somewhat before 3000 B.C., a circle of rocks and a central stone cairn were built at Majorville, near the community of Cluny in southern Alberta. There are several outlying cairns and a series of spoke lines. The site has been badly damaged, but the main features can still be discerned (see Figure 6.40a). Portions of 26 spokes can be seen, although on the basis of later structural parallels and structural analysis of this site, it is likely there were originally 28 spokes. It is possible that all the spokes were added later, but no evidence precludes their presence in the original structure. Major excavations were carried out at the site over a period of several years under the general supervision of Richard Forbis of the Department of Archeology of the University of Calgary with much of the field work by James Calder (1977). A wide range of artifacts were recovered in good stratigraphic sequence. Apparently, the cairn was being increased in size from ~3200 B.C. until after 1800 A.D., except for a hiatus in building, although not necessarily in use between ~1000 B.C. and 200 A.D. Table 6.8 lists the archeological phases, components of which were found at Majorville.

Table 6.8. Archaeological phases at Majorville.

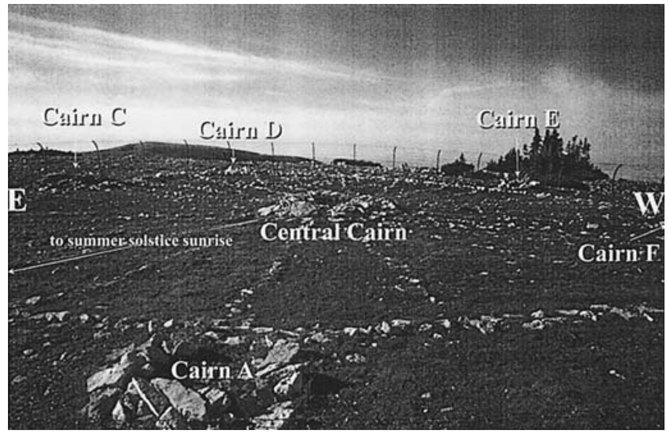
Date	Phase/complex
B.C.	
3200–2500	Oxbow Complex
2500–1500	McKean
1500–1000	Duncan-Hanna
A.D.	
200–1000	Besant/Avonlea
600–1725	Old Women
1725–1800	Historic

Astronomical alignments have been claimed for this site but are not yet fully demonstrated, and the degree of damage to this site is so extensive that convincing demonstration is difficult. A museum model of Majorville at the Department of Archeology of the University of Calgary shows alignments to the summer solstice sunrise and to heliacal rise points of Sirius, Aldebaran, and Rigel. Studies by Gordon and Phyllis Freeman (1992) maintain that there are several types of distant foresights and local equinoctial markers as well. They raise the interesting point that the equinox, defined as the date at which the Sun crosses the equator, does not actually correspond to the date when day and night are equal because of dip and refraction considerations. They maintain that the alignments work best about three days before the vernal equinox, which is the date when observationally day and night were equal. However, they do not explain how people could have observed or calculated the small temporal difference involved. The current value of the site is its demonstrated antiquity and its structural similarity to younger, but less complex sites, for which astronomical alignments can be shown.

6.3.1.2. Moose Mountain

Moose Mountain is located in southern Saskatchewan (see Figure 6.39b). It has five major outliers connected by long spokes to an egg-shaped ring of small stones surrounding a central cairn. There are also smaller, isolated piles of stones that appear to be shaped. The alignments have been studied by Kehoe and Kehoe (1977, 1979) and by Alice Kehoe (1981) in conjunction with J. Eddy. Their work indicates that a line from the southwestern outlier along a continuous

(a)



(d)

(b)

(e)

(c)

FIGURE 6.39. Three principal medicine wheels: (a) Majorville, Alberta. Air photo, courtesy J. Calder. (b) Ground photo, courtesy Tom Head. (c) Moose Mountain in Saskatchewan on the morning of June 21, 1978. Although impressive in appearance, the photo indicates that the expected alignment was not seen, according to Rodger, leading to doubts about the purpose of the monument. Photo, courtesy David Rodger. (d) Big Horn, Wyoming, view from Cairn A. Principal cairns and directions are marked. (e) Big Horn view from Cairn C. The foreground fence posts indicate, from the left, respectively, (1) cairns D (near) and E (far); (2) F; (3) A; and (4) B. Big Horn photos courtesy, Sharon Hanna.

spoke that ends at the central cairn and through the center of the cairn points directly to summer solstice sunrise. The three lines of sight from the northwestern outlier suggest stellar alignments: The most obvious is that along the spoke, which again crosses the ring to terminate at the central cairn, and through the cairn's center. The alignment is to the rise point of the star Sirius, which Eddy indicates is correct over a large range of dates. A line from the NW outlier through an outlier to the NNE aligns with the rise of Aldebaran, α Tau at ~1 A.D. or somewhat earlier, and a line through the eastern cairn points to Rigel for a later date. These alignments are found more convincingly at the Big Horn site. Ovenden and Rodger (1978) argue that the alignments are not convincing and that the monument was constructed for other purposes.

6.3.1.3. Big Horn

Of much more recent vintage, the Big Horn Medicine Wheel is located in Wyoming's Big Horn mountains, at close to the 3000 m level. At present, the site is inaccessible in winter months, and its remoteness has saved it until recently from despoiling vandalism. A branch of a tree found in the central cairn has been dated by the tree ring method to ~1760 A.D. The site has been discussed at length by Eddy (1974, 1977a,b, 1978a, 1979).

From the layout (Figure 6.39c), the number of spokes is 28, suggestive of a sidereal month calendar device and of Indian Sun lodges with their 28 rafters and central pole. There is a flattened ring of small stones distributed at an approximate distance of about 7 m from the central cairn, which is much less prominent than that at Majorville. The central cairn is the oldest part of the site. The circle and spokes were added later. Some archeological evidence suggests use of the site into the 19th century. Five outlying cairns are found just outside the ring, and one is found just inside. The Southwestern cairn is farthest away from the ring and linked to it and to the central cairn by a spoke. John Eddy (1974) recognized the possible astronomical importance of the site and argued that it was designed to emphasize the summer solstice both by solar and stellar alignments. A line across this outlier through the central cairn, along the spoke points to the summer solstice rise part of the horizon. A line drawn through from the southeastern outlier through the central cairn points also to the summer sunset point. The northwestern "outlier," which alone stands inside the ring, suggests stellar alignments. A line to the NNE outlier points, with a modest precessional correction, to the rise point of Aldebaran; through the eastern outlier, a line points to Rigel, β Orionis; finally, a line through the central cairn points to Sirius. The alignment date to give the appropriate precession correction is ~1700 ± ~200^y, in agreement with the archeological evidence for the time of use of the site. The only cairn not used in these alignments was found by Jack Robinson to mark the heliacal rise of Fomalhaut about a month before the summer solstice between A.D. 1050 and 1450, earlier than the other evidence would suggest.

The Big Horn Medicine Wheel is a central feature of an area that has been considered sacred by many American Indian tribes. According to Tribal Elders (Price 1994, p. 260), this area has always been a neutral ceremonial area for all tribes, even during times of warfare. The continuing sacredness of the site has created conflict with the Forest Service, who have used the area for a multitude of economic purposes and with tourists who wish to see this interesting site (see Price 1994 for a full discussion). The sacred status of the area has recently been recognized, and some provision has been made to protect the site from damage that tourists often cause, whether due to carelessness or vandalism.

Vogt emphasizes that the particular stars in alleged use at Moose Mountain and Big Horn are not found as important markers at other sites and that there is no ethnoastronomical evidence for the importance of the alignments. However, our knowledge of ethnoastronomy is not so great that the absence of references should be considered a strong argument. Vogt (1993) also suggests the possibility that alignment targets are more likely to have been asterisms than individual stars, which would substantially reduce precision.

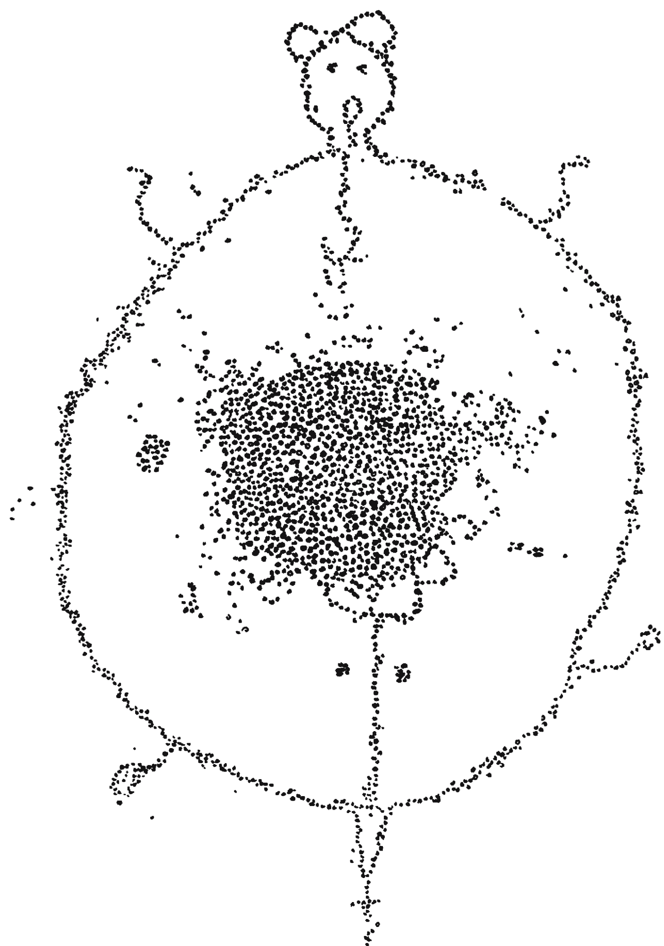


FIGURE 6.40. The Minton Turtle effigy in south-central Saskatchewan: The principal alignment from the tail to the head would have coincided with the helical rising of Sirius at summer solstice at ~2300 B.C. Drawing by Sharon Hanna.

6.3.2. Other Medicine Wheels

Eddy (1977a, pp. 160–162) discusses a medicine wheel at Fort Smith, Montana, which has six spokes. One of these is aligned to the summer solstice sunrise, but the other spokes are not discussed.

Alice and Tom Kehoe (1979) describe effigy figures and medicine wheels that coincide with astronomical alignments. The most striking of these is the Minton Turtle effigy in south-central Saskatchewan (see Figure 6.40).

The principal alignment is from the tail to the head; it would have coincided with the heliacal rising of Sirius at summer solstice at ~2300 B.C. At 1 A.D., there would have been a shift of about 4° off this axis according to Eddy (cited in Kehoe and Kehoe 1979, p. 13). There is also a good summer solstice sunrise alignment and a possible sunset alignment for the same day. The height of the central mound would have prevented observation of the Sirius rising (at the horizon) with any precision unless there were a marker, perhaps a pole or a standing human. It is also possible that the central cairn was built later. But whereas at the 2300 B.C. date, Sirius's horizon rising could not have been observed along the axis if it was blocked by the central cairn (given the present height of the cairn), at about 1 A.D., Sirius would have appeared to rise over the center of the cairn (again at present height). The height of the central cairn also would have affected the visibility of the Sun at horizon rising, but a precessional shift would not have helped in this case. This monument has been identified as a representation of a badger by Brace (1987, pp. 92–93) on the basis of information from Cree and Assiniboine informants. This reflects the assumption that the uppermost features of the figure are "ears"; however, they also correspond strikingly with the eyes of a turtle viewed ventrally (see, for example, Figure 15.3).

At the Roy Rivers wheel, there seems to be a marker for summer solstice sunset. Although the Kehoes do not make such an argument, it could also be postulated that one of the 15 small cairns at the site marks summer solstice sunrise, which, however, still leaves 14 cairns unexplained. This brings us to the more general idea of the multiple purposes evidenced by the many different forms of medicine wheels.

6.3.3. Astronomical Meaning of the Medicine Wheels

The importance of the medicine wheel alignments lies in their alignments; the solar connection is expected and seen. The stellar alignments are meaningful if the heliacal rise dates of the three bright stars are noted; functioning in this way, the Majorville, Moose Mountain, and Big Horn medicine wheels have a solar calendrical importance. The evidence of these three sites suggests that there was a continual tradition of the use of medicine wheel sites, although it has not been shown thus far if the astronomical usage is older than Moose Mountain or if lunar observations were indeed made from any of these sites.

All wheels that show characteristics that suggest astronomical intent also have cairns or alignments that are still unexplained archaeoastronomically. This weakens the case for accepting the astronomical purpose underlying these monuments. If anyone could offer probable astronomical explanations for any of these unexplained alignments, the case for accepting the interpretations of Eddy and others would be correspondingly strengthened.

This concludes our discussions of the stone monument building traditions in the Old and NewWorlds. We proceed now to the Mediterranean to discuss the roots of western astronomy.

7
Antecedents of the Western Tradition

As general sources of information on the science of this area, we strongly recommend the following: George Sarton's *A History of Science*, Vol. I: *Ancient Science through the Golden Age of Greece* and Vol. II: *Hellenistic Science and Culture in the Last Three Centuries B.C.*, 1952/1970; Bartel L. van der Waerden's *Science Awakening II: The Birth of Astronomy*, 1974; and several works by Otto Neugebauer (*Exact Sciences in Antiquity*, 1959/1967; *Astronomy in History: Selected Essays*, 1983, and for Mesopotamian data, *Astronomical Cuneiform Texts* I, II, and III, 1955/1983).

7.1. Mesopotamian Civilization

So much of our contemporary culture and civilization stems from the Mediterranean basin and ultimately from Mesopotamia that it is not surprising to find the roots for astronomical concerns and practices there too. It is an understatement to say that this ancient world has had a profound effect on the development of our own, but it may not be realized that astronomical records have illumined much more than how the ancients carried out their observations. In his Henry Norris Russell Lecture to the American Astronomical Society in 1967, Otto Neugebauer described the history of decipherment of Babylonian astronomical texts, and said of Fr. J. Epping, that "Few modern historians know that their chronological framework for the history of the 'Hellenistic' period (from Alexander to the Roman imperial period) rests on astronomical data established by Epping." Although this is an overstatement,[1] it conveys something of the importance not only of our heritage, but also of how we continue to benefit from the ancient root and source of science. The heritage is demonstrated in such widely diverse matters as the way we refer to angles and time intervals and adminster legal systems. Here, however, we summarize only the most basic aspects of our knowledge of the astronomy of ancient Mesopotamia, and for further details refer the reader to studies by Neugebauer, Sachs, Aaboe, and van der Waerden, cited below.

The region between the Tigris and Euphrates Rivers has been traditionally known as the "cradle of civilization" because of the origin of many ideas carried forward into modern society, including that most important early incentive to stationary life, agriculture. The chronology of the region is given in Table 7.1. For a good summary, see A. Leo Oppenheim's *Ancient Mesopotamia* (1977) and the *Cambridge Ancient History*, Vol. I and II. Most of the characteristics that have been used to define civilization first appeared together in Mesopotamia about 3500 B.C. Writing seems to have developed out of the use of tokens to represent animals in various sorts of exchanges. Architecture had been getting more complex in Anatolia, the Syrian coast, and Mesopotamia over nearly two millennia, and thoroughly urban walled cities with massive monumental buildings for religion and administration had become normal. The building material was normally baked or sun-dried clay, because all stone had to be imported to this sandy area. The transport systems included elaborate use of reed and skin boats, with sails, and good canals and docking facilities. A variety of carts and wagons were in use both to supply the needs of the cities and for warfare. Food was supplied primarily by farming, using plows, and heavily dependent on sophisticated irrigation systems. The most important crops were wheat in Assyria and barley in Babylon. Emmer wheat and millet were also grown. Among the vegetables, only onions, garlic, and leaks were important. Many fruit trees were grown, among which only the date palms were economically important. Flax was grown primarily for its fibers and secondarily for its oil. Sheep and goats supplied meat, wool, and perhaps milk, and cattle and pigs were important sources of meat. There were special birdkeepers for many kinds of birds; ducks and geese were most important. Donkeys, mules, and horses were important in transport and farm work, although not ridden. Chariots were used from

[1] See, for example, Bickerman's 1968/1969 *Chronology of the Ancient World* for a more comprehensive and detailed view.

TABLE 7.1. Chronology of Ancient Mesopotamia.

Age/tradition	Date	Culture/group	Kings/events/inventions	Literary sources	Cross-dating
Neolithic	6000 B.C.		Earliest irrigation canals		
Chalcolithic	5500	Halaf			
	4500	Ubaid			
Bronze Age	3750	Uruk	1st cities		
	3200	Jemdet Nasr			
	3000	Early Dynastic		Fara Tablets	
	2600				Egypt, Dyn. VI, Pepi (pre-Ebla)
	2300	Old Sumerian	*Akkad* *Assyria*		
			Sharrukin (Sargon), king ↔ **1.** Tudiya, king	Ebla Archives	
	2100	Neo-Sumerian	(end of Akkad, ~2050 B.C.)		
	2000			Sumerian King list completed	Egypt. Dyn. XII (1991 B.C.)
			Gudea, king Lagash ↔ Utu-hegal conqs. Gutians[b]		
			King of Ur murdered[b]		
			Ibbi-Sin conquered[b]		
			Babylon		
			Naplanum (1961 B.C.)[b]		
	1900				Egypt. Sesostris III in yr. 7[a] (1872 B.C.)
	1800	Old Babylonian	Bel-Ibni repl. Irra-imitti (1798 B.C.)[b]	Gilgamesh Epic written	Egypt. King Neferhotep
			Hammurabi (1728 B.C.) ↔ **39.** Shamshi-Adad ↔	Mari archives (Zimri-Lim)[b]	Hyksos in Egypt
	1700		d. in yr 33 (1718?)		Thera eruption (1644 B.C.)
	1600		Ammisaduqa (1582 B.C.)[b]	Venus tablets	Egypt: Amenhotep, in yr. 9, 1537 B.C.[a]
			(end of Babylon I, 1531 B.C.)		
	1500	Middle Babylonian	**10.** Burra-Burlash I, **61.** Puzur-Ashur III		Egypt. Thutmose III, 1462–5 B.C.[a]
	1400		(Kassite) **63.** Nur-ili; **65.** Ashur-rabi		Rujm el Hiri
			68. Ashur-nerari	Ugarit archives	Egypt. Ikhnaten
Late Bronze Age			**73.** Ashur-uballit	Amarna archives (Egypt)	1321 B.C., begin. Sothic Cycle
	1300		Kassite **19.** Burra-Buriash	*Enuma Anu Enlil* compiled;	Egypt. Rameses II, yr. 34, 1257 B.C.
			(end of Kassite kings)		
	1200	Middle Assyrian		Fixed stars text	
		Neo-Assyrian		Astrolabes	
	900	Late Babylonian		Culmination stars	
	800			*limmu*, solar eclipse 763 B.C.	
	700			*Mul-Apin* compiled	
Iron Age		Late Assyrian		Assyrian king list completed	**110.** Sharrukin (Sargon) III builds Khorsabad
				Great library of Esarhaddon	**112.** Ashur-akha-iddina (Esarhaddon)
	600		Babylon conquers Assyria (608 B.C.)		conquers Egypt 671 B.C.
		Neo-Babylonian			Persia conquers Israel (546 B.C.)
			Persia conquers Babylon (539 B.C.)		Persia conquers Egypt (525 B.C.)
	500				Building of Persepolis

[a] Sothic dates.
[b] Lunar eclipses.

the early 2nd millennium onward. A full bronze technology was in regular use for tools and weapons, as well as for ornaments. A variety of social and professional distinctions had become normal, with hereditary rulers and nobles, full-time government officials, standing armies, and many kinds of professional craftsmen, such as potters, weavers, metallurgists, scribes, priests, and boatmen. The lowest echelons consisted of free laborers and slaves.

7.1.1. Methodology and Iconography

Although there is a great deal of knowledge of the mathematical systems of later Assyro-Babylonian astronomy, there is little agreement about the nature or the importance of astronomical knowledge in the earlier periods.

The central problem was addressed by Willy Hartner (quoted by Beer 1970, p. 139):

> The possibility of a symbol's original meaning falling into complete oblivion and of a new one being attributed to what would else be meaningless, can never be wholly excluded; but from the point of view of methodology, it seems objectionable to make such an assumption the starting-point of an investigation before all other attempts have proved futile.

In the case of Mesopotamia, substantial iconographic similarities from pre-dynastic periods to Seleucid times have always been admitted. However, most of the scholars working most closely with these problems have assumed that the deities and myths had an "original" meaning independent of astronomy and that astronomical identities and processes were somehow attached to them secondarily at a later date. We think that neither the assumption of continuity of interpretation nor the opposing assumption of the introduction of a radical discontinuity should be left unexamined and untested. The most striking early evidence of attitudes toward the planetary gods is to be found in an inscription of Gudea, King of Lagash, telling of a dream he had and of the temple building program that it inspired. According to Gudea (Campbell 1970, pp. 117–118),

> "My Shepherd," said the goddess, "I shall read for you your dream. The man whose stature filled sky and earth, whose crown proclaimed him a god, and at whose side was the Imdugud bird; storm at his feet, and to right and left two lions, was the god, my brother, Ningirsu. His command to you was to build his temple Eninnu. Now, the sun that rose from the earth before you was your guardian god, Ningizzida: like a sun, his serpent form rises from the earth. The woman holding a stylus and tablet of constellations, rapt as it were in thought, was the goddess, my sister, Nisaba, showing to you the auspicious star for your building of the temple. The second man, a warrior, with lapis lazuli tablet, was the god Nin-dub, designing for you the temple's structure. And the ass, laden, at the right of the king; that was yourself, ready for your task."

The attitudes seem strikingly similar to those expressed by Esarhaddon, King of Assyria, nearly two milennia later (Luckenbill 1929, pp. 250–251):

> At the beginning of my kingship, in my first year of reign, when I seated myself on the throne of deity and put on my head the royal crown, there appeared favorable signs in heaven and on earth, for the restoration of the city and temple, favorable (oracles) were disclosed to me. (The planet) Jupiter arose and in the month of *Simânu*, drew near and approached the station of the sun. It stood still. The appearance of its countenance was ruddy. It changed . . . heavy rains and great floods of mountain water. . . . In the month *Pît-bâbi* it reached the place of its "watch" and stood (still) in its station. For making . . . a favorable oracle was disclosed. Monthly Sin [Moon god] and Shamash [Sun god], at their appearance, were in agreement with each other as to the restoration of the (images) of the gods, the complete rebuilding of the metropolis, the security of my dynasty, and the stability of my priestly throne.

In this excerpt, we include the author's interpolations in parentheses and our own in square brackets, but have omitted the restoration and reconstruction marks.

Gudea's mention of a tablet of constellations (if correctly translated) makes it clear that the Sumerians of this date already had a named series of constellations. Although it is not impossible that they were markedly different from those of later periods, we would then have to suppose both that iconographic scenes that would refer to planets and constellations in later periods do not do so at this time and that constellations that were then known did not have similar representations in later periods. Additionally, one would have to suppose that many mythical ideas that were represented in Gudea's time became attached secondarily to constellations. This seems to us to violate Ockham's razor sufficiently to raise questions about the classical interpretation: It is much simpler and in better accord with the data that the constellations and associated mythology represent a continuous tradition. The fullest treatment to date of Mesopotamian asterisms referred to in texts is that of Reiner and Pingree (1981). They specifically assume continuity of identification.[2] In Figure 7.1, we show a sky map of Mesopotamian representations based on this assumption.

7.1.1.1. Iconographic Representations on Cylinder Seals

Kathleen Adamson's Ph.D. dissertation was an extensive examination of Inanna, Ishtar, and cognate deities that provides a basis for examining iconographic representations in a reasonably clear chronological and geographical framework. The representations can be shown to cluster in ways that are easily understandable in terms of their later astronomical meanings but difficult to understand otherwise. Scenes from cylinder seals of the Neo-Assyrian period, when no one doubts that the gods were associated with planets and many constellation names have been identified, furnish a useful starting point. Adamson (1988, Figs. 221–38, 248–251) shows the remarkable similarities of these eight seals to each other. Ishtar is always shown sometimes with the pointed star symbol that is typically hers (although associated with other planets, also, during the Seleucid period). The Pleiades are shown as seven dots, an identity attested

[2] "A basic hypothesis that we have followed in attempting to identify the constellations names that occur in our texts is that they refer to essentially the same groups of stars as do the same constellation names in the Astrolabes and MUL.APIN. Of course, we cannot be certain of the boundaries of any of these constellations and they may well have varied over time as did the Greek constellations; . . ." (Reiner and Pingree 1981, p. 2).

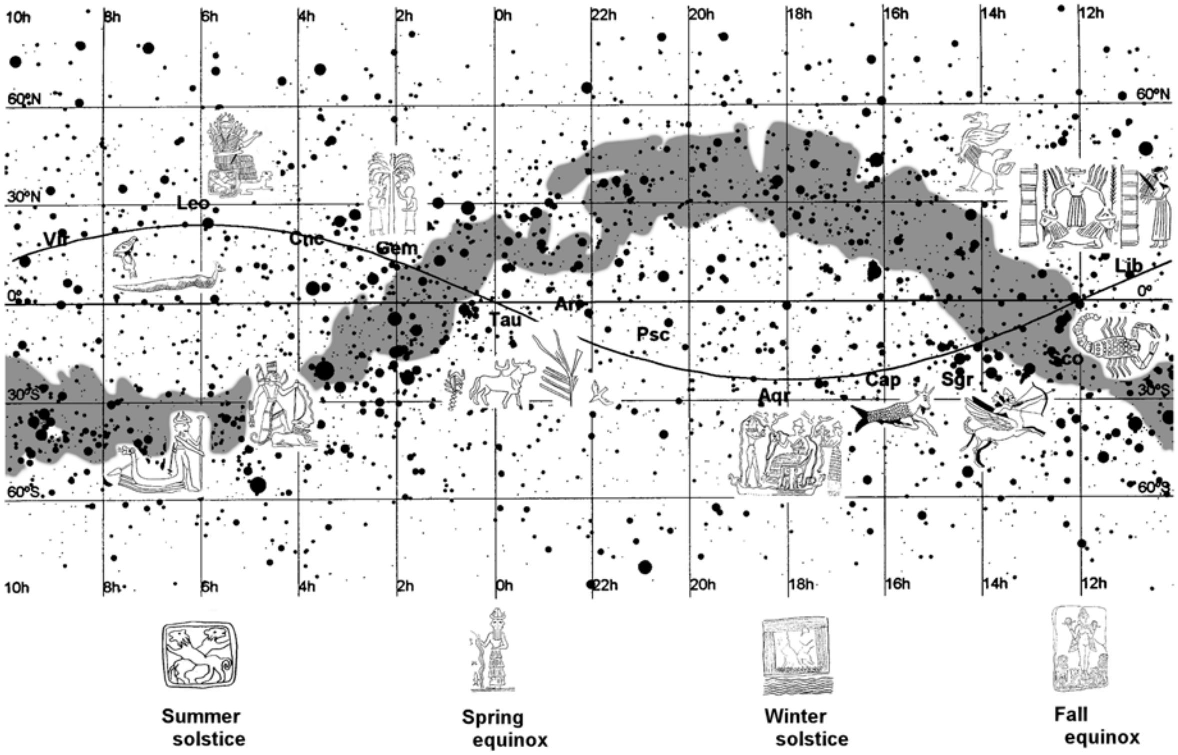


FIGURE 7.1. Mesopotamian representations of the constellations superimposed on a simulation of the sky of 2500 B.C. Drawings by Rea Postolowski and Sharon Hanna on simulation by E.F. Milone with Redshift software package.

from the Seleucid period. The lunar crescent is always present. A second deity figure is also always present, with the arms held in a closely comparable position on all these seals. A third deity, Adad, usually standing on a bull (Taurus), appears frequently. Two different kinds of staves are shown on most of the seals. A scorpion man appears on four seals, and the frit vulva, a symbol of Venus, on five. The unity of these different seals is extraordinary. Perhaps even more remarkable is their similarity to a symbol set on a monument of Esarhaddon, from Zinjirli (Figure 7.2).

However, the seals show the interaction of Ishtar and the other deity figures. The monument shows only the symbols. The interaction seems to imply that the deities were together in the same part of the sky. The scorpion man has been identified as the constellation Scorpio, but if there is a direct interaction with the Pleiades, a second scorpion at or near Betelgeuse, as suggested by parallel evidence elsewhere (§9.3), would fit much better with the Pleiades and Taurus. However, interaction between rising and setting figures (12^h apart) should not be excluded as a possible interpretation.

The astronomical symbolism of these Neo-Assyrian seals has clear prototypes among seal representations extending back to the time of the Sumerian domination. We discuss some of these seals in turn. In Adamson (1988, Figs. 57 and 60), we see two representations of Inanna-Ishtar from the Akkad period. Both show the goddess with maces, accompanied by a crescent, presumably representing the Moon, and, in one case, a clear solar symbol; the other has a symbol that could be either the Sun or Venus. In both cases, she is depicted on a lion throne, marked by two lions, whose bodies cross, facing in opposite directions. In Hellenistic times, lions were associated with the Sun and with the constellation Leo. The lion at the feet of Inanna-Ishtar, and often attached to her by a cord, would be a suitable symbol

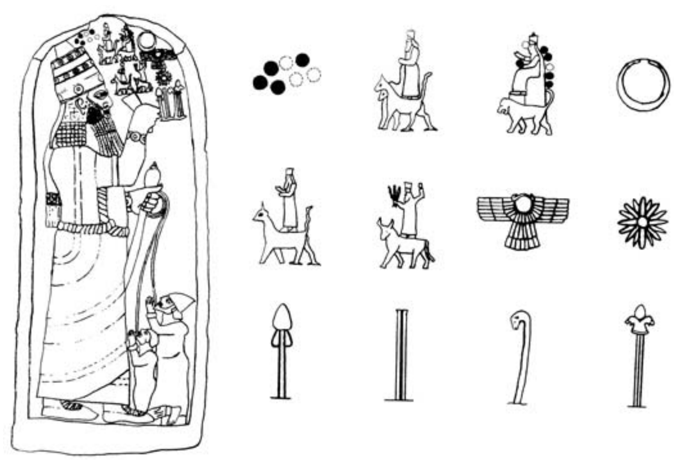


FIGURE 7.2. A monument of King Esarhaddon of Assyria from Zinjirli: The symbols on the right are extracted from the monument on the left, and they seem to represent, among other objects, the Pleiades and seven planets. The four lower staff symbols are unidentified. Sketch by Rea Postolowski and Sharon Hanna.

because Venus and the Sun can never be separated by more than 47° (see §2.4.3). In that case, the lions facing in opposite directions may suggest one of the major points of the year, either a solstice or an equinox. In the later of these two representations, two figures are shown picking dates. We know that the date-palm was an Assyrian constellation (Reiner and Pingree 1981, p. 7, Enlil 11) and a date-palm and olive goddess, *Lat*, known in Palestine and Egypt, is identified by Graves (1957, p. 57) with Leda, mother of the twins, Artemis and Apollo, the latter said to have been born under an olive tree and a date-palm. The date-palm is one of the few trees that have separate male and female forms. The Mesopotamians at a later date recognized two pairs of twins, of whom the greater pair was associated with our constellation Gemini. Overall, the scene suggests the planet Venus in Leo, perhaps with an associated representation of Gemini. Even if this interpretation is rejected, the astronomical association with Ishtar seems clear already in these Akkadian seals.

Another Akkadian seal (Adamson 1988, Figs. 68, 92) shows Ishtar associated with a bull, a swallow, and a ploughman. The bull has the crescent staff on his back, which in later times, clearly marks him as the Bull of Heaven (Taurus). The ploughman is marked by a star above his head, which strongly suggests reference to the constellation *Apin*, the plough incorporating Triangulum and some nearby stars. The bird, presumably the swallow, in later scenes, certainly represents the constellation "Swallow," now part of northern Pisces. The three constellations are near on the sky. The scorpion that accompanies them in Neo-Assyrian times is also with them here. A substantially earlier Sumerian seal again shows a ploughman (with his plough on his shoulder in this case, and a star above his head), a bird, two bulls, and a building marked with symbols, which Adamson has shown are associated with the goddess, Inanna. This scene is not as obviously astronomical, but the star above the ploughman is suggestive.

In Adamson (1988, Fig. 65), there is an Old Babylonian period representation from Mari, which shows a partially unclothed Ishtar. It also shows seven dots circling an 8th, which resembles some depictions of the Pleiades (later normally just seven dots), a bull, and a bird. There is also a scene of conquest and a depiction of a hunter holding a rabbit.

Mountain warfare is also shown on two Akkadian seals (Adamson 1988, Figs. 77, 78), which also depict Ishtar and accompanying deities, two of whom are marked by stars (one on each of the seals), one holding a lion-man by the tail. As in the example of the Neo-Assyrian seals considered earlier, these two scenes seem to incorporate a surprising number of similar details, although the visual impression of the two seals is quite different.

In another Akkad period seal, Ishtar (Venus) and Shamash (the Sun) appear in a mountainous area (Adamson 1988, Fig. 86). Bull and swallow both appear. *Ea* (the Sumerian god *Enki*) appears as lord of fish, accompanied by his servant, a two-faced god. Another god, holding a bow and staff (possibly an arrow) stands by Ishtar. Adamson interprets this as referring to the first appearance of Venus as Morning Star—rising heliacally. The weapons are typical of Venus when seen in the eastern sky (Adamson 1988, pp. 133, 349). The bull and swallow indicate the sky area from Taurus to Pisces, and the two-faced god[3] appearing in this region suggests a god of one of the solar positions, in this case, probably the spring equinox. The fish god is identified in later texts with Saturn, and the 5th deity may be Jupiter. The lion accompanying this last deity is unexplained at this time. The scene may be intended to represent a near conjunction of Jupiter, Saturn, and Venus shortly before a spring equinox, although Adamson suggests only the relationship of Venus and the Sun. This minimal degree of astronomical interpretation is very plausible and seems difficult to reject.

Four depictions show the presence of Ishtar at the killing of the Bull of Heaven (Adamson 1988, Figs. 300–303). In one of these, the god doing the killing is holding a forked stick, which we suggest is typical of Marduk (Jupiter). On a Mari seal, Adamson identifies the god doing the killing as Adad, a god of thunder and lightning, and apparently an aspect of Marduk. The accompanying depiction of water pouring down probably marks both Adad and, as Adamson (1988, pp. 408–409) suggests, the rainy season. Here, it suffices to point out the presence of a crescent moon in the Akkadian version, which supports the view that the Bull of Heaven was, as one would expect, in the sky.

One of the factors in the establishment of kingship was, at least sometimes, a symbolic marriage between the king and Ishtar. Such a marriage was, of course, both a re-enactment of myth and a historical event. Representation of such scenes need not necessarily involve any astronomical content. However, we will argue subsequently that their prototype was an astronomical myth and some astronomical symbolism does seem to be present at least on some occasions. A wall-painting from Mari shows Ishtar associated with what is usually regarded as the investiture of a local king. Among the associated figures are two goddesses holding pots from which water streams flow. Such vases were later typical of the constellation Aquarius, which was identified in late times with a goddess, *Gula*. Another Mari painting shows a god sitting among mountains with a crescent on his head, identified as *Sin/Adad* (a god with characteristics both of the moon god and of the thunder god) by Adamson. A pot with flowing water also appears in that scene.

In a series of representations (Adamson 1988, Figs. 83–84, 90–91) of the so-called "god boat" in which the prow is a deity, Ishtar is shown in or accompanying the boat and Shamash, the sun-god, is usually shown in the boat. Adamson interprets the boat as the vehicle that conveys the Sun through the underworld at night. The body of the ship is formed by the extended foot of the god, ending in a serpent head, in some depictions. Most of the depictions are ancient, from early Sumerian to Neo-Assyrian. However, one is a medieval Arabic design in which this watercraft has replaced the classical Argo. Ishtar's lion appears in many of these scenes with a human head. The plough appears, although no one is ploughing. A bird, presumably the swallow, appears, and the earliest of the scenes shows half a

[3] There are other cultures in which year beginnings are associated with a two-headed god. For example, in Rome, Janus was the god of the doorstep and of the turn of the year.

bull, corresponding to later concepts of the constellation Taurus. The lion man is accompanied by a pot, which suggests the constellations Leo and Crater, the cup, known to be a Mesopotamian constellation. However, their relative position in the scene changes, sometimes ahead of the boat, sometimes in it, and sometimes behind it. Santillana and Dechend (1969) suggest that the pot may represent Aquarius. This is more suggestive of a planet than of a set of constellations. Moreover, Leo and Crater are a considerable distance from Taurus (see Figures 7.1 or B1). In several cases, the prow-god or the figure in the boat holds a forked stick, apparently used as a punting pole. In one case, the prow-god holds the pitch fork-like symbol normally associated with Adad or Taurus. In only one case is the plough apparently being used as part of the action. In the others, it seems to be functioning solely as a toponym.

Adamson is, in this case, not alone in considering that this is the boat that carries the Sun on its nightly voyage through the underworld—mythical, but clearly designed as astronomical explanation. DHK would suggest that it is a scene of disappearance of Venus in Taurus, prior to superior conjunction. Scenes of Ishtar discarding her garments (referred to as the "unveiling") relate to her descent into the underworld, whereas the presence or absence of weapons probably refers to Morning or Evening Star configuration. This will be considered later in connection with the myth of Inanna.

Additionally, there is a miscellaneous series of depictions that show Ishtar as Bow-Star (δ Canis Majoris), with an ear of grain (presumably Virgo), with what appears to be a goat-fish, with flowing water vases (presumably Capricorn and Aquarius), and, finally, with a griffin (a later Mesopotamian asterism in Cygnus and Cepheus).

7.1.1.2. Inanna as Venus

There may well have been changes in the interpretation of some of these conceptions, as well as both losses and additions, but the overall iconography seems to coincide with later astronomical identifications and interpretations, massively and consistently, at least as far back as the Akkadian period. Prior to that period, the iconographic evidence is not nearly as clear, but Adamson points out that some of the earliest Sumerian representations of Inanna show her as a star, and that the goddess is called "shining Inanna" in early texts from Uruk (period III) and specifically "star Inanna" in Lagash texts of Early Dynastic date. They also show that a month was named "Journey of Inanna"; another name for the same or a different month was "Inanna is my deity" corresponding to Semitic Ululu, about September/October. Still another month name was "the month in which the shining star descends from its zenith" (if a reference to Venus, then the term "zenith" is not a technically correct translation, because Venus can never quite reach the zenith at $\phi = 30°$). We do not think that it is reasonable to doubt the identification of Inanna with the planet Venus even at the time of the earliest existing references to her. There seems to be no opportunity for a break in the continuity of this identification and no reason to postulate such a break. Although many earler studies accepted such continuity, most recent work by professional scholars working on early Mesopotamia has ignored astronomy. There are, however, some recent studies published in archaeoastronomical journals that relate to these materials and parallel earlier studies.

Clyde Hostetter has made three proposals of considerable potential importance in this area. One is that Inanna, the name of the goddess of the planet Venus also among the Batak people of Sumatra (see §9.3), derives her name, her attributes, and her astronomical and calendrical functions from the Sumerian goddess Inanna (Hostetter 1988/1991). The second is that the Sumerian myth of Inanna's descent to the underworld is simply an anthropomorphized description of the movements of the planet Venus (Hostetter 1979a, cf. 1979b/1982). The third is that the Sumerians were already predicting eclipses, using an eclipse series of 112 years, which was also tied to movements of Venus (Hostetter 1979, 1991).

These ideas will be considered separately. In DHK's view, the Batak evidence and apparently related material from Northern India offer strong support for the view that Sumerian Inanna was, indeed, identified with the planet Venus. The Bataks also say that there were two celestial scorpions, one in Scorpio, and one in or near Betelgeuse, thus explaining an iconographic element that seemed anomalous on the sole basis of presently available Mesopotamian evidence.

7.1.1.3. Rujm el-Hiri

A site that may have been associated with Dummuzi, the Spouse of Inanna, is Rujm el-Hiri. Aveni and Mizrachi (1998) have published an extensive summary of this site that attempts to integrate archaeology and archaeoastronomy with cosmology on the one hand and local environmental features and topography on the other. The site is in the Golan Heights, formerly the Land of Bashen and later the territory of the tribe of Dan. It is one of many "Levant Megalithic" sites. Whether there is any archaeological connection between such sites and the western European Megalithic is a problem that we will not attempt to resolve. However, we note that the handling of large stones seems different, more like some of the North American medicine wheels (see §6.3).

At Rujm el-Hiri, there are a number of rough approximations to concentric circles of boulders surrounding a central burial mound, with an entrance passage. This area of the site is badly damaged. The largest circle is 145 m in diameter. The burial mound was apparently built in the Late Bronze Age.[4] Aveni and Mizrachi (1998, p. 347) maintain that the circles were built as much as 1500 years earlier, in the Early Bronze Age, but they admit that the archeological evidence does not preclude a date nearly as late as the burial mound. The solar stations are well marked. Walls run out from the outside circle at good approximations to the north, south, and west points of the horizon. The two largest boulders of the site (each about 2 m high and 2.5 m wide) are positioned to create a notch in which the Sun would have been seen rising, as viewed from the center of the complex,

[4] The dating is based primarily on association with imported pottery. No local pottery of that date is known. See Table 7.1.

within one day of the equinoxes. In this area, the September equinox is a very good marker for the beginning of the rainy season and the March equinox is an equally good marker for the end of the rainy season, and the beginning of the dreaded sirocco winds from the east—harsh and dry. These last only for a short while and are followed by the dry season proper, which brings cooling western winds and, with them, dew. The summer solstice was marked by an elaborate southeast entryway to the complex. This is associated by Aveni and Mizrachi with Dummuzi, god of vegetation, and his marriage to Inanna. The entryway is not, however, aligned to the winter solstice sunrise, possibly because during this season, it would frequently have been invisible because of cloud. However, Mt. Tabor [originally, perhaps *tabbür*, navel] looms to the southeast in nearly the direction of the winter solstice and so may have served as a distant natural foresight. The alignment marker to the north points directly to Mt. Hermon (which has connotations of "sacred mountain"[5]) and Aveni and Mizrachi (p. 492) think that the Rujm el-Hiri was deliberately constructed where it is in order that that alignment would hold. If both sacred mountain alignments were deliberate, the location of the site would have been fixed with substantial precision.

There are a number of walls that run radially from one circle to another (but none from center to outer rim). There is no evidence that these walls served any practical function, and Aveni and Mizrachi believe that they were celestial markers. The azimuths of the walls were checked against the rise/set azimuths of the 22 brightest stars over a range of dates from 2000 to 3500 B.C. On average, the declinations of these stars change by ~10° in three millennia. They mention no testing of lunar or planetary extremes, although Inanna's identification with Venus might have suggested that as a possibility. They found no overall statistical significance in alignments "hits" taken in 500-year increments, but there are temporal clusterings of hits that suggest deliberate intent to Aveni and Mizrachi (p. 488). They find a peak of 37 hits (whereas by chance 16 alignments are expected) for 3000 ± 250 B.C., which involves several radial walls (9, 10, 13, and 14 on their site plan). They also find a paucity of apparent alignments to the circumpolar region of the sky (where no stars rise or set), which strengthens their hypothesis. The only star they specifically discuss is Sirius, which, they say, set acronychally (see §2.4.3) in 3200 B.C., three days before the winter solstice. A fuller consideration of these stellar alignments and possible mythical identifications would be desirable. We emphasize here again that crucial alignments in many cultures often involve fainter stars.

7.1.2. Marduk and the Frame of Heaven

Marduk, the great god equated with Jupiter, tells in the Era-Epos of a flood and the heavens awry:

> When I stood up from my seat and let the flood break in,
> then the judgement of Earth and Heaven went out of joint . . .
> The gods, which trembled, the stars of heaven –
> Their position changed, and I did not bring them back.
> (Santillana and Dechend 1969 p. 325, following P.F. Gössman.)

However, Marduk is also Nangar, the Carpenter (equated in turn with Procyon), and is the measurer and builder who rebuilt the heavens and established astronomical order:

> He constructed stations for the great gods,
> Fixing their astral likenesses as constellations
> He determined the year by designating the zones:
> He set up three constellations for each of the twelve months
> After defining the days of the year (by means) of (heavenly) figures,
> He founded the station of Nebiru to determine their (heavenly) bands,
> That none might transgress or fall short.
> Alongside he set up the stations of Enlil and Ea.

If we understood all of these statements precisely, we would know substantially more about Mesopotamian astronomy. Thompson (1900, Omen #94) translated a passage on various names of Jupiter, which reads:

> Marduk is Umunpauddu at its appearance; when it has risen for two (or four?) hours it becomes Sagmigar; when it stands in the meridian it becomes Nibiru.

Santillana and Dechend (1969, pp. 430–437) deal with the meaning of *Nibiru*, and they conclude that it is semantically "ferryman," but that it had a technical astronomical meaning that is still undetermined. They have no specific discussion of how this "ferryman" is related to Urshanabi, the "boatman" at the time of the flood.

7.1.2.1. The 360-Day/Degree Year and the Months

Although a number of scholars have mentioned a calendar of 12 months of 30 days each, used in some Assyro-Babylonian astronomical texts, we have not seen an adequate discussion of this calendar. We will consider statements relative to the Venus table, the Sun, the series of heliacal risings of stars, the list of culmination stars, and lunar dates.

We begin with the omens from the movements of Venus given in tablet 63 of *Enuma Anu Enlil*. Reiner and Pingree (1975) have provided a critical edition of the text with extensive comments on textual variations, on details of translation, and on the astronomy. No less than 20 (often fragmentary) copies of the text are now known that provide a substantially more reliable version than that published by Langdon Fotheringham (1928), with the tables of Schoch (1928b), which used only 7 copies. The text is divided into four sections. The first deals with a series of observations made during the first eight years of the reign of Ammizaduqa, which will be discussed in connection with tests of Babylonian chronology. The third section is another series of observations also usually believed to belong to the reign of Ammizaduqa. We accept Pingree's judgment that this is not based on any reliable evidence. The fourth section puts the entries of sections I and III into a monthly sequence. The second section is a series of statements about the dates of first and last visibility of Venus as Morning Star and Evening Star, and the intervals between them, in a formalized table. The structure of these statements is shown in

[5] Its name means "set apart," and thus sacred, and from its base flows the Jordan (Metzger and Coogan 1993, p. 280). It was also associated with the Canaanite god, Baal (Judges 3:3, I Chronicles 5:23).

Table 7.2. Calculated intervals[a] in the Venus tablets of *Enuma Anu Enlil*.

Γ	Σ	Ξ	Ω	Γ
2 Nissanu	7 Kislimu	7 Addaru		
		3 Aiaru	8 Tebetu	15 Tebetu
4 Simanu	9 Shabbatu	9 Aiaru		
		5 Duzu	10 Addaru	17 Addaru
6 Abu	11 Nissanu	11 Duzu		
		7 Ululu	12 Aiaru	19 Aiaru
8 Tashritsu	13 Simanu	13 Ululu		
		9 Arachsamna	14 Duzu	21 Duzu
10 Kislimu	15 Abu	15 Arachsamna		
		11 Tebetu	16 Ululu	23 Ululu
12 Shabbatu	17 Tashritsu	17 Tebetu		
		13 Addaru	18 Arachsamna	25 Arachsamna
14 Nissanu	19 Shabbatu	19 Addaru		

[a] Interval between alternate row entries of Γ: 62 + ($n \times 360$).
Interval between one set of alternate rows of Ξ: 56 + ($n \times 360$).
Interval between other set of alternate rows of Ξ: 6 + ($n \times 360$).
Interval between single-row entries in columns Γ and Σ (Western Elongation): 245 days.
Interval between single-row entries in columns Σ and Ξ (near Superior Conjunction): 90 days.
Interval between single-row entries in columns Ξ and Ω (Eastern Elongation): 245 days.
Interval between single-row entries in columns Ω and Γ (near Inferior Conjunction): 7 days.

Table 7.2, which records the successive dates of the Venus configurations (in Neugebauer's 1957/1969 notation):

Γ = first appearance as a morning star
Σ = last appearance as a morning star
Ξ = first appearance as evening star
Ω = last appearance as evening star

See §2.4.3 and Figure 7.10 for the relationship between these instants and other planetary phenomena; for a full review of the Neugebauer planetary configuration notation, see §7.1.4, and for a newer interpretation of the original meanings of the table entries, see §7.1.3.2. As Pingree points out (Reiner and Pingree 1975, p. 17), all intervals are computed on the assumption that all months are 30 days long. The statements are arranged in such a way that each statement is one month and one day after the preceding statement, in an arithmetic progression. van der Waerden (1974, pp. 55–56) regards this as the first known application of an arithmetic progression to astronomy and describes it as "primitive." DHK, however, thinks that it is an interesting mnemonic tool embodying a complex and sophisticated series of statements. If one accepts that the dates are, indeed, referring to repetitive phenomena of Venus, then the interval between 2 Nissanu and 4 Simanu is not merely 62 days, but is 62 plus ($n \times 360$), in which the solar cycle is close to an even multiple of the synodic period of Venus. Indeed, this interval holds for the entire first column (Γ, which marks the first visibility as morning star). DHK has found a periodicity linking the alternate pairs of dates of first visibility, viz., 2 Nissanu, 6 Abu, 10 Kislimu, . . . in one series, and 4 Simanu, 8 Tashritu, 12 Shabbatu, . . . i nanother, but the linkage between the two series, that is, how one gets from one series to another, is not clear. The interval in each case is

$$(24 \times 360) + (2 \times 62) = 8764 \text{ days.}$$

This interval is only ~2^{d} more than 24 tropical years (each of $365^{d}.2422$ length) or sidereal years (each of length $365^{d}.2564$). The mean interval of 15 synodic periods of Venus (with P_{syn} = 583.92 MSD; see Table 2.9) is 8758.8 days. This is 5.2 days less than 8764 days. Going from 6 Abu as first appearance as Morning Star to 11 Duzu as first appearance as Evening Star, we have 335 days. However, the calculation from first appearance as Evening Star to the next first appearance as Morning Star does not start from 11 Duzu but from 5 Duzu, six days earlier. This is a good approximation to the correction demanded by the mean synodic period of Venus. It has been supposed from this table that the Babylonians calculated the mean synodic period of Venus as 587 days. Over 15 synodic periods, this would have amounted to an error of about 46 days, which surely would have been obvious to anyone doing systematic observations. We suggest that our interpretation of the table is more realistic, and that it is far from "primitive." There is still a great deal about this table that is unexplained, but we think that explanations that assume first-rate mathematical and observational skills are more likely to be correct than are those assuming incompetence. It seems to us clear from this table, and other evidence, that the Babylonians made extensive use of a 360-day calculating year with months shifting through all seasons. If the same set of month names was, indeed, being used in two chronologically different ways, interpretation of dates in particular texts may often be difficult. To maintain that there was still a third way compounds that difficulty, yet there is evidence favoring such a conclusion. van der Waerden (1974, p. 80) cites from *Mul Apin* (or ^{mul}*Apin*), tablet 2, the following statement (Roman numerals indicate months; arabic numerals indicate days):

From XII 1 to II 30 the sun is in the path of Anu: Wind and storm.
From III 1 to V 30 the sun is in the path of Enlil: Harvest and heat.
From VI 1 to VIII 30 the sun is in the path of Anu: Wind and storm.
From IX 1 to XI 30 the sun is in the path of Ea: Cold.

Mul Apin also says, repeatedly, that the spring equinox occurred on 15 Nisannu (Huber 1982, p. 9).

Furthermore, Mul Apin gives lists of heliacal risings for 36 stars or constellations and another list of intervals in days between risings of some of the most important of these stars, starting with Sirius. The statements of the two sources are in agreement if one assumes a year consisting of 12 months of 30 days each. However, it is very difficult to see how a 360-day year could have a generalized structure associating heliacal risings of stars with particular dates. Another interesting list gives the dates at which a number of stars culminated over Babylon. By making the two classes of observations together, it was possible to diminish the inaccuracies caused by missed data due to atmospheric conditions. The observer was supposed to begin observations on 20 Nisannu.

These texts on the sun and stars are consistent with each other, but are utterly unreasonable in their lack of correspondence with reality if "day" is taken in its normal meaning, or if the months are equated with lunations. Heliacal risings, whether of fixed stars or planets, would be shifting about 5 1/4 days a year. The statements about the Sun imply precise boundaries among the zones of Anu, Enlil, and Ea, but deny the inequality of the seasons, and would rapidly cease to be true with a 360-day year. However, the Sun moves slightly less than a degree a day. It would have been entirely natural to extend the meaning of "day" to mean, also, "a degree." Much technical vocabulary has arisen through defining a popular term more precisely, and somewhat differently. If "day" in the above statements is to be understood as "movement of the sun by 1 degree," the statements become astronomically reasonable.

With respect to the months, there are a number of statements that imply that months were lunations beginning with the first visibility of the moon after conjunction. There are also statements of omens that imply a different calendar structure. Thompson (1900, Omen No. 249, pp. lxxvii–lxxviii) says that the moon waned on the 27th and reappeared on the 30th. More remarkably, his numbers 119–172 deal with occasions when the Sun and Moon were seen together on the 12th, 13th, 14th, 15th, and 16th of the month. These can hardly refer to a system in which the moon was full on the 14th of each month.

7.1.2.2. Babylonian and Hebraic Calendars

The names of the 12 Babylonian months, as noted by Sachs and Hunger (1988), are listed in Table 7.3. The Babylonian calendar survives in a somewhat modified form in the Jewish Calendar, the corresponding month names of which are indicated in parentheses. The Arabic numbers preceding the Hebrew months indicate the order in the civil calendar; the sacred calendar is indicated by the Roman numerals. Because the calendar was lunar, intercalations were required to keep step with the seasons. When a 13th month was deemed necessary, it was usually added after Addaru, but occasionally, it was added after Ulūlu; these extra months were called simply "second Addaru" or "second Ulūlu." The counterpart of the former in the Hebrew calendar is *Veadar*. See van der Waerden (1974, pp. 47–48) for historical details of the Babylonan intercalation.

TABLE 7.3. Babylonian (and Hebrew) month names.

I	Nisannu	(7. Nisan)[a]	VII	Tašrītu	(1. Tishri)
II	Ajjaru	(8. Iyyar)	VIII	Arahsamnu	(2. Chesvan)
III	Simānu	(9. Sivan)	IX	Kislīmu	(3. Kislev)
IV	Dūzu	(10. Tammuz)	X	Tebētu	(4. Tebeth)
V	Ābu	(11. Ab)	XI	Šabatu	(5. Shebat)
VI	Ulūlu	(12. Elul)	XII	Addaru	(6. Adar)

[a] The Arabic numbers preceding the Hebrew months indicate the order in the civil calendar; the sacred calendar is indicated by the Roman numerals. In some years, an intercalary month was added after month VI or month XII ("second Ulūlu" or "second Addaru"); the counterpart of the latter in the Hebrew calendar was *Veadar*. See van der Waerden (1974, pp. 47–48) for historical details of the Babylonian intercalation.

According to Morgenstern (1935), the calendar was borrowed during the Babylonian exile, between about 450 and 419 B.C., and first came into regular use, in existing materials, in the writings of Nehemiah. The beginning of the Babylonian civil year occurred in the lunar month Nissanu, around the date of the March equinox. The Jewish year evolved somewhat, under the influence of Babylon, into a luni-solar calendar, using true lunations,[6] and between 400 and 250 B.C. (according to Morgenstern 1935, pp. 103–104) probably involved the Metonic cycle of intercalations. It replaced an earlier solar calendar, borrowed from the Canaanites, which began the year on the September equinox. For a time, the Jews adopted the Babylonian beginning point of the year near the March equinox with the month Nisan/Nissanu but eventually returned to a beginning point near the September equinox, which corresponds to the Babylonian month Tašrītu, hence, the Civil vs. Sacred numbering of the months in Table 7.3. Morgenstern (1935) discusses at length the impact of the various calendars on the celebration of festivals and associated religious ideas.

The temple at Jerusalem, built during the period when the Canaanite calendar was in use, was constructed so that at the equinoxes, "the first rays of the rising sun shone straight through the eastern gate of the temple at Jerusalem, opened at this specific moment, and down into the long axis of the temple into the . . . holy of holies at its western end" (Morgenstern 1935, p. 5; see also Josephus, *Antiquities*, Book VIII, Ch. III, §2). Josephus (*The Jewish War*, Williamson tr., rev. by Smallwood, 1981, pp. 305, 449) refers to the elaborate vestments worn by the high priest when he entered the innermost shrine, once a year—alone—on the Day of Atonement. The high priest's ephod, a breastplate-like garment, was secured by golden brooches in which were set large sardonyxes (engraved with the names of the 12 tribes of Israel) on one side and on the other, 12 additional, named

[6] Psalm 104:19: "Thou hast made the moon to mark the seasons; the sun knows its time for setting." This psalm has affinities with Ikhnaton's hymn to the sun (Chase 1962; and §8), but its date of composition is unknown because not all the Psalms were composed by David, and their origins may extend over 800 years to the post-exilic period (Schonfield 1962, pp. 125–126).

precious stones, each of which refers to a tribe of Israel.[7] Josephus (*Antiquities*, Book III, Ch. VIII, §9) asserts that

> the one of [the sardonyxes] shined out when God was present at their sacrifices, I mean that which was in the nature of a button on the right shoulder, bright rays darting out thence and being seen even by those that were most remote; which splendour yet was not before natural to the stone.

Lockyer (1894/1964, pp. 92–93) seems to suppose that this statement refers to Solomon's temple, but in fact, Josephus is writing about the priesthood and the tabernacle instituted by Moses. Josephus (*Antiquities*, Book III, Ch. VI, §3) asserts that Moses set the front of the tabernacle to the east so that "when the sun arose, it might send its first rays upon it."

Many Hellenized Jews apparently identified Jehovah with the Sun (Campbell 1964/1970, pp. 274–275), but the drama and imagery of dawn sunlight may well have had more ancient roots. Of further interest are Josephus's (*Antiquities*, Book III, p. 304) statements about the temple: that the "seven lamps branching off from the lampstand symbolized the planets," "the twelve loaves on the table the Zodiac circle and the year," and that "worked into the [two-story embroidered Babylonian] tapestry was the whole vista of the heavens except for the signs of the Zodiac." In the *Antiquities* (Book III, Ch. VII, §7), Josephus asserts that

> when Moses ordered twelve loaves to be set on the table, he denoted the year, as distinguished into so many months. By branching out the candlestick into seventy parts, he secretly intimated the *Decani*, or seventy divisions of the planets, of which that is the number.

Clearly, Josephus is attempting to provide a Hellenized, if somewhat confused, rationale for the sacred numbers.[8] Such Hellenistic, syncretic thinking is reflected in the symbology of amulets and charms in the Greco-Roman period (Goodenough 1953–1968) and appears clearly on a mosaic floor of the synagogue of Beth Alpha. Here, we see the chariot of the Sun, the 12 zodiacal figures, the four winds, a series of nine figures, mostly animals, a second series of 12, mostly geometric, figures (for the 12 tribes?), and, at the top, a representation of the high altar, with two seven-branched candelabras.

7.1.2.3. *Origin of the Constellations*

It is no surprise that most of the depictions of the familiar northern sky constellations come to us from Southern Eurasia. The astronomer M.W. Ovenden (1966) argued that the constellations as we have inherited them originated in the Mediterranean region ca. 2800 ± 400 B.C. Corresponding zodiacal constellations between Mesopotamians and Greeks (van der Waerden 1974, pp. 287–288) are Taurus, the "Bull of Heaven"; the Twins; the Lion (or Lioness); Spica, the ear of corn held by the grain goddess (corresponding to Virgo); the Scorpion; the centaur as Bowman (Sagittarius); the Goatfish (Capricorn); the Fishes (Pisces). This view and similar ideas by R.H. Allen (1899/1963, pp. 14–15) and E.W. Maunder (1908/1909, 157–159) have been sternly criticized by Dicks (1970, pp. 160–161), who considers the arguments that constellations were designed at some particular time and place as a system of coordinates are illusory, and the arguments circular. Ovenden's argument, however, was based on the assumption that the constellations were symmetric about the north celestial pole of that epoch. Dicks criticized the hypothesis as an example of anachronism—of attributing theories about constructs of the celestial sphere to people of an earlier time. Although it may well be true that there is no written evidence for notions of great circles and poles at very early epochs, it is also true, on a much more basic level, that the actual disposition of the constellations in the sky requires no formal theory to be discerned and that they can, therefore, be used as position markers for the moving heavenly bodies.

As many examples from the Megalithic (§6) onward illustrate, intelligent perception is found not only in modern times and in classical Greece. Dicks's scathing criticism of Ovenden appears to be, therefore, both unjust and fallacious.

Babylonian constellations included such familiar representations as a lion, raven, eagle, fish, scorpion, and bull, some of which we noted above. van der Waerden (1974) has a good summary of several Assyrian-period (within the range 1356 B.C. to 626 B.C.) asterisms and constellations; a more comprehensive list by P. Huber may be found in van der Waerden (1965/1968, pp. 294–297); a still fuller series of names and identifications appears in Reiner and Pingree (1975). Table 7.4 is excerpted from this list (see also Figure 7.1).

Many of these are from a star catalogue called ^{mul}APIN dated prior to 687 B.C. The oldest rendition bears the label "Copy from Babylon." The superscripted *mushen* means bird and *mul* means star. Capital letters indicate Sumerian word-signs, and lowercase words indicate later Babylonian words; these conventions and the simplification of some of the names, such as the omission of the word "star" preceding each name, follow normal usage among Assyriologists. The ancient Sumerians used cuneiform, but the later, Babylonian, civilization used the older word-signs as well as adaptations of them to their own language (Assyro-Babylonian).

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[7] In the *Antiquities* (Whiston tr., Book III, Ch. VII, §5), Josephus describes the priest's vestments in the time of Moses as being somewhat different. The sardonyxes were on each shoulder, and the other stones were inserted in the breastplate proper, in four rows of three stones each, according to the description. Josephus's statement is that the stones "stood in three rows, by four in a row"; compare to Exodus 28:17–21 and 39:10–14: *And they set it in four rows of stones: the first row was a sardius, a topaz, and a carbuncle: this was the first row*. (*Ex* 39:10). The Exodus accounts also say that each of the 12 stones was inscribed with the name of a tribe of Israel, but identifications are not made, and, indeed, the identifications of the Hebrew names for the precious stones are far from certain in many cases.

[8] The more complete statement of the divisions of the "candlestick" is given in Josephus, Ch. VI, §7: "It was made with its knops, and lilies, and pomegranates, and bowls (which ornaments amounted to seventy in all;) by which the shaft elevated itself on high from a single base, and spread itself into as many branches as there are planets, including the sun among them. It terminated in seven heads, in one row, all standing parallel to one another; and these branches carried seven lamps, one by one, in imitation of the number of the planets."

Table 7.4. Assyrian constellations.[a]

Name	Meaning	Modern equivalent
A[mushen]	Eagle	Aquila
APIN	Plough	Triangulum + γAndromedae
BAN	Bow	Canis Major + Puppis
GAG.SI.SA	Arrow	Sirius
GIR.TAB	Scorpion	Scorpius
GUD.AN.NA	Bull	Taurus
IKU	Field	Great Square in Pegasus
EN.TE.NA.MASH.LUM	Centaur	Centaurus
KUA	Fish	Piscis Austrinus/Fomalhaut
LU.HUN.GA	The farmer/the god Dumuzi (Tammuz)	Aries
MAR.GID.DA	Wagon	Ursa Major
MASH.TAB.BAGAL.GAL	The great twins	Gemini
MUL.MUL	The seven-fold divinity	the Pleiades
SHU.GI	Old manor/charioteer	Perseus
SIBA.ZI.AN.NA	True shepherd of the sky	Orion
UGA[mushen]	Raven	Corvus
UR.GU.LA	Great dog/lion	Leo
UZA	Goat	Lyra

[a] See Reiner and Pingree (1981) for a more complete list.

Table 7.5. Babylonian "normal stars."

Number	Star	λ	β	Number	Star	λ	β
1	η Psc	350.73°	+5.23°	17	ε Leo	104.59°	+9.51°
2	β Ari	357.88	+8.39	18	α Leo	113.90	+0.35
3	α Ari	1.52	+9.90	19	ρ Leo	120.29	+0.02
4	η Tau	23.90	+3.78	20	Θ Leo	127.28	+9.65
5	α Tau	33.65	–5.65	21	β Vir	140.49	+0.64
6	β Tau	46.47	+5.17	22	γ Vir	154.40	+3.01
7	ζ Tau	48.68	–2.53	23	α Vir	167.77	–1.88
8	η Gem	57.38	–1.23	24	α Lib	189.04	+0.65
9	μ Gem	59.16	–1.09	25	β Lib	193.30	+8.80
10	γ Gem	62.98	–7.06	26	δ Sco	206.48	–1.66
11	α Gem	74.23	+9.86	27	β Sco	207.09	+1.34
12	β Gem	77.54	+6.48	28	α Sco	213.68	–4.23
13	η Cnc	89.23	+1.33	29	θ Oph	225.30	–1.48
14	Θ Cnc	89.66	–1.00	30	β Cap	267.94	+4.88
15	γ Cnc	91.49	+2.96	31	γ Cap	285.56	–2.28
16	δ Cnc	92.59	–0.03	32	δ Cap	287.33	–2.13

The ideograms were succinct, and most could be represented with a single symbol. The Babylonians also used combinations of cuneiform symbols pronounced phonetically to create written words that sound like the Akkadian spoken word. van der Waerden's example is that of the constellation Libra, which in Sumerian is *RIN*, and the symbol combinations *zi-ba-ni-tum* for *zibanitum* in Babylonian.

Several of the Babylonian constellations were adoped by the Greeks, especially the zodiacal constellations. There are also many important differences, as Table 7.4 indicates, but the probability of getting this degree of similarity between two independent lists is so low that it may be dismissed as a reasonable possibility. See §15 for a discussion of what constitutes adequate evidence of cultural contacts.

The Mesopotamians had a list of stars, called "normal stars" after Epping's (1889) "Normalsterne," that is, stars used as positional standards in measuring planetary locations. The Akkadian term for these stars, *MUL SID[mes]*, was most likely read kakkabu-minâti (Sachs and Hunger 1988, p. 17). These may have come into general use in the 4th century B.C. or slightly earlier (Lindsay 1971, pp. 38–39). The list of these stars appears in Table 7.5. They have been numbered for convenience and appear in the order and with the ecliptic positions for the year 601 B.C., as given in Sachs and Hunger.

As with the Indian and Chinese lunar mansions, these stars are not uniformly placed around the ecliptic. Note the very large gap between the end of the table and its beginning, and between stars 29 and 30. In the gaps, there are stars that are as bright as the normal stars. No satisfactory explanation for these gaps has yet been found. The list overlaps those of Tables 15.3 and 15.4, but is not identical to either.

7.1.3. Chronology

A combination of historical, archeological, and astronomical data is crucial to developing the chronology. Because of its continuity, the most important single source at this time is the Assyrian king list, known in several badly damaged copies and in a much better preserved list from Khorsabad, listing 107 kings, which was found in excavations in 1932–1933 and published by Poebel in 1952–1953. The text is clearly based on a number of different sources of different kinds, and the compiler may sometimes have erred in putting them together. The first section is a list of 17 kings said to have lived in tents; the second section gives the pedigree of the 26th king back to the last two kings of the first section; and the third section lists six kings mentioned on brick inscriptions. Starting with the 33rd king, the text gives the name of the ruler, the length of his reign, and (usually) his relationship to earlier kings. There are sometimes scribal errors and damage to the text; so the king-list does not give a completely full and accurate chronology, but its general accuracy is vouched for by its agreement with other sources. Many of the kings are known from their own inscriptions and from inscriptions of neighboring rulers, as well as from many kinds of private documents. It is known from later sources that there were an additional 10 (or possibly 11) kings to the final conquest of Assyria by the Babylonians in 608 B.C. There are cross-ties with Egypt, Israel, the Phoenician states, the Hittites, Elam, and, above all, with the Babylonians and Sumerians, which provide checks on the chronology. The earliest king of the list, *Tudiya*, usually regarded as a legendary figure when the list was first published, is now attested by contemporary records of *Ebrum*, king of Ebla. Tudiya and Ebrum were also contemporary with *Sharrukin* (Sargon), king of Akkad. In the early part of the list, the 30th to 35th kings of Assyria are now all attested by contemporary records that verify both their sequence and their genealogical relationships as given in the king list. A genealogy of the ancestors of the First Dynasty of Babylon claimed 11 of the first 12 kings of the Assyrian list as Babylonian ancestors, although not in the same order (Wilson 1977, pp. 106–113).

The latter part of the Assyrian list was tied down also by many copies of a list of high Assyrian officials, who gave their names to years. These are called *limmu* in Assyrian, usually translated "eponym," and the privilege of giving one's name to the year was determined by casting lots among the high officials. One entry reads (ff. Luckenbill 1929, p. 2, 435) "Bur (Ishdi)-Sagale (governor) of Guzana, revolt in city of Assur. In the month of *Simanu* an eclipse of the sun took place." Claudius Ptolemy gave a chronological list of Near Eastern rulers and associated astronomical events. His chronology of late Assyrian and Babylonian kings overlapped the *limmu* list and made it clear that this date should refer to 763 B.C. There was, in fact, an eclipse in the year 763 B.C.,[9] and it occurred in the month *Simanu*, thus, verifying the chronological sequence of the list as then known from 1103 B.C. to 648 B.C.

The prophet Amos, who was active during the first 14 years of king Azariah (or Uzziah) of Judah, relates the impending disasters that were to overtake Israel, and its king, Jeroboam; he includes among them an eclipse[10] that many think is this one. Azariah is referred to as Azriyau of Judah by the Assyrian king, Tiglath-Pileser (Tukulti-apil-ešarra), in whose reign the Assyrian king list of Khorsabad was compiled. His brother had been ruling in 763 B.C. At the time that the Assyrian king list from Khorsabad was prepared, the Assyrian scribes apparently had access to *limmu* lists extending before 1800 B.C., but only fragments of the earlier sections are known to us. An interlocking mass of Assyro-Babylonian planetary data, historical references, and eclipses now verifies the chronology from the 8th to the 1st century B.C.

There was once a Babylonian king list as extensive as the Assyrian one, but only very incomplete versions survive. Early Sumerian king lists are also preserved, along with various synchronistic chronicles. Several archives and libraries are known that bear upon Mesopotamian chronology. The collection of letters from Mari was of particular importance, because it demonstrated that the Assyrian king Shamshi Adad (the 39th of the official list) was briefly an older contemporary of Hammurabi, of Babylon, and that Zimri Lim's reign fell entirely during the time span of Hammurabi. Unfortunately, the Assyrian king list was damaged so that the record of the lengths of the reigns of the 65th and 66th kings is unknown. Ashur-uballit of Assyria lived at the time of the Pharaoh Ikhnaten, a fact known from contemporary letters in the archives at El Amarna in Egypt. On Egyptian evidence, Hall (1913a, p. 262) dated Ikhnaten from 1380 to 1365 B.C. Poebel' s date for 73 Ashur-uballit (the only king of this name in the list), which can be modified only by choosing different variants of the copying errors, or rejecting the authority of the king list, was 1362 to 1327 B.C. The other possibilities are 1363–1328, 1353–1318, and 1352–1317 B.C. Later Egyptian evidence has suggested that Ikhnaten should be placed about 15 to 30 years later (Gardiner 1966 gives 1367–1350 B.C.; Aldred 1988 gives ~1352–1335 B.C.). See Bierbrier (1975/1993) for a fuller chronological discussion. Given the various uncertainties involved, this is very good mutual support (we argue in §8.1.5 that the reign of Ramses II began in 1290 B.C., which would certainly make Ikhnaten a contemporary of Ashur-uballit).

The Assyrian king list shows 296 years from the beginning of the reign of 39, Shamshi-Adad, to the end of the reign of 64, Ashur-Shaduni, who was succeeded by his uncle, Ashur-Rabi followed by his son, 66, Ashur-nadin-akhe II, the two kings whose reigns are missing because of damage in the existing king list. Venus observations, combined with lunar

[9] Although the 763 B.C. date was challenged by R.R. Newton as representing an "identification game," Ptolemy's *Canon* has been widely supported by detailed contemporary records, from late Assyrian times forward. Mitchell (1990, p. 23) shows that the magnitude of the 763 B.C. eclipse was greater than that of any suggested alternative eclipse and that it fits better with other calculations of clock time error than do any of the other proposals. See also Stephenson (1997, pp. 125–127).

[10] "And it shall come to pass in that day, saith the Lord God, that I will cause the sun to go down at noon, and I will darken the earth in the clear day" (King James Version, Amos 8:9).

data and presumed historical limitations, have suggested four possible chronologies that will be considered in more detail later. With the Short Chronology, these two reigns would cover 20–30 years, which is very reasonable. With the later of the two Middle chronologies, this would be increased to about 75–85 years, with the earlier chronology to ~85–95 years. For the Long Chronology, the two would reign about 140–150 years and Ashur-nadin-akhe was followed by his two brothers for 13 years so that two generations would span a total of 150 years of reign. Biologically, this span is not impossible, but is not seen anywhere else in the king list and is inherently unlikely. Defenders of the Middle and Long Chronologies have tended to attack the validity of the Assyrian King List, particularly because the official list does not include all known claimants to rule. However, this is true of most king lists. It seems unwarranted to postulate the Long Chronology unless other evidence is compelling.

In Anatolia, a great deal of work has been done on tree ring dating (c.f. §4.3). A 1503-year "floating" sequence of tree rings has been placed in real time by Kuniholm et al. (1996). The sequence starts with tree ring year no. 262 and continues to tree ring year no. 1764. The latter marks the outside ring of logs cut for the building of a massive Phrygian tomb at Gordion. An extended series of 18 sequential ^{14}C dates on a single log that covered 350 years suggested a range of about 1170 B.C. to 820 B.C. for that segment of the sequence, rings 1325–1675, respectively. The tie-down to specific years is provided by the calibration of the Anatolian to western European tree ring sequences. There are two major times of abnormal growth, one at ring 854 and one at ring 1324, separated by 470 years. In the tree ring sequence of western Europe, there are major anomalies at 1628 B.C., and at 1159 B.C., separated by 469 years. There are several possible explanations of the one-year time difference, either through local variation in determining the tree rings or in delays in the solar screening effects of particles in the upper atmosphere. The anomaly of 1159 B.C. coincides with the eruption of Hekla III in Iceland, and it has been widely accepted that the origin of the growth anomaly of 1628 was due to the eruption of Thera (Santorini in the Aegean).[11] Therefore, the hypothesis that ring 854 of the Anatolian sequence corresponds to 1628 B.C. seems highly likely.

The tree ring sequences also provide precise connections with other chronological evidence. Among them are the dating of the Amarna period and the kingdom of Phrygia and a tie-in for the Babylonian chronology.

Of great interest is the date 1316 B.C., of the outermost preserved ring of wood being carried as cargo in a ship wrecked off the Anatolian coast. The ship was carrying a gold ring bearing the name of Nefertiti, wife of Ikhnaton. The ship's cargo also included Helladic IIIB pottery, typical of the time just after the intense international contacts of the Amarna period of Egypt. Hence, the tree ring dates, like the Assyrian king list and the usual interpretation of the Egyptian evidence, put the Amarna period somewhat before 1300 B.C. Regardless of the precise placement of the tree ring dates, they indicate a difference of ~600 years between the Amarna period dates and the Phrygian kingdom. This difference is in agreement with accepted chronologies. The tree ring chronology puts the building of the Phrygian mound in 718 B.C. during the rule of King Midas (Mita). The tree ring date of 1810 B.C. for the building of the Warśama palace at Kultepe makes the Babylonian Short Chronology far more likely than the Long Chronology.

Rohl (1996) has emphasized the importance of a possible synchronism between Neferhotep I of the 13th Dynasty and Hammurabi of Babylon. Hayes (1971) had pointed out that Neferhotep I, whose reign he places at about 1740–1730 B.C., seemed to be recognized as overlord by Yantin, the ruler of Byblos. Rohl points out that Albright had suggested that this Yantin of Byblos is identical with Yantin-Ammu, ruler of Byblos, who gave a gold cup to Zimri-Lin of Mari, whose reign fell within that of Hammurabi of Babylon. In the Short Chronology, the reign of Hammurabi began in 1728 B.C. Although the identity of the pharaoh Neferhotep of the Byblos monument is not absolutely certain, and it is not impossible that there were two rulers named Yantin, the identification does offer historical support for the Short Chronology. Next, we discuss the astronomical evidence.

7.1.3.1. Records of Lunar Eclipses

Our recorded knowledge of astronomical events in Mesopotamia begins with records of lunar eclipses. These eclipses are known mostly from their use (as models for predicting disasters) in the collection called *Enuma Anu Enlil* from the 7th century B.C. We know of seven references to lunar eclipses and two to solar eclipses prior to the 8th century B.C. These eclipses are important both to our understanding of Mesopotamian astrology and for determining the chronology of the area. They need to be considered together and to be integrated both with the evidence from chronicles and from Venus observations. In some cases, the available information contains a month date or a statement about the time of occurrence of the eclipse that aids greatly in reducing possibilities. Most of these eclipses are considered extensively by Huber (1982), by Mitchell (1990), and by Stephenson and Clark (1978). The earliest omen refers to the death of an unidentified ruler of the dynasty of Agade, and Mitchell (1990, p. 14) found 16 possibilities between 2400 and 1800 B.C. The next eclipse omen referred to the time that *Utu-hegal*, king of Uruk, conquered the Gutian people. According to Jacobsen (1939, p. 203), the special gods of the Gutians were *Inanna* and *Sin*. *Inanna* is the Sumerian prototype of *Ishtar*, who was (at least in the late period) identified with the planet Venus. *Sin* (now more commonly transcribed *Suen*) is the Sumerian name of the Moon god. Today, we realize that there had been many Gutian battles, including defeats, and many previous lunar eclipses which were not associated, but the decisive defeat of the people of the Moon God at the time of a lunar eclipse made an indelible impression on the Mesopotamians. This event may even have been an important factor in the development of beliefs about the relationship of celestial and terrestrial events that ultimately crystallized as astrology.

[11] The eruption of Thera marked the end of the Late Minoan IA period. Pottery above the eruption layer is consistently of Late Minoan IB style.

Details come from *Enuma Anu Enlil*, but Jacobsen (1939, p. 203) points out that an inscription of *Utu-hegal*, unfortunately destroyed in crucial places, mentions that *something* happened "in the midst of the night." Schoch (1927) calculated the date of this lunar eclipse as 20 July 2403 B.C. (a backcalculated Gregorian calendar dating). In the backcalculated Julian calendar usually used by historians, it would have been 9 August 2403 B.C.

Shortly afterward, *Ur-Nammu*, the governor of Ur under Utu-hegal, wrested domination from him and became king, establishing the Third Dynasty of Ur. This dynasty ruled for 109 years and the last king, *Ibbi-Sin* (whose name incorporates that of the Moon God), was conquered by the Elamites. He and his "gods" were carried off to Elam (in modern Iran). This conquest reenforced the impression created by the Gutian conquest that lunar eclipses were associated with disaster. The conquest was associated with a lunar eclipse calculated by Schoch as occurring on the night of the 17th–l8th February, 2283 B.C. These "gods" were finally recovered by Ashur-banipal, King of Assyria, who conquered Elam in 605 B.C. According to his inscriptions, the gods had been in Elam for 1635 years, which would have placed the Elamite conquest in 2285 B.C. (Luckenbill 1924–1927, vol. 2, pp. 311, 357). Despite this virtual agreement, there are major problems with this chronology, as will be seen.

There is also an account of the murder (by his son) of an unidentified king of Ur of this dynasty, apparently one of the three kings: Ur-Nammu, Shulgi, or Shu-Sin. The murderer, who expected to become king, picked the time of a lunar eclipse for the killing, but it was the parricide's brother who succeeded to the throne. Parrot (1953, vol. 2, pp. 427–428) discusses various eclipses proposed as possibilities for this eclipse by Schaumberger, and decided that the one that fitted best was the eclipse of 16 May 1999 B.C., if associated with the death of Shulgi. This chronology is very different from that of Jacobsen, who does not consider this eclipse, but, accepting Schoch's dates for the two previous eclipses, would put the death of Ur-Nammu in 2374 B.C., of Shulgi in 2326 B.C., and of Shu-Sin in 2308 B.C. In terms of the attitudes of the period, there would be a particular reason for picking a lunar eclipse date for the murder, if the intended victim was Shu-Sin, whose name incorporates that of the Moon God.

In the dynasty that followed Ibbi-Sin, extraordinary steps were taken to evade the predicted malevolent effects indicated by omens. Of one of these kings of Isin, we are told, in a historical chronicle rather than an omen:

> Irra-imitti, the king, installed Bel-ibni, the gardener, on his throne as a "substitute king" and he (Irra-imitti) (even) placed his own royal crown on his (i.e. Bel-ibni's) head. (During the ceremonial rule of Bel-ibni) Irra-imitti died in his palace while sip[ping] hot porridge, and Bel-ibni who was (still) sitting on the throne did not rise (any more), he (thus) was elevated to (real) kingship. (Pritchard 1955, p. 267)

Bel-ibni assumed the name Enlil-bani and ruled for 24 years as King of Isin. Ungnad (1943) suggested that King Irra-imitti was threatened by a lunar eclipse. Jacobsen (1939, Table II, ff. 208) puts the death of Irra-imitti 75 years before the accession of Hammurabi, whereas Brinkman (1977) separates these events by 69 years.

There was also a lunar eclipse during the reign of Zimri-Lim, king of Mari, which is attested in a contemporary record: "The taking place of this eclipse was evil." Unfortunately, students of this period have not yet determined the year of Zimri-Lim's long reign during which the eclipse occurred, nor does the account specify any details of the eclipse. The primary value of this record is that it demonstrates that the attitudes attested in the later records were already present.

Much later, in the time of Esarhaddon, king of Assyria, we have two contemporary accounts that provide a close parallel to the story told of Irra-imitti. According to the first account,

> during the *eternity* of the eclipse and the conjunction of the gods he (the king) must not in fact go to the (palace?) *limits*.
>
> If it is acceptable to the king my lord, (15) a commoner should be appointed to the bishopric[12] as previously. He should offer the daily sacrifices before the high-altar; on the days of the monthly-feasts and (the feast) of the "Greeting of the temple" he should pour out the incense on the censor-stands [before] the Lady of Akkad, (and then) should (the moon) bring about an eclipse (and with it) affe[ct] Akkad, (20) [. . .] he should serve as the king's substitute (21–25 fragmentary). (Pritchard 1975, p. 179)

This was done, and a later letter reports (with original line numbers)

> (5) the [substitute] king, who on the evening of the fourteenth took his se[at] (upon the throne), then spent the night of the fifteenth in the palace [of *Ashur*], (and) whom (the moon) affected with the eclipse, entered (10) Akkad safe and sound on the evening of the twentieth, (and) took his seat (on the throne). In the light of day I had (him) recite the traditional formulae of the scribal guild; he took upon himself all the signs of heaven and earth, (and) assumed the hegemony over all the universe. For the informa[tion] of the king my lord.
>
> (15) This eclipse, which (the moon) brought about in (the month of) Tebet, concerned the land of Amurru. The king of the land of Amurru will die, his land will diminish, (or) in another interpretation, will disappear. Surely the scholars can tell the king my lord (20) something about the land of Amurru: the land of Amurru means the land of the Hittites and the land of the Sutaeans, (or) in another interpretation, the land of Chaldaea. Someone or other of the kings of the land of the Hittites, or of the land of Chaldaea, (reverse) or of the land of the Arabs, must bear (the consequences of) this sign. For the king my lord (there is to be) contentment: the king my lord will achieve his desire. The rites and prayers (5) of the king my lord are acceptable to the gods. Either the king of Cush, or the king of [Tyre], or Mugallu must meet the appointed death; (10) or, the king my lord will cap[ture him], the king my lord will diminish his land, the women of his harem will enter the service of the king [my lor]d. The king my lord should be gratified.
>
> However, the king my lord should be careful, and (his) vigilance great. The apotropaic rituals, the lamentations for the pacification (of the gods), the spell against malaria (and other forms of) (15) pestilence should be carried out for the k[ing my lor]d and the sons of the king, my lords. (Pritchard 1975, pp. 186–187)

12 We regard "bishopric" as an inappropriate translation, however, analogically apt.

Table 7.6. Mesopotamian eclipse and Venus data.

	Early interpretations	Long chronology	Middle chronologies	Short chronology	Ultrashort chronology
Solar eclipse under Sargon					
Lunar eclipse (historical and astronomical details insufficient—Naram Sin ??)					2035 B.C.
Lunar eclipse—end of Gutian rule	2403 B.C. (Schoch)	2163 B.C.		2049 B.C. or 2041 B.C.	1908 B.C.
Lunar eclipse—death of King of Ur				No possible matches	1835 B.C.
Lunar eclipse—end of Ur III	2283 B.C. (Schoch)	2053 B.C.	No eclipse matches	1932 B.C.	1793 B.C.
Lunar eclipse (no astronomical details—end of rule of Irra-imitti—beginning date of Isin)				1801 B.C.	
(First year of Hammurabi)	(1904 B.C.)	(1848 B.C.)		(1728 B.C.)	(1565 B.C.)
Lunar eclipse predicted—no astronomical details—during long reign of Zimri-Lim of Mari					
Venus observations years 1–8 of	1702 B.C.	1646 B.C.	1638 B.C.	1582 B.C.	1419 B.C.
Ammizaduqa—21 years } Samsuditana—31 years }	{ About 52 years	Interval: 43 years		50 years	57 years
Lunar eclipse followed by solar eclipse	(1713 B.C.)	1659 B.C.	No eclipse pairs	1532 B.C.	1362 B.C.
End of reign of Samsuditana and of dynasty of Hammurabi					

A major problem that is raised by these letters is how the diviners anticipated the eclipse and how closely they could determine its conditions. Time, expense, and inconvenience to many people were involved. Although the possibility that the eclipse might not occur was left open, a commoner was placed on the throne, however briefly, and the eclipse did occur. It seems unlikely that substitute kings were put in every time that the diviners thought that there might possibly be an eclipse somewhere. From what we know both of attitudes toward the Moon and of Mesopotamian mathematical capabilities, it seems unlikely that geometric techniques were used. Some sort of cycle of local repetition seems the only likely solution. The account of Irra-imitti implies that such prediction was already occurring prior to the First Dynasty of Babylon.

Bottero (1992, pp. 138–155) has an extended discussion of the substitute king with much additional detail, well worth reading. He emphasizes the fact that the substitute had to be killed in order to be a satisfactory scapegoat.

The last king of the Hammurabi dynasty was Samsuditana, the successor of Ammisaduqa. The end of this dynasty was marked by a lunar eclipse on the 14th of Šabatu, followed by a solar eclipse on the 28th Šabatu. A pair of eclipses matching the descriptions given in the omen texts is extremely rare. Only five pairs have been discovered by Huber (1982), who found three such pairs between 1950 and 1350 B.C., and by Mitchell (1990), who found two others over a wider range of dates and using different eclipse parameters.

These eclipse records are important for Mesopotamian chronology. The most desirable way of examining the chronology is to look at the various eclipses as a group and to examine how this group can be equated with the Venus observations, in the light of the historical information. Table 7.6 shows various possibilities.

7.1.3.2. Venus and Eclipse Observations and Chronology

The earliest surviving Babylonian observational records that refer to appearances and disappearances of Venus are from the reign of the king Ammisaduqa (or Ammizaduga), king of Babylon 146 years after the accession of his ancestor, Hammurabi. Alternative possible dates for Ammizaduqa's reign have been determined from the Venus data[13] in combination with historical records, in particular the contemporaneity of Hammurabi and Shamshi-Adad, 39th King of Assyria. It has been generally accepted that these data permit only four alternative interpretations for the beginning date of the reign of Ammizaduqa: B.C. 1702 (the "Long Chronology" favored by Huber and Weir), 1646 (favored by Rowton in the *Cambridge Ancient History*, the most influential source in English), 1638, and 1582 (the "Short Chronology," vigorously defended by van der Waerden 1974).[14] Rowton argued that the average length of reign of

[13] The text referring to these observations, which are tied into the lunar months, is known in a large number of fairly late copies and has been published by Langdon and Fotheringham with Schoch (1928) and more recently by Weir (1972). The text has been further updated by Reiner and Pingree (1975), who emphasize that the first of the two sets of apparent observations seems much more reliable, whereas the second set might have been completed from some other set of observations entirely. A discussion by Weir (1983) has much new data and interpretation. Weir (1995) is probably the most understandable account of the nature of the data and the problems of interpretation.

[14] Mitchell (1990) has recently proposed an "Ultra-Short Chronology" that meets the astronomical criteria very well but requires massive rejection of the information in the Assyrian king list and reinterpretation of much else.

contemporary Hittite kings was too high under the Long Chronology and too low under the Short Chronology. This does not seem to us a strong historical argument. Average reign lengths vary greatly depending on many different cultural and biological factors, particularly mechanisms of inheritance. van der Waerden's astronomical arguments seem to us considerably stronger. He demonstrated clearly that the rising dates of Venus were consistently too early with the 1646 solution and consistently too late with the 1638 solution. Neither the 1702 solution nor the 1582 solution showed much consistency but rather varied in both directions from the norm, as would be expected with real phenomena. Therefore, the two middle chronologies were the least likely, astronomically. In 1974, Huber discovered that the *arcus visionis* (see §3.1.5) values determined from late Babylonian sources clearly indicated that the position in the text that had been uniformly identified as the "last visibility" of Venus, was instead the "first invisibility." This discovery improved the correspondence between the tablet and astronomical backcalculations for all solutions. Unfortunately, all solutions still contained some apparent impossibilities. Weir's analysis for the first time differentiated between western observations, uninterupted across the desert to the horizon, and eastern observations looking toward the mountains.

The chronicles assign 21 years to Ammizaduqa and 31 to his successor, Samsuditana. Of the five solar-lunar eclipse pairs that have been suggested as possibly relevant to the end of the reign of Samsuditana in their relationship to postulated Venus dates of Ammizaduqa, the pair of 1713 B.C. would fall 45 years after 1758 B.C. (when the appropriate Venus phenomena are found), 56 years still earlier than the "Long Chronology." The pair of 1659 B.C. are 43 years after the 1702 B.C. date of the "Long Chronology." There is no eclipse pair to match either of the two middle chronologies. The eclipse pair of 1532 B.C. matches the Venus data of 1582 B.C., 50 years earlier. Huber (1982, pp. 40–41) argues that the physical conditions of the eclipse pair of 1713 B.C. match the description better than do either of the other two. Mitchell found an eclipse pair in 1362 B.C., some 57 years after Venus phenomena that fit 1419 B.C. These dates constitute his preferred solution, which we think is incompatible with the Assyrian king list, with the Anatolian tree-ring data, with the Egyptian historical data, and with our astronomical date for Ramesses II.

Mitchell found another eclipse pair in 1178 B.C., some 30 years after appropriate Venus phenomena of 1208 B.C. The discrepancy between the 30-year interval and the 52-year interval of the chronicles would be enough to eliminate the last possibility. Clearly, the 50 years between 1532 B.C. and 1582 B.C. come closer to matching the 52 years of the chronicles than do any of the others. Both Huber and Mitchell have emphasized the bad fit of the lunar data of Ammizaduqa's reign with an accession in 1582 B.C.; in particular, known inscriptions have an excessive number of 30-day lunations when contrasted with backcalculations for that period. In light of what we wrote earlier about the 30-day months of the 360-day year, we ask whether it is possible that some of these 30-day months were not lunations. Only a careful study of the originals by a competent scholar of Assyro-Babylonian can answer this question. On nearly all other grounds known to us, the Short Chronology seems to be the most acceptable.

Some problems remain with respect to the appropriate dating of the earlier lunar eclipses. The death of Irra-imitti of Isin is not included in Mitchell's account because we have no astronomical details. If we accept the Short Chronology, with the accession of Hammurabi in 1728 B.C., the death of Irra-imitti should fall on historical grounds between 1803 B.C. and 1797 B.C. The total lunar eclipse of 1801 B.C. seems a probable candidate, but this selection is based on the historical evidence rather than on astronomy. This would put the accession of Ishbi-erra of Isin at about 1964 B.C. He was a contemporary of Ibbi-Sin, the last king of the Third Dynasty of Ur. According to Huber, the only probable lunar eclipse fitting the conditions in this time period is the partial eclipse of 26 April 1932 B.C., with the next earlier eclipse at 2004 B.C. Although Mitchell substantially increased the number of possibilities for this eclipse, he added no others for the relevant time period. Because the Ur III Dynasty lasted 109 years and began shortly after the defeat of the Gutians, the latter eclipse should date within a few years before 2040 B.C. There was, in fact, an eclipse matching the specifiable conditions on 26 August 2041 B.C., but the total eclipse of 26 July 2049 B.C. is probably more likely, assuming that Utu-hegal's defeat of the Gutians was near the beginning of his short reign (less than eight years).

Surprisingly, there are apparently no lunar eclipses at Ur between 2056 B.C. and 1946 B.C. that agree with the descriptive data and, hence, no possible matches for a king of Ur murdered by his son during the entire III Dynasty in the Short Chronology.

There seem to be four possible explanations for this discrepancy:

(1) The Short Chronology is wrong.
(2) There are errors in the description of the eclipse.
(3) The astronomical calculations somehow missed an appropriate eclipse.
(4) The King of Ur (who is not named) was not one of the Kings of Dynasty III, but one of the Kings of Dynasty II.

The data on the eclipse during the Dynasty of Agade seem to us insufficient to identify a lunar eclipse that may be associated with any of seven rulers in a realistic range of about 200 years for any of the proposed chronological schemes. The solar eclipse during the reign of Sargon may ultimately be more promising.

Mitchell (1990, p. 24) maintains that the only solution that fits all of the eclipse data and the Venus data is the Ultrashort Chronology, which also provides a very good fit for the lunar data. We agree with him that solutions should be made with respect to sets. If it is true that the best solution astronomically is contrary to the best nonastronomical evidence, we think that this presents an important methodological problem. We are also bothered by the evidence, particularly on lunations (assembled by Huber) and on Venus (assembled by Weir), which supports the Long Chronology. Overall, in spite of doubts and problems, we continue to favor the Short Chronology.

7.1.3.3. Astronomy and Boundary-Stone Markers

Vladimir Tuman (1983, 1987, Tuman and Hoffman 1987/1988; Cullens and Tuman 1986) has proposed that a substantial number of ancient monuments, especially of Assyria and Babylonia, can be dated through their astronomical iconography. He holds that symbols on these monuments that correspond to later symbols of constellations represent those same constellations and that the symbols associated in later periods with planetary gods also had the same associations on earlier monuments. Most of the monuments considered are *kudurrus* or boundary-stone markers of the kind first used extensively by the Kassite kings of Babylon. Boll (1903, pp. 198–202) knew of over 30 of these monuments, and Tuman claims over 100. Massive sets of symbols and deity representations are partially repeated on monument after monument. An example of one of these monuments is seen in Figure 7.3.

These representations do not have any of the iconographic unities expected of scenes of mythic interaction. Boll and other early scholars had no doubt of their astronomical content, whereas van der Waerden among more recent scholars has indicated that they may be astronomical. However, a consistent set of interpretations has been lacking prior to Tuman's work, which probably accounts for the apparent doubt of many scholars.

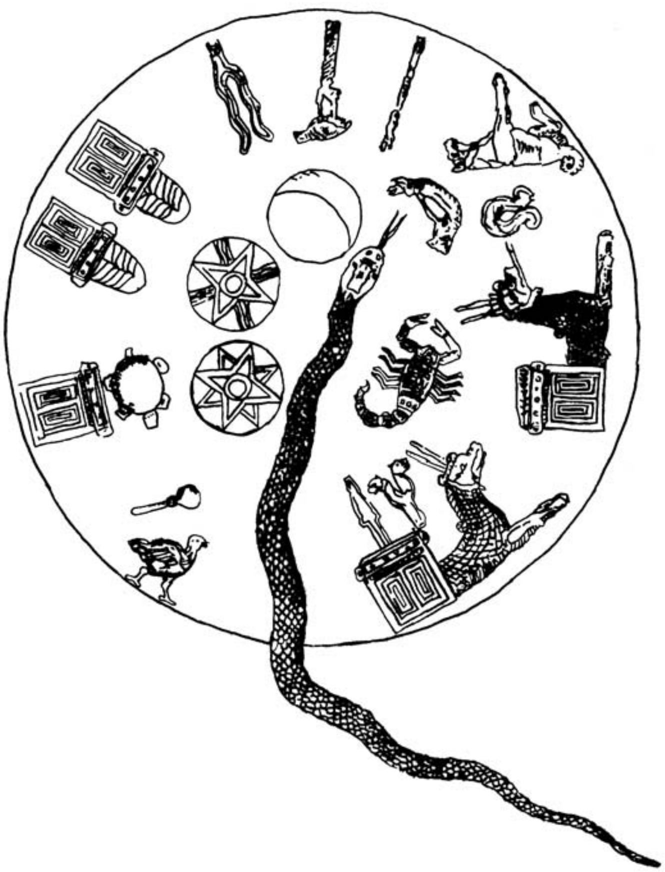

FIGURE 7.3. A Kassite boundary-stone with probable symbols of constellations. Drawing by Sharon Hanna.

Tuman argues that the stones indicate dates by referring to the positions of planets relative to specified constellations, corresponding to observational texts of the *Mul Apin* series. He has given a list of 22 monuments that he has dated and mentions in passing the dates of two others. In Table 7.7, adapted from Tuman (1987) with modification, his astronomical dates are compared with Brinkman's Kassite and post-Kassite dates. Tuman is the first scholar in many years to address this problem, and his generic premises that the monument references are observational and that they refer to contemporary astronomical features of different parts of the sky, in accordance with known observational techniques, seem very reasonable. This material, if accepted, will enlarge our knowledge of the Kassite period substantially. The information will also make it possible to date a number of monuments and verify or refine the chronology in some cases.

At present, reasonably adequate discussions are available for only three monuments (BM 908558, SB 22, and the Esarhaddon stela from Zinjirli) and minimal discussions for two others (BM 90834 and 102485, which do not appear on the date list). Of the 15 dates studied by Brinkman, one date is too late and ten dates are too early. If Brinkman's dates could be shifted by as much as seven years earlier, there would then be three dates too early and two dates too late, and the dates would be in better accord with Tuman's interpretation. Resolution of the issue may require additional historical data.

As in any major reinterpretation dependent on massive detail, one may expect errors. One possible case is posed by images of two snakes, which Tuman identifies with Hydra and Serpens. One is entirely reptilian, and the other has a mammalian horned head and extended front legs on a snake's body. The latter corresponds entirely with Seleucid period representations of the constellation Hydra, but Tuman identifies it with Serpens. The reptile with no mammalian features is the one that appears more frequently, and Tuman identifies it with Hydra. All dates dependent on these two identifications may be doubtful, therefore. Unfortunately, Tuman maintains that no date associated with Hydra can be appropriate for SB 22, which has the reptile with the mammalian head.

The evidence for planetary associations includes information on structural complexes. A major example is the building of Dur Sharrukin (modern Khorsabad). In the year 706 B.C., Sharrukin (Sargon II), 110th king of Assyria, dedicated his new capital city and palace compex, called Dur Sharrukin. The length of the city wall was 16,283 cubits, "the numeral of my name," said the king. Unfortunately, we do not know how this numerological value was calculated. By no later than the Hellenistic period, a number was assigned to each letter in an alphabetic sequence and the numbers were simply summed. Although Sargon II was using cuneiform, it is probable that he had scribes familiar with alphabets. Of the gates of the wall of the complex, Sargon II's inscription reads (Luckenbill 1929, p. 65):

> Front and back, and on both sides, I opened eight gates toward the eight winds of heaven. *Shamash-mushakshid-irnittia* ("Shamash Makes My Might prevail"), *Adad-mukîl-heallishu* ("Adad Is the Bringer of Its Abundance"), I called the names of the gate of Shamash and the gate of Adad which face the east; *Bêl-mukîn-*

Table 7.7. Dates proposed by V.S. Tuman on the basis of his interpretation of the astronomical iconography of monuments compared with the historical dates proposed by J.A. Brinkman. The identity of the monuments concerned can be found in Tuman 1987/1988. Tuman's spellings of the names are used. There are some modifications of the presentation of Brinkman's dates. Tuman's dates are given to the day, but only the year is indicated here.

Ruler (when known)	Tuman date	Minimal disagreement	Brinkman dates of rulers
1. Nazi-Marutash	1293 B.C.	+5	1323–1298 B.C.
2. (Solar eclipse)	1261 B.C.		
3. Summer solstice festival	1203 B.C.		
4. Melishipak	1198 B.C.	–10	1188–1174 B.C.
5. Melishipak	1194 B.C.	–6	1188–1174 B.C.
6. Melishipak	1194 B.C.	–6	1188–1174 B.C.
7. Melishipak	1190 B.C.	–2	1188–1174 B.C.
8. Name unknown	1175 B.C.		
9. MardukApalIdina	1154 B.C.	+7	1173–1161 B.C.
10. Nabuchadnezzar	1139 B.C.	–15	1124–1103 B.C.
11. Nabuchadnezzar	1133 B.C.	–7	1124–1103 B.C.
12. EnlilNadinApli	1109 B.C.	–7	1102–1099 B.C.
13. MardukNadinAhe	1105 B.C.	–7	1098–1081 B.C.
14. MardukNadinAhe	1091 B.C.	0	1098–1081 B.C.
15. NabuMukinApli	949 B.C.	0	977–942 B.C.
16. MardukZakirSumi	889 B.C.	–35	854–819 B.C.
17. MardukZakirSumi	840 B.C.	0	854–819 B.C.
18. MardukApalIdina	838 B.C.	–121	721–710 B.C.
19. NabuSumaIskun	769 B.C.	–9 or less	760 (or earlier)–748 B.C.
20. MardukApalIdina	720 B.C.	0	721–710 B.C.
21. Sargon II	715 B.C.	–6	709–705 B.C.
22. Esarhaddon	681 B.C.	–1	680–669 B.C.
23. Samas-Sum-Ukin	658 B.C.	0	667–648 B.C.

ishdi-alia ("Bêl Establishes the Foundation of My City"), *Bêlit-mudishshat-hisbi* ("Bêlit Increases Plenty"), I designated as names for the gates of Bêl and Bêlit which face the north; *Anu-mushallim-ipshit-kâtia* ("Anu Prospers the Work of My Hands"), *Ishtar-mushammihat-nishêshu* ("Ishtar Enriches His People"), I gave as names to the gates of Anu and Ishtar which face the west; *Ea-mushtêshir-nakbishu* ("Ea Makes His Springs Flow Abundantly"), *Bêlit-ilâni-murap-pishat-talittishu* ("Bêlit-ilâni Spreads Abroad His Offspring"), I called the names of the gates of Ea and Bêlit-ilâni which face the south; *Ashur-mulabbir-palê-sharri-êpishishu-nâsir-ummânâtishu* ("Ashur Makes the Years of the King, Its Builder, Grow Old and Guards Its Troops") was (the name of) its wall, *Urta-mukîn-temen-adushshi-ana-labar-ûmê-rukûti* ("Urta Establishes Foundation Platform of the House for All Time to Come") was (the name of) its outer wall.

Here, we see the earliest mention of the directional winds, later so prominent in Mediterranean cultures, and they are associated with gods who are known to be planetary gods. We also find each of the planetary gods given a gate and associated with a metal or mineral. Although eight gates are mentioned, the gods Anu and Ishtar seem to share a single gate. Sargon buried tablets of material associated with the gods at the gates:

On tablets of gold, silver, bronze, lead, *abar* (magnesite), lapis lazuli and alabaster, I wrote the inscription of my name and placed (them) in its foundation walls. (Luckenbill 1929, p. 59)

Excavations at Khorsabad in 1854 revealed a chest with six tablets that correspond to those described by Sargon. It is striking that there are no further known sources for such associations until Origen's much later list of the associations among the planetary gods, and the metals (see Table 7.8, which follows Chadwick's edition of Origen's *Contra Celsus*).

Table 7.8. Planetary associations in the Mediterranean.[a]

Metal	Planet	Angel[b]	Animal
Lead	Kronos (Saturn)	Thaphabaoth	Ass
Tin	Aphrodite (Venus)	Erathaoth	Dog
Bronze	Zeus (Jupiter)	Thauthabaoth	Bear
Iron	Hermes (Mercury)	Gabriel	Eagle
Alloy	Ares (Mars)	Raphael	Serpent
Silver	Selene (Moon)	Suriel	Bull
Gold	Helios (Sun)	Michael	Lion

[a] Adapted from lists attributed by Celsus to the Persians and the Ophites, in Origen's *Against Celsus*, *vi*, 22 (Chadwick 1953/1965, pp. 334 and 345–346).
[b] Described by Origen from an Ophite diagram.

7.1.4. Mathematical Astronomy

Observational studies in Babylonia led to an interest in methods of predicting planetary phenomena. Careful records were kept of planetary phenomena (and in this context, the word "planet" includes the Sun and Moon), including celestial longitudes. The angular speed of, say, the Moon, was obtained by comparing its longitude at successive risings. Once tabulated, mean values of the longitude differences could be calculated, which could be applied in one of two ways. For real planets—other than the Sun and Moon, that is—there were even more methods in use. Tables

Table 7.9. Table structure in Babylonian Ephemeris tablets.

Column	System A	Column	System B
T	Dates	T	Dates
Φ	Lunar speed w.r.t. Sun	A	Solar speed
B	Lunar longitude	B	Lunar longitude
C	Length of daylight	C	Length of daylight
		D	Half-length of night
E	Lunar latitude	E	Lunar latitude
F	Lunar speed	F	Lunar speed
G	First appx. of Lunar month	G	First appx. of Lunar month
		H	Difference in J
J	Correction of G (solar speed)	J	Correction of G (solar speed)
C′	2nd correction of G (epoch)		
K	Length of month	K	Length of month
		L	Date of syzygy, midnight epoch
M	Date of syzygy, evening epoch	M	Date of syzygy, evening or morning epoch
		N	Δt between syzygy and sunset/rise
		O	Elongation of first/last visibility
		Q	Influence of the obliquity
		R	Influence of the latitude
P	Duration of first/last visibility	P	Duration of first/last visibility

of predicted positions are widely used today—for comparison with observations in order to improve the theory of planetary motion or to plan future observations. In ancient times, astrological purposes probably demanded knowledge of the planetary configurations regardless of the weather.

7.1.4.1. The Step and Zigzag Functions

The construction of the lunar ephemerides from Systems A and B (§4.1.2) are extensively discussed by Neugebauer (1948, 1983) and by van der Waerden (1974). Therefore, we merely summarize the two basic methods. The ephemerides are recorded on baked clay tablets, inscribed with reed stylus pens, and often cover both sides and even the edges of the tablets. The tablets record the successive dates, and associated data, of lunar conjunctions or oppositions.

One method involved a constant velocity for the Sun over a certain number of days (hence, over a certain region of the ecliptic), followed by another constant velocity for a similar number of days. When the longitude is plotted against month number, therefore, it describes a *step function*. Neugebauer (1957/1969, p. 114) refers to the theory behind this method as "System A."

A second method involved solar velocities that changed month by month, each value differing from the next by a constant value over a range of months. The latter differences changed sign after a certain number of intervals so that when these differences are plotted against time, they portray a zigzag pattern, hence, the name *zigzag functions*. Neugebauer refers to the theory behind this method as "System B."

The two methods differ in sophistication and accuracy, so that most scholars infer an earlier origin for the simpler *System A*. However, both were in use for the entire interval for which we have records: 250 to 50 B.C. (Neugebauer 1955/1983, Vol. 1, p. 42), and Neugebauer thought that elements of *System B* might even antedate *System A*. Neugebauer (1957/1969, p. 115) expresses doubts that the simultaneous use of the two methods implies the existence of separate schools of astronomy, because they are found in both centers from which we have sufficiently attested data, Babylon and Uruk. On the other hand, in *Astronomical Cuneiform Texts*, Neugebauer (1955/1983, Vol. 1, p. 42) expresses less reservation about the idea. The origin and the founders of the schools, if this interpretation is correct, are unknown.[15] In any case, zigzag and step functions may be found together in the same tablet (e.g., in Babylon Tablet 5, described below); the method in the tablets may be determined by whether the solar motion (revealed in Column B) is dual or multiple-valued.

The structure of the tablets is summarized in Table 7.9, adapted from Neugebauer (1955/1983, Vol. I, p. 43), with his notation. As a rule, the first column gives the date of either a conjunction of the Moon and Sun (astronomical new moon) or opposition (full moon) in the year of the Seleucid Era and the month (and sexagesimal fractions thereof). The contents of the other columns differ depending on the method. The columns are read from top to bottom, with parallel columns read from left to right, as in modern tables.

In general, the first column contains a date (the year in the Seleucid era and then each month in that year). In texts of *System A*, the second column gives a quantity, designated Φ, analogous to the lunar velocity. Fr. Kugler, a pioneer in the study of the Mesopotamian astronomical texts, thought

[15] In Roman sources (Strabo, Pliny, and Vettius Valens), two names appear that are also found in tablets from Babylon: The name *Naburimmannu* appears on a tablet displaying System A material, and the name *Kidin* (or *Kidinnu*) on another in System B. They were the basis for the belief that the individuals named were the founders of the respective schools. However, Neugebauer (1955/1983, p. 16) indicates that no Greek or Mesopotamian source explicitly names these two as the founders, that the tablets are from a late period, and that tablets from Uruk, which are older, do not mention them.

that this column recorded the lunar diameter, in units of the quarter-degree, a unit not attested outside the Φ columns of *System A* texts (Neugebauer 1955/1983, Vol. I, p. 44). Subsequently, the mystery was solved through a Babylonian text of procedures discovered by Neugebauer (1957) and cited by van der Waerden (1974, p. 226). The text states

17,46,40 is the increase or decrease in 18 years.

Interpreting the "18 years" as an approximation to the *Saros*, van der Waerden (1974, pp. 226–229) argues that Φ is the difference between a "Saros" period (223 synodic months)[16] and the interval 6585 days. The *Saros* in its modern usage (not in its ancient usage of a fixed interval of 3600 years) is an interval of exactly 223 synodic months, but the actual length of the synodic month varies for reasons already discussed in §2.3.5 (the synodic *period* given in Table 2.6, $29^{\mathrm{d}}.530589$, being an average value of the length); hence, any true repetition of eclipses in a *Saros* "interval" must vary. With the mean value, $223P_{\mathrm{syn}}$ equals $6585^{\mathrm{d}}.32135$, so that the residual, $0^{\mathrm{d}}.32135$, in sexagesimal notation is 19,16,51. More to the point, however, it must be asked what value or values were used in Mesopotamia for the lunar synodic period. The answer to this question lies in the tablets. To find it, we must analyze them.

7.1.4.2. System A

van der Waerden (1974, p. 227) notes that the units of Φ are the same as for column C, in large hours (60° or 4 hours) in the *System A* tablets. Column B gives the calculated longitude of the Moon in ***uš***, degrees of a zodiacal sign, based on the assumption of constant solar speed. Column C contains the length of the day in large hours during the month. Column E gives the latitude of the Moon in units of še (literally "barleycorn," 1/72 of an uš or degree). Column F is the velocity of the Moon in degrees per day. Column G gives the length of the lunar month in large hours, assuming a constant solar velocity of 30°/month, but variable lunar velocity. Column J is a correction to be applied to column G for too high a velocity of the Sun during half of the year. The underlying assumption here is that the Sun moves according to a two-step function with either a high speed or a low speed. Column C′ expresses what Neugebauer calls the epoch of *syzygy*[17] in civil time, which began at sundown. The unit is the uš. Column K is the corrected length of the month, the sum of columns G, J, and C′. Column M gives the day, month, and large hours of syzygy (conjunction in this context). Column P is the time between sunset and moonset or between moonrise and sunrise. The designations and contents of some of the columns change if the ephemerides are for full rather than new moons. In addition, there are variants and additional columns, as our examples illustrate.

Some of the important features can be seen in Table 7.10, excerpted from Neugebauer's (1955/1983, Vol. III, Text No. 5, p. 10) interpretation of eight fragments of a tablet (No. 5) from Babylon (see Figure 7.4). The tablet deals with the interval 145–148 SE (Seleucid Era), corresponding to 166–165 to 164–163 B.C. This particular tablet provides one of the most complete examples of the usage of *System A*.

The structure of the table is revealed in plots of the columns against month number, *n*; the date column is designated by Neugebauer as Column 0. The first line marks the lunar conjunction that occurred at the 13th month of the previous year (145 S.E.), which we designate month 0. Each entry designates positions in terms of a length of arc along the ecliptic, measured in the zodiacal sign given in the text. Each sign is 30° long. This angular quantity, which cuneiform text scholars call the "longitude," is the forerunner of the much later *celestial longitude* (§2.3.3); however, the counting begins again at the start of each sign; so that the sign must be specified.[18] A single value of the longitude is given for both Sun and Moon because they are in conjunction at each entry. In each successive entry, the Moon has completed a 360° sidereal period and ~30° more for a total revolution of ~390°, when it meets the Sun (which moved ~30° eastward in the course of the month) once again. A plot (Figure 7.5) of the continuously increasing values, i.e., column II (B) against month number with the addition of 30° to the column B entries at each change in zodiacal sign, shows merely the progression of the Sun eastward among the stars. Such a plot is less revealing than that of the *differences* between successive entries of Column B (Figure 7.6).

Each ordinate value is $y(x + 1) - y(x) + 30°$, plotted here against the month number, *x*, and is a measure of the solar velocity in degrees per month. It reveals the step function that characterizes the System A approach. Notice the constancy of the solar speed for an interval of months followed by a change to another constant velocity. The intermediate values between the steps are merely differences between the end of one series of constant velocities and the beginning of the next; the actual change is sudden and occurs at a fraction of a month number between the two series. It is these instants that we would like to determine because the *period* of the function can be found by calculating the moments of intersection among three successive line segments of Figure 7.6. The equation for a straight line,

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[16] For detailed critical assessment of an early Babylonian origin for the "Saros" eclipse cycle, see Neugebauer (1957/1969, pp. 141–144). The significance of the interval of 223 synodic months is that it is equal to 242 draconitic months (see §2.3.4 and §5.2.2) and could be used to predict eclipses. This interval is not an integral number of days, and thus successive Saros eclipses may not be seen from the same place on Earth.

[17] The term *syzygy* may refer to the situation when the centers of the Earth, Moon, and Sun are in a line, but Neugebauer and many others use the term in a slightly broader sense, to mean either the conjunction or opposition condition. In the first usage, a syzygy must result in an eclipse; this is certainly not the meaning in most of the tables.

[18] At this time in Babylonia, the vernal equinox was located at 10° of Aries in System A and 8° in System B (van der Waerden 1974, Vol. II, p. 215). In any case, as can be seen in Column B of Tablet 5 (Table 7.10), the tabulated quantities appear to be measured from the beginning of the signs: The longitude at date 2,28 III is given as 0,48,45 *kusu* = 0.8125° Cancer and is followed in month IV by 28,56,15 *kusu* = 28.9375° Cancer. In month V, the entry is 27,3,45 *a* = 27.0625° Leo. The difference between successive entries, after adding 30° to the later entry when needed, is 28.125°/month.

Table 7.10. Babylon Tablet 5: An example of System A.[a]

T(Date) (S.E.)		Φ(Moon)	B (uš)	C (H)	E (še)	F (uš)	G (H)	J (H)	C′ (uš)	K (H)	M mon. day (H) before ss	P₁ (H)	P₃ (H)
[b]2,25[y]XII₂[M]		1,58,27,13,20	[27,11,15 hun]	[3,11,27,30]	+3,12,8,39	[11,1]3	{4,55,34,4,[26,40]}	[57,3,45 lal]	[9,22,30 lal]	[3,49,8]	[dirig 29 5,29,42 su′]	[bar 1 . . .]	2,26bar 27
145[y]	13[M]	1.97423	27.1875 hun	3.19097	+3.20240	11.21667	4.92613	0.95104 lal	9.37500 lal	3.81889	dirig 29 5.4950 su′	[bar 1 . . .]	2,26bar 27.000
146	1	2.02032	25.3125 mul	3.43542	+0.04608	11.91667	4.74259	0.95104 lal	7.33333 lal	3.67194	bar 28 1.8231 su′	[gu4 1 . . .]	sig 27.2917
146	2	2.06641	23.4375 mas	3.56319	−3.15632	12.61667	4.31241	0.95104 lal	3.83333 lal	3.29722	gu4 28 4.5258 su′	[sig 30 ..]	sig 27.2333
146	3	2.11250	21.5625 kusu	3.57431	−5.13568	13.31667	3.88224	0.95104 lal	0.33333 lal	2.92556	sig 28 1.6003 su′	[su 1 ..]	su 26.3667
146	4	2.15859	19.6870 a	3.46875	−7.11504	14.01667	3.45206	0.95104 lal	3.16667 tab	2.55361	su 28 5.0247 su′	[izi 30 ..]	izi 27.2833
146	5	2.20468	18.1333 absin	3.24296	−5.28412	14.71667	3.02188	0.78831 lal	6.77351 tab	2.34611	izi 28 2.7006 su′	[kin 30 ..]	kin 27.45
146	6	2.25077	18.1333 rin	2.90963	−3.17985	15.41667	2.68966		10 uš tab	2.85611	kin 29 5.8444 su′	[du6 1 ..]	du6 27.233
146	7	2.27248	18.1333 gir	2.61244	+0.24903	15.78333	2.66667		8.91556 tab	2.81528	du6 28 3.02917 su′	[apin 30 ..]	27.3611
146	8	2.22639	18.1333 pa	2.44859	+3.42888	15.08333	2.66667		4.91556 tab	2.74861	apin 28 0.28056 su′	[ga]n 30.239	gan 28.217
146	9	2.18030	18.1333 ma’s	2.41807	+5.53324	14.38333	2.28662		0.91556 tab	2.88139	[g]an 29 3.3991 su′	ab 1.383	ab 27.319
146	10	2.13421	18.1333 gu	2.52089	+6.76240	13.68333	3.29554		3.08444 lal	3.24417	ab 28 0.15528 su′	zi’z 30.236	ziz 28.217
146	11	2.08812	18.1333 zib	2.75704	+4.65804	12.98333	3.72572		7.08444 lal	3.60750	zi’z 29 2.54778 su′	se 1.333	se 27.253
146	12	2.04203	16.8125 hun	3.07569	+2.64174	12.28333	4.15590	0.66996 lal	9.55972 lal	3.32639	se 29 5.22139 su′	bar 1.417	bar 27.158
147	1	1.99594	14.9375 mul	3.36625	−1.07525	11.58333	4.58608	0.95096 lal	8.71667 lal	3.48972	bar 28 1.73167 su′	gu4 30.222	gu4 27.253
147	2	1.97680	13.0625 mas	3.54104	−3.71699	11.25000	4.93333	0.95096 lal	5.21667 lal	3.89528	gu4 29 3.83639 su′	sig 1.236	sig 27 . . .

[a] An excerpt from Neugebauer’s (1955/1983, Vol. I) interpretation of Tablet 5, annotated and transcribed in decimal notation here. Units are given below each column header.

[b] At the top is the first line of the original table in Neugebauer’s notation. Because of the length of the hexadecimal digits, some numbers overflow their columns.

[c] Columns are identified as follows (see text for a full description):

Column T: The date of the syzygy in years and months of the Seleucid Era, which began in April, 311 B.C. (see §4.1.5).

Column Φ: The “monthly variation.” Related to the Saros. See text for details.

Column B: The longitude in degrees from the start of the zodiacal sign. “hun” = Aries, etc., as per the order in Table 2.4.

Column C: Length of daylight at Babylon. The unit H is “large hours,” equal to 60° or 4 hours.

Column E: Latitude of the Moon’s center, in units of the barleycorn (še) = 50 arc-sec or 0.01389 degrees.

Column F: Lunar “velocity” represented as a linear zigzag function measureed in degrees per day.

Column J: Correction to the const. solar speed assumed for col. G; “lal” means “subtract,” i.e., all corrections in the J column in this table are negative.

Column C′: “lal” here means “subtract”; “tab” means “add.” All quantities in this column are in degrees; divide by 60 to convert to large hours.

Column K: The corrected length of the month: G + J + C′.

Column M: Date of syzygy. dirig = month XII_2, bar = month 1, etc.

Columns P_1, P_3: Durations of first and last visibility. These involve approximations to equatorial arcs computed from ecliptic longitude differences.

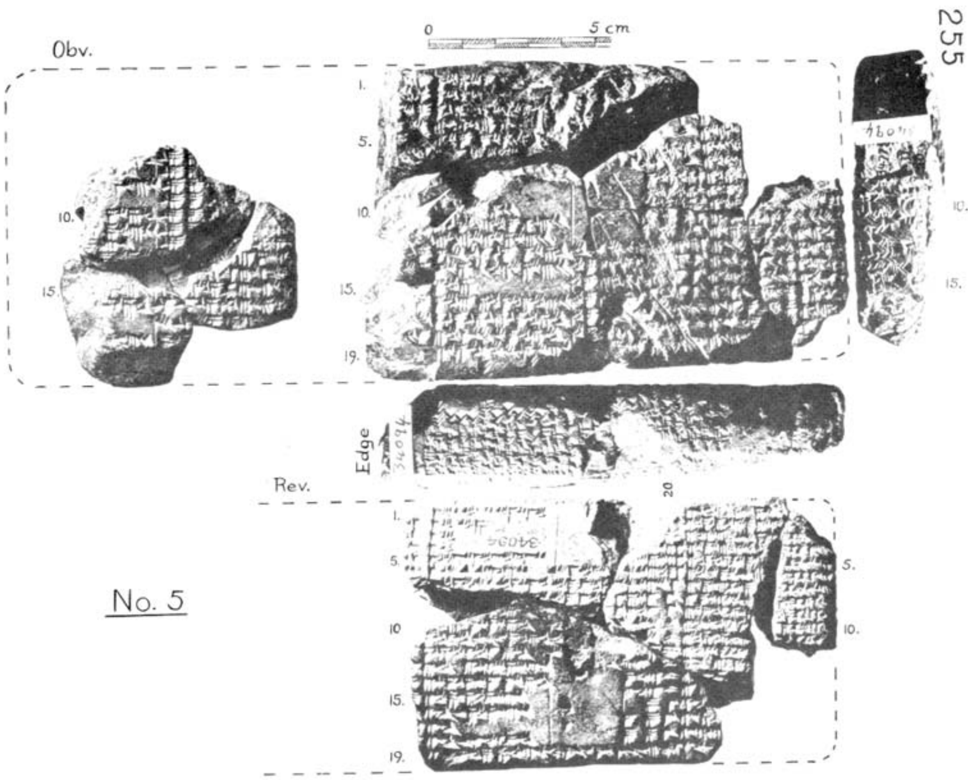


FIGURE 7.4. The fragments of a cuneiform tablet from Babylon: This particular tablet provides one of the most complete examples of the usage of System A; its data are for the years 146–148 Seleucid Era, 166–165 to 164–163 B.C. From Neugebauer 1955/1983, Vol. III, Text No. 5, p. 10.

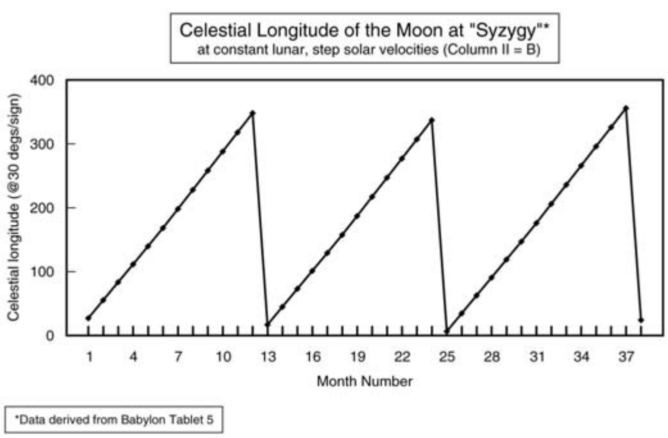


FIGURE 7.5. A plot of column II (B) against month number from a tablet from Babylon (No. 5), for the interval 146–148 Seleucid Era (166–165 to 164–163 B.C.). Thirty degrees have been added to the ordinate on each change in zodiacal sign of the columnar entries to show the progression of the Sun eastward among the stars.

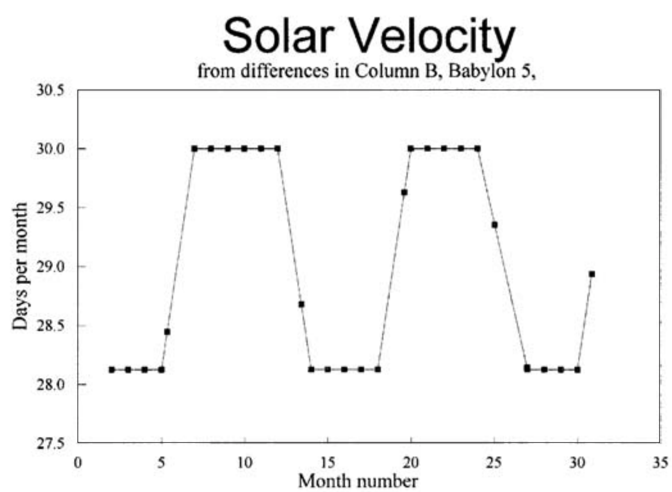


FIGURE 7.6. The *differences* between successive entries of Column B of Babylon Table 5 [viz., $y(x+1) - y(x) + 30°$], plotted here against month number, provide a measure of solar velocity in degrees per month. The plot shows the solar velocity as a step function, constant for a number of months, and then shifting to another constant velocity, characteristic of *System A* tablets. The intermediate values between the steps are merely differences between the end of one series of constant velocities and the beginning of the next; the actual change is sudden and occurs at a fraction of a month number between the two series.

$$y = a \times x + b, \qquad (7.1)$$

can be used to describe each of three lines; the coefficients a and b quantify the properties of the zigzag function. We will use subscripts to distinguish between the parameters and variables of the three equations. For the first decreasing segment, the slope, a_1, is the difference between two successive values in Table 7.10, namely, −1,52,30 in sexagesimal notation, or −1.8750 in decimal notation.[19] The intercept, b_1, is easily calculated from the value of y at a given value of x. So, at $x_1 = 1$, $y_1 = 25,18,45 = 25.3125$. Therefore,

$$b_1 = 25,18,45 - (-1,52,30) \times 1 = 27,11,15$$
$$(\text{or } 25.3125 + 1.8750 \times 1 = 27.1875).$$

This is the y-value at "month 0." Because the second line segment is horizontal, $a_2 = 0$. Therefore, $b_2 = y_2 = 18,8 = 18.1333$. For the third line segment, for, say, $x_3 = 15$, $y_3 = 11,11,15 = 11.1875$. Again $a_3 = -1,52,30 = -1.8750$; so

$$b_3 = y_3 - a_3 \times x_3 = 11,11,15 - (-1,52,30) \times 15$$
$$= 11.1875 + 28.125 = 39.3125.$$

The intersections of any two line segments are found by setting the pairs of equations equal. From the first pair of lines,

$$a_1 \times x_1 + b_1 = a_2 \times x_2 + b_2$$

so that the intersection values x' and y' are

$$x' = x_1 = x_2 = \frac{b_2 - b_1}{a_1 - a_2} = \frac{-9.0542}{-1.8750} = 4.8289 \text{ month}.$$

From (7.1),

$$y' = y_1 = y_2 = a_2 x_2 + b_2 = 0 \times (4.8289) + 18.1333 = 18.1333.$$

The intersection of the second and third line segments is again at $y = 18.13333$, and the intersection values x'' and y'' are

$$x'' = \frac{y'' - b_3}{a_3} = \frac{-21.17917}{-1.87500} = 11.29556 \text{ month}.$$

The difference between the two x intercepts is

$$x'' - x' = 11.29556 - 4.82889 = 6.46667.$$

If the segments of the function shown in Figure 7.6 were completely symmetric, we could multiply this interval by 2 and find the period. This is not the case, however, as can be seen by considering the next intersection: At $y''' = y_4 = 7.06667$,

$$x''' = \frac{y''' - b_3}{a_3} = 17.19778.$$

Hence,

$$x''' - x'' = 5.90222.$$

Instead, the correct period is determined by taking the difference $x''' - x'$:

$$P = x''' - x' = 12.36889 = 12,22,8.$$

When this number (lunations per year) is multiplied by the mean length of the synodic month (29.53059^d),[20] the result is 365.261^d, a reasonable approximation to the length of the year. On the other hand, dividing the quantity 12.36889 into a round 365.25-day year gives a lunar synodic period of $29^d.52973$. With this period, 223 lunations amounts to $6585^d.1301$, the decimal part of which is 7,48,24. This is not the value "17,46,40" for the residual from 6585 days noted earlier, but, in any case, the difference is small. The remainder 17,46,40 implies that $P_{syn} = 6585.2963/223 = 29^d.53048$. We next check the lunar periodicity in a System B tablet.

7.1.4.3. System B

An example of the use of System B is found in the translation of Tablet 120 (Neugebauer 1983, Vol. III, Text No. 120, p. 68; excerpted in Neugebauer 1957/1969, pp. 110–112). A reconstruction of the first 12 columns of the obverse side of this tablet provides the data shown in Table 7.11. The first column (Col. A) is the date, as per System A texts; the second column (Col. B) gives the solar rate of motion in degrees during the month; the third column (C) gives the Sun's position on the ecliptic. Other columns are as indicated in Table 7.9 and in the notes to Table 7.11. A plot of the successive lines of data in Column A against month number (Figure 7.7) shows a characteristic zigzag pattern that indicates changing velocity month by month, but by the same constant value. Exceptions to the constancy are again found only in regions of turnaround, where the monthly difference changes sign and applies in mid-month. The equations for straight line segments are given in Table 7.12 for three line segments 1, 2, and 3, respectively, from which we derive the minima and maxima of the zigzag functions from the intersections of these line segments.

At minimum, $x' = 2.516950$, $y' = 28.177685$, and at maximum, $x'' = 8.701517$, $y'' = 30.033055$. From these, using Neugebauer's terms, we derive the amplitude (essentially $y'' - y'$), $\Delta = 1.855370$, the mean, $\mu = 29.105370$, and the period, $P = 2\Delta/|a| = 12.36913$, where $a = 0.03$ is the slope. In the sexagesimal system, the arithmetic is more complicated, but instructive to do. Using Neugebauer's notation, the minimum is $m = y' = 28,10,39,40$ and the maximum is $M = y'' = 30,01,59,00$, so that a direct manipulation of each place yields $\Delta = M - m = 1,51,19,20$. Note that the treatment of the last place requires a borrowing of 60 from the column to the left. $M + m = 58,11,98,40 = 58,12,38,40$, and from this, we calculate the mean $\mu = (M + m)/2 = 29,6,19,20$. Because $\Delta = 1,51,19,20$, and $|a| = 0,18$, we calculate

$$P = 2(1,51,19,20)/(0,18) = (2,102,38,40)/(0,18)$$
$$= (3,42,38,40)/(0,18).$$

[19] The conversion is obtained by dividing the rightmost segment by 60, adding the result to the quantity to the left, dividing that by 60, and so on.

[20] A close match to this modern value is determined for the period of Column G from Tablet 120 by Neugebauer (1955/1983, Vol. I, p. 78).

TABLE 7.11. Babylon Tablet 120: An example of System B.[a]

T(Date) (S.E.)	A (us)	B (us)	C (H)	D (H)	ΔΨ $\frac{1}{2}'$	Ψ (f)	F′ (°/H)	F (°/d)	G (H)	H (us)	J (us)	K (H)
[b]2,58^{y}XII$_{2}^{M}$	28,55,57,58	22,8,18,16 hun	3,8,29	1,25,45	46,4,33,20	1,16,38,22,13,20	2,14,1,40	13,24,10	3,16,31,40	16,10	[20,21,30 lal]	[2,]56,10,10
178^{y} 13^{M}	28.93277	22.13841 Aries	3.1910	1.4292	46.07593	1.27732510	2.233796	13.4028	3.27546	16.1667	20.3583 lal	[2.]93616
179 1	28.63277	20.77118 Tau	3.3850	1.3075	45.52037	1.91233539	2.333796	14.0028	2.90046	9.3750	[29.7333 lal]	[2.]40491
179 2	28.33277	19.10394 Gem	3.5369	1.2314	44.96481	1.16292181	2.433796	14.6028	2.52546	2.5833	[32.3167 lal]	1.98685
179 3	28.32260	17.42655 Can	3.5667	1.2156	45.154938	0.41033951	2.533796	15.2028	2.15046	4.2083	[28.4083 lal]	1.67699
179 4	28.62260	16.04915 Leo	3.4464	1.2767	45.710494	0.35150206	2.455556	14.7333	1.97708	11.0000	[17.4083 lal]	1.68694
179 5	28.92260	14.97175 Vir	3.2303	1.3847	46.266049	0.52260288	2.355556	14.1333	2.35208	17.7917	[.3833] tab	2.35847
179 6	29.22260	14.19435 Lib	2.9381	1.5308	46.821605	1.30296296	2.255556	13.5333	2.72708	17.4167	[17.800] tab	3.02375
179 7	29.52260	13.71695 Sco	2.6619	1.6689	47.377160	1.85575103	2.155556	12.9333	3.10208	10.6250	[28.425 tab]	3.57583
179 8	29.82260	13.53956 Sag	2.4817	1.7592	47.932716	1.05687243	2.055556	12.3333	3.47708	3.8333	32.2583 tab	4.01472
179 9	29.94351	13.48306 Cap	2.4183	1.7908	47.947531	0.25774691	1.955556	11.7333	3.85208	2.9583	29.7167 tab	4.34736
179 10	29.64351	13.12657 Aqr	2.5342	1.7328	47.391975	0.53211934	1.855556	11.1333	4.22708	9.7500	19.9667 tab	4.55986
179 11	29.34351	12.47008 Pic	2.7447	1.6275	46.8364197	0.71272634	1.939352	11.6361	4.37963	16.5417	[3.4250] tab	4.43671
179 12	29.04351	11.51359 Aries	3.0350	1.4825	46.2808642	1.48407407	2.039352	12.2361	4.00463	18.6667	[15.2417 tab]	3.75060

[a] A 13-month excerpt from Neugebauer's (1955/1983, Vol. I) interpretation of Tablet 120 from Babylon, transcribed here in decimal notation.

[b] At the top is the first line of the original table in Neugebauer's notation. Due to missing material, many entries were recreated from other tablets.

[c] Column explanations are as folows:

Column T: The date of the syzygy in years and months of the Seleucid Era.

Column A: The solar velocity in degrees of longitude per mean synodic month. See text for details.

Column B: The longitude of the Moon (and Sun) at conjunction, measured in degrees from 8° from the start of the zodiacal sign. "hun" = Aries. The corresponding column on the reverse side bears the longitude of opposition, i.e., full moon.

Column C: Length of daylight at Babylon. The unit H is "large hours," equal to 60° or 4 hours.

Column D: Half the length of the night, in large hours. Note that D = 1/2 (6 – C).

Column Ψ: A quantity related to the lunar latitude, and a measure of the magnitude of eclipse if the lunar latitude is close to zero; measured in fingers (f) = 1/2 degree.

Column ΔΨ contains the differences in units of 1/60 finger.

Column F′: Lunar "velocity" represented by a linear zigzag function in degrees per large hour.

Column F: Lunar "velocity" represented by a linear zigzag function in degrees per day.

Column G: An approximation to the length of the synodic month (over 29 days), computed with a linear zigzag function.

Column H: Differences between the monthly corrections given in Column J; these differences form a linear zigzag function.

Column J: Correction to the const. solar speed assumed for col. G; "lal" here means "subtract"; "tab" means "add."

Column K: The corrected time interval between successive syzygies: $K + 29^{d} = G + J + 28^{d}$; G and K are in large hours.

The fraction 18/60 = 3/10, so that the division is reduced to

$$P = (30/3, 420/3, 380/3, 400/3) = (10, 140, 126\tfrac{2}{3}, 133\tfrac{1}{3})$$
$$= (12, 20, 128\tfrac{2}{3}, 13; 20) = (12, 22, 8, 53; 20) = 12^{d}.369136.$$

The number after the semicolon is the sexagesimal fraction of the place to the left. The result gives a slightly larger value for the solar year than was found for the step function of Tablet 5; the year length becomes 365^{d}.268, again a good approximation, with P = 12.369136, still assuming a lunar synodic period of 29^{d}.530589. Instead, though, supposing a year length of 365^{d}.25, we derive a lunation length of 29^{d}.529144; this yields a 223-lunation interval of 6584^{d}.9991, the residual (from 6585) of which is –00,03,04;41.

Perhaps we should rephrase the question: What synodic month and tropical year lengths are needed to recover the residual 17,46,40? The answer is 6585^{d}.2963/223 = 29^{d}.53048 for the period of the Moon, which gives a year-length of 12.369136 × 29^{d}.53048 = 365^{d}.266. Thus, both numbers are respectable and consistent with the derived periodicity. The corresponding year-length from our derived periodicity of Tablet 5 yields a year-length of 12.36889 × 29^{d}.53048 = 365^{d}.259 (fortuitously close to the length of the anomalistic year). Thus, the results of the analyses are not at all inconsistent with either the hypothesis that the number *17,46,40* represents the residual value of 223 lunations above a fixed interval of 6585 days or with the Mesopotamians possessing relatively accurate values for both the lunar and solar periods. Moreover, their tables indicated clearly the variable length of the synodic month.

The zigzag function is also present in the System A Tablet 5 discussed earlier, but in that case, the zigzag does not describe the assumed solar velocity. It is demonstrated in

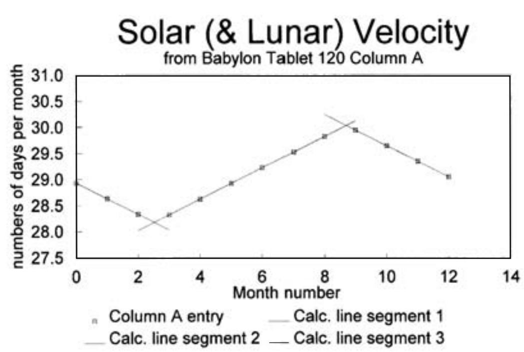


FIGURE 7.7. A plot of the Column A entries (solar velocity in days/month) in Babylon Tablet No. 120 against month number, demonstrating the characteristic zigzag function of System B.

Tablet 5 Column F, which contains the lunar velocity, under the assumption of constant solar velocity (corrections in other columns were applied to get the "final" prediction). Column F found in Tablet 120 is also a zigzag function and represents a calculation of the lunar velocity. The Tablet 5 zigzag function is plotted in Figure 7.8a. The analysis results are shown in Table 7.13. The lunar velocity is high, especially that from Tablet 5, 13°.5. Similarly large values are found from Column F on other System A tablets (Neugebauer 1955/1983, I, p. 58).

A final example of the zigzag function usage is in Column Φ of Tablet 5 (Figure 7.9). The analysis results for all of the selected columns are shown in Table 7.13. Notice the difference between the period of the Φ function and that of Column F of Tablet 5, but the similarity of the period with that of Column F in Tablet 120. Thus, we find that System A is scarcely cruder than System B, despite a simpler initial assumption about the Sun's motion.

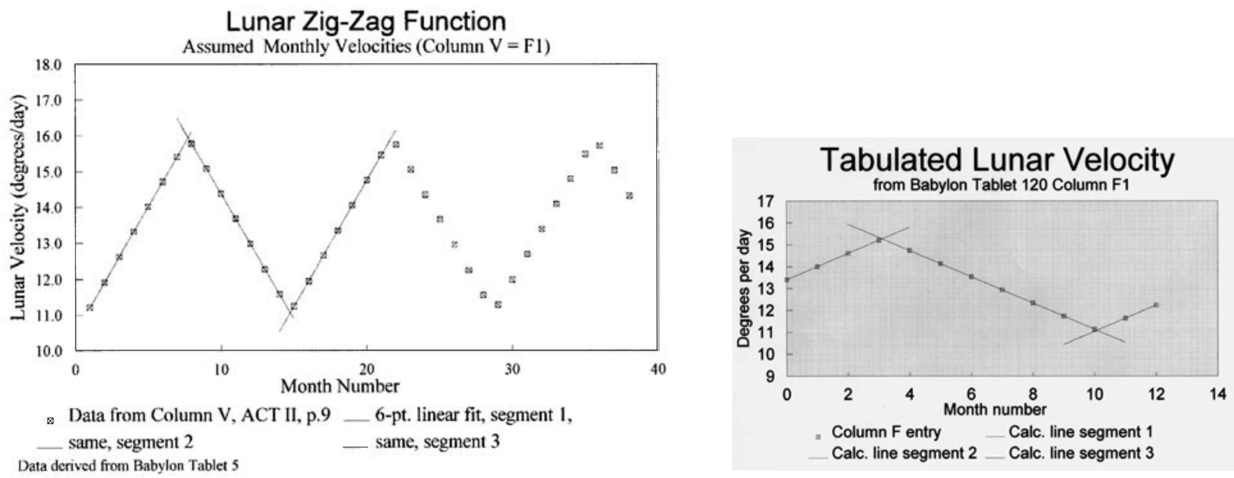
The determinations of the rate of motion might have been obtained as follows: First, the Moon's longitude is directly measured by noting its position relative to that of reference stars near the full moon, month after month. The result is a tabulation of lunar longitude, as in Column B of Tablet 120. A table of the monthly differences in position from month to month is then drawn up (Column A), and the maximum, minimum, mean values, and period found. Once the function representing the run of values of the difference table is characterized by these variables, future positions of the Sun or Moon are obtained. The result is evocative of the modern mathematical process of integration. The relationship of Column A to that of Column B is revealed in rows 4 and 5 of Table 7.13, where the determined parameters of the zigzag function from Column A and the differences in Column B are essentially identical. Now, we discuss the treatment of the planets in the Mesopotamian tables.

7.1.4.4. Planetary Tables

Other texts deal with planetary positions. Neugebauer (1955/1983, Vol. II, p. 279) lists 11 ephemerides for Mercury, 9 for Venus, 8 for Mars, 41 for Jupiter, and 12 for Saturn; the procedural texts are also heavily weighted in favor of Jupiter. Nevertheless, taking all five planets together, there are fewer than half the number of lunar texts, indicating that the planets had distinctly less importance for Mesopotamia at that time. Neugebauer (1955/1983, Vol. II, pp. 279–281) notes how little the theory behind the planetary tables reflects observations. Moreover, although the data are sparse, they seem complete enough for scholars to conclude

TABLE 7.12. Parameters for intersecting lines.

Tablet	(Column)/parameters	a_1	b_1	a_2	b_2	a_3	b_3
5	Φ	+0.04609	1.92814	–0.04609	2.6412	+0.04609	1.28545
5	ΔB	–1.875	27.1875	0.0	18.1333	–1.875	39.3125
5	F	+0.7	10.51667	–0.7	21.38333	0.7	0.7500
120	A	–0.3	28.93277	+0.3	27.42260	–0.3	32.64351
120	ΔB	–0.3	28.63277	+0.3	27.72260	–0.3	32.34351
120	F	+0.6	13.4028	–0.6	17.1333	+0.6	5.0361



(a) (b)

FIGURE 7.8. The zigzag function found from data in Column F of Babylon Tablets (a) 5 and (b) 120. The functions are decidedly similar, despite the fact that these tablets demonstrate the methods of System A and System B, respectively. The Columns F contain the lunar velocity, under the assumption of constant solar velocity (corrections in other columns were applied to get the "final" prediction).

TABLE 7.13. Analyses of columns of Babylon Tablets 5 and 120.

Tablet	(Column)/parameters	*M*	*m*	Δ	μ	*P*
5	Φ	2.28467	1.963325	0.321345	2.123998	13.94424
5	Δ*B*	18.13333	7.06667	11.06666	12.60000	12.36889
5	*F*	15.95000	11.06666	4.88335	13.50833	13.95239
120	*A*	30.03306	28.17769	1.85537	29.10537	12.36913
120	Δ*B*	30.03306	28.17767	1.85539	29.10537	12.36912
120	*F*	15.26805	11.0847	4.18335	13.17638	13.94450

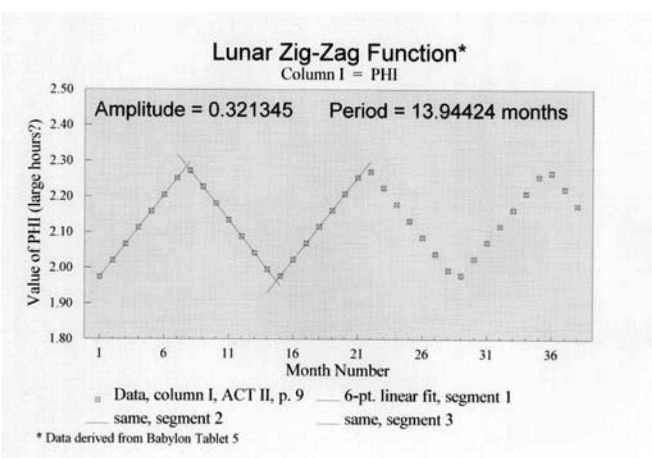


FIGURE 7.9. A final example of the zigzag function usage, Column Φ of Tablet 5.

that Babylonian planetary theory was less developed than was the lunar theory. The planetary tables are, first and foremost, a set of uniform computations of planetary positions (positions, that is, of specific planetary configurations), with no direct reference to ecliptic latitude, for instance. However, this must be tempered by the circumstance that the precise method they used to do the calculations is not fully known. Neugebauer considers the relative difficulty of planetary motions and their lack of calendrical importance as the basic reasons for the relative neglect they received; nevertheless, Babylonian astronomers had a theory for the motion of each planet and which provided the dates and longitudes when the planets were at critical configurations. They also had the means to apply certain corrections to the tables to account for varying intervals of invisibility, a circumstance to which the celestial latitude contributes. In any case, the purpose of the tables seems to be clear: to provide the instants of important configurations.

Figure 7.10 demonstrates the phenomena among the changing celestial longitudes of the inferior and superior planets, respectively, and that of the Sun. See the description of the planetary phenomena in §2.4.2 and §2.4.3 to connect the geocentric to the heliocentric motions, to trace the corresponding positions in the orbit, and to see the modern terminology. Because notation can become confusing, we again describe the progression of the tabulated phenomena for Mercury and Venus, in Neugebauer's notation and terminology (italicized), with our annotations:

(1) *First visibility in the east* (Γ). This is a morning star configuration (west of the Sun) in retrograde motion (i.e.,

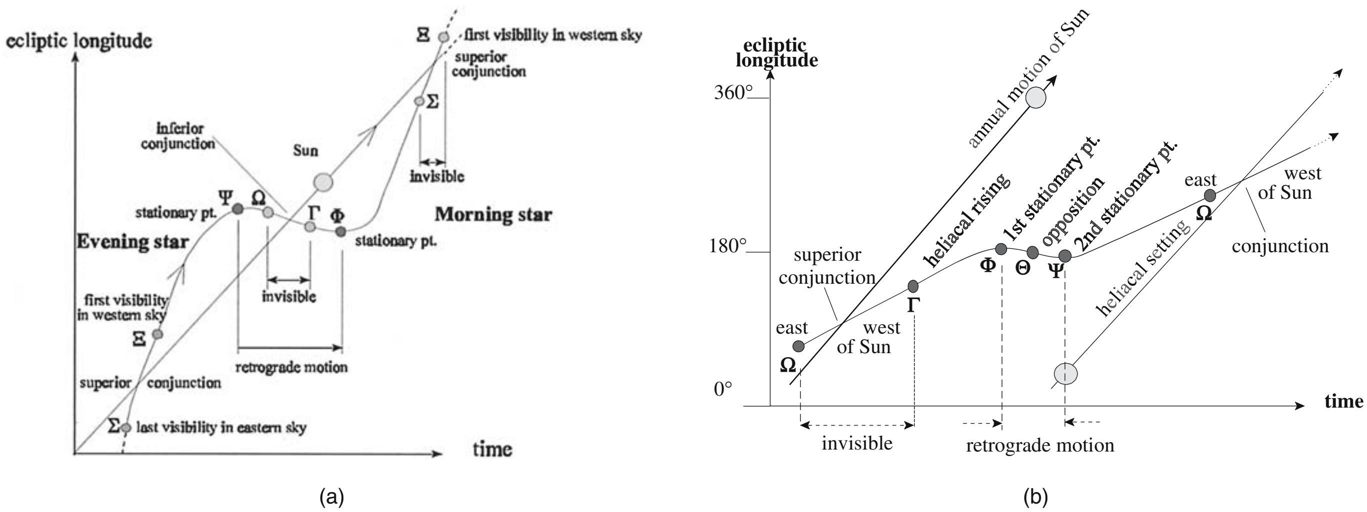


FIGURE 7.10. Planetary phenomena as understood in Babylonian astronomy: The planetary configurations are marked along ecliptic for (a) inferior and (b) superior planets. Drawings by E.F. Milone, after Neugebauer (1955/1983, Vol. II, pp. 280–281, Figs. 55a,b).

moving westward). First visibility is also known as the heliacal rising, first appearance before the rising sun.

(2) *Stationary point in the east* (Φ). This marks the end of retrograde motion and the beginning of direct (eastward motion, toward the Sun). This is the instant of greatest *western* elongation (because the object is west of the Sun).

(3) *Last visibility in the east* (Σ). This marks the end of the morning star phase and just precedes what we call "superior conjunction."

(4) *First visibility in the west* (Ξ), *just after sunset*. The first appearance as an evening star, east of the Sun, still in direct motion, but now moving away from the Sun.

(5) *Stationary point in the west* (Ψ). The end of direct and onset of retrograde motion and moving back toward the Sun. This is greatest eastern elongation.

(6) *Last visibility in the west* (Ω). The end of the evening star phase and heliacal setting. This phase precedes what we call "inferior conjunction."

For Mars, Jupiter, and Saturn, the progression is as follows:

(1) *First visibility in the east* (Γ), *just before sunrise*. The heliacal rise is followed by direct but slowing motion.
(2) *First stationary point* (Φ). This marks the onset of retrograde motion.
(3) *Opposition* (Θ). Here, the planet rises acronychally (and sets cosmically) because it is opposite the Sun.
(4) *Second stationary point* (Ψ). This marks the end of the retrograde motion and the resumption of direct motion.
(5) *Last visibility in the west* (Ω), *just after sunset*. The heliacal setting precedes conjunction.

The planetary tablets bear pairs of columns of the date and the longitude for each of the configurations, with each successive cycle repeated in successive rows. The period of each column is the same, and it is based on observation of essentially horizon phenomena, except for the stationary points, for which the daily motion with respect to nearby stars, would be measurable. The period of repetition of the rows, i.e., the number of cycles until the table begins to repeat, indicates the time for the phenomena to arrive back at the same celestial longitudes as the first row. This period is an integer multiple of the time interval between successive repetitions of the same phenomenon; between each repetition, the phenomenon travels an arc length $\Delta\lambda$ along the ecliptic. The relationship can be expressed as

$$P_{\text{rows}} = n \times P_{\text{“sid”}} = m \times P_{\text{syn}}, \tag{7.2}$$

where

P_{row} is the interval of time between the two rows of data.
$P_{\text{“sid”}}$ is the period to return to the same celestial longitude, that is, the same position on the zodiac (a kind of sidereal period conceived from a geocentric standpoint—to see how this can work, when the planetary configuration also repeats, refer to Figure 2.24b).
P_{syn} is the synodic period, the time interval between successive occurrences of the same planetary configuration or phenomenon. Recall that a *synodic period* is the relative period of the planet with respect to the Earth. In the context of ancient Mesopotamia, it is the time to appear at the same configuration in the sky with respect to the position of the Sun.

Mathematically, to paraphrase Neugebauer,[21] m is the smallest integer such that m repetitions of a certain phenomenon, say, Γ, corresponds to n "sidereal rotations" of Γ. In other words, after m occurrences of phenomenon Γ, that phenomenon appears again at the same place on the zodiac;

[21] In Neugebauer's (1955/1983, p. 182) notation, II = m, and $Z = n$, all integers, and he refers to the number of complete mean synodic arcs, each of arc length $\Delta\lambda$, contained in a complete circle, as $P = 360/\Delta\lambda = \text{II}/Z$. From this and (7.2), it follows that $P = P_{\text{“sid”}}/P_{\text{syn}}$.

during that time interval, the phenomenon appeared around the sky in various zodiacal signs and required n complete circuits (360°, or in Babylonian notation, 6,0 degrees of rotation) to return to the same point among the stars.

Additional work is required to relate this motion of the phenomenon among the stars to the apparent motions of the planet and the Sun. The Sun and the planet must wind up at the same locations in m synodic years (during which interval, the configuration has repeated n times). Neugebauer's method of determining the motions is first to write the separate motions of the Sun and planet:

$$\Delta S = \left(i + \frac{n}{m}\right)(360), \qquad \Delta\Lambda = \left(k + \frac{n}{m}\right)(360). \tag{7.3}$$

Multiplying both sides by m,

$$\Delta S \times m = (im + n)(360), \qquad \Delta\Lambda \times m = (km + n)(360). \tag{7.4}$$

The upper of (7.4) gives the time for the Sun to go through m repetitions of the phenomenon and therefore to get back to the same location with respect to the stars. The period for it to get back to the same place with respect to the stars (the right-hand side of this equation) is therefore given in sidereal years. The same motion for the planet in this interval allows us to equate the upper and lower parts of (7.4), so that in m occurrences

$$(im + n)\text{ years} = (km + n)\text{ sidereal rotations.} \tag{7.5}$$

Now the idea is to find the smallest values of n and m that satisfy (7.5), which Neugebauer refers to as the *fundamental period relation* for the planet under consideration. Neugebauer uses this equation to establish mean motions. He establishes empirically that for the inferior planets, $i = k$ and for superior planets, $i = k + 1$. Moreover, for Mercury, $k = 0$; so $i = 0$ and for Venus, $k = 1$, $i = 1$; for Mars, $k = 1$, $i = 2$; for Jupiter and Saturn, $k = 0$, $i = 1$. The argument for Mercury goes as follows: Mercury proceeds from, say, one Γ to the next Γ in ~1/3 year. The Sun does not travel a full circle in this time, hence, $i = 0$; but because Mercury is always very close to the Sun, $k = 0$ also. Similar reasoning can produce the values for the rest of the planets. Neugebauer uses these relations to determine the mean motions. The application of (7.5) to the inner planets gives the result that after m occurrences of a phenomenon, the number of rotations to come back to the same point on the zodiac is the same as the number of elapsed years, and there are m occurences in $(n + km)$ years. For the outer planets, the number of years is the sum of the number of rotations and the number of occurrences of the phenomenon:

$$m\text{ occurrences over }(km + n)\text{ rotations in }(km + n + m)\text{ years.}$$

With i and k known, the ratio m/n can be determined. This ratio is just the number of times the phenomenon can occur over a complete circle; Neugebauer calls this a period: $P = m/n = 360/\Delta\lambda$. Neugebauer (1955/1983, p. 283) gives an example of the role that these numbers played in the Babylonian planetary theory. In Tablet 801, Saturn is said to make 256 appearances in 265 years, in which time, it completes nine "rotations" = 3240°. Therefore, $m = 256$, and $n = 9$. We have from (7.5), $(im + n)$ years = $(km + n)$, so that with $k = 0$, $i = 1$, $m + n$ years = n rotations, or 256 + 9 years for the nine rotations (the same result is achieved for the expression for the number of years vs. rotations explicitly for outer planets, given above). The number of repetitions (appearances at a particular configuration) in a full 360° is $P = m/n = 28.4444\ldots$ or in Babylonian notation, 28;26,40. The mean "rate" follows: $\frac{\Delta\lambda}{\Delta t} = \frac{360}{P} = 12.656$, or 12;39,22.

However, the speed of a planet in moving from one type of configuration (see Figures 2.23, 3.18, and 7.10) to another is not constant, due to: the eccentricity of the planet (see Table 2.9; §2.3.5); the varying distance from Earth, hence, apparent angular speed; the varying relationship between the orbital path of the planet and the ecliptic; and the motion of the Earth. Consequently, systems of interpolation involving step functions (System A) and zigzag functions (System B) were used, as per the lunar tables, to get "true synodic arcs" per time interval. Further details can be found in Neugebauer (1955/1983, Vol. II, pp. 284ff.).

Of the 300 astronomical texts, none appear to be earlier than the year 4 (~308 B.C.) of the Seleucid Era and the last is from 353 S.E. (~41 A.D.). All in all, the tables reveal the remarkable extent to which astronomical progress had been made in the Seleucid Era and furnish abundant evidence of the critical importance of astronomical data to Mesopotamia. As far as Babylonian interest in planetary motions is concerned, Neugebauer (1955/1983, p. 279) remarks that the main thrust seemed to be toward determining the sequences of the phenomena, and that the daily motions are secondary. Indeed, he notes further (1955/1983, fn. 5) that the Babylonian ephemerides would not have been much use to Hellenistic astrology, because the positions of planets in a zodiacal sign at the moment of birth are not immediately solvable from the ordinary planetary ephemerides; moreover, he states that "the characteristic phenomena listed in these ephemerides play no role whatsoever in astrological practice." This was certain to change, as we will see.

7.1.5. Relation to Greek Astronomy

One surviving application of zodiacal signs from Mesopotamia was the use of differences in rising times to distinguish places of different latitudes. The latitude of a place in the ancient world (indeed into medieval times) was expressed in terms of the ratio of lengths of the longest to the shortest days. For example, the latitude of Babylon was expressed as 3 : 2. This is the ratio of the rise time for the sequence of six signs, Cancer (the summer solstice), Leo, Virgo, Libra, Scorpio, and Sagittarius, to those for the sequence: Capricorn (the winter solstice), Aquarius, Pisces, Aries, Taurus, and Gemini, at the latitude of Babylon. Note that although exactly half the sky is involved in each sequence, the rise times are unequal because of the varying angle of rise made by the ecliptic on the horizon.

A related benefit has been the legacy of the degrees of a sign: the quantitative measurement of position of celestial objects that was so noticeable in the tablets described in §7.1.4. This method of specifying a longitude with respect to the start of a zodiacal sign was used for centuries prior to the adoption of ecliptic longitudes (§2.3.3).

There is little agreement about more ancient connections between Greece and Mesopotamia, however. For the Greek context, Dicks (1970, p. 167) thinks that "there is no good evidence that the planets were even distinguished from the fixed stars before the latter half of the fifth century B.C." This is based on the hidden assumption that the planets took their names from preexistent deities. However, a strong case can be made that the reverse is true and that the gods were the planets and other celestial deities, in various differentiated phases. In Babylon, Ishtar is clearly identified with the planet Venus already in the earliest relevant texts. The Greek Aphrodite is remarkably similar in concept and probably a borrowing from Ishtar. Even students of mythology with little knowledge of astronomy have interpreted the reference to Ares and Aphrodite entangled in the net of Hephaestos as a reference to a conjunction of Mars and Venus. Hermes, as messenger of the gods, darting back and forth between the Sun and various planets and constellations, on winged feet, seems a very appropriate personification of Mercury. Ares as the bloody red war god is equally appropriate for Mars. No one has ever doubted that Helios and Selene were Sun and Moon. To think that such coincidences have nothing to do with a distinction of planets from fixed stars seems to us very unlikely. See §9.3 for a lengthy discussion of Inanna and Venus.

The broader question of the nature of the relationship between Greek and Babylonian astronomy continues to be incompletely answered. Neugebauer (1969) cites a continuous tradition of practical mathematics in both Mesopotamia and Greece as exemplified by the writings of Hero (sometimes called Heron) of Alexandria (1st century A.D.)[22] and argues that the Euclidean type of mathematics appears to be a purely Greek achievement. It seems reasonable that just as trade was brisk, so was the exchange of astronomical ideas, if not always of practices.

7.2. Hellenic Civilization and Its Precursors

7.2.1. Early Groups

One of the early Mediterranean cultures was that of the Minoans, who developed on the island of Crete between 3200 and 2000 B.C., building shrines at the beginning of this interval and temples at the end of it. At its peak, Crete dominated a colonial empire, trading with communities as far away as Syria and Egypt. Its decline after the great volcanic eruption of Thera (~1500 B.C.) and the subsequent invasion by Mycenaeans is well documented (for a recent summary, see Castledon 1990). Images of the Sun and Moon are found that have suggested worship of these objects. A disk, probably of the Sun, is sometimes depicted between the horns of a bull's head. The bull's horns were a prominent feature of sacred altars, and they still can be seen in the ruins of the Minoan complexes. Although a version of the sea-god Poseidon, the main deity in mainland Greece during the Mycenean period, may have been a principal deity, a multiple role for deities seems likely. According to Castledon (1990, p. 129), Poseidon probably had three manifestations: In the sky, he was worshipped as the Sun and Moon, and on Earth, in the form of a bull, and beneath the earth, he took the form of tsunamis and earthquakes. This is analogous to the late Orphic aspects of the goddess Artemis (her aspect on the earth), manifested as Persephone (below) and Selene (above). The later Myceneans were ancestral Greeks.

The Greeks had a typical Mediterranean culture, dependent on a wide range of crops. Dominant were the grains, especially wheat; vegetables included peas, chick-peas, lentils, and onions; grapes were grown, particularly for wine; flax was used for linen; a wide range of fruit trees included olives, oranges, lemons, apples, peaches, pears, and others. They also raised domesticated donkeys, sheep, goats, cattle, pigs, and horses and tamed a wide range of other animals. They did substantial amounts of fishing and a little hunting, mostly for show. They were great enthusiasts for sports, theatre, and warfare. Each city was independent in the earlier period and governed by a hereditary king, later largely replaced by a variety of elected officials. There was a large body of specialists, including physicians, whose office was hereditary (they claimed descent from the god Asklepios, son of Apollo, who was sometimes identified with Mercury and sometimes with the Sun). Menial tasks were performed by serfs and slaves. Iron and bronze metallurgy were well developed, and weaving (earlier wool, later linen and cotton) was important, but they had no tailored clothing. Trading was extensive, both among the city states and with outside groups; important commodities included wine and slaves. Silk was imported. Water transport was in moderately good sailing vessels, and on land they used a variety of wagons and chariots, sometimes on well-paved roads. They had writing, first a script borrowed from Crete, soon replaced by a form of the Phoenician alphabet. There were extremes of wealth and poverty and great pressure on resources that resulted in massive infanticide, especially of females. Coinage furnished an economic exchange and lending at interest was a regular feature of the economy (the most common lenders were the temples). Except for Dionysiac orgies, religious festivals seem to have been generally orderly, but certainly occasions for merriment and feasting. As Cyrus Gordon (1965) has emphasized, much Greek mythology is close to Canaanite and Hebrew beliefs and ultimately partly of Mesopotamian derivation. Festivals varied from city to city and were regulated by a variety of chaotic local calendars (fully described by Ginzel 1906, Vol. 2).

[22] Hero mentions Archimedes and is in turn mentioned by Pappas; so his dates must fall in the period ~200 B.C. to 300 A.D.; to the extent that a description of a lunar eclipse described by Hero represents a record of Hero's own observation of it, Neugebauer (1938, 1939) finds only one eclipse that fits this description: that of Mar. 13–14, 62 A.D., hence the 1st century date (see §5.2.1.2, Table 5.2 for further details).

For the most part, the Greeks lived in homes of plastered mud; occasionally, they lived in stone houses. By the 6th century B.C., they were building large and impressive public structures, including temples.

7.2.2. Alignments and Astronomical Measurement

Modern archaeoastronomy began with a discovery by F.C. Penrose, that some of the public buildings in the region showed possibly significant astronomical alignments. These data were used by Lockyer (1894/1973, pp. 416ff) to demonstrate building dates for these structures, which did not adequately consider archeological evidence, and thus lost credibility with a large segment of the scientific community of his time. Lockyer (1894/1973, p. 416) claimed that Penrose's (1892/1893) observations supported a claim that the Parthenon was oriented to the rising of the Pleiades at a date of 1150 B.C.; Penrose surveyed 28 temples and found orientations between 21° N of east to 18°25′ S of east. He considered the bright stars that could rise within the limits established by the range of azimuths and suggested 17 stars that might have been used, and that the purpose was to use the heliacal rise of a particular star as a warning of the arrival of a feast day. Penrose, whose comments are reproduced in Lockyer (1894/1973, 417ff), asserted that seven temples were (equinoctially) aligned to α Arietis, whereas no Egyptian temple had been, but many Egyptian and "early" Greek temples were (solticially) aligned to Spica. This he attributed to precession, as the vernal equinox moved westward from Taurus into Aries. Because, he claimed, the solsticial "year was thoroughly established" in Egypt, there was no need to erect "temples to the new warning star α Arietis."

Orientations of cities, buildings, and temples from before ~2200 B.C. to Roman times are shown in Pedley's (1993) attractive compilation of Greek art and archeology. Among temples having E-W orientations are the temples of

(1) Artemis at Corcyra,[23] dating to ~580 B.C. (Pedley 1993, Fig. 6.7)
(2) Apollo at Syracuse in Sicily, from ~560 B.C. (Pedley 1993, Fig. 6.22)
(3) Hera, ~550 B.C., and a second ~470–460 B.C. (Pedley 1993, Figs. 6.26, 7.15), at Poseidonia
(4) Athena (~500 B.C.) at Poseidonia (Pedley 1993, Fig. 6.26)
(5) Zeus at Olympia, ~460 B.C. (Pedley 1993, Fig. 7.1)
(6) Zeus at Akragas (modern Agrigento in Sicily), ~480–406 B.C. (Pedley 1993, Fig. 6.25) (see Figure 7.11)
(7) Athena Polias at Priene, ~340 B.C. (Pedley 1993, Fig. 9.17)
(8) Artemis at Magnesia, ~175 B.C. (Pedley 1993, Fig. 10.5)

[23] The west pediment (triangular relief sculpting at the top) of this temple has as its central figure the Medusa (Pedley, Fig. 6.8). The head of the Medusa has been associated with the variable star Algol; among the Greek constellations, the head was held aloft by the hero Perseus, and Algol is one of four or five stars shown on it.

All of these temples face east. Many others face somewhat north (as the Parthenon on the Athenian Acropolis (447–432 B.C.), the temples of Apollo at Corinth, ~560 B.C., and Didyma, ~550 and ~330 B.C., and those of Hera, earliest of which may be 8th century B.C.). Some earlier temples and important buildings, on the other hand, appear to open to the southeast. One interesting example is a 13th-century (B.C.) palace at Pylos (Blegen and Rawson 1966) on an acropolis that trends northeast-southwest. In this well-presented complex, there is a large hall with a central, circular hearth. Four surrounding columns were placed at the cardinal points.

Whatever one thinks of the Penrose/Lockyer conjectures, the alignments of structures do not require notions about the celestial sphere. As discussions in §6.2 indicate, solar alignments can be established relatively easily, with simple tools. The early Greeks probably used gnomons to establish dates of solstices and equinoxes and directions to the rising and setting Sun. Anaximandros of Miletos (~610 to ~545 B.C.), a younger contemporary of Thales (also of Miletos, ~624 to ~545 B.C.) is reported to have done so (Sarton 1952/1970, **I**, p. 1740). Dicks (1970, p. 88; cf. also pp. 45, 174), however, writes: "Now, recognition of the equinoxes and of the inequality of the seasons implies a comparatively sophisticated stage in astronomical thought, and presupposes at least some knowledge of the concept of the celestial sphere and a spherical earth." We disagree. On the contrary, any use of a gnomon should lead easily to the identification of the equinoxes (when the morning shadow is in line with the evening shadow) and simple counting of days should lead to recognition of what modern astronomers call the "inequality of the seasons" (see below). Dicks (1970) moreover asserts that it is easiest to determine the summer solstice. Solsticial observations were certainly attributed to Aristarchos and Hipparchos, but given the slow movement of the Sun along the horizon at that time, they were not favored by ancient astronomers. Ptolemy says that

> since observations of solstices are, in general, hard to determine accurately, and since, furthermore, the observations handed down [from the schools of Meton, Euktemon, and Aristarchos] were conducted rather crudely (as Hipparchos too seems to think), we abandoned those, and have used instead . . . equinox observations. . . . (*Almagest*, III 1, H203; in Toomer 1984, p. 137)

Another early accomplishment may have been at least a limited ability to predict eclipses (see §5.2.2 for a discussion of Thales's possible prediction of ~585 B.C.), although this knowledge does not seem to have been generally shared, if it existed.

The notion of the celestial sphere seems to arise with the Greeks. According to Dicks (1970, pp. 169, 175), the Babylonians had no concept of the celestial sphere or of longitude and latitude, or of circular motion, which he states was the principal mathematical tool of Greek astronomy, just as arithmetic progression was for the Babylonians (p. 176). Anaximenes of Miletos (d. in 63rd Olympiad, 528–525 B.C.) is said to be the first Greek to conceive of a rotating sphere of fixed stars (Sarton 1952/1970, **I**, p. 178).[24] The 5th-century

[24] An Etruscan depiction of Atlas holding a celestial sphere may be of similar date.

FIGURE 7.11. Ruins of the temple of Olympian Zeus at Akragas (modern Agrigento), Sicily, one of the largest Greek temples ever constructed: Built by Carthaginian captives in 480 B.C., it was destroyed in the Carthaginian sack of Akragas in 406 B.C. (a) View from the south along main axis. (b) A now prone Telemon pillar. (c) A capital of the massive pillars. Marie Milone provides scale. Photos by E.F. Milone.

(B.C.) Pythagorean astronomers Parmenides of Elea and Philolaos of (Croton/Tarentum) may have been the earliest Greeks to conceive of a series of concentric celestial spheres and to envisage a rotating Earth, respectively (Sarton 1952/1970, pp. 288–289). The first major cosmological scheme that seems to have been solidly based on extensive observational data joined to spherical concepts was that of Eudoxos. Eudoxos of Cnidus (~408–355 B.C.) came from Asia Minor (Cnidus was in Caria, South of Miletus, in what is now southwestern Turkey), but his ideas were shaped and tempered by study in Athens, Alexandria, and elsewhere. He was taught by the Pythagorean mathematician Archytas, and he heard Plato and other philosophers in Athens. A detailed account of his life is given by Dicks (1970, 151ff). Eudoxos wrote an account of the constellations that was later used by Aratos in his lengthy poem, *Phainomena* or *Phaenomena*, according to the later Greek astronomer Hipparchos (see §7.3). The poem was a major source of knowledge about the relationship of the Greek myths to the constellations,[25] throughout the medieval period and even into the 19th century. The constellations as described by Aratos show positional discrepancies with respect to the sky of his time, and it has been maintained that these are evidence of precessional changes from as early as 2200 B.C. Most scholars (beginning with Hipparchos) have regarded them as errors (Dicks 1970, pp. 153–157).

There is some evidence that Babylonian observations were widely used by Greeks. Ptolemy claimed that some observations were available from as far back in time as the reign of Nabonassar, and that planetary observations were made by Egyptians and Syrians. Aristotle emphasized that many occultation observations were available from these sources and that they provided much knowledge of the planets, and Aristotle's nephew, Callisthenes brought back from Babylonia a great number of records, a gift of Aristotle's famous pupil, Alexander the Great. However, there is no direct evidence that Eudoxos was trained by Babylonian astronomers, that he had access to the tablets containing the Babylonian planetary data, or that he knew cuneiform. He did use Babylonian planetary periods (Dicks 1970, p. 167), but later sources (e.g., Ptolemy) also reported that he made many observations himself. Dicks (1970, pp. 257–258, Fn 355) cites the Roman architect Vitruvius (2nd century B.C.), who says in connection with sundials, that Eudoxos invented the *arachne*, "spider." Dicks notes that "Later, the movable disc (representing the ecliptic) of the planispheric astrolabe was called the 'spider' . . . but Eudoxos certainly did not know this instrument."

7.2.3. Concentric Spheres

Eudoxos's basic cosmological scheme is illustrated in Figure 7.12.

[25] Greco-Roman period maps of the constellations are known only from a celestial globe that amplifies the frequent depiction of Atlas holding the heavens into a full-scale celestial map, known as the Farnese globe. See §2.1.1.

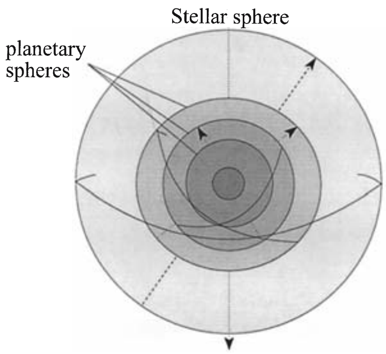


FIGURE 7.12. Sketch of the concentric spheres cosmological concept of Eudoxus: The spheres carrying the planets are nested within the sphere carrying the fixed stars. Several spheres are needed to create the motions of each planet, and the axial offset is required because of the inclinations of the planetary orbits. Drawing by E.F. Milone.

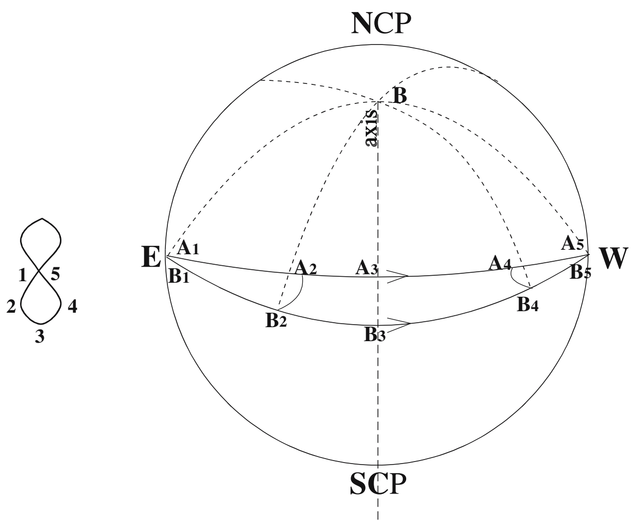


FIGURE 7.13. The rolling motion of one planetary sphere on another: In this illustration, the labeled axis emerging from the sphere at point **B** gives rise to motion along the arc B_1 to B_5. The comparison of this motion to that on the arc A_1 to A_5 (the celestial equator in this example) gives rise to the relative motion shown to the left. This is the *hippopede*. Drawn by E.F. Milone, after Pannekoek (1961/1989, Fig. 8, p. 109).

The rolling motion of one planetary sphere on another resulted in a curious motion on the sky (somewhat like the solar analemma cf. §4.1.2), known as the *hippopede*, after a hobble used on the front legs of horses. The hippopede motion is illustrated in Figure 7.13. In all, Eudoxos required an elaborate series of 26 nested spheres, with some rotating counter to the adjacent one in an attempt to decouple one planet's motion from another.

The concentric sphere cosmology was further elaborated by Kallippos (or Callippus in Latin) [fl. 4th century B.C.] of Cyzicus, on the Sea of Marmora, who studied with an associate of Eudoxos in that city, Polemarchus. Simplicius[26] states that Polemarchus was aware that Eudoxos's model could not account for planetary brightness variations, brought on by their varying distances from Earth. Dicks (1970, p. 191) speculates that Kallippos introduced seven additional spheres (two each to the Sun and Moon, one each to Mercury, Venus, and Mars) to provide retrograde motion for Mars and Venus and that these motions were not in Eudoxos's original model. If true, this would have been a more glaring omission than the brightness variation, the true cause of which could scarcely have been known to Eudoxos. Aristotle [Athens, 384–322 B.C.] elaborated the model still further: He added 22 celestial spheres to Calippos's 33, making 55, in order to counteract the motions of the driving spheres for each planet.

The Hellenic period marked a highpoint for the concentric spheres; observations compelled astronomers of the Hellenistic and Roman periods to displace both the physical centers of these spheres from the Earth, and their centers of uniform motions (the *equants*). Elaborate systems of epicycles were further required to "save the phenomena." In a subsequent period, schools of Islamic astronomers strove to recapture the perfection of the uniform circular motion that the spheres represent. Visions of the celestial spheres dominated European cosmological thinking through the Middle Ages, and into the Reformation period, when Tycho's geo-heliocentric model broke through the crystalline spheres with overlapping orbits, and the Copernican system as elaborated by Kepler destroyed the perfect circular motion once and for all.

7.2.4. Classical Cosmologies

Aristotle's prolific ideas ran far beyond the elaboration of the concentric spheres, in astronomy as in all fields of thought. Among his astronomical views were the following:

(1) The universe is finite, because an infinite universe cannot have a center (the Earth).

(2) The sphere of the fixed stars was the prime mover, hence, the highest god; yet, behind that sphere was an unmoved mover, influencing all the others as the "beloved" influences the "lover" (this view is somewhat reminiscent of Plato's view of the universe as a living soul).

(3) The Earth is spherical, and not of tremendous size; he cites the results of certain mathematicians (presumably Eudoxos and Kallippos) for the circumference of the Earth: 400,000 stadia.

(4) Comets and the Milky Way were atmospheric phenomena, "fiery exhalations."

Sarton (1952/1970, **I**, pp. 509–511) intimates that, on the whole, Aristotle was a great philosopher but a poor astronomer and the canonization of his ideas impeded the advance of astronomy for centuries—but that there is one

[26] A 6th-century A.D. commentator, originally from Cilicia, and one of the last teachers at the Academy founded by Plato. The academy was shut down by the Roman emperor Justinian in 529 A.D.

area where his views redeem him to a slight degree: by planting a seed that bore fruit at the end of the 15th century:

> There is much change, I mean, in the stars which are overhead, and the stars seen are different, as one moves northward or southward. Indeed there are some stars seen in Egypt and in the neighborhood of Cyprus which are not seen in the northerly regions; and stars, which in the north are never beyond the range of observation, in those regions rise and set. All of which goes to show not only that the Earth is circular in shape, but also that it is a sphere of no great size: for otherwise the effect of so slight a change of place would not be so quickly apparent. Hence one should not be too sure of the incredibility of the view of those who conceive that there is continuity between the parts about the Pillars of Hercules and the parts about India, and in this way the ocean is one. As further evidence in favor of this they quote the case of elephants, a species occurring in each of these extreme regions, suggesting that the common characteristic of these extremes is explained by their continuity. Also those mathematicians who try to calculate the size of the Earth's circumference arrive at the figure 400,000 stades. This indicates not only that the Earth's mass is spherical in shape, but also that as compared with the stars it is not of great size. (De Caelo, 298A, Stock tr., 1922; reproduced in Sarton 1952/1970, Vol. I, p. 510).

The Hellenic world certainly held concepts closer to modern views than did Aristotle's four misconceptions (mentioned earlier)—as his spherical Earth and the work of Heracleides and Aristarchos (discussed in §7.3) illustrate.

Heracleides [388–≥310 B.C.] of Pontos, on the Black Sea, was a student of Plato and Plato's successor at the Academy, Speusippos [400–339 B.C.]. He held that the universe was Earth-centered, but infinite, and that the Sun, Moon, and superior planets revolved around the Earth, but the inferior planets, Mercury and Venus, revolved around the Sun. The latter scheme satisfactorily accounts for the elongation limits of the inferior (in modern usage, interior) planets (see §2.4.3). The later writers Aetios [Historian of philosophy, fl. ~1st century A.D.] and Simplicios [Greek philosopher, fl. 529] reported that he held that the Earth rotated on its axis, a motion that made unnecessary the rotation of the stars around Earth. Sarton (1952/1970, **I**, p. 507) notes that similar ideas reappeared in the works of many subsequent scholars, including Chalcidius [Platonic philosopher, fl. 315, probably in Rome], Macrobius [Greek writer, fl. 395–423], Martianus Capella[27] [fl. 430, Madaura, Carthage], John Scotus Eriugena [Irish theologian, ca. 810–877], and William of Conches [Natural philosopher, fl. 1122 in Paris]. Heracleides's universe was the first of the blended geo-heliocentric universes proposed through the centuries, culminating[28] in the expanded scheme of Tycho Brahe in the 16th–17th century, where all the planets except Earth revolve about the Sun and the Sun alone revolves about the Earth. It is interesting to note that objections to one or more features of the planetary spheres surfaced several times. The astronomer Autolycos of Pitane[29] (~300 B.C.), whose life bridged the transition from classical Greece to the hellenistic world of Alexander, wrote at least three books on spherical astronomy, two of which were preserved by the Arab world and are still extant. His books on spherical astronomy (*On the Moving Sphere* and *On Risings and Settings*) are the earliest we have that give geometric solutions for spherical triangles on the celestial sphere, but unproved theorems in them suggest at least one earlier work (see Sarton 1952/1970, **I**, p. 512 for further details). They were used for generations if not centuries and were preserved in the *Little Astronomy* (as opposed to the *Almagest*, a corruption of the Greek word for "the greatest") by Arab copyists. Autolycos criticized the Eudoxos spheres scheme on the basis of its inability to explain the planetary brightness variation and the changing sizes of the Sun and Moon.

We cannot leave the classical Greek period without mentioning Plato's astronomical views. Although Plato (Athens, 427–347 B.C.) was certainly not known as an astronomer, he held views on cosmology, and on the value of astronomy. In *The Republic*, Plato discusses the purposes of higher education, and he identifies the areas that are most enlightening. For Plato, factual evidence is of little value; the goals are the underlying ideas that invest everything with meaning. In the dialogue, Plato has Socrates ask Glaucon, "What form of study is there . . . that would draw the soul from the world of change to reality?"[30] The studies proposed are basically mathematics: arithmetic, plane and solid-body geometry, astronomy, harmonics, and dialectic (the latter understood as a kind of synthesis of understanding). Astronomy is an essential science in that examination of astronomical phenomena lead, in Plato's mind, to numbers.[31] In Plato's understanding, however, the observational study in astronomy, is not particularly rewarding, because

> No one . . . can ever gain knowledge of any sensible object by gaping upwards any more than by shutting his eyes and searching for it on the ground, because there can be no knowledge of sensible things.
>
> These intricate traceries in the sky are, no doubt, the loveliest and most perfect of material things, but still part of the visible world, and therefore they fall far short of the true realities—the real relative velocities, in the world of pure number and all perfect geometrical figures, of the movements which carry round the bodies involved in them. These, you will agree, can be conceived by reason and thought, not seen by the eye.

---

[27] Capella wrote *Satyricon*, an encyclopedia that was widely read in the Middle Ages. In it, he formulated the classification of the seven liberal arts: the *trivium*—grammar, rhetoric, and logic; and the *quadrivium*—arithmetic, geometry, astronomy, and music. He also speculated about the heliocentric solar system.

[28] Culminating but not concluding: A less expanded, somewhat reactionary system was proposed by the Jesuit astronomer John Baptiste Riccioli in the mid-17th century. Fortuitously, Riccioli is more noted for discovering the first telescopic double star (*Mizar*) in 1650, and for devising the present lunar crater-naming scheme—after eminent astronomers and philosophers (in *Almagestum novum*, 1651).

[29] On the coast of present day Turkey, opposite the island of Lesbos.

[30] *The Republic*, Cornford tr., Chapter XXVI, p. 237.

[31] *Timaeus*, p. 47: "the sight of day and night, of months and the revolving years, of equinox and solstice, has caused the invention of number and bestowed on us the notion of time and the study of the nature of the world, whence we have derived all philosophy." *Gorgias*, p. 451: Socrates indicates that astronomy deals with "the relative speeds of the motions of the sun, moon, and stars."

The genuine astronomer . . . will admit that the sky with all that it contains has been framed by its artificer with the highest perfection of which such works are capable. But when it comes to the proportions of day to night, of day and night to the month, of month to year, and of the periods of other stars to the Sun and Moon and to one another, he will think it absurd to believe that these visible material things go on for ever without change or the slightest deviation, and to spend all his pains on trying to find exact truth in them.[32]

This idea is based on the unreliable nature of the changing material world, most clearly illustrated in the allegory of the cave.[33] In this elaborate analogy, the world perceived by the senses is likened to shadows cast on the wall of the cave by figures illumined by a light behind prisoners who are unable to turn their heads to see the source of the shadows. Thus, the "real" world is unseen and must be explored by the mind alone; the ideal forms are not simply "in the mind" but are the reality behind each of the particular objects that we construct and see and use in everyday life. A physical chair, for example, is but an imperfect manifestation of the ideal chair. This idea is at the core of Platonism and appears again and again in western thought from the classical period down to modern times.

7.3. Astronomy in the Hellenistic and Roman Periods

The conquests of Alexander spread Greek culture throughout the Mediterrean, the Near East, and as far as India. Among the ancient histories of Hellenistic astronomy, two stand out: the Commentaries on Aristotle's De Caelo by Simplicios of Cilicia (fl. 6th century A.D.) and a work of Eudemos of Rhodes, (fl. ~325 B.C.), who was a pupil of Aristotle. Sarton (1952/1970, **I**, p. 505) regards Eudemos as the first historian of mathematics and, with Menon, the first historian of medicine and another student of Aristotle. Eudemos's writings included histories of arithmetic, geometry, and astronomy, all of which are now lost, but some of his material is cited by Aristotle, and the works are mentioned in the writings of Proclus (d. 485 A.D.). A tertiary source is Simplicios (6th century A.D.), who cites Sosigenes (Julius Caesar's astronomical consultant, responsible for the reform of the Roman calendar) who had access to Eudemos's astronomical history.

7.3.1. Establishing Scale: Aristarchos and Eratosthenes

Few of the early sources survive, but an important source is the writing of Aristarchos (310–~230 B.C.) of Samos, of the Alexandrian school of astronomers. He made an important estimate of the relative distances of the Earth, Moon, and Sun. Aristarchos's experimental method consisted of measurement of the precise time interval between 3rd and 1st quarters of the Moon. The ratio of this interval to the synodic period of the Moon would be equal to the ratio of the angle subtended at the Earth by the Moon at these two points to 360° (or, in radian measure, 2π) if the orbits were purely circular. The cosine of half this angle is the ratio of the distances of Moon and Sun from Earth. Figure 7.14 illustrates the geometry.

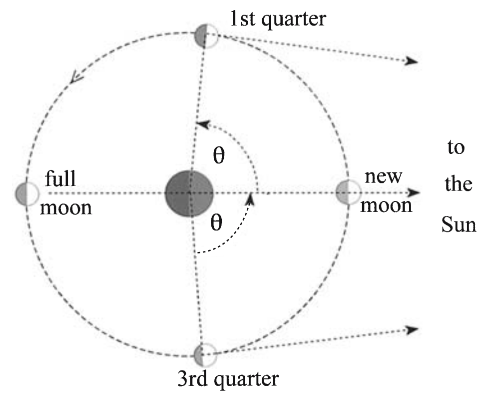


FIGURE 7.14. The geometry of Aristarchos's method to find the ratio of the distances of Moon and Sun from Earth. Drawing by E.F. Milone.

In addition to this experiment, which Aristarchos could not possibly have carried out to the requisite precision over a single lunation—if it was ever carried out at all—he was able to make the distinction between the *apparent* size as opposed to the *actual* size of an object.[34] This led directly to estimates of the relative sizes of Sun and Moon. Aristarchos's values compared with modern values (in brackets), in units of Earth diameter, are

Solar distance:	200	[11700]
Lunar distance:	10	[30]
Lunar diameter:	1/3	[0.272]
Solar diameter:	7	[109]

Presumably on the basis of the relative sizes of Earth, Sun, and Moon, he asserted the primacy of the Sun and heliocentricity. Copernicus was later to cite him as one of the ancient astronomers who had come to a similar conclusion about the nature of the solar system.[35]

The geometrical approach of Greek astronomers that has proven so effective for more than two millennia can be readily illustrated in an important case. Earlier Greek "mathematicians" mentioned by Aristotle had estimated the circumference of the Earth as 400,000 stadia, but Eratosthenes (283–200 B.C.) provided a much more accurate result.

[32] *The Republic*, Cornford tr., Chapter XXVI, pp. 247–248.

[33] *The Republic*, Cornford tr., Chapter XXV, pp. 227–235.

[34] A distinction that evidently eluded the 1st-century B.C. writer Lucretius (*On the Nature of Things*, VI, lines ~360–~430).

[35] In fact, Gingerich (1993, pp. 186–204) argues that Copernicus was only indirectly aware of Aristarchus's cosmology, and that the one passage in which he mentions his cosmology was deleted by Copernicus prior to *De Revolutionibus*'s publication. It mentions that Philolaus believed that the Earth moved and that "some even say" that Aristarchus held a like opinion.

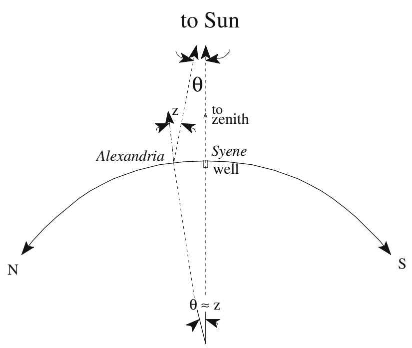


FIGURE 7.15. The geometry of Eratosthenes's method to determine the circumference of the Earth: The method needed a measurement of the noon Sun's zenith distance at Alexandria on the same date that the Sun was seen to appear at zenith at Syene. The method assumes that the Sun is at an infinite distance from the Earth and requires accurate knowledge of the physical distance between two sites involved in the measurement. Eratosthenes's method of the size of the Earth. Drawing by E.F. Milone.

The determination rested on the measurement of the zenith distance of the Sun at Alexandria at the same date that the Sun was seen to appear at zenith at Syene. The measurement required the assumption that the Sun is at an infinite distance from the Earth, i.e., that the solar parallax is ignorable; it also required accurate knowledge of the physical distance between two sites involved in the measurement. The geometry is illustrated in Figure 7.15.

The relation between the zenith distance, z, and the difference in latitude, $\Delta\phi$, between these two sites on approximately the same longitude circle is simply

$$z = \Delta\phi \tag{7.6}$$

so that the relation between the linear separation of these sites, s and z, is

$$\frac{z}{360} = \frac{s}{C}, \tag{7.7}$$

where C is the circumference of the Earth. Because $C = 2\pi R$, the radius of the Earth is thus found. Eratosthenes found z to be 7°.2 or 1/50 of the circumference of a circle.[36] His value for the distance between the two sites was 5000 stadia, and the resulting circumference, *250,000 stadia*. This number cannot be directly and independently compared to modern units of length because the unit of *stadium*, whereas clearly refering to an athletic stadium is not uniquely defined in the ancient world; *stadia* were not of uniform dimensions. If there were 10 stadia to the mile, Eratosthenes's result is 25,000 miles or 40,200 km), very close to the modern value, 24,900 miles (40,070 km). From Eratosthenes's data, the Earth's radius is then 39,800 stadia, and so 3980 miles (6400 km); the actual equatorial radius is 6378 km. If, however, there were only 8.5 or even 7.9 stadia to the statute mile, values found, for example, in the writing of the Roman historian Cassius Dio[37] (Humphrey 1990), then the corresponding radius for the Earth is 4680 or 5040 miles (7530 or 8100 km), respectively. The distance between Syene and Alexandria is approximately 890 km, however, and if this represents the accurate distance between the two observing sites used by Eratosthenes, then $890 \times 50 = 44{,}500$ km, giving a relative error of about 11%. A similar but inherently more inaccurate technique was used by Poseidonios[38] (140–150 B.C.), who used the difference in altitude of the star Canopus at two sites. At the island of Rhodes, it was just on the horizon, whereas at Alexandria, it was about 5° above the horizon.[39] In principle, the method is fine. The refraction-corrected difference in altitude of a star observed at two sites differing in latitude by an amount $\Delta\phi$ would be

$$\Delta h = \Delta\phi. \tag{7.8}$$

So, if the linear distance along the Earth's surface between the two sites is known, the circumference of the Earth is found. Due to refraction, the result, $R_{\oplus} = 4600$ km, is less accurate than that seemingly obtained by Eratosthenes. Experiment §4 of Schlosser et al. (1991/1994) provides a modern challenge to carry out a slightly more accurate version of this ancient experiment (performed using zenith observations) and improve on the results.

7.3.2. The Canonical Geocentric System: Hipparchos and Ptolemy

Hipparchos of Nicaea, Bithynia [fl. 2nd century B.C.] has been called the greatest astronomer of antiquity. He built an observatory on the island of Rhodes, and he made numerous observations and, with these carefully recorded data, made several important discoveries.

Hipparchos is credited by Ptolemy with a list of treatises:

(1) "On the displacement of the solsticial and equinoctial points"
(2) "On the length of the year"
(3) "On intercalary months and days"
(4) "On sizes and distances"
(5) "On parallaxes"

[36] Sarton (1970) states that the difference in latitude between Alexandria (27°31′N, 31°12E) and Syene (30°35′N, 24°05′E) is actually 7°07′ and that they do not actually lie on the same longitude circle. The latter just means a slight difference in time between the two events, but the former indicates a slight error in angular measurement.

[37] From Bithynia, ~163–~235 A.D. In his *Roman History*, Dio often used 7.5, but also cited data implying 8 stadia to the Roman mile. The latter value was used more widely. One Roman mile (*mille passus*) = 0.947 statute mile.

[38] Poseidonios, who was born in Apamea on the Orontes River in Asia Minor, was a stoic philospher (and head of the school in his day) as well as an astronomer and geographer. Sarton (1952/1970, **I**, pp. 604–605) notes that he settled in Rhodes, where Cicero attended his lectures.

[39] Refraction is greatest at the horizon, where it is ~½°. Therefore, the difference in refraction (which varies with the temperature and pressure) at the two sites, especially if the observations are made at different dates, can cause unnecessary loss of accuracy. See §3.1.3 for the causes of and corrections for refraction variation.

all of which are lost except for fragments quoted in other books, especially by Ptolemy in the *Almagest*. What we have is nevertheless astonishing; they convincingly demonstrate his prowess as an observer and a modeler. For example, in the third treatise, Hipparchos examined the intercalation problem, further improving on the solution of Kallippos (itself an improvement over Meton—see §4.2). Kallippos took an exact value of 365¼ (and Meton and an astronomer named Euktemon had used 365¼ + 1/76 d) for the length of the tropical year, but Hipparchos found a more accurate length (1/300 of a day shorter or $365^{\rm d}.2467$ compared with the modern $365^{\rm d}.2422$). Comparing his observed (fractional) date of a summer solstice in 135 B.C. with that made by Aristarchos in 280 B.C., Hipparchos is quoted as writing (in the second treatise listed above) that

> It is clear, then, that over 145 years, the solstice occurs sooner than it would have with a [365]¼-day year by half the sum of the length of day and night. . . . (*Almagest*; III, 1, H207; in Toomer 1984, p. 139)

(yielding $365^{\rm d}.2466$) and in the third treatise, is quoted as saying,

> As for us, we find the number of whole months comprised in 19 years to be the same as they [Meton, Euktemon, Kallippos] but we find the year to be even less than ¼[-day beyond 365], by approximately 1/300 of a day. Thus in 300 years its accumulated deficit is 5 days compared with Meton, and 1 day compared with Kallippos'. (*Almagest*; III, 1, H207; in Toomer 1984, p. 139)

Hipparchos's study of the length of the year led to the realization that the length of the year—i.e., the time for the Sun to complete an annual circuit of the ecliptic—depended on whether it was measured with respect to the stars or to the equinoxes and solstices.

One of his most famous works was the compilation of a star catalog, the first of which we are aware. It contained 850 objects and gave both the position on the sphere and a measure of their brightnesses: *magnitudes*. In comparing previously measured positions of stars by Aristyllos and Timocharis (who lived in the first quarter of the 3rd century B.C.) with his measured positions, Hipparchos, we are told by Ptolemy,[40] discovered the precession of the equinoxes (see §3.1.6 for a detailed discussion of precession):

> The ancients were in disagreement and confusion in their pronouncements on this topic, as can be seen from their treatises, especially those of Hipparchos, who was both industrious and a lover of truth. The main cause of the confusion on this topic which even he displayed is the fact that, when one examines the apparent returns . . . to . . . equinox or solstice, one finds that the length of the year exceeds 365 days by less than 1/4-day, but when one examines its return to . . . the fixed stars it is greater . . . Hence Hipparchos comes to the idea that the sphere of the fixed stars too has a very slow motion, which just like that of the planets, is towards the rear. . . . (Toomer 1984, p. 131)

His value for the precession was ~45 arc-sec/year (compared with the modern value, 50.29 arc-sec/year) and was more accurate than was Ptolemy's asserted value, 36 arc-sec/year. It has been argued (*see* citations given by Sarton 1952/1970, **I**, p. 445) that it was possible that Hipparchos made use of very old Mesopotamian data. However, Ptolemy (*Almagest*, Toomer 1984, p. 321) says that Hipparchos

> had found very few observations of fixed stars before his own time, in fact practically none beside those recorded by Aristyllos and Timocharis, and even these were neither free from uncertainty nor carefully worked out. . . .

Hipparchos is credited also with working out the inequality of the seasons, a result based on precise measurements of the dates of the equinoxes and of the solstices. This discovery led him to establish a theory for the Sun's motion based on the notion of an *eccentric*, a circle whose center is offset from the Earth. He found the size of the offset to be 1/24 of the radius of the orbit. This formulation accounts for the apparently faster motion of the Sun on the ecliptic during one-half of the year (when the Earth is nearer perihelion) and slower at the other (when the Earth is nearer aphelion), and because an offset circle is a close numerical approximation to an ellipse of very small eccentricity, such a theory is suitably precise for predictions of solar motion to the limited precision of naked-eye astronomy before Tycho Brahe. Hipparchos studied the Moon as well, improving on Aristarchos's values for the Moon's distance,[41] arriving at 29.5 Earth diameters (compared with the modern value, 30.1). Finally, his theories of the Moon and Sun permitted the calculation of eclipses to a precision not previously possible; and the determination of the effect of lunar parallax on eclipses made possible a prediction for the location for the eclipse to be visible.

The last great astronomer of classical antiquity was Claudius Ptolemaeus, better known to us as Ptolemy [100–175 A.D.]. He worked in Alexandria, the most prominent astronomical center at the time. His important astronomical writings, μαθηματικὴ σύνταξιζ (*A Systematic Mathematical Treatise*), became the standard text for more than a millennium, an endurance record exceeded only by Euclid's *Elements*, among scientific books. By the 16th century, it was found in numerous Greek, Arabic, and Latin versions under its Arabic title, the *Al Magest*. Toomer's (1984) English translation is accompanied by copious and informative notes, and it is indispensable for anyone studying the astronomy of Hellenistic Greece. Toomer (1984, p. 5) believes that a considerable number of erroneous interpolations, placed there in antiquity, are found in all existing versions. The work that has been handed down to us now consists of 13 books, possibly organized this way long after Ptolemy's death. Table 7.14 briefly summarizes the content of each of the books.

The *Almagest* was not intended as a primer, but for those who had "*made some progress in the field*" (Toomer 1984, p. 6) and were acquainted with the spherical trigonometry in the writings of Autolycus, Euclid's *Phaenomena*, and Theodosius's *Sphaerica*. The work contains many observations of

[40] *Almagest*, Book VII (Toomer 1984, p. 321).

[41] Hipparchos made use of a solar eclipse that was total at the Hellespont, but partial at Alexandria, for example, to compute the distance to the Moon. The maximum angular extent of the uneclipsed part of the Moon is the angle at the Moon between the two sites at Earth; the linear distance between the sites was known, and the distance to the Moon follows.

TABLE 7.14. Brief summary of contents of the Almagest.

Book	Nature of the material
I	The Earth and its relations to the heavens
II	The sky as seen from different places on Earth
III	Solar motion; the year
IV	Lunar phenomena and motions
V	The astrolabe; the lunar orbit and the distances and sizes of the Earth, Sun, and Moon
VI	Solar and lunar conjunctions and eclipses
VII	The fixed stars; precession; northern hemisphere constellations
VIII	southern hemisphere constellations; rising and setting phenomena
IX	Planetary orbits; Mercury
X	Venus and Mars
XI	Jupiter and Saturn
XII	Retrograde motions and greatest elongations
XIII	Planetary latitudes and orbital inclinations

the Moon and other objects both by Ptolemy and by others, including Hipparchos, Timocharis, Menelaus, and Agrippa, descriptions of phenomena and of instrumentation needed to make careful positional measurements, and a number of hypotheses regarding planetary motion and the layout of the cosmos. He presents the geocentric theory with eccentrics and epicycles to satisfy the observations. It is from this work that the geocentric solar system received its canonical form, and against which post-Renaissance and Reformation European science had to struggle. In his view, the planets Mercury and Venus revolved epicyclically, around a (mean) center that was either on—or very close to—the Earth-Sun line. The Sun, of course, revolved about the Earth and, therefore, so did the inferior planets. However, planetary motion suggested that the deferent orbits were eccentric, i.e., not centered on Earth, which meant that the planets are sometimes closer to, and sometimes farther from, the Earth. Ptolemy determined the apogee and perigee locations of the inferior planets by observing the maximum elongations of these planets from the Sun and noting when the elongations reached extremes. A large maximum elongation angle was assumed to arise because of a smaller distance from the Earth. The geometry is illustrated in Figure 7.16, adapted from Toomer (1984, Fig. 9.5, p. 454). Because Earth and Venus are in resonance, Ptolemy was not able to explore the full extent of Venus's orbital geometry, and the results are not as good as for Mercury.

Among Ptolemy's major improvements were an accurate distance of the Moon, a better lunar theory, and a new star catalog. The lunar distance determination involves parallax, measured, naturally enough, with a "parallactic instrument" (see Figure 3.20; Toomer 1984, Fig. G, p. 245), which was used to measure the meridian zenith distance of the Moon at each solstice. First, Ptolemy observed the range of extremes of the Moon's celestial latitude: ±5°0′. With the symmetry of the Moon's declination variation assumed, the difference of the Moon's extreme zenith distances could be compared, and the departure from symmetry attributed to parallax. At summer solstice, Ptolemy writes, the Moon appeared very nearly in the zenith ($z = 2\frac{1}{8}°$ for the Moon's center) as viewed from Alexandria, and at winter solstice, the Moon appeared at its greatest zenith distances. Comparing its true and apparent zenith distances, Ptolemy determined the lunar parallax to be 1°7′ = 1°.12 when the Moon was at $z = 49°48'$, where the refraction correction is less than 1′ (see §3.1.3). This can be compared with the modern value for the lunar mean equatorial horizontal parallax: 0°.951, a difference of less than 20%. Ptolemy was also aware that the Moon's distance varied with its position in the orbit. Ptolemy presents a table of lunar parallaxes, however, that are rather divergent, varying between a minimum of 53′34″ to a maximum of 63′51″ at full and new moons, when the moon is at the highest and lowest points of the epicycle, respectively, but also as high as 1°19′ and 1°44′ at the quarters; presumably, these are derived from the theory rather than observationally determined. It must be remembered that both Hipparchos and Ptolemy were attempting to describe the motions of Moon and Sun by differences in angular rates due to distances, alone, assuming constant orbital speeds (see §2.3.5). Ptolemy also measured the angular diameters of the Sun and Moon, but failed to find any variation in the size of the Sun over the course of the year.

His orbital theory for the Moon marked a substantial improvement over Hipparchos's. Gingerich (1993, pp. 59–62) summarizes Ptolemy's approach very nicely by illustrating the errors in lunar longitude against lunar phase. In the first instance, a theory that Ptolemy attributes to Hipparchos features a deferent centered on Earth + an epicycle + an advance of the perigee. It fits the data well at full and new moons and nowhere else, with largest errors ~±3° at the quarter phases. In the second instance, Ptolemy's correction to this model involves an eccentric, the center of which is permitted to rotate. The effect, known as the *evection*, was thus first reported by Ptolemy. This reduced the longitude errors in the orbit by more than 1/3. The largest residuals now appeared at the octants of the orbit (a further improve-

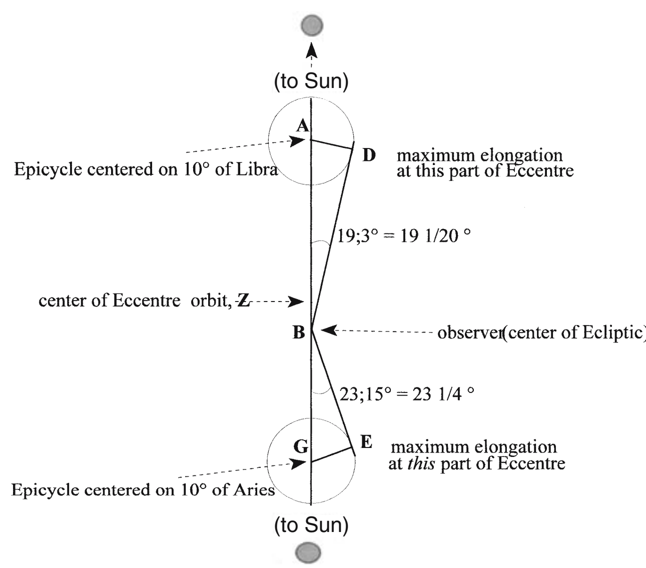


FIGURE 7.16. The geometry of Mercury's epicycle and eccentric deferent, according to Ptolemy. Drawing by E.F. Milone, adapted from Toomer (1984, Fig. 9.5).

ment came only many centuries later when Tycho Brahe discovered the *variation*, with 40-arc-min amplitude). More refined treatment by Ptolemy resulted in a further reduction in residuals to ~±1½°. Here, however, one of the several mysteries surrounding Ptolemy's work arises: The improvement is said to be based on only two observations that modern authorities agree are very unlikely to have produced the refinement indicated. This is characteristic: Brilliant results and exposition and unclear observational evidence. We illustrate further.

The star catalog, although useful for several purposes, does not seem to demonstrate great ability on Ptolemy's part as an observer. Some authorities maintain that the catalog positions are merely those of Hipparchos with a constant (2°40′, according to Newton 1977) added to all celestial longitudes to approximate a precession correction. Ptolemy's determination of the value of the precession was 36 arcsec/year, exactly 1° per century, certainly no improvement over Hipparchos's work. This sort of result has caused some modern scholars to question the methods and motives of Ptolemy's data treatment, which often disagree with modern calculations using his mathematical methods. Toomer (1984, p. viii) suggested that a critical summary dealing with all aspects of this question is yet to be done. Gingerich (1993) has provided part of the response. Some of the other difficulties and modern scholarly responses are indicated below.

Several recent studies bear on this question, but it is likely to persist for some time. Concerning the star catalog, reevaluation by Shevchenko (1990) suggests that the source of this additive constant is an uncertainty in solar longitude, to which the stellar positions are ultimately linked through reference stars, and appears to be based on observation, according to the methods described in the *Almagest*. Moreover, Shevchenko (1990) discusses Ulugh Beg's catalog, the observations for which were carried out with the instrumentation and methods of the *Almagest*; the accidental and systematic errors are shown to be comparable to those of Ptolemy's catalog. Concerning errors that are found in some of Ptolemy's tables for use in calculating lunar and planetary (celestial) longitudes, Van Brummelen (1994) demonstrates that those in auxiliary lunar tables are due to roundoff errors in the linear interpolations of functions of two variables, errors in angular measurements resulting in increases in the errors in the resulting longitudes. Work by Nevalainen (1996) suggests that errors due to linear interpolation are not important in the case of Mercury data, but he also indicates that Ptolemy's model for Mercury has a smaller mean motion than is actually the case, resulting in systematic discrepancies in predicted position. Nevalainen attributes this circumstance to the use by Ptolemy of values of the stellar longitudes that are too small by an average of –1°.7; moreover, because Ptolemy compared these too small values with those of Hipparchos, he obtained too small a value of the precession. Newton (1982) also criticizes three of the four observational lunar eclipse records of Ptolemy (see Table 5.2). The maximum deviation is about 50 minutes according to sources used by Schove (1984, pp. 25–27), but the match seems better than this, for at least the last three. For the first, there is some question about whether Ptolemy quotes the time of maximum eclipse in equinoctial or equatorial hours. See Toomer (1984, pp. 198, 205–208) for a fuller discussion.

In the cases of solar, lunar, and planetary observations, Gingerich (1993, pp. 55–73) notes several cases in which Ptolemy's reported observations do not agree with modern theory, but they do agree with Ptolemy's theory. Fraud on Ptolemy's part (as argued, for example, by Newton 1977) is unlikely on several grounds. As Gingerich notes, "How can Ptolemy's parameters, which seem generally more accurate than his data base, be derived from observations that are simply fabricated?" We are left with an incomplete knowledge of how he was able to formulate those theories. It appears likely, at least in some cases, that Ptolemy selected the observations as illustrative of the correctness of his theories rather than as evidence of independent, positive proof. The situation may be analogous to a lecturer working out an illustrative example in a modern science classroom. This is in fact the viewpoint already taken by Delambre (1817; cited in Pannekoek 1989, pp. 149–150). Clearly, Ptolemy had sufficient confidence in his theories of motions of the planets to provide ephemerides, and perhaps, this was sufficient enough reason to create "virtual facts"—i.e., illustrative examples.

A subsequent work by Ptolemy, entitled Ὑποθέσεζ τῶν Πλανώμενων, *Planetary Hypotheses*, was meant to provide improvements to results obtained in the *Almagest* because they were based on "more continual observations" (see Murschel 1995 for explicit details). In this work, much of which was lost until this century, Ptolemy argues for a solar system distinctly different from the rolling spheres of Eudoxos and Aristotle. There are a set of outer, concentric shells to provide the diurnal motion, the precessional motion, and additional "mover" shells to move the planets. Thus, Ptolemy's planets participate in the diurnal motion of the stellar sphere, but in order to explain their peculiar motions, and to avoid the many countermotion spheres of Eudoxos, they each require a different character than do the passive objects of earlier Greek astronomy. The planets have souls that enable them to move with "voluntary motion" and, thus, perform their individual epicyclic and deferent motions.

Ptolemy was an encyclopedist with a wide range of interests. Astronomers tend to regard the *Almagest* as his most important work, whereas historians and geographers think of him for his *Geographia*. He also wrote major works on optics and on musical theory. Another of Ptolemy's works, the *Tetrabiblos*, had much the same impact on the acceptance of astrological views that the *Almagest* had on epicyclical astronomy (see §7.4.3). The first distinction between the terms "astronomy" and "astrology" appears to have been made by Ptolemy in these works.

7.3.3. Astronomy and Religion in Late Antiquity

Throughout the Roman world, there were numerous soothsayers and astrologers; auguries and omens were eagerly sought. The requirements of civil governments and commerce, however, continued to respect practical things, such as devices to tell the time.

We discussed sundials and clepsydras in §4, but one construction is especially worthy of further note. Andronicus Cyrrestes [1st century B.C.] is known to have constructed the Tower of Winds in Athens. De Solla Price (1967) suggested a clock mechanism, the moving part of which was a celestial disk representing the equatorial plane, with punched holes representing solar positions along the ecliptic. A peg could be placed in the hole, and the disk could be made to rotate past a fiducial line representing the celestial meridian, thus, giving a uniform set of hours throughout the day or night (if the water held out that long). A fragment of such a disk was found in Vienna in 1902 in Roman ruins in Vienna. The rotation could be accomplished through the actions of a water clock. Clock-like gears were discovered in 1900 by sponge divers in a sunken Greek ship from ~80 B.C. A reconstruction, known as the *Antikythera* mechanism, after the island near the shipwreck site, is more likely a tallying device to keep track of dates, than a self-propelled time-keeping device, but is none the less intriguing.

As we noted in §4, Greek and republican Roman calendars were luni-solar calendars. The repetition of the phases of the Moon and the return of the Sun to the same place among the stars through its annual path were two nonsynchronous intervals of time; their reconciliation appeared to be one of the the main concerns of Greek astronomy.

A curious practice of numbering days in the month backward was carried out in pre-Julian, Roman Republican times. In this calendar, the phases of the Moon were explicitly noted three times during the month: the *Kalends*, the first day; the *Nones*, the 5th day in eight months but the 7th in four others; and the *Ides*, the 13th in most of the months but the 15th in four—*Martius*, *Maius*, *Quintilis* (July), and *October*—the 31-day months. Days other than these three were counted backward from them. Thus, two days before the *Ides* of March would be expressed *ante diem tertium Idus Martiae*, i.e., three days before the Ides. They may have derived originally from the phases of the Moon, but even in antiquity, the origins were lost, and they were instead attached to the "vestigial" luni-solar months (O'Neil 1975, pp. 45, 80).

Astronomers continued to work during the time of Roman dominance, but Ptolemy's syntaxis seemed to have such an overpowering influence that it effectively stifled further astronomical progress. Toomer notes that in Ptolemy's generation, some scholars continued to refer to the books of Hipparchos, but by the 3rd century, these and most older texts were not copied, having been supplanted by Ptolemy's books, for both teaching and research. Despite the changes in society that were going on, it is still curious that the importance of the phenomenon of precession was not widely recognized by post-Ptolemaic astronomers; only two[42] are known even to have discussed it. Of course, Ptolemy cannot be blamed for the failure of later generations of astronomers to envisage new models and to develop new methods of observations to test them. The decline of astronomy over the next century paralleled that of Mediterranean society generally. The reasons for the fall of Rome are beyond our scope, but clearly involved such elements as plagues (that carried by the army from Asia in 188 A.D. was particularly devastating); excessive spending on military conquests and maintenance; and finally, ever-more successful invasions by waves of warrior tribes from the east. Rostovtzeff (1927, p. 8) argued that already in the 1st century B.C., a bankruptcy of learning developed as a result of cruel oppression, exhausting wars, and general misery of the times, both in the Roman-dominated west and the Hellenistic east. Of course, if the climate for science in the era of Roman domination was miserable, the fortunes of science during the decline of the Roman empire can only be described as catastrophic, as the astrologers would put it.

[42] Theon of Alexandria (4th century) and Proclus (5th century). The latter denied its validity, and the former believed that the precession was periodic with a period of 1600 years, oscillating along an arc 8° wide. In the Middle Ages, this oscillation was called "trepidation." See §7.7 for further discussion of precession to the time of Copernicus.

Following Ptolemy, studies of the stars and planets were more and more concerned with the nature rather than with the movements of these bodies. Were they material or spiritual beings? Anaxagorus had argued that they were hot, incandescent matter. Were they alive? Most thought so. Were they gods? These were questions considered by the Academy since the days of Socrates, but the answers in late Hellenistic and Roman times were as divergent as the many religions and philosophies that swept the Mediterranean world. For a comprehensive treatment of Hellenistic and Roman philosophical world views, see Scott (1991), and further discussion in the context of the descent of the gods in §15.

Astrology became more important in the Roman period than it had been in the Hellenistic world. Observations of transient phenomena, especially of meteors and comets—signs of the times, so to speak—were widely recorded in the Mediterranean in the early Christian era. Among the better known records is the following excerpt. On describing the conditions and state of mind of Pompey on the eve of the battle of Pharsalus, Plutarch [Chaeronea, Boeotia, 46–≥120 A.D.] in *Fall of the Roman Republic: Six Lives* (tr. R. Warner 1954/1972, p. 204), says

> he was woken up in the night by various panic disturbances which went sweeping through the camp. Then during the morning watch a great light shone out over Caesar's camp, when everyone was fast asleep, and out of it came a flame like a torch which darted down upon the camp of Pompey. Caesar himself says that he saw this while he was inspecting the sentry posts.

The study of transient phenomena that involved observations of comets and other natural phenomena was a respected activity. Lucretius (~96–55 B.C.), a poet and epicurean philosopher, who opposed astrology, and Seneca (~4 B.C.–A.D. 65), a philosopher, man of letters, defender of astrology, and tutor to the emperor Nero, both wrote about comets; Pliny the Elder (A.D. 23–79) compiled a catalog of cometary forms and was killed studying an eruption of Mount Vesuvius. In 45 A.D., the emperor Claudius, knowing that a solar eclipse would occur on his birthday, made a public announcement explaining the circumstances of the eclipse in an effort to preclude negative public reaction to what would be regarded as an unfortunate omen (Lindsay 1971, p. 270). The emperor Hadrian (76–138) dedicated statues to the sun and moon gods (Anthony Birley, tr., Plutarch's *Lives of the Later Caesars*, p. 78). Hadrian was deeply interested in astrology and his great-uncle, an astrologer, was said to have predicted that Hadrian would become emperor. His horoscope for 26 January, 76 A.D., is extant, and begins with the phrase, "He became emperor because . . . [of highly favorable astrological circumstances]," indicating that the accession was regarded as a matter of astrological causation rather than of influence or mere signification[43] (Lindsay 1971, p. 309). Although his dedication to solar and lunar gods was in keeping with his conservative image, on at least two occasions, he spent nights on mountain tops in order to see the sunrise (pp. 71, 72). On Etna, he was interested in seeing multicolored sunrises that had been reported; on the other occasion, it was to make a sacrifice. The importance of omens and signs became paramount.

Eclipses and meteor showers are mentioned in the synoptic Gospels, both in Jesus's prophecy of the disasters to befall Jerusalem[44] and at the time of his crucifixion (Matthew 27:45, Mark 15:33, Luke 23:44–45). The former description is strongly reminiscent of the prophecy of Amos (8:9) and Joel (3:15–16); Bultmann and Kundsin (1934/1962, pp. 98–100) attribute such phrases to the interpolation of "eschatological-apocalyptic views" by the early Christian community into the Gospels. As for the Star of Bethlehem (discussed in §15), the dating of Easter has involved a great deal of scholarly discussion, beyond the question of historical attestation. The traditional date of the celebration of Easter is the first Sunday after the first full Moon following the vernal equinox. Good Friday precedes Easter by two days, so that the time of year is usually assumed to be near the vernal equinox. The descriptions of the crucifixion eclipse in Matthew and Mark are less explicit ["Now from the sixth hour there was darkness over all the land (*or* earth) until the ninth hour"], but in Luke, the cause is made clear ["It was now about the sixth hour, and there was darkness over the whole land (*or* earth) until the ninth hour, while the sun's light failed (*or* the sun was eclipsed; *or* the sun was darkened)"]. The 'hour' (ὥρα) was measured from dawn during this Roman period (Arndt and Gingrich 1952/1957, p. 904), although some earlier Jewish traditions used this type of reckoning as well (Metzger and Coogan 1993, pp. 743–744); the usage was such that the term referred to the hour just ended. Therefore, "sixth hour" refers to noon, and the "ninth hour" to 3 p.m. So that the darkening phenomenon took place in daylight hours. The Gospels confirm the daytime circumstance by indicating that the body was taken down from the cross because of the preparation of the sabbath to follow the next day. This circumstance would seem to rule out a lunar eclipse, because a full moon would not have been above the horizon during the crucifixion and, of course, would be in direct contradiction with the alternative reading of Luke. Oppolzer (1887/1962, Chart 60) shows a local solar eclipse as occurring in the region on Nov. 24, 29 A.D., but there appears to be no good candidate for a local solar eclipse taking place within the months of March–April for the years 27 to 36 A.D. (the interval when Pontius Pilate was the procurator). Passover must have occurred near full moon. The Synoptic Gospels suggest the crucifixion to have taken place on the date Nisan 15, although the matter is disputed among the churches because the information in the Gospel of John is usually taken to imply that the crucifixion took place on Nisan 14, and that the Last Supper was not the celebration of the Passover (Jeremias 1966, pp. 16–26). The new moon in the year 33 A.D. was on March 19 (this is astronomical new moon, not first visibility of the waxing crescent, which was used in calendrics and was probably March 20 or 21); full moon occured on April 3. Therefore, if an eclipse took place on the latter date, it would have had to be a lunar eclipse. Humphreys and Waddington (1983, 1990) argue that the event was meant to describe a lunar eclipse that occurred on Apr. 3, 33 A.D. The traditional date had been Mar. 25, 29 A.D. (at least since the time of Tertullian, ~200 A.D.), but this date did not coincide with Nisan 14/15. (The multiple calendars in use in Judaea at this time may, however, have included one in which March 25 did coincide with Nisan 14/15.) In any case, according to modern calculations (Liu and Fiala 1992), March 25, 29 A.D. was not the date of a lunar eclipse. Schove (1984, p. 328) suggested a lunar eclipse on Apr. 7, 30 A.D., which he claimed would have been more spectacular, but Liu and Fiala (1992) show an eclipse on May 6, 30 A.D. of magnitude 0.036, and on June 4, 30, A.D. of magnitude 0.145, neither spectacular; and no lunar eclipses in March or April of that year. These interpretations ignore the references in the Synoptic Gospels to an earthquake, the rending of the temple in two, and the dead rising from their open graves. Taken altogether, the language of the Synoptic Gospels suggests that these descriptions, too, may fall in the category of interpolated statements representing the eschatological beliefs of the early Christians, who would certainly have expected these kinds of events to accompany the self-sacrifice of God. Regarding the eclipse, except for one account, the Synoptic Gospels do not explicitly mention an eclipse, and alterna-

[43] There are at least three basic astrological approaches: that the stars in some way dictate the future; that they exercise some kind of influence, not always compelling; or, finally, that they provide warning signs or indications of possible future events.

[44] Immediately after the tribulation of those days the sun will be darkened, and the moon will not give its light, and the stars will fall from heaven, and the powers of the heavens will be shaken; then will appear the sign of the Son of man in heaven, and then all the tribes of the earth will mourn, and they will see the Son of man coming on the clouds of heaven with power and great glory; and he will send out his angels with a loud trumpet call, and they will gather his elect from the four winds, from one end of heaven to the other. (Matthew 24:29–31)

But in those days, after that tribulation, the sun will be darkened, and the moon will not give its light, and the stars will be falling from heaven, and the powers in the heavens will be shaken. And then they will see the Son of man coming in clouds with great power and glory. And then he will send out the angels, and gather his elect from the four winds, from the ends of the earth to the ends of heaven. (Mark 13:24–27)

And there will be signs in sun and moon and stars, and upon the earth distress of nations in perplexity at the roaring of the sea and the waves, men fainting with fear and with foreboding of what is coming on the world; for the powers of the heavens will be shaken. (Luke 21:25–28) tive interpretations exist. There are many reports of well-documented instances of profound darkness occurring in daytime, unrelated to eclipses. Humphreys and Waddington (1983) argue that the solar dimming was due to a duststorm, and suggest this (and a lunar eclipse) as the reason for Peter's recitation of Joel's prophecy (especially, Acts 2:19–20),[45] seven weeks later. Similar dark skies phenomena, related to volcanism or weather, are listed by Schove (1984, p. 327). Therefore, the darkness reported in Matthew and Mark and the failure of sunlight reported in Luke do not necessarily require an eclipse.

Evidence of associations between religious beliefs and astronomical ideas can be found in the Mithraic mysteries. Mithraism was one of a number of mystery religions that competed to some extent with Christianity in the early years of the Christian era, reaching a peak of popularity in the 3rd century, and dying off in the 4th. Although its belief system was unknown outside the sect, depictions on the walls where the cult held its meetings, images on cups, and the comments of ancient writers provide some clues. There are representations of seven figures on a large mixing cup discovered in Mainz in 1976; another cup, from Cologne, bears among other images seven stars. These representations and other evidence suggest a close association of the grades of Mithraism with the seven classic planets. A strong case has been made also for association of these figures with the four seasons and other key dates in the year. See Beck (1994a,b) for details on both matters. Frescoes typically portray the hero Mithras in the act of stabbing a bull; nearby are a scorpion, a cup, a snake, and a dog. Sun and Moon goddesses (so identified by the symbols on their heads) are also depicted farther removed from the action. Ulansey (1989) has argued that Mithras is in fact Perseus, and the bull, Taurus. The other characters in the drama represent constellations that were on the celestial equator on or below the ecliptic when the spring equinox was in Taurus; the cup, representing not the constellation *Crater*, however, but Aquarius. The slaying of the bull symbolizes to Ulansey the moving of the vernal equinox from Taurus into Aries, marking the beginning of a new age. The blood flowing from the wound is indeed shown in the form of ears of wheat, and other symbols of Spring (as well as autumn) are shown. Moreover, Mithras was identified by Porphyry [Tyre, 233–304 A.D.] as the "lord of genesis," thus, having an important role in world creation and maintenance; Ulansey's Fig. 7.4 shows Mithras as *kosmokrator*, supporting the celestial sphere. The interpretation depends on the notion that the constellation Perseus extended into what is now considered Taurus, and included the (then) location of the vernal equinox. A larger Perseus was mentioned by Porphyry and previously by Aratos (who was criticized by Hipparchus for placing the Pleiades on the knee of Perseus instead of on the more conventional location of the bull's shoulder). Webb (1952, Ch. 7), however, had an extensive critique of the view that the bull killed by Mithras was the constellation Taurus, and that this referred to the precession of the equinox into Aries.

Mithraism became popular among the Roman army and was thereby spread through out the empire, but other religions were locally popular as well. The Eleusinian mysteries originated at Eleusis near Athens and centered on the myth of Kore (Demeter). The efforts of Demeter to recover her daughter, Persephone, who was carried off by Hades to the underworld, were ultimately successful, but required Persephone to return once a year to the underworld. Thus, the mystery of the recurrent seasons was embodied in this myth, which later became embodied not only in the Eleusinian mysteries, but incorporated in the Athenian state as well. Thus, the mystery religions and their relationship to astronomy represent important aspects of the ancient world.

An important concern in the ancient as in the modern world, was the nature of the universe. The rise of Christianity did not put to an end classical philosophical and scientific speculation. Origen [Alexandria, 184–254] was a Christian theologian and Neo-Platonist who wrote about the multiplicity of worlds, on all of which he expected the events of the Creation, Fall, and Redemption to occur. Scott (1991, p. 165) argues that Origen stood firmly in a tradition that started with the Ionian Greeks and the importance of which Plato recognized: "Correctly understood, the stars were proof of a higher design in the Cosmos." See §15.1 for a further discussion of Origen's stand on the classical and traditional belief of the descent of the soul through the cosmos to Earth and its subsequent return. St. Augustine (354–430, North Africa; Bishop of Hippo), who distrusted the evidence of the senses, nevertheless speculated about the nature of time and space (Confessions, Book IX).

Macrobius (fl. 395–423; Greece) wrote a dialogue, Saturnalia, in which he argued that all forms of worship ultimately derived from that of the Sun. The Neo-Platonic philosopher Proclus (411–485; Constantinople) wrote on astronomy and mathematics. Martianus Capella (fl. 430) wrote an encyclopedia, the Satyricon, in which the liberal arts were classified into seven parts: grammar, rhetoric, and logic (the trivium), and arithmetic, geometry, astronomy, and music (the quadrivium). This usage was widely adopted in the Middle Ages. He also put forward the theory that the Sun is a center about which the solar system revolved. The age of tolerance for pagan philosophy came to an end with the closing by the emperor Justinian of Plato's academy in 529 A.D.

With the end of classical civilization, Islamic astronomy came to ascendancy. We resume the discussion of the Middle Ages through the time of the Reformation after reviewing the main contributions of Islamic and late Indian cultures.

7.4. Arabic Culture and Islamic Astronomy

The decay and destruction of the Roman empire carried with it much of the classical inheritance from Greece. Although part of the heritage was preserved by the monasteries and Byzantium, the majority of the works of antiquity were lost. Some of the Greek material was translated into

[45] "And I will show wonders in the heaven above and signs on the earth beneath, blood, and fire, and vapor of smoke; the sun shall be turned into darkness and the moon into blood, before the day of the Lord comes, the great and manifest day."

Arabic in the first millennium (e.g., the *al Magest*) and was later rediscovered by Europe.

An example is seen in the writing of Abu Ma'shar [astrologer, d. 886] (Pingree 1968), who used a Persian translation of 542 of the *Sphaera Barbarica* of Teukros [Babylonian? Lived between 100 B.C. and 50 A.D.] (Boll 1909, cited in Neugebauer 1957/1969, pp. 171, 189). This astrological work also contains material from India (see §§7.5 and 9.1.3). Islamic astronomy flourished under the 9th-century Abbasid Khalifate in Baghdad, and in addition to Abu Ma'shar, the astronomers Thābit ibn Qorra [from Harran on the Euphrates; 836?–901] (see Morelon 1987) and al-Khwārizmī lived during this time. Al-Khwārizmī developed astronomical tables that again demonstrate both Hindu and Greek influences. The Jewish astronomer Sind ben Ali [fl. ~830] was a principal contributor to tables drawn up under Sultan Maimun, and other Jewish scholars were involved in drawing up the Toledo Tables, ~1080.

Al-Battani or, as Europe knew him, Albategnius [Moslem astronomer, also from Harran, fl. 851–929], was one of the greatest of the Arab astronomers. He wrote commentaries on the astrological work of Ptolemy, *Tetrabiblos*, and wrote astronomical treatises and tables of lunar and solar motion. He found improved values of the obliquity of the ecliptic and the length of the tropical year, found a value for the precession of the equinoxes, 55 arc-secs/year, better than any since the time of Hipparchos, and rejected the theory of trepidation (§§7.3.3, 7.7). He used measurements of the lengths of the seasons ($93^d\,14^h$ of spring; $93^d\,00^h$ for summer) to derive the properties of the solar eccentric and in essence discovered the apsidal motion of the Sun's orbit by noting a difference between his value for the longitude of the apogee (82°17′) and Ptolemy's (65°30′). Al-Battani was a gifted observer who accurately recorded the circumstances of lunar and solar eclipses and developed a theory to determine the first visibility of the new (i.e., waxing crescent) moon. Finally, he also developed solutions to spherical trigonometry problems by the use of orthographic projections. His observations and books were translated and used for several centuries in Europe, as we note below.

Ibn Yūnus [Arab astronomer, d. 1009] developed the Hakemite Tables and quoted Persian observations of the solar apogee from ~470 and 630 A.D. Works of Teukros and the Ptolemy contemporary Vettius Valens appeared in a Middle-Persian translation (Nallino, cited in Neugebauer 1959/1969).

Al-Bīrūni [fl. ~1030] (see Sachau 1910) played a direct, although late, role in the cultural transmission process. He wrote

> I am... composing for the Hindus a translation of the books of Euclid and of the Almagest, and dictating to them a treatise on the construction of the astrolabe, being simply guided herein by the desire of spreading science.

He also translated Indian astrological works into Arabic.

Islamic astronomers also criticized Ptolemy. Alhazen [Ibn al-Haytham, 965–~1040] attacked Ptolemy's model for the Moon and, more generally, the equant as an unsatisfactory mechanism for preserving uniform circular motion. Averroes [Ibn Rushd, Cordoba, 1126–1198] also criticized the equant, as well as other aspects of Ptolemaic theory. Naṣīr ad-Dīn at-Ṭūsī [Khurasan, d. 1274] of the Māragha Observatory[46] similarly attacked the equant, but for the first time proposed an alternative. His replacement mechanism, known today as the *Ṭūsī couple* (Kennedy 1966), consisted of two additional small-amplitude epicycles. This device was later to find its way into Copernicus's procedures (cf. §7.7) Alternative mechanisms were furnished by other astronomers at the Māragha Observatory, Mu'ayyad ad-Dīn al-'Urdī and Quṭb ad-Dīn ash-Shīrāzī. Finally, Ibn ash-Shāṭir [Damascus, ~1350] reworked Ptolemy's models for Mercury and the Moon with the help of the *Ṭūsī couple*. This work enabled the deferent orbits to be fully concentric, thus, permitting the return of the concentric spheres. Although marking a great achievement, the legacy of this work was ultimately limited; Ibn ash-Shāṭir's success in transforming Ptolemaic mechanisms of Mercury and the Moon to the outer parts of the model, and thereby making possible a re-nesting of the celestial spheres, was generally unknown in the Middle Ages, and rediscovered only in the 1950s (Gingerich 1993, p. 141).[47] One astronomer whose work was influential in Europe, Al-Bitruji (late 12th–13th century) also favored the system of concentric spheres. His work on the homocentric system is said to have caused great controversy in Europe when it was translated into Latin.

7.5. Late Indian Astronomy

The writing of Abu Ma'shar, described above, contains asterisms taken from the works of Varāhamihira [a single name often written as Varāha Mihira; Indian astronomer, <505–~590]. This is of interest because among Varāhamihira's writings are the *Pañca Siddhāntikā*, summaries of five astronomical treatises that are no longer extant. Sections of them demonstrate the use of Babylonian linear methods (the step functions of system A, actually; see Neugebauer 1957/1969, pp. 172–174). It contains the following passage:

> The Greeks, indeed are foreigners, but with them . . . [astronomy] is in a flourishing state. (Neugebauer 1957/1969, p. 174).

The work, however, does not contain details of the Ptolemaic theory, thus, indicating transmission of these materials prior to ~150 A.D. Thus, the transmission of astronomical ideas from Babylon of Hellenistic times to India and back to the Middle East is demonstrated. Varāhamihira was also used as a source by al-Bīrūni (fl. ~1030) for his famous work on India (Sachau 1910). Another work, the *Sūrya Siddhānta*, dated to >~400 A.D., does contain elements of epicyclic motion along with much older material, and acknowledges "Romaka" (Romans and Greeks of the Byzantine empire) as the source of astronomical knowledge. See §9.1.3 for further discussion of the *Pañca Siddhāntikā* in the context of Indian astronomy.

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[46] Founded by Hulagu il Khan, a grandson of the Mongol emperor Genghis Khan.

[47] We are indebted to Gingerich's insightful essay *The Search for a Plenum Universe* (in Gingerich 1993, pp. 136–157) for most of the source material for this paragraph.

7.6. Astronomy of Medieval Europe

Astronomical work in the Middle Ages centered mainly on its utility in setting the feast days of the Church, that is, the construction of church calenders, but the continuing interest in astrology also caused a demand for improved astronomical accuracy for horoscopes and astrological forecasts of a wider nature; such practices were officially condemned but frequently and sometimes widely practiced. In fact, Tertullian [~150–~220 A.D.], one of the early Fathers of the Church, made use of an astrological argument, among other tactics, to attempt to alleviate persecutions of Christians. His letter to Scapula, the Roman governor, refers to the portents of the solar eclipse of August 14, 212:

> That sun, too, in the metropolis of Utica, with light all but extinguished, was a portent which could not have occurred from an ordinary eclipse, situated as the lord of day was in his height and house. You have the astrologers, consult them about it. (Roberts and Donaldson/Coxe 1869, Ante-Nicene Fathers III, Tertullian (repr. 1994), "Letter to Scapulla," p. 106; quoted by Schove (1984, p. 34)).

Augustine, Bishop of Hippo [354–430], distinguished between astrology and astronomy, noting that the latter was useful but the former pernicious. Thomas Aquinas [and other influential theologians (but not all)] took a similar position. The struggle over astrology continued throughout the Dark and Middle Ages; it was resolved in academia first, but more generally only after the start of the scientific era.

The Middle Ages, loosely defined as the millennium between the 5th and 15th centuries, are sometimes divided into three sections because of the outbreaks of waves of plague in the 6th and again in the 14th centuries. The later outbreaks were known as the Black Death. The onset of epidemics was sometimes blamed on planetary conjunctions, comets, or aurorae. Conjunctions imply an astrological—and therefore presumably predictable—origin, but the essentially unpredictable character of comets as a class (as opposed to individual, short-period comets) suggests the opposite. Curiously, the waves of epidemics had an 11-year cyclicity—just as one would expect of aurorae, which are strongly affected by the 11-year sunspot cycle (see §5.3.1). Dendrochronology (see §4.3) suggests that the 540s and 1340s, when the plagues began, were years of cold summers in Northern Europe. Meteorological conditions, also linked to the solar cycle, may have affected the vectors of the disease (the rat and the black flea).

The calendrical uses for astronomy, which were rooted for millennia in Europe (refer to §6.2 for the Neolithic evidence), were pursued throughout the Middle Ages. The Ecumenical Council of Nicaea in 325 A.D. adopted a formula for the date of Easter.[48] It was noted that the Vernal equinox had shifted from March 25 to March 21 (in the prevailing Julian calendar). Dionysius Exiguus proposed a 19-year cycle of fixing the dates of Easter in 532 A.D. that gradually came to be accepted in the West (cf. Percival 1899, pp. 54–56). In the eastern churches, the date of Easter was further constrained to occur after Passover ("the Zonaras Proviso") (Patrinacos 1992, pp. 125–127). The Venerable Bede (English monk and theologian, 672/673–735), who was interested in ecclesiastical history and chronology, adopted the Dionysian cycle. Among Bede's works are an essay on the calendar (*De Temporis*) and a major work, *The Ecclesiastical History of the English Nation*. Bede wrote also about a comet of 678 and popularized the use of the backcalculated birth of Christ to specify the year. Church scholars had previously favored the date of the crucifixion as the era base.

Astronomy became increasingly important starting with the reign of Charlemagne,[49] (768–814) who brought the English monk Alcuin [732–804] to his palace at Aix-la-Chapelle (Aachen) to reform education, and who proclaimed that each school should have a scriptorum. Because "calculation" was one of the subjects to be taught, and the seven liberal arts, the Carolingian renaisssance benefited astronomy too. Dall'olmo's (1978) compilation of medieval European meteor sightings includes at least one seen by Charlemagne, a bright *fax* ("torch") seen before dawn sometime in 810, during a campaign against the Danish king Godofridus. An earlier possible sighting by him, in 776, may have been the aurora.

One of Europe's scourges during Carolingian times was the fierce onslaught of the Vikings. Indeed, the major sacks of Rome indicate the difficulty the Roman empire and its successors faced in attempting the preservation, let alone advancement, of learning in the Middle Ages: 410 (Goths), 455 (Vandals), 846 (Saracens), and 1084 (Vikings). The Vikings were intrepid warriors and sailors, mastering seafaring navigation in the West just as islanders were doing so in the Pacific. They had tables of the altitude of the noon Sun, with which the latitude could be determined and maintained. Moreover, even on cloudy days, they had the use of calcite crystal (Icelandic spar), which they called *sólarsteinn* or sunstone, which had the property of analyzing the direction of maximum polarization of sunlight by scattering in the atmosphere (Jones 1964/1984, pp. 5–14; but see Roesdahl 1987, p. 92, for a more skeptical view). Like the Pacific islanders, however, they also made use of dead reckoning, wave swells, and birds (see §11). In any case, the Vikings or Norsemen raided and later settled in parts of what would become the British Isles (from the early 9th century), Russia (9th century), France (9th–10th centuries; Normandy still bears their name), and from Normandy, Sicily (early 11th century), and, again, from Normandy, England (1066). They raided the Mediterranean as well as Eastern Europe, and even attacked Byzantium during the absence of the emperor. Their attacks on monasteries such as Lindisfarne at the beginning of the expansion, in 793, shocked Alcuin and the Christian world. By 1000 A.D., they had colonized Iceland, Greenland, and gone on to Vineland in North America. The Vikings eventually came to adopt Christianity and other aspects of European community. Islam was another source of conflict with Christianity in southern Europe and the Near East. The history of that conflict is lengthy and complex, and it will not be discussed here.

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[48] The first Sunday after the first spring full moon (i.e., the full moon following the date of vernal equinox).

[49] Also known as Karl der Grosse, who lived from 742 to 814, reunited Europe, and restored learning.

Instead, we concentrate on the transmission of classical knowledge through the Arab and, more broadly, the subsequent Moslem world. We have already mentioned (§5.6) the effect of the intense and widespread April 1095 meteor shower on helping to create the groundswell for the First Crusade. Meteors, along with comets, and other transient phenomena, were considered to be omens for most of the Middle Ages.

Like most of the classical learning, many Greek astronomical writings came to Europe through Islamic sources (cf. §7.4), such as Al-Battani (Islamic astronomer; b. <858), Avicenna (physician, ca. 980–1037), and Averroes (Ibn Rushd, Islamic philosopher, 1126–1198) late in the Middle Ages.

The great Jewish philosopher, Moses Maimonides [Cordoba; 1135–1204], wrote on astronomical matters as well as the Torah. Adelard of Bath [fl. 12th century] translated Euclid's *Elements* from Arabic into Latin for use in schools, and he wrote on astronomy and the abacus. Gerard of Cremona (~1114–1187) translated the *Almagest* from Arabic into Latin in 1175; he headed a school of translation of scientific and mathematical treatises in Toledo. The treatises and tables of Al-Battani were first translated by Robertus Retinensis [d > 1143] and, independently, by Plato Tibatinus [1st half of 12th century]; still later, Alfonso the Learned [or Alfonso X, king of Castile and Leon, 1252–1282] had them translated into Spanish. A Latin translation of one of Al-Battani's books, *De Motu Stellarum*, was published in Nuremburg in 1537. His spherical trigonometry solutions were used by Johannes Müller, better known as Regiomontanus [1436–1476], the leading European astronomer of his day.

After the translation of the works of Al-Bitruji into Latin in the 13th century, controversy arose between adherents of the epicyclical Ptolemaic system and those of the Eudoxian homocentric system. Roger Bacon (1214–~1292), the *doctor admirabilis* of the Middle Ages, participated in the debates, but accepted neither system. Bacon was a Franciscan monk and was among the most learned scholars of his time; he studied and wrote both philosophy and science. Among his writings is a book on optics, in which he discussed experiments with concave mirrors. He said that the Milky Way should be examined *cum specilis* in order to understand its nature; although the meaning of the phrase is unclear, it suggests the use of a speculum concave mirror as a primitive telescope. Along with one of his teachers, Robert Grosseteste [Franciscan monk, then Bishop of Lincoln; fl. 1175–1253],[50] he recognized the inadequacy of the Julian calender and attempted to reform it, but without success. A similar attempt by John de Meurs in the 14th century also failed. Calendar reform succeeded only through the forceful advocacy of Pope Gregory in the 16th century.

Others who were interested in optics included Dietrich of Freiberg [Dominican monk; ~1250–~1311], who formulated a theory for the rainbow involving the action of sunlight within water droplets and advocated the use of experimentation in science, and the mathematician and philosopher Witelo [Silesia; b. 1225], who studied the propagation and transmission of light through material.

Although there was a clear increased interest in general empirical science in the 13th century, time, calendrics, and position determination were recognized as appropriate applications of astronomy throughout the Middle Ages. One of the great promoters of astronomy (and astrology) in the Middle Ages was King Alfonso X, the Scholar (*El Sabio*), who ascended the throne of Castile and Leon in 1252. He commissioned translations of many Arabic astronomical treatises and created a major compendium of Arabic astronomy; when astronomical topics were missing, additional material was written by Alfonso's scholarly teams. Besides descriptions of planetary motions and constellations, there is an important section on astronomical instruments. The translation of the Al-Battani tables was produced by a team headed by the Jewish astronomer Isaac ibn Sid, around 1270. Alfonso also commissioned the Alfonsine Tables, which began to appear elsewhere in Europe (in slightly different forms) in the 1320s and were issued multiple times over the next 120 years (Gingerich 1993, pp. 115–128).

Geoffrey Chaucer [ca. 1340–1400] wrote *A Tretise on the Astrolabe* in 1391, which indicated its use in calculations of declinations and latitudes as well as for observations (see §3.3). John D. North (1988) has shown that many of Chaucer's tales are anthropormorphized descriptions of astronomical events (comparable in many ways to ancient myths). The descriptions contain enough detail that North was able to determine the precise dates of a number of the phenomena that Chaucer described. Richard of Wallingford (fl. 1320) designed observational instruments and an astronomical clock for the abbey of St. Albans, where he was abbot.

As noted in §7.2.1, a number of individuals believed with Heracleides of Pontus that a rotating Earth made the rotation of the sphere of fixed stars unnecessary. Among them was Nicholas Oresme [scientist and economist, later Bishop of Lisieux; 1320–1382]. Like Jean Gerson [Theologian at Paris, pietist and mystic, 1363–1429], and St. Thomas Aquinas [1225–1274], he attacked astrology. Oresme also used three-dimensional rectangular coordinates to represent geometric figures and wrote an astronomical *Treatise on the Sphere* (1377). Nicholas of Cusa [1401–1464; Cardinal] championed the movement of the Earth around the Sun and the existence of other worlds (Avey 1954/1958, p. 112; Jaki 1972/1975, p. 48). Giovanni Pico de la Mirandola [1463–1494] opposed astrology on the grounds that it degraded free will, which he believed was not constrained from above. The lapsed priest, Giordano Bruno [1548–1600; Italy] was influenced by Nicholas of Cusa and Copernican cosmology, and he believed that the stars were distant suns circled by planets (cf. §15.1).

One of the principal philosophic movements of the later Middle Ages was realism. Stemming ultimately from Plato and transmitted through the Neo-Platonism of Plotinus and the Greco-Roman world, realism encompassed the idea that essences underlay everything conveyed to us by the senses, and they were in a more fundamental way more real than were the things we perceive through the five senses. Moreover, it was possible for the mind of a person to comprehend and know these essences. Philosophers and theologians of the Middle Ages generally agreed on these principles. One

[50] Who wrote on optics and on the theory of refraction.

of the best known medieval philosophers was Anselm, Bishop of Canterbury [1033–1109]. In his *Proslogium*, he produced a proof for the existence of God on the basis of reasoning alone. The syllogism, known ever since as the ontological proof, is as follows:

(1) God is that greater than which nothing can be conceived.
(2) To exist in reality is greater than to exist in the imagination alone.
(3) Therefore, God exists.

The major premise of this syllogism, "God is that greater than which nothing can be conceived," is a statement about a principal property of God, universally accepted in Anselm's time. The minor premise, "To exist in reality is greater than to exist in the imagination alone," would seem to be unassailable. The conclusion then follows. Nevertheless, the proof was criticized by a contemporary monk named Gaunilon, and later by Thomas Aquinas and Immanuel Kant among many theologians and philosophers. Gaunilon argued that thinking about money in one's pocket did not perforce create any there, but Anselm's response rested on the idea that God alone is superlative so that parallel arguments regarding the merely finite are not relevant. One can argue that the proof has meaning only in a context in which ideas have real substance, and in particular, in which the idea of God has the force of reality. Modern readers who are not rooted in a tradition of faith or of Platonism may regard this as strange, but they should consider that no reasoned discourse is without its philosophical preconceptions, even if they remain unrecognized by either writer or reader.

In contrast to the ontological argument for the existence of God, Thomas Aquinas [1225–1274] in his *Summa Theologica* asserted that the existence of God could be proved from evidence of the world of experience, in five different ways:

(1) From motion in the world, which requires a first mover

(2) From the necessity of a first efficient cause (of things in the world)

(3) From the existence of things, which requires the existence of a necessary preexistent necessity in order to come into being

(4) From the gradations of heat, goodness, and so on, which, from an Aristotelian argument that the source of a gradation is its maximum form, implies a fire for heat, or God for goodness

(5) From the governance of the world, because things (even things lacking intelligence) act always, or nearly always, in such a way as to bring about the best result. From this, Aquinas concluded that they act not fortuitously, but by design.

Aquinas's arguments involve evidence from the created universe and are known as the cosmological proofs of the existence of God. The existence of a universe perceived to be designed is the essence of these proofs, and although again the eye of faith is required to accept the underlying premises, the latter have modern echoes, such as the *anthropic principle*, which holds that even a modestly changed universe would be unable to support the development and existence of human life.

7.7. Post-Renaissance Astronomy

The Middle Ages ended with the Renaissance, in which classical learning was once again widely studied, and the Reformation, in which the power of the Roman Catholic Church as exercised through the Pope was successfully challenged in many parts of Europe.

In astronomy, the posthumous 1543 printing of *On the Revolutions of the World* by Nicholas Copernicus [Polish physician and canon lawyer; 1473–1543] marked the revival of the heliocentric theory, although its success was not immediately apparent. Copernicus's model involved circular motions of the planets, including the Earth; so it was hardly the modern heliocentric theory. In agreement with noted Islamic astronomers, Copernicus rejected the equant as a device to save the phenemonena; instead, he adopted small epicycles to explain the residuals in the planetary distances. His solutions tended to be the same: He made use of Ibn al-Shāṭir's models for lunar and planetary motions, and the *Ṭūsī couple* (§7.4) to model planetary oscillations in latitude, as well as the variation of the obliquity. Although Copernicus's work was often cited over the following century, his cosmology was rarely advocated in the universities of this period.

Copernicus entrusted the publication of his work to a Wittenberg academic named Georg Rheticus, and it was done (*Narratio prima*, "First Report" 1540; and *De revolutionibus orbium coelestium*, "On the Revolutions of the Celestial Orbs" 1543). In the course of the printing, however, an unsigned preface was added by Andreas Osiander, a Lutheran clergyman (and co-signer of the *Augsburg Confession*, one of the principal Lutheran doctrinal statements). The preface essentially justifies the printing of what was anticipated to be a controversial work, in words that must have been designed to protect it (and Copernicus) from attack:

> Since the novelty of the hypotheses of this work has already been widely reported, I have no doubt that some learned men have taken serious offense because the book declares that the Earth moves; these men undoubtedly believe that the long established liberal arts should not be thrown into confusion. But if they examine the matter closely, they will find that the author of this work has done nothing blameworthy . . . For these hypotheses need not be true nor even probable; if they provide a calculus consistent with the observations, that alone is sufficient . . . Now when there are offered for the same motion different hypotheses, the astronomer will accept the one which is the easiest to grasp. . . . So far as hypotheses are concerned, let no one expect anything certain from astronomy, which cannot furnish it. . . . (excerpted in Gingerich 1993, pp. 289–290)

The introduction infuriated Rheticus, who knew Copernicus's views on the subject, but may have helped to save the book from the censor in many Catholic and Protestant areas (with few exceptions, the book was frequently censored only in Italy; see Gingerich 1993, 281ff). Philipp

Melanchthon [Theologian and classicist, 1497–1560], Luther's principal lieutenant in the Reformation, championed the interpretation of Copernicus's work as a computational improvement. As a consequence of this circumstance (aided by Melanchthon's more general educational reforms of German universities), the *Revolutionibus* was widely used by astronomers at Protestant universities, beginning at Wittenberg.

The attitude of one of the leading astronomers in the generation following Copernicus is instructive. Erasmus Rheinhold [astronomer, Wittenberg, 16th century] agreed with the spirit of Osiander's introduction, and, with many other astronomers of his day, did not teach the heliocentric cosmology in his classes. He used Copernican methods to construct tables (the *Prutenicae tabulae coelestium motuum* or "Prutenic Tables," computed for the longitude of Königsberg, were produced in 1551). From the tables, ephemerides of the day-by-day positions of the planets could be generated. Gingerich (1993, pp. 204–251) has computed and compared the planetary positions from the precepts of Copernicus, Reinhold, and Rheticus, with the true positions. He found that Copernicus's method could produce positions within 10 arc-mins for all of the planets except Mercury, for which the error exceeded 20 arc-mins. These errors were dwarfed by those of the Alphonsine tables, based on purely Ptolemaic devices. Thus, progress in prediction was apparent, regardless of the hesitation to accept heliocentrism. In his treatment of precession, however, Copernicus did not represent progress.

In §7.3, we mentioned the "trepidation" or alleged oscillation of the precession. This fictitious notion was accepted throughout the Middle Ages, and up to the time of Copernicus, who provided a theory[51] for it (Swerdlow and Neugebauer 1984; Goldstein 1994). Swerdlow and Neugebauer (1984) evaluated Copernicus's model on the basis of data that were available to him and found it to fit them very well. The "trepidation" can be expressed in an equation as follows (from Mercier 1977, cited in Goldstein):

$$\lambda = 5;32 + \frac{360n}{25816} - \sin\left(\frac{360n}{1717} + 13;30\right), \qquad (7.9)$$

where λ is the old analog of the celestial longitude (ecliptic longitude in degrees from the beginning of the zodiacal sign), the zero point terms are in degrees and sexagesimal fractions thereof, n is the number of Julian years (of 365^d) from the date 31 December 31 B.C. = JDN 1684898, and the denominators of the fractions are the periods of those terms. The 25,816 Julian year period is the secular term, i.e., the variation in longitude due to the gradual westward shift of the vernal equinox among the stars (the classical precession), and 1717^y is the alleged period of the trepidation. The physical basis for the theory was in fact nil: the erroneous value of Ptolemy's precession value, 36″/y, but Ptolemy's reputation was such that this value went unchallenged, until Tycho Brahe. Table 7.15, from Swerdlow and Neugebauer [1984, (pt. 1), p. 132], with Copernicus's estimates of time intervals and corrections of the longitude of Spica, illustrates the source of the problem. Table 7.16, from Swerdlow and Neugebauer [1984, (pt. 1), p. 147], compares the results using Copernicus's model and the data available to him. Copernicus noted the changing value of the obliquity also, but concluded, for reasons not apparent to us, that it had to be periodic also, with twice the period of the trepidation and with the maximum obliquity occurring at the same instant as the minimum of the trepidation (Swerdlow and Neugebauer 1984, (pt. 1), p. 133).

TABLE 7.15. Basis for Copernicus's trepidation.

Observer interval	Date	Δt[a]	$\Delta\lambda$[b]	Δp
Ptolemy-Timocharis	138 A.D.–294 B.C.	431	4;20	$1°/100^y$
Ptolemy-Hipparchos	138 A.D.–128 B.C.	266	2;40	$1°/100^y$
al Battani-Menelaos	880–90 A.D.	782	11;55	$1°/66^y$
al Battani-Ptolemy	880–138	741	[11;30]	$1°/65^y$
Copernicus-al Battani	1525–880	645	9;30	$1°/71^y$

[a] In years, as per Copernicus's reckoning (see Swerdlow and Neugebauer 1984).
[b] In degrees.

TABLE 7.16. Copernicus estimates of precession.

Observer(s)	Date	p_{obs}	p_{calc}
Timocharis	B.C. 294	2;20	2;18
Hipparchos	129	4;0	4;0
Menelaos	A.D. 99	6;15	6;15
Ptolemy	138	6;40	6;40
al Battani	880	18;10	18;10
Copernicus	1515	27;14	27;14
Copernicus	1525	27;21	27;10

Tycho Brahe [Danish noble and astronomer, 1546–1601] subsequently attempted to disprove the Copernican heliocentric theory by observation. His observational project did not, however, achieve this goal. Brahe devised a scheme that combined the elegance of the heliocentric system (with planets revolving about the Sun) with the canonical Earth-centered system, but Johannes Kepler [German mathematician, 1571–1630] concluded that Brahe's observations were unable to fit the equant model of Ptolemy in any version. He attributed the inaccuracy of Ptolemy's model to the imprecision of Ptolemy's data. Tycho Brahe had developed new instruments and improved techniques to measure angles with them (see §3.3). Consequently, Kepler estimated the uncertainty in Brahe's sextant observations of Mars as 2 arc-minutes or less, in agreement with the residuals of his own theory, which required a heliocentric ellipse. Pannekoek (1961/1989, p. 238) cites the relevant passage from *New Astronomy:*

> From this so small a deviation of 8′ the reason why Ptolemy could be content with bisecting the eccentricity is apparent. . . . Ptolemy did not claim to reach down beyond a limit of accuracy of 1/6° or 10′ . . . It behoves us, to whom by divine benevolence such a very careful observer as Tycho Brahe has been given, in whose obser-

[51] The term *theory* is used here to mean theory of motion as opposed to an underlying physical theory. Such a theory is a mathematical model, and effectively "saves appearances."

vations an error of 8′ of computation could be disclosed, to recognize this boon of God with thankful mind and use it by exerting ourselves in working out the true form of the celestial motions. . . . Thus these single eight minutes [of arc] indicate to us the road toward the renovation of the entire astronomy; they afforded the materials for a large part of this work.

This departure from circular motion, which was held to be the most perfect kind of motion in antiquity, was entirely novel. The "breaking of the circle" (Nicholson 1960/1962) had a profound effect on the subsequent development of scientific inquiry. Principally, it challenged the authority of all classical Greek science that posited the cosmos as the realm of the circular. This was, in a sense, the epitome of pretelescopic astronomy. Kepler's *Survey of Copernican Astronomy* (*Epitome astronomiae Copernicanae*, 1618) has been described as the first astronomical manual based on modern principles (Pannekoek 1961/1989, p. 242). Kepler claimed in a letter (cited by Pannekoek 1961/1989, p. 243) that the *Epitome* was written as an explanation of his *Rudolphine Tables* (1627) of planetary positions. The improved relative accuracy of the planetary predictions was verified by Pierre Gassendi's observation of the transit of Mercury on Nov. 7, 1631, and by Jeremiah Horrock's observation of the transit of Venus on Nov. 24, 1639. The accuracy for these events exceeded that of earlier predictions by two orders of magnitude (Gingerich 1993, p. 321; Athreya and Gingerich (1996/1997). Whereas previous predictions were accurate to only a few degrees at worst and tens of minutes at best, with Kepler's tables, agreement to several arc-mins became possible. For details of Kepler's orbital studies, see Stephenson (1987).

Kepler's work on optics (*Astronomiae Pars Optica*, "Optical Part of Astronomy" 1604) also provided the basis for modern work in that field and discussed the inverse square law of light.

More significantly, Kepler sought the causes of the phenomena that he studied, such as the reasons for the elliptical paths of the planets. He was acquainted with William Gilbert's seminal work on magnets, and he thought that the planets were constrained to move as they did because of the magnetic attraction of the Sun. The mechanism was the libration theory. Kepler supposed that the Sun rotated (at what rate he did not know, because Galileo had not yet discovered sunspots, which he subsequently used to determine the rotation period of the Sun). The scheme was as follows. Kepler supposed that the Sun acted on some physical property of the planets, such as some kind of magnetic "fibers" that maintained the same direction in space regardless of the location of the planet in its orbit around the Sun. His discussion is given in *Astronomia Nova* (1609) and appears in modified form in the *Epitome*. The theory goes as follows: One end of each of the fibers is attracted, and the other end repelled, by the Sun. The fibers were pictured to be perpendicular to the line of apsides with the attracted end trailing the planet's orbital motion when the planet is at aphelion (Stephenson 1987, Fig. 29, p. 146). At this point, neither fiber end is closer to the Sun; so neither attraction nor repulsion occurs; however, just slightly beyond aphelion, the attracted end is slightly closer to the Sun, and so the planet is attracted to the Sun; the maximum attraction occurs midway between aphelion and perihelion. The fall toward the Sun continues until the planet reaches perihelion, when the fibers are again perpendicular to the Sun-planet line; shortly thereafter, the repelled ends of the fibers are closer to the Sun, and the planet is repelled. The successive positions reverse the process that brought the planet closer to the Sun, ending again at aphelion. Thus, although the inverse square law of gravity had to wait for Isaac Newton, Kepler was able to theorize about the nature of the force joining planets to the Sun resulting in elliptical orbital motion.

Kepler's striving to uncover the physical causes of planetary motions led Gingerich (1993, p. 321) to argue that Kepler well deserves the title of first astrophysicist.

The contemporary observational and experimental work of Galileo Galilei [Pisa, 1564–1642], who used the telescope for his astronomical discoveries, further weakened the authority of both Aristotelian physics and Ptolemaic astronomy and led, ultimately, to modern empirical science. A full discussion of Galileo's many important contributions to modern science generally and to physics particularly, is beyond our scope, so to speak, pretelescopic astronomy. Therefore we conclude this summary of the development of astronomy in Europe and the Near East and proceed to Africa.

8 African Cultures

8.1. Egypt and Nubia

The serious study of Egyptian antiquities through archeology was professionalized before that of any other area of the world. This means that there are massive numbers of books on most aspects of ancient Egyptian life. General books on the country range from well-documented accounts by professional Egyptologists through good popularized summaries to a large number of wildly inaccurate summations from the crackpot fringe. A useful summary from the 1st dynasty to the 20th century, presented as a series of specialized articles by leading scholars, is Malek (1993). A more unified account to the end of the 18th dynasty is Kemp (1989/1995). For reference, the dictionary of Shaw and Nicholson (1995) is very convenient, and for a straightforward chronology emphasizing the rulers and summarizing the sources, there is Clayton (1994). The best recent study of Egyptian chronology from an archeological viewpoint is Kantor's study (in Ehrich 1992, pp. 3–21). There are three intermediate periods in Egyptian history in which the chronology is difficult to establish. The dating of the crucial Third Intermediate Period is discussed by Kitchen (1973) and Bierbrier (1975). An interesting and sophisticated study by Rohl (1996) suggests shifts by as much as several hundred years in some sections of the chronology. Although his central conclusions are unlikely, some of his arguments will be considered later because they involve questions about the appropriate way to use astronomical evidence. Much of Rohl's work is closely tied to that of Peter James (1991). Our summary of the chronology is given in Table 8.1.

The Perfect Discourse, attributed to Asclepius (i.e., the Greek equivalent of the deified Imhotep), says that Egypt was "the image of heaven" and the world's temple (Fowden 1986, p. 39). Any account of Egypt must start with the fertile valley of the Nile cutting through desert country to the Mediterranean. Rich vegetation and many kinds of animals attracted human hunters and gatherers. Polished stone tools, including grinding stones, had a longer history in Africa than in the rest of the world, and the other elements of a full Neolithic, including pottery and domesticated plants and animals, were present before 5000 B.C. The rural population became extremely dense. The presence of water sharply defined the boundaries between farmland and desert; irrigation techniques were used even in predynastic times to extend the farmlands. Various types of watercraft were developed, from reed rafts to long plank ships, moved by poles, paddles, or sails.

At a date probably somewhat before 3000 B.C., there were marked cultural changes in the area. Writing came into use, as did metal tools and stone architecture. A hierarchical political structure, ruled by a living "god," unified the whole area, partly by warfare. However, the scale of military conflicts at this time was not large.

Some of these developments were probably spurred by the presence of a Mesopotamian trading post in the Delta, but the already distinctive Egyptian culture rapidly transformed incoming ideas. Wheeled vehicles (in the form of chariots) only began to be used somewhat before the 18th dynasty, nearly 3000 years later than in Mesopotamia. The true arch in buildings was equally slow to be used in Egypt. Towns became politically important, but none of them came close to equalling the size of the great cities of Crete, Assyria, and Babylon until the New Kingdom.

One of the most distinctive Egyptian technologies was the practice of mummifying the bodies of the dead, associated with grandiose tombs, elaborately painted with scenes of the life of the times. From these, we have learned a great deal about Egyptian culture. The religious beliefs and stories that motivated these practices were elaborately incorporated in their calendar and included astronomical observations of planets and fixed stars that embodied deities, often represented as animals or animal-headed humans. The identification of the ruler as a son of the Sun and an incarnate deity meant that astronomy, in a minimal sense, pervaded the social structure. Egyptian temples and tombs emphasized the importance of Sun, Moon, and the starry sky.

TABLE 8.1. Chronology of Ancient Egypt.

Period	Dates	Features
Mesolithic	~8000 (B.C.)	Small, perhaps seasonal sites, near Elkab.
	~7000–4000	Domestication of plants and animals.
	~5000	Farming communities with animals and pottery in SW delta; the Fayum, and Upper Egypt, near Asyut.
Neolithic (Chalcolithic)	4000–3500	Badari farming community; grave goods of copper, black-topped red pottery, rings, and beads; Amratian, Naqada I: bricks, clay ivory figurines, white incised pottery (plus older red pottery).
	3500–3100	Gerzean, Naqada II: densely packed towns; use of inlay; finely wrought flint, ivory, and bone implements. Walled towns: Naqada, Hieraconpolis. Painted motifs in tombs.
	~3100	Merger of local kingdoms to form unified state. Earliest Dynastic Period. Writing appears.
Dynasties 1–3 (Bronze Age)	3100–2613	Eight kings buried at Abydos. Memphis founded. Royal burials at Saqqara (Memphis) and at Abydos; Temple enclosures of brick; massive tombs; Step Pyramid of Netjerkhet ("Djoser") later celebrated as work of Imhotep, first minister of the king. Worship of the sun god, Ra; large-scale reliefs of king performing rites.
The Old Kingdom		
Dynasties 4–8	2613–2160	Pyramids at Gizeh, Meidum, Dahshur; Royal sun temples at Abusir, Abu Gurab; Saqqara pyramids with Pyramid Texts.
First Intermediate Period		
Dynasties 9–11	2160–2040	Decans; Charts on coffin lids.
The Middle Kingdom		
Dynasties 11–13	2040–1750	Sothic date 1872 B.C., year 7 of reign of Sesostris III.
Second Intermediate Period		
Dynasties 14–17	1750–1650	
	1650	Invasion of "Hyksos" (heqa-khesut) people in delta.
The New Kingdom		
Dynasties 18–20	1550–1086	Expulsion of Hyksos by Ahmose I.
		Sothic date 1537 B.C., year 9 of Amenhotep I.
		Sothic date 1462–1465 B.C., in reign of Thutmose III.
		Star clocks in tombs of Ramses VI, VII, and IX.
Third Intermediate Period		
Dynasties 21–25	1086–661	Fragmentation; invasions. Esarhaddon captures Memphis in 671 B.C.; Assyrians under Ashurbanipal sack Thebes and occupy Lower Egypt.
The Late Period		
Dynasties 26–30	661–332	Assyrian governor becomes king; defeated by Nebuchadnezzar in 605 B.C.; defeated and occupied by Persians under Cambyses in 525 B.C.; Persian rule ended by Alexander, 332 B.C.
Ptolemaic Period	332–30	Alexandria becomes cultural (and astronomical) center.
Roman and Byzantine Period		
	30 B.C.–642 A.D.	Alexandrian library destroyed in Arab conquest. Coptic religion survives in minority status.

Even in ancient times, the region beyond the fertile belt beside the Nile was desert waste. The Sun and the other retinue of heaven traveled across this belt from east to west. This cruciform paradigm (John Romer 1981, pp. 12, 21) is seen copied in the great temples, including what must be one of the largest temple and religious edifices in the world, the temple of Amon Re (or *Amen-Ra* among several variants) at Karnak.

8.1.1. Egyptian Astronomy and Its Role in Religion

For many years, the most important work on Egyptian astronomy was that of Neugebauer and Parker (1960/1969). This has been amplified and in many ways superseded by the work of Clagett (1995). Among the Greeks and Romans, it was widely believed that Egyptian astronomy was greatly superior to their own. Modern scholars have found nothing to justify such a belief. There is no indication that any sort of mathematical astronomy comparable to that of Mesopotamia flourished in Egypt prior to the Greek takeover. However, there is substantial evidence that many Egyptian deities were identified as Sun, Moon, planets, or asterisms. The importance of astronomy in the religion and calendar is evident. In the tomb of Thutmose III in the Valley of the Kings near Thebes, the religious context of the hours of the night are made clear. The entire text of the *Amduat* or *Book of What is in the Underworld* appears on the burial chamber wall; it can be found in Clagett (1989). It is set out in 12 chapters or hours, which mark the hours of the night, and transformed through the power of myth into the passage of the soul of the king through the underworld to be reborn, like the Sun. It begins with the lines:

> The writings of the hidden chamber, the places where the souls, the gods and the spirits stand. What they do. The beginning of the Horn of the West, the gate of the Western Horizon. This is the knowledge of the power of those in the Netherworld. This is the knowledge of what they do: the knowledge of their sacred rituals to Re; the knowledge of the mysterious powers; knowledge of what is in the

hours as well as of their gods, knowledge of what he says to them; knowledge of the Gates and the way on which God passes; knowledge of the powerful ones and the annihilated.

During the first hour, the Sun orders the dead king, his physical body, to open the underworld's doors, beginning the process of bringing light and life to the underworld, and awakening its gods, hour by hour. The dead king too is restored to life, through an encounter with the scarab beetle god, who ultimately rolls the Sun up to the eastern horizon. Later, resurrection became an important theme of the religion of the masses as well, especially through the Osiris myth. This powerful myth involved several key elements:

(1) The killing and dismemberment of Osiris by his brother, Seth
(2) The persistence and success in the reconstitution of Osiris's body by his wife (and sister), Isis
(3) Osiris's achievement of eternal life
(4) Their successful union, which produced Horus, who then avenged his father

Parker (1950, p. 80, f.n. 23) has suggested that the entire Osiris myth is lunar and based in astronomy. Much of his monograph is devoted to the proposition that the 25-year lunar cycle (see §8.1.4) had been recognized prior to the adoption of the 365-day civic year in Egypt. Parker writes, "The new crescent is the symbol both of the reborn Osiris as king of the dead and of his son and successor Horus as king of the living." He associates the "dying Horus" with the waning moon, but the death of Osiris is the central theme of the myth. The cutting up of the body of Osiris would coincide well with the night-by-night diminution of the waning moon. The rebuilding of the body of Osiris by Isis would correspond with the waxing moon, and the complete Osiris with the full moon. We think that the occasional blood-red lunar eclipse might be considered the killing of Osiris.

Parker also thinks that the Sed festival, or "jubilee," celebrated in or after a king's 30th year of rule may be based on the symbolic equation of the 30 days of a lunation with the 30 years of royal rule. Although he does not mention it, such an equation is widespread in mythology. Moreover, it can be used to support Parker's views of the original lunar calendar. The names of the days of the lunar month (given in Table 8.2) include the 26th day, Peret, and "going-forth," "emergence," and normally interpreted as "heliacal rise" with reference to Sirius may refer to the 26th year as the beginning of a lunar cycle. If this is accepted, then the reference to the 29th day as "Peret Min" may refer to the 29-year sidereal cycle of Saturn and would identify the ithyphallic Min as one aspect of Saturn, perhaps relating Saturn to the Sed festival.

8.1.2. The Pyramids and the Myth of Osiris

The concerns of Egyptian religion with the resurrection of Osiris, and the funeral texts involving the glorification of the pharaohs after death, raise the possibility that the burial places of some of these kings may demonstrate alignments. Popular literature on alleged "mysteries" of the pyramids abounds, and one of the more recent pyramid books entertains just such an idea (Bauval and Gilbert 1994). The argument does not concern the pyramids, which have a good, although hardly miraculous, cardinal points alignment precision (see Neugebauer 1980 [or 1983a, p. 211ff], for a terse and convincing description of how it was done). We are unconvinced that the shadow produced by the Sun's disk did not provide sufficient precision to accomplish this alignment because of the fuzziness of the shadow. Neither, of course, can it be proved that the Sun or indeed any star or combination of stars was used for this purpose.

TABLE 8.2. Named days of the Egyptian lunar month.[a]

1. Pśḏntyw, earlier Pśḏtyw
2. (Tp) ꜣbd, "New crescent day"
3. Mśpr, "Arrival day"
4. Prt śm, "Day of the going-forth of the śm-priest"
5. i̓ẖt ẖr ẖꜣwt, "Day of offerings on the altar"
6. Śnt, "Sixth day"
7. Dni̓t, "Part day, first quarter day" (see 23)
8. Tp
9. Kꜣp
10. Śi̓f
11. Śtt (= 25)
12. (reading uncertain)
13. Mꜣꜣ śṯy
14. Siꜣw (= 17)
15. (Tp) śmdt, "Half-month day, 15th day, day of full moon"
16. Mśpr śn-nw "Second arrival day"
17. Śi̓ꜣw (= 14)
18. i̓ꜥḥ, "Day of the Moon"
19. Śḏm mdw.f
20. Śtp
21. ꜥprw
22. Pḥ ꜥspdʾ
23. Dni̓t, "Part-day, last-quarter day" (see 7)
24. Knḥw
25. Śtt (= 11)
26. Prt
27. Wšb
28. Ḥb-śd Nwt, "Day of the jubilee of Nut"
29. ꜥḥꜥ . . .
30. Prt Mn, "Day of the going-forth of Min"

[a] ff. Parker 1950, pp. 11–12.

The discovery of narrow shafts within the Great Pyramid of Gizeh erected by Khufu provides a new line of inquiry. The astronomical data are succinctly summarized by Trimble (1963), reproduced by Bauval and Gilbert (1994, pp. 237–241). Two shafts ascend upward from the burial chambers of the king and queen to the north face of the pyramid. The angle of rise of the outer part of the shaft from the King's Chamber is 31°. A line through the shaft would have intersected the upper culmination of α Draconis at ~2620 B.C. Because the souls of the dead rulers were expected to ascend to the skies, the northern shafts would provide the means to reach the realm of the "eternal," undying circumpolar stars. There are two other shafts that ascend from the same chambers to the south face of the pyramid. These too may have a religious significance. The altitude of the south-facing shaft from the King's chamber is ~44.5°; at a latitude of 30° (the latitude of Gizeh is given as 29°58′51″), this corresponds to a meridian-crossing declination $\delta = h - (90 - \phi) \approx -15.5°$, approximately that of ε Orionis, the center star of the star of Orion's belt, at about 2600 B.C. With the coordinates obtained from Table 3.1, and the rigorous formulae (Eqs. 3.19 and 3.20) of §3.1.6, we can calculate the declination[1] of ε Ori: $\delta = -15°22'$ in 2620 B.C., in agreement with the tabular value given by Neugebauer (1912) cited by Trimble (1963). Why should the Belt stars have any significance? Trimble (1963) notes that *Sah*, or *Osiris*, "the god who crosses the sky," is one of the few identifiable asterisms; the equivalence with Orion, in the words of Neugebauer and Parker (1969, p. 24), "must be taken as likely in the highest degree."

The legend of Osiris and Isis was an essential part of Egyptian religion[2] and symbolized the strong belief in resurrection. *Seth* so hated his brother, Osiris, that he held a banquet at which he offered a finely crafted coffin to whomever it fit. When Osiris entered it, the coffin was closed, sealed with lead, and thrown into the Nile. Isis recovered the body, but Seth again stole the body, this time hacking it to bits and distributing it all over Egypt. Isis again recovered all of it except the penis, which she fabricated, and then brought Osiris back to life, long enough to be impregnated. Their son, Horus, eventually killed Seth. During the struggle, one eye of Horus was injured and became the Moon; the good eye became the Sun. Horus is often portrayed as the falcon of the skies, whose outspread wings center on the solar disk and encompass the sky. The name Horus may derive from *hor*, face, and in other contexts, Horus was identified with the Sun. Osiris became judge of the newly dead and oversaw the weighing of souls against the feather of truth. In many depictions, the jackal-headed god Anubis is shown presenting the souls to Osiris.

Precession has been responsible for the development of, and changes in, the stories of Osiris (Orion), Isis (sometimes identified with Sopdet, i.e., Sirius), Horus, and Seth, according to arguments of Sellers (1992). She regards crucial dates in this evolution as the time when the last star of their constellation *Sahu* (more or less Orion) ceased to rise heliacally at the spring equinox (by about 6700 B.C.) (Sellers 1992, pp. 29 and 43) and the later time when Aldebaran (representing Taurus) ceased to rise heliacally at the spring equinox at about 4866 B.C. At present, there are few if any ways to check this possibility. However, Sellers thinks that descriptions of the darkening of the Eye of Horus (equated with the sun) strongly suggest solar eclipses. The myths include a statement of a continuing battle between Horus and Seth over a period of 80 years, which Sellers thought referred to eclipses. Although recognizing the major problems involved in back-calculating eclipse paths, she found one interesting set of eclipses. In southern Egypt, there were three total solar eclipses and one annular eclipse over a period of 80 years. The first was on 27 July, 4867 B.C. (Gregorian date, 20 June, summer solstice). The next was on 6 August 4849 B.C., and the third on 16 April 4787 B.C. The annular eclipse had occurred on 26 May 4864 B.C. (Sellers 1992, pp. 74–85).

Sellers also found some suggestive evidence that dynastic changes in Egypt sometimes occurred following an eclipse that was total at the capital of the particular dynasty that lost power. Given uncertainties in the backcalculation of eclipses and other uncertainties in the calculation of ancient Egyptian chronology, it would be rash to consider this more than a reasonable hypothesis, but given the identification of the Pharaoh as the son of the Sun, one would expect solar eclipses to be regarded as extremely bad omens. The coincidences of dynastic changes with eclipse dates as calculated by Sellers (1992, p. 277), shown in Table 8.3, are more than we would have expected. We should make it clear that Sellers is proposing a causal connection based in the emotional reactions of the Egyptian people in terms of their mythology. If there was such a correlation, later people might have interpreted it as astrological causation, but nothing indicates that this was an idea present in Egypt earlier than, perhaps, the time of the Assyrian invasions.

Part of the funeral ritual, prescribed in the *Book of the Dead*, is the "opening of the mouth," a procedure requiring the use of an adze to pry open the mouth of the corpse. The instrument, which is often depicted in burial chamber paintings, bears a strong resemblance to a dipper, such as the Little Dipper. The angle of rise of the northern shaft from the Queen's Chamber is ~39°, and it could have targeted the bowl of the Little Dipper, a circumstance that supports the association with the adze. Although Horus was said to perform the "opening of the mouth" ceremony on his father, the association with the "Queen's Chamber" may not be contradictory, because the names of the chambers were given by Egyptologists.

Bauval and Gilbert (1994, p. 222) argue that the orientation of the Belt stars of Orion as it rose was strongly similar to the orientation of the three pyramids of Gizeh and perhaps two others, analogs of the stars of Orion. However, the site map of the region shows that the smallest, slightly off-line Menkaura pyramid is to the SW, not to the NW as it is in the sky. Thus, if this is to be a geographic reflection of cosmogony, an inversion as well as a reversal is required.

8.1.3. Planets

Little is known of the planets during the Old Kingdom, and even references to them are rare. A text from the time of Ramses VI refers to Mercury as "Seth in the evening twilight, a god in the morning twilight" (Neugebauer and Parker 1969, p. 181), which shows that the Egyptians had recognized Mercury as both evening star and morning star. The identification with Seth ties Mercury firmly into the Osiris cycle of myths, but we have seen no study attempting to relate the myth to astronomy. Neugebauer and Parker (1969, p. 181) say that calling Jupiter "southern star" or calling Saturn "eastern" or "western" tells us nothing; however, if an implicit time of observation could be determined, the statements would be highly meaningful. We are not willing to accept the view that such statements are meaningless vagaries. Gleadow (1969, pp. 195–196 and table 20) has taken the view that they are meaningful and has

[1] This includes a declination component of proper motion of $-0.002''$/year for a declination correction $\Delta\delta = +9''.2$.

[2] Details of this myth as summarized here are first reported by Plutarch in *De Iside et Osiride*, although some aspects can be attested in early Egyptian texts.

TABLE 8.3. Egyptian dynastic eclipses.[a]

Chronology				Egyptian capitals	Total solar eclipse dates over capitals
Gardiner (dates)		Clayton (dates)			
I	Narmer/Menes	0	Scorpion (3150)	Nekhen	3109 Feb. 5
	(3100 ± 150)	0	Narmer (3050)	Thinis	3046 Feb. 28
		I	Aha/Menes (3050)		
V	(2480)	V	Userkaf (2498)	Pe	2471 Apr. 1
VI	(2340)	VI	Teti (2345)	Nekhen	2340 Mar. 23
		IX	Meryibre (2160)	Memphis	2159 June 29
			Intef III (2069)	Heliopolis	2079 Sept. 11
XVIII	(1575)	XVIII	Ahmose I (1570)	Memphis	1533 May 9
	Smenkare (1350)		Smenkare (1336)	Akhetaten	1338 May 14
	Tutankhamen (1347)		Tutankhamen (1334)		
XXI	(1087)	XXI	Nesbanebjed (1069)	Thebes	1063 July 31
	(1061)		Amenemnisu (1043)		
XXII	(945)	XXII	Shoshenq I (945)	Thebes	948 May 22
			Shoshenq III (825)	Tanis	831 Aug. 15
	Wahibre (589–570)		Wahibre (589–570)	Sais	582 Sept. 21

[a] Dynasties are indicated by Roman numerals (see Table 8.1). All dates are B.C.

calculated dates when the statements would be valid. Unfortunately, he gives no adequate explanation of his procedures.

The identification of Venus with a heron has not yet been put into a satisfactory context, to our knowledge. The name of the planet Venus may be accompanied by the names of two deities, one of whom is Osiris, which may be, here, a name of Venus (Neugebauer and Parker 1969, p. 180). If Venus was sometimes equated with Osiris and Mercury with Seth, this gives a very strong indication of an astronomical basis for the myth. Heron depictions in mythical scenes may concern Venus. Neugebauer and Parker suggest that depictions (in late texts) of Venus as a god with one human head and one animal head may refer to the dichotomy of evening star and morning star.

8.1.4. The Calendar

We discussed some of the instruments used in Egypt and their use in calendrical operations in §3.3. Aside from shadow clocks and sundials (cf. Figure 4.4a), and from the vague suggestions of funerary texts, however, we do not understand fully what was observed or how it was done. What we do know is that observations must have been made to determine the time and the seasons. According to van der Waerden (1974, pp. 8–10) and other usually reliable sources, astronomical references from the Old Kingdom of Egypt are rare, but one possible reference to the star Sirius (*Sopdet* or, in Hellenistic form, *Sothis*) is mentioned in an ivory tablet from a tomb at Abydos. The reference is said to associate Sirius with the Nile flooding and the new year. Clagett (1995, pp. 9–11) shows that it is unlikely that there is any mention of Sirius, of Nile flooding, or of the new year in this text. They were, however, certainly associated through most of Egyptian history.

The civil year of ancient Egypt was a 365-day year, later called the "Egyptian Year," or the "Astronomer's Year." The Egyptian year was divided into three seasons of four months each. Each month was a fixed length of 30 days, summing to 360 days for the year. Within each month, the days were organized into decades. Already in the Old Kingdom, these 10-day periods were marked by asterisms, which have been called decans (see §3.3 and §4.1). A period of five days, called *epagomenal* days, was added to the calendar at the end of the calendar year. The months are shown in Table 8.4. Parker (1950) suggests that this calendar had its basis in an unattested, older 12-month luni-solar calendar, in which the month began the day after the last visible waning crescent. The same set of names was used both for lunations and for the 30-day period throughout the time when both were in use. This results in statements of the form "1 Tybi [lunation] fell on 10 Mechir [civil]," which can be confusing even to those who understand the basic principle.

TABLE 8.4. The Egyptian month names.

akh·t Inundation or winter		per·t Cultivation or spring		shemu Harvest or summer	
1	Thoth	5	Tybi	9	Pachon
2	Phaophi	6	Mechir	10	Payni
3	Hathyr	7	Phamenoth	11	Epiphi
4	Choiakh	8	Pharmuthi	12	Mesore

A 25-year lunar/solar cycle is given in a document written in or after 144 A.D. This was being used in spite of the fact that the internal details were no longer correct. According to Parker, they had been correct for a cycle starting in 357 B.C. Neugebauer thought that the cycle may have been recognized as early as the 5th century B.C. The fact that it uses lunar invisibility as the first day of a lunation, contrary to the Greek practice of beginning with first visibility, is strong support for a purely Egyptian origin. The document is given by Clagett (1995, pp. 295–306) with much of Parker's commentary.

The intercalation was based on the equation: 25 Egyptian years ≈309 lunations ($25 \times 365 = 9125 \approx 309 \times 29.530\,589 = 9124.95$ days). The text indicates that the 309 months are composed of 16 "small years" of 6 "double-months" of 59 days each and 9 "great years" of 6 "double-months" of 59 days and an extra month of 30 days. After every five years, the Egyptians added a half-day to each of the last two months to give them a length of 30 days instead of 29.5 days.

Although Parker did not think that the formal lunar cycle antedated the 4th century B.C., he thought that the repetition of lunations in a 25-year interval was recognized prior to the invention of the civil calendar, and that it was regulated by the heliacal rising of Sirius. Once the civil calendar had been adopted, and the discrepancy between the 30-day civil "months" and the lunations of the same name had been recognized, a simple rule would have created the structure later formalized as the 25-year lunar cycle. The rule would have been "whenever the first day of lunar Thoth would fall before the first day of civil Thoth, the month is intercalary" (Parker 1950, p. 26). Contrary to Clagett (1995, pp. 8–13), DHK thinks that the associations of the lunar cycle with the heliacal rising of Sirius, postulated by Parker, is plausible *a priori*, although Clagett demonstrates that some of the evidence used by Parker to support that position is invalid or may be differently interpreted. Thus, we think that Clagett (1995, p. 37ff.) is entirely justified in rejecting Parker's use of the Ebers calendar as evidence for his position.

The names of the three divisions, "Inundation," "Cultivation," and "Harvest" were presumably appropriate to the seasons at some instant in the past, prior to the adoption of the 365-day year. A good approximation to the beginning of the season of Inundation was given by the heliacal rising of Sirius. This association continued after the adoption of the civil year. During the historic period, however, the months slipped regularly through the seasons. The rate of slippage is obtained by comparing the "Egyptian Year" to the tropical year. It can be seen that $365 \times (1/0.2422) = 1507.0$ tropical years = 1508 civil years. There was a comparable slippage of the heliacal rise of Sirius through the civil year. Because of factors involving both precession and proper motion, the heliacal rising of Sirius occurred through much of Egyptian history at intervals closely approximating the Julian year. The cycle of the slippage was calculated by Censorinus[3] as 1460 Julian years. Such a calculation must be based on a close approximation to the mean length of the sidereal year (365.2564 days).[4] The last previous cycle, ending in 139 A.D., was called by Censorinus the "Era of Menophres," and presumably began in 1322 B.C. The Egyptians probably thought that the tropical year and sidereal year slippages were identical. During the Ptolemaic period, an attempt was made to modify the civil year to remain in step with Sirius and the seasons. Ptolemy III (Euergetes I, 246–222 B.C.) issued what is known today as the Canopus Decree, from the location of an inscription. The decree, issued in 238 B.C., stated that a 6th epagomenal day was to be added to the calendar every four years. In 238 B.C., it is stated that the heliacal rising of Sirius corresponded with 1 Payni, in full agreement with the testimony of Censorinus. However, no reform was carried out until a similar decree was issued during the reign of Octavian as Caesar Augustus. Relative to the previous civil year, this reform would have created a 1460-year cycle.

Clagett (1995, pp. 331–333) translates an inscription of Ptolemy IV that he dates to 218 B.C. and shows that it is direct evidence of the recognition of a Sothic cycle (sometimes called the *Sothic period*; see §4.2) of 1460 years at that time. His translation (omitting his textual comments) is

> Hail to you, Isis-Sothis, Lady of 14 and mistress of 16 who has followed her dwelling place for 730 years, 3 months, 3 days, and 3 hours.

His interpretation is that the 730 years is a reference to the time needed to move through half of the civil year, that the three months refer to an additional shift of a quarter year (implicitly taking 360 years) then a shift of three days (taking 12 years) and finally three hours, referring to a half year. The base would be 1320 B.C., which corresponds to the same 4-year period as the "era of Menophres" of Censorinus, although slightly off. This important discovery by Clagett shows clearly that the concept of the Sothic cycle was not something developed in the Roman period as some scholars have claimed.

Between 4236 and 2776 B.C., the one-day shift of the heliacal rising of Sirius occurred after five years instead of four in one case; between 2776 B.C. and 1318 B.C., there was one case in which it occurred after three years instead of four; in the period 1318 B.C. to 139 A.D., there were three times when the heliacal rising shifted one day in the civil calendar after three years instead of four (Clagett 1995, p. 313). This undoubtedly meant that observers at a particular location would expect recurrence to shift every four years. They would certainly have known that observers at different locations would have seen the rising at different dates. A small number of heliacal risings of Sirius are given in terms of the civil calendar (including one prediction), and these have been used to create an astronomical framework for Egyptian chronology. Lunar dates in the civil calendar have been used to give greater precision to such a framework.

Parker (1950, pp. 33–39, 63–69) discussed all inscriptions then postulated to refer to heliacal risings of Sirius. There are three that have been particularly important: one in the 7th year of a 12th Dynasty monarch, unfortunately unnamed, but apparently either Sesostris (Senusert) III or Amenemhet III; the Ebers calendar, dated to year 9 of Amenhotep I; and a date in an unspecified year of Thutmose III. More recently, all have been considered by Clagett (1995, especially pp. 37–48).

Parker, by examining reign lengths in conjunction with a schematized lunar cycle of 25 years and a range of dates for heliacal rising of Sirius, concluded that the document came from year 7 of Sesostris III and referred to July 17, 1872 B.C., thus, fixing the chronology of the XII Dynasty and the final part of the XI Dynasty. This was widely accepted until Krauss (1987) challenged the place of observation, the appropriateness of the *arcus visionis* values used, and the

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[3] Censorinus (writing in 238 A.D.) reported that the 1st day of the month Thoth occurred on JDN 1772028 or July 20, 139 (A.D.) in the Julian Calendar and coincided with a heliacal rising of Sirius.

[4] $365 \times 1460 = 532,900^{d}$ and $365.2564 \times 1460 \approx 533,274^{d}$, differing by $1^{y}\,9^{d}$.

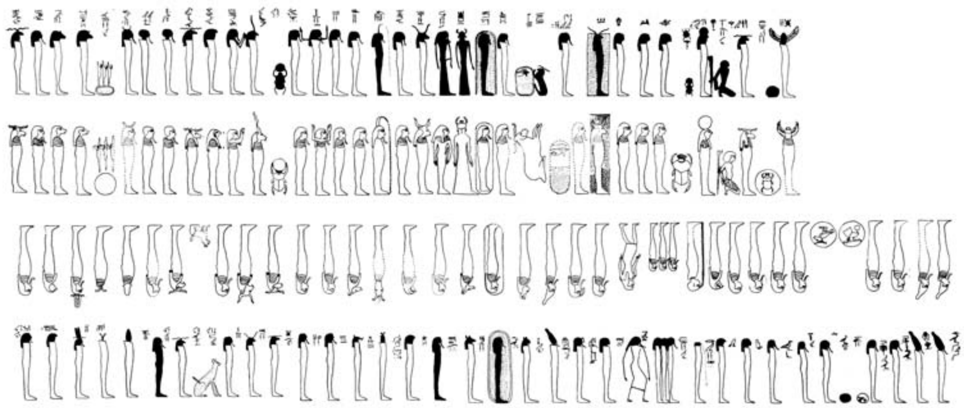


FIGURE 8.1. Depiction of the 75 manifestations of Re from the reigns of Thutmose III and Seti I. Drawing by Sharon Hanna (Neugebauer and Parker 1969, Vol. III, p. 565).

schematized pattern of lunations used by Parker. Krauss considered lunar data that became available after Parker's work, and, assuming Elephantine as the place of observation, argued for a date of 1536 B.C. [Clagett 1995, p. 141, f.n. 49]. More recently, Rohl (1995, pp. 390–391) cites the work of Rose on lunar observations, maintaining that the month lengths attested in XII Dynasty documents do not fit any of the placements that have been suggested. Rohl also challenges the interpretation of peret as "heliacal rise," pointing out that the same term is used to mean the bringing forth of the statue of a deity for a ceremonial procession. It is, however, used for the heliacal rising of Sirius in the Canopus decree, and Clagett (1995, pp. 357, 377, 380, 391, f.n. 36) shows that the *Book of Nut* describes the heliacal rising of Sirius on the very day that appears in the XII Dynasty "year 7" text. The description and the context seem to DHK to make it certain that this was, indeed, a heliacal rising of Sirius. It is said that the rising followed 70 days after the setting. Rohl (1995, pp. 134–135) also argues that the ditto marks under *peret Sopdet* in each successive month in the Ebers calendar mean that the phrase cannot refer to a heliacal rising of Sirius. Many Egyptologists now reject the conventional interpretation of this document, although it is still defended by Clagett (who rejected Parker's view of the correlation of the civil year with a lunar calendar). If it is accepted as a date in the Sirius cycle, the limits would be 1544–1537 B.C. for observation at Memphis or Heliopolis; 1525–1517 B.C. if the observations were made at Thebes. Krauss, arguing for observation at Aswan and stipulating a lunar interpretation as well, opted for 1506 B.C. (Clagett 1995, pp. 41–42). The limits could be slightly broadened for exceptionally good viewing conditions and a particularly sharp-eyed observer (see §3.1.4).

It has been calculated (assuming observations from Heliopolis) that the rising mentioned under Thutmose III occurred between 1465 and 1462 B.C. but could be placed anywhere in his reign of more than 50 years.

An interesting text (which has been studied with reference to Egyptian cosmology, but not astronomically) refers to the 75 manifestations of Re, depictions of which sometimes show only 74 figures (see Figure 8.1).

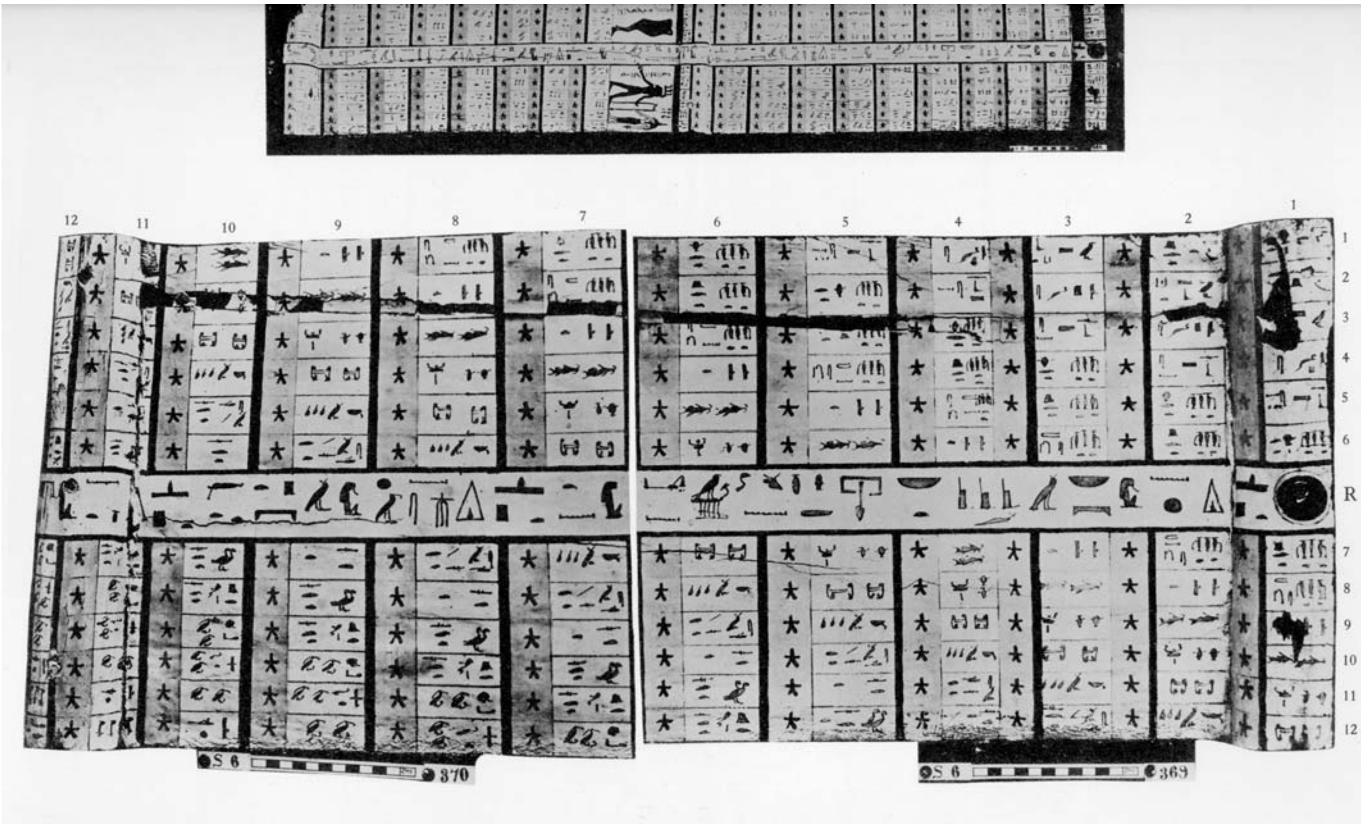
The number is a close approach to 1/5 of a year ($5 \times 73 = 365$) and may suggest that the sequence implies some sort of division of the sun's path into segments of about 5. The 74th figure might have been added to represent the portion of the year beyond 365 days. There is an absolute correspondence between the sequence of representations in the tombs of Thutmose III and Seti I. So far, no one seems to have recognized sequential correspondences with other lists, although many individual depictions have parallels.

The Egyptian Year was used throughout the Hellenistic world because of the ease of calculation it afforded in obtaining the interval of days between two dates (see §4.1.2).

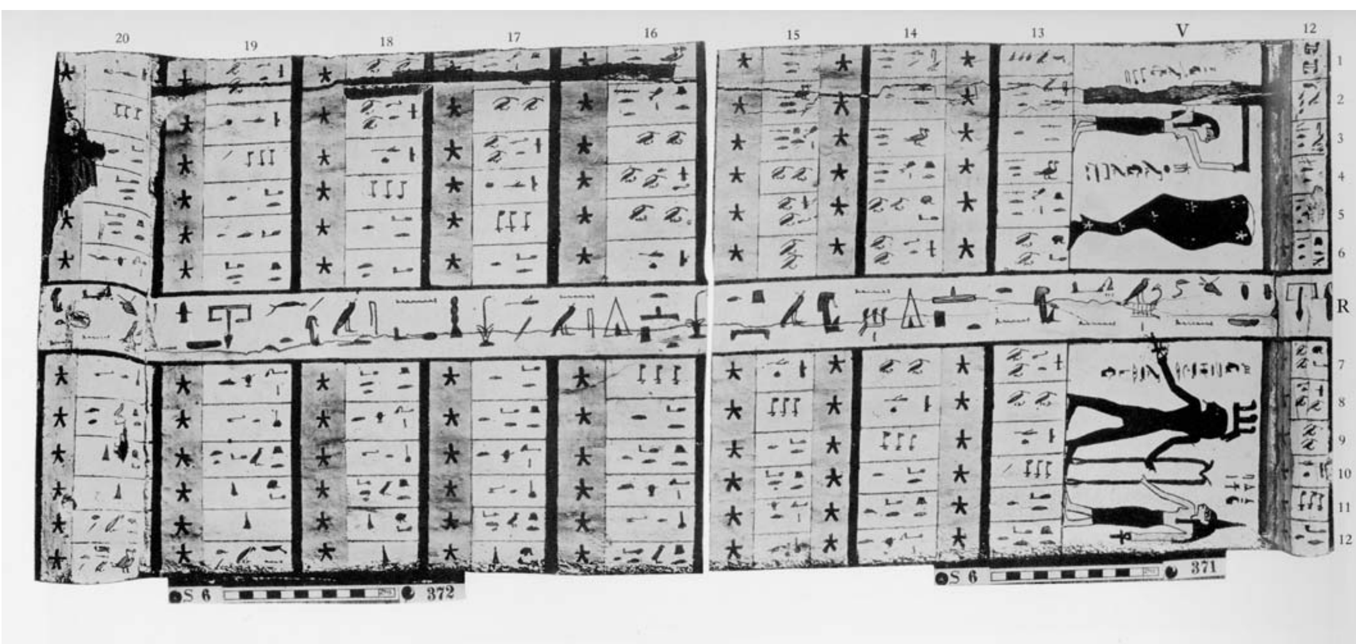
Sirius was one of the 36 asterisms known as decans. From the time of the Middle Kingdom, these were used in tables known as diagonal calendars or star clocks. A single column shows the progression of the stars rising through the night, and the different columns chronicle the changing list of such stars in the course of the year. We briefly discussed the historical importance of the decans in §4.1 for both the 24-hour day and calendrics. Neugebauer and Parker (1969, Vol. III) published a collection of diagonal calendars drawn on the interior surfaces of coffin lids. One of these, reproduced in Figure 8.2, is a coffin lid from the time of the IXth and Xth dynasties (about 2100 to 2150 B.C.) from Tomb 7, sepulchral chambers, pit 3, at Asyût.

Other coffin lid interiors portray Nut, the goddess of the sky[5] covering the deceased as the night enfolds the Sun, awaiting the morning's resurrection. The locations of the zodiac suggest that it was intended to provide temporal orientation for the resurrected soul, but the information about the date of birth and the incantations suggests a different purpose, an introduction of the deceased to the gods of the underworld and supplications for his passage through it. Neugebauer (1964a) discusses the star clocks in these tombs and suggests that the 24-hour day had its origins in the decans. The tombs of the Ramesside kings (Romer 1981, p. 66) were known as "the corridor of the Sun's path," and they have abundant astronomical depictions. Constellations from a temple at Dendera (or Denderah) dating from the Ptolemaic period, 2nd century B.C., shows the Greek zodiac amidst traditional Egyptian constellations, such as

[5] R.A. Wells (1996/1997) has proposed that the goddess Nut originated as a perception of the Milky Way as it was seen in the skies of ancient Egypt at about 3500 B.C.



(a)

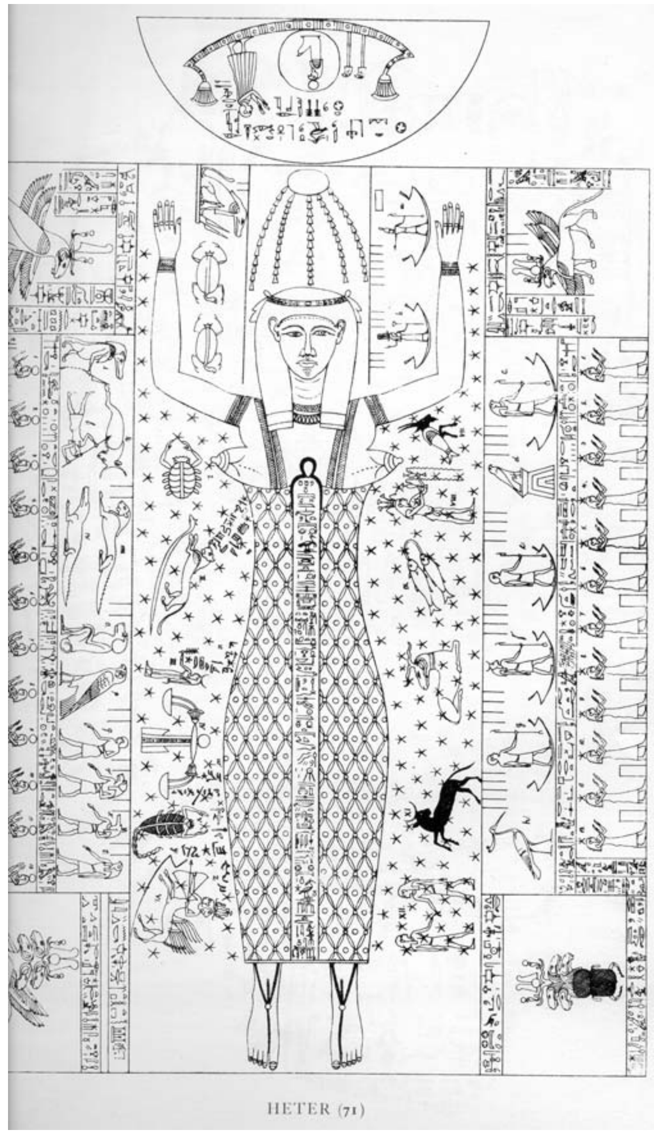


(b)

FIGURE 8.2. A coffin lid interior from ~2100 B.C., which illustrates the diagonal calendar. (a) Entire coffin lid in miniature, and detail of right half. (b) Detail of left half. From Neugebauer and Parker (1969, Vol. I, Plates 5 and 6, "Coffin 3"). Oriental Institute of the University of Chicago photographs 27047-51, the Coffin Texts Project Documentary Photographs, reproduced here with permission.

(a)

(b)



(c)

FIGURE 8.3. (a) and (b) Details from Dendera: Note the combination of Greek with traditional Egyptian constellations. Photos courtesy of Jon Polansky. (c) The coffin lid of Heter, who died in Egypt in 125 A.D.: The planets among the zodiacal constellations confirm a date of birth of October 1, 93 A.D. From Neugebauer and Parker (1969, Vol. III (Plates), Plate 50, "HETER (71).")

the foreleg of the bull. A figure holding a grain of wheat is Virgo, near Libra and Leo in Figure 8.3a. We take up the identifications of the traditional Egyptian asterisms in §8.1.6.

Personal astrology was introduced with Hellenistic culture. An example of how astrology can be useful is provided by the details on the lid of the coffin of an Egyptian named Ḥtr (Heter), who lived in Hellenistic times (Figure 8.3c). He died at age 31^{y} 5^{m} 25^{d}, according to a demotic inscription on his coffin. The dominating female figure is that of the sky goddess, Nut. The zodiacal constellations flank her. Heter's birthdate is given by the location of the planets among the zodiacal constellations. Over Leo is the inscription, "Jupiter and Saturn in Leo." Over Virgo, it reads, "end of Virgo," and "Mars." To the left of and above Scorpius: "Mercury in Scorpius" and "ascendant," respectively. Finally, between Scorpius and Sagittarius, the inscription reads, "Venus." From these locations, Neugebauer and Parker (1969, Vol. III, Texts, pp. 93–95) were able to show that a date in the first half of October, 93 A.D., satisfies the planetary positions for the birth of Heter, who, therefore, died in 125 A.D.

8.1.5. Alignments

The study of the alignments of Egyptian temples began with Lockyer, and some of his conclusions seemed so obviously wrong to the Egyptologists that this was a crucial factor in the dismissal of his work. It seems also to have created a strong bias against alignment studies of any sort on the part of most Egyptologists. However, the inscriptional evidence at Dendera seems a very strong indication that both the Temple of Hathor and the Temple of Isis at that site had stellar alignments. The two temples are at right angles to each other. The two goddesses were equated in Roman times (when the temples were built); both were styled "mothers" of the King, and each was equated, in separate sources, with Sopdet (Sirius).[6] At the Temple of Isis, it was written, "She shines into her temple on New Year's Day, and she mingles her light with that of her father Ra on the horizon" (Lockyer 1894/1964, p. 194). This is as clear a statement as one could hope to find that the temple was aligned on the heliacal rising of Sirius at the New Year as Lockyer pointed out. He did not enter into a discussion of what "New Year" meant in this regard. In terms of his measurement, he calculated that the prototype of the Roman temple would have been aligned on the heliacal rise. With respect to the Temple of Hathor at Dendera, an inscription said

> Looking to the sky at the course of the rising stars [and] recognizing the *āk* of the Bull's Thigh constellation, I establish the corners of the temple of Her Majesty.

Lockyer was puzzled by the fact that *ak*, "middle," seems elsewhere to refer to culmination but is here associated with risings and had problems relating the Bull's Thigh (Big Dipper) to the orientation. We shall not attempt to resolve these problems but draw attention to the fact that Hathor/Isis was symbolized as a Hippopotamus (discussion by Lockyer 1894/1964, pp. 216–217). An alternative name for the Bull's Thigh was "The Foreleg of Seth," which is mentioned in a text of the time of Ramses VI quoted by Neugebauer and Parker (1969, III, pp. 190–191), "as to this Foreleg of Seth, it is in the northern sky, tied to two mooring posts of flint by a chain of gold. It is entrusted to Isis as a hippopotamus (*rrt*) guarding it." A text from Esna (Sais) says that it is Sirius "who tethers the Foreleg (*msẖt*) in the northern sky, not letting it go upside down into the Duat." These and other texts cited by Neugebauer and Parker (1969, III, pp. 190–191) show a clear identification of the Hippopotamus goddess attested in the Ramesside "star clocks" with the goddess in the "northern constellations." Clearly, Isis as Hippopotamus and Isis as Sirius are both tied to the Bull's Thigh in some fashion. Neugebauer and Parker (1969, III) argue that the mythology somehow confused the two Mooring Post constellations, and two postulated Hippopotamus constellations, but the involvement of both Sirius and the Bull's Thigh in alignments at Dendera makes that seem less likely. Interestingly, one of the identifications of Hathor is with the goddess Menat (Lockyer 1894/1964, p. 211); *menat* is also the word for mooring post. That the Sun was supposed to travel in a boat suggests that the two mooring posts may be star markers for the places where the boat stopped, viz., the solstices.

Lockyer also tried to demonstrate that the temple of the Sun god, Amun-Re of Karnak, had various solar alignments but a calculated date of 3700 B.C., for an alleged summer solstice sunset was completely unacceptable and meant that scholars did not bother to examine his other suggestions. This was partly remedied by Hawkins (1973), whose studies indicated that the solar chamber of Ra-Hor-Akhty, high in the major temple, had a window looking toward the winter solstice sunrise. A smaller temple of Ra-Hor-Akhty to the southeast was also aligned to the winter solstice sunrise (noted by Lockyer and confirmed by Hawkins).

In Plate 1 (see color insert), we look east along the approach to the entrance of the temple of Amun-Re at Meroe far to the south. The picture, taken the day before the winter solstice, clearly shows that Amun-Re's temple there was oriented to the winter solstice sunrise, interesting support for the view that the similar alignments at Karnak were intentional.

The temple complex at Abu Simbel, built by Ramses II, and carved from the solid rock, is substantially north of Meroe but still far south of Karnak. It was built to celebrate the king's Sed festival, in his 34th year. The festival included a ritual race by the king and was supposed to be celebrated only after 30 years of rule. It is disputed whether the Sed festival was normally celebrated on the anniversary of the king's accession or on the first day of the "season" of "Emergence" (1 Tybi), and whether associated dates refer to the celebration of the festival or to the proclamation of the festival. The first of Tybi is mentioned in years 42 and 45 of Rameses II's reign in connection with the 5th and 6th Sed festivals. However, the 10th and 11th Sed festivals in years 57 and 60 seem to refer to 17 Tybi in a comparable context. There is an extended discussion by Parker (1950, pp. 61–62). In any case, it seems clear that 1 Tybi was importantly associated with the Sed festivals of Rameses II. Lockyer (1894/1964, p. 276) refers to Krall's interpretation that 1 Tybi was the mythical date of the coronation of Horus. At Abu Simbel, colossal statues of Rameses II flank the entrance to a sanctuary, 200 feet into the sandstone cliff, containing statues of Ra-Hor-Akhty, Rameses II, Amon, and Ptah. The sanctuary, including three of the statues, is lit by sunlight in February and October (Gregorian calendar), although the statue of Ptah, a lord of the underworld, appropriately remains in darkness. Hawkins (1971) stated that the first of Tybi corresponded to October 18 (Gregorian) about 1260 B.C. The study with the most precise site measurement data is that of Hawkins (1965a). The data consist of the azimuth of sunrise at the notch on the date when it illuminated the temple just prior to its relocation in modern times (100°.55), latitude (22°.1 N), skyline altitude (0°.5), and the elevation of the horizon (123 m). The Sun shone through a notch approximately 0°.3 deep in the cliffs on the east bank of the Nile. It has been proposed that the accession of Ramses II occurred in 1304 B.C. or 1290 B.C. or 1279 B.C. based on a combination of historical data on the lengths of the reigns and of statements about the position of the Moon both within a lunation and the civil calendar. It is, therefore, reasonable to suppose that the date when the statue was lit by the Sun corresponded with the date of the Sed festival. Because the first of Tybi fell on October 18 for only four years and would not do so again until a cycle of 1508 years had passed, this alignment gives us good evidence to choose

[6] Hathor of Dendera is equated in her temple with a substantial number of other goddesses, each of whom is assigned to a particular place. Sopdet is called "of Elephantine," in the far south.

between the possibilities, without the problems posed by the Sirius datings. Accepting that the date was the 34th[7] year of Ramses's reign, it must be 1271 B.C., 1257 B.C., or 1246 B.C. In 1271 B.C., the first of Tybi fell on Julian Day 1257498 on the 4th of November (Julian) with the Sun at $\lambda = 212°$. In 1257 B.C., the first of Tybi fell on J.D. 1262608 on the 31st of October (Julian) with the sun at $\lambda = 208°$. In 1246 B.C., the first of Tybi fell on J.D. 1266623 on the 29th of October (Julian) with the sun at $\lambda = 205°$. The correction to shift backcalculated Julian dates to backcalculated Gregorian dates at this time was 13 days. Hence, 4 November (Julian) 1271 B.C. was 23 October (Gregorian); 31 October (Julian) in 1257 B.C. was 18 October (Gregorian); 29 October (Julian) in 1246 B.C. was 16 October (Gregorian). We do not know with certainty that the Sed festival was held on the first of Tybi, but the fact that the Sun would have been shining into the sanctuary on that date in 1257 B.C. supports that view and indicates that the accession of Ramses II was probably in 1290 B.C. Hawkins very properly emphasized the play of sunlight as an important factor in the festival "bringing life and rebirth to Ramses and starting a process of deification." That same interplay of light and shadow seems equally crucial in dating his reign. It may be significant that the first day of the year, 1 Thoth, fell the day before the summer solstice in 1257 B.C.

Another smaller temple at Abu Simbel was dedicated to Nefertari, one of Rameses's queens, and to Hathor, the protectress of Rameses. Their temple is aligned on the winter solstice sunrise. This is in agreement with an interpretation of "Mooring Post" as referring to the solstices.

More recent work on alignments is scanty, but R.A. Wells, in 1986, referred to work in progress on using alignments of temple foundations to specifiable stars to determine the temple dates through precession. Christian Leitz (1989) used such techniques, and others, to reject Krauss's work on Sirius dates (Clagett 1995, pp. 141–142, f.n. 49). Leitz's information on the location and alignment of the site was not as precise as Hawkins's and he apparently knew nothing of the notch. Like Hawkins, he makes no allowance for the shift in the inequality of the seasons (see §2.3.1). He apparently did not realize that the winter solstice in the 13th century B.C. was on Dec. 18, not Dec. 22, and that the controlling celestial longitude had since shifted 3–4 days in the Gregorian calendar. These deficiencies invalidate his further arguments and conclusion about the date of the Sed Festival associated with the temple.

8.1.6. Egyptian Asterisms

Serious attempts to identify the asterisms of the Egyptians are few, despite an abundance of star maps firmly tied in Ptolemaic times to the signs of the Zodiac. Sopdet, also identified as Satet, the Archer goddess, is Sirius. The Boatman includes Orion's Belt and some other stars, and the Foreleg of the Bull is the Big Dipper. Neugebauer and Parker, who provide massive documentation of relevant material, are reluctant to go much beyond this and give reasons for doubting earlier attempts to do so. However, with zodiacal signs and decans clearly associated with asterisms, often with the star diagrams shown, a number of scholars have attempted to do so. There is still value in LePage Renouf's study (1874) of the Ramesside star clocks (criticized and extensively quoted by Clagett 1995, pp. 59–65, 413–414).

Renouf argued that the 6th hour of the night had to correspond with midnight, that "in the middle" indicated culmination and that the culmination of Sirius at Thebes in the first 15 days of the month Choiak provided a rough date of about 1450 B.C. Neugebauer and Parker estimated the date as 1470 B.C. and calculated their tables for 1500 B.C. Having the dates of culmination of the other named stars, it is certainly possible to get a good idea of their approximate location in the sky and hence probable identity.

The earliest known example of a "sky map" as the ceiling of a tomb (shown in Neugebauer and Parker 1969, III) comes from Thebes from the tomb of Senmut, the adviser of Hatshepsut. This includes the decans on the south half of the ceiling. The north half has the so-called northern constellations and wheels of the 12 months. Vertical lines run from the Thigh of the Bull to the near vicinity of the Mooring Post. Four months are left of these lines, corresponding to "Emergence" (Peret). Eight are on the right, corresponding to "Inundation" and "Harvest." Pogo (in Clagett 1995, pp. 115–116) identifies the vertical lines as "meridian cords":

> The three stars attached to the bull of the Senmut ceiling correspond to the position[s] of Delta, Epsilon, and Zeta Ursae Majoris. Around 3000 B.C., Zeta was the only 2nd magnitude star within ten degrees of the pole; the upper culmination of Eta Ursae Majoris coincided, for the latitude of Thebes, with the setting of Sirius. Observations of [the] culminations of circumpolar stars for the determination of the meridian were certainly made by Egyptians when Eta and then Zeta Ursae Majoris were the nearest of the bright circumpolar stars. . . . The star surrounded by a circle on the Senmut ceiling corresponds, obviously, to the early recognizable bright star, Zeta Ursae Majoris—the one with the conspicuous companion. The scorpion goddess Selqet (Serqet) stands behind the bull Meshketi in such a way that it seems as if she were trying to grasp the two cords stretched from the culminating star Zeta—over the invisible pole—down to the northern horizon.

Pogo is thus suggesting that the sky represented in the northern half of Senmut's ceiling is much older than the time of Senmut. The month divisions in such a context may suggest a reference to the time when "Inundation" began with the heliacal rising of Sirius at a date that was then near the summer solstice; in short, that the star chart refers to the beginning of the system of 360 days plus five when the name "Inundation" was actually appropriate.

When all five planets are represented in Egyptian art, they normally appear in the order Jupiter, Saturn, Mars, Mercury, and Venus. Two Turtles, an asterism, normally appears between Mars and Mercury. The planets follow Orion and Sirius. The appearance of the planets in a fixed order in a normal relationship with a particular set of asterisms strongly suggests that they represent a single point in real time. Gleadow (1969, Chap. 12) maintained that the representation refers to the near mass conjunction at the summer solstice in 2767 B.C. (JDN 710973). Mars, Jupiter, Saturn, and

[7] Some scholars assert that this occurred in Ramses's 33rd year, which would bring the dates, discussed in the material below, back to Nov. 4, Nov. 1, and Oct. 29, respectively.

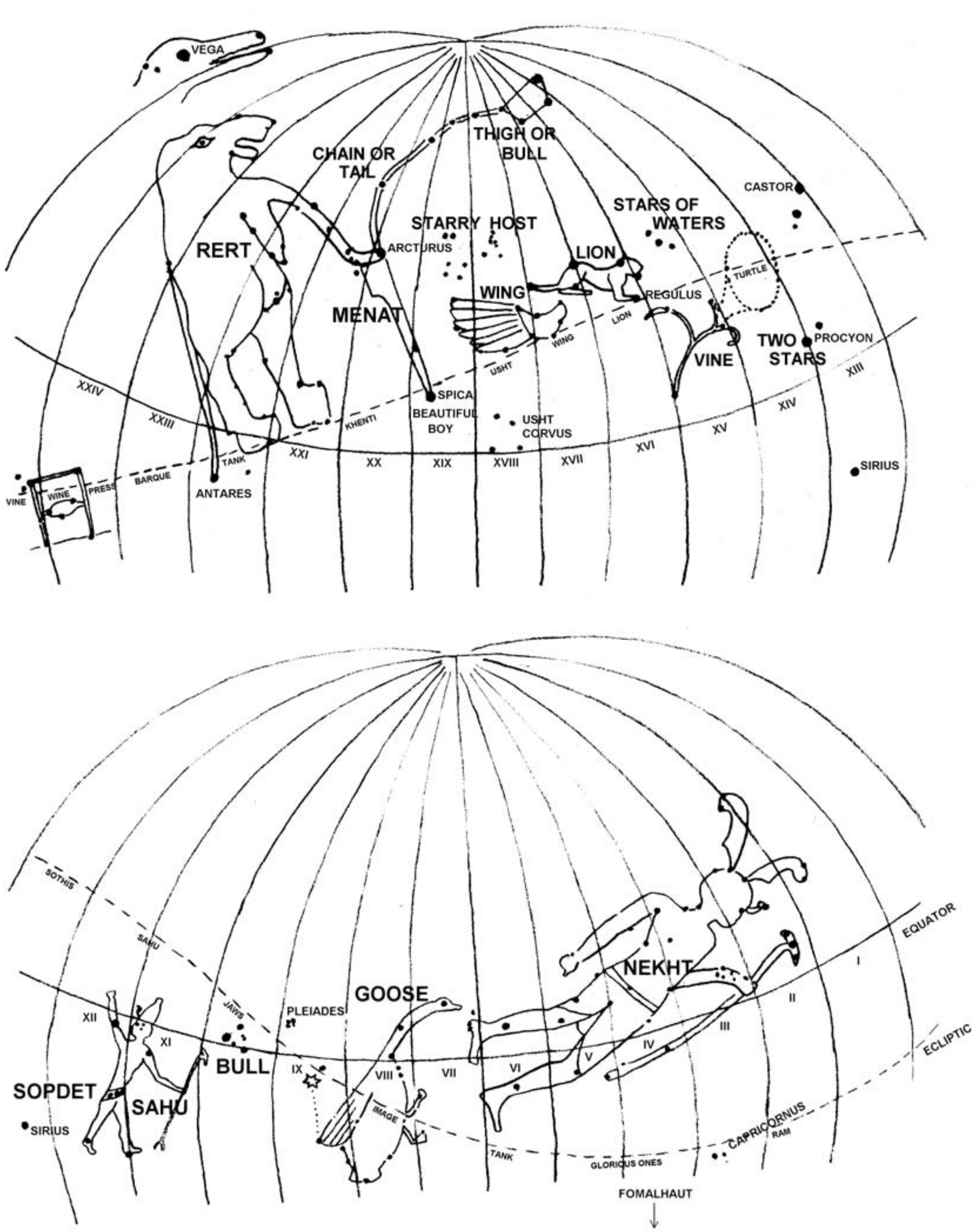


Figure 8.4. Petrie's (1940) star map of Egyptian constellations. After Petrie (1940, cited in Clagett 1995, Figs. III-84a and b). Drawing by Sharon Hanna.

Venus appeared in that order clustered within seven degrees of celestial longitude just after the rising of the Two Turtles (identified by Gleadow as δ and γ Cancri). The date was the heliacal rising of Sirius and corresponded to 1 Thoth of the civil calendar period. Gleadow thought that the date occurred during the reign of Djoser of the III Dynasty, but the early chronology is very confused. This interpretation implies that Mercury was added later.

Neugebauer and Parker (1969, III, p. 3) comment that the decan list of the Senmut ceiling is derived from their "Coffin Group V" (which they date to about 1870–1820 b.c.) and refer to linguistic evidence of Old Egyptian (XII Dynasty or earlier) in the Senmut text.

One of the few scholars to have attempted a star map of many of the Egyptian constellations was Petrie (1940, cited in Clagett 1995, figs III-84a and b). See Figure 8.4. He attempted to integrate material from the decan lists, the Ramesside star clocks, and the various star maps, including the ones that incorporate the signs of the zodiac, much more comprehensively than anyone else has done. This version deserves careful attention, although Neugebauer and Parker did not think it worth mentioning.

A study by Biegel (1921) is mentioned by Neugebauer and Parker as too naive to warrant discussion, but Clagett (1995, pp. 160–161) summarizes her work and criticisms by Pogo. Because some of the star maps contain dots, apparently representing stars, within the figures, Biegel tried to use these to make stick figure representations of the constellations, which she then attempted to identify in the sky. DHK thinks that this sort of naivete may be closer to an Egyptian view of the heavens than is easily recognized by sophisticated mathematical astronomers. One of Pogo's objections was to her use of some bright stars while ignoring others and the use of faint stars as connecting points. However, on a comparative basis, both of these practices are widespread. Pogo attempted some identifications and is extensively quoted by Clagett (1995, p. 164). His identifications of the Pleiades and the Hyades are certainly reasonable and are shared with several of his predecessors and successors.

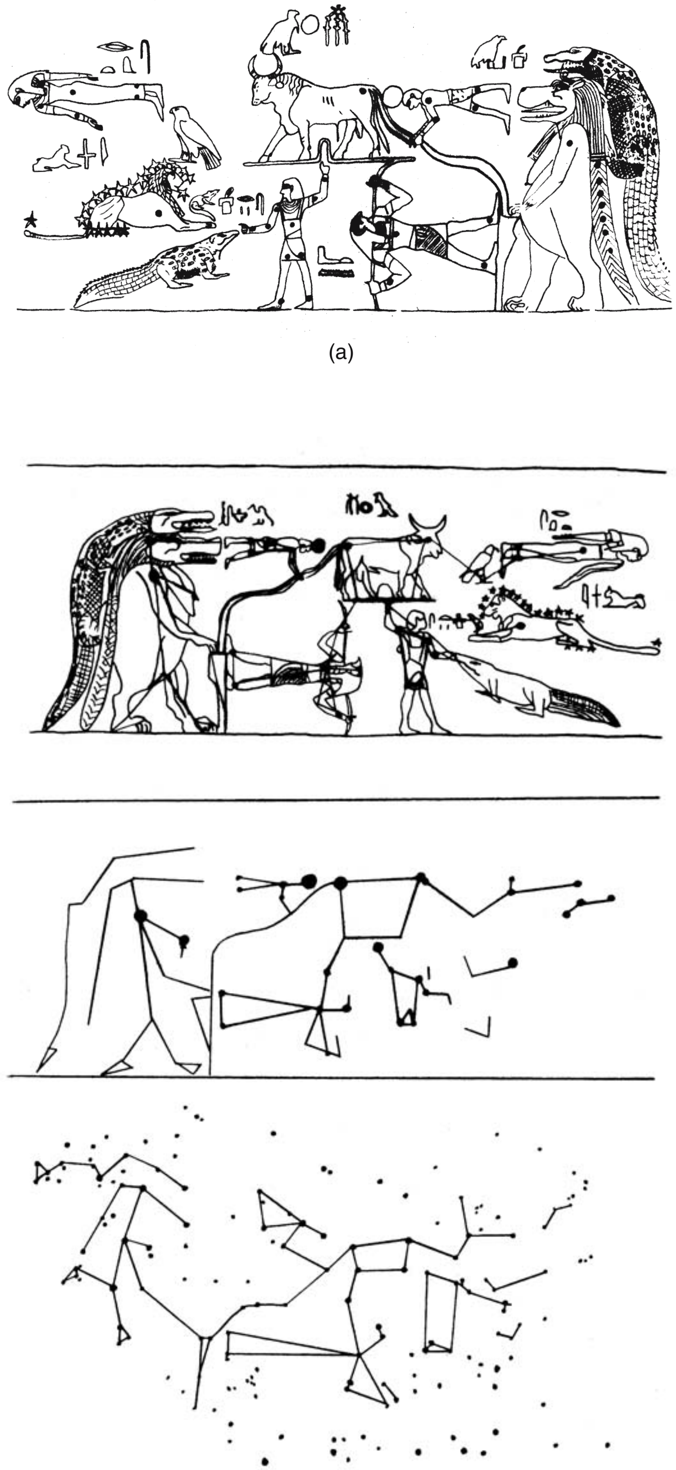
Gleadow (1969, pp. 191–192) attempts to identify the main stars of the Ramesside star clocks (excepting the Hippopotamus and the Giant, which take up about half the sky), although he doubts that they were originally conceived as hour markers. There is substantial similarity between his identifications and those of Renouf.

Davis (1985) has argued that the Sun and the dead king cross what she translates as "the Shifting Waterway" from south to north and back. She identifies this waterway with the Milky Way and as the division between the Egyptian regions of the "northern sky" and "southern sky." She points out that the crocodile god, Sobek, is "Lord of the Shifting Waterway" and that the crocodile asterism is a consistent member of the northern grouping of asterisms.

The Boatman's association with Orion's Belt would support the waterway interpretation of the Milky Way. The presence of another boat in the decan sequence, roughly half way around the sky, suggests the passage of the ecliptic through the Milky Way, in or around Sagittarius. Depending on these reasonable intrepretations and the clear identification of the Foreleg of the Bull with (the Big Dipper in) Ursa Major, Davis tentatively suggests the following identifications:

Falcon-headed human	Ursa Minor
Lion	Leo
Bird	Leo Minor
Large crocodile	Hydra
Small crocodile	Cancer
"Man in front"	Gemini
Scorpion goddess	Virgo
Hippo with crocodile on back	Ophiuchus + Libra + Scorpio
"Man behind the bull"	Bootes
Cords and stake	Hercules + Libra + Scorpio

Davis's identifications are based largely on relative positions in various depictions. Kurt Locher (1981, 1985) takes a very different approach. He attempts to correlate star patterns with the outlines of depictions (see Figure 8.5), in the manner of Biegel. EFM finds the attempt unconvincing.



(a)

(b)

Figure 8.5. (a) Constellations from the tomb of Seti I. (b) Locher's (1981, 1985) correlation of star patterns with outlines of depictions. Drawings by Sharon Hanna.

TABLE 8.5. The Coptic (Ethiopic) month names.

1	Tūt (Maskaram)	8	Baramūndah (Miyāzyā)
2	Bābah (Teqemt)	9	Bashans (Genbot)
3	Hātūr (Khedār)	10	Ba'ūnah (Sanē)
4	Kiyahk (Tākḫśāś)	11	Abīb (Ḥamlē)
5	Ṭūbah (Ṭer)	12	Misrā (Naḥasē)
6	Amshīr (Yakātit)	13	al-Nasī (Pāguemēn)
7	Baramhāt (Magābit)		

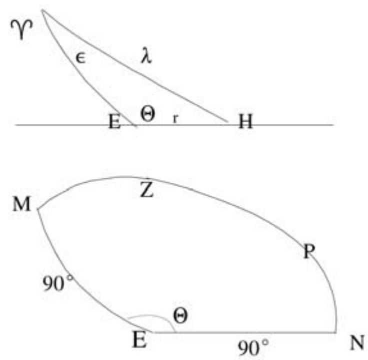


FIGURE 8.6. The geometry of the Lunar "gates." The arc MZPN indicates the celestial meridian. See text for identifications of the symbols. Drawings by E.F. Milone.

8.2. Ethiopia

Both Coptic Egypt and Ethiopia share a variation of the Egyptian Calendar, as amended to conform to the Julian Calendar during the reign of Augustus. The month names clearly derive from the Egyptian counterparts: *Thoth* becomes *Tut*, *Mesore* becomes *Misra*, and so on. The Coptic calendar, with Ethiopic variants in parentheses, is shown in Table 8.5. The months are of 30 days each except for the intercalary period of 5 days (or 6 days in leap years). The Ethiopic era base is the older of the two, starting on A.D. 7 August 29 (Julian). The Coptic era base starts on A.D. 284 August 29 (Julian). This is the year of accession of Diocletian as Roman emperor, and it is referred to as the "Era of the Martyrs" because of the accompanying persecutions of the Copts. See Dershowitz and Reingold (1997) for futher details.

The contents of certain Ethiopic Coptic texts are discussed by Neugebauer (1964; 1983, p. 467). He notes that there are essentially three sources of astronomical ideas in these texts, which are medieval in date: Alexandrian-Christian (for the computation of the dates of Easter), Hebraic-Hellenistic (for the idea of "gates" to reckon the rising and setting of Sun and Moon, as given in the Book of Enoch), and Islamic (for zodiacal signs, lunar mansions, and planets, the names of all of which appear to be transcribed from Arabic).

Neugebauer investigates and rejects the interpretation of "gates" as regions of the ecliptic because of the variation in the number of days the Moon is said to spend in them, ranging from one to eight. The older interpretation arose from statements such as the following:

The Sun rises through (the gate of) Aries (ḫâmâl) on the 17th day of Magâbît, i.e., the first day of spring (rabî').

Neugebauer (1964, p. 58; 1983, p. 476) notes that this date is equivalent to March 13 in the Julian calendar and would be appropriate for the 14th century. Similarly, a statement such as

On the 17th day of Yakâtît, the sun rises through the gate of Pisces (ehût).

In both cases, as Neugebauer argues, the text indicates that the Sun rises through the same gate as the zodiacal sign of the particular month. In addition, though, there is a manuscript published by Grébaut (1918) that contains the gates in which the Moon rises during the 12 months of the Ethiopic calendar:

Rise (of the moon) in (the month of) Měyâzyâ: in the fourth gate 2 (days). In the fifth gate 2, in the sixth gate 8, in the fifth gate 1, in the fourth gate 1, in the third gate 2, in the second gate 2, in the first gate 8, in the second gate 6 [2],[8] in the third gate 1, in the fourth gate 1. Total: 30 days, month of Měyâzyâ.

Clearly, a horizon phenomenon is being discussed because the relatively small N-S motion near the solstices results in a very small change in rise/set azimuth; the 6th and 1st gate in this interpretation represent the extremes of the azimuth of rise. The length of horizon arc of a "gate" can be understood in terms of spherical astronomy (refer to §§2.2, 2.3, 6.2.4; Fig. 2.17a). Figure 8.6 illustrates the geometry.

The arc from the vernal equinox (♈) to H (on the horizon) is a portion of the ecliptic measuring the celestial longitude, λ. The point M in the lower portion of the figure marks the point on the celestial equator that is on the celestial meridian. The angle Θ may be seen to be equal to 90 + ϕ, where ϕ is the latitude (the altitude of the pole, here indicated by the arc PN). The arc from the vernal equinox to E, ♈E, runs along the celestial equator, and the angle between the celestial equator and the ecliptic is the obliquity, ε. The arc EH is equal to 90 − A (where A is the azimuth) and is what Neugebauer refers to as r, the extent of a particular "gate." The relations among these quantities can be found from successive applications of the sine law of spherical astronomy. In the upper triangle,

$$\frac{\sin\Theta}{\sin\lambda} = \frac{\sin\varepsilon}{\sin r}, \tag{8.1}$$

and in the lower triangle,

$$\frac{\sin\Theta}{\sin(90+\phi)} = \frac{\sin(90)}{\sin(90)} = 1, \tag{8.2}$$

so that

$$\sin\Theta = \sin(90+\phi) = \cos\phi. \tag{8.3}$$

Hence, (8.1) may be written

$$\sin r = \frac{\sin\lambda \times \sin\varepsilon}{\cos\phi}, \tag{8.4}$$

which is Neugebauer's (1964, p. 53; 1983, p. 471) Eqn. 1. The maximum value of $\sin r$ is achieved when $\sin\lambda = 1$, or when the vernal equinox is on the celestial meridian. This gives the

[8] Neugebauer suggests "6" to be a scribal error, and that it should read "2."

maximum “gate” width. For $\phi = 36°$, $\varepsilon = 23.5°$, $r_{max} = \sim 30°$; for $\phi = 28°$, $r_{max} = \sim 27°$. Neugebauer uses the association of the lunar gates with limited horizon arcs to explain references to lunar motion contained in the Book of Enoch, transmitted from Jewish sources to Ethiopia. His Table 1 (Neugebauer 1964, p. 53; 1983, p. 471), which summarizes this motion, shows six “gates” of equal horizon arc lengths, with the 1st and 6th reserved for the lunar “solstices.” Although not exact, he demonstrates that arcs of ~10° suffice to describe the approximate, although not the precise, range of lunar motion, because of the effect of nodal regression on the amplitude of the Moon’s horizon motion (see §2.3.4). Neugebauer’s Table 2 (Neugebauer 1964, p. 59; 1983, p. 477), which summarizes the solar motion in the Book of Enoch, demonstrates a similar scheme, also involving “gates.” It is not clear if the solar and lunar “gates” were of different arc lengths. Twelve additional “gates” are mentioned for the winds (on both east and west sides, providing a sum of 36 “gates” and thereby completing the circumference of the horizon), whereas “windows” are mentioned for the risings and settings of stars, but these lack specificity.

8.3. North Africa

We know little of the astronomy of North Africa. Native populations of the Berber group, Moors, Mycenaean Greeks, Phoenicians who settled Carthage, and Romans all had a role in developing the ideas of the area. Libya had intimate relationships with Egypt, sometimes friendly, sometimes hostile. In the Roman period, the culture was typically Mediterranean in many ways, but the trade routes down to the Niger brought a constant influx of people, products, and ideas from the Niger and Lake Tchad regions.

Throughout much of the area, the principal deity, under many different local names, was identified with the planet Saturn. There are also references to the seven gods who are represented on a Roman-period monument from Vaga (Béja) with their names in Latin letters.

These included two goddesses, both depicted in capes that have been variously interpreted as feathers or serpent scales. The goddess Vihinam is shown holding forceps with a child at her feet corresponding with the widespread concept of the Moon goddess as patroness of childbirth. The other goddess, called Varsissima, should correspond with Venus. The figure of Macurgum holds a book and a staff with two serpents coiled about it. He is clearly an equivalent of Mercury. There are two horsemen, Macurtum and Junam, one of which is expected to be the Sun, and the other, Mars. The lantern held by Macurtum suggests that he is to be equated with the Sun. At the center, holding a club, is the figure of *Bonchor*, presumably the local designation of Saturn, as head of the pantheon. Finally, *Matilam*, presiding at the sacrifice of a ram, must represent Jupiter.

A Libyan monument, reused in the Roman period, from Annaba, Algeria, shows a set of eight symbols, of which the top two are the Sun and Moon. The others may be symbols of planetary deities (plus, perhaps, the Pleiades), but that is not presently demonstrable.

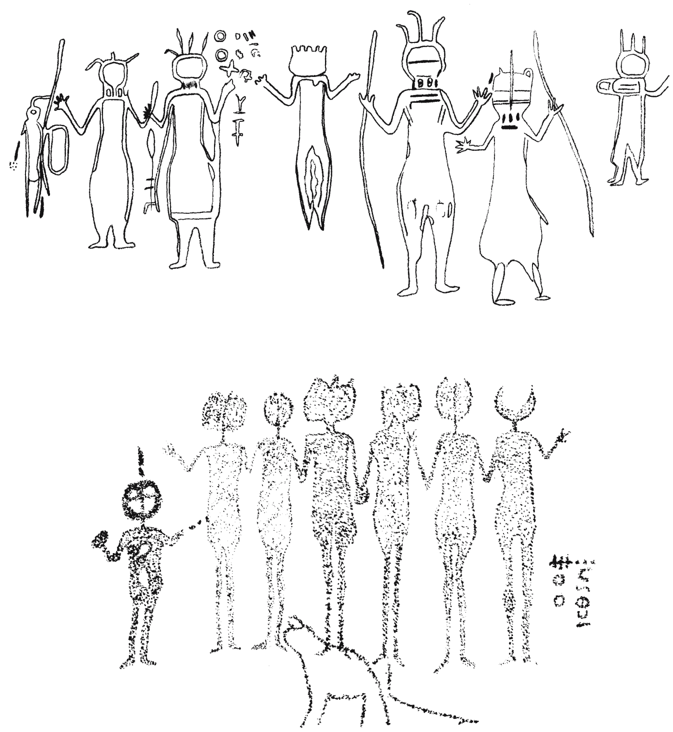


FIGURE 8.7. Representations of a set of seven figures, which may be the planetary gods: These are from the Tuareg-related peoples to the south in the Sahara. The figure with a crescent-shaped head suggests a lunar deity; a smaller figure has a cross-in-circle head which resembles the Sun-symbol from Annaba. Drawing by Sharon Hanna.

Among Tuareg-related peoples to the south in the Sahara, inscriptions and “rock art” from the late centuries B.C. include representations of a set of seven figures, which may be the planetary gods. In the representations shown in Figure 8.7, one of the figures has a crescent-shaped head suggesting a lunar deity and a smaller figure has a cross-in-circle head, resembling the Sun-symbol from Annaba. Accompanying short inscriptions give no help in interpretation at present.

8.4. The Dogons

In Mali, formerly called the French West Sudan, live a tribe called the Dogon. They are village farmers, planting millet, beans, and cotton, and keeping sheep, goats, and fowls, and they are also weavers of beautiful cotton garments, but they still have some minimal dependence on hunting. Among them are many expert horsemen. Most villages contain forges for ironworking, traditionally located on the north side. Their buildings are impressive structures of *terre pisée*, sometimes set in high cliffs and often painted with elaborate designs. Their territory lies across trade routes leading from the Mediterranean to the Gold Coast, but they were incorporated into the French colonies only in 1920, although French attacks on the area had begun in the 1890s. Historically, they have remained resistant to the encroachments of both Christianity and Islam, although the latter is now gaining ground.

In 1931, the French scholar Marcel Griaule began a lifetime of work among the Dogon. His *Dieu d'Eau*, an important work for nonspecialists, published in 1948, gave an account of Dogon cosmology as explained to him by his friend, Ogotemmeli. According to this account, the world has the form of a square platform, of dimensions 8 × 8 (in units that are not understood and may be inexplicable), erected on a circular base of 20 units diameter and a height of 10 units. Four stairways, each 10 steps high, climb the structure; on these steps live beings of various kinds. These have been diagrammed to scale in Figure 8.8. Five steps are said to be vacant, so that 35 classes of beings (mostly animals) are enumerated. The form of this diagram is similar to that of the heavenly diagram from Chellambaram and not unlike a Chinese *shih* (Figure 10.7) with base and top reversed. The arrangement of the animals is different, but it bears a generic similarity to the animal lists that are discussed in §§9 and 15; the west stairway, in particular, shows similarities in sequence to the Asian lists, if not enough to be certain of a historical relationship.

Again according to Griaule (1948/1966, pp. 210–211), the Dogon show a remarkable development of symbolic associations among different kinds of data, such as colors, directions, grains, internal organs of the body, "constellations" (one of which is Venus), stringed instruments, and regions. These are decidedly like the tremendous elaboration of such symbolic correspondence in Han China, except that the Dogon use a base of eight rather than five, as in Han China. It is curious however, that the other structural dimensions are simple multiples of 5, and that the Dogon indicate the "quality" of individuals in just five cases. We can see no suggestion of Mediterranean or Egyptian similarities in most of the described material, but derivation from Asia seems a structural possibility. Despite these interesting matters, what has attracted the most interest to Dogon cosmology is a report by Griaule and his colleague Germaine Dieterlen giving a Dogon account of the star Sirius.

An English translation of the Griaule and Dieterlen (1950) account of the astronomical and cosmological beliefs of the Dogon is found in Temple (1976), and a good summary is given by Cornell. At the heart of the Dogon cosmology appear a series of astronomical statements that are unexpected and remarkable. Mention is made in the Griaule and Dieterlen account of the four moons of Jupiter, of the ring around Saturn, of the revolutions of the planets around the Sun and of their elliptical orbits, and of the orbit of the binary star system involving Sirius. The binary contains a white dwarf (see §5.8.1) in a mutual eccentric orbit with a period of 50^y. Although "Eagle-Eyed" Dawson

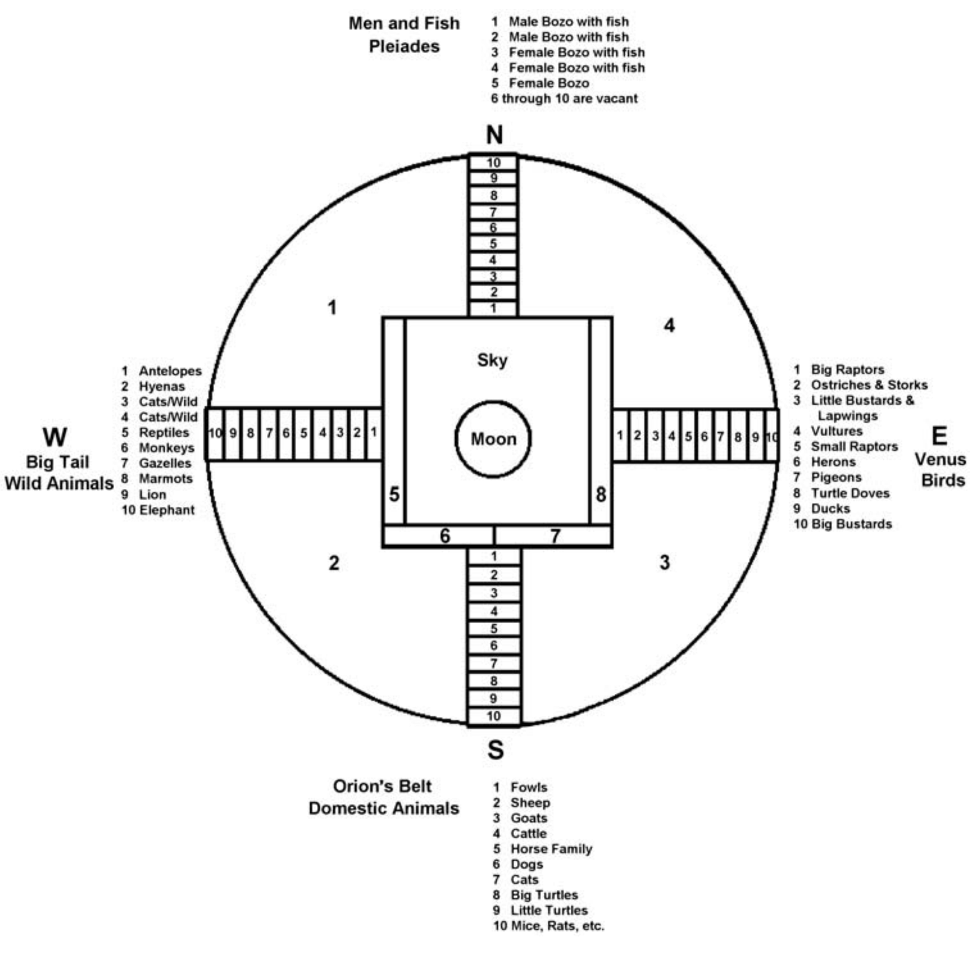


FIGURE 8.8. Dogon cosmology according to Marcel Griaule: The world has the form of a square platform, of dimensions 8 × 8 (in units that are not understood), erected on a circular base of 20 units diameter and a height of 10 units. Four stairways, each 10 steps high, climb the structure; on these steps are live beings of various kinds. Five steps are said to be vacant, so that 35 classes of beings (mostly animals) are enumerated. Drawing by Danny Zborover.

(Bobrovnikoff 1984) may have been able to discern the moons of Jupiter, there is no evidence of he or anyone else observing by unaided eye the other phenomena. Thus far, five explanations have been offered, Kelley feels none plausible.

The first is that the highly respected anthropologists who reported this information faked the data. This simple solution has been suggested (Brecher 1979, p. 109), but no one has espoused it.

If the anthropological reports are accepted as reliable, it is important to note that the Dogons reported that they learned these things from beings somewhat like men and somewhat like fish, who came from the Sirius system. Robert Temple (1976) has devoted a book to the defense of this view, but somewhat modified. Although Temple has developed some interesting comparative mythological data associated (sometimes very indirectly) with Sirius, the evidence hardly seems adequate to support such a radical hypothesis, notwithstanding that the supporting scholarship is of a high caliber, unlike the unreliable presentations normally associated with such ideas.

The third hypothesis has been supported by Sagan and Brecher in partly independent analyses that suggest that some European, perhaps a Jesuit priest, interested in astronomy, passed on the latest interpretations of Sirius and his white dwarf companion in the 1920s. Against this hypothesis is the situation that the informants of Griaule and Dieterlen would have been already mature individuals in the 1920s, and it seems difficult to believe that such a central part of their belief system could have been introduced in their lifetimes without their knowledge, particularly as apparently derivative beliefs seem to be widespread within the Mali region. Indeed, from an anthropological viewpoint, it is difficult to understand the mechanism by which such ideas could be introduced in such a crucial area of belief.

For those inclined to accept intervention by extraterrestrials as a legitimate theory, it should be instructive that Jupiter has more than 60 and not 4 moons, and therefore, the extraterrestrials would have been poorly informed, as would an itinerant clergyman-astronomer of the 1920s. The four brightest moons were discovered by Galileo in 1610 with only a modest telescope, whereas the others are far fainter and require much larger telescopes to see. The four Galiliean moons suggest, therefore, that unless the Dogons had among them an exceptionally sharp-eyed individual, either they had access to a concave mirror or to another modest telescopic aid or that they were in contact with an outside informant between the years 1610 and about 1892, when Jupiter V (Amalthea) was discovered. The apparent knowledge of the rings of Saturn, if this is correctly described, also limits the date of possible transference. Although Galileo was certainly the first astronomer to observe them, the first clear detection of the rings of Saturn as rings was done by Christiaan Huyghens in 1655 (Ashbrook 1984, p. 123), published in his book *Systema Saturnium* in 1659. A variant of Brecher's theory, suggested by Kelley—that the Dogon incorporated telescopic information into their system at a substantially earlier date than anyone else has suggested (except, of course, for the extraterrestrial enthusiasts)—appears to Milone to be the most viable theory. The duplicity of Sirius is no handicap to this theory either, although a 17th- or 18th-century Dogon discovery is effectively eliminated by it. The binary nature of Sirius was detected because of the variation in proper motion of Sirius by the astronomer Friedrich W. Bessel in 1844, who also determined its 50^y orbital period, before the companion to the dog star ("the pup") was detected telescopically by Alvin G. Clark with an 18.5-in refractor in 1862. Although calibrations were less accurate than today, the approximate mass of Sirius A could be surmised and the mass and thus the orbit of the companion could be deduced by Bessel's time. Thus, the most logical dates of contact were between 1844 and 1892, and probably, because an observational confirmation would be attention-getting at the time, between 1862 and 1892. It would be instructive to search for records of travels by astronomically aware clergy or other outsiders in this interval.

Brecher has suggested two alternatives to the "wandering Jesuit" theory. One is simply that with a thousand cultures, more or less, each with its myths, some myths may randomly approach reality. The probability of coincidence in such cases is very difficult to gauge, because the belief components of the Dogon are not exactly the same as the simply stated modern facts, and the question of degree of correspondence makes such an assessment extremely difficult. Kelley feels that none of the series of astronomical statements by the Dogon have parallels in mythology elsewhere, except for statements about twin stars, mostly, like Castor and Pollux, clearly not referring to binary stars; he suggests further that for cosmological myths that mention the period of revolution of one star relative to an invisible companion, we have a sample of one—the Dogon myth. Thus, he argues, the statistical likelihood of this one being by coincidence a scientifically verifiable fact is essentially zero.

Finally, Brecher has cited the view (described here in §5.8) that the companion star of Sirius was a red giant that evolved into a white dwarf within fairly recent historic times. As noted earlier, there is substantial if controversial evidence that the system appeared red between one and two millennia ago, implying that the then red companion to the white main-sequence star Sirius dominated the visible light of the system. However, at a distance of 2.65 pc, the maximum angular separation of the two components, if indeed there were a red giant in the system then, would not have exceeded 12 arc-seconds[9] (recall that the resolution of the human eye of 2 to 4 arc-minutes), at any time, at least in the current orbit, so that the two stars would have appeared as one merged star to the unaided observer. It is possible that the Dogon possessed a concave mirror capable of resolving these two objects at that time. The size of a light gathering mirror or lens that could resolve such a separation is theoretically only 1 cm in diameter (assuming excellent quality optics). The resolution of two objects differing by a factor of several hundred or less in brightness could be thus achieved, but this would be inadequate for the modern pair because of their great disparity in brightness (about 10 magnitudes or a brightness ratio of 10,000 times). Clark needed a finely made refractor with an aperture 18.5 in in diameter

[9] The maximum separation is actually 11.3 arc-seconds.

in order to observe the white dwarf and, even then, was assisted in having the bright companion artificially occulted by the edge of a building (Warner 1968, retold in Ashbrook 1984). Consequently, it is extremely unlikely that the Dogons would have discovered the binary nature of Sirius telescopically within a millennium of the present; in fact, if they had a telescope in this interval, it is much more likely that they would have discovered hundreds of other stars in the sky to be doubles; yet none of these seems to be mentioned, nor were any of the other phenomena associated with improved resolution, including the craters of the Moon, except the Galilean satellites and the rings of Saturn. Thus, a 19th-century transmission theory appears to us to be the most viable. Because it is the case that an alternative and viable theory exists, we are certainly not constrained to accept the view that the anthropologists incorrectly reported data from alleged interviews with Dogon informants. If there was no other viable theory, we would have been forced to conclude that this was the case.

Whether there is a viable explanation for the Dogon beliefs or not, Kelley notes that there are a number of interesting parallels in the beliefs of the Dogons to those of Polynesia, as unlikely as that may seem from their geographical separation. In no place in Polynesia are they found as a fully unified system and in no place do they seem to include astronomical details of the sort that make the Dogon account so unusual. However, a number of arbitrary details are so closely similar to Dogon beliefs that hypothesizing a historical relationship of some sort seems necessary. This lends some support to the antiquity of the Dogon cosmological scheme. Directly or indirectly, Sirius is associated in both cultures with a similar concept of *po* as origin of all things, with Twins, with the Rainbow, with a spiral, with *Digitaria* grain, with fish-men, with the term *lena*, and with crucifixion. In both cultures, Sirius is referred to as a red star, as in earlier Mediterranean references (§5.8.4). In Hawaii, the name *Red star* is applied to Sirius (Johnson and Mahelona 1975, p. 41). The name *Rehua*, which is a plant (usually with bright red blossoms, but sometimes with white ones), was applied to Sirius among the Maori; it was applied to Antares among the Maori, in the Tuamotus, and in Hawaii, and it was probably applied also to Betelgeuse among the Maori (Johnson and Mahelona 1975, p. 105). Moreover, on Mangaia, the god *Rongo* (PP **Lono*), identified with Sirius, was said to be the twin of *Tangaroa* (PP **Tan*aloa, "Long Jaw"), sometimes the Milky Way, sometimes an unidentified star. All things were divided between Rongo and Tangaroa, but the share of Tangaroa consisted of red things (and fair-haired children).

The Dogon applied the term *po* both to the invisible companion of Sirius, which they said was the origin of all things, and to the very small grain called *fonio* or *Digitaria*. Throughout Polynesia, *po* was the name of the primal night or darkness, from which all things came. It was sometimes conceived of as preceding *kore*, "nothingness," sometimes as the successor of *kore*. Tregear (1891, p. 168) says that *kore* is "the primal Power of the Cosmos, the Void or negation, yet containing the potentiality of all things afterwards to come." Both *kore* and *po* appear as the names of a lengthy series of ages. *Po* is also related in various ways to **Vatea*, "daylight" (Maori *Atea*, Mangaia *Vatea*, Hawaiian *Wakea*). In Mangaia, *Vatea* is a "god, half-man and half fish in shape . . . the father of gods and men" (Tregear 1891, sub *kore*). *Vatea* and his wife, *Papa*, had twin children, *Tangaroa* and *Rongo* (**Lono*) (Tregear 1891, p. 28, sub *Atea*). The concept is close to that of the bisexual *Nommos*, of whom there were five pairs of twins, with bodies supple as water, and one leg either a drumstick or a fish (Laude 1973, catalog numbers 1–7). *Nommos* may be drawn almost entirely fish-like (cf. Temple 1976, pp. 210–212). In the Marquesas, it was believed that *Atea*, as Light, "evolved himself" and then brought forth *Ono* (**Lono*, "sound"). Light and Sound then made war on *po* and set limits to night. In Hawaii, *Wakea* made land and sea, the heavens, sun, moon, and stars from the calabash (*ipu*) of his wife *Papa*. *Lono* (*Lono) is once called *Hakuakea*, "Lord Atea" (Tregear 1891). *Lono-meha*, "solitary Lono" is a name for Sirius, as is *ipu-o-Lono*, "the calabash of Lono" (Johnson and Mahelona 1975, pp. ix, 1, 3)[10] Among the Maori, *Rongo* is said to have had 13 brothers, including five pairs of twins (Tregear 1891, p. 424). In Mangaia, *Lono was the 1st of 13 gods of night and was said to be incarnate in the spiral-shaped conch shell (Gill 1876, pp. 95–96).

Also in Mangaia, *te-aka-ia-roe* is translated as "the root of all existence" (Tregear 1891, p. 168), and in Hawaii, *'a'ā* from **ʻaka*, "root" is a name of Sirius. Another Hawaiian name of Sirius is *lena*, "to stretch out, extend"; "to bend, as a bow," which is suggestive of widespread identification of Sirius as the Bow Star, although that does not appear among the Dogon, apparently. However, it is said that one of the *Nommos* was crucified on a *kilena* tree. Among the Maori, it is said that the great *Rongo* is *Rongo-nui-a-tau*, and among the Hawaiians, one of the cognate forms is *kau* (from **tau*), which may mean "to suspend or hang up . . . to crucify . . . a (human) sacrifice spread out in the form of an 'x' " (Tregear 1891, sub *tau*). Allen (1899/1963, p. 125) refers to "the Egyptian Cross" as an asterism formed of Procyon, Betelgeuse, Naos (ζ Pup), Phaet (α Col), and Sirius, with the latter "at the vertices of the two triangles and the centre of the letter."

In Mangareva, it is said that *Rongo* was visible as the rainbow; among the Maori, Rongo was god of the sweet potato, which he brought in his belt, which in turn, was identified as the rainbow (Tregear 1891, sub *Rongo*). Temple (1976, p. 215) writes that "the great *Nommo* manifests himself in the rainbow." According to Laude (1973), the 7th *Nommo* stole coals from the sun and fled down the rainbow as a spiral path.

Perhaps the most striking similarity is that in Hawaii, *Kama-pua'a*, "pig-youth," is a form of *Lono* and has at least 17 other forms, one of which is a surgeon fish, and one is *Digitaria pruriens*—a different species of the grain that gives Sirius its name among the Dogon (Handy and Handy 1968, pp. 47–48).

Finally, the widespread Polynesian myth of lifting up the sky, most commonly attributed to Maui, is occasionally ascribed to **Lono*, and Sirius is associated with *'amo*, "the balance pole which is used across the shoulders to bear

[10] For a discussion of the significance of the calabash for Polynesian navigation, see §11.3.

heavy weight," the pole being associated with Orion's belt (Johnson and Mahelena 1975, p. 127). Is the sky-lifting myth perhaps to be associated with the heaviness of Sirius's invisible companion in Dogon myth?

Temple draws attention to the identification of parts of the diagrams of the Sirius system with a knife and the circumcision ritual among the Dogon as evidence for the relationship of the Dogon with Egyptian practices and beliefs. Although we know of no association between circumcision and Sirius in Polynesia, circumcision was an important element of some Polynesian cultures.

Thus, although we are unconvinced by interstellar diffusion theories, we seem to have a major puzzle in earthly diffusion for a number of astronomical/mythological ideas about the Sirius system. If these indeed have a common origin, this may have important implications about the spread of other ideas and mythical beliefs, and the curious similarities that appear in widely separated cultures.

8.5. Other African Cultures

Elsewhere in Africa, Cornell (1981) discusses the sites of Namoratunga I and II, which are in the territory of the Cushitic-speaking Borana tribe, near Lake Turkana in NW Kenya. These people are cattle-raisers, with a strong emphasis on warfare and conquest, and who have become dominant in much of this area. In the modern Cushitic calendar, lunar months are identified and named during half the year by risings of the new moon in conjunction, successively, with Triangulum, the Pleiades, Bellatrix, central Orion, Saiph, and Sirius. Then the second half of the year begins with the rising of Triangulum in conjunction with the full moon, and that half is measured entirely by relationships of Triangulum to lunar phases. It is alleged both that the year is 354 days long (12 lunar months) and that it is adjusted "to make the lunar year correspond closely to the tropical year," although it has "no relation to the sun" (Cornell 1981, pp. 201–203). Actually, the description suggests a basic sidereal calendar with superimposed lunations so that the lunations automatically adjust to the sidereal, and not to the tropical, year.

The Namoratunga sites are two graveyards, dated by ^{14}C to the late centuries B.C. In one of them, huge standing stones outline the graves. In the other, on the slope of a mountain above a lake, with a clear view of the eastern horizon, 19 stone columns were formed into rows. B.M. Lynch and L.H. Robbins, who investigated the sites, assumed that pairs of stones marked alignments to the rising points of the asterisms of the Cushite calendar at about 300 B.C. and checked the rising azimuths. They found 12 alignments to the 7 asterisms. In nine cases, they found a match within 1 degree, and in the other three cases, not quite so close alignments were found. Aside from one stone only 15 cm high, all the other stones of the complex were used in one or another of the alignments. Because of precession, only four of the azimuths are still valid today. This remarkable result shows that a combination of ethnographic data about the modern calendar with archeological evidence can make the existence of deliberate archaeoastronomical alignments much more likely than would be possible with the alignments alone, and supply a fairly tight astronomical dating to the archeological remains. The match of the alignments with the modern calendar is also a remarkable demonstration of intellectual continuity over more than 2000 years.

9 Indo-Iranian Cultures

9.1. India

9.1.1. Historical and Cultural Background

We know the India of today as a subcontinent containing a very large population of diverse peoples but of two principal religions: Hinduism and Islam. There are, however, many other ancient religions on the subcontinent, such as Christianity, Judaism, Sikhism, and Zoroastrianism. India is the birthplace of Mahavira and Buddha and of the two great ancient religions that they are credited with founding—Jainism and Buddhism, respectively. Indeed, Hinduism is much more complex than can be summarized by the word religion, because it involves a synthesis of many ways of living and beliefs, with roots stretching back in time to more than two millennia before the beginning of the Christian era. Table 9.1 summarizes the Indian chronology.

Animal remains, weaponry, and flint tools indicate a human presence in India for nearly two million years. The Lower, Middle, and Upper Palaeolithic of the Pleistocene period have their counterparts in the west, but also show regional differences; a similar statement holds for the Mesolithic, from the beginning of the Holocene, around 9000 B.C., to the beginning of the Iron Age, about 1000 B.C. or later (Allchin and Allchin 1982, pp. 33–35). The earliest cultural period, the Acheulian from the Lower Pleistocene, is characterized by the use of stone tools. Acheulian habitation of several rock shelters in the area of Bhimbetka hill near Hoshangabad in Central India has been discovered (Allchin and Allchin 1982, pp. 38–41). These shelters revealed much rock art, although it is likely that this rock art stems from the Mesolithic rather than from any earlier time. Agrawala (1965) reports more than 50 rock shelters with rock painting within 5 miles of Pachmarchi alone. The paintings are of human and animal figures (Agrawala 1965, Plate 1) and show primarily hunting and dancing scenes. Rock art from rock shelters near Mori show geometric figures, including “a four-armed cross inside a circle, an eight-spoked wheel,” and “a solar orb with multiple rays” (Agrawala 1965, p. 13).

Technically advanced farming settlements are first known in a region that today comprises areas of Iran, Afghanistan, and northwestern India. The Elamite civilization developed in this region. The recent decipherment of the early Elamite script has given us information about the language that makes it clear that Elamite is distantly related to the Dravidian languages. The Dravidians were probably in the Indus region before ~2500 B.C. and evolved from a pastoral to an urban, trading culture. Dravidian languages spoken today include Tamil, Telegu, Kannada, and Malayalam, restricted to the central and southern regions of India. As far as is known, the first major civilization in India was that of the Indus or Harrappan culture (~2250–1750 B.C.) in the northwest. The major excavated sites are Harappa, Mohenjodaro, and Lothal, all in the Indus River valley. The Indus civilization is characterized by writing, and by large cities, with monumental architecture, broad streets, indoor plumbing, public granaries, and baths. Specialized craftsmen made elaborate painted pottery, and metal was used both for luxury items and tools.

The writing of the Harappan culture is still undeciphered, but Parpola (1994) has produced a compendium that will be an indispensable aid to anyone attempting this task. In his discussion, Parpola (1994, Part IV) provides a mass of new evidence for identifying the language of Harappa as Dravidian and has extensive material on direct and indirect evidence for Harappan astronomy. Parpola, along with a number of earlier scholars, reads a fish hieroglyph as **men*, which means both “fish” and “star.” There are reasons for doubting this interpretation (Kelley and Wells 1995), but in the present state of decipherment of the Indus script, it is certainly possible. In any case, Parpola gives good linguistic evidence that Sanskrit borrowed Dravidian astronomical terms and concepts along with associated mythology. His discussion should be read by anyone interested in early astronomy.

The Harappan cities were laid out with the walls slightly off the cardinal directions. It has been suggested that they were oriented to the setting point of the Pleiades, which

TABLE 9.1. A brief chronology of India.

Culture/governance	Dates	Area	Personages/events
Paleolithic	≤38000 B.C.	Panjab, NW; central	Tools; petroglyphs
Early Indus Valley	<5000 B.C.	NW	Cattle; pottery
Early Harappan	<2500 B.C.	NW	Centralized grain storage citadel towns; water supply,
Harappa and Mohenjo-Daro (Indus Civilization)		NW	drainage systems; mother-goddess worship
Vedic (Indo-Aryans)	1500 B.C.	NW	Sanskrit texts: Rig-Veda;
	1000–400 B.C.		Sama-, Yajur-, Atharva-Vedas; Brahmanas; rise of Buddhism and Jainism (Buddha: 563–483; Mahavira: 540–468)
Magadha	~500 B.C.	Ganges valley	
Persian	400 B.C	NW	Foreign invasions: Achaemenid (Cyrus)
Macedonian	327 B.C.	NW	Alexander (2 years)
(Maurya dynasty)	321–185 B.C.	All but S	Ashoka (~269–232) (decree of nonviolence)
Indo-Greeks	185 B.C.	NW	
Satavahanas	100 B.C.	S central	Bilingual coinage
Shakas	–200 A.D.	N,W	
Kushanas (Kanishka dynasty)	78–248	N	
Classical age (Guptas)	300–400	N	Greco-Babylonian astronomy; Brahmin states; visit of Suan Sung to obtain Buddhist ms. (405–411)
Arabs and Turks	400–1600	NW	Sultanates; Varāhamihira (6th century); Moslem conquests; last Hindu regime 1565; new influx of Greek astronomy
Mogul Empire	1526–1858	N, central	Moguls; Persian invasion (1739)
European	1701–1947	All	British imperialism

marked the vernal equinox about 2240 B.C. and were the closest asterism to the equinoctial point in the interval ~2720–1760 B.C. (Parpola 1994, pp. 204–205), corresponding closely to the Mature Harappan Period. In Hindu lists, the Pleiades are the first of a series of 28 lunar mansions marked by asterisms (called in Sanskrit *nakṣatras*, *nakṣatra* in the singular, sometimes anglicized to *nakshatra*). The nakṣatras delimited 28 divisions of the sky that were used to define the positions of the Moon and other heavenly bodies and were of unequal widths. A comparative listing of the lunar mansions is given in Table 15.3. The 20th in the Indian series, called *Abhijit*,[1] was identified as Vega and was eliminated from the series possibly because of precession, as the degrees allocated to it on the ecliptic began to overlap those of the neighboring nakṣatras.[2] Six other nakṣatras formed three pairs[3] of stars, in each case in the form of a tetragon, possibly conceptualized as a square. In later Indian tradition, the square was associated with the Moon (Parpola 1994, pp. 200–201). In later India, a list of 28 animals is associated with nakṣatras. There is some variation in the lists, but usually one of the animals associated with the paired nakṣatras is a cow, mythologically associated with the Moon, with the horns of the crescent Moon regarded as cattlehorns. Parpola (1994, p. 204) argues that the nakṣatra series fits best on the ecliptic of about the 24th century B.C. Another factor, worked out on the related system of Chinese mansions (*xiu*s), is a tendency to have paired markers of about equal width on opposite sides of the sky. Precession will change the widths of the individual mansions over time, if they were used as we construe them to have been used. Assuming that the original xius were paired with equal-width opposites, the best fit was calculated by Saussure to indicate a date ~24th century B.C. In India, certain stars called *Yogataras* or "determinative" stars were used as indicators of the boundaries of the nakṣatras. A boundary line associated with the beginning of the nakṣatra ran from the equatorial pole to the ecliptic/equator. As precession changed the declinations of these stars, the boundaries diverged or converged. The *Yogataras* are attested from a relatively late date, but are presumed to have existed from earlier times (see §15 for a fuller discussion). The congruence of these independently derived dates with that of the mature Harappan culture is suggestive. There is indirect evidence of Dravidian origin also. Personal names derived from the naksatras are now very common in India and go back to late Vedic times. At a slightly earlier date, the Code of Manu (a Brahmanic text, cited by Parpola 1994, p. 208), prohibited marriage between an Aryan and a woman "named after a constellation, a tree, or a river, one bearing the name of a low caste, or of a mountain, or one named after a bird, a snake, or a slave, or one whose name inspires terror." The constellation names seem to be associated with low castes and slaves—presumably the conquered Dravidian enemies of the Aryans. Parpola (1994, p. 206) also draws attention to an old name for the nakṣatras, *bhēkuri*. He shows that an alleged Sanskrit origin for this name is incorrect, and it is probably borrowed into Sanskrit from Dravidian.

Parpola (1994, pp. 110–113) draws attention to a series of Harappan tablets that contain short texts and pictures of

[1] Among the Jains, the equivalent of Abhijit was the first in the series.
[2] A similar change concerning Vega as a *xiu* (the Chinese equivalent of a *nakṣatra*) occurred in China (Needham 1959, III, p. 251); in this case, the *xiu* was redefined by other stars. How this may have happened is illustrated in Figure 10.3.
[3] One of the pairs was also part of a paired set both in China and in Ethiopia. See §15.4.1.

animals. Unfortunately, the context is unclear. More different animals appear than would be necessary for the later 12 animal cycles, and there is no way of determining if the animals were conceptualized as a series. On one of the tablets, an "endless knot" appears rather than an animal. This resembles a known Burmese asterism, and most of the animals appear in Burma (currently, Myanmar) as asterisms; so the Harappan depictions may be asterisms also.

Parpola (1994, pp. 218–224) has drawn attention to the presence of seven fire altars at the Harappan site of Kalibangan. He argues that they are associated with a phallic cult and compares them to Vedic rituals associated with Soma, both the Moon and a drink, perhaps originally derived from a hallucinogenic mushroom. The guardians of Soma are the Seven Sages (the stars of the the Big Dipper). In later times, the construction of the fire altars involved elaborate numerological symbolism. Menon (1932, pp. 74–75) points out that the *Śatapatha Brāhmaṇa* states that the fire altar is the universe and composed of 756 bricks. This number is the product of two numbers, 27 and 28, of lunar significance (see §4.1.4). Again, the indications of Vedic borrowing from Dravidian sources are strong.

Early seals depict a god who may be the forerunner of Shiva, a principal god of Hinduism, although the Indus culture to which these seals belonged is thought to have been Dravidian, not Sanskrit-speaking. Among other mythical themes that are attested at Harappan sites and are probably of Dravidian origin, are the following:

(1) The god of the Fig tree (Dravidian: *vaam*) identified as a pole star god (Dravidian: *vaa*, north) (Parpola 1994, pp. 243, 256–261);
(2) The conflict of Lion and Bull (Parpola 1994, pp. 246–256);
(3) The tale of the Buffalo Wife (Parpola 1994, pp. 256–267); and
(4) The many stories of Krishna, the amorous cow-herd, identified with the Moon and said to have been born "under" the nakṣatra *Rohini* (Parpola 1994, pp. 221, 269).

Parpola (1994, pp. 255–256) also emphasizes the similarity between a building of the Dashly-3 period (~1900–1700 B.C.) in Bactria with the format of the tantric temple called *Mahākāli* ("Great Black"?), an epithet of Umā, wife of Śiva.

Most scholars believe that a group known as the Aryans invaded the area around 1700 B.C. from the NW and settled the area between the Indus and the Ganges. Their language was proto-Sanskrit, their priests were the Brahmins, and their sacred hymns were the Vedas, which were written much later.

The Vedic texts include the four Veda *Samhitas* (hymns, prayers, and spells directed to the gods), a primary source of Hindu literature; and three commentaries: the Brāhmaṇas (ritual treatises), Āraṇyakas (forest treatises), and the concluding commentary on the Vedas (*Vedanta* = end of the Vedas), the Upanishads (treatises by various philosophical schools treating cosmological and theological questions). The four Veda Samhitas are the Rigveda Samhita, the Samaveda Samhita, Yajurveda Samhita, and the Atharvaveda Samhita. The Rig (or Ṛg) Veda is said to be the oldest religious text,[4] bearing hymns to the gods, chiefly, but not exclusively: *Indra* (god of the heavens), *Varuna* (creator and sustainer god), *Agni* (god of fire), *Surya* (Sun god), and *Yama* (god of death).

The Rigveda relates the creation of the world and of the gods. Following the creation and sacrifice of *the Man*, his mouth became the brahmin or priestly caste, his arms the warrior caste, his thigh "the people" (the merchant caste), and his feet, the servants. The Moon was born from his mind, the Sun from his eye, *Indra* and *Agni* from his mouth, and the wind from his breath. There are references to the "ancient gods," the *Sadhyas*, who dwell in the "dome of heaven," and who performed the sacrifice of "the Man." There are 33 heavenly gods, each in a separate heaven, and each more powerful than those of Earth.

The principal gods on Earth are the *trimurti* (triad): Brahma (the creator), Vishnu (the preserver), and Shiva (the destroyer). Brahma is usually depicted as a four-faced god, or sometimes with four heads, but nearly always facing the four directions.[5] He lives at the summit of the world, Mt. Kailasa. These gods may take different forms in different times and places; Vishnu's avatars (incarnated life-forms on Earth) include Krishna (Kṛṣṇa) and Rama. Shiva demonstrates the attributes of both Death and Time; one of his aspects is Nataraja, Lord of the Cosmic Dance, with the power to create as well as to destroy worlds. One of Shiva's forms is that of the spirit of the underworld and of cremation. His creative aspect is seen in the *linga* (phallus), which is placed in the very heart of the *garbha griha* (sanctuary), beneath the *shikhara* (high tower) of a temple complex. Shiva is said to ride the cosmic bull, Nandi; a statue of Nandi is also found in the temple complexes. According to Stierlin (1998, p. 142), in the complex at Khajuraho, famous for its erotic friezes, the sanctuary of the Kandariya Mahadeva Temple is utterly in darkness except for "certain days of the year," when "the rays of the rising sun strike, as if to waken the image of the deity from its slumbers." The connection between the erotic art and the linga image of Shiva seems relatively clear, but the relationship of these to the sunrise illumination, if indeed intentional, is not elaborated on. Seasonal renewal may plausibly play a central role. We return to the temple as cosmos in §9.1.2.

The Vedas and the two epic poems of Hindu literature, the *Ramayana* (of which Rama is the hero) and the *Mahabharata*, were transmitted orally for generations before being written down, no mean feat when it is realized that the latter has 90,000 verses. This should be remembered later when we discuss the technique observed by Europeans for predicting an eclipse in modern India. The Upanishads emphasize the peace and freedom of the human spirit, and they became a principal source for later Hindu philosophy. Hinduism crys-

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[4] Bridget and Raymond Allchin (1982) suggest that the completion of the Rigveda occurred between 1500 and 1300 B.C.; Coward, Dargyay, and Neufeldt (1988/1992, p. 9), suggest between 1200 and 900 B.C. for the Rigveda and ~900 B.C. for the Atharvaveda, the most recent of the Samhitas. See §9.1.6 for an astronomical attempt to date this body of literature.

[5] See Watts (1963, Fig. 20b) for an image of a modern folkart sculpture that bears four heads facing one direction.

tallizes from Vedic ideas in the late centuries B.C., and the cosmology is well attested in concepts of the cosmic egg. A Hindu painting of the cosmic egg (shown for comparative purposes by Caillat and Kumar 1981, Fig. 12, p. 59) shows the tortoise at the base, surmounted by a white boar with the Ŝeṣa (many-headed snake) behind. On the snake lies Vishnu, from whose navel a lotus grows through the seven underworlds. Brahma sits on the lotus. The diagram shows upper worlds and, above all, the paradise of Krishna. Seven colored bands surround these representations (from the center out: yellow, light blue and white, red, green, dark blue, white, and gray). Elsewhere in Hindu culture, the boar is identified as Mars and the tortoise is identified as Saturn. Whether these astronomical identifications are intended here is uncertain, however. For a different representation of similar concepts, see §15.3.2.1.

9.1.1.1. Jainist Cosmology

Jainist practitioners consider Mahavira ("Great Hero") to be the 24th and last of a series of saints entitled "the ones who lead to the other shore" (*Tirthaṃkaras*), also known as heroes or victors (*jinas*). Their followers are called "sons of victors" (*Jains*). Jains extended the idea of nonviolence to an extraordinary degree: Compelled by their somewhat atomistic doctrine to regard all matter as being composed of minute particles, all of which have souls, they wear masks to avoid breathing in the small, airborne particles, and sweep ahead of their steps to prevent others from being crushed to death. Each of the 24 *Tirthaṃkaras* is represented by a symbol, of which 16 are animals, three are plants, and the others varied. The 24 *Tirthaṃkaras* are correlated with 24 *Yakṣas*, "goblins," and their consorts, *Yakṣinis*. Four of the *Yakṣas* had two consorts each; so there are 28 consorts, the third of whom was named *Rohini*, which is also the name of the third lunar mansion counted from *Asvini*. A correspondence with the goddesses of the lunar mansions is suggested.

The Jain cosmos is divided into an upper world of layered heavens, a middle world where humans reside, and a lower world of layered hells. The middle world consists of alternating rings of continents and oceans. At the center is *Jambū-dvīpa*, the "continent of the rose-apple tree," centered on Mt. Meru (Caillat and Kumar 1981, pp. 19–28), where the gods dwell. One of the surrounding continents is *Nandīśvara-dvīpa*, "where the gods go to celebrate the birth of the Tīrthaṃkaras," (Caillat and Kumar 1981, p. 27). Their Fig. 52 shows a plan representing the features of the 52 main sanctuaries of *Nandīśvara-dvīpa*, 13 in each of the main directions. There are four doors leading into the main temple, and statues of four Tīrthaṃkaras are set on platforms. Outside the main temple, there are four lesser temples of the same pattern, so that 20 of the 24 Tīrthaṃkaras are shown. Each of the stupas (temples) is marked with a tree, a flag pole, and auspicious emblems. The trees, although drawn in virtually identical form, are supposed to be emblematic of four different kinds. The 12 lower heavens (*kalpas*) are characterized by animal symbols that are markedly distinct from other animal lists. They are antelope, black bull, boar-headed human, green lion wearing a red and white striped choker, goat, frog or leopard, horse, elephant, snake, rhinoceros (with flowers), and a different kind of antelope (Caillat and Kumar 1981, Fig. 33). Another interesting animal series is that of eight hunting animals with their prey, called by the Jains "birth-companions"—surprisingly, one of these couples is a prince and princess sitting in a swing; another is a black bowman hunting a white goat-like animal and a rabbit (Caillat and Kumar 1981, Fig. 26).

Kirfel (1928, Fig. 19) gives a depiction of the 28 lunar mansions in a Jain version, beginning with the equivalent of *Abhijit*, with the stars defining the outlines of the depictions. Caillat and Kumar (1981, pp. 182–183) show an 18th-century painting of the "cosmic man" marked with asterisms: the 28 lunar mansions and several others, some of which correspond to symbolic representations of the mansions in Hindu sources. The cosmos has also been depicted as a woman[6] with a spider at her navel wearing a stepped pyramidal skirt with a checkered pattern, and a checkered "blouse" in a stepped diamond pattern. The arrangements suggest the layers of heaven and hell. The spider at the navel is surrounded by a circle, also in layers (Kirfel 1928, Fig. 2). In another version, the skirt has seven main steps, divided into 24 levels, marked off in squares. Each of the seven main layers portrays an anthropoid figure in an athletic pose which is different for each layer (Kirfel 1928, Fig. 3).

Caillat and Kumar (1981, Fig. 5) show a diagram of a Tīrthaṃkara preaching from a pillar at the center of a circular mound surounded by three circles. The first circle contains gods, princes, monks, and sect members, the second circle contains 20 animals, and the third circle contains people traveling by various means of transport. There are four monumental staircases (each said to have 80,000 steps) cutting across the circles.

9.1.1.2. Buddhist Cosmology

The Buddha was born Gautama Siddharta and raised as a prince in the city of Kapilavastu in northeastern India. On observing the dreadful conditions in which ordinary people led their lives, he became a monk, evolving through stages of asceticism, contemplation, and preaching. In subsequent times, Aśoka or Ashoka (*ca.* 269–232 B.C.), considered the greatest king of the Maurya dynasty, converted to Buddhism, and became its foremost missionary. Aśoka had followed the way of *dig-vijaya* (military conquest) successfully, but after he witnessed the extent to which his campaign brought death and devastation to a neighboring kingdom—the Jain kingdom of Kaliṅga (see below)—he renounced this way of conducting statecraft and thereafter followed the way of *dharma-vijaya* (spiritual conquest). Records of his edicts survive; at Dhauli in southeastern India, not far from the temple complex of Bhubaniswar, for instance, there is a rock inscription bearing 14 edicts, among which is one calling on his magistrates to exercise fair and impartial judgments for everyone in this conquered land. The site is marked by a sculpted elephant emerging from the rock, a symbol in this

[6] The figure resembles Jain depictions of women, but is sometimes called a "cosmic man"; perhaps there had been a reversal of sex roles for the cosmos.

case of the Buddha (*gajatame*, or, in Sanskrit, *gajottamah*, "best of elephants").

As we note elsewhere, Indian traders brought both Hinduism and Buddhism to southeast Asia. In Sri Lanka, where Aśoka's missionary work was especially fruitful and where Buddhism prevailed well after its suppression in many parts of India, Pali Buddhism has preserved texts that contain information about Aśoka's reign, among other historical detail.

Buddhist doctrine is rich in numerical symbolism, which is reflected in Buddhist art and architecture. Some Buddhists consider Gautama to be the 4th of five (others to be the 5th of six or the 7th of eight) great teacher-Buddhas[7] and to have been in his 500th and final incarnation. The other lives of Gautama are described in the *Jataka Tales*; the recountings of the last 10 lives, considered the most important, are collected in the *Dasajati*. After the death of his mother, a week after he was born, Gautama is said to have ascended into the 33 heavens to preach; his ascent, commemorated in Buddhist art, was accompanied by Brahma and Indra. Buddhism seeks to combine meditation through Yoga with understanding to find a solution to the terrible sufferings of individual lives. In the Buddhist cosmological framework, there are five components to everything in the universe:

rūpa (form and matter)
vedanā (sensation)
saññā (perception)
saṃkhārā (disposition)
*viññā*na (consciousness)

Individual beings have these components in different degrees, and they are constantly changing. The nature of the universe is a hard truth: That the world and everything in it is full of sorrow, impermanent, and without a soul. Impermanance is so widespread that even the gods are held to be merely transient, and Brahma is not the creator of the world, as in Hinduism, but the first god to emerge in a new cycle of the universe. Despite this profoundly pessimistic view, the recognition of which is held to be necessary to salvation, there is remedy. The main Buddhist prescription is encapsulated in the "Four Noble Truths": That suffering (*dukkha*) exists, that it has a cause, that it can be overcome, and that this overcoming of suffering can happen by following the "Noble Eight-Fold Path":

Right Belief
Right Resolve or Attitude
Right Speech
Right Conduct
Right Livelihood
Right Effort
Right Mindfulness or Self-Awareness
Right Concentration or Meditation

The ultimate goal is *nirvāna*, when one ceases to be reborn, and achieves a final, ineffable stage of existence.

There are two main schools of Buddhist doctrine: Theravada ("Doctrine of the Elders") and Mahayana ("The Greater Vehicle") Buddhism.[8] The former, more conservative and, in the views of its practitioners, more pure, is practiced in Burma, Cambodia, Laos, and Thailand as well as in India and Sri Lanka. It focuses on the individual attainment of nirvana. There may be many Buddhas—those who achieve *nibhan* or *nirvana*—but most are not preachers who enlighten others but nonpreaching *Pachekas*. Mahayana Buddhism, which is prevalent in China, Korea, Nepal, Japan, and Tibet, arose around the 1st century B.C. It emphasizes postponement of nirvana on the part of those who have attained enlightenment in favor of helping others along the path. Theravada is sometimes referred to as *Hinayana* ("the lesser vehicle") by Mahayana practitioners, but it is not a name the Theravada Buddhists use for themselves. Aside from terminology, both branches extol the absence of conflict or animosity between them.

The rise of Buddhism and Jainism led to further intellectual development and particularly to the Six Systems of thought. The emergence of yoga (as an intellectual and physical discipline) is an example of one of these later developments, and another is the *Vedanta Sutra*, an elaboration of the short aphorisms of the *Vedanta*, and from which several systems arose in attempts to interpret it. Still later, Christianity, Islamic incursions from the Middle East, and the rise of Sikhism,[9] a monotheistic, warrior religion that combines elements of Hinduism and Islam, helped to complete the patchwork quilt of India's religions. In many areas of Asia, syncretism resulted from the widespread influences of the ideas associated with some of these religions; such influences continue to the present day.

9.1.2. The Cosmographic Role of the Temple

9.1.2.1. The Hindu Temple

The temple[10] is the architectural expression of its creators' aspirations to transcendance above the illusions of the present world to the state of pure knowledge and truth. The cyclicity of time and of the movement of the soul toward a higher truth is played out in the architecture and ritual of the believer who traverses the perimeter, and enters into ever more holy spaces, passing ultimately into the center of the sanctuary. The temple is also a temporary abode of the gods, made attractive to them by the presence nearby of groves of trees, rivers, gardens, springs, and mountains. Some early temples were carved out of rock. The cosmic aspect of temples is reflected in the frequently assigned names *Meru*, the navel of the world, and *Kailasa*, the celes-

[7] The last (*Maitreya*) of these Buddhas is to appear 5000 years after Gautama. The Pali scriptures specify seven: Vipassi, Sikhi, Vessabhu, Kakusandha, Konagamana, Kassapa, and Gautama.

[8] The Tibetan Buddhists, often considered Mahayana, refer to their form of Buddhism as Vajrayana or "Diamond Vehicle."

[9] The founder of Sikhism, Guru Nanak (1469–1539), left a number of hymns, elaborated and handed down by subsequent *Gurus* (teachers), as the *Adi Granath*. In the *Rag Maru*, God first shaped the universe, and then created "the high gods, Brahma, Vishnu, and Shiva," as well as the goddess Maya, "the veil of illusion" (cited in Coward et al. 1988, p. 243).

[10] A fuller discussion of the purposes, characteristics, and construction of Hindu temples than we are able to do here can be found in Mitchell (1977) and beautifully illustrated examples in Stierlen (1998).

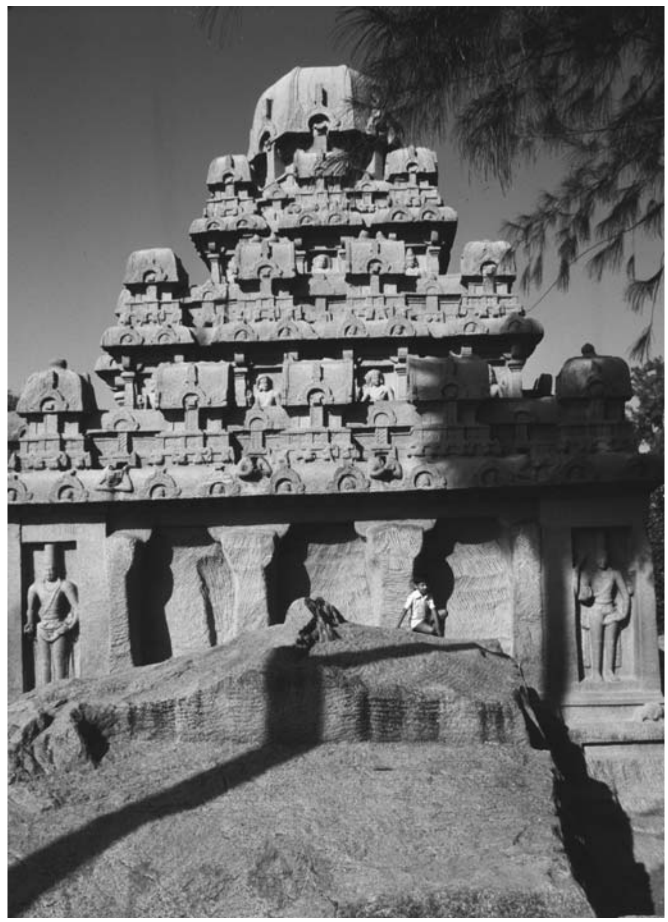
tial home of Shiva. The holiest place in the temple is on its vertical axis, on a line with the highest point, therefore symbolically in the core of the mountain—the navel of the universe. The plan view of a Hindu temple recreates a *mandala*, a sacred checkerboard-like pattern that, in effect, diagrams the basic structure of the cosmos, and in the *padas* or individual squares on which each of the pantheon of gods may find a resting place. The center square is reserved for a creation deity, around which squares are occupied by planetary gods, gods of the spatial directions, and other astronomically related gods. In some *mandalas*, a cosmic man (*mahapurusha*) is depicted, arms along two sides, legs along two sides, head in a corner opposite feet, and at the center, his navel. Thus, the temple unites in concept, humanity, the gods, and the universe. The construction of a temple is characteristically along an east-west axis, that is, the underlying *mandala* traces the diurnal movement of the Sun. It is not coincidental that early architectural treatises are also astrological works.[11] Temples vary in style from place to place, especially between northern and southern India, and they were built primarily from the 5th to 13th centuries, but temple building continues in the valleys of the Himalayas, Nepal, Bengal, and Kerala. We cite among our examples, temples in the region of the ancient Kaliṅga, to which Aśoka brought so much destruction. The early kings of the Pallava dynasty, who were seafaring and spread Hinduism to the Indian archipelago, constructed temples in caves and carved rock. Figures 9.1 to 9.5 provide examples of temples at Mahabalipuram, Kanchipuram, and Bhubaniswar in southeastern India. The *ratha* temples (Figure 9.1) were carved from solid rock in the 7th century (Sivaramamurti 1978).

The relatively narrow, east-facing shore temple (Figure 9.2), built by Narasiṁhavarman II [690–715], is an example of early stone masonary construction in this region. The soaring temples at Kanchipuram (Kāñchī, the Pallava capital) and Bhubaniswar (20°15′N, 85°50′E), ~438 km SW of Calcutta, shown in Figures 9.3 and 9.4, respectively, are testimony to the perfection of this art.

Between the 7th and 11th centuries, changes occurred in temple design and in iconography at Bhubaniswar. A result was the addition of the invisible planet *Ketu* (the descending node), to the representations of *Rahu* (the ascending node) and the rest of the pantheon of planets, to make nine. The west-facing Mukteśvara temple (Figure 9.4c) at Bhubaniswar is the first at this location to depict Ketu. Although the nine-day week and thus presumably the acceptance of a nine-planet cosmos had been known for centuries at the time of this construction, the addition of Ketu along with the association of *Kārttikeya* with a cock, and the appearance of a mouse atop *Gaṇeśa*, mark stylistic changes. The gateway to the temple (Figure 9.4d) conceals a well, *Marichi-kuṇḍa*, the water of which is traditionally believed to make women fertile. Thus, temples can be seen to embody the cosmos and the attempt to bring humanity into harmony with it.

One particular type of temple complex was centered on the Sun god, *Sūrya*. The devotees of the Sun (Sauras) were

(a)



(b)

FIGURE 9.1. The five *Ratha* (chariot) monolith temples carved from solid rock near the village of Mahābalipuram between Madras and Pondicherry in southern India: (a) All five temples—Note the rock-carved animals as well as the buildings. (b) Detail of the tallest temple in the complex, Dharmarāja-ratha—The Pallava king, Narasiṁhavarman I [630–670], in whose reign the monuments were excavated, is carved in deep relief to the lower left. Photos by Dr. A.R.F. Williams.

[11] The *Brihatsamhita* and the texts *Shastra* and *Agama*.

FIGURE 9.2. View from the southwest of the shore temple at Mahābalipuram, once the Pallava seaport on the Bay of Bengal: This east-facing, spray-washed temple was constructed by king Narasiṁhavarman II [690–715]. Note the rows of *Nandi*s that line the path. Photo by Dr. A.R.F. Williams.

FIGURE 9.3. The temples at Kanchipuram, India, some of which were constructed by Narasiṁhavarman II and by Nandivarman [~717–779]. Photo by Dr. A.R.F. Williams.

among the six major philosophical schools described by Shankara in the 8th century. In its earliest form, this movement did not involve temples or priests (Malville 1989), and institutionalization may have come about through the imported influence of Persian sun priests (*Magas*) brought by invaders. In any case, temples dedicated to individual gods are not rare in India. The Konarak temple as well as many early Shivaite and Vishnaite temples,[12] appear to be stone replications of elaborately carved wood, which suggest a revered but less permanent earlier form. In the case of the Suryan temples, the wooden temple makes a periodic return: It is reconstructed in massive but mobile form for festivals. The temple is the chariot of the Sun god; supported on wheels, it is rolled through streets, where its momentum makes it difficult to stop (the "Juggernaut," a corruption of *Jagannath*, but more generally associated with movable Hindu shrines). Figure 9.5 is one of the Konarak chlorite sculptures of *Sūrya* in his traditional place in a heavenly chariot. In a similar carving from Gangā Sāgar, now in the Philadelphia Museum of Art (reproduced in Craven 1976), his charioteer, *Aruṇa*, the god of dawn, symbolically holds the reins of the horses at the bottom of the sculpture.

The largest temple in India devoted to worship of the Sun god is at Konarak ($\phi = 19°53'$) in Orissa, on the Bay of Bengal. It erection is attributed to the Ganga dynasty king Narasimhadeva I [1238–1264] between 1242 and 1258 A.D. to commemorate a victory against a Muslim army led by Tughan Khan in 1243 (Chatterjee 1985). Figure 9.6 show the temple in various facings and detail.

Although the temple fell into disrepair by the beginning of the 17th century, it is still the site of a great festival each year when up to 50,000 pilgrims greet the dawn of the 7th day of the month of Magh. In fact, well before this particular temple was built, the Sun was an object of worship in India. Malville (1989) cites (from Stutley and Stutley 1977) the *gayatri* mantra:

> We meditate on that excellent light of the divine Sun; may he illuminate our minds.

The Konarak temple included representations of *Sūrya* in secondary shrines and on the main shrine, or *deul*. The sanctuary was estimated to have been 70 m (225 ft) high (Harle 1986, p. 252), but Craven (1976, p. 181) doubts that the sandy foundation could have supported the weight of such a structure, and suggests that it was left unfinished for this reason. The jagomohana, the great hall adjoining the deul, contained one of the largest interior spaces of any Hindu temple. Into its main platform were carved 12 giant stone wheels, about 4 m (12 ft.) in diameter, six on each side (see Figures 9.6b and 9.7).

Seven stone horses are found on the sides of the steps leading to the front hall of the temple (Figures 9.6a and 9.8). Chatterjee (1985, p. 14) connects these to the seven horses mentioned in the *Bhagavat Gita*.

The overall impression is that of a *ratha* (chariot, in this case, a celestial one), and is in accord with the traditional depiction of *Sūrya* riding in a chariot drawn by seven horses (Harle 1986, p. 252). There is also a pillar (*stambha*) of *Aruna*, confirming the association. According to Malville, the wheels represent the zodiacal constellations; this seems reasonable for a solar temple, but they also may represent, perhaps less plausibly, the 12 lunar months. Each wheel has eight major and eight minor spokes. This too is symbolic because each half day was divided into eight time units analogous to hours called *praharas*. Less clear is the purpose for the erotic sculpture that surrounds the plinth of the shrine and adjoining structures (e.g., that seen in Figure 9.9), although Craven (1976) suggests that the couples may symbolize the "ecstatic bliss experienced by the separated soul of man when reunited with the divine." A more prosaic interpretation would regard them as related, in origin, to ideas about planetary conjunctions or, more plausibly, to the renewal theme described earlier in connection with the Shiva-linga at Khajuraho. At one time, the temple at Konarak may have been one of a number of tantric cult

[12] That is, devoted to the worship of Shiva or Vishnu/Krishna, respectively.

(a)

(b)

(c)

(d)

FIGURE 9.4. Temples of Bhubaniswar, India: (a) The 7th-century Paraśurāmeśvara deul (tall sanctuary) faces west. The architrave (not visible here) bears images of eight *Grahas* (planets), *Ketu* being omitted in the iconography of the time; (b) The 11th-century Brahmeśvara Temple, constructed in the 18th reign year of Oddyotakesari by his mother who had a Shiva Linga constructed at the core of the structure. Images of the Buddha were found in the vicinity of this temple, well after the coming of the Jainist and then Hindu (Saivist) kings of the Pallava and later dynasties. The side (c) and entranceway (d) of the Mukteśvara temple, which the Archaeological Survey of India refers to as "the gem of Orissan architecture" (Mitra 1984). Here, *Ketu* makes an iconographic entrance as the 9th planet. All photos by Dr. A.R.F. Williams.

FIGURE 9.5. *Sūrya* in his traditional place in a heavenly chariot, one of three large chlorite sculptures of the Sun god at Konarak: This one shows a vigorous Sun god in full strength at midday. The other two show the youthful Sūrya, with a fresh team of horses represented at the very bottom of the sculpture, and a tired but satisfied Sūrya completing the journey on the last surviving horse of his team at the end of the day, respectively. Photo courtesy, Dr. A.R.F. Williams.

(a)

(b)

FIGURE 9.6. The *Jagomohana* or great hall of the largest temple in India devoted to worship of a Sun god: Konarak in Orissa, on the Bay of Bengal, was built between 1242 and 1258 A.D. (a) Front view, with stone horses on either side of the steps leading to the front hall. (b) Side view, which shows modern brickwork, designed solely to protect the building from further collapse, and some of the wheels of the solar chariot (see Figure 9.7). All photos by Dr. A.R.F. Williams.

centers, in which eroticism was practiced, and which were later suppressed by orthodox Hinduism (Craven 1991, p. 182). The suggestion has arisen with respect to one other solar temple, as we note below. Interpreted merely as symbolic of the "wheel of life" (Chatterjee 1985, p. 14), the erotic sculpture in the hubs is perfectly comprehensible. Erotic temple sculpture is found widely in India, and in temples devoted to other gods, so the presence of erotic sculpture elsewhere in the Konarak temple is hardly a problem. There is, after all, a linga at the core of the temple.

Malville (1989) notes that the year of the beginning of the temple's construction, 1242, was also the year of a solar eclipse that was visible at the site, and that an area in the temple was dedicated to *Rahu*, the head of the dragon, devourer of the Sun at the moment of a solar eclipse. He

FIGURE 9.7. Examples of the 12 great stone chariot wheels: Together with the horses, the conveyed impression is that of a great *ratha* (chariot). Photos courtesy, Dr. A.R.F. Williams.

FIGURE 9.8. One of the remaining horses lining the stairway of the great solar temple at Konarak. Photo by Dr. A.R.F. Williams.

FIGURE 9.9. A sample of erotic sculpture from the solar temple at Konarak: Craven (1976) suggests that the couples may symbolize the "ecstatic bliss experienced by the separated soul of man when reunited with the divine." Another interpretation would regard them as related to ideas about planetary conjunction or to a renewal theme as per the Shiva-linga at Khajuraho. Photo by Dr. A.R.F. Williams.

asserts that during the time of the winter solstice, the statue of Sūrya would have been carried into the precinct of Rahu in order to be illuminated by the Sun, because the narrowness of the apertures along the predominant E-W axis of the temple precluded direct illumination. The symbolism of such an event is not fully demonstrated, however.

We know less about other Indian Sun temples. Lād Khān, a 6th/7th-century temple at Aihole in the Deccan was probably dedicated to Sūrya-Narāyana according to Harle (1986, p. 172). The largest Hindu temple in Kashmir is an 8th-century temple of the Sun at Martrand. Several of its features are suggestive of derivative Greco-Roman influences (Harle 1986, pp. 189–191). Others are seen in Orissa, north of Gujarat at Modherā (11th century), at Rānakpur, and at Rājasthān in western India. Occasionally, however, an image of Sūrya is found in other types of temples as well, such as that in Vaitāl also in Orissa, where Harle (1986, p. 161) suggests an association with the tantric Cult of the Mothers.

Elaborate associations of a multiplicity of gods, animals, plants, numbers, asterisms, and planets are manifested in representations from two Shivaite temples on the Coromandel Coast at Chellambaram (now Chidambaram) and (somewhat inland on the Coleroon River) at Trichinopoly (now Tiruchchirappalli) (Mollien 1853). A list of the associations are given in Table 9.2. At Trichinopoly, surrounding a central lotus flower, are six concentric circles and, concentrically distributed around the outermost circle, are 16 deities. In order of increasing radius, the circles contain the following:

(1) The seven planets
(2) The nine planets (i.e., including *Ketu* and *Rahu*)
(3) A series of 11 animals
(4) The 12 signs of the zodiac

TABLE 9.2. Associations at Trichinopoly.[a]

Directional gods (Associated animal)		Lunar mansions				Lords of Tithis
		Gods	Animals	Bird	Tree	
E:	Vina Bherava					
(Dog)		1. Bad Spirit	Horse	Falcon	Etti	1. Agni
		2. Vayou	Elephant	Crow	Velli (*Phyllan*)	
ESE:	Indra					2. Sourya
(Elephant)		3. Agni	Ram	Peacock	Fig	
SE:	Bherava					
(Dog)		4. Ganga devi	Snake	White Owl	Naga (*Euphorbia*)	
						3. Viswadevata
SSE: (Water buffalo)	Agni	5. Bad Spirit	Snake (M)	Fowl	Carangalis (black tree)	
		6. Milky Way	Dog	Swan	Tchampaca	4. Ganeśa
		7. Vayou	Cat (F)	Swan	Bamboo	
S:	Vadouca Bherava					
(Dog)		8. Gangâ devi	Ram	Crow	Aquatic Coconut	
SSW:	Yama					5. Adisecha
(Ram)		9. Vayou (Alesha)	Cat (M)	Vitchouli	Paeme	(5-headed snake)
SW: (Dog)	Kchetrapala Bherava	10. Agni	Rat	Eagle	"Multipliant"	6. Son brahmanya
		11. Vayou	Rat (F)	Eagle (F)	Vahni (*Premnus spinosa*)	
WSW:	Nirriti					7. Tchandra (Moon)
(Bird?)		12. Agni	Ox	Turtle dove	Pla (Arlocarpus)	
		13. Ganga devi	(cattle)	Kite	Arca (Giant *Asclepias*)	
W:	Vadouca Bherava					8. Iswara
		14. Agni	Tiger	Kite	Grenadier	9. Rama
		15. Milky Way	Ram	Kite	Teli	
WNW:	Varouna					
(Crocodile)		16. Bad Spirit	Tigress	Cock	Vihna	10. Brahma
		17. Agni	Doe	Goose	Maquila (*Mimitsops e.*)	
NW:	Kala Bherava					11. Roudra
(Dog)		18. Bad Spirit	Buck	Conil (*Caniculus*)	Kla (shrub)	
NNW:	Vayou					
(Ibex)		19. Vayou	Monkey (F)	Wasp	Vahni	
		20. Ganga devi	Monkey (M)	Crow	Coconut palm	12. Vichnou
N:	Scanda Bherava					
		21. Milky Way	Cow	Lark	Vahni	
NNE:	Couvera	22. Milky Way	Monkey (F)	Pigeon	Pla (bread-tree)	13. Ananda
(Horse)		23. Bad Spirit	Ox	Crow (F)	Taley (spiny plant)	14. Iswara
NE: (Dog)	PadaVatha Bherava	24. Bad Spirit	Mare	Crow (F)	Cadamba (*Nandea c.*)	
		25. Milky Way	Tiger	Snipe	Pippwala (*Ficus relig.*)	
ENE: (Bull)	Isana	26. Agni	Buck	Brown goose	Meurukha (*Balen frondosa*)	
						15. Pitri Devala
		27. Milky Way	Elephant (F)	Eippy	[*Bassia latifolia*]	New/full moon

[a] ff. Mollien 1853.

(5) The Lords of the 15 *tithi*s (lunar nights)
(6) 27 lunar mansions, each with its god, its bird, its tree, and its animal
(7) 16 directional gods each with an associated animal mount

All animals in the entire diagram face the CCW direction, but in all cases, the sequence proceeds CW (toward the face of the next figure). The series of 11 animals is

rat, snake, dog, sacouni (a bird), cock, bull, elephant, horse, pig, tiger, and lion.

Six of the series are derived from the "rat zodiac" by a regular procession:

$$\text{Rat} + 5 = \text{Snake};\ \text{Snake} + 5 = \text{Dog};\ \text{Dog} + 15 = \text{Bull};$$
$$\text{Bull} + 5 = \text{Horse};\ \text{Horse} + 5 = \text{Pig},$$

where the names refer to the rat zodiac (see Figure 10.2). The Cock and Tiger are in both lists but not in regular correspondence. The sacouni seems to replace the Hare; the elephant and lion are absent from most versions of the rat zodiac. The gods ruling the Trichinopoly lunar mansions are not the usual ruling deities, but instead are repetitions of the gods associated with the five elements:

(1) *Agni*, fire
(2) Vayu, wind god, air
(3) *Ganga-Deva*, god of the Ganges River, water
(4) Evil Spirit, earth
(5) Milky Way, ether

The 12 signs of the zodiac show five, typically Indian, replacements:

(1) Makara (a composite, crocodile-like animal) for Goat-Fish
(2) Pot for Aquarius
(3) Bow for Sagittarius
(4) a single Fish for Pisces
(5) a male and female figure (as in Egypt) for Gemini

The representations of Chellambaram are as illuminating as those of Trichinopoly. The center is occupied by an unusual 5 × 5 magic square, containing only 5 different numbers (10, 18, 4, 13, 6) totaling 51 in all directions. However, although all magic squares give the same result horizontally, vertically, and diagonally, the normal 5 × 5 square is the only one that gives the same result starting from a corner and adding numbers as by a knight's move in chess. In the Chellambaram representation, the figures united by the knight's move are repetitions of the same number. Each of these positions is associated with a symbol or word. At least some of these symbols are used elsewhere to mark astronomical relationships. A square "wall" with four gates at the cardinal points surrounds the magic square. Three deities stand in each of the gates, and four others are at the inside corners. Outside the gates are four pairs of named elephants, and outside the corners are four pairs of named serpents. The Sun is centered on the east gate, and the other eight planetary gods (in their weekday day order reckoning CW) are arrayed along the walls. The planetary gods are accompanied by gods ruling Earth, Fire, Water, and Wind, and by four other gods. Arranged circularly outside this area are eight animals of the Eight Regions: Cock, Cat, Lion, Dog, Bull, Hare, Elephant, and Crow, and then the 12 signs of the zodiac appear in a circular arrangement. Finally, there is a circle of the 27 lunar mansions marked by their deities. The magic square of 5 also has an unusual distribution of odd relative to even numbers, such that there are odd numbers in all four corners and the remaining odd numbers constitute a cross, centered on 13:

11		7		3
		25		
17	5	13	21	9
		1		
23		19		15

According to Mahdihassan (1987/1988, p. 300), the cross (Heaven) symbolizes "cosmic soul" and the four corners symbolize "universe." In any case, the cruciform shape is characteristic of Hindu temples across India. The whole symbol is read as "heaven and earth." The numbers of the corners (Earth) total 52. The cross consists of 117 (i.e., 65 + 52). The possible significance of this numerology will be taken up again in §15.

The cosmographic framework represented by the temple is an important facet of Indian ethno-astronomy. The Jains had many holy places, which were laid out in accord with cosmological astronomic principles, among them the magnificent 15th-century Ādinātha temple at Rānakpur in western India. Ranakpur is also the site of an older temple dedicated to Surya, the Sun god. Temples cut in bed rock at Ellura are particularly notable. We now turn to the construction of Buddhist temples. We take up this discussion yet again for sites elsewhere in Asia, in a later section.

9.1.2.2. The Buddhist Temple

Along the Wagora River, in an area called Ajaṇṭā (in west-central India, east of Bombay), there is a monastic complex consisting of 28 rock-hewn temples, set within a horseshoe cliff. A 29th temple is set back on the west side of the complex. We refer to each carved structure as a "temple" although most were used as dwelling places by the monastic community. Collectively, they are often called the "Ajaṇṭā caves." The earliest temple (No. 10 in the notation of Bechert and Gombrich 1984/1989, p. 98) on the site dates from the 2nd century B.C. and to the 7th century A.D. Although there are more than a thousand rock-cut monasteries in India, these are famous for their exceptional preservation of early Buddhist art. Since they were abandoned prior to conflicts with other religious groups, notably Islam, they were not destroyed as were many other Buddhist sites.

It is possible that an underlying conception was involved in the creation of these temples despite the fact that they were carved over an interval of eight centuries or so. The relationships among cosmos, calendar, and deities is so intimate that it seems reasonable to suggest that there is a correspondence between the 28 temples and the 28 lunar mansions (see Table 15.2 for a numbered list). Only four of the Ajaṇṭā temples (Nos. 9, 10, 19, and 26) have the rounded back wall of a *caitya* hall (a shrine or reliquary). Three of them (9, 19, 26) are geometrically related because lines through their axes, extended across the river, meet at a single point. The 9th and 10th temples form a paired set, and in a sense, so do 19 and 26, both of which are adjacent to very small caves, 18, and 25, respectively. Pursuing the analogy with lunar mansions, we note that nakṣatras 9 and 10, counted from *Krittika* (the Pleiades) as the first mansion, are the paired set *Purva-Phalguni* and *Uttara-Phalguni*. nakṣatras 18 and 19 are the paired set *Purva-Asadha* and *Uttara-Asadha*, and the nakṣatras 24 and 25 are the paired set *Purva-Bhadrapada* and *Uttara-Bhadrapada*, all mentioned earlier in §9.1 as particularly associated with the Moon. Although the correspondences are not of exactly the same kind, it is not clear that the same correspondences held throughout the construction period. It is not clear, for example, that the present numbering of the temples corresponds exactly with the numbering of the mansions or that all the builders had exactly the same interpretation. Some may have thought in terms of a system of 28, others of a system of 27, mansions. Reckoning consecutively in a CCW sense, temple No. 29 is at the 21st position of the present series of temples. Its setback position would fit well with that of the 20th mansion, *Abhijit* (Vega), which is omitted in the 27 series (see §§9.1.1, 15.4.1.1). It is interesting to note that of all the nakṣatras, Vega is the most distant asterism from either ecliptic or celestial equator. The 29th temple faces due east, and its E-W axis passes through the center of the propylon[13] of temple 1. This E-W axis through temple 1 thus associates *Krittika* with the equinox sunrise, even though temple 1 faces southwest (see §9.1.1). We note that the 6th temple is the only one that has a plan corresponding to some degree with the Kalachakra mandala (see §9.4). The 6th lunar mansion from Krittika is *Pusya*, "flower," and is ruled by Brihaspati (Jupiter). DHK thinks that Jupiter is also the lord of the Kalachakra mandala. Finally, we note that temple 7 faces due south. A careful study of the iconography of these temples would probably verify or disprove this hypothesis but is far beyond the scope of this book.

An important feature of Buddhist temples is the central *stupa*, or mound. Often a massive structure, it typically functions as a shrine or reliquary. The development of stupas into pagodas carries symbolism to an extreme. Lauf (1976, pp. 122–123, 130, 139) shows that the ideal form of such buildings embodied the five elements and Sun and Moon with associated colors and Tathâgatas ("teachers of gods and men"). In a typical Tibetan change, the colors of the elements are different from the colors of the associated Tathâgatas. In other contexts, Tibetans typically associate the five elements with the five planets.

9.1.3. Development of Indian Astronomy

A massive amount has been written about Indian astronomy—several thousand manuscripts (Pingree 1970/1981; Sarma 1990a,b,c,d). The best way for a western scholar to approach Indian astronomy at present is through the compilation and translation of selected sources by Subbrayappa and Sarma (1985) with guidance from Pingree (1978; 1981). In particular, Pingree (1978) summarizes the major features of Indian astronomy and its evolution. The relationships of astronomy to architecture and to mythology are hardly mentioned in this material but are the subjects of a great deal of additional literature. Michell (1977/1989) provides a useful introduction to architecture that keeps its cosmic features constantly in mind. Hopkins (1915/1969) provides a convenient guide to mythology but has no systematic consideration of astronomical features. Pingree (1978) describes Indian astronomy in terms of five chronological divisions:

(1) Vedic (1000–400 B.C.)
(2) Babylonian (400–200 B.C.)
(3) Greco-Babylonian (200 B.C.–400 A.D.)
(4) Greek (400–1600 A.D.)
(5) Islamic (1600–1800 A.D.)

Pingree thinks that there was no mathematically based astronomy during the Vedic period. The presence in Vedic literature of references to *adhimāsas* (intercalary months) show that the problem of relating synodic months to the solar year was already a subject of study, but Pingree (1976/1996) doubts that any systematic form of intercalation was in use. The year was supposed to consist of 12 months of 30 days each, but how this was reconciled with synodic months and the tropical year is unknown. Reference points in the sky were provided by the 28 lunar mansions or asterisms regarded as markers for the nightly movement of the Moon. The identities of the stars of these asterisms are first attested in the 5th century A.D. Pingree does not discuss the problem of identifying these asterisms during the Vedic period and seems to doubt that it is possible, but DHK thinks that perhaps 2/3 of these can be determined from identities of particular asterisms with those in cognate systems in China and Arabia. There were two kinds of month names: one descriptive, and one derived from the names of 12 of the 28 lunar mansions. The months begin either with *Phālguna* or, more commonly, with *Caitra*, as the first month of spring. The month *Kārttika*, named after the first of the lunar mansions, is associated with the beginning of autumn. In an early period, there were three seasons, then five, and finally six. Two halves of the year were measured from the solstices. Lunar months were also divided into a period from new moon to full moon and from full to new moons. It is not known if the months began with new moon or with full moon. Pingree sees the further development of Indian astronomy as largely due to different foreign influences.

Indian astronomy seems to have had its roots in several sources. In addition to the ancient Vedic and Dravidian sources, much technical astronomy was derived from Babylonia, Greece, and Islam. Features of foreign origin in Indian astronomy are discussed in detail by Pingree (1963). Although there have been suggestions from time to time of a Babylonian origin for the 360-day year mentioned in the Vedas or for the nakṣatras, these are unconfirmed. The earliest intrusion of well-dated astronomical material occurred

[13] An entrance or vestibule to a temple or group of buildings.

in the later 5th century B.C. Mesopotamian material can be discerned in a Sanskrit text, Lagadha's *Jyotisavedānga*. For example, an equivalent to the *tithi,* 1/30 of a lunar month, is mentioned in the Seleucid Babylonian texts, but there it refers to the mean synodic month (see §4.1.4); in the *Sūrya Siddhānta*, it is of fixed length, but in later Hindu astronomy, it became 1/30 of the true lunar month, and thus variable (see Neugebauer 1957/1969, pp. 128, 186, f.n.2). The material includes also a luni-solar calendar with a cycle of 62 synodic months; Pingree suggests it is a less accurate analog to an 8-years intercalary cycle proposed by the Greek Cleostratus of Tenedos (~6th century B.C.). The Lagadha calendar is mentioned also in a number of other works: in the Arthaśâstra of Kautilya (possibly from Maurya), in the *Sûryaprajñapti* (a Jain work), and in the earliest versions of the *Gargasamhitā* (~1st century A.D.?), and the Paitâmahasiddhânta, in which an epoch dated at 80 A.D. is given). Other Babylonian features from this time include a linear zig-zag function to describe the length of a noon shadow during the year, and a ratio of the length of the longest to the shortest day as 3:2 (a ratio appropriate to and used extensively in Babylon but applicable only to extreme NW India). See §4.1.1 and Table 4.1 for the connection between latitude and length of daylight.

By the end of the 3rd century A.D., Greek astronomical materials had been translated into Sanskrit, and formulas for the interrelations among various time intervals established. The work *Yavanajātaka*, completed by Sphujidhvaja by 270 A.D., contains, among many Babylonian techniques, planetary phenomena (principally elongations) designated by Greek letters, like that described in Neugebauer (1957/1969, p. 126ff; §7.1.4.4). In classical sources, they are found in a Greek manuscript attributed to Rhetorius (Boll 1908, 213ff; Pingree 1968, 245ff).

Pingree (1996, p. 127) points out that the *Panchasiddhāntika* gives the longitude difference between Alexandria and Ujjain as 7;20 nadis (44°; the modern difference is 45;50) and between Alexandria and Varanasi as 9 nadis (54°; modern 73;7). He thinks that the only way values that close to reality could have been obtained would have been from simultaneous observations of a lunar eclipse from both places, which implies scientific cooperation between astronomers in Alexandria and Ujjain.

Pingree (1978, p. 534) recognizes five main schools (*pakṣas*) of astronomy, each associated with slightly different parameters and computing methods. The dates of origin and principal areas of influence of these *pakṣas* are as follows:

(1) Brāhmanpakṣa, ca. 400 A.D., W & NW India
(2) Āryapakṣa, ca. 500 A.D., S. India
(3) Ārdharātrikapakṣa, ca. 500 A.D., Rajasthan, Kashmir, Nepal, Assam
(4) Saurapakṣa, ca. 800 A.D., NNE, S India
(5) Gaṇeśapakṣa, ca. 1500 A.D., W. & NW India

Brahmagupta of the first of these schools wrote the *Brāhmasphuṭa-siddhānta*, in 628 A.D., which formed the basis for the *Mahāsiddhānta*, which, in turn, was largely adopted by al-Fazārī [Islamic astronomer, late 8th century] in his *Zij-al-Sindhind*. This was translated by Adelard of Bath in 1126, and it was the primary source of Hindu influence on European astronomy (Pingree 1978, p. 580). Among the distinguishing characteristics of the different schools were somewhat different definitions of the positions of the *Yogataras* or junction stars. Other distinctions included the following:

(1) The time intervals used in calculating planetary, solar, and lunar periods
(2) The parameters used in the calculations
(3) The particular form of epicyclic theory that underlay the calculations
(4) The techniques of computation, in some of which the Indian scholars made substantial improvements over their sources

Although the Indians invented the system of decimal numbers, they preserved much of their astronomical information in verse. For this purpose, they used a large number of synonyms for numbers. Usually, these had a small number of other meanings. Thus, there are 40 words for "1," all of which also meant "Earth" and "Moon." The equivalents for some of the numbers are as follows:

0 = Sky	1 = Earth, Moon	2 = Eye, Hand
3 = Fire, Worlds	4 = Ocean	5 = Arrow
7 = Horse, Mountain	8 = Elephant, Serpent	11 = Śiva
12 = Sun	14 = Indra	27 = Star, Asterism
32 = Teeth	33 = Gods	

Such a way of representing numbers with such consistent associated meanings would lend itself easily to iconographic interpretation. We know of no direct evidence that this occurred, but the possibility should be kept in mind when studying Indian art.

Roger Billard's (1971) work *L'astronomie Indienne*, despite its name, is not a history of astronomy in India but an attempt to date the principal canons of astronomy on the basis of internal structural evidence. The work is ingenious, textually and historically, and statistically sophisticated, but ultimately unconvincing. His evidence suggests that Mercury was systematically omitted from the observations on which the canons are based (in his view). He offers no suggestion why careful observers, who included Mercury parameters in their corrections, should not have had an observational basis for these parameters. When all the mean longitudes, excluding those of Mercury, converge to indicate a particular date that is within an appropriate historical range, the technique seems fairly convincing. However, when one looks, for example, at Billard's (1971, p. 154) analysis of the parameters included in the revised version of the *Sūryasiddhānta*, one finds that some parameters are said to be based on observations of 955 A.D., some on observations of 1031 A.D., one on observations of 1185 A.D., and others on observations of 1230 to 1273 A.D. This is certainly not a consistent set of observations, and only consistent sets could provide satisfactory evidence that they are indeed based on observations. The premise of an observational basis controls the interpretation of such inconsistencies. There has been some criticism also of Billard's historical placement of the canons (Pingree 1976, 1996). From the standpoint of consistency, probably the least satisfactory of all conclusions would be that the parameters of some canons were based on observations and others were not.

Mercier (1985), who used slightly different modern parameters than did Billard for checking the ancient parameters but accepted Billard's premises, verified Billard's dates and showed that the use of the meridian at Ujjain for the observations optimized the results for most canons. He showed that the *Romakasiddhanta*, which he dates to 505 A.D., seems to be based on observations at Alexandria. Mercier, like Billard, thinks that the Kaliyuga era base of 3102 B.C. was "defined and fixed as a direct consequence" of Āryabhaṭa's work of 499 A.D., equivalent to the year 3600 of the Kaliyuga. We certainly agree that the year 3600 of the Kaliyuga era would have seemed important to any Indian astronomer, whether it was created at that time or was preexistent. Possibly, a preexistent era base was modified by Āryabhaṭa. Pingree (1996) has demonstrated that the role of observation in establishing corrections was normally limited to providing a choice among long-established parameters.

Around the beginning of the 6th century, Āryabhaṭa[14] of Kusumapura (b. 476 A.D.), one of the greatest Indian astronomers, argued for the plausibility of a rotating Earth and was thus one of a select company prior to Copernicus to whom such a notion seemed reasonable. Āryabhaṭa's works were written in Sanskrit verse and began with an invocation to Brahma. They were divided into three sections: mathematics, time and astronomy, and the celestial sphere. In the mathematics section, units are defined, using as numbers the consonants of the Sanskrit alphabet.[15] In astronomy and spherics, Āryabhaṭa proposed that Sun and Moon moved in epicycles, of size 13.5 and 31.5 units (of 360), respectively, and that planets had two epicycles, which expand and contract with time. Āryabhaṭa obtained a value of the obliquity of the ecliptic of 24°; he developed a procedure for calculating the magnitude and duration of eclipses, given the Moon's latitude, and he described a model of a celestial sphere that was rotated by means of a hydraulic mechanism.

Varāhamihira's (6th century) *Pañca Siddhāntikā* is a collection of five treatises on astronomy, placed by Pingree in what he calls the "Greek" period. The treatises are as follows:

(1) The *Sūrya Siddhānta*
(2) The *Romaka Siddhānta*
(3) The *Pauliśa Siddhānta*
(4) The *Vasishṭha Siddhānta*
(5) The *Paitâmaha Siddhānta*, one of several *Brahma Siddhāntas*[16]

Among other things, the treatises contain solar and lunar theories, linear planetary theory, and rote methods for the computation of eclipses, using pre-Ptolemaic operations and geometry imported into India from the west.[17] Greek influence is explicit:

> The Greeks indeed are foreigners, but with them this science is flourishing.

The title *Romaka Siddhānta* indicates a reference to "Romans" (probably, as Neugebauer surmised, Greeks of the Roman or Byzantine empires). The *Paulisa Siddhānta* was attributed by al Biruni to an astrologer named Paulus Alexandrinus (fl. ~380 A.D.). The *Sūrya Siddhānta* was considered by Varāhamihira to be the most important of the five and today is still considered the main canon of Hindu astronomy (Neugebauer 1957/1969, p. 174). Dating from the early 5th century, some manuscripts contain the command of the Sun (*Sūrya*) to Maya Asura:

> Go therefore to Romaka-city, your own residence; there, undergoing incarnation as a barbarian, owing to a curse of Brahma, I will impart to you this science.

See §7.5 for a discussion of the *Pañca Siddhāntikā* in the context of the transmission of ideas from Greece and Babylonia.

An interesting feature of Indian astronomy was the concept of the periodicity of comets already by the 6th century A.D. (Sharma 1987). Unfortunately, we do not know how this was established. Perhaps it was an inference from the observation that most celestial bodies reappear periodically, or perhaps it was suggested by details from cometary orbits. We do know that Varāhamihira already recognized that some comets at different apparitions could be the same despite appearing in different directions. Sharma suggests that "The periods might have been determined by noting velocity over the visibility period." The 6th-century astronomer Bhadrabāhu is quoted as saying,

> the maximum period of disappearance of a comet is 36 years; the average period is 27 years; and the minimum period is 13 years.

The 10th-century astronomer Bhaṭṭotpala, on the other hand, cited particular named comets having periods between 100 and 1500 years. These statements show clearly that the concept of cometary periodicity was present, but hardly ensures that any of the periods was correctly determined. The difficulty with the assertions is that the apparent trajectories of comets, even those with similar orbital elements, differ from apparition to apparition because of different distances from Earth and locations in the sky. The length of a tail at perihelion, for example, will be much greater if the comet is on the same side of the Sun as the Earth than if it is on the far side. If one could assess the time of perihelion by the relative angular velocity and, somehow,

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[14] Translated by Clark (1937, cited in Neugebauer 1957/1969, p. 183) and by Shukla and Sarma (1976). See Pingree (1970/1981: **1**, 308–310).

[15] The first 25 consonants correspond to the numbers 1–25 (e.g., $k = 1$, $kh = 2$, $g = 3$, $gh = 4, \ldots$); the next 8 consonants indicate tens from 30, 4 0 , . . 100. The nine vowels indicate multiplication by powers of 100. Thus, $a = x1$; $i = x100$; $u = x10{,}000$; $\d{r} = 1{,}000{,}000$; $\d{l} = x10^8$; $e = x10^{10}$; $o = x10^{12}$; $ai = x10^{14}$; $au = x10^{16}$. Thus, the combination *khuyughṛ* = 4,320,000 (the number of years in a *Yuga*).

[16] Others are (a) the *Brāhma* (unfortunately, referred to as the *Paitâmaha*) *Siddhānta*, a short prose treatise dealing with a later phase of Indian astronomy than Varâha Mihira's work (it is part of a longer work, the *Vishṇudharmottara*), (b) The *Sphuṭa Brahmasiddhānta* written by Brahmagupta, which is based on (a), and (c) the *Brāhma Siddhānta* known as the *S'âkalya Siddhānta*.

[17] One of the interesting developments stemming from the theory of epicycles was the invention of power series for sine and cosine by Mādhava in the 14th century, and according to Pingree, in Europe, these were first established by Newton (Pingree 1978, p. 632, f.n. 60).

could establish the distance from Earth at that time, some comparison in properties, such as the perihelion distance to the Sun, could be established. However, the angular size of the tail alone is not a sure guide because the tail development is determined by the intrinsic length of the tail and this in turn depends on the amount of material in the comet and on the number of previous passes. A classical work describing the state of Indian astronomy in the Middle Ages is *al Biruni*'s India (translated by Sachau 1910), dating from ~1030 A.D.

9.1.4. Indian Constellations and Asterisms

We have found no good historically oriented summary of the asterisms recognized in India. Derivatives in SE Asia may show most of the features of 5th or 6th century A.D. Indian asterisms but probably also incorporate local data of non-Indian origin. The Jain tradition may reflect ideas of the Greco-Babylonian period. Indian constellations or asterisms that seem to have principal importance were the lunar mansions, treated in detail in §15. Among them are the Pleiades and the Hyades, and several of the brighter stars, as well as several asterisms comprised of dim stars. The selection of the stars of the asterisms seem to be more dependent on their locations on the sky, i.e., as markers of the positions of the Moon and planets, than on their brightnesses. Other asterisms that are mentioned by Subbarayappa and Sarma (1985) include the stars Canopus (*Agastya*), Sirius (*Lubdhaka*), and the Seven Sages (*Saptarsayah*), our Big Dipper. One Brahmana source says that the "Seven Sages" were earlier called the "Seven Bear" (Parpola 1994, p. 222).

9.1.5. Astronomical Instruments

Early instruments included the gnomon (śaṅku) to determine the length of the noon solar shadow and to keep track of the year and a water clock in the form of a pot (*ghata*) with a small hole at bottom for water flow and thus time measurement; both were known to have been used in Mesopotamia (Pingree 1963, p. 232). Pingree notes that Hipparchos (as reported by the Roman Strabo) and Eratosthenes mention that Seleucid ambassadors at the court of the Mauryan king made observations with the gnomon in India. Even in Vedic times, the gnomon was used to establish east-west lines using equal solar altitude shadow directions. These were established by noting the directions when the solar shadow reached a preset length marked on a radius established with a cord equal to the height of the gnomon (so that the altitude was 45°) on either side of the celestial meridian. A line joining the termini of the shadow lengths then established the east-west line (see Parpola 1994, p. 206).

In the 18th century, the Maharajah Jai Singh of Jaipur constructed elaborate observatories using classical instruments both at Jaipur and at Delhi. Both observatories are well preserved and constitute popular tourist attractions. The Delhi Observatory is known as the *Jantar Mantar*. The instruments, described more fully in §3.3, include the *Samrat Yantra*, used to measure hour angles and declinations (Figure 9.10a); the *Rama Yantra*, cylindrical towers used to measure altitudes and azimuths (Figures 9.10b,c); the *Jayaprakāśa Yantra*, hemispherical bowls, also used to measure altitudes and azimuths (Figure 9.10d), but practical only for the shadow-casting Sun and Moon; a combination instrument called the *Miśra Yantra* (Figure 9.10e). The latter consisted of four instruments: the *Samrat Yantra*, the *Niyat Chakra Yantra*, which indicates the declination of the Sun at four specified times of day, when apparent noon (solar transit) occurs at four other observatories around the world (Notke, Japan; Saritchen; Zurich; and Greenwich); the *Dakshinobhitti*, to calculate meridian altitude or zenith distance; and the *Kark Rashivala*, which gave the zodiacal sign of the Sun's location—a classical Indian (and Greek) way of referring to the position of an object in the sky.

9.1.6. Astronomical Units of Measure and Era Bases

Menon (1932) describes several divisions of the ecliptic used in traditional Hindu astronomy; among these, in his view, are the *Rig-Veda* (a 12-spoked wheel) and the *nakṣatras* or lunar mansions. He reconciles the latter by suggesting that the length of a lunar day (from moonrise to moonrise) could have been used to obtain the 28 divisions sometimes associated with the Indian lunar mansions (see §15). Among Menon's insights are a recognition of the relations among several of the Indian cycles and the divisions of the year or of the ecliptic, which he holds to have been considered equivalent to the year and its subdivisions of time. The astronomer Brahmagupta (ca. 628 A.D.) used a 60-part circle, and the Indian units of time include successive subdivisions of the day (1 d = 60 *nādis*; 1 *nādi* = 60 *palas*; 1 *pala* = 60 *vipalas*; 1 *vipala* = 60 *prativipalas*). The *Jyotisa* cycle of 5^y = 62 synodic months is related to the Jupiter cycle of 60^y = 12 *Jyotisa* cycles, which marks the return of the Sun, Moon, and Jupiter to the same lunar mansion. A cycle of 60 years, in which each year is given a different name, is also known (see §10 for parallels in China). Still longer cycles may derive from the sexagesimal divisions: the *Kali-Yuga* is 2×60^3 years, whereas the *Dvāpara-Yuga* is 4×60^3 years, the *Treta-Yuga*, 6×60^3 years, and the *Krita-Yuga* is 8×60^3 years in length,[18] but Āryabhata used a system of four yugas of equal length.

Periods were used to represent the motions of the nodes and line of apsides (see §2.3.5) and were important to Indian astronomy. Another important set of divisions is the subdivision of each *naksatra* into 124 *amśas*. Sources differ about the importance of various units. The day is said to be divided into 124 *lavas* in one source; another source suggests much smaller units were in use: the *kala* (1/603 days) = 124 *kāsthas*.

Sarma (1990a, p. 334) says that in Vedic times, the beginning of the year was marked by a bright star or stars near the full moon nearest to the fall equinox. Stars that had this function in various hymns have been used to determine "the

[18] Because 60^3 years corresponds to 216,000 years, these intervals amount to 432,000 years, 864,000 years, 1,296,000 yeas, and 1,728,000 years, respectively.

(a)


(d)


(b)


(e)


(c)


FIGURE 9.10. The Observatories of the Maharajah Jai Singh and their instruments: At Jaipur, (a) the Samrat Yantra and (b) the Jayaprakāśa Yantra. At the Jantar Mantar in New Delhi, (c) and (d) the Rama Yantra, and (e) the Misra Yantra, a combination of several instruments. See text and §3.3 for details. Photos by E.F. Milone.

TABLE 9.3. Sarma's dates of Vedic hymns from luni-solar correspondences.

Star deity	Lunar mansion	Star (λ)	Approximate date (B.C.)
Aditi	Punarvasu	Pollux (113°)	6200
Daksa	Abhijit	Vega (284°)	5400
Rudra	Ārdra	Betelgeuse (88°)	4350
Rohini	[Mr̀gaśiras]	Aldebaran (69°)	3070
Agni	Kritikā	Alcyone (59.5°)	2350

dates when the respective hymns have been composed." The technique and the results of using it have been challenged by Pingree and many other scholars. Sarma gives the determinations indicated in Table 9.3.

The view that linguistically intelligible hymns could have been transmitted from before 6000 B.C. is incompatible with what is known of linguistic change elsewhere. Alternative interpretations may be that not all deities had the same identity in Vedic times as currently or that the calendar year may have begun differently among different groups and at different times. Dates of composition between 2500 and 800 B.C. would be more acceptable to most western scholars.

Sarma (1990a, p. 335) also cites with apparent approval a determination by P.C. Sen Gupta that a solar eclipse mentioned in the Vedas occurred in 3928 B.C. Given the difficulties in determining the correct dates of much later eclipses, and the partially repetitive nature of eclipse cycles, we see no reason to accept this date, although we have not seen the original discussion.

The great war celebrated in the epic poem the *Mahābhārata* is often associated with the beginning of the Kaliyuga age later calculated as 3102 B.C., and made an era base (Pradhan 1927). In the epic, a considerable number of astronomical events appear as portents. The sage Vyāsa reports the evil omens to the blind king Dhṛtarāṣṭa (Sharma 1986, p. 79):

> [T]he planet Saturn oppresses Rohini . . . Rāhu constantly eclipses the sun. The white planet (Venus) after passing over Citrā (Spica) stays there. . . . A fierce comet is afflicting Puṣya. The fiery bodied (Mars) is retrograde in Maghā and Jupiter in Śravaṇa. The sun's offspring (Saturn) approaches Bhaga and oppresses it. Venus ascending toward Pūrva Bhādrapadā shines brilliantly, and is wheeling toward Uttara Bhādrapadā. The dark planet (Mercury) blazing up like fire . . . having attacked the Nakṣatra Jyeṣṭhā, stays there. . . . The moon and the sun both are oppressing Rohinī. The cruel planet (lunar node) has come between Citrā (Spica) and Swāti. The ruddy planet (Mars) . . . after its uneven motion overpowers Śravaṇa, close to Jupiter. The two blazing planets Jupiter and Saturn having approached the nakṣatra *Viśākhā* have stayed there for one whole year. . . . Th eplanet Mercury also rises with a terrible appearance indicating fearful happenings ahead. Rāhu of fierce deeds is . . . afflicting Kṛttikā.

The parentheses are those of Sharma. The date at which the poem was composed is put by some traditional scholars before 3000 B.C., whereas some modern scholars think that composition began as late as 200 B.C. and others would argue that some additions are as late as 400 A.D. The astronomical portents are of interest for the light they throw on attitudes toward astronomical events regardless of the date of composition. The portents are useful for dating only if they are part of a genuine set of observations over a relatively short interval. V.N. Sharma (1986) cites previous attempts to use these portents for dating:[19] Chandra (1978) [3137 B.C.], Vaidya (1967) [2786 B.C.], Sengupta (1947) [2432 B.C.], and Daftari (1942) [1197 B.C.]. We add Pradhan (1927, p. 268) [1150 B.C.], who argued that a solar eclipse at the time of the *Mahābhārata* war was that of 1151 B.C. as (mis)calculated from a Saros cycle of 65851/3 days.[20] He got comparable dates both from precession relative to the summer solstice and from genealogical traditions. None of these earlier writers was able to make systematic computer checks. Sharma thought that the most useful statement referred to a conjunction of Jupiter and Saturn in the nakṣatra *Viśākhā* (in Libra), where they remained for a year. Allowing substantial variation, Sharma showed 23 possibilities, of which only two showed a reasonable match with other statements of the epic, in his opinion. The resulting dates are 1493/1492 B.C. and 2110/2109 B.C. We note only that differences in position up to 45° between planets in a single nakṣatra are accepted as matching the descriptions.

9.1.7. Eclipse Prediction and Tamil Astronomy

Probably the best-known story about Indian (actually Tamil[21]) astronomy is that told by Warren (1825), recounted in Neugebauer (1952; 1983a, p. 435) about a "kalendar maker" in Pondicherry, who demonstrated to Warren a technique to predict a lunar eclipse by means of memorized tables and the movement of shells on the ground. Neugebauer cites this as an example of a continuous tradition stemming from the 6th century (with Varāhamihira) in India, back through the 3rd-century Roman empire, and ultimately to Seleucid era cuneiform tablets, no later than the 2nd century B.C. Apparently, the key to the tables lay in word association, because Warren writes about "certain artificial words and syllables" being used, and ". . . he did not understand a word of the theories of Hindu astronomy, but was endowed with a retentive memory, which enabled him to arrange very distinctly his operations in his mind, and on the ground." The demonstration consisted of the computation of the circumstances of the eclipse of 1825, from May 31 to June 1, with a surprising degree of accuracy: Differences from the actual moments of beginning, middle, and end of the eclipse were $+4^m$, -23^m, and -52^m, respectively. The predictability of the recurrence of eclipses in this way implies a

[19] Note the curious inverse relation between the date of the work and the dating of the *Mahābhārata*. For a different view, the Tibetans held that Nyatri Tsepo, defeated in the *Mahābhārata* war, fled to Tibet and became the first king there about 127 B.C. (Bryant 1992, p. 78).

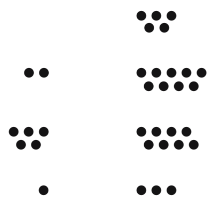
[20] The closest relevant eclipse from Oppolzer is 19 Aug. 1157 B.C. at JDN 1299060. Stephenson and Houlden (1986) show a partial eclipse track through SE Asia (eastward from southeastern Burma) for 12 Feb. 1156 B.C. (JDN 1299237).

[21] A Dravidian-speaking group of Southern India and northern Sri Lanka.

knowledge of the motions of the Moon—synodic, nodal, and perhaps anomalistic—which we discussed in §2.3.4 and §2.3.5. Neugebauer documents the connections from Babylonia to India, citing (1983a, p. 435) masses of lunar and planetary theory in the *Pañca Siddhāntika*, with close parallels in Babylonian texts from the Hellenistic period. Thus, the bases are ultimately observational, but how could such material be conveniently coded to permit a rote-learned technique to predict a lunar eclipse? Both Warren and Neugebauer attempt an explanation of the particular method used by the Tamil informant.

The use of the shells was illustrated by Warren as follows. The number 248 was given the simple representation

whereas the sum of five zodiacal signs (of 30° each) and 29°58′13″ was denoted by



which can be understood by writing the count of these shells exactly as given:

	5	(signs)
2	9	(degrees)
5	8	(arc-minutes)
1	3	(arc-seconds)

The parentheses contain our interpretation. The isolated *5* on the top of the second column is somewhat reminiscent of Babylonian notation,[22] although the example is nearly all in base-10 notation. Neugebauer's explication of the eclipse prediction procedure is as follows. First, a date must be known; how it is known is not clear, but a recurrent cycle could be used to predict the day of an eclipse (see Schlosser et al. 1991/1994, pp. 12–15 for examples of such "rules of thumb"). Although we cannot say if a trial-and-error type of method was used, it is certainly the case that if the result indicates that the cycle used was faulty, another attempt perhaps with a different cycle can be made. In any case, given the date,

(1) the true longitudes of the Sun and Moon ($\lambda_\odot$ and λ_M) are found for a given day;
(2) by extrapolation, the moment when $\lambda_\odot = \lambda_M$ is found;
(3) by computation, the λ_{node} is found for this instant;
(4) from a table (or some analog), the lunar latitude is found;
(5) from the lunar velocity and the latitude, the magnitude of the eclipse is found; and
(6) the magnitude permits the track length across the shadow to be determined, and thus, with the rate of motion, the duration in the shadow cone is found, and the moments of first and last contact.

Step 1 involves computing the number of days since a particular but variable epoch, called *ahargana*, which is counted from the beginning of the (present) Kali yuga (3102 B.C.) and marks the moment when the Sun is at a vernal equinox. From this, the number of zodiacal signs (the Greco-Babylonian zodiacal signs) traversed by the Sun since the *ahargana* is worked out, and the number of days taken by the Sun to traverse these signs, is obtained from an encoded form of a rate table. The traversal time for each sign differs because of the eccentric orbit of Earth, which causes it to move most slowly at aphelion. Reflexively, the eastward motion of the Sun is slowest at this time (Jan-Feb in the current calendar), and this occurs when the Sun is in the sign of Gemini. Similarly, when the Earth moves most quickly, at perihelion, the Sun's reflexive eastward motion will be most rapid. The difference from one extreme to the other is slightly more than two days/month and, dividing the motion per sign by 30, amounts to 56′50″/day at apogee and 1°1′20″/day at perigee. Note that the motion per day is effectively 1°/day plus or minus a small correction. The informant apparently memorized a table of average corrections over eight-day intervals and thus corrected the Sun's longitude by the sum of the corrections, with some interpolation within the eight-day intervals for any excess over a multiple of eight. Thus, the date at which the Sun reached the beginning of the sign in which it is located at the time of the eclipse gives the number of days that the Sun must traverse within that sign; this difference in numbers of days since the Sun entered the last sign and the date of the eclipse gives the longitude within that sign: Taurus 19;6,48,5 (or 19°06′48″ 5/60 in Taurus). This type of expression of longitude was used by the Greeks and Babylonians from whom the notation was borrowed.

The longitude of the Sun is only one part of what needs to be known. The position of the Moon is another. The number of days since an epoch when the Moon was at apogee and the rate of the Moon's motion on successive days are tabulated along with the sum of elapsed motion: the total travel in degrees of longitude since apogee. The length of an anomalistic month is $27^{\text{d}}.55455$ (see §2.3.5 and Table 2.5) or roughly 27 5/9 days (in decimal notation, $\sim 27^{\text{d}}.55556$). The latter approximation is expressible without fractions by setting

$$9 \times P_{\text{anom}} \approx 248^{\text{d}}.$$

In nine months, the error accruing from this approximation is only $0^{\text{d}}.00606$. From §2.3.5, the anomalistic period is shorter than is the *tropical* period of the Moon because of the advancement (in the direction of the Moon's motion) of the line of apsides. The tropical period—the time taken for the Moon to move 360° of celestial longitude—is similar to the *sidereal* period over a nine-month interval; so the difference need not concern us here. The advance of the line

[22] In Baylonian notation, if a number is divisible by 60, the integer part of the quotient precedes the remainder by a comma; thus, 121° is written 2,1. In the current example, 248 can be written 4,8 and the number (5 × 30°) + 29°58′13″ can be written: 2,59;58,13°. Note the use of the semicolon to denote the fraction (58 + 13/60)/60.

of apsides amounts to ~40°/year or 3.08°/month. Therefore, over a nine-month interval, the apogee will have slid forward 27°.735. Thus, the correction to the anomalistic interval is applied and the longitude of the Moon determined, after some additional corrections.

9.2. Persia

After the Neolithic and Chalcolithic periods, writing appears in the "Proto-Elamite" period (~3200 to 2800 B.C.). The Elamites developed in the western area of Persia, modern Iran, between Luristan in the southwest to Fars in the south-central region. Among the important sites that have been excavated are Susa, an ancient trading center on the route between Mesopotamia and Baluchistan (in present-day Afghanistan) and perhaps India. Persia was a source of raw material for the artisans of the Middle East, and locally mined and crafted steatite (chlorite) vases and seals were shipped, for example, to India. Copper smelting, and the trading of gold, silver, tin, lead, lapis lazuli, carnelian, building stone, and wood were other activities. Around 2200 B.C., the Akkadians under Sargon occupied Susa, and later the kings of Ur claimed the area, but Elamite kings attacked Mesopotamia and brought the last king of Ur to their eastern city of Anshan in 1932 B.C. (see §7.1.3.1). In the middle Elamite period (13th–12th centuries B.C.), Elam was the preeminent power. The Medes and Persians slowly encroached from the north and east and severed the old trade routes, eroding the Elamite dominance. In 639 B.C., the Assyrians under Ashurbanipal devastated the western part of the kingdom.

The best-preserved monument from the Elamite period is a four-sided, broadly stepped, pyramid at Chogha Zanbil, which is aligned so that its corners faced the cardinal directions (Ferrier 1989, p. 13). Assyrian records of 639 B.C. indicate that a similar *ziggurat* once existed in Susa with a blue-glazed temple with bronze horns at the top.

Following Elam, the area that is now Iran came under the domination of the Achaemenian Empire (550–330 B.C.), which was established by Cyrus following a power struggle with a faction of the Zoroastrian priesthood. The prophet Zoroaster (a Greek corruption of the Persian Zarathustra) thus predates the empire, but the section on Zoroaster's life in the religion's sacred book, the *Avest*a, is lost and exact dates are not known. Attributions place him between 630 and the 10th century B.C. (Smart 1989/1992, p. 215). The creator god in Zoroastrianism, which became the state religion in Cyrus's empire, was *Ohrmozd* or *Ahura Mazdā* (the Wise Lord). He fathered the twin spirits *Spenta Mainyu* (Beneficent Spirit) and *Angra Mainyu* (Hostile Spirit), which lead to later dualistic developments in the religion. Later, the protagonists become the all-knowing, eternal Ahura Mazda (still the creator of all things good) and the ultimately defeated, evil Angra Mainyu or *Ahriman*. The cosmological time-line in Zoroastrianism involves an interval of 12,000 years, divided into four intervals of 3,000 years:

(1) 3000 years of the initial creation
(2) 3000 years according to the will of Ohrmazd
(3) 3000 years of the mixing of good and evil
(4) Defeat of the evil spirit, Ahriman

The last interval is divided into four segments, each associated with a specified metal. This obviously late construction is thought to have started with the birth of Zoroaster, whose life constitutes the first of the last periods:

(1) Gold for the time of revelation of the Good Religion to Zoroaster
(2) Silver for the time period when Zoroaster's patron accepted the religion
(3) Steel for the time of the Sasanids
(4) Iron for the present age of decline and dissolution

The end is marked by an unparalleled onslaught by evil forces led by Ahriman: The Sun's light is weakened, as is that of the Moon; the Earth will shake similar to a paroxysm that occured when the Earth was created, when the evil spirit caused mountains to form (Persia is surrounded by a triangle of very rugged mountains). There will then be droughts, famine, and war. A shower of stars will mark the birth of the first of three savior figures, all conceived through the miraculously preserved seed of Zoroaster and born of Virgins. Ahriman will be sealed up and possibly destroyed through the release of a sea of molten metal. The world will then be renewed, and the good creation restored. There is an optimism about the end times that is not found in a later form of the religion known as Zurvanism, sometimes called a Zoroastrian heresy, in which Zurvan, the ultimate creator deity, is the unfeeling, impartial abstraction, time.

There are sufficient similarities to gods in India to suppose that the Aryan and Elamite gods were ancient Indo-Iranian deities. There are many gods in Zoroastrianism, and some of them can take several forms, because the belief was widespread that spiritual beings can take any material form (Hinnells 1973/1985, p. 29). Herodotus (131, Rawlinson tr. 1942, 131, pp. 73–74) mentions that the Persians offered sacrifices to a god that "represents the whole circuit of the firmament" [Ahura Mazda], to the Sun, Moon, the Earth, fire, water, and the winds, and that the Persians, unlike the Greeks, do not imagine the gods to have the same nature as men. Ahura Mazda is the creator god. In his inscriptions, Darius I [521–486 B.C.] states,

> Darius the King says: By the will of Ahuramazdā I am king. Ahuramazdā delivered the kingship to me.[23]

In the small, Hellenized kingdom of Commagene on the west bank of the Euphrates (see §15.2.1), in the 1st century B.C., Ahura Mazda or *Oromasdes* is equated to Zeus (Jupiter), manifesting the planetary association.

The second of the Persian gods to Ahura Mazda is *Mithra*, whose Indian counterpart was *Mitra*, "Friendship" or "Contract." In India, Mitra was linked with *Varuṇa*, "True Speech," and together they mount a chariot and ride before the Sun. In Persia, Mithra was accompanied by *Rashnu*, "judge." In an ancient *Yasht* (hymn), he is "the first supernatural god to rise across the *Hara* [range], in front of the

[23] (Malandra 1983, p. 48).

swift-horsed Sun,"[24] "goes along after sunset,"[25] and is "the swiftest of the gods."[26] He is also acompanied by Rashnu. According to Malandra (1983, pp. 9, 58), varieties of the name mean "the Sun," and *Mitra* has been interpreted as a more abstract "first light" of dawn, although in the above hymn, *Mitra* appears to be connected to the planet Mercury.[27] The yashts clearly describe Mithra as a warrior god; so it is not too surprising that Roman soldiers would worship such a god (their version of this god, *Mithras*, was carried to and worshipped in the most remote parts of the Roman empire). At Commagene, Mithra is equated with Stilbon (Hermes, Mercury), but more precisely with "Apollo-Mithras-Helios-Hermes," from the *Nomos* inscription of Antiochos at Nemrud Dag. Apollo was equated with the Sun and with Mercury in Greece. The Commagene inscription shows the close association with Hermes and Helios, which evidently paralleled the ambiguity in Mithra, considered the Persian equivalent.

Another such warrior god is *Verethragna*, "Victory," who may take the form of strong wind, bull (with golden horns and yellow ears), white horse, bad-tempered camel, vicious boar, teenaged youth, swift bird (raven?), wild ram, fighting buck, or a man with golden sword (Hinnells 1973/1985, p. 29). At Commagene, he was associated with Heracles and with Ares (Mars) [see §15.2.1].

The god, *Atar*, Fire, the equivalent of *Agni* in India, is a mediator between Earth and sky and between humans and gods. The phenomenon *fire* is one of the seven bounteous creations and is referred to as "the son of god" (Hinnells 1985, p. 32). Fire is naturally associated with the Sun and therefore with Mithra (Malandra 1983, p. 59).

The goddess *Ardvi Sura Anāhitā*, "strong undefiled waters," is said to be the source of all of Earth's bodies of water and the source of the "cosmic oscean" (Hinnells 1985, pp. 27–29). She was a fertility goddess, who purified seed, wombs, and milk. She is depicted wearing a golden crown with "eight rays and a hundred stars" (Hinnells 1985, p. 28), drives a chariot pulled by the horses "wind," "cloud," "rain," and "sleet" and is described as "strong and bright" and beautiful (Hinnells 1985, p. 28). She is associated with the restoration of life. Parallels with the Mesopotamian Ishtar, the Caananite goddess *Anat*, and the Semitic god *Athar*,[28] are substantial. Neither Gray (1969/1982) nor Hinnells (1985) mention a planetary manifestation for Anahita, but the explicit associations of Ishtar and Athar (Gray 1969/1982, p. 24) with the planet Venus are suggestive.

Vayu, Wind, is depicted as a strong warrior, carrying a spear and weapons of gold. He is both a worker for good and a destroyer and is said to hurl thunderbolts; he rules in the intermediate void between the Light (ruled by Ahura Mazda) and Darkness (the domain of Angra Mainyu) and has aspects of both good and evil (Hinnells 1985, pp. 24–25). There is no explicit planetary association for this god, despite his martial attributes.

Tishtrya, god of rains, has battles with the Demon of Drought, *Apaosha*. Tishtrya is generally identified with the star Sirius, an association evocative of Egypt (cf. §8), but regarded as ill suited in Persia because the heliacal rising of Sirius occurs at the height of the dry season (Malandra 1983, pp. 9, 142). Malandra thinks a possible solution may lie in the identification (or opposition) of Tishtrya and the god *Tīr*, who is sometimes identified with Sirius, sometimes with the planet Mercury, in the Pahlavi books. Forssman (1968, cited in Malandra 1983, pp. 142–143) argues for an identification of the Vedic astral god Tisya, and an etymology indicating that the name relates to "Three Stars," which, it is argued, are Orion's Belt. Forssman provides Indic evidence as well as a Persian hymn (Yasht 8.6,[29] Malandra 1983, p. 144) to show an association of these gods with archery.

The kings of the Achaemenian dynasty are familiar to western readers through Herodotus's *The Persian Wars:* Cyrus, Darius, Xerxes, and Artaxerxes. Darius I built a new capital at Persepolis; the columns of the royal palace are aligned so that the shadows of each row of columns strikes the next row at the summer solstice (Plate 2, see color insert). Stone reliefs frequently show the god *Ahura Mazdā* as a winged disk, often hovering over depictions of the king. As is known from Herodotus and Diodorus Siculus, the Achaemenian Empire was eclectic and incorporated many features of other cultures, and its arts and monuments were constructed by artisans from many regions. The Achaemenian Empire was defeated and overthrown by Alexander the Great.

The Achaemenians were succeeded by the Seleucid dynasty established by Alexander's general, Seleucus. Already in the late Achaemenian dynasty, the ideas of Zurvanism (from a preeminent god, *Zurvan* (Time) were evolving. The Subordinate dualism was symbolized by the new twins Ohrmazd (Ahura Mazdā) and Ahriman (Angra Mainyu).

Alexander had founded new cities and populated them with Greeks, but there is little information about the extent to which the underlying culture was hellenized. In ~250 B.C., the Greeks in Bactria and Sogdiana broke away from the Seleucid empire, and were eventually conquered by nomadic groups from eastern Asia. The Parthian kingdom was founded by Arsaces in 248 B.C., but was continually attacked by the Seleucid empire and by Bactria, until Mithridates I (r. 170–138 B.C.) gained control of most of Eastern Iran, and with his son, Phraates II (r. 138–127 B.C.) extended the empire to the Euphrates. Mesopotamia was under Parthian influence by 88 B.C. Parthian kings claimed the title of Phil-Hellen on their coinage from the time of

[24] Yt IV, v13 (Malandra 1983, p. 60).
[25] Yt XXIV, v 95 (Malandra 1983, p. 70).
[26] Yt XXIV, v 98 (Malandra 1983, p. 70).
[27] The ambiguity is visible in two hymns: According to Yasht 10.142 (Malandra 1983, p. 75), "Mithra . . . , the well-created, greatest god, who in the morning (re)creates the many forms, the creatures of Spenta Mainyu, as he illuminates himself, like the Moon, with his own light"; but in Yasht 10.145, "We worship the exalted righteous who (ensure) freedom from danger, Ahura and Mithra, as well as the Stars, the Moon, and the Sun."
[28] The Arabic word *athara* means "to irrigate."
[29] "We worship the opulent, glorious star Tishtrya who flies as swiftly to the Wouru.kasha sea as the supernatural arrow which the archer . . . shot from Mount Airyō.xshutha to Mount Xwanwant."

Artabanus I (r. ~128–123 B.C.). But although a strong degree of Hellenism was evident at court, and among the wealthier classes, the effect on the population as a whole is doubted. Were the priestly classes Hellenized? Did they practise Hellenistic astrology, for example? The Avesta is completely silent about astrology. The Magi of the Star of Bethlehem (§15.2.2) are traditionally assumed to come from the Medes of Western Persia.

The Semitic sun god *Shamash* is depicted on the main temple in Hatra (in an Arab kingdom of western Parthia) as a human face enclosed by a leaf-shaped beard, in the hair of which appears to be a coiled serpent (Ferrier 1989, p. 58). Artabanus V, the last Parthian king, was defeated by Ardashir ~227 A.D., and the Sasanian Empire was established in this region. Although the Parthians had moved their capital to Seleucia, which they had captured in 141 B.C., and came under heavy Greco-Roman influence, the Sasanians claimed descent from the Achaemenians and were centered in Persia. Ahura Mazdā was again worshiped, as inscriptions indicate on reliefs cut into rock cliffs to celebrate Adashir's triumph. Pingree (1963, p. 240) states that "virtually nothing" was known of astronomy in Iran prior to the Sasanian empire (~227–~651), but notes that a Greek astrological text was attributed to the religious leader Zoroaster, even though it contains mostly Babylonian material.

Petri (1967) notes a parallel between the Kâlacakra (see §9.4) and the worship of Time (*zrvân*) as the supreme deity in Persia. The four yugas of Indian astronomy are found here also, with equal lengths of 5400 years (not in the proportions of 4:3:2:1, and lasting 4,320,000 years to complete; both usages were found in India). Petri (1967) suggests that the cycle length of 21,600 years (4 × 5400) may represent an approximation to the precession cycle.

9.3. Southeast Asia

The pervasive influence of India can be seen in the art and religious ideas expressed in the temples of Southeast Asia. Indian trading colonies are thought to have been the vehicles for the transmission of Indian culture (Rawson 1967, p. 7), brought to differing forms of fruition in each of the Southeast Asian areas, according to the individual genius of each group.

The astronomy of Burma (today, Myanmar) is derived with few changes from that of India and is particularly close to Cambodia. The fullest summary of Cambodian astronomy is by Faraut (1910). A technical summary of Burmese astronomy is provided by Desilva (1914). From this area, we have a series of depictions of 68 asterisms with their names, collected by Buchanan (1807); unfortunately, the western equivalences are not provided. They include the 27 lunar mansions and 8 northern constellations. The latter have been identified by Zaw (1937). Some of the other asterisms may be identified with fair probability from references in other areas of Indian culture. Nishiyama has found many additional examples of star maps from Myanmar, mostly from the period 1600–1850; they are found on walls and ceilings of buildings (Plate 4, see color insert). The Burmese and Cambodian evidence makes it likely that the animals associated with lunar mansions in India were asterisms, as is also indicated by Jain evidence in India.

Throughout Burma, Thailand, Cambodia, and Laos, a frequently used era base was that of Saturday/Sunday, Mar. 21/22, 638 A.D., corresponding to Kaliyuga day 1365702. T.E. Morgan (1980) suggested the coincidence of new moon and spring equinox was the basis for this era. He accepts the derivation of this era from India, but nonetheless, dismisses as unimportant the fact that this was the date of an annular solar eclipse extending across central India, because the eclipse did not extend as far as Burma. This date corresponds to Billard's (1971, p. 74) interpretation of a correction to the *Sūryasiddhānta*. Faraut (1910) presents a Cambodian astronomical diagram. An era base that is probably the same is iconographically marked by a deity, centrally placed, riding on a bull or ox, the feet of which are above the 15th and 16th lunar mansion. The animal is that of the 16th mansion. The 16th mansion is included in the 5th region, that of the Bull, of the Chellambaram representation (cf. §9.1.2.1). Another diagram from Cambodia shows the 27 lunar mansions mostly animal series (with the following nonanimals: a spindle whorl, a plow handle, a ship, a tree, and two humans) arranged in a circle with 12 divisions.

Billard (1971, pp. 123–124) points out that a Cambodian inscription of 612 A.D., and several other inscriptions of about the same date, show the first use in an inscription of an era base (in this instance, the Śaka era), the decan system, the Zodiac, the "ascendant," fully developed personal horoscopes, and the numerical symbols used in Indian astronomy. Among the Zodiacal signs is the name *Tavura*, a borrowing from the Greek, *Tauros*. This is the earliest attestation of any of a set of Greek Zodiac names borrowed into Sanskrit and then into Cambodian.

One of the earliest kingdoms in the area to reflect the Indian influences was that known as Fou Nan, a name given to it in Chinese records. The beginning of the kingdom is not known; 3rd-century Chinese records mention the legend of a Brahmin who traveled to Fou Nan, married into royalty, and became the first king. This legend was shared with several other regions, however. Sanskrit inscriptions mention an Indian ruler in A.D. 357 who claimed descent from Scythian kings. Rawson (1967, p. 21) speculates that he may have established the worship of Surya, depicted widely in sculpture. To the north of this region, the Chen La kingdom was created among the Mon-Khmer people, called *Kambuja* in Sanskrit, from which the name Cambodia is derived (Rawson 1968, p. 22). The two kingdoms were united through marriage around the 6th century A.D. and lasted until around the 8th. Although the ruling families of these kingdoms were Hindu, Buddhism began to assert itself, and the earliest depictions of Buddha are from the 6th century. The Shailendra dynasty, centered in Java, which became important in the 8th century, when the Chen La kingdom disintegrated, was Buddhist.

In 790, a member of a former royal family of Cambodia, who had spent much of his life in Java, returned to become Jayavarman II of a reestablished Hindu kingdom that became the Khmer empire. He built a temple-mountain at

Phnom Kulen and constructed a sacred *lingam* according to Brahman ritual. Later kings constructed similar structures, at Bakong and at Phnom Bakheng. The latter was built in 893 by Yashovarman. Rawlins (1967, p. 55) describes it as having seven levels, including the base and summit, with 108 towers around a central tower, representing the power of the deity, whose earthly representative is the king. Here, unlike the Buddhist temple at Borobodur (described below), the levels do not represent stages of enlightenment but the seven heavens; the number of towers that can be seen at any side is 33, the number of Hindu gods. Rawlins (1967, pp. 55–56) intimates that the numbers of seasons, lunar mansions, and planets play various roles in deciding the numerology of the structure, which thus encrypts and encapsulates the structure of the universe.

9.3.1. Angkor Wat

One of the capitals of the Khmer empire was Angkor, founded by Indravarman in the 9th century. It contains hundreds of temples, the best known of which is at Angkor Wat ($\phi = 13°27'$ N). The temple complex at Angor-Wat, built by Sūryavarman II (1113–1150 A.D.) in the 12th century, marks the crowning achievement of Khmer architecture. Consecrated to Vishnu, the complex is unusual in facing toward and entered from the west (a trait shared by only two other, much smaller temples in the Angkor region). The complex is a series of five nested rectangular walls and galleries surrounded in turn by a moat, the external dimensions of which are 1500 m (E-W) × 1300 m (N-S). The central part consists of five shrines surrounded by two series of enveloping colonnades and linked to the outside world by a bridge flanked by serpentine balustrades. The insides of the colonnades contain scenes of the cosmic myth *Mahabharata*, as well as images of Hindu gods and scenes from the life of Sūryavarman II. Stencil, Gifford, and Moro'n (1976) examined detailed site plans produced by Nafilyan (1969) and concluded that first, great precision was used in establishing the lengths and orthogonality of the linear features, and second, that the site bears extensive astronomical references, among which are planned locations for observation of solar and lunar alignments, and the placement and content of bas reliefs according to the movement of the Sun through the seasons. Stencil et al. (1976) found a total of 18 alignments from various positions inside the complex. Paris (1941) had previously noted four, three of which (equinox and winter and solar solstices) are observable from just inside the western entrance. On the day of the spring equinox, the Sun rises over the central tower, at an elevation of 6°. The winter solstice sunrise rises to the southeast, over a temple at Prasat Kuk Bangro, 5.5 km distant; the summer solstice sunrise occurs over a prominent hill, Phnom Bok, 17.5 km to the northeast. Stencil et al. (1976) conjecture that these alignments required the facing and entrance to be placed to the west and argue against a westward facing for purely funerary purposes. For all of the alignments, they searched for those that suggested declinations of ±23.5°, ±5°, ±19°, and ±29° for the Sun (at 1110 A.D.), the Moon at midcycle and minor and major standstills, respectively. An uncertainty of 0.5°, required by eroded tower tops, was assumed. Stencil et al. (1976) conclude from an examination of angular frequency histograms that

(1) all computed angular lines show a 2-σ peak at each of the angles: 0, ±5°, ±23°, and ±29°;
(2) lines to points along the causeway show a 3-σ peak at ±5° (six projections); and
(3) alignments are associated with "all major points" on the plans.

Stencil et al. (1976) also examined the dimensions of 200 linear components of the temple complex and found that dividing them by the number 0.4345 m produced the largest number of integer multiples. This value they assume was close to the value of the Cambodian cubit or *hat* as used at this site. There could well have been slight variations in the mean length of the *hat* in the construction of the different temples and other structures over time. In this reconstructed unit, they find a strong correspondence (marked with the symbol ↔ in the listing below) between the lengths of features in the complex with astronomical units such as lunar months and lunar mansions, components of the solar year, and the four Yugas of Indian cosmology:

(1) distances between sets of steps of the central sanctuary (E-W: 11.88; N-S: 12.11 *hat*); ↔ 12 months in solar year;
(2) total interior lengths of nine chambers in central tower (E-W: 28.13; N-S: 27.21 *hat*); ↔ numbers of lunar mansions of Hindu astronomy: 27 and 28;
(3) exterior axial lengths of central tower (E-W: 45.53; N-S: 45.30; total: 90.83 *hat*); ↔ average number of days between solstices and equinoxes ≈ 91.3;
(4) interior lengths of four axial entrances (E: 45.36, N: 43.75, W: 46.04, and S: 45.70 *hat*); the sum ≈ 180 *hat* ↔ one-half the length of a divine year of the gods (360 solar years);
(5) total of all interior axial lengths of all chambers (358.83 *hat*) ↔ the divine year in solar years;
(6) exterior axial lengths of topmost level (E-W: 189.00; N-S: 176.37, sum = 365.37 *hat*) ↔ the solar (Julian) year, 365.25;
(7) interior axial lengths of libraries in second gallery [E-W: 15.85; N-S: 11.14 (or 12.11 including doorway indentations); sum: 26.99 (27.96) *hat*) ↔ 27 or 28 lunar mansions;
(8) exterior axial lengths of libraries in second gallery (E-W: 43.98; N-S 28.25 *hat*); in *phyeam* units (4 *hat*) ↔ 11 lunar gods (*karana*), 7 days in lunar week;
(9) distances between N and S libraries and "sacred deposit" of the temple (N: 29.53; S: 29.60 *hat*); ↔ mean lunar (synodic) month, 29.53 days;
(10) height of libraries above terrace level (23.88 *hat*); ↔ 24 lunar half months in one lunar year; and, in a somewhat different category;
(11) the width of the moat[30] (439.78 *hat*); ↔ 432,000 years of the Kali Yuga;

[30] The authors note that if the *edge* of the water is used, the distance more closely approximates 432 *hat*.

(12) from the entrance to the balustrade wall (867.03 *hat*); ↔ 864,000 years of the Dvapara Yuga;
(13) from entrance to the the central tower (1296.07 *hat*); ↔ 1,296,000 years of the Treta Yuga; and
(14) from the bridge to the temple center (1734.41 *hat*); ↔ 1,728,000 years of the Krita Yuga.

An explanation for the great interest in the Sun, which is clearly implied by the apparent alignments, may be seen in the name of the king who ordered the Angkor Wat to be built. Stencil et al. point out that the name Sūryavarman means "protected by the sun." Finally, they suggest that depictions on the walls reflect the seasons; such depictions often have even broader astronomical content. Proceeding counterclockwise (the direction of the annual solar motion), these depictions are as follows:

(1) a scene of the "churning of the sea of milk" to produce the elixir of immortality, an act of renewal and therefore evocative of springtime, on the east wall;
(2) a scene of all the gods (the "day of the gods" lasts six months; presumably summer), on the north wall;
(3) a depiction of the great battle of Kurukshetra from the *Mahabharata*, possibly symbolizing the setting of the Sun and decline and perhaps destruction associated with fall, on the west wall; and
(4) a depiction of the kingdom of *Yama*, the death god, suggesting winter, on the South wall (the north wall is in darkness during this season, possibly symbolizing the "night of the gods"; winter is the dry season when animals and plants become dormant or die).

Thus, the complex has blended elements of time, the calendar, and Hindu mythology. The apparent interest in the Moon, as evidenced by many of the alignments, may appear out of place, but Stencil et al. (1976, pp. 282–283) cite in translation (Pelliot 1951, p. 22) the comment of a visiting Chinese merchant in 1296:

> There are people (in Angkor, just as in China) who understand astronomy and can calculate the eclipses of the sun and moon.

Therefore, it was very important to track the motions of the Moon, lest the protector of the king be eclipsed and the kingdom placed in peril through lack of preparation.

More recent work on Angor Wat has been done by Mannikka (1996), whose work is discussed in §15.3.2.1. By the late 12th century, Mahayana Buddhism had started to supplant Hinduism in Cambodia and temples were built or rededicated to the worship of Buddha.

9.3.2. Other Temples in Southeast Asia

In Thailand, more traditionally known as Siam, Theravada Buddhism is widely practiced and the sacred texts are in Pali, a language derived from Sanskrit (see §9.1.1 for a brief description of the main branches of Buddhism). This is one of the older and more basic forms of Buddhism. As elsewhere in Southeast Asia, Thailand has many *wats*, or temple complexes, aligned on east-west axes. The Wat Phra Si Sanphet in Ayutthaya is a fine example (Figure 9.11). It is located on the site of the first palace of the founder of the Ayutthaya kingdom, Ramathibodi I. His Son, Ramathibodi II, constructed these temples in 1491 with *Chedi*s (memorials) for his father and elder brother, and eventually for himself.

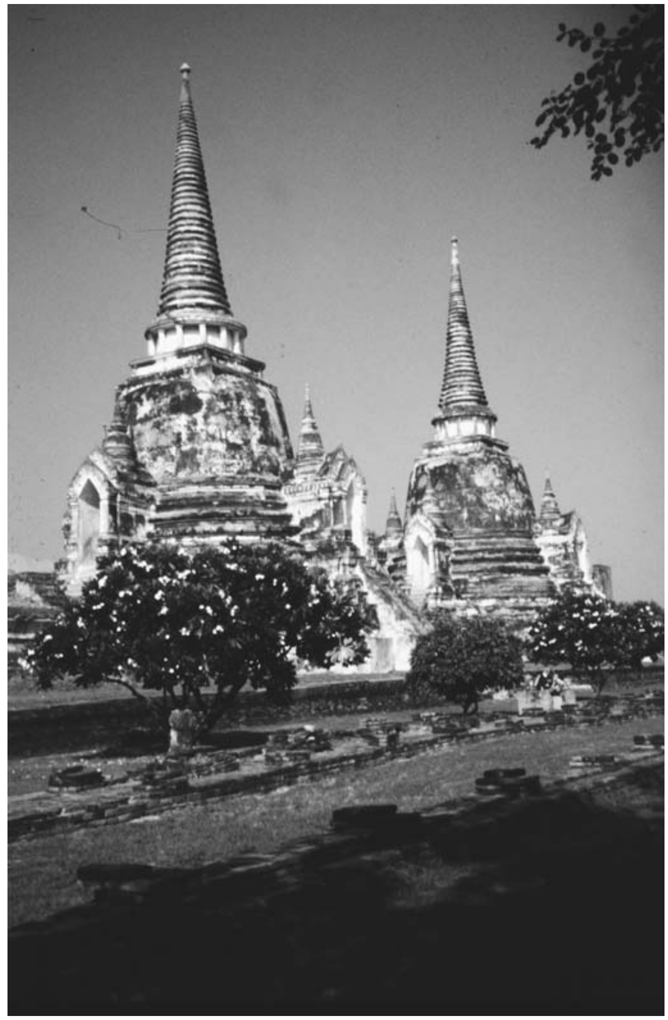


FIGURE 9.11. Temples of the Wat Phra Si Sanphet in Ayutthaya, central Thailand: At one time, this complex housed the largest sculpture of the Buddha in the world. Photo by E.F. Milone.

The well-known temple complex, Wat Phra That Doi Suthep, is on a hilltop with a commanding view of Chiang Mai in northern Thailand (see Figure 9.12). The central towers or *prangs* of these temples typically have 33 levels in the forms of rings or other divisions to symbolize the 33 heavens of Mt. Meru. The Temple of Dawn at the Wat Arun near Bangkok contains a great porcelain inlaid prang. In Vietnam, surviving Hindu temples date from the 10th century, and the Mongol invasion in the 13th century marked the decline of Hinduism in the area.

To the south, across the South China and Java Seas, temple building succeeded grandly. The Javanese are a Malayan group who successively adopted Brahmanism, Buddhism, and Islam. The Brahmanic practices were traditionally adopted as early as the 1st century A.D. In Java,

FIGURE 9.12. A chedi in the Wat Phra That Doi Suthep in Chiang Mai, northern Thailand, one of the better-known Thai temple complexes. Photo by E.F. Milone.

Indian temples were built as early as the 8th century, during the Shailendra dynasty. The most famous is that at *Borobodur*, dating from around 800, and in use until ~1000 A.D. It is one of the most impressive Buddhist temples, built onto and above a mountain, crowned with a massive central *stupa* (mound) representing the axis of the world. Arising from the base, there are seven walled terraces, of square shape with three doglegs per side. The exterior faces of the walls are lined with relief sculpture depicting Buddhist doctrine. The pilgrim is expected to view the reliefs by traveling clockwise around each terrace, and thus move in a clockwise spiral, with continual ascent from one symbolic stage of enlightenment to the next. Each stage contains niches with images of the Buddha that become less human and more transcendant with ascent. Near the top are three unwalled circular platforms containing 32, 24, and 16 stupas, respectively, each containing a stone Buddha figure that is barely visible. At the very top is an unfinished, invisible, and therefore entirely spiritual Buddha.

9.3.3. Constellations, Calendars, and Cosmology in Southeast Asia

The people of Bali are closely related to those of Java, and their Brahmanic ideas include many early doctrines, which were completely eliminated in Java by Islamic conquerors. Their astronomy and calendar contain many elements that may have roots as early as the 1st century A.D. and are, in some aspects, apparently more archaic than are most of the surviving astronomical texts from India. The major components of the Balinese calendar are the solar year, the lunar year, a 32-month lunar cycle, the lunar (synodic) month, and 10 concurrently running series of *waras*, usually translated "weeks" from one to ten days in length. See Table 9.4. The various waras are related to a cycle of 210 days called the *Pawukon* cycle, which contains 30 named 7-day weeks, (it also contains 70 weeks of 3 days, 42 weeks of 5 days, and 35 weeks of 6 days). For the 4-day week, the 8-day week, and the 9-day week, intercalations bring them into step with the 210-day cycle! Considering first the sequences without intercalation, the most important by far are the 5-day and 7-day weeks. The 7-day week corresponds to our week, with the first day, *Redite*, corresponding to Sunday. The association with the planets is direct and exactly corresponds to the western usage. This derives directly from the Hindu week (with modified Sanskrit names) and thus relates back to Hellenistic times. The Balinese culture is alone in having named 7-day weeks. As seen in Table 9.4, the 30 names begin with the week *Sinta*, which in modern Bali is always considered the lst week of the Pawukon.

Among the weeks with intercalations, we discuss first the 9-day week. *Dangu* is the 1st day of the 9-day week. The 210-day cycle begins (in *Sinta*) with 4 days that repeat the name *Dangu*, and continues for the rest of the 9-day week sequence, which is then repeated sequentially until the 210-day cycle is completed. The intercalations in the 4-day and 8-day also take the form of repetitions at the beginning of *Dunggulan*, the 11th of the named 7-day weeks and, therefore, at day 71 of the Pawukon. At the beginning of *Dunggulan*, in the 4-day week, there are three successive days named *Jaya*, and in the 8-day week, there are three successive days named *Kala*.

The days of the 1-, 2-, and 10-day weeks are not sequential but are determined by numerology. Each day name in the 5- and 7-day weeks has a ritual number (*urip*). One determines the day in the 2-day week by adding the numbers of the particular day in the 5-day week and the corresponding day in the 7-day week. If the result is even, the day is *Menga* and if odd, *Pepet*. The day name of the 1-day "week" is *Luang*, which, however, only occurs on days *Pepet*. Days corresponding to *Menga* have no name in the 1-day week. For the 10-day week, the sequence of days is similarly determined from the combined *urips* of the 5- and 7-day weeks; the remainder of the fraction: (sum + 1)/10 determines the number of the day in the 10-day week. Thus, the *urip* associated with the day *Paing* in the 5-day week is 9; the *urip* associated with *Wraspati* in the 7-day week is 8; so the sum + 1 is 18 and the remainder, modulo 10, is 8. Therefore, the day is *Raja* in the 10-day week (see Table 9.4).

TABLE 9.4. Components of the *pawukon* or 210-day cycle of the Balinese calendar.

Non-sequential components of the *pawukon*	Sequential components of the *pawukon*	Sequential components of the *pawukon* needing intercalation	The named seven-day weeks of the *pawukon*
One-day week	Three-day week	Four-day week	1. Sinta
Luang or nothing	Pasah	Sri	2. Landep
	Beteng	Laba	3. Ukir
Two-day week	Kajeng	Jaya—intercalary	4. Kulantir
Menga	(Tri-wara—70 weeks = 210)	Menala	5. Taulu
Pepet		(Catur-wara—52 weeks + 2	6. Gumbreg
	Five-day week (urip)	intercalary days = 210	7. Wariga
Ten-day week (Dasa-wara)	Umanis 5		8. Warigadian
Pandita 1	Paing 9	Eight-day week	9. Julungwangi
Pati 2	Pon 7	Sri	10. Sungsang
Suka 3	Wage 4	Indra	11. Dunggulan
Duka 4	Keliwon 8	Guru	12. Kuningan
Sri 5	(panca-wara—42 weeks = 210)	Yama	13. Langkir
Manuh 6		Ludra	14. Medangsia
Manusah 7	Seven-day week (urip)	Brahma	15. Pujut
Raja 8	Redite (Sun) 5	Kala—intercalary	16. Pahang
Dewa 9	Coma (Moon) 4	Uma	17. Krulut
Raksasa 0	Anggara (Mars) 3	(26 weeks + 2 days = 210)	18. Merakih
	Buda (Mercury) 7		19. Julungwangi
	Wraspati (Jupiter) 8	Nine-day week	20. Medangkungan
	Sukra (Venus) 6	Dangu—intercalary	21. Matal
	Saniscara (Saturn) 9	Jangur	22. Uye
	(sapta-wara—30 weeks = 210)	Gigis	23. Menail
		Nohan	24. Perangbakat
	Six-day week	Ogan	25. Bala
	(35 weeks = 210)	Erangan	26. Ugu
		Urungan	27. Wayang
		Tulus	28. Kelawu
		Dadi	29. Kukut
		(Sanga-wara—23 weeks	30. Watugunung
		+ 3 days = 210	

A very interesting astronumerological chart called a *pelelintangan* is a diagram to show the fortune associated with a 35-day sequence created by the combination of the 7-day week and the 5-day week (Plate 3 shows one of these, given to D.H. Kelley by Norman Totten; another one is published by Eiseman, 1990, p. 199; see color insert).

The diagram has 49 divisions, the seven across the top associated with the seven days of the week, each showing, ideally, a god, a tree, a bird, a shadow puppet character, and an animal, each associated with a particular day and a particular planet. Across the bottom are seven animals, identified as heads of a seven-headed demon and associated with the days of the 7-day week. Strangely the list of these given by Eiseman (1990/1996, p. 196—Elephant, Dog, Horse, Crow, Human, Cow, and Water Buffalo) shows no similarity to those shown in his chart.

The remaining 35 rectangles in the middle five rows show the *bintangs*, the named correspondences between a day of the 5-day week (in order vertically) and a day of the 7-day week (in order horizontally); each column of the bintangs is read from top to bottom to enable one to find a combination quickly in order to read the accompanying book of characteristics of that *bintang*. The word bintang means "star," and a number of the bintangs are known to be stars or constellations. Kartika, the Pleiades, has a name derived from the Sanskrit *kttika*; Kumba, "waterpot," is known to be the name of Aquarius; Ru, "arrow," shown shot into a deer, corresponds closely to the story of Prajapati in stag shape, shot by an arrow that is Orion's Belt (recall the "three stars" of §9.2); Uluku, "plow," is a well-known southeast Asian constellation; and Gajah mina, "elephant fish," is a name for Capricorn.

In Figure 9.13, we show the names of the combinations and their sequences, from the *pelelintangan* published by Eiseman (1990/1996), but rearranged by DHK into 10-week sequences.

The similarities are enough to suggest that the name *bintang*, "star contellation," should be taken seriously. When one compares the *bintang* series with the 68 Burmese asterisms, a substantial number of additional correspondences appear (see Figure 9.14). As a continuously repeating set, one would expect the *bintang* series to represent a division of the sky into 35 segments in rising order, but not enough of the asterisms can be identified with certainty to be sure of this. One might expect a relationship between the bintang asterisms and the 36 decans [introduced into India from Egypt probably by the 3rd century (Pingree 1963b, 1964–1965)] but, at present, this cannot be demonstrated.

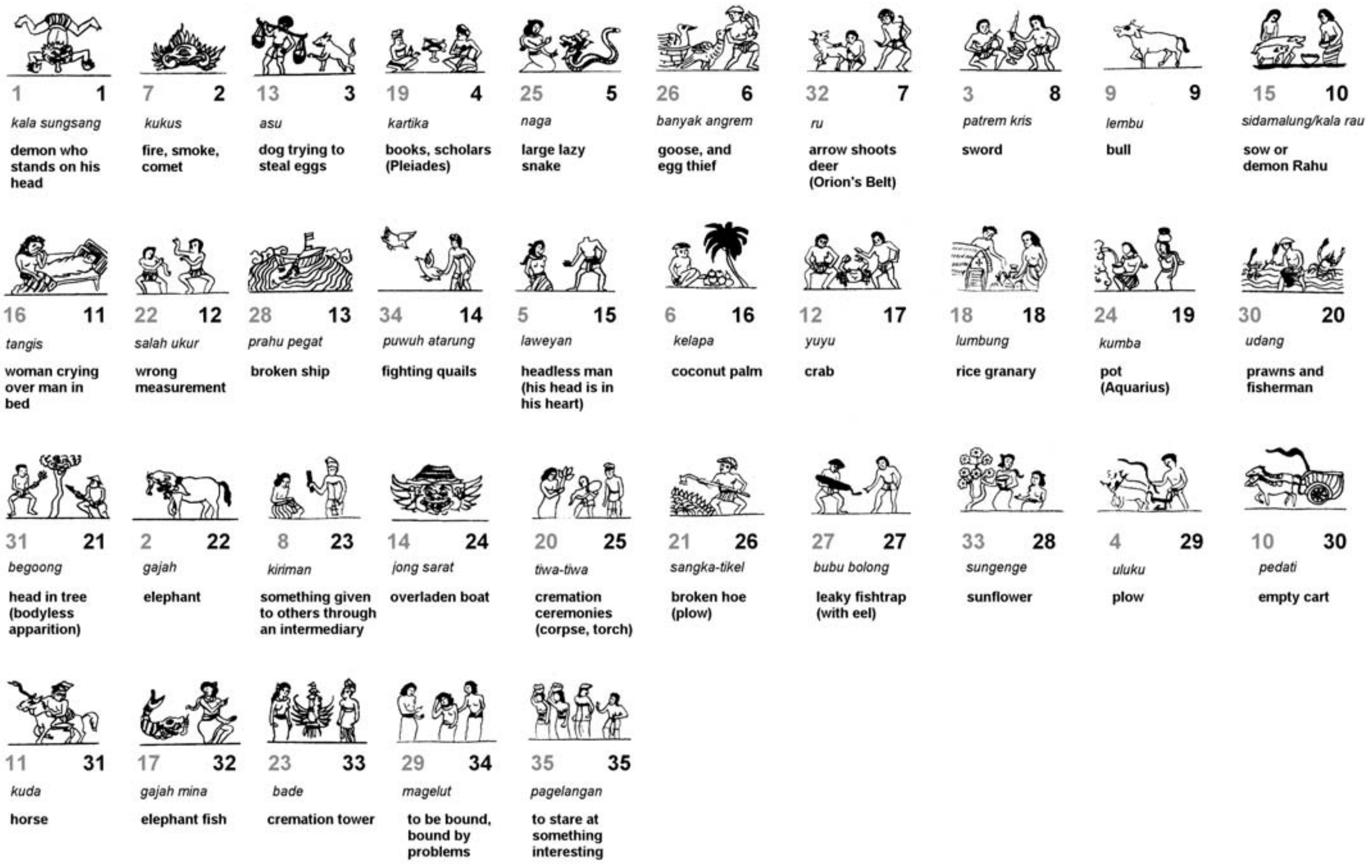


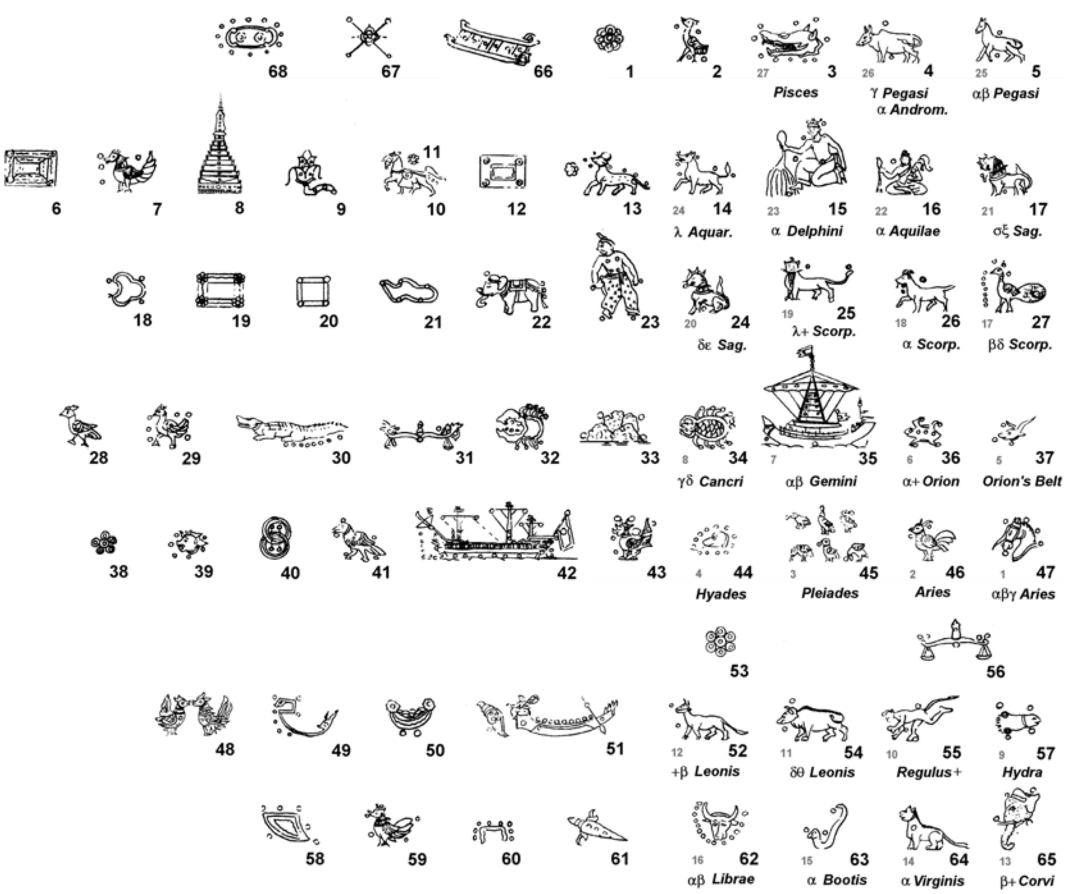
FIGURE 9.13. Elements of the charmingly illustrated *pelelintangan* published by Eiseman (1990/1996), but rearranged by DHK into 10-day week sequences. Drawing by Rea Postoloski and Sharon Hanna.

The lunar component of the Balinese calendar is tied to the Saka era of 78 A.D., and lunar cycles are identified as Saka cycles, although the years of the Saka era are solar years, because of intercalation of extra lunar months. All lunar measurements use lunar days that are defined as 1/30 of a lunation and hence are somewhat shorter than solar days. In fact, 64 lunar days are very close to 63 solar days, and the coincidence is noted and called *ngunalatri* (literally, "minus one night").[31] Because 63 is 9 × 7 this coincidence will occur on the same day of the week until an additional day's error has accumulated after 800 lunations, somewhat more than 68 years. Eiseman's discussion of this is not very clear and has some terminological confusion of solar days and lunar days. He apparently does not realize why the day of the week shifted and says (Eiseman 1990/1996, p. 188) that the officials at the Department of Religion say that it should change once every century. This suggests that they also do not fully understand the mechanism or were using a different value (in solar days) for the length of a lunation. In older calendars, Eiseman says that he found the coincidence of solar and lunar days sometimes fell on several different days of the week in one year! This could only happen if different bases were being used for different purposes. The relationship of this 64-lunar-day cycle to the phases of the Moon repeats every 32 months in a cycle, which contains 15 months of 29 solar days (Eiseman 1990/1996, p. 189, shows 19 months, a typographical error) and 17 months of 30 solar days, totalling 945 solar days (15 × 63) or 960 lunar days (15 × 64).

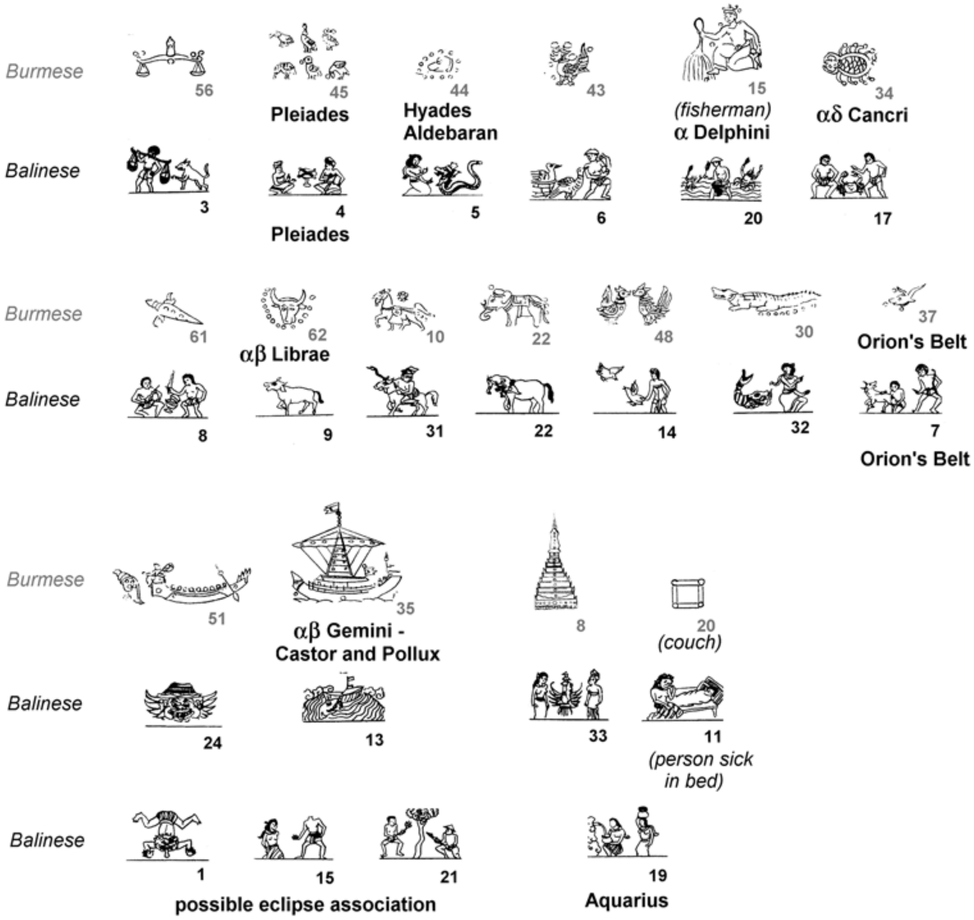
The lunar year consists of 12 lunations with an intercalary month added when needed and very erratically as late as the 1930s. What we call new moon is defined by the Balinese as the 15th lunar day of the waning moon, and at present, an intercalary month is added when the new moon (the last day) of the 7th lunar month would not fall in January. The new moon of January, nearest to the December solstice, is traditionally associated with Siwa (Shiva) and is supposed to be the darkest night of the year (i.e., the length of the night is longest). Although this is true north of the equator where the system originated, in Bali, the December solstice is the summer solstice when the nights are shortest. Nonetheless, Eiseman (1990/1996, p. 190) found no Balinese who knew that.

The calendrics are one aspect of the ethnoastronomy of the region; other aspects also reveal cosmological beliefs. In Bali, the great "mother" temple at Besakih is aligned toward

[31] Using the lunar synodic period of Table 2.5, §2.3.5, viz., $29^{d}.530\,589$, a lunar "day" can be defined as 1/30 of this value or $0^{d}.984\,352\,97$. Therefore, 64 lunar days = 62.998 590 mean solar days.



(a)



(b)

FIGURE 9.14. (a) The 68 Burmese asterisms from Buchanan (1807). (b) A subset of these asterisms with the names of recognized Balinese bintang parallels. Drawing by Rea Postolowski and Sharon Hanna.

the volcano Gunung Agung, held to be the center of the cosmos in Balinese Hinduism. At 3142 m, it is the highest point on Bali and is the abode of Batera Gunung Agung, or Mahedewa, the supreme manifestation of Siwa (Shiva).

The Toradja of central Sulawesi are said to claim descent from the Pleiades, as their name would suggest. There is a legend, reported in Kaudern (1938, p. 124) from older sources, of the migration of the Toradja led by six brothers and one sister from an area just north of Lake Poso, said to be their ancestral home. Before leaving, they set up seven "menhir-like" stones (although a variant mentions only five stones). Although there is no direct connection with the Pleiades, this asterism is a seasonal marker; other legends tie the Pleiades into migrations and seasonal agriculture more firmly.

Among the Tami, there is a legend (cited in Riesenfeld 1950, pp. 354–356) that involves tattooing of the wife's thighs (or alternatively, adultery, as in other groups) between Kalomatu and his brother's wife. This results in the death of the wife and the attempted slaying of Kalomatu and his family, who take refuge in a large tree. As the tree is being chopped down, Kalomatu shoots a succession of arrows into the sky to create a ladder, which they climb to safety. As he leaves, he cries out, "when I disappear you will lack taro [and so die] . . . , but when I reappear you will again have food." Riesenfeld (1950, p. 356) notes that in the eastern part of the Huon Gulf, the Pleiades are not visible in May and June when food is scarce. The taro of the previous season is finished, but the yams are not yet ripe. They are not dug up until "the Pleiades appear again." Riesenfeld (1950) rejects the notion that Kalomatu is the personification of the Pleiades on the basis that he prefers another explanation, namely, that recently departed are often said to take the best things with them, but we find the equation of Kalomatu (or Nagogale among the Jabim, Qat in the Banks Islands, Tagaro in Aoba, the sons of the "sky woman" of Fate, among others), suggestive. In this circumstance, the escape of the family makes for several stars, an appropriate symbol for the Pleiades, although the number of family members in the legend is not stipulated.

In Sumatra, the Bataks preserved their Indonesian inheritance and ancestral patterns, including a well-deserved reputation for ferocity, into the last century. They borrowed little from their Islamic and Buddhist neighbors. They had a writing system unlike those of India or the Arabs, but ancient documents in the script are apparently unknown. Although the Bataks are now largely Christians, Hostetter found that a ritual calendar was still in regular use with some knowledge of older beliefs, remembered particularly in the calendrical context. Hostetter's account of these beliefs may be supplemented and occasionally amplified from the work of Winkler (1913, translated by Kimball 1989–1993) and of Kimball (1989–1993). The Batak calendar consisted of 12 or 13 lunar months of 30 days each. The days were named and involved four repetitions of a borrowing of the planetary names of the 7-day week from Sanskrit, with two additional days at the end. Thus, each month began with a day named after the sun, although this type of repetition completely destroys the mathematical-divinatory bases of the 7-day planetary week.

The year begins with the first new moon after Orion's Belt disappears in the west (its position marked by Betelgeuse, "like the tail of a rooster," which is still above the horizon), whereas Scorpius is rising in the east, dominated by Antares. The "pair of scorpions are sitting facing toward one another" (Winkler/Kimball, p. 21), that is, both Orion and Scorpius are identified as scorpions. A scorpion figure is marked on the Batak calendar charts for four successive days of each month, gradually shifting through the months. Scorpion's opposite appears on the charts 12 days later during the first seven months of the year and 11 days later during the last five months of the year. Hostetter (1988, pp. 16–19) suggests that "originally" the scorpion's tail marked the first crescent moon and the "opposite" marked the full moon. He points out that the alternation of 11-day and 12-day intervals would never have been appropriate near the equator (which runs through Sumatra), but that it does work between 30° and 40° N, which, of course, includes Mesopotamia. Hostetter also suggests that the Batak new year once began with the crescent moon following the vernal equinox and had shifted to its present position, about May 20, due to the precession of the equinoxes. Checking backward, he found that Antares and Betelgeuse were simultaneously visible at opposite sides of the sky just before the vernal equinox at about 2400 B.C., a very good date for Sumerian Inanna. The importance of the opposition of Antares and Betelgeuse is also attested from India (Santillana and Von Dechend 1969/1983, p. 361).

Hostetter (1991, p. 1152) makes passing mention of another Batak deity, Boraspati, "an underworked fertility god who is a lizard." The name is, in fact, a borrowing of Sanskrit Brihaspati, the planet Jupiter, but Hostetter makes no mention of astronomical lore associated with Boraspati among the Bataks, and Winkler maintained that the Bataks had virtually no planetary knowledge. Kimball found that some native Batak calendar experts still knew that the names of the days were planetary names, but an informant specifically denied that this applied to Boraspati. Hostetter's discovery that the name Inanna is still applied to Venus, who is regarded as a mother figure, has not been known to previous western investigators.

The name *Inanna* probably derives from Mesopotamia via India. Hostetter (1991, pp. 153–155) draws attention to the work of B.N. Mukherjee, who has pointed out numerous and detailed similarities between Mesopotamian Inanna-Ishtar and a goddess called *Nana* among the Kushans of northwestern India (about 200 A.D.). The representation of the goddess on a Kushan coin corresponds closely to Neo-Assyrian representations of Ishtar, but DHK thinks that the name is derived from Ishtar's Sumerian prototype, Inanna. This supplies a clearcut intermediary between Mesopotamia and the Bataks, which in turn, makes it extremely likely that Inanna was the Sumerian name of the planet Venus, just as her Semitic derivative, Ishtar, was the Assyro-Babylonian name of the planet. The data support Hostetter's conclusions from the "scorpion" evidence that the ultimate derivation of the Batak ideas was from Mesopotamia in the mid-3rd millennium B.C.

The native theological views of the Toba tribe among the Batak are discussed extensively by Sinaga (1981), whose views we summarize. Although planetary gods are not specifically discussed as such, Sinaga (1981, pp. 87–89; Appendix I) describes their lunar myth, drawing on its monthly cycle as a source of a pre-Christian disposition among the Batak toward a sense of rebirth and resurrection. The myth concerns the *Sideang Parujar*, whom Sinaga identifies as the most important of the beings after the High-God, *Mulajadi na Bolon*. In the religious world view of the Toba Batak, *Mulajadi na Bolon*, the creator, resides in the Highest (the Seventh) Heaven; He created Bird *Hulambu Jati*, who produced three eggs that hatched into the first human men. These were provided human wives through the "hatching" of three canes provided by *Mulajadi na Bolon*. The children intermarried according to ritual laws, and this continued for 10 generations, until betrothal transgressions occurred to disrupt the process. Immorality followed, which was punished by *Mulajadi na Bolon* through conflagration that resulted in the Earth, and the Sun, Moon, and stars, to which many of the transgressors had fled, being hurled into the abyss. *Sideang Parujar* (or *Siboru Deangparujar*) was betrothed to the son of *Mangala Bulan*, the lizard-like *Tuan Tuima Uhir* (or merely less attractive *Siraja Odopodap*), and sought to escape the marriage because of his ugliness by spinning and weaving on the Moon, as long as possible. There are several versions of what happens next, but they all result in the interruption of her weaving, which gets snagged. Out of mercy, she is given a ball of Earth, from which she fashioned the solid Earth on the waters, in what is called the Middle World. After some vicissitudes, she is provided seeds that flower into all the animals, fish, birds, and vegetation of the world; accepts her fiancee; and ultimately transforms the world into a "strong, sacral, fertile, prosperous, and happy place" (Sinaga 1981, p. 83). Her offspring become the first people of the Middle World. In the end, according to one version, she returns to the Upperworld, where, on the Moon, "she could spin to her heart's content" (p. 83).

9.4. Tibet

Tibet lies in the highest mountainous region of the world between the Indian subcontinent and the deserts of central Asia. Although the dominant cultural relationships have been with India, there have been frequent Chinese intrusions.

Christopher Beckwith (1987/1993) is the first "western" scholar to treat central Asian politics during the time of the great Turkish and Mongol empires from a Tibetan viewpoint. Tibetan historical sources have been little known to western scholars and frequently denigrated, especially when they seemed to contradict Chinese documents. Beckwith's analyses make such positions untenable in principle and frequently in detail. Tibet's central role as an intermediary between China, India, and the Turko-Mongol cultures is now much clearer. There is a statement in the 10th-century Chinese *Tang Annals* that Tibetans descended from the Qiang people, who are mentioned as early as 200 B.C. (Chan 1994, pp. 26–35). Over much of its history, Tibet has had a theocratic government, drawn from one of its many monasteries, and often it acted at least quasi-independently under the formal control of Mongolian or Chinese emperors. Buddhism is said to have been introduced from above by scriptures falling from the sky during the reign of the (legendary) 28th king, Lhatori. Although occasionally suppressed, Buddhism has been the principal religion of the country throughout its history, and even today, as the "Xizang Autonomous Region" of the People's Republic of China. Tibetan Buddhism derived mainly from two sources: the Mahayana system, itself having developed from a 1st-century form of Buddhism known as *Theravada*, and Tantrism. Mahayana Buddhism emphasizes enlightenment not for the benefit of the individual pursuing it but for the salvation of all beings; the true spiritual ideal is the *bodhisattva*, who defers the achievment of *nirvana* to prevent the sufferings of others. The 24 *bodhisattva*s of some forms of Tibetan Buddhism (Bryant 1992, p. 202) show parallels in their cosmic role with the 24 Tirthakaras of the Jains and, like the Tirthakaras, are sometimes called "conquerers." Tantrism was known in both Hindu and Jain communities. Tantrism is less doctrinal and emphasizes meditation with yoga practices; the achievement of enlightenment requires experience as well as pure meditation (Gombrich 1984, p. 14). There have been five main sects of Buddhism in Tibet: the *Nyingma*, *Sakya*, *Kagyü*, the *Kadam*, and the sect of the Dalai Lamas, the *Gelug*, who ruled secularly as well as spiritually, up to the annexation by China in the mid-20th century. The first two of these are the oldest and are based on Tantric teachings; the *Kagyü* emphasize individual ascetism and yoga; the *Kadam* emphasized the Mahayana sutras; the Kadam monasteries were absorbed by the Gelug in the 15th century. The *Gelug* represents a reformation against moral and doctrinal departures in the 14th century. Its founder, Tsong Khapa (1357–1419), studied the teachings of the *Sakya*, *Kadam*, and *Kagyü* and reinvigorated Tibetan Buddhism with, basically, *Kadam* teaching, enforced with rigorous discipline. They are now the predominant sects in Tibet.

Tibetans share a belief in reincarnation with other groups on the subcontintent, and one of the motivations for pilgrimages is the expiation of sins in preparation for a better rebirth. Sacred sites for pilgrimages include mountains, bodies of water, and caves, especially those used by saints and other personages. Mountains were considered the points of entry into the world for the early, legendary kings of Tibet, and so are especially important sites. In Buddhism, to attain *nirvana* is to become liberated from the cycle of death and rebirth; in pursuit of this, a Tibetan Buddhist may totally renounce the world and maintain a permanent pilgrimage. Paradise, the quest of many pilgrimages, is said to exist already, in multiple, hidden valleys (*beyuls*), such as *Shambala*, the northernmost of five sacred sites associated with the cardinal directions. The others are *Wutai Shan* (East), *Potala* (South), *Uddiyana* (West), and *Bodh Gaya* (center). These have symbolic counterparts: the four continents at the cardinal points around the cosmographic center, the navel of the universe, Mt. Meru. Tantric meditation can achieve the objects of pilgrimage too: The spine is conceived as Mt. Meru, whereas the limbs are the continents. Aside from the paradises, the three most sacred pilgrimage sites are Mt. Kailash, Lapchi Kang above the Ronghar Valley, and Mt. Takpa Shelri in the Tsari Valley. Mt. Kailash (6714 m) is venerated by both Hindus (as the abode of Shiva) and Buddhists as Kang Ripoche, the "Precious Snow Mountain," also known as the Swastika Mountain, for its markings and symmetrical crown (Chan 1994, pp. 46, 273–279). The most important festival in the Mt. Kailash region is *Saga Dawa*; it is held in the 4th lunar month at full moon.

The oldest temples in Tibet date from the 7th century, during the reign of Songsten Gampo; he placed 12 temples arranged at the corners of three nested squares centered on Lhasa, and extending beyond the borders of the kingdom. The intention was allegedly to pin down a great demoness, whose presence was divined by his Chinese bride, the Buddhist princess, Wencheng. Each temple is said to be associated with a color, and an animal, in the Chinese tradition, which links these items with the cardinal directions (Chan 1994, pp. 43–45). At the center of this complex is the great temple of Jokhang.

A passage from the Mahānirvāna Tantra (Avalon 1963, cited in Rawson 1973/1978, p. 154) explains roles played by the planetary deities and their relationships to directions, colors, and iconography through instructions attributed to Siva:

Now I shall speak of the yantra of the Planets, which promotes all kinds of peace. If the guardians of all the directions and all the planets, Indra and the others, are worshipped in it they grant all desires. Three triangles should be drawn with a circle round them, and eight petals touching the circle. Then around it should be drawn a beautiful city-plan with four gates. Between the east and north-east corners a circle should be drawn . . . and another between the west and south-west corners. Then the nine triangles [created by intersections of the three triangles] should be filled in with the colours of the nine planets, and the left and right sides of the middle triangle should be made white and yellow, the base black. The eight petals should be filled in with the colours of the eight governors of the quarters [of the world]*. The walls of the city-plan should be decorated with white, red, and black powder, and O Goddess, the two circles . . . should be coloured, the upper red and lower white. . . . In the inmost triangle the Sun should be worshipped, and in the angles on the two sides of his charioteer [Aruṇa]* and his Radiance [Śikhā]*. Behind the Sun with his halo of rays the standards of those two fierce ones should be worshipped.

Then worship [the Moon]* the maker of night in the triangle above the Sun on the east; in the south-east Mars [Maṅgala]*, in the south Mercury [Budha]*, in the south-west Jupiter [Bṛhaspati]*, in the west Venus [Śukra]*, in the north-west Saturn [Śani]*, in the north Rāhu [the ascending node where the moon cuts the ecliptic in passing northward]*, in the north-east Ketu [the moon's descending node]*, and last, encircling the Moon, the crowd of Stars. The Sun is red, the Moon white: [sic] Mars is tawny, Mercury pale yellow-white, Jupiter yellow, Venus white, Saturn black, Rāhu and Ketu variegated. . . . One should meditate on the Sun as having four hands, one pair holding lotuses, the other pair making the gestures of dispelling fear and of blessing; the Moon should be visualized as holding nectar in one hand, giving with the other. Mars should be slightly bent, holding a staff in his hands. Mercury, the Moon's son, should be meditated on as a boy with locks of hair loose on his forehead. Jupiter [who is the Guru of the Gods]* should be seen to have a sacred thread [like a Brahmin], holding a book in one hand and a rosary of Rudrakṣa berries in the other. Venus, who is the Guru of the Demonic beings, should be blind in one eye, and Saturn should be lame; Rāhu should be visualized as a severed head, Ketu as a headless trunk, both deformed and evil.

(a)

(b)

Figure 9.15. The planetary gods housed in a structure at Konarak: (a) From left to right, Surya (Sun), Chandra (Moon), Maṅgala (Mars), Budha (Mercury), Vrihaspati (Jupiter), Śukra (Venus), Śani (Saturn), Rāhu (ascending node of the Moon's orbit), and Ketu (descending node). (b) Detail of the last four. Note that Rāhu hold symbols of the Sun and Moon and is mainly head; Ketu holds a sword and the head of a serpent, but is hardly "headless." Photo by Dr. A.R.F. Williams.

Brackets contain comments by the authors, and starred brackets are by the cited sources (Avalon/Rawson). The passage continues to discuss the governors of the directions. The description of the planetary gods is similar (if not identical) to those depicted on a 20-ft (6-m) long slab of chlorite (Figure 9.15), once used as an architrave of the Hindu Sun god shrine at Konarak, discussed above in §9.1. Chatterjee (1959/1985) comments that "their attributes are not correctly attended to."

The order on the former architrave of the Konarak temple is identical to the order in which the colors are assigned in the Mahānirvāna Tantra, with the Sun at the far end, and Ketu at the near. Venus, Saturn, Rāhu, and Ketu are shown in detail in Figure 9.15b. Note that the order is essentially that of the Mediterranean week, with the addition of Rāhu (the ascending node) and Ketu (the descending node), at the opposite end from the Sun and the Moon. At Konarak, Rāhu is depicted without a lower body and is holding symbols for the Sun and Moon. Ketu's lower body is that of a serpent.

In 1027, a system of Buddhist teaching known as the Kâlacakra (Wheel of Time) was introduced into Tibet from northwestern India (Petri 1967). The text is in Sanskrit and Tibetan, and it describes the world in human scale. The stars revolve about the center of the universe, Mt. Meru.[32] The Earth is flat. There are abbreviated instructions for the calculation of planetary positions along with tables of the corrections to mean motions due to relative motion (epicycle) and eccentricity. Petri notes that other, much smaller works similarly emphasize the Indian source of the astronomy. These sources contain a list of the Indian lunar mansions (*rgyuskar*), various asterisms (the Big Dipper, the zodiac, and the Pole Star), sexagesimal numbers (suggesting an ultimate Mesopotamian origin), comments about eclipses and a comet (Petri suggests a possible reference to Encke's comet, currently not naked-eye visible, but provides no supporting detail), but no Greek words (as there are, for example, in the Siddhântas) or geometry. In the Kâlacakra, eclipses are caused by Râhu (Head of the Dragon) and Ketu (Tail of the Dragon), the invisible planets that cause eclipses, and are identified with the ascending and descending nodes of the Moon's orbit, respectively. Râhu is further connected to Time (kâla), itself considered to be a manifestation of Âdibuddha, the supreme and transcendant being. Petri (1967) mentions a possible rate of precession of "1½ days" per century[33] as the "famous counting of Kâlacakra." This quantity is a somewhat greater value than the 21,600-year cycle cited in connection with the variant 5400-year lengths of each of four yugas in §9.2.

Related to the system and text that bear this name, the "Kâlacakra" as the wheel of time is also known in sacred art. Although there is a three-dimensional version of a Kâlacakra mandala in one of the Tibetan temples, the usual version is a "sand painting" prepared on the ground by a group of monks. Such a sand painting is normally destroyed immediately after its ritual purpose has been fulfilled, but Barry Bryant (1992) gives a full description of such a sand painting that was created expressly for interested non-Buddhists with the authorization of the Dalai Lama, who also wrote an introduction to Bryant's book. The diameter of the circle of the outside perimeter of the Kâlacakra mandala is defined as 13 units of measurement. A piece of paper of the length of the diameter is folded by trial and error until there are 13 equal length divisions. These are then used as the primary units for all other features of the mandala. A high precision is achieved in the formal relationships of the different levels of the mandala. Both the geometry and the iconography are reproduced from memory by the monks, and no plans or texts are used. The mandala represents a 5-story "palace" that resembles a stepped pyramid. The top of the pyramid is shown as the center of the mandala, and each level is described as a distinct mandala. The mandala of "Enlightened Great Bliss" at the top contains 14 deities and the mandala of "Enlightened Wisdom" (just below) contains 16 deities. The deities of these two distinct mandalas seem to be omitted from the calculation of the total number usually stipulated for the Kâlacakra mandala. The mandala of the "Enlightened Mind" contains 70 deities; the mandala of "Enlightened Speech" contains 116 deities, and the mandala of "Enlightened Body" contains 536 deities. The sum of the last three numbers is 722, the number of deities said to be represented in the entire sand painting (Bryant 1992). It is clear from his statements that one would find difficulty in recognizing any such number of deities. At the very center of the mandala in a lotus flower are said to be six gods. However, representations of four of these were covered through multiple layering. On the surface are a representation of a *vajra*, the lightning weapon of the god Kâlacakra, honored in the mandala. Here, the *vajra*, in fact, represents the god, and a dot of colored "sand" material represents his wife, Vishvamata. We are told that the animals of the 12 months carried the individually named gods of 360 days. Each of the animals carries a cluster of 30 deities indicated by dots, but only 29 are visually apparent in most cases. The centers of the clusters contain different colored dots for the full moon and new moon deities. But, although some dots represent gods, other dots represent offerings and still others seem to be "decorative" background. Offering goddesses appear as anthropomorphic figures, as dots, and in still other cases, are represented by letters of the Tibetan alphabet. "Possible humans" (a defined category of figures) appear in totally human form when female and may have an animal head when male. The "possible humans" are supernatural but are unnamed and are not gods. Similarly, the Snow Lion and King of the Birds (fully depicted) are major named supernaturals but are not counted among the gods. There are also subordinate snow lions represented by dots.

The four elements are represented by different colors in the four directions in the inner squares, but there are five concentric circles surrounding the squares defined ultimately by the same colors but including also a 5th ring of many colors representing the æther. The 116 deities of the mandala of the "Enlightened Speech" may refer to Mercury. The Kâlacakra is particularly associated with the 60-year Jupiter cycle (Bryant 1992, pp. 234–235) created by a combination of the five elements and the cycle of 12 animals (see §10.1.3, Figures 10.3, 10.6, 10.7; Tables 10.3, 10.4). The 12 animal cycle alone was used to define the 12-year Jupiter sidereal period. The 12th part of the latter cycle is a 361-day year. The 722 deities of the Kâlacakra mandala apparently represent two such years. *Vrihaspati*, teacher of the gods, and Lord of the lunar mansion *Pusya*, "flower," is identified with Jupiter, and "flower" may be a reference to the lotus at the heart of this mandala. A Hindu prototype of the Kâlacakra is mentioned by Hopkins (1969, p. 168). It describes the *Asvini*, "horsemen," as follows:

> Primeval gods, eternal, two fair-nosed beings, birds divine, weavers of light, creating the wheel of time (which has seven hundred and twenty spokes; or nave of six seasons with twelve spokes; also the year as calf of three hundred and sixty cows), supreme Brahman, powers creating space (the ten directions) and sky, who set sun and moon in the sky.

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[32] Petri calls attention to a parallel with an early 18th-century Mongolian astronomy treatise as recorded by Baranovskaya (1955), in which the Sun and the Moon are said to move about Mt. Meru on the "mantle of a truncated cone."

[33] Assuming that this is equivalent to 1.5°/century, 360/1.5 = 240 centuries or 24,000 years.

FIGURE 9.16. Silk coffin shrouds from Astana on the ancient Silk Road to China and now in the National Museum, New Delhi: Note the interwined lower torsos of the Sun and Moon deities, not an inapt portrayal of their bodies' circling and spiraling motions in the sky. Photos by E.F. Milone.

The Tibetan version seems to involve a shift from the Asvins and the 720 gods to 722 gods, perhaps indicating a switch from a solar to a Jupiter cycle.

Astronomical knowledge and associated ideas traveled back and forth to China along the Silk Road and by sea. Astronomical cycles were certainly among these ideas. A series of silk coffin shrouds from Astana on the Silk Road show Sun and Moon deities with intertwined serpentine lower bodies (Figure 9.16) that give a sense of those cycles.

Via the Silk Road, we travel to Eastern Asia.

10
China, Korea, and Japan

10.1. China

10.1.1. Archeological and Historical Background

Chinese archeology covers a very large area, and new information, often radically changing earlier ideas, continues to pour in. The present summary relies heavily on Chang's (1986) general study and on his study of the Shang (1980). A million years or more of the Palaeolithic of China, with slow changes in the human physical type and the stone tools in use, provided an already well-diversified group of populations at the end of the Pleistocene. There are some microlithic cultures succeeding the Palaeolithic, but by around 6500 B.C., there were several different varieties of Neolithic culture in existence in North China, which Chang groups together in the P'ei-li-kang Culture. The people lived in round or rectangular houses with plastered floors, usually sunk somewhat below ground level. Pottery was in regular use, as were polished stone tools, including axes, hoes, and mortars and pestles. Shells were used to make blades for sickles. Underground storage chambers were used for grains. At least two species of millet seem to have been domesticated, and both dogs and pigs were also domesticated, although hunting was still an important aspect of the cultures. Bone spearheads, arrow points, and harpoons were in use. Turquoise ornaments served for decoration, and clay figurines of pigs have been found. People were buried in cemeteries.

In South China and neighboring Thailand, pottery seems to go back as early as 8000 B.C., and domesticated pigs were comparably early. A wide range of plants were recovered from Thailand, but it is not certain which were domesticates, although some probably were.

Between ~5000 and 3000 B.C., spindle whorls, needles, the use of silk, human figurines, and fishhooks were important innovations in the Yang-shao culture of north-central China. Houses were bigger and more complex, and the layout both of villages and cemeteries suggests a division of the people by clans and lineages. Basketry designs are known from impressions on pottery, and some pottery is elaborately painted with designs of plants, fishes, birds, mammals (including humans). Most strikingly, a number of symbols on the pottery resemble later writing. There is, as yet, nothing to suggest that these symbols were actually being used as writing, but they furnish possible prototypes that may have led to writing. Chang (1980, p. 165) suggests that particular symbols may be connected with particular lineages. Comparable changes occurred elsewhere in China, and there is good archeological evidence of extensive interaction between the various regions by 3000 B.C., which leads to increased homogenization of the culture. By 2000 B.C., some bronze was in use but still as a relatively unimportant element of the culture.

Chinese traditions of their origins extend before 2000 B.C. and tell of mighty deeds of the first five emperors (regarded as mythical by nearly all modern scholars[1]). In the Middle Yellow River area, the Lung-shan culture developed out of the local version of the Yang-shao culture; a Lungshanoid horizon was widespread. In this period, walled towns appear (some nearly square and oriented about 6° W of N), and burials have been discovered with people who had been killed and scalped; warfare had become important. Towns were drained by well-made pottery pipes. A major change in pottery technology was the use of the potter's wheel. Pottery spindle whorls are known from this period. Stone net sinkers suggest the importance of this type of fishing. Cattle and chickens appeared as farm animals. Water buffalo and sheep are known as domesticated animals from other contemporary sites. Crocodile skin drums and music stones

[1] Exceptions are K.C. Wu and K. Pang. Wu (1982) has attempted to defend and interpret the historicity of these kings and their immediate successors of the Xia (Hsia) and Shang dynasties. Pang (1987) and Pang and Bangert (1993) have attempted to determine certain dates relevant to that period on the basis of astronomical evidence.

were found in some elite burials. These are mentioned in later texts among the insignia of royalty. Jade became extremely important as a symbol of elite status. A curious jade tube, called a *ts'ung*, was rectangular in cross section, with a round central opening. Needham (1959) argued that these tubes were astronomical sighting devices. Although still unimportant economically, a few copper and bronze tools have been found, which show a technologically well-developed metallurgy.

From the Lung-shan culture, the Three Dynasties (Xia, Shang, and Chou) developed; this is the first period for which we have some contemporary historical evidence. Although traditionally considered to be sequential rulers, archeological evidence has made it clear that they represent regionally distinctive developments out of the Lung-shan culture. Political supremacy did pass from one to the other, but the underlying distinctions remained. An early phase of the Shang culture, called Cheng-chao, is already important archeologically and is potentially important historically, but for present purposes, the late Shang culture is of primary importance.

The historical accounts of the Xia and Shang dynasties were widely regarded as untrustworthy by many scholars. For the Shang Dynasty, inscriptions on bronze vessels had been a good indicator of the dynasty's existence, but details were scanty. However, the discovery of inscribed oracle bones [Chang (1980, p. 39) quotes estimates of about 100,000 pieces known at that time] and the subsequent location of their place of origin, Anyang, completely altered that situation. So far, however, there have been no discoveries of books or historical texts of any sort.

The Shang civilization was using a fully developed bronze technology that included mining of both tin and bronze. Pottery kilns have been uncovered in some places, which gives us a good knowledge of their technology of pottery making. Local city states with hereditary rulers constantly jockeyed for power. Effective horse-drawn chariots were in regular use. There were standing armies, and one oracle bone mentions an army of 10,000 troops of the king supplemented by 3000 troops of the queen (Chang 1980, p. 195). Warfare was accompanied by extensive human sacrifice. In one case, over 600 people were sacrificed in connection with the building of a single house. Kings were buried in chariots, accompanied by horses, charioteers, and other servants. Farming had been expanded to include soybeans, wheat, and rice. However, although later tradition ascribed irrigation and water control to the emperor Yao, no archeological evidence of irrigation, even in late Shang times, has yet been found. Chang believes that political power developed in this area from shamanistic practices associated with divination and that shamans were the political forerunners of kings. Our first direct astronomical evidence comes from this period and suggests that the power of the kings may have been partly rooted in their astronomical knowledge, particularly the ability to foretell eclipses. Traditionally, a leading Chinese astronomer of the Shang period was Wu Hsien; however, this name was used by an otherwise anonymous scholar of the 4th century B.C.

For ease of identification of the approximate dates associated with Chinese dynastic periods, a somewhat simplified chronology of China is provided in Table 10.1. An extensive treatment of the historical aspects of Chinese astronomy can be found in Joseph Needham (1959, Vol. 3).[2]

10.1.2. Early Astronomy

According to Pang (1987), pottery images of the Sun, Moon, and at least one constellation are known from the late Yang-shao and Dawenkou cultures dating from the period 4500–2300 B.C., and the desire to predict extraordinary floods in China, required some knowledge of astronomy. One of the two earliest recorded texts involving astronomy is found in the *Canon of Yao*, recorded in the *Book of Documents*, allegedly edited by Confucius. According to mythic tradition, Yao was one of the "sage" kings who ruled China prior to the first hereditary dynasty (the Xia or Hsia) noted in Table 10.1. Although the historicity of Yao is doubtful, this citation from Legge (1865/1960) indicates the study of the calendar as a credible motive for carrying out systematic astronomical observations:

> Thereupon (King Yao) commissioned Hsi and Ho reverently to follow the august heaven, and calculate and delineate (the movements of) the sun, moon and (other) celestial bodies; and respectfully give the seasons to the people. Separately he ordered Hsi Zhong to reside among the (eastern) Yu barbarians at a place called Yanggu and there to respectfully receive as a guest the rising sun. . . .

Even if purely mythical, it is interesting that the myth should incorporate astronomers in it. Although practical concerns may have been at least part of the motivation behind early astronomy in China, other aspects were probably important, and at times would dominate. From the same *Canon of Yao* comes the story, famous among modern astronomers, of Hsi and Ho being decapitated at the orders of the emperor[3] for failing to prevent an eclipse (Needham 1959, p. 188). The story has been euhemerized to make their failure merely one of prediction. Skeptics who doubt the story should be convinced by the fact that the decapitated heads of Hsi and Ho are still to be seen—the double cluster in Perseus has been referred to by this name in China according to Staal (1984, p. 161). References outside the *Canon of Yao* refer to Hsi Ho as a single individual, either the charioteer of the sun or the mother of the sun (Needham 1959, p. 188). The date of the eclipse was calculated by various modern scholars anywhere from –2165 to –1948 (2166 to 1949 B.C.); but most scholars in Needham's time regarded the account as a forged interpolation of the 4th century A.D., and even the few defenders of the text regarded the account as legendary rather than historical. Pang (1987, p. 149) (following the Mucke and Meeus eclipse

[2] This monumental work, *Science and Civilisation in China*, was published in several volumes. Volume 3, which deals with astronomy, was first published in 1959. Ronan's "The Shorter Science and Civilisation in China" in two volumes is an abridgement of Vol. 3 and the first part of Vol. 4; Ronan's second volume is cited in the References and Bibliography as Needham/Ronan (1981, 2).

[3] Said to be the 4th Xia emperor, Zhongkang (Wu 1982, pp. 121, 144, fn. 60).

TABLE 10.1. Chinese chronology.

Dynasty	Dates[a]	Personages/events (dates)
Neolithic [Yang shao culture]	5000–2000 B.C.	Farming Settlements; painted pottery.
Xia (Hsia)	2180–1600	Tradition; no archaeological data.
Shang	1600–1027	Bronze Age; royal burials; oracle bones; 60-day cycle.
Zhou (Chou)	1027[a]–249	Confucius (522–479 B.C.). Full *xiu* list.
Warring States	481–221	Iron age. Marquis Yi; comet classification.
Qin (Ch'in)	221–206	Unification; Great Wall.
Han	206 B.C.–220 A.D.	Civil bureaucracy; Silk Road; introduction of Buddhism; paper and block printing.
Wei	220–265	Breakup of empire.
Three Kingdoms	222–280	
Chin	265–420	Flowering of the arts.
South and North	420–589	Tartars in north; Buddhism at height; gunpowder.
Sui	581–618	Empire reestablished; Grand Canal.
Tang	618–907	Internationalism; extensive western trade.
Five dynasties	907–960	Lyric poetry.
Song (Sung)	960–1279	Reunification; Neo-Confucianism; major retreat in last century. Tartars in north.
Yuan (Yüan) [Mongol]	1271–1368	Marco Polo visits Khan at Tatu (Beijing[b]).
Ming	1368–1644	Jesuit mission; western astronomy.
Qing [Manchu]	1644–1908[c]	

[a] Dates uncertain for first four entries.
[b] This is the pinyin romanization, used by the People's Republic (and adopted by the New York Times in 1979); in the Wade-Giles romanization, used in English-speaking countries since the 19th century, it is "Pei-ching," although "Peking" has been more generally used. The correct pronunciation is approximated by "Bay-jing." Where the romanizations differ for dynasty names, the Wade-Giles version is in parenthesis.
[c] End of imperial rule.

canon, 1983) maintains that the "only correct match" of the alleged conditions of the eclipse is with an eclipse of 16 October 1876 B.C. (J.D. 1036503), which was said to be a *keng-xu* date (day 47) of the sexagenary cycle (discussed later).

Alleged occurrences of severe floods that "assail the heavens" during the reign of the legendary king Yao provide another motive to study astronomy because flood prediction requires good calendrical and tidal information. Yao was credited in Chinese belief with creating a canal system to drain away the waters of a tremendous flood. Finally, as in the west, astrological implications of occurrences in the heavens became very important for state security.

We have no direct information on the *Xia* (*Hsia*) dynasty astronomy, but Pankenier (1984; 1994, p. 9) and Pang and Bangert (1993, p. 13) have drawn attention to a loose conjunction of all naked-eye planets and the Moon in the dawn sky in Pegasus on March 3, 1953 B.C. Julian (Feb. 13 Gregorian). These may have marked a new calendar version and justified the beginning of the Xia dynasty. According to Han dynastic records, an ancient calendar known as the *Zhuanxu* is said to have begun with a gathering of all seven planets (Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn) in the constellation *Yingshi* at dawn on a day in early spring. Pang emphasizes that the conjunction could not have been calculated as being in *Yingshi* because precession was not known, even if the planetary parameters were accurate enough to backcalculate a conjunction. Moreover, the date does not correspond to traditional Xia dates. The constellation *Yingshi* is identified as the Great Square in Pegasus and Andromeda (Schlegel 1875/1967, pp. 275–285), and it corresponds to the 13th and 14th lunar mansions. The associated animals in the 28-animal list were the Boar[4] and Porcupine. Curiously, the animal of the Xia dynasty was said to be the Boar, although there is little evidence that this association is ancient. *Yingshi* was also known as the Palace of Darkness, as the Ancestral Temple, and as the Four Supports of Heaven. It was said that the culmination of *Yingshi* (presumably at midnight) was the time for building palaces. This corresponded to the 10th month of the year of the Xia dynasty, defined astronomically by the pointing of the handle of the Big Dipper,[5] (*Beidou*). According to Schlegel, this began to be true in the 20th century B.C. *Yingshi* was the "home" of the "Imperial Star," Saturn, identified particularly with the "Yellow Emperor," and of the "Year Star," Jupiter. The conjunction date March 3 Julian (although a tighter conjunction occurred on Feb. 26 Julian = Feb. 8 Gregorian) would probably have fallen in very early spring[6] in the Chinese calendar. These facts suggest a genuine tradition associating the calculated date and the Xia dynasty. Krupp (1995, pp. 60–61) describes possible associations. If the tradition correctly preserved an account of this mass conjunc-

[4] In India, the boar was the avatar (incarnation, epiphany) first of Brahma, and later of Vishnu.
[5] Referred to as the "Northern Dipper" and equated to the "Great Bear" by Needham (1959, cf., especially, Fig. 90 on p. 241 and his index entry for "Northern Dipper").
[6] The Chinese seasons did not begin at the equinoxes and solstices but effectively spanned them. The popular western usage of "midsummer's eve," which refers to a celebration of summer solstice corresponds more closely to the Chinese usage. The Chinese Spring in Xia times similarly began well before the equinox.

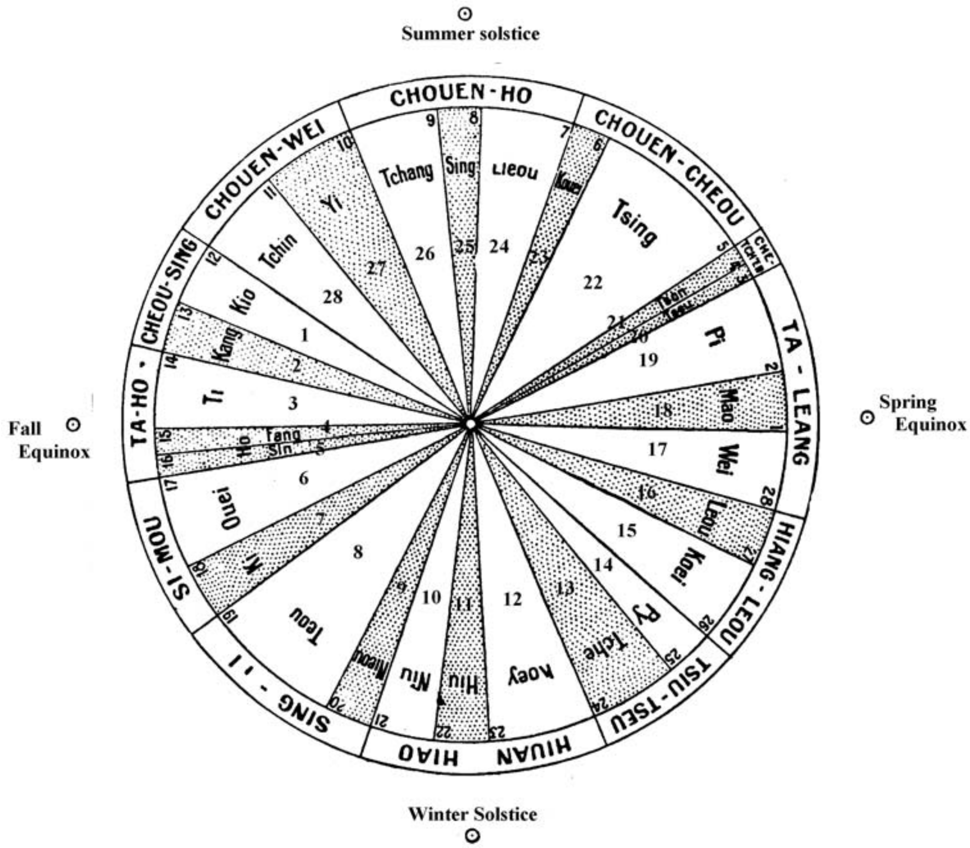

Figure 10.1. Pairings of the *xius* according to the calculations of Saussure (1930): The sizes are said to match best around the equator of ~24th century B.C. Drawing by Sharon Hanna.

tion, then the plausibility of a real eclipse underlying the story of Hsi and Ho is somewhat increased.

The astronomical evidence from the Shang oracle bones can best be understood after a consideration of structural features in later calendrical and astronomical data, which may suggest an origin in Shang times or earlier. Of these, changes due to the effects of precession predominate. First, there are a series of names that seem to identify various stars as former pole stars ("Celestial Emperor," "Crown Prince," "Celestial Pivot", etc.). Next, there are texts discussing the technique used to find the pole. Shen Kua (≥1068) built a series of sighting tubes of increasing diameter, with which he established over a three-month interval that the pole star at the time was 3° from the pole (Needham 1959, p. 262). Needham (1959, pp. 259–260) identifies a number of possible pole stars in use in China; according to his designations, i Dra, either 42 or 184 Dra, β UMi (~1000 B.C.), γ UMi, a3233 UMi, and b3162 UMi, and 4339 Cam (during the Han). See Figures 3.9 and 3.10a. A structurally valid beginning point for the list is ~3000 B.C., which would precede both the Xia and Shang dynasties.

10.1.2.1. *Evidence for Early Use of the Lunar Mansions*

Precession is also important in attempting to date the system of the *xiu* (*hsiu* in the Wade-Giles transcription), traditionally "lunar mansions," and now often translated as "lunar lodges," the 28 asterisms that define the 28 regions of the sky. Although first attested as a complete list in 433 B.C., all structural features indicate a much earlier origin. The system was used to measure divisions along the equator, and the equatorially projected widths of the individual *xiu*s vary at the present time from as little as 2° to as much as 33°. Because they are equatorial measurements relative to particular stars, they are constantly changing with precession. The earliest direct evidence for the irregular sizes of the *xiu*s is an inscribed lacquered disk from 169 B.C. There was a tendency for approximate pairing of the size of *xiu*s on opposite sides of the sky that would have been helpful in observations near sunrise and sunset. There was also a link between stars near the equator and circumpolar stars, and this was used as a guide for locating stars hidden by the local horizon. All of these factors change with precession. The sizes of the pairings of the *xiu*s best match the equator of ~24th century B.C. according to the calculations of Saussure (1930); see Figure 10.1.

Needham (1967, p. 249) cites work by the Chinese astronomer Chu Kho-Chen that the best fit of lunar mansions with a celestial equator occurred for the interval 2300 to 4300 B.C., which, however, Needham doubts on archeological and literary grounds.[7] Needham discusses changes in the ordering of the *xiu* and points out that Vega, which

[7] Later archeological evidence makes this date seem more plausible, even in China, than it did to Needham. Certainly, it would be entirely reasonable if the Chinese system derived from India, as DHK thinks.

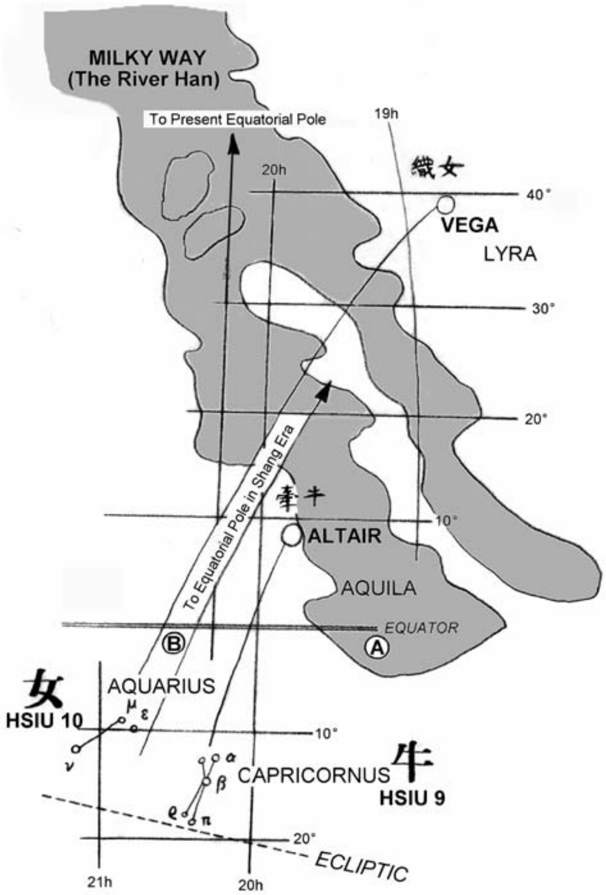

FIGURE 10.2. Elimination of Vega, the Weaving Maiden, from the *xius* because of precession. Drawing by Sharon Hanna.

apparently was once the determining star of *xiu* 10, changed its position relative to the equator to the extent that the entire *xiu* was eliminated and had to be redefined with differing stars.

Walters (1992, pp. 99–103) points out that the Weaving Maiden is Vega and her lover, the Ox-herd, is Altair (α Aql), but that Altair is never included in *xiu* 9, the Ox, although central to the story (see Figure 10.2). Certainly, the story makes more sense if Altair is included with *xiu* 9, as Walters suggests. Alignments that would fit the story would have been valid in Shang times. Needham also discusses a passage from the *Canon of Yao* (the passage is given in full in Chinese with an interlinear translation by Walters (1995, p. 143), which gives

(1) *Niao Hsing* ("Bird Star," later simply *Hsing*, "the star"), Alphard (α Hya), as the marker of Spring;
(2) *Ta Ho* ("Great Fire"), (elsewhere, *Huo Hsing*, "Fire Star"), Antares, as the marker of summer;
(3) *Hsü* ("Void," β Aqr) (elsewhere, *Hsu*), as the marker of autumn; and
(4) *Mao* (the Pleiades), as the marker of winter.

Needham (1959) assumes (with most previous scholars) that the markers refer to heliacal risings of the named stars, but there is no time period when these stars would give a consistent date if so interpreted. Needham (1959, pp. 245–246) points out that Hsu indicates a date of about 350 B.C., and Mao (the Pleiades) a date of about 1500 B.C. It is said in the same text (the *Canon of Yao*) that the year has 366 days,[8] and the number is written in a way found in the earlier Shang oracle bones, but not on the latest ones. Most of the other linguistic data suggest a date between the 8th and 5th centuries B.C.

In the early 2nd millennium, Hsing (Niao) and Hsu were solstitial while Mao and Huo were equinoctial in terms of conjunctions (hence, invisible). However, the quarter-day divisions could also be used to determine the annual positions of the star markers. As conjunction markers, the system would have worked best about 2400 B.C. Walters (1992, pp. 143–147) has a possible if simple solution: the orientation of Arcturus and the three end stars of the handle of the Big Dipper, as a time/seasonal calendar timepiece.

The *xiu* determinative stars were also "keyed" to circumpolar markers (Needham 1959, pp. 231–233). Some of these ceased to be circumpolar fairly early. Thus, the Huai Nan Tzu says that when Chiao Yao points to Yin, it is the first month of spring. Needham (1959, p. 250) thinks that Chiao Yao is Gamma Bootis, which ceased to be circumpolar (in the sense of being constantly visible) about 1500 B.C.

The "Ten Heavenly Stems" (*gan* in Pinyin; *kan* in Wade-Giles) is a cycle mentioned in Shang inscriptions in connection with a cycle of the "Twelve Earthly Branches" (*chih* or *zhi*), later associated with the animal series known as the "rat zodiac," or the "oriental zodiac," equated to the western zodiac in the 17th century by Jesuits in China. See Figure 10.3 for an illustration of the rat zodiac, as depicted on the back of a mirror, and §15 for further discussion of the connections.

Needham (1960) estimated that the twelve Earthly Branches were associated with 12 double hours by or before the 3rd century B.C. Both "Stems" and "Branches" are shown in Table 10.2. The Twelve Earthly Branches were traditionally displayed in a circle, whereas the Ten Heavenly Stems were arranged in a rectangle. The two series mesh together starting with the first stem and the first branch, to give a cycle of 60 days (as in the Shang Dynasty, as recorded on oracle bones) and, later, 60 years.[9] Table 10.3 demonstrates how the cycle works; the last (the 7th) row shows the return to the beginning of the cycle after 60 combinations. The use of the sexagenary 60-year cycle is reported to have come into practice only in the former Han dynasty, in the 1st century B.C. (Needham/Ronan 1981, p. 184), but this is disputed (cf. Sima Qian). Boodberg (1940) argues that the 12 animal cycle was already being used to mark years in late Chou times and that this is indicated by the use of appropriate animal names for some historical figures, which agree with known dates of birth.

One of the earliest surviving texts deals with the use of this 60-day cycle in connection with Chinese 5-element

[8] Even small fractions of a day were probably counted as whole days.
[9] Needham (1959, p. 396) uses the image of two cogwheels, of 12 and 10 teeth, respectively, meshing to produce a repetition after 60 combinations.

FIGURE 10.3. The animal series known as the "rat zodiac," rubbing from the back of a Chinese mirror. Photo by E.F. Milone.

theory. The account appears in the *Huai Nan Tzu* of the 2nd century B.C. and is partly quoted from the *Kuan tzu* of the 4th century B.C. It apparently represents much older ideas (Walters 1992, pp. 30, 74–79). The text shows that the year was conceptualized as a period of 360 days, divided into 5 seasons (each ruled by one of the 5 elements). The seasons were marked by the "arrival" of particular named days of the 60-day cycle. This material and the accompanying astrological predictions are shown in Table 10.4. The 60-day cycle is a close approximation to 2 months and, in the context of a 360-day year, strongly suggests 12 months of 30 days each. Taken as a continuous sequence, such a calendar would shift through the tropical year so quickly that it would be out of step by a full 72-day season (and a day) in only 14 years. However, the specific prognostications clearly imply a seasonal distribution. This indicates that the sequence is not continuous, but that the cycle began again each year with some annual marker, perhaps the heliacal rising of a specified asterism.

The Chinese theory of the Five Elements first appears in the work of Chou Yen (~350–270 B.C.). The elements were identified with planets to the extent that a reference to "wood," for example, in an astronomical context, was understood as Jupiter. In the same way, "fire" referred to Mars, "earth" to Saturn, "metal" to Venus, and "water" to Mercury. By 239 B.C., in the *Spring and Autumn Annals*, the history of the Chinese dynasties was phrased in terms of the progres-

TABLE 10.2. Ten heavenly stems and twelve earthly branches.

Stems				Branches				
Order	Name	(Pinyin)	Meaning	Order	Name	(Pinyin)	Double-hour associations	Animal[a]
1	*chia*	(*jiă*)	First, armor	1	*tzu*	(*zi*)	11PM–1AM	Rat
2	*i*	(*yi*)	Second, twisted	2	*chhou*	(*chou*)	1–3AM	Bull
3	*ping*	(*bing*)	Fish tail	3	*yin*	(*yin*)	3–5AM	Tiger
4	*ting*	(*ding*)	Fourth, nail, strong	4	*mao*	(*mau*)	5–7AM	Hare
5	*wu*	(*wu*)	Lance, halberd	5	*chhen*	(*chen*)	7–9AM	Dragon
6	*chi*	(*ji*)	Self	6	*ssu*	(*si*)	9–11AM	Serpent
7	*keng*	(*geng*)	Evening star	7	*wu*	(*wu*)	11AM–1PM	Horse
8	*hsin*	(*xin*)	Bitter, hot, toilsome	8	*wei*	(*wei*)	1–3PM	Sheep
9	*jen*	(*ren*)	Carry on shoulder	9	*shen*	(*shen*)	3–5PM	Monkey
10	*huei*	(*gwei*)	—	10	*cyu*	(*you*)	5–7PM	Cock
				11	*hsü*	(*xu*)	7–9PM	Dog
				12	*hai*	(*hai*)	9–11PM	Pig

[a] Associated "rat zodiac" animal.

TABLE 10.3. Illustration of sexagenary cycle.[a]

i	1	ii	2	iii	3	iv	4	v	5	vi	6	vii	7	viii	8	ix	9	x	10
	11		12		1		2		3		4		5		6		7		8
	9		10		11		12		1		2		3		4		5		6
	7		8		9		10		11		12		1		2		3		4
	5		6		7		8		9		10		11		12		1		2
	3		4		5		6		7		8		9		10		11		12
i	1	i i	2	. . .															

[a] Roman numerals represent the Ten Heavenly Stems (repeated only in row 7), and arabic numerals represent the Twelve Earthly Branches, so that six rounds of the Stems mesh with five rounds of Branches.

Table 10.4. Divination by the day cycle in the five seasons.[a]

Number	Day name	Element	Seasonal event	Approximate Gregorian date
1	CHIA TZU	Wood		1 Mar.
13	Pung Tzu		Insects early; thunder	13 Mar.
25	Wu Tzu		Danger to unborn young, unhatched eggs	25 Mar.
37	Keng Tzu		Military operations	6 Apr.
49	Jen Tzu		Frosty spring	18 Apr.
61	Chia Tzu			30 Apr.
73	PING TZU	Fire		12 May
85	Wu Tzu		Loud thunder	24 May
97	Keng Tzu		Lightning	5 June
109	Jen Tzu		Hail	17 June
121	Chia Tzu		Earthquakes	29 June
133	Ping Tzu			11 July
145	WU TZU	Earth		23 July
157	Keng Tzu		Calamity to the five grains	4 Aug.
169	Jen Tzu		Summer cold; rain, frost	16 Aug.
181	Chia Tzu		Silkworms not formed	28 Aug.
193	Ping Tzu		Drought	9 Sept.
205	Wu Tzu			21 Sept.
217	KENG TZU	Metal		3 Oct.
229	Jen Tzu		No fish	15 Oct.
241	Chia Tzu		Trees and grass live/die alternately	27 Oct.
253	Ping Tzu		Trees and grass flourish anew	8 Nov.
265	Wu Tzu		Harvest may continue or fail	20 Nov.
277	Keng Tzu			2 Dec.
289	JEN TZU	Water		14 Dec.
301	Chia Tzu		Winter, but no stores	26 Dec.
313	Ping Tzu		Meteors fall	7 Jan.
325	Wu Tzu		Hibernating insects out too early	19 Jan.
337	Keng Tzu		Winter thunder	31 Jan.
349	Jen Tzu			12 Feb.
361	CHIA TZU			24 Feb.

[a] From the 2nd century B.C. or earlier. Based on Walters (1992, pp. 75–77, ff. *Huai Nan Tzu*, ff., in part, *Kuan Tzu*).

sion of the Five Elements, and the ideas were supposed to be already known in the time of the mythical emperors (Walters 1992, pp. 37–39). From Han times on, the role of the Five Elements in divination became of crucial importance. If similar ideas were present earlier, they were either very unimportant or restricted to a small group of specialists in divination. The identification of the Five Elements with the five seasons in the calendar of the *Hsia Hsiao Cheng* might be regarded in one of three ways: as a secondary accretion to that work; as evidence that the Five Elements did, indeed, go back to Shang times or earlier; or as evidence that the *Hsia Hsiao Cheng* was late Han in date. We can now consider Shang eclipse records.

10.1.2.2. Eclipses from the Shang and Later Dynasties

The little that we know about the relationship between the emperor and natural phenomena in Shang times is largely congruent with later attitudes. Later, we know that it was important for the emperor, and therefore for the astronomers, that eclipses be predicted. Successful prediction implied a kind of harmony with the celestial realm; unpredicted eclipses were ominous and were taken very seriously. It was a sign of moral imperfection in the emperor's person, for it was his virtue that enabled him to keep in harmony with the rhythms of the cosmos. A portion of the commentaries from the *I Ching*[10] or "Book of Changes," says that

> The character of the great man is identical to that of Heaven and Earth; his brilliance is identical with that of the sun and the moon; his order is identical with that of the four seasons, and his good and evil fortunes are identical with those of spiritual beings.

The astronomers' predictive power was thus essential to the empire's stability. The predictive techniques were codified several times, and they were not error free. By Han times, the rules of the game usually eliminated unpredicted events because of three factors. First, a prediction of an eclipse that did not occur was not considered a failure. In this sense, the official predictions were *eclipse warnings* only. Second, an eclipse could occur 5 or 6, or even 11 to 12, months off, and the prediction would still be considered a success. At the beginning of the Christian era, Han astronomers were making extensive use of the equation of 23 eclipse syzygies

[10] A compilation of ancient sources from various periods, beginning, according to tradition in the reign of King Wen, the Chou ruler contemporary with the end of the Shang dynasty. Both Confucianists and Taoists treasured it. The text quoted is from Chan (1963, p. 264).

with 135 lunations (3 five-month and 20 six-month eclipse intervals).[11] This relation was a guiding rule of Han astronomy. Therefore, an eclipse occurring during another eclipse season would still indicate harmony. Eclipses that were off by 1–4 or 7–10 months, however, were considered unpredicted. Finally, not every failure of the predictive theory was observed; i.e., eclipses that occurred beyond the borders of China might not have been seen. China even in ancient times was extensive, although often fragmented, but it still covered only a fraction of the Earth's circumference.[12] The accuracy expected of the official astronomers increased through time. Needham (1959, p. 422) points out that in the 13th century A.D., a private individual said that the time of an eclipse would be different from that predicted by the Astronomer Royal. The Astronomer Royal was wrong, and he and his officials "were found guilty of negligence and severely punished."

There are only about 17 solar eclipses per 135 lunations worldwide. There are, however, several *series* of eclipses proceeding during any given interval. Indeed, in a 135-lunation interval (the *Tritos*), there are *23* such series in progress. Therefore, it is possible for a Tritos-based eclipse warning system to have been put into practice. Sivin (1969, p. 49ff) points out how this could have been done.

The astronomer I-Hsing [fl. ~8th century A.D.] is known to have made calculations involving Shang and Xia eclipses (Needham/Ronan 1981, 2, pp. 194–195). Even earlier, the Astronomer Shih Shen (4th century B.C.) provided instructions for predicting eclipses based on the relative positions of the Sun and Moon, although there is evidence that sun spots were considered as potential eclipses in the making (Needham/Ronan 1981, pp. 197–198). A clear statement that the Moon comes between the Earth and Sun during solar eclipses is not seen until ~20 B.C. in *The Fundamental Ideas of the Five Classics* (*Wu Ching Thung I*) by Liu Hsiang. Nevertheless, prognostications and omens continued to be part of the astronomers' language and thought for many centuries to come.

The earliest records of eclipses occurred during Shang times, from oracle bones[13] and on tortoise shells. There have been several attempts to date the dynasty by the mention of lunar eclipses and solar eclipses on particular days of the 60-day cycle, in determinable reigns and sometimes in specified months. In §12, we point out that the probability is high that eclipse cycles were first recognized by observing lunar eclipses. The discovery that related cycles determined solar eclipses was a later phenomenon. In the case of the Shang, it is notable that we have a 1st series of five or six lunar eclipses attested under the emperor Wu Ting and that solar eclipses (six have been noted) are 1st mentioned about five generations later. Because there are inconsistencies in the chronology of the Chou (Zhou) dynasty before 841 B.C., the precise nature of the chronological relationship of the Chou and Shang dynasties is strongly disputed. We thus have a "floating chronology" that can be placed in real time at several different points. The problem of "clock error," the quantity ΔT of §4.5, makes it very difficult to be sure which eclipses are relevant. Alternative possibilities for five lunar eclipses are considered by Chang (1980, pp. 324–328). The descriptions seem to imply that the king (or other diviner) was forecasting the eclipses, but the forecast is phrased in terms of coming misfortune, not specified as an eclipse, until after the eclipse had occurred.

The primary assumption behind the search for eclipses to match those recorded on the oracle bones is that the records are correctly interpreted and accurate. It is also assumed that the 60-day cycle as recorded on the bones is continuous and unbroken from then to the 4th century B.C. when it is first possible to assign dates. It is assumed that lunations were tied to the tropical year in such a way that the first lunation would fall somewhere in December, January, or February (Chang 1980, p. 326). Finally, Chang assumed that the eclipse canon established by Homer Dubs, somewhat modified by Liu Pao-lin, correctly gives ancient eclipse dates.

Five inscriptions[14] mentioning eclipses are known from the reign of Wu Ting (traditionally, 59 years). Chang (1980, pp. 324–325) lists them as follows:

1. Day Jen-Shen (9) Lunar Eclipse
   Hsün. Jen-Shen, evening-night, the moon had eclipse.
2. Day Kuei-Wei (20) Lunar Eclipse
   [On day Kuei-Wei] (divined). Cheng inquired: The ensuing day Chia-Shen gives sun? That evening-night, the moon eclipsed. [on day] Chia ( ), it didn't rain.
3. Day Yi-Yu (22) Lunar Eclipse
   [On day] Kuei-Wei, divined. Cheng inquired: No ill fortune in the ensuing Hsün? Three days later, on evening-night of Yi-Yu, the moon eclipsed—[so it was] heard. In the eighth moon.
4. Day Chia-Wu (31) Lunar Eclipse
   (On day [Chi-] Ch'ou, divined. Pin inquired: The ensuing Yi [-Wei] offer wine and millet to Tsu Yi? [The King] made the prognostication and stated: "there will be misfortune: [there will not] be rain" Six days later, in the evening-night of day [Chia-] Wu, the moon eclipsed.
5. Day Keng-Shen (57) Lunar Eclipse
   [Day] Kuei-Ch'ou, divined. Inquired: No ill fortune in the ensuing hsün? The king made the prognostication and said, "There will be misfortune." Seven days later, Chi-Wei, yin. Keng-Shen, the moon eclipsed.
   Day Kuei-Hai, divined. Inquired: No ill fortune in the ensuing hsün?
   Day Kuei-Yu, divined. Inquired: No ill fortune in the ensuing hsün?
   Day Kuei-Wei, divined. Inquired: No ill fortune in the ensuing hsün? The King made the prognostication and stated "There will

[11] 23 eclipse seasons ≈ 3986.13; 135 lunations ≈ 3986.63^d; $(3 \times 148^d) + (20 \times 177^d) \approx 3984^d$.

[12] Of course, an imperial astronomer might have argued that any unexpected eclipse that occurred outside of China would not be a "failure"; indeed, that may be a problem for barbarians but not for China.

[13] One type of these records is characterized by the ideograms: *ri* (Sun) *yu shi* ("being eaten") and another is *ri yu chan* ("Sun crossed," presumably by the Moon). The character "chan," we are told, signifies the stick crossing a primitive loom, connoting the crossing of threads in the weaving process.

[14] The numbers in parentheses following the day names indicate their positions in the 60-day cycle. The term *hsün* refers to a 10-day week. The day *Ping-wu* may be an error for *Ping-shu*, the day that follows *Yi-yu*. The reference to the 13th month has been interpreted as referring to the eclipse on *Keng-shen*, but may refer to *Ping-shu*.

be misfortune". Three days later, day Yi-Yu, evening night, yin. Day Ping-Wu, indeed came, entered into the teeth.
The thirteenth month.

The exact dates of acceptable lunar eclipses depend partly on the time when the days began. The most probable times are daybreak and midnight. A midnight beginning is implicit in the double hour system but that is not directly attested until much later.

Unfortunately, there is no set of five lunar eclipses that matches all of the assumed constraints within any archeologically reasonable time frame, and indeed, all of the assumptions may be challenged. We have already suggested that the 360-day (or 6×60) count during the Shang dynasty might not have been continuous with the later count and that differing calculations of clock error introduce doubt into the modern astronomical calculations. If we knew definitely how the 360-day count was calculated at that time, it may provide alternative possibilities.

The usually reliable Ssuma Chhien (Sima Qian) has an extremely garbled account of lunar eclipse prediction (Walters 1992, p. 219). One can only suppose miscopying of the numbers during later transcriptions.

Unlike the generalized predictions of "misfortune" shortly preceding lunar eclipses, one oracle bone gives a specific prediction of a solar eclipse accurate to the day:

Divined on the day 'kuei-yu', a solar eclipse is to take place in the afternoon. Is everything auspicious?

Divined on the day 'kuei-yu', a solar eclipse is to take place in the afternoon. Is everything not auspicious?

Chang (1980, p. 329) gives a list of solar eclipses as calculated by Chang P'ei-yu (or Zhang Peiyu) of the Purple Mountain Observatory and discussed by Xi Zezong (1984, pp. 36–37). These (given in more detail than by K.C. Chang) are listed in Table 10.5.

It will be seen from our comments that it is unlikely that all of these dates are correct, even if the assumption of a continuous 60-day count is accepted. It is interesting that the minimum eclipse interval from Wu-shen to Yi-ssu is 177 days and from Jen-tzu to Wu-shen is 178 days. We have checked Stephenson and Houlden (1986) and find that between 1500 B.C. and 1050 B.C., they show only three cases of pairs of eclipses separated by only 177 days in their map area and only two cases of eclipses separated by 178 days. There is also a major problem in the dates indicated by the 60-day cycle. All eclipse identifications that we have mentioned show a consistent pattern using the 60-day cycle that is congruent with the modern 60-day cycle. However, according to Needham (1959, p. 407, fn. e), a beginning day of the sexagenary cycle was the day of the new moon at the winter solstice in a calendar of –366/–370. Goldstine (1973) shows that new moon and winter solstice coincided in –370 on 25 December (J.D. 1586274). If this is regarded as the zero date for backdirected calculations, all of the dates we have been considering are off by 16 days. Thus, the lunar eclipse of J.D. 1290392, 25 Nov. –1180 is said to have fallen on *Yi-yu*, day 22 of the cycle. If one subtracts this J.D. from 1586274, one gets 295882 days. Divided by 60, there is a remainder of 22 days to be subtracted from the zero date, giving day 38, not day 22.

If the highly specific correspondences in Needham's source (the *Chuan hsü* calendar) are correct, then there has been a shift between that date and the earliest attestation of the modern system. It seems to us more likely that Shang eclipses would agree with the cycle as recorded in the 4th century B.C. rather than with the later system, if there was continuity.

The repetitions of these eclipse pairs are, themselves, in a cycle of 19756 days (the *triple saros* cycle—see §5.2.2 and Table 5.4). By a curious coincidence, this cycle has a remainder of 16 days over the sexagenary cycle, so that the sexagenary positions in the modern cycle of one pair of eclipses are identical with the sexagenary positions of the next pair of eclipses based on the –370 position. It is noteworthy that the days of the attested eclipses on *Wu-shen* and *Yi-ssu*, which led to an investigation of this possibility, are the days of the eclipses in –1305 and –1304 (1306 and 1305 B.C., respectively) in the conventional sexagenary cycle and are the days of the eclipses in –1251 and –1250 (1252 and 1251 B.C.) in the cycle based on the 4th-century B.C. data. Each of the two variations also picks up one other attested eclipse name—*Keng-chen* for the eclipse of –1197 (in agreement with Chang P'ei-yu) in the conventional cycle and *Kuei-yu* for the eclipse of –1116 (1117 B.C.) in the other cycle. We think that these eclipse identifications are reasonable alternatives to previous suggestions.

One of the oracle bones refers to a "great new star" near Antares, which has been interpreted as a nova (Needham 1959, p. 424, who reproduces the original text). The Shang astronomers also describe a solar corona as "three flames ate up the sun" (Needham 1959, p. 423).

A poem, plausibly attributed to the time when the Chou dynasty replaced the Shang, shows the use of a fixed star to determine the proper time to start building the palace of the ruler and that the houses of the commoners were supposed

TABLE 10.5. Calculated Shang solar eclipses.

J.D.N.	Julian date	Year B.C. (ast.)	Cyclical date	Remarks
1284147	21 Oct.	1198 (–1197)	Keng-ch'en (17)	S. of Anyang
1291618	4 Apr.	1177 (–1176)	Jen-tzu (49)	Not in S. and H.
1292120	19 Aug.	1176 (–1175)	Kuei-yu (10)	Central, Anyang
1293507	6 June	1172 (–1171)	Hsin-ssu[a] (18)	E. of Taiwan, S and H
1297495	7 May	1161 (–1160)	Wu-shen (45)	Not in S and H
1297672	31 Oct.	1161 (–1160)	Yi-ssu[a] (42)	E. of Japan, S and H

[a] *ssu* wrongly appears as *chi* in the K.C. Chang list.

Table 10.6. Selected Chinese asterisms.

Constellation location	Asterism	Translation
Auriga	We chhê (Wuche)	The five chariots
Boötes	Hsüan ko (Xuan ge)	The sombre axe
Canis Major	Hien lang	Sirius (wolf of heaven)
Capricorn	Niu	Ox
Centaurus	Nan men	Southern Gate
Corona Australis	Pi (Bi)	Tortoise
Corona Borealis	Kuan so (Guan suo)	A coiled thing
Leo	Hsüan yuan (xuan yuan)	Dragon backbone (parts of Imp. chariot)
Orion	Shen	Mythological figure (warrior chief)
Scorpius	Fang	Room (dragon breast)
	Hsin (Xin)	Heart
	Wei	Tail
Ursa Major	Pei tou (Beidou)	Northern Dipper, bowl of dipper
	Khuei	Chiefs (handle)
	Piao (Biao)	The spoon

to be aligned in some way with the sun (Chang 1980, p. 160, ff. Waley 1960):

> The ting-star is in the middle of the sky;
> we begin to build the palace at Ch'u
> Orientating them by the rays of the sun,
> we set to work on the houses at Ch'u.

10.1.2.3. Chinese Constellations and Asterisms

Table 10.6, based on Needham (1981), lists Chinese asterisms among selected western constellations. A more extensive list of Chinese constellations may be found in Yi et al. (1986), and a series of charts with Chinese constellations superimposed on modern constellation boundaries is given in Ho (1962). The *xiu* (or *xius*) are compared with the *nakshatra* of India and the Arabian *menazil* in §15. These asterisms are markers of the Moon's motion during the sidereal month. The Chinese *xiu* are located neither on the ecliptic nor on the orbit of the Moon, but as a group are closer to the celestial equator. That they do not coincide exactly with the celestial equator could be considered both as evidence, first, that all were not intended to be on the celestial equator but merely served as markers of equatorial positions and, second, of the great antiquity of the *xiu* system due to precessional changes in equatorial coordinates, as we discussed earlier.

Stephenson (1994) has written a wide-ranging and critical summary of what is known about Chinese and Korean asterisms, star catalogs, and star maps. This incorporates a great deal of archeologically recovered information updating and largely replacing Needham in these categories. There is, however, minimal consideration of the mythology or traditions associated with the asterisms.

The supernatural figures associated with the xiu from the time of the Tang dynasty are shown in Figure 10.4. Other examples of Tang representations of the Xiu can be seen in "magic mirrors," shown in Figures 10.5 and 10.6.

In 1978, the excavation of the tomb of Marquis Yi of Zeng provided important material (Stephenson 1994, pp. 519–520; Xi 1984, p. 41). An engraving on a large bell showed his importance: It was given to the Marquis by the king of Chu, one of the "Warring States" in 433 B.C. The tomb goods contained a lacquered box cover bearing the names of 28 *xiu*, arranged around a large character (*dou*) signifying the Northern Dipper (*Beidou*, or *Pei-Tou*), our Big Dipper. Thus far, this is the earliest such record of the complete list of *Xiu*s from China. Flanking the *xiu* are depictions of a green dragon and a white tiger, two of the four directional animals ruling the four palaces and associated with the four seasons. The names of the *xius* show some interesting variations from those previously known. Among other differences, *Mao*, the name of the Pleiades is written with the characters for *Mao*, "lance," and the name of *Kuei/Guei*, usually written with characters read "astride" is, instead, written with the characters for *Guei*, "jade sighting tube." This is particularly interesting, because the next lunar mansion is *Pi* and according to the Han-dynasty book *Yüeh Ling*, in the second month (during which the equinox occurred and weights and measures were checked) instead of animal sacrifices, there were sacrifice of the jade "ornaments" *Kuei* and *Pi* (Walters 1992, pp. 166–167). From the Han dynasty on, Chinese constellations are usually depicted in the ball-and-link convention, an example of which is seen in Figure 10.7.

The greatest historian of ancient China was Ssuma Ch'ien (Sima Qian) (163–85 B.C.), the first person known to have used chronological grids to summarize history. He was the Grand Astrologer in charge of the Bureau of Astronomy (which had 28 officials in his time), and his work includes important information on the history of astronomy in China, including a lengthy section on the interpretation of the relationships between planets and fixed stars and how they affected human affairs. The importance of this work, finished ~90 B.C., is emphasized by Needham (1959, pp. 199–200) (55 pages of Walters's book are devoted to a translation of this segment of Ssuma Ch'ien's work) (Walters 1992, pp. 16, 180–237). His role in China combines features of the roles played by Herodotus and Claudius Ptolemy in the west.

The practice of putting star maps on the ceilings of tombs is first attested in the Han period. A tomb at Xi'an (Stephenson 1994, p. 523; color photographs, Stephenson 1993, pp. 32–34) shows a concentric circle with ball-and-link diagrams of the 28 lunar asterisms, with accompanying figures—an ox, for

FIGURE 10.4. The supernatural figures associated with the 28 xiu in the *Jade Box Scriptures*. Drawings by Rea Postolowski and Sharon Hanna.

example, with the xiu called "Ox." Inside these are the sun with a crow and the moon with a rabbit, with many other figures. The associated images seem to be Daoist (Taoist).

The placing of star maps on tomb ceilings was a continuing tradition. The tomb of Yuan Yi (d. 526 A.D.) at Luoyang has a map on the ceiling showing over 300 stars, with some ball-and-link asterisms and a crudely drawn Milky Way. The Sun is red with a golden crow, and the Moon is white with a jade rabbit. The map seems to be more symbolic than realistic (Xi 1984, pp. 41–42).

Two far more realistic star maps appear on stelae in the tombs of Qian Yuanguan ruler of Wuyue (d. 941) and his wife Wu Hanyue (d. 952). They are polar projections. The "circle of constant visibility" (i.e., the region of circumpolar stars) has a radius of ~37°, and the edge of the chart is about 38° S of the equator, appropriate for a site of latitude ~53°. The equator is shown on Qian's stela. Typical errors in star placement are about 3° (Stephenson 1994, pp. 539–540).

The tomb of Zhang Shiqing, an official of the Tartar court who died in 1116 A.D., yielded depictions of both the 28 *xiu* and a Chinese adaptation of a 12-sign zodiac.[15]

The harmony of Heaven and Earth implied a reciprocity between them, and both rituals and structures were designed to replicate various aspects of Heaven. Perhaps the most striking example of this relationship may be seen in the

[15] For example, the Capricorn goat-fish is replaced by a dragon with the tail of a fish; Virgo is replaced by a male and female couple in Chinese adornment.

FIGURE 10.5. A Tang "magic mirror" shows the 28 xiu, the 8 trigrams, the 12-animal (oriental or rat zodiac) cycle, and the 4 great directional animals that also represent the seasons. Note that the animals face counterclockwise, but their positions in the sequence run clockwise. Drawing by Sharon Hanna.

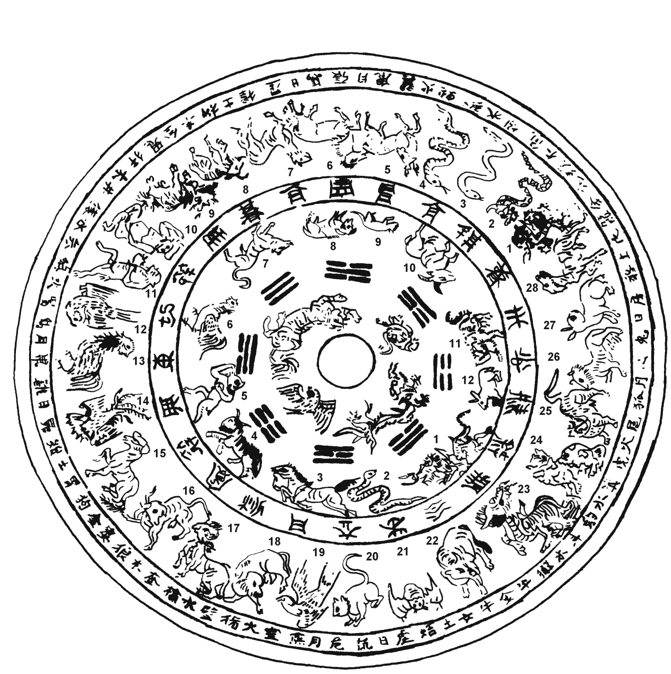

FIGURE 10.6. Another Tang "magic mirror" shows the 28 xiu as animals in a counterclockwise order, the 12-animal cycle (but here all the animals face CW), then the 8 trigrams, and again the 4 great directional animals that also represent the seasons. Drawing by Rea Postolowski and Sharon Hanna.

Han period capital city of Chang-An (or Ch'ang-an, Chang'an, now Xi'an). The region of Ursa Major was clearly conceptualized as the center of the celestial empire. During the Han Dynasty, this image was brought to earth and the walls of Chang-An became a large-scale celestial map. The northern wall was essentially a grand map of the Big Dipper (*Bei-dou*, "Northern Dipper"), whereas the southern wall represented the "Southern Dipper" (*nan-dou*) in Sagittarius. The eastern wall is aligned due north and demonstrates that β UMa (Merak) and α UMa (Dubhe) were already being used as pointers to the north celestial pole at the time of the construction (194–190 B.C.). See Figure 10.8.

The fixed stars are organized into three compounds or "walls," the 28 lunar mansions, and the "magistrates," which are stars of the center and "exterior" regions, presumably those beyond the walls. The enclosures are called the *Tzu-Wei Yüan*, *Tai-Wei Yüan*, and the *T'ien Shih-Yüan*. Text accompanying the *Soochow* or *Suchow* (in Pinyin, *Suzhou*) star chart (see Figure 10.7) carefully explains that the central "official" stars symbolize the counselors, feudal princes, the nine ministers, the cavalry, and the imperial guard of the imperial court; in the "country," they symbolize animals such as the cock, dog, wolf, fish, tortoise, the turtle (presumably, the more aquatic component of the family), and so on (Rufus and Tien 1945, p. 5). It is noted that these fixed stars rotate uniformly with Heaven, remaining in their places, "just as in the case of the numerous classes of officials and myriads of common people, each one minds his own affairs and obeys the orders of the Seven Directors." A warning is issued about departures from the established order, concluding with the phrase "just as a shadow (follows the body) or an echo (responds to a sound), so prognostications may be deduced from these appearances and events may be foretold." The circumpolar stars had important functions: they served as indicators of the *xiu*, whether invisible or not. The *xiu*, in turn, provided markers of the Moon's location with respect to the stars, whereas the phases of the Moon located the Sun and helped in regulating the seasons (the full Moon appears to have been the most useful in this regard, because its appearance indicated the relatively precise position of the Sun in direct opposite part of the sky). Within constellations, the position of a star was given in terms of two equatorial coordinates similar to right ascension and declination (see §2.2.3). The 1st coordinate gave the location along the celestial equator, eastward in terms of *du*[16] from a reference star associated with one of the *xiu*. The number of *du* from the north celestial pole gave the 2nd coordinate, similar to an antideclination $(90 - \delta)$.

As far as we know, the first Chinese star catalog was produced by Shi Shen and similar work was done by his contemporary Kan-te (Gan-de) in the 4th century B.C. Although no full early copy of the catalog survives, it gave the equatorial coordinates of 121 stars (six names have been lost in copying). Needham thought that some of the stars represented observations of the 4th century B.C., whereas others derived from corrections in the 2nd century A.D. The catalog

[16] There were $365\frac{1}{4}$ *du* in a complete circle, approximating western *degrees*. The mean motion of the sun is thus 1 *du*/day.

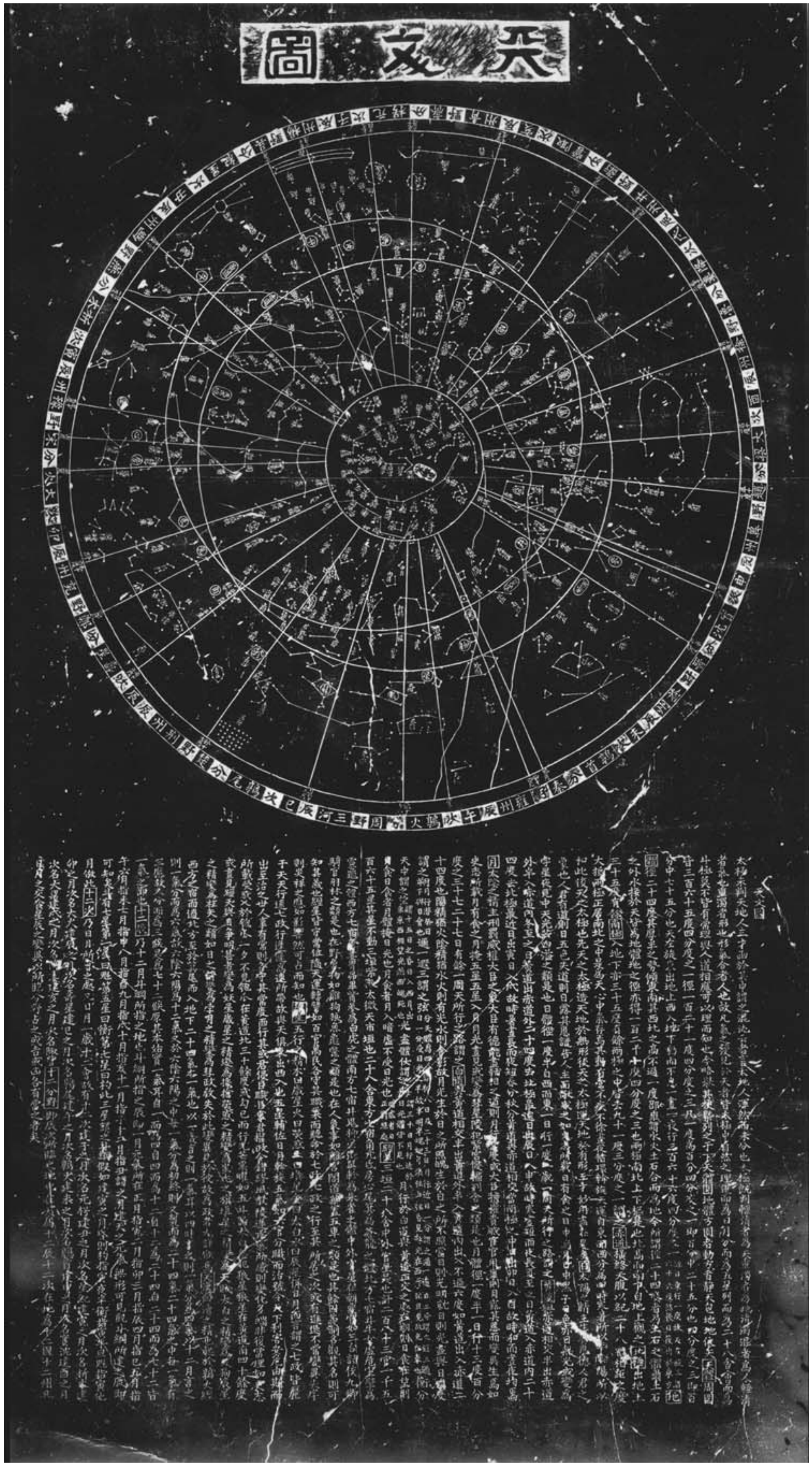

FIGURE 10.7. The *Suchow* planisphere from the southern Sung Dynasty, 1193 A.D., created for the instruction of a future emperor: Note the ball-and-link convention to identify constellations. The celestial equator is the circle equidistant from the north celestial pole. Also shown are the ecliptic, the lunar mansions, and the Milky Way. Photographic print obtained from J. Greene-Smith and reproduced here, with permission.

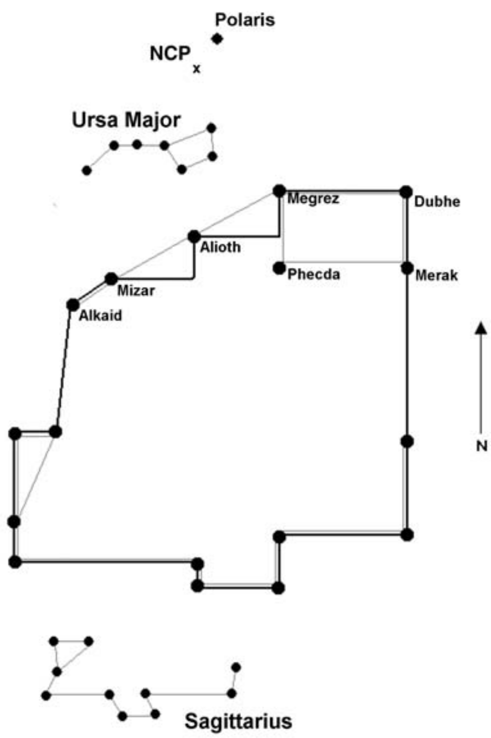

FIGURE 10.8. A map of the walls of the Chinese imperial city Chang-An. Drawing by Sharon Hanna, modified by E.F. Milone.

was apparently produced with the help of an armillary sphere (Needham 1959, p. 197) (Shuren 1983, pp. 15–17). Stephenson (1994, pp. 518–519) points out that recent work has shown that the stellar coordinates in the existing copies of the catalog belong to about 70 B.C. and that the attribution to Shi Shen is incorrect, although it is possible that Shi Shen prepared a catalog that was corrected in the 1st century B.C.

We do not know the date of first appearance of star maps, but they were in use in Han times. About 130 A.D., Ma Hsu mentioned 783 stars grouped in 118 asterisms. Chen Zhou (Chhen Cho) of the kingdom of Wu made a map in 310 A.D. with 1465 stars in 283 asterisms. A famous map discovered at Dunhuang (or Tun-huang[17]) shows over 1350 stars; it is apparently copied from an earlier map. Chang Heng of the 2nd century A.D. mentioned 2500 bright stars and 11520 "very small stars" (Needham 1959, pp. 264–265). In about 725 A.D., I Hsing (Yixing) found that over 10 stars from ancient maps showed a north-south movement relative to the ecliptic, although it is not clear whether this was a genuinely astronomical effect (proper motion? See §3.1.7, §10.1.6) or due to errors of observation or manuscript transmission in his sources (Needham 1959, p. 271).

The most extensive commentary on Chinese asterisms, accompanied by identifications of the individual stars, is that of Schlegel (1875)—valuable for its analyses of beliefs and stories connected with the stars. Schlegel maintained that the internal structure of the names and inferred changes in equinoctial and solstitial positions only made sense if there had been a developed Chinese imperial civilization with a full bronze age technology, including war chariots, before 15,000 B.C. This view was utterly unrealistic even in 1875 and is contrary to the massive archeological data that have accumulated since. However, in 1984, Julius Staal, F.R.A.S., published an English summary of Schlegel's descriptions, with some additions from other sources (largely unspecified). This is not as scholarly as Schlegel's work but is better organized and makes Schlegel's ideas and data more accessible than they are in the original. Although Staal cites Saussure and Needham, he prefers Schlegel's interpretations; this preference is incomprehensible to us. Staal describes 185 asterisms, and identifies the component stars, and lists nearly 600 names for them. He gives a useful star map with the Chinese names, unfortunately based on a planetarium reconstruction of 15,600 B.C.! The names make it abundantly clear how different Chinese nomenclature was from that of other areas. We have made a rough estimate of categories of names, eliminating near synonyms, but keeping other variants. The most common category (about 150 names) is that of things made or built by humans: roads, walls, temples, houses, barns, chariots, watercraft, sword and sickle, and flags and drums. Over 100 asterisms were named for members of the imperial family, bureacrats, and military officers. Fewer than 10 were named for lesser mortals: cowherd, weaving girl, flute player. Twelve states gave their names to asterisms. Aside from these items, a small number of asterisms were named for natural phenomena: green hills, rivers, ponds, thunder, lightning, clouds and rain, and fire—strikingly, Sun and Moon are each identified as fixed stars on the ecliptic separated by 180°; finally, there are a couple of plants and about 15 animals from dragons to bees. Any meaningful similarities to identifications of asterisms in other cultures must be found in the smaller categories.

10.1.3. Chinese Chronology

Chinese Chronology is essentially independent of western chronology, although the 60-year Jupiter cycle in China is related to that of India. Apparently, the 60-year cycle was not in general use until the 2nd century A.D., but already at ~100 B.C., Sima Qian (Ssuma Chien) was complaining that the "cycle of the elements" (correlated with the Ten Stems) was out of step with the reign lengths of various rulers.

General agreement in Chinese sources starts with the expulsion of the Western Zhou emperor Li in 841 B.C. (Chang 1905/1967, p. 40). Chang assigns 37 years of reign to Li and 16 years to his father, the emperor I (Yi). The first year of I's reign was marked by the "double dawn," apparently a sunrise eclipse at Tcheng (see §5.2.1.3). This eclipse has been equated with eclipses at 966, 926, 919, 903, and 899 B.C., but none seems entirely satisfactory. Because the traditional account, perhaps wrongly, assigns 53 years to the reigns of I and Li (a long interval for two reigns), it would seem that dates later than 899 B.C. should also be examined.

[17] In western Kansu in far northwestern China.

10.1.4. The Purposes of Chinese Astronomy

The Han dynasty was the 1st to establish imperial rule over a political entity roughly comparable to modern China. It is only from this time that we can discern the establishment of the main outlines of Chinese astronomical and cosmological thinking. According to Sivin (1969), the success of Chinese astronomy as a predictive science owes much to its divorce from traditionalist cosmologies, which, as in the west, tended to restrict experimentation and rethinking. The predictive science in itself was not part of a deductive scheme, except insofar as it occasionally required expedient correctives.

Our knowledge of the astronomy of the period has been considerably increased by the discovery of the burial of a man named Li, the son of the 1st Marquis of Yi in 168 B.C. at Mawandui (or Ma-Wang-tui), Ch'ang-sha, Hunan, with 20 silk books. These included *Classics on Stars*, which incorporated the writings of the astronomers Gan De (or Kan-te) in his *Astronomy*, and Shi Shen (*Astrological Astronomy* or perhaps *Astronomical Astrology*), written between ~370 and 270 B.C. However, this version of *Classics on Stars* contained a study of the movements of Jupiter from 246 B.C. to 178 B.C., contemporary with Li. The book gives the synodic and sidereal periods of the planets and contains a catalog of the shapes of comets. The synodic period and sidereal periods for Jupiter are given as 395 105/240 = 395.438 days, and 12 years, respectively; the corresponding numbers for Saturn are 377 days and 30 years, respectively. The configuration information provided for the planet Venus is that it is a visible morning star for 224 days, invisible for 120 days, an evening star for 224 days, and "hides away" for 16 96/240 days = 16.400 days. These values can be compared with the modern values given in §2.4.4 and Table 2.9. Mention is also made of a pre-Han armillary sphere (Ng 1987; Xi 1984, pp. 38–39; Sivin 1981).

Chinese astronomers had several tasks:

(1) to keep track of the calendar; and, related by,
(2) to observe the periodicities of heaven;
(3) to predict eclipses; and
(4) to record the astrological omens—such as unpredicted eclipses and "guest stars," both those with tails (comets) and those without (usually novae and supernovae).

Why were these important? Astronomy in China was driven to provide precision in the timing of events because the political realm had to be in rhythm with the natural one. This is clear from many inscriptions and records, such as the the "instructions" for future emperors drawn up during the Sung Dynasty (see §10.1.7).

10.1.4.1. Chinese Time-Keeping and Calendar

According to Eberhard (1983/1986, p. 54), the calendar was probably lunar originally because many festivals and holidays are connected with the phases of the Moon, and a lunar calendar was used into modern times. A major lunar festival began on the 15th day (always a full moon) of the 8th month of the old calendar. By Xia times, we have already mentioned evidence for the existence of sidereal markers, thus suggesting a mixed calendrical system even at that early time. But the seasons demanded attention to the Sun's movements, hence, the need for accurate measurements, and thus, observatories such as the solar meridian tower near Luoyang (Wade-Giles: Loyang) (see §3.3). Equal double hours, 12 to the day, were used in ancient China.

The reconciliation of lunar and solar motions occupied the attention of Chinese as it did European astronomers. The Chinese name for the Metonic cycle was the *chang*, an interval of 235 lunar synodic months, which was approximately equal to 19 tropical years (see §4.2.1). In the west, the Callippic cycle consisted of four Metonic cycles; the corresponding cycle in China was called *pu* (76^y Julian years). Other intervals were in use as well: A *hui*, an eclipse interval of very nearly 513 years, was equal to 27 *chang*. Three *hui* in turn made up a *thung*, ~1539 years, and 3 *thung* (~4617 years) was the shortest interval for reconciliation of these cycles and a 60-day sexagenary cycle. In addition, 20 *pu* = 1 *chi* (or *sui*) = (~1520^y), 3 *chi* = 1 *shou*, and, according to one Han source,[18] 7 *shou* = 1 *chi* (~$31{,}920^y$). After this interval, the same source says that all things will end and return to their "original state." This is equal to four Julian cycles of 7980 years each. The Julian cycle was invented, independently presumably, by Joseph Scaliger in the 16th century. The concept of a grand cycle of ages was widely held throughout the world. Liu Hsin (46 B.C.–A.D. 23) used an era base of 143,231 B.C. (Chang 1980, pp. 16–17). In the Han dynasty, it was supposed that the planetary cycles repeated every 138,240 years. When this was combined with the three-thung cycle of 4617 years, the result was a "world-cycle" of 23,639,040 years (Needham 1959, p. 408).

10.1.4.2. Lunar and Planetary Observation

Needham (1959, p. 392) states that native Chinese astronomy never attempted an advanced analysis of the lunar motions, but the results of Chinese studies of the Moon are impressive nevertheless. Although Needham asserts that the synodic month has been determined to be $29^d.53$ from oracle bones of the 14th century B.C., we think this determination (and the assigned date for the oracle bones allegedly containing the data) highly uncertain. However, by 237 A.D., Yang Wei provided the value $29^d.530598$, and later determinations brought this to $29^d.530591$ (compared with the modern value of $29^d.530588$) by 463 A.D. The departure of the Moon from the ecliptic and the variation of the Moon's orbital speed was recognized by the astronomer Shih Shen [fl. ~371—~340 B.C.]. The effect of the advance of the Moon's line of apsides is provided in the graphical "Nine Roads of the Moon," first mentioned by Liu Xiang [~11 B.C.]. Needham (1959, pp. 392–393) states that these "roads" were originally assigned the colors green, white, red, and black. Because the period of apsidal motion is $3232^d.575 \approx 8^y.85$, they essentially demonstrate the annual change in the orientation of the elliptical orbit among the background stars.

The regulation of seasons involved the planets as well as the Sun, because of near-commensurabilities among the

[18] The *Chou Pei Suan Ching*, "Arithmetical Classic of the Gnomon and the Circular Paths of Heaven" (Needham 1959, pp. 406–407; Ronan/Needham 1981, p. 193).

Table 10.7. Planetary associations.

Planet	Title	Direction	Element	Purpose
Jupiter	Sui-Hsing (Year Star)	East	Wood	Year regulation
Mars	Ying-Huo (Glitterer)	South	Fire	—
Saturn	T'ien-Hsing (Filler)	Center	Earth	Filling the country[a]
Venus	T'ai-Pai (Great White)	West	Metal	Day regulation
Mercury	Ch'en-Hsing (Hour Star)	North	Water	Hour regulation

[a] Or "filling the lunar mansions"; the Chinese "sidereal" period for Saturn (the time to return to the same position in the sky) was 28^y, thus, in their view, spending an average of ~1 year in each mansion.

Table 10.8. Color–asterism associations.

Color	Direction	Element	Asterism	Lunar Mansions
Blue	East	Wood	Blue Dragon	Jiao, Kang, Di, Fang, Xin, Wei, Ji
Black	North	Water	Black Warrior[a]	Dou, Niu, Nü, Xu, Wei, Shi, Pi
White	West	Metal	White Tiger	Kui, Lou, Wei, Mao, Bi, Zi, Shen
Red	South	Fire	Red Bird	Jing, Gui, Liu, Xing, Zhang, I, Chen
Yellow	Center	Earth	—	—

[a] Also known as "Spirit Tortoise."

planets, as noted in §2.4.4. Thus, Jupiter could be described as "the Year Star," because it moves about 1/12 of its sidereal period, equivalent to a zodiacal sign, in a year. Five sidereal-period intervals is a 60-year cycle. From one of Li's silk books, we find that at spring equinox, Jupiter "stays" in *lou*; at summer solstice, in *jing*; at autumnal equinox, in *kang*; and at winter solstice, in *niu*, these lunar mansions also are the locations of the Sun at the equinoxes and solstices. Because Jupiter's sojourn in each of the mansions lasts ~12/28 years, on average, the significance of the statement may have something to do with the orbital inclination of Jupiter, the lowest of the naked-eye planets. Although one can belabor periodicities and cyclicities, the near-commensurabilities between Jupiter and Saturn, and the triple conjunction of Mars, Jupiter, and Saturn, for example, appear to have been significant for Chinese astronomy. The apparent motion of Mercury with its retrograde motion is shown in Needham (1959, Fig. 181, p. 400). Although the figure is from a 1726 book, the terms noted on the figure are from the *Chin Shu* (635 A.D.).

The planets are described as the "essences" of the five elements. The association between elements and the planets in Han times is shown in Table 10.7. The planets are said to assist the Sun and Moon to regulate the five "emanations": rain, sunshine, wind, heat, and cold, "just as the six ministries have their own duties and issue orders, so, throughout the whole empire, prosperity or adversity, peace or peril, comes thereby." The text goes on to press home the point:

> During the periods of good government all human affairs are well regulated, and at those times the Seven Directors move with regular constancy. But, if it happens that the emperor interferes with the office of the ministers or the latter usurps the imperial power, the political administration falls into confusion and error, morals and precepts become perverted, also the malign influences change strangely and behave irregularly.

The text then gives examples: Mars disappeared in *P'ao-Kua* and was invisible all night, even though that asterism was more than 30° North of the Yellow Road; once it went "zigzag" in the direction of *Ssu*, its rays "as wide as a five-bushel measure." Once Venus "suddenly ran into *Lang-Hsing* (Wolf Star, Sirius), although it is more than 40° S of the Yellow Road." On some occasions, it goes on to say, the planets changed into "phantom stars" (evil omens), such as Jupiter changing into a comet of the class *Ch'an Ch'iang* ("confusion") or Venus turning into a meteor of the class *T'ien-Kou* ("celestial dog"), and so on:

> Thus when the official orders are unable to maintain quiet, these strange appearances predominate, and the governing officials should pay great heed to these phenomena.

The antiquity of the planetary associations listed in Table 10.7 are supported by details from one of Li's silk books from tomb Mawandui No. 3, dated to 168 B.C., and referred to earlier. We next discuss the associations among colors, seasons, and astronomical objects.

10.1.5. Associations with Heaven and Earth

The associations of colors and directions is common in many areas of the world, including Mesopotamia and Mesoamerica, but in China, we have a strong, continuing tradition, and abundant literature to document the degree to which the various associations of directions and colors with all aspects of life were carried. Table 10.8 summarizes the associations among colors, directions, elements, and major directional asterisms that are made of seven lunar mansions each.

Needham (1956, pp. 262–263) gives an elaborate table that shows the desire of Han philosophers and scientists to group all possible phenomena into five classes and to correlate those classes. Such classes were created for animals, grains, places of sacrifice, musical notes (in the pentatonic scale), tastes, smells, numbers, bureaucratic ministries, various sorts of instruments, and many other sets. Thus, the seven eastern mansions compose the body of the Blue Dragon, the seven

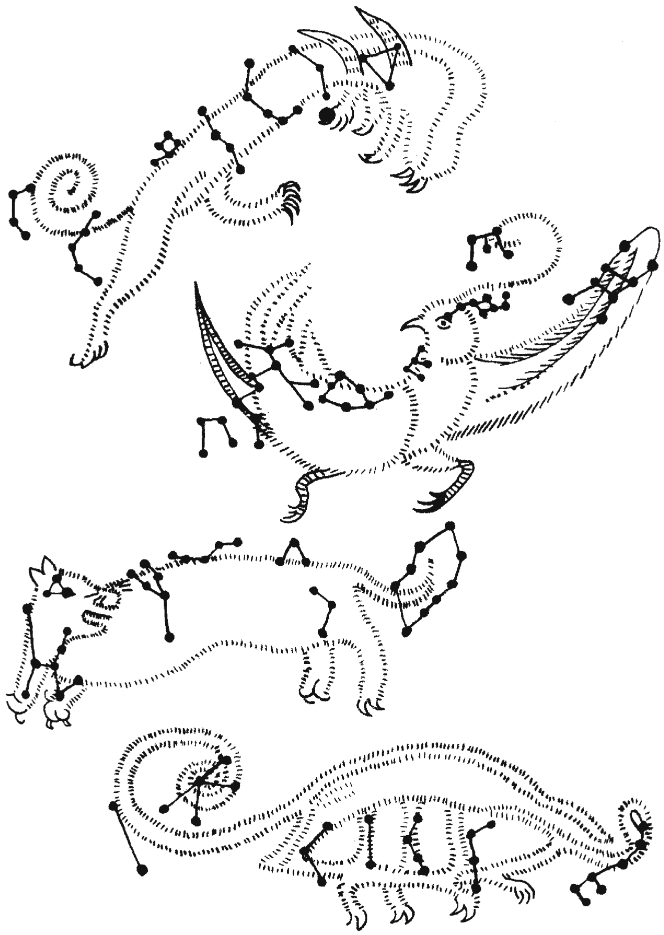

FIGURE 10.9. The four directional animals represent divisions of the year as asterisms. Drawings by Sharon Hanna.

northern mansions are the body of the Spirit Tortoise, the seven western mansions are that of the White Tiger, and the seven southern mansions make up the Red Bird. In mythology, the directional animal of the north emerges after a flood, a property better associated with a turtle rather than the nonaquatic tortoise. Figure 10.9 shows the four directional animals that represent divisions of the year as asterisms, each containing seven lunar mansions. In §10.3, we describe a Japanese version.

The turtle is a major figure in the astronomy and cosmology of China. It is normally depicted with an intertwining serpent and is associated with the 3×3 magic square. Other Chinese turtle images are discussed in §15.3.2.1.

Of associations generally, one can say that there are many levels of symbolism, and symbols may be "formal," as the concept for reason or principle, *dao*, which has analogs in nature, as a "way" constructed in a muddy field so that "order" could be restored; or they may be "phonetic," as in the word for good luck, *fu*, which is also the word for bat, which symbolizes good luck. Associations of ideas with symbols are also common. For example, the concept of change is epitomized by the eight trigrams (*gua*), which may have been originated in the Chou (Zhou) dynasty (~1050 B.C.). The *Book of Changes* is based on them. Each trigram consists of three lines, which may be broken (female) or unbroken (male), and symbolize heaven, earth, water, fire, moisture, wind, thunder, and mountain. The number of combinations of two types, taken in groups of three, is $2^3 = 8$. The superposition of any two trigrams gives a total number of possible combinations of $8^2 = 64$. The 64 hexagrams thus contain an array of conditions and events; the *Yi-jing* oracle book describes the hexagrams and their meanings. The trigrams are associated with the five elements and directions in various ways. Number symbolism was greatly extended. Even numbers are considered *yin*; odd are considered *yang*. One (*yi*) is therefore masculine and is associated with the Sun or Heaven; two (*er*) is feminine and is associated with Earth, whereas three (*san*) was associated with man (*san cai*), who is between heaven and earth; four (*si*) is associated with the west, sometimes Earth, and the square, the four directions, and so on; five (*wu*) is associated with the five directions (including the middle). See Eberhard (1983/1986, p. 13) for a broad exploration of the many layers of meaning in Chinese thought, language, and religion. These associations were important in many forms of divination, including astronomy.

A *shih*, or "diviner's plate" may occasionally be found on reliefs from the Han dynasty, and actual specimens have been found in Han tombs. An astronomically more technical forerunner of these *shih* was found in a tomb dated to the Former Han Dynasty and is the earliest known artifact that shows the unequal divisions (in degrees) of the 28 *xiu*. It is illustrated in Figure 10.10.

The plate usually consisted of a square, representing the earth, and thus bearing the Earthly Branches and the directions, and surmounted by a rotating disk or semisphere representing heaven. The 28 lunar mansions are marked both on the square base and on the rotating semisphere. The divining boards are associated with games as well as divination (Needham 1959, pp. 303–306). See also the discussion in §15.

A recently discovered *shih* of the Sui Dynasty (581–681 A.D.) has the Branches and eight of the Stems both on the earth-plate and on the sky-plate (see Figure 10.11). The outermost division of the square names 36 animals, similar to that in an 18th.-century. Japanese list, the only 36-animal list previously cited by western scholars. The sketchiness of our knowledge in this area is highlighted by this new discovery, which extends our knowledge of this animal cycle by more than a millennium.

10.1.6. The Role of Buddhism

Indian influence in China was extensive from Han times on. It is hard to determine what kinds of information might have been brought by mariners and merchants, but Buddhist missionaries brought in major cosmological ideas and associated beliefs and practices. Many Buddhist texts were translated from Sanskrit into Chinese. Buddhist monks from India settled in China and established families that sometimes maintained contacts with India. Converts were numerous, and Buddhism became a major force in China from the 4th century A.D. onward.

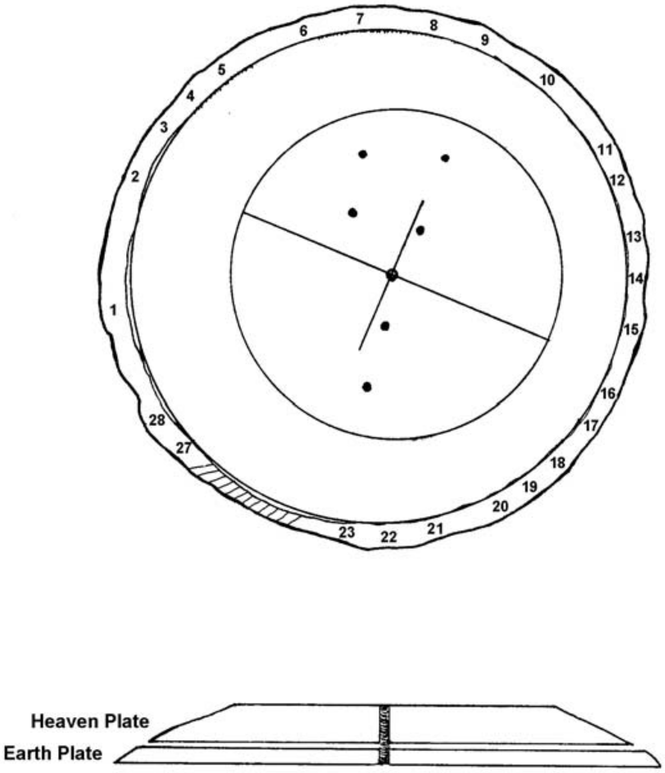

FIGURE 10.10. A forerunner of the *shih* ("Diviner's Plate") found in a Han tomb: It is the earliest known artifact that shows the unequal divisions of the 28 *xiu*. Drawing by Sharon Hanna.

In the reign of the Former Ch'in (Qin) dynasty king Fu Chien (357–384), the first of a remarkable set of finely decorated caves excavated from solid rock faces was dedicated at a scarp 10 miles (16 km) north of the oasis city of Dunhuang in western China: the Caves of the Thousand Buddhas. The Dunhuang caves were constructed where the Buddhist monk Lo Tsun saw a vision of a thousand Buddhas over three nearby mountain peaks in 366 A.D. Buddhist cosmological ideas from across the five centuries of construction are evident. Painted cave roofs center on the lotus, here held (Gray 1959, p. 36) to represent Mt. Sumeru (or Mt. Meru), the navel of the world, seen from the inside. In the paintings of the "Thousand Buddhas" (Gray 1959, Fig. 45; p. 58), rows of 19, 21, 24, and 26 Buddhas are shown on the best preserved side. Extrapolating this count to the damaged and unshown sections on the other three sides gives a more interesting total: 360 Buddhas. Other paintings depict the Sun and Moon on chariots (Gray 1959, Fig. 22a and b; p. 44). The latter is interesting because the Sun chariot is drawn by four horses and is in a Sasanian style, rather than the seven-horse chariot of Surya. Another painting is revealing in a different way. The previous Buddha Prabhūtaratna is depicted sharing his throne with Gautama (see §9.1.1.2 for a general discussion of Buddhism and of the Seven Buddhas in particular). Prabhūtaratna is said to have thrown open his jewel-encrusted stupa and to have invited Gautama to join him. Together, they appeared amid the jewels as "meteors in the sky" (Gray 1959, p. 18, citing *Saddharma Pundarīka*, tr. H. Kern 1884, pp. 236–237). Similar caves are also found at Lung Men (near Loyang) in Honan as well as at Yun-Kang. In 1900, a great Buddhist library was found preserved at Dunhuang; it had been walled up around ~1035 A.D. to protect it from Tibetan marauders.

One of the most noted of the medieval Chinese astronomers was the Buddhist monk, I Hsing (or Yixing, 682–747 A.D.). His possible discovery of proper motion, 1000 years before Halley, has been mentioned (§3.1.7, §10.1.2). In 721, he attempted to recalculate the dates of the Xia (Hsia) and Shang dynasties using improved eclipse parameters. His 11-year change from the calculations of the Han astronomer, Liu Hsin, has been adopted by Tung Tso Pin, one of the leading modern authorities on Chinese chronology (Chang 1980, p. 17). In 725, he and his colleague Lueng Ling-tsan were the first persons to invent an escapement for a mechanical clock. Unlike other Chinese astronomers, he made an armillary sphere with ecliptically mounted sighting tubes (Needham 1959, pp. 202, 313). He was also an influential figure in introducing Indian astrological ideas to China, and one of the earliest Chinese examples of a western-type personal horoscope appears in a work he wrote about 710 A.D. (Walters 1992, p. 271). Horoscopes came with, or slightly after, the western zodiac in an Indian form. Even without the abundant literary evidence for Buddhist influences, the iconographic representations alone would be enough to indicate derivation from an Indian form of the zodiac. These zodiacs normally show Gemini as a male and female pair, the Bow for Sagittarius, the Water Pot for Aquarius, the single fish for Pisces, a series of characteristics attested in Indian culture, but not elsewhere.

Calendar experts in three families of Indian origin became important members of the Bureau of Astronomy [*Kasyapa* (in Chinese, *Chiayeh*), *Gautama* (*Chhuthan*), and *Kumara* (*Chumolo*)]. The most prominent among these scholars was

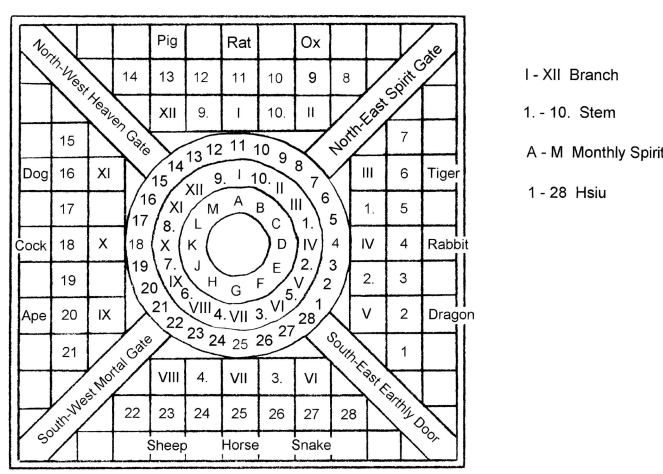

FIGURE 10.11. A recently discovered *shih* of the Sui Dynasty (581–681 A.D.) has the Branches and eight of the Stems both on the earth-plate and on the sky-plate. Drawing by Sharon Hanna.

Chhuthan Hsi-ta (Gautama Siddharta), who is the first person in China known to have used a zero symbol, in a work written in 729 A.D. (Needham 1959, pp. 202–203).

10.1.7. Instructions for New Emperors

During the southern Sung Dynasty, in 1193 A.D., a lengthy set of instructions for a new emperor, presumably Ning Tsung [1195–1224], was drawn up, containing the astronomical knowledge necessary for a successful reign. A copy engraved on a stele dating from 1247 in the Confucian temple at Suchow, Kiangsu province, is still extant and was first described in western literature by Chavannes (1913). The text contains a description of the Suchow star chart (see Figure 10.7) and contains important insights into the cosmological framework and world outlook of the China of that era.

The beginning of the text reads as follows (Rufus and Tien 1945, p. 2):

> Before the Great Absolute had unfolded itself the three primal essences, Heaven, Earth, and Man, were involved within it. This was termed original chaos because the intermingled essences had not yet separated. When the Great Absolute unfolded, the light and pure formed Heaven, the heavy and impure, Earth, and the mingled pure and impure formed Man. The light and pure constitute spirit, the heavy and impure constitute body and the union of spirit and body constitutes man.
>
> Hence, all manifestations of spirit emanate from Heaven, for a natural reason, as they are inherent in the Great Absolute. This evolves into the sun and moon, divides into the five planets, arranges in order as the twenty-eight mansions, and meets to form the directors and the circumpolar stars. All of these, being involved in the immutable reason, are also in harmony with the rational principle in Man, hence they may be interpreted by reason.
>
> Now let us consider and expound the general essentials of the subject, as follows. The body of Heaven is round and the body of the Earth is square. The round is in motion and the square is at rest. Heaven embraces Earth, and Earth complies with Heaven.

The "directors," according to the translators' note, are here the seven stars of the Big Dipper, but the term "Seven Directors" is applied to the Sun, Moon, and planets elsewhere in the text. The dipper stars are later called the "regulators of Tou" [or *Dou*, dipper]. The text goes on to describe the sky (the circumference of which is given as $365\frac{1}{4}°$), the Earth, the celestial poles,[19] the Sun, Moon, Fixed Stars, and planets, and the "roads" of heaven. The *Red Road* is midway between the poles ($91\frac{1}{3}°$) and is the Celestial Equator. It is said to produce the seasons, cause heat and cold to "equalize," and cause *Yin* and *Yang* (feminine or weak and masculine or strong natural principles) to "cooperate." The *Yellow Road* is the path of the Sun, the ecliptic, and the hours for its rise at different times of the year are stipulated.[20] The *White Road* is the Moon's path; the text indicates that the White Road crosses the Yellow Road ("half within and half without, but not more than 6 degrees, like the Yellow Road which passes 24 degrees both inside and outside the Red Road"). It is recognized that the Moon must be at the White and Yellow crossroads at new Moon in order to eclipse the Sun and that if it crosses the node at full Moon, a lunar eclipse will result. Curiously, there is no mention of the Earth's shadow: a lunar eclipse occurs when the Moon "enters into empty darkness." In addition to the roads, there is the "River of Heaven," the Milky Way. The discussion of the Sun and Moon are important for defining the role of the emperor and the prime minister, respectively (Rufus and Tien 1945, pp. 3, 4):

> The Sun is the essence of the Tai-Yang. It rules with beneficient virtue, producing life and sustaining it, and symbolizes the sovereign of mankind. When the sovereign possesses virtue, then the sun is five-colored; when he loses virtue, the sun displays his blemishes, thus reprimanding and warning him. So all sorts of phenomena are chronicled, such as an eclipse of the sun, a crow in the sun, dark spots in the sun, a red color of the sun, or a sun without light or transformed into a comet, appearing at night in the midst of Heaven with sparkling rays overflowing the four directions. . . .
>
> The Moon is the essence of Tai-Yin. It rules with stern authority, to punish and chastise, and thus symbolizes the prime minister. When this official has virtue and is able completely to fulfill the duties befitting his high office, the moon will move constantly and regularly. If he usurps power, or if the relatives-in-law of the emperor, or the eunuchs, are in power, the moon will likewise display its faults and strange phenomena will occur, like the prodigies recorded in the chronicles—such as, "The moon was eclipsed," or "The moon occulted the five planets," or "They entered the moon," or "Moonlight appeared in the daytime," or "The moon changed itself into a comet which invaded or offended the Purple Palace ('Tsu-Kung') or assailed the mansions arrayed in order," and so forth.

The five colors of the Sun may refer to the five divisions of the sky.

10.1.8. Chinese Records of "Guest Stars" and Comets

There are many Chinese records of transient events, as we noted in §5. *Kho-hsing* (Wade-Giles Romanization of "Guest stars") are usually not visible, but like certain human guests, they suddenly appear, stay for a while, and then leave. In general, the term refers to novae or supernovae, which are bright enough to command attention and were completely invisible both before and after their appearance in the sky. However, there was a type of comet, the *po-hsing* ("sparkling" comet) that was not easily distnguished from a "guest star," so that *po* may occasionally refer to a nova/supernova and "guest star" may occasionally refer to a comet (Ho 1962, p. 137). Examples are cited by Ho (1962), such as the event of 1315 A.D., in which "guest stars" turn into *hui* comets[21] ("broom stars"), or the reverse (the event of 1145 A.D.).

[19] The altitude of the northern pole is given as being more than 35° "above the earth," indicating that the instructions were drawn up for a latitude greater than 35°, near the city of Kaifeng, site of the capital between 1214 and 1267.

[20] The lengths of day (twice the hour angle of rise or set) at summer and winter solstices for selected sites are reproduced in Table 4.1 in §4.1.1.

[21] *hui-hsing*, also referred to as *sao-hsing*. Another type of comet discussed in the *Official Dynastic Histories* of Ma Tuan-Lin is *chhang-hsing* ("tailed stars"). In the Astronomical Section of the *Chin Shu*, 21 types

Among the more remarkable books describing transient phenomena is a catalog of types of comets from the Mawandui No. 3 Tomb. It lists 29 types. Needham/Ronan (1981, pp. 207–208) report that between 613 B.C. and 1621 A.D., 372 comets were recorded. In some cases, the data are so detailed that orbital computations were possible; 40 comet orbits are based on observations made prior to 1500 by Chinese sources alone. Needham (1959, **3**, pp. 430–431) cites a passage from the History of the Ming Dynasty (*Ming Shih*) to illustrate the detail [comments within round brackets are Needham's original interjections; square brackets indicate ours, with star members, Pinyin constellation names, and translations taken from Yi, Kistemaker, and Yang (1986), or from Schlegel (1875/1967)]:

In the 7th year of the Chhêng-Hua reign period (1472), in the twelfth month, on a *chia-hsü* day (in the sexagenary [60-day] cycle; [Ho (1962) gives this as Jan. 16]), a comet was seen in the star group *Thien thien* [*Tiantian*: σ, τ, 64, 78, 84, 90, 92 Vir]. It pointed toward the west. Suddenly it went to the north, touched the star "Right Conductor" [*you she ti*: η, τ, υ Boo +6 others], and swept through the *Thai Wei Yuan* (the "Enclosure" of the stars in Virgo, Coma Berenices, and Leo), touching *Shang chiang* [*dongshangjiang*: α Com], *Hsin Chhen* [HD104207 in Com],[22] *Thai Tzu* [*taizi*, "crown prince": E Leo = 93 Leo], and *Tshung kuan* [*congguan*, "page": 92 Leo].[23] Its tail now pointed directly towards the west. It swept transversely along the *Lang wei* ["seat of the general": 18 stars in Coma Berenices[24]] of the *Thai Wei Yuan* [*taiwei youyüan*, in Yi et al., "right wall of privy council"]. On a *chi-mao* day [Ho (1962) gives this as Jan. 24] its tail had greatly lengthened. It extended from east to west across the heavens. The comet then proceeded northwards, covering about 28°, touched *Thien chhiang* [*tianqiang*, "celestial battle spear": ι, θ, χ, 13, 24, 39, and 44 Boo], swept through the Great Bear [*beidou*], and passed near the *San Kung* [*sangong*, "three distinguished persons": 21, 24, and a fainter star to the south of 24 CVn] and *Thai Yang* (*taiyangshou*, "sunguard": χ UMa), finally entering the *Tzu Wei Yuan* ("Purple forbidden enclosure": circumpolar stars enclosing and ~15° of the pole). It was now perfectly visible in full daylight. At various times it was seen in the *Khuei* ["the chiefs": α, β, γ, δ UMa] (the "box" or "body" of the Great Bear) and near *Thien ti hsing* [*di*, "emperor or king": β UMi], *Shu tzu* [*shuzi*, "concubine sons": 5 UMi], *Hou fei* (b3162 UMi), *Kou chhen* [*gouchen*, "line of guards": ζ, ε, δ, α UMi],[25] *San shih* [*sanshi*, "three master instructors" ρ, σ, +2031 UMa], *Thien lao* (*tianlao*, "prison of heaven": ω, 47, 49, 56, 58, 57, 55 UMa), *Thien huang ta ti* [*Tianhuang Daidi*, "great emperor of heaven in the miniature Purple Court": ζ, ε, δ, α, "2 UMi" {HD 5848} + other stars in Cepheus; but possibly *daxing*, "big star": (α UMi)],[26] *Shang wei* (χ Cep), *Ko tao* [*gedao*, "stepped road to audience room": ο, ν, θ, ϕ, ε, ι Cas], *Wên chhang* [*Wenchang*, "prince of glorious wisdom": θ, υ, ϕ, 15, 18 UMa], *Shang thai* [*shangdai*, "high dignitarian/step": ι, κ UMa], etc. On an *I-yu* day [Ho (1962) gives this as Jan. 27] it moved to the south, touched the *hsiu* [*xiu*] *Lou* ["carve or hook of reaper": α, β, γ Ari], and passed through *Thien a* [*tian'a*, 'celestial dike': 62 Ari], *Thien yin* [*tianyin*, "celestial yin": δ, ζ, 63 Ari + 2 stars in Tau], *Wai phing* [*wai ping*, "outer fence": α, δ, ε, ζ, μ, ν Psc] and *Thien yuan* [*tianyuan*, "celestial orchard": $\nu_{1,2,3,4}$ γ, θ, κ, ϕ, χ Eri + δ Phe]. In the first month of the 8th year, on a *ping-wu* day [Ho (1962) gives this as Feb. 17], it was going toward *Wai phing* in the hsiu *Khuei*. Gradually it faded, and it was a long time before it finally disappeared.

Thus, the report is sufficently detailed that an orbit could be attempted based on the positions and the changes in position with time (Yeomans 1981), and an even more detailed description is given in the Korean annals, *Sŏngjong Sillok*.[27]

Needham (1959, pp. 431–432; Needham/Ronan, pp. 208–210) further notes that Halley's Comet was observed and described in China at least from 240 B.C. (possibly as early as 467 B.C. or even 613 B.C.). Kevin Yau (1996) and Yeomans, Weissman, and Yao (1996) indicate that the Comet Swift-Tuttle was observed in China in 69 B.C. and in 188 A.D., two of the five returns in which the comet has been observed (see Table 5.7 in §5.5).

The Chinese were the first to observe that comet tails point away from the Sun. Of course, comet tails *almost always* point away from the Sun (see §5.5); in any case, we can accept that, to present knowledge, the earliest recorded comments about the usual orientation of comets are from China. Comets were thought to originate from the planets, so that the association of comets with the Earth's atmosphere prevalent in the west was not made.

In addition to comets, novae and supernovae were also observed in number. Probably the best known record is that of the supernova of 1054 A.D., the "Crab" supernova. This object was identified in both Chinese and Japanese records as a guest star. As we note above, some objects identified as *po* could well be guest stars instead of comets, and vice-versa, but some known comets are indeed called *po* comets, and, as with the 1054 event, "guest stars" may be novae/supernovae. See Ho (1962) for a comprehensive list and discussion of Chinese, Korean, and Japanese records of both comets and novae. The *Sung Hui Yao* ("History of the Administrative Statutes of the Sung Dynasty") identified the reason for the records: prognostication (see §5.8.2). In 2001, another pulsar was identified as resulting from an historically recorded supernova event (see §5.8.5 for the importance of this event to modern astrophysics).

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of "ominous stars," which include both novae and comets, are mentioned (see Ho 1962, pp. 136–137). They include *thien-chhan* ("celestial magnolia tree"); *Chhih-Yu chhi* ("flag of Chhih-Yu"), with a red or yellow and white structure; *chu-hsing* ("candle star"); *phêng-hsing* ("tangle star") or *wang-hsing* ("king star"), which appears like a "flame in the night"); *chhang-kêng* ("long path"), like a roll of cloth splayed across the sky.

[22] Yi et al. (1986, Chart 5, 12) place the characters next to this gM4 star at V = 6.94 but do not otherwise discuss it; Schlegel (1875/1967, pp. 470, 850) identifies the asterism as *Hing-tchin*, "Officers of happiness," "No. 2629 ou No. 2 de Flamsteed." The star 2 Com = HD 104827, V = 5.87, F0IV–V.

[23] This asterism is identified as *Tsoung-koan*, "*La Suite*": 92 Leo in Schlegel (1875/1967, pp. 470, 830).

[24] This Chinese asterism, which Schlegel (1875/1967, p. 471) calls "Le Siége des Officiers," said to consist of 15 stars, contains the brightest of the Coma Cluster of stars. Yi et al. (1986, p. 37) indicate that it contains the stars 4, 9, 10, γ, 14, 16, 17, 13, 12, 21, 18, 7, 23, 26, 20, 5, 2, and a faint star near 14, 16, and 17 Com (possibly HD108642?).

[25] Neither Needham nor Schlegel include α explicitly, but "others" are indicated.

[26] Needham identifies *Thien huang ta ti* as α UMi, which, by itself, Yi et al. (1986) identify as *daxing*.

[27] Vol. 13 (14a to 14/5b), cited in Ho (1962, pp. 206–207).

10.1.9. Other Records of Transient Phenomena

Meteors and meteorites were reported from China from early times, as we noted in §5.6. There was a Chinese belief in a three-legged crow in the Sun—because the word for crow also means black, this belief may indicate an early if unrecognized reference to sunspots. Observations were made from ~69 B.C. either at sunrise or sunset, when the photosphere is dimmed by extinction of the Earth's atmosphere, or with the possible use of filters such as thin or transparent jade, mica, or rock crystal (Needham 1959, p. 436; Needham 1981a, p. 212), but Stephenson and Clark (1978, p. 91) indicate that supporting historical evidence has not been found.[28] There was a paucity of observations in the interval that coincided with the "Little Ice Age."

10.2. Korea

The Han people moved into the Korean peninsula from central Asia in the 3rd millenium B.C. The Korean language belongs to the Ural-Altaic group, which does not include Chinese. The earliest period of recorded history on the Korean peninsula is that of the Three Kingdoms, beginning ~57 B.C., with the founding of the *Silla* kingdom in southeastern Korea. The kingdom of Koguryo was founded in northern Korea in 37 B.C., in an area formerly under the control of China. The kingdom of Paekche was founded in southwestern Korea in 18 B.C. These kingdoms fought among themselves for the next 700 years. Japanese colonies were established on the peninsula at various times and places,[29] and Japan frequently attacked Silla. With Chinese help in the mid-7th century, Silla defeated the other major kingdoms and unified the peninsula. Chinese influences, including Buddhism, were strong, and the arts and sciences flourished for the next three centuries.

In 918 A.D., General Wanggon, who led a successful rebellion, was recognized by the king of Silla as ruler of a new state, near the present capitol of Seoul. In 935, the last king of Silla abdicated and Wanggon established the kingdom of Koryŏ, which lasted until 1392. During this period, the government was administered by Buddhist monks. Mongol forces invaded the country in 1231, but were finally defeated in 1364 by an army led by General Yi Tae-jo, who deposed the last Wang king in 1392. Yi's leadership was recognized by the Ming emperor of China, which called the country *Chaohsien* (Chosun). The Yi dynasty lasted until the Japanese annexation of 1910. During this interval, the influence of Buddhism was checked, and land formerly owned by the monasteries redistributed. Again, the arts and sciences, including astronomy, flourished. The Japanese invaded Chosun in 1592 but withdrew after seven years; in this interval, the Korean navy inflicted a major defeat on the Japanese fleet in Chinhai Bay, with the help of an ironclad ship, constructed in the form of a turtle. The Manchus invaded in 1627, but after forcing the king to admit Manchu sovereignty, withdrew and permitted the Koreans self-rule.

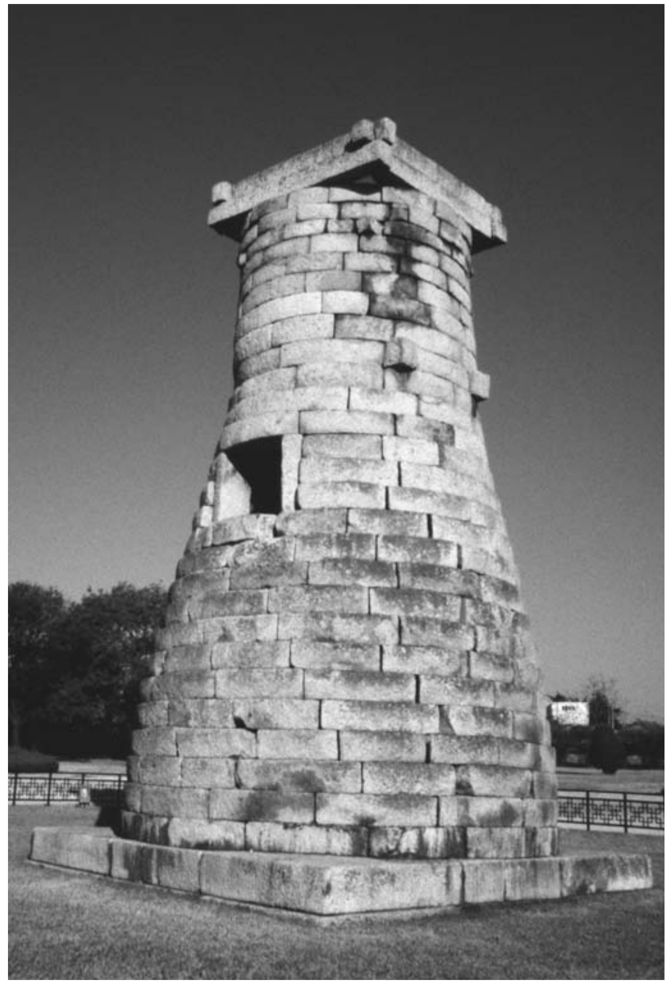

FIGURE 10.12. Champsong-dae or "Star Tower" near Kyongju in southeastern Korea, built in the 7th century during the reign of Queen Songduk of the Silla kingdom. Photo by E.F. Milone.

Royal tombs belonging to the Koryŏ period king Kongmin (r. 1330–1374) and his wife Noguk have been found near Kaesong. There are asterisms such as the Big Dipper on the ceilings and the oriental or rat zodiac on the wall (Kim and Ahn 1993, cited in Portal 2000, pp. 83–84). Portal states that the practice of painting constellations on ceilings of tombs started in the Han dynasty in China and came into use in the Koguryo kingdom of northern Korea. Near the town of Kyongju in the southeastern part of the Republic of Korea, the *Champsong-dae* or "Star Tower," built in the 7th century during the reign of Queen Songduk of the Silla kingdom, can still be seen (Figure 10.12). To the southwest, tumuli of royal graves can be seen. The tower has been assumed to have had an astronomical use; if so, it is the oldest standing observatory known.

Nha (1981) has investigated the shape, layout, and orientation of the site and finds no impediment to its having been

[28] Ronan and Needham state that a 16th-century naturalist, Li Shih-Chen, cites evidence from books about jade that some types were used to look at the Sun.

[29] Including, it is thought, a country called Karak (42–562 A.D.) centered around the present-day city of Pusan, which was eventually incorporated into the Silla kingdom.

used as an observatory. Although there is no direct evidence that the structure was indeed actually used as an observatory, the details of the structure are suggestive. The tower contains 365 stones, and there are 28 rows starting at the lower base level up to the brim, which contains two additional square sections. The 30-ft structure has one opening, midway up the tower facing south. The structure is now filled to just below the opening with earth and rock. A platform was in use at the top of the tower and reached from midlevel by stone protrusions on the inside of the tower.

As in China, astronomical records were kept, which provide records of supernovae, eclipses, comets, and meteor showers (see §5). See Ho (1962) for a list of cometary and novae/supernovae observations and a comparison of his list of comets to the catalog of Korean comets by Tamura (1958). *Koryŏ-sa, the History of the Kingdom of Koryŏ*, contains numerous records of sunspot observations during the interval 1150–1210. Stephenson and Clark (1978, pp. 97–102) plot the numbers of observations of naked-eye sunspots along with those of atmospheric phenomena and eclipses. Of special interest is their suggestion that enhanced solar activity indicative of the peak of the sunspot cycle (i.e., within ±2 years of "sunspot maxima") may have occurred during the years 1151, 1160, 1171, 1185, 1202, 1355, 1362, 1373, and 1382. They note that these "maxima," however, do not coincide with the predicted cycles of Hill (1977), a result they attribute to inadequacies of the model.

10.3. Japan

The evolution of Japan's culture proceeded differently from that of China and Korea due mainly to its relative isolation from mainland Asia, and indeed parallels have been drawn between Britain and Japan, although the latter's isolation was much greater: Japan is separated from Korea by ~185 km across the Straits of Tsushima, whereas the Straits of Dover are less than 34 km wide. Much of its early culture was therefore developed indigenously (Fairbank, Reischauer, and Craig 1989, p. 324ff). Nevertheless, Palaeolithic cultures reached Japan in at least two waves, the first of which occurred between 100 and 200 millennia ago.

The Jōmon was the earliest neolithic culture; it appeared about 11000 B.C. and was characterized by a rich and highly distinctive pottery and by mounds of shells. The Japanese neolithic started earlier than did any other neolithic culture and extended later than did most. The people were deep sea fishers and probably whale hunters who lived in pit houses. The Yayoi culture appeared in the 3rd century B.C. and over the next two centuries expanded over much of the country. These people possessed iron and bronze artifacts, pursued agriculture, developed irrigation methods, and had wheel-made pottery. Chinese coins and bronze mirrors from the Han dynasty attest to cultural links with China. In the third century A.D., funerary tumuli began to be erected by this culture, and the type of jewelry buried in them suggests a strong influence of the Silla kingdom of present-day Korea.

Among prehistoric structures with possible astronomical usage are the stone circles (actually somewhat irregular ovals of about 10-m thickness) of Nonakadō and Manza at Ōyo and similar structures at Hokkaidō and Ōmachi in Nagano. Hawkes (1974) cites an approximate date of these structures of the 1st millennium B.C. and attributes them to the late Jōmon culture, whose pottery has been excavated at the site, along with stone axes and vessels. The Nonakadō structure consists of two not-quite concentric ovals (of differing major axes), the outermost of which has dimensions ~41.5 m E-W × 38.5 m N-S. The rings have various structures: stone pillars, centered in small round cairns, and lines of stones in arcs or square patterns. At the south side of the larger oval, an incomplete (three-sided) square is located just to the west of the N-S axis, and to the east of this axis lies a pentagon with the vertex directed opposite to the center. Between the inner and outer rings, about 8 m from the center, and located ~55° west of north from the center of the ovals, is a 4.5-m standing stone surrounded by a cairn that contains elongated incumbent stones radiating from the central pillar. This configuration is surrounded by long stones extending around the circle. The structure is referred to as a "sundial," and indeed, the declination of the Sun at midsummer setting on a level western horizon would be ~24°.4. The Manza structure, located on the same high river bank, is similar, with a similarly placed "sundial," but with a slightly larger outer ring.

A stone circle near Hokkaidō is held sacred by the *Ainu*; this site too contains Jōmon pottery. The Yayoi tumuli builders erected *kofun* tombs, elaborate oblong chambers of massive, rough stone, in a keyhole design, earlier, and with a long rectangular shaft and a round chamber later, and overlayed the structure with mounds of earth. One that has been thoroughly excavated is the Ishibutai Kofun at Asukamurijima, Takaichi-gun. It was surrounded by a bank 82 m in diameter and by an inner ditch. The inner tomb dimensions are 7.7 × 3.5 × 4.7 m. Larger imperial tombs and smaller tombs belonging to nobles of various ranks are known. At this writing, as far as we know, there has been no systematic study of the astronomical significance of these structures.

Steven Renshaw and his collaborators (Renshaw 1996, private communication)[30] have created a repository of articles on aspects of ancient Japanese astronomy. Among the most relevant articles are identifications of the Japanese asterisms of the 28 lunar mansions (*sei shuku*) and their associations. Renshaw and Saori Ihara describe four "palaces," which correspond to the four seasons, each containing seven lunar "stations" or mansions. As in China, the animals and colors associated with these seasons are the Azure Dragon of the east with spring, the Red Bird of the south with summer, the White Tiger of the west with fall, and the Black Tortoise of the north with winter. The earliest reported use of these associations in Japan is at the Pine Tree Burial Mound (*Takamatsu Zuka Kofun*) dated to the 7th century A.D. The associations are rendered plausible by associated charts. The spring rains come from the east, and three of the mansions in this "palace" are in Scorpio; six of the seven

[30] See also the Japanese astronomy Web site, www2.gol.com/users/stever/jastro.html, for an attractive series of illustrated articles with star charts.

mansions constitute various parts of the Dragon. The horns of the Dragon are α and ζ Vir, for example; the heart of the Dragon consists of α, σ, and τ Sco; and the tail includes ε, η, θ, μ, λ, and ν Sco. The historical background of Japanese astronomy in particular, including its roots in Chinese astronomy, is treated extensively in S. Nakayama (1969).

One of the earliest references to Japanese calendrics is in the *Nihongi*, "Chronicles of Japan" (Engl. tr. by W.G. Aston 1896), where it is noted (pp. 68, 72) that the emperor in 533 A.D. requested Korean experts in calendar-making as well as medicine and divination. Such experts, including a professor of calendrics, did arrive, beginning the following year, from the Korean state of Paekche. And as late as 602 A.D., Korean help on astrology and calendars was still being welcomed. In 604, the traditional lunar *Hi-oke* calendar was supplanted by the Yuan Chia Li calendar, attributed to Ho Chieng-Thien [~443 A.D.] (Needham 1959, p. 391, fn d), and from then on, intercalation to achieve harmony between solar and lunar calendars would be needed. According to Nakayama (1969, p. 10), the time-keeping system of the Chinese was adopted in 628, and a water clock was constructed at this time. Chinese-style calendars were subject to several revisions between 690 and 861.

There is no mention of any working Japanese observatory until 675. Education in astrologically based astronomy and calendrics began to be regulated by the Taiho civil code of laws in 702.

Buddhist cosmology and astronomy were introduced to Japan from China as Korean influence waned. The items that came at that time included the cosmic diagrams called mandalas (cf., §9.1.2.1). The most complex mandala we have seen is that of the Garbhadata or Taizoukai mandala published with a preliminary commentary by Nishiyama (1999). This Chinese Buddhist mandala is said to have been brought to Japan from China in 806 A.D. Over 300 deities seem to be represented. The ruling deities of the 28 lunar mansions appear, as do the nine planetary lords and the 12 signs of the zodiac. Interestingly, comet (*ketu*) and meteor (*Nirghataketu*) are also represented, generically (recall that in India, *Ketu* is a deity, one of the nine planets). This is a good integration of ideas that originate as far west as Mesopotamia with Indian and Chinese concepts. The cosmos is laid out with east at the top.

This concludes our treatment of Old World astronomy. We discuss next the astronomies of the Pacific and regions of the Western Hemisphere.

11 Oceanic Cultures

11.1. Australia

Little research has been done on the archaeoastronomy of the ancient inhabitants of the bush, but there is evidence of a rich ethnoastronomical if not archeoastronomical heritage. It is known that the Aborigines originated in southeastern Asia and migrated probably in major, infrequent episodes. The earliest attested arrivals were around 40,000 B.C. The Pleistocene Ice Age (ending by about 8000 B.C.) facilitated travel because ocean levels were lower by ~90 m, enlarging islands, connecting island chains, and generally reducing open water between land masses. Open water still needed to be crossed at any epoch, however.

Prior to European contact, there were an estimated 300,000 people living among "tribes" or bands of people having some common characteristics, among which could be territory, family relatives, language/dialect, tribal name, unique social/ritual identity, and sometimes sections, subsections, or moieties (a moiety is a state of dual division in a tribe, mainly for ceremonial purposes). There were 228 languages (O'Grady, Voegelin, and Voegelin 1966, pp. 26–29) in 29 Phylic families of Australia's Macro-Phylum (28 of which were in Arnhem Land and one in the Kimberley District) and 5 other Phylic families; however, there were 117 still linguistically unclassified "tribes."

Humans were using and decorating rock shelters in Australia far back in the Upper Palaeolithic; such material is notoriously difficult to date. McCarthy, cited in Reed (1969/1974, p. 37), distinguished several types of rock engravings: abraded grooves; human, animal, and inanimate object outline figures; pecked versions of these figures; and geometrical designs, both curvilinear and rectilinear. The rock galleries are found all over Australia; those at Broken Hill, New South Wales, and Port Headland, Western Australia, are extensive. Deep limestone caverns in the Nullarbor Plain of Australia are decorated with cave paintings, some of which represent ancestral heroes, men and gods of the *Dreamtime*.[1] Categories similar to those for the rock galleries have been devised for cave paintings, but in this case, the figures can be found in both black and white and in extensive colors (Reed 1969/1974, pp. 120–121). Among the finest examples of cave paintings are the Wondjina in the Kimberleys and the region of the Oenpelli-Liverpool River, Northern Territory.

The people of the region were until recent times hunter-gatherers, to whom the observation of rites prior to food gathering and hunting was a necessary and sacred duty. To ensure a plentiful supply of food, such a ceremony was held at the heliacal rising of the Pleiades in May, which marked the beginning of a new year. At this time and during the Australian winter, which followed, cries of "The earth is turning itself about" would be heard from the elders as they observed the night sky (Reed 1969/1974, p. 16).

Constellations were named and associated with the "spirit people" of the *Dreamtime*. Stories about the origins of individual constellations and asterisms, such as the Southern Cross and the Pleiades, vary from tribe to tribe. The principal sky deity was the *All-Father*, known in various areas as *Baiame* (among the Kamalaroi and other tribes in New South Wales), *Beral*, *Bunjil* (among the Wotjoballuk and Kurnai; a hero who introduced the tribal moiety system, among the Kulim), *Daramulun* (among the Yuin), *Goin*, *Mangan-Ngana*, *Nepele*, and *Ngurunderi* by various tribes (Reed 1969/1974, p. 75). In northern and central areas of Australia, the notion of a single creator god was not prevalent. In Arnhem Land, there was a Mother Goddess,

[1] Basically, it is the time when the ancestral heroes, the "Old People" lived. In a broader meaning, it is the time when the basic patterns of the world and living things were created, but it is not completed: It is a continual, eternal process. Thus, all the gods, the spirits, and the ancestors who performed the sacred rites are living, still, now and forever. The people keep within the *Dreamtime* by song, dance, and ritual (Reed 1969/1974, p. 57).

associated with the Rainbow Snake. The proliferation of religious beliefs is not particularly surprising, considering the antiquity of human habitation in Australia.

Some tribes believed that the sky was the repository of the spirit after death, but more generally it was felt that the spirit was essentially immortal, undergoing many reincarnations and travels, but eventually reaching its home on either the Earth or in the sky—among the heroes, where it would find eternal youth. Mourning and disposal ceremonies had to be performed carefully or the spirit of the newly dead could haunt the locale, with negative consequences for all activites.

Initiation ceremonies (*bora*) are held at sacred and secret *bora grounds*, which consist of two cleared circles joined by a path. Both men and women must undergo the rigors of these ceremonies, although the women's is said to be less challenging (Reed 1969/1974, p. 91). A legend of the origin of the Pleiades from southeastern Australia describes the trials of a group of seven women who insisted on enduring the more sacred and severe trials of the young men and were rewarded for their endurance and perserverance by being taken up into the sky as the Seven Sisters (Reed and Reed 1965, pp. 83–87 cited in Reed 1969/1974, pp. 90–91).

The Iuwalarai tribe called the Sun, who was female, *Yhi*, and the Moon, who was male, *Bahloo*. *Yhi* was said to lust after and chase *Bahloo*, among whose duties it was to produce girl babies. In a society where arranged marriages were common, especially between young females and old males, such stories are revealing. Important assemblies were held at full Moon. An important mediator at assemblies involving more than one tribe was the medicine man, who also mediated between spirits and the tribe; he had the power to visit the sky home of the spirits (Reed 1969/1974, p. 106).

Astronomical content in Australian paintings may go back 30,000 years or more, according to Cairns (1993). He points out (p. 75) that modern Australians make explicitly astronomical bark paintings dealing with the Moon's phases, the movements of the Sun, and planetary phenomena. There are widespread stories associated with asterisms—one, about a man, a dog, and a kangaroo rat, is associated with the constellation Hydra, which is used as a directional guide. The morning star also appears as a guide. In the Kimberleys, a figure identified by local people as *Wandjina*, a Moon goddess, is associated with 28 small lines (Cairns 1993, p. 78). Some paintings, possibly as early as 11,000 B.C., are interpreted by tribesmen whose groups have long lived in the area as references to the sky (Cairns 1993, p. 71). The Sydney site, in Ku-ring-gai Chase National Park, which is oriented to the cardinal points, shows more than 100 possible star patterns with meters of rock art depicting celestial personages and marks of lunar numbers (Cairns 1993, pp. 75–76).

11.2. Melanesia, Micronesia, and Polynesia

Dotted on islands, large and small, throughout the Pacific live groups of farmer-fishermen of the cultures identified as Micronesian, Melanesian, and Polynesian. The Micronesian languages are very diverse. The Melanesian and Polynesian language families are grouped together within the great Austronesian linguistic stock, but there is much more homogeneity within the Polynesian subgroup. The archaeological history of Micronesia apparently starts earlier and is both more complex and less related to archaeoastronomy than that of Polynesia, according to present evidence; however, the abundant ethnographic evidence on Micronesian navigation and calendrics suggests that this situation may change.

The ancestors of the Polynesians, from the time of their first spreading into the farther reaches of the Pacific,[2] have been farmers with a wide range of root crops, including the Asian yam and, later, the American sweet potato, as well as many planted trees. The coconut palm alone supplied food and drink as well as construction materials for homes and watercraft. They had domesticated pigs and chickens as well as dogs, and they were usually accompanied by rats (which could be regarded almost as semidomesticated). Hunting was relatively unimportant in most areas and became less so as local birds were exterminated, but fishing was always a major subsistence base and fish pools were eventually constructed in many areas to make the supply even more reliable. Sturdy houses and impressive religious structures were common, and there was some development of building with dressed stones. Major fortifications seem first to have appeared from about 1000 to 1200 A.D. Tools were of stone, bone, shell, or wood, but there was no use of metals, which were not to be found on the atolls where many of the islanders lived. Although pottery was known archeologically in Melanesia and western Polynesia and even reached the Marquesas, it was unknown anywhere in Polynesia when Europeans arrived. Cloth was not woven, but barkcloth, or *tapa*, a felted fibre from the inner bark of certain trees, particularly the mulberry, served for clothing and wrappings of all sorts.

Throughout Micronesia and Polynesia, hereditary chieftains (many claiming a common origin from Samoa to Tahiti and Hawaii) were regarded as sacred and accorded exceptional status and privileges, even on small islands where there was little other differentiation among the people. The most complex society was that of the Hawaiian Islands, with dense populations and many kinds of specialists. Warfare was endemic throughout the area, and the values of warlike society were widely accepted. Exploration in giant, often double-hulled canoes was the only reasonable alternative to in-group warfare when conditions became too crowded. Good descriptions of the oceanic cultures are to be found in Bellwood (1978) and in Kirch (1985). A good general ethnology is in Oliver (1989). Goodenough (1953) gives the most detailed current exposition of Micronesian astronomy and calendrics that may usefully be supplemented by Gladwin (1970) and Stephen Thomas (1987). Makemson (1941) has summarized Polynesian astronomy, and much additional material may be found in Johnson and Mahelona

[2] Approximate settlement dates: Solomon Islands, 1600 B.C.; Fiji, 1250 B.C.; Tonga, 1000 B.C.; Marquesas, 200 B.C.; Hawaii, 300 A.D.; New Zealand, 800 A.D.

(1975). Our knowledge of oceanic navigation has been greatly increased by the work of David Lewis (1972/1975, 1974, 1978).

In Oceania, astronomy served the principal purposes of navigation and calendrics, including the setting of the times of religious rituals and festivals. Such elements of the legal system as the execution of criminals were associated with religious rites and their times were determined astronomically. The identification of stars and asterisms by the names of deities and mythical places shows the important religious element in astronomy.

There is clear evidence that Polynesian astronomers used the stars as temporal markers for planting and harvesting and for seasonal appearances of fish and birds. Stimson (1928) believed that fishing auguries were basic to the invention of the system of lunar nights, although he later became convinced that the names suggested an ancient phallic cult. Polynesian astronomers also judged probabilities of abundance and scarcity from the characteristics of certain stars and made predictions with regard to voyages (which have an important seasonal component, properly marked by stars) and warfare. For details, consult Makemson (1941), especially Chapter 4.

In both Micronesia and Polynesia, the nights of the Moon are named. A single system prevails throughout most of Micronesia and a structurally related list is known from the western Polynesian island of Futuna. Most of the western Polynesian islands have only a loose system of named lunar phases. A formal series of named nights of the Moon, of common origin, is found throughout eastern Polynesia.[3] Reconstructed prototypes of the two lists appear in Table 11.1. The Mamari Tablet from Easter Island (Figure 11.1) shows a sequence believed to relate to the Lunar Nights.

Table 11.1. Named nights of the Moon in eastern Polynesia.

Tahitian Nights of the Moon		Maori Nights of the Moon	
1.	Hiro hiti	1.	Whiro
2.	Hoata	3.	Hoahoaata
3.	Hami ami mua	4.	Ouenuku
4.	Hami ami roto	5.	Okoro
5.	Hami ami muri	6.	Tamatea Kaiariki
6.	Oreore mua	7.	Kani Tamatea
7.	Oreore muri	8.	Ngaha Tamatea
8.	Tamatea	9.	More Tamatea muto
9.	Huna	11.	Hune
10.	Ari	10.	Ari
11.	Maharu	13.	Mawharu
12.	Hua	12.	Ohua
13.	Maitu	15.	Atua
14.	Hotu	14.	Hotu
15.	Mara^ci	16.	Maure
16.	Turutea	17.	Turo
17.	Raau mua	18.	Rakau nui
18.	Raau roto	19.	Rakau matohi
19.	Raau muri	20.	Takirau
20.	Oreore mua	21.	Ongohi
21.	Oreore roto	22.	Korekore te whiwhia
22.	Oreore muri	23.	Korekore hahani
23.	Taarua mua	24.	Korekore piri Ki te Tangaroa
24.	Taarua roto	25.	Tangaroa a mua
25.	Taaroa muri	26.	Tangaroa a roto
26.	Tane	27.	Tangaroa Kio Kio
27.	Roo nui	28.	Otaane
28.	Roo maori	29.	Orongonui
29.	Mutu	30.	Mauri
30.	Teriere	31.	Mutu, mutuwhenua
		32.	Tirea

Although the names are now assigned to the phases of the Moon, the fact that many of the Polynesian names recur as star names is a strong indication that they may once have been applied to the days of a sidereal lunar month. Many of the names are also found to be deity names, as seen in Table 11.2. The identifications of lunar nights as star names and deity names have not been greatly exploited in interpretation thus far. The Maori lunar night named Matohi (which appears in Samoa as Matohi, third quarter of the Moon, one of the few suggestions of the extension of the lunar nights into western Polynesia) seems reasonable as a descriptive term for a phase of the Moon. However, a Maori myth relates [Makemson 1941, pp. 233–234]:

> Matohi, one of the stars, occasionally disputes with Tangaroa-whakapau as to which of them should enter the calendar. Sometimes one, sometimes the other enters. If Tangaroa-whakapau enters, then fish both of the sea and inland waters are plentiful. . . . Matohi, the star, is never seen by man except during the Tangaroa days.

Only this one passage identifies Matohi either as a god or a star, but this one makes clear that Matohi is both and calendrically important as well. That the star is "never seen by man except during the Tangaroa days" is another suggestion of traditional lore applying to a sidereal lunar month rather than a synodic month. Table 11.3 shows those Polynesian star names of reasonably certain identification that have given their name to months and the chaotic association with our months. There has clearly been some major distorting factor at work in these associations.

Interestingly, in Tahiti, the births of various deities are assigned to particular nights of the Moon. Kelley and Stewart (*in preparation*) discuss this at length and point out similarities with Mesoamerica (see also Kelley 1957).

In Polynesia, apparently time periods approximating our months were originally named for stars, probably at heliacal rising. Reconstructions based on lists from widely separated areas show that there were originally considerably more than 12 names, and the separation of known stars in the sky when identifications are clear is less than would be necessary if only 12 or 13 months were named. However, months seem later to have been identified with lunations. One way in which this was done was to begin the year with the heliacal rising of a star or an asterism and then to name each successive lunation. Johnson and Mahelona (1975, pp. 61–62) have pointed out that although the Hawaiian language is a branch of the East Polynesian linguistic grouping, the calendar names have their primary affinities with

[3] Eastern Polynesia is defined by ethnographers and linguists from shared cultural traits; geographically, this is somewhat anomalous, because the region includes New Zealand, well to the west of Samoa, Tonga, and the other islands of western Polynesia.

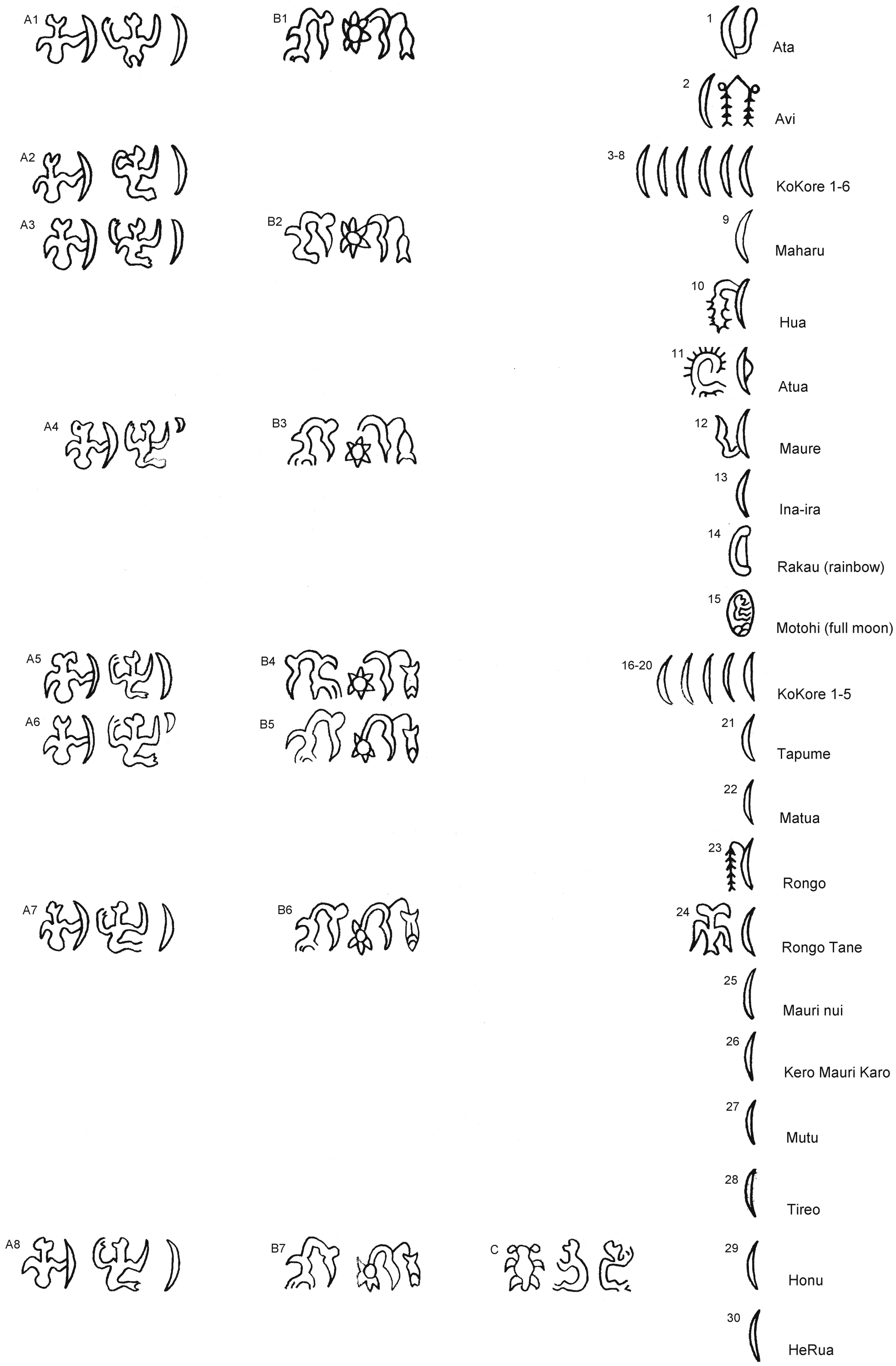

FIGURE 11.1. The Mamari Tablet from Easter Island shows a sequence believed to relate to the Lunar Nights. Drawings by Sharon Hanna.

Western Polynesia (especially Tonga and Uvea) and apparently into Micronesia.

The sky is conceptualized as a giant house among the Gilbert Islanders of Micronesia (Figure 11.2, after Makemson (1941, Fig. 4, p. 109), who, however, claim to have come from the Samoan group. Makemson (1941, p. 107) has pointed out that this contains one striking anomaly, for the zenith is associated with the southern star, Rigel (β Orionis, now at $\delta = -8°$; in 1000 A.D., its declination was $-10°$, and in 500 A.D., $-11°$), whereas the Gilbert Islands extend from about 4° north of the equator to about 4° south. Recall that the declination of the zenith is equal to the lati-

TABLE 11.2. Those names of the Polynesian Nights of the Moon that can be identified as deity names: In DHK's opinion, the Tahitian list corresponds structurally with the eastern Polynesian prototype.

Tahiti		Deity names and comparisons
1.	Tireo	
2.	Hiro-hiti	Simply *Filo in most lists. PP *Filo, god of thieves. Cf. Mao. Whiro, brother and enemy of Hua (cf. 13)
3.	Hōata	
4.	Hamiama-mua	Mao. alternate Uenuku, "shake-earth," a Rainbow god
5.	Hamiama-roto	
6.	Hamiama-muri	
7.	Tamatea-mua	Tah. Tamatea, fire-god, associated with origins of human sacrifice–Mao. ruled the dawn
8.	Tamatea-roto	
9.	Tamatea-muri	
10.	Huna	
11.	'Ari	Twin brother of Hua, cf. 13, 2 (Mao.)
12.	Maharu	
13.	Hua	Mao. brother of Whiro, 2, twin of Ari, 11
14.	Māitu	Cf. PP *Atua, gods
15.	Hotu	"Fierce" (personal name in traditions)
16.	Māra'i	PP *Ma-langi, "From Heaven"
17.	Turu	"Prop," a name of the personified Props of heaven
18.	Rā'āu-mua	Alternate, Kaniva, "rainbow"; alternate, Rakau Matohi,
19.	Rā'āu-roto	Mao. Matohi, a god and a star
20.	Rā'āu-muri	
21.	'Ore-'ore-mua	
22.	'Ore-'ore-roto	
23.	'Ore-'ore-muri	
24.	Ta'aroa-mua	PP *Tangaloa, "long jaw," god of ocean
25.	Ta'aroa-roto	
26.	Ta'aroa-muri	
27.	Tane	PP *Tane, "male," a major god with solar characteristics
28.	Ro'ō-nui	PP *Longo, god of sweet potatoes and cultivated plants
29.	Ro'ō-māuri	
30.	Mutu	Mao. Mutu, a god of evil

tude of the observer, and thus, the historical indications of declinations can indicate past locations of observations. This latitude-declination anomaly is repeated in New Zealand, far to the south ($\phi = -36°$ to $-47°$), where the name *Puanga* means both "zenith" and "Rigel." This suggests that there is a common element in at least some Micronesian and Polynesian astronomy and that it originated with a people living near 10° south latitude, probably somewhere between southern New Guinea and northern Peru on a line passing through the Solomons, the Ellice Islands (somewhat south of the Gilberts), Tokelau, and the Marquesas. The importance of Rigel is further attested by the fact that the Moriori of the Chatham Islands, an offshoot of the New Zealand Maoris, began their year with the heliacal rising of Rigel. The first month of the Moriori year was named after *Rongo*, god of agriculture. Some Maori tribes also marked the year using the rising of Rigel, whereas others used the much more widespread year marker, the Pleiades. This difference was commemorated in Maori myth (Makemson 1941, pp. 78–79):

> the task of *Puanga* [Rigel] is to strive with *Matariki* [Pleiades] that he may gain possession of the year.

Seasonal divisions were also marked by the Milky Way as in Pukapuka, where the Great Rift, which extends from Cygnus to Scorpius, was called *Te Mango*, "shark," and it is said that the "shark-of-winter" had its head to the south and the "shark-of-summer" had its head to the north (Makemson 1941, p. 185).

11.3. Oceanic Seafaring: Techniques and Instruments

We know little of the original Polynesian techniques of navigation. Much of our understanding of Polynesian navigation is derived from extant knowledge of Micronesian techniques, especially those of the Gilbert Islanders.

A remarkable teaching device of Micronesia is the "stone canoe" from which apprentice navigators learn the important astronomical components by which they can determine directions and latitude. Archeologists finding one of these could easily recognize the north-south orientation and the symmetrical placement of the stones. With just two examples, they would notice that the number of stones was constant. If they would postulate an observation point within the "canoe," they might be able to determine the most likely stars marked by each stone, but the apparent precision would be very low. Even if this were done, it is unlikely without the ethnographic evidence that they would realize that this was a practical training device. We are accustomed to thinking of alignments in terms of calendar observations and ceremonies, but it is well worth remembering that a knowledge of the locations of stars is a vital necessity to any group whose livelihood is heavily dependent on the ocean. Navigation and ceremony are not opposed but complementary. Myth and ceremony helped the navigators to hold the sky geography in their heads. However, charts were in use. A traditional school of navigation on Puluwat in the Caroline Islands used constellation charts for the sky and maps of the ocean identifying islands, reefs, and areas of converging currents. In the Marshall Islands, a "stick chart" consisted of a stick frame to which sticks were tied together to illustrate currents and punctuated with shells that represented islands (D'Alleva 1998, pp. 14–15).

In the language of the Gilbert Islanders, the word for a savant of the stars was *tiaborau*, navigator (Grimble 1931, p. 197; cited in Lewis 1974), and not "astronomer," for which there was no specific term. The sky is known as *uma ni borau*, the "roof of voyaging" in Gilbertese. A similar priority for navigation was to be found in Tonga and in Tahiti (Collocott 1922, p. 157; Forster 1778, p. 501, respectively, cited in Lewis 1974). Oceanic navigators were often of royal rank, and their knowledge and techniques were well-guarded secrets. That they work is beyond question, according to Lewis (1971, 1974): In 1969, a navigator from the Carolines named Hipour navigated solely by a "star

TABLE 11.3. Micronesian and Polynesian star names as month names: Although most Polynesian months are named for stars, sometimes with widespread agreement on the identity of the star or asterism, there is no correspondence in the month named by the star. Thus, *Mataliki is the name of the Pleiades. In the Hawaiian group, it corresponds approximately to April on Molokai, to October on Oahu, to August and December on different parts of Hawaii and to still other months elsewhere in Polynesia. In the Marquesas, two names are given for many of the months; so the total number of names was 19, of which 14 are known to be star names. In Micronesia, 20 star names were used to name the months. Matters are further complicated by the fact that in Hawaii, the months were sometimes "ruled" by stars that were not the ones for which they were named. Names of these "ruling stars" may appear elsewhere in Polynesia or Micronesia as month names.

Composite of Micronesian star names (used as month names) in order of heliacal rising	Proto-Polynesian reconstructions of star-names known to have been used to name months. Identifications as specific stars may vary in different sources
1. Tumwur Antares, Scorpio	PP *Pipiri Scorpio (confusion with Castor and Pollux)
2. *Maacik Hercules	
3. Meen Vega, Lyra	
4. Maanap, Pillar of Heaven Altair, Aquila	PP *Poutu-o-te-Rangi, Pillar of Heaven Altair (cf. PP *Turu, Pole, Altair, not attested as a month name)
5. Seeta, Bowl Delphinus, Cygnus, Equuleus	(cf. PP *kumete, Bowl, similar asterism, not attested as a month name)
6. Naa Fomalhaut, Pegasus	
7. Kyyw, Porpoise β Andromedae	
8. Jenimate γ Andromedae	
9. Mweriker Pleiades, Taurus	PP *Mataliki, Little Eyes Pleiades
10. Wuun, Penis Aldebaran, Taurus	PP *puanga (see text) Rigel
11. Jenywen Orion's Belt	PP *Takelo, wet Mercury (probably at a particular asterism) PP *Takulua (cf. PP *Lehua) Siriu or Antares
12. Maan, Bird (Castor, Pollux, and Procyon)	PP *Mahoe (as a month, follows *Iti) Castor and Pollux
13. *jiic, Rat Regulus, Leo	PP *Iti, *Itiiti (from Micronesian, Rat) Regulus
14. Jonumas Crater	
15. Jinnenikak Virgin	
16. Pwuupw Southern Cross	Tapeka, Napeka, (month names) cf. *Peka, cross, bat, rayfish (manta) Southern Cross (identified in Malayan as bintang Pari, rayfish)
17. Serepwen (Soropuel, Sarapoli, etc.) Corvus	PP *Mele (Hawaiian, song) Corvus (also Sirius, "Evening Star") Twin of *Polapola, possibly related to Sarapoli etc.
18. Jaap Spica, Virgin	
19. Joromoj Arcturus, Bootes	
20. Ceew, Net Corona borealis	

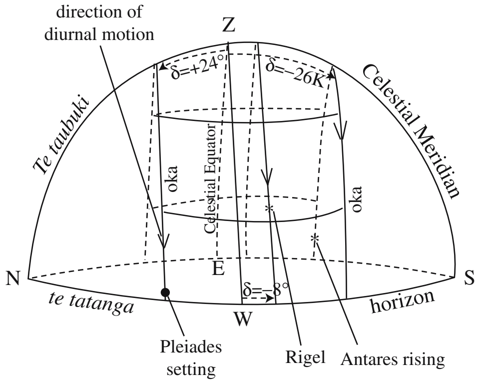

FIGURE 11.2. The sky pictured as a giant house, in which the celestial meridian is the ridgepole, the horizon, the "roof-plate," and the diurnal circles, the vertical rafters, *oka*. Drawing by E.F. Milone.

compass" (which had been passed down to him across generations since it was last used) and accurately achieved landfall after crossing more than 700 km of open ocean. There is an even longer successful voyage by a traditional navigator.

In the Caroline Islands, as elsewhere, the ancient traditions of navigation in the native manner are rapidly fading as charts and sextants replace the old conceptions. Still, Stephen Thomas (1987) was able to get training in the ancient practices. A teaching device similar to that used in the Gilbert Islands is still found. They lay out a circle of 32 rocks with a model canoe in the center. These mark the rising and setting points of 16 named stars. Their resemblance to some megalithic stone circles elsewhere in the world is striking, despite the difference in scale. These primary navigational stars were also important in giving names to the months, although there were also many months that took their names from other stars.

The process of Polynesian navigation has been described by David Lewis (1972/1975) after he had undertaken successful sailings with crews using traditional methods. He also took part in a navigation experiment involving a native craft piloted by a native navigator from Hawaii to Tahiti, a voyage of 5370 km. The voyage and the events and trials that led up to it have been discussed by Finney (1976b/1977/1979). The two-masted, twin-hulled, sailing craft was called the *Hokule'a*, and it was one of two ships constructed to test the ocean-faring capability of traditional water craft. With a fully loaded displacement of 11,400 kg, it was large enough to contain provisions for a lengthy voyage and the animals and plants needed to begin a new colony. The experiment demonstrated that such craft had a surprising ability for windward travel, permitting a great deal of control in the face of the predominant easterly trade winds on either side of the equator.[4] This is critical for regular eastward travel, such as that from Hawaii, which lies about 5° west of Tahiti, to the island groups to the southeast. It also demonstrated convincingly that traditional navigational methods and craft could have been used to support migrations in the Pacific.[5]

The navigational techniques involved both astronomical and nonastronomical means. The native navigator, Pius Piailug, known also as Mau, used a combination of astronomical methods to determine latitude, including the observation of the altitude of Polaris north of the equator, and the direction of the risings and settings of key stars, from "pits" on the horizon, both north and south of the equator. The nonastronomical methods included the sighting of direction of islands of known bearing, and a kind of dead reckoning, whereby the rate of motion was gauged from the feel of the wind and waves on the boat and the craft's rocking and rolling motion through the water. In the daytime, use of the Sun could be supplemented by ocean swell angles. Once the navigational methods succeeded in getting a craft within tens of miles from land, the presence of birds signaled the proximity of the shore. The range can be determined to some extent by the type of bird seen:

(1) Black tern: 10–15 miles
(2) *Itata'e* (white tern): 20–25 miles
(3) *Otaha* (frigate bird): 30 miles
(4) *Eua'ao* (brown booby), white booby: 40 miles

Clouds were also used as important markers, and changes in ocean currents were often discernible to a trained navigator at considerable distances from land. Ammarell (1999), writing from personal experience among the Bugis[6] in the archipelagos of Indonesia, points out that the chop of colliding winds and local currents, the change in wavelength of the waves as the water depth decreases near shore, and debris from shore all provide additional markers.

The nonastronomical techniques were particularly important for reckoning E-W motion, because time and longitude are inextricably bound, and in the absence of a chronometer or other precise way of marking time, hour angles are not particularly helpful in determining longitude. However intrinsically difficult it may have been to determine the eastern or western progress, the *bearing* of the craft could have been determined with high precision: The Sun always rises somewhere on the eastern horizon, and the time of year governs the point on the horizon from which it rises at a given latitude on Earth, as we have discussed in earlier chapters (see, especially, §3.2.1). Moreover, stars on the *celestial equator* will always indicate the direction of true east as they rise. Dodd (1972, pp. 48–55) demonstrates how a sequence of fore-and-aft stars arising from horizon pits could have been used while sailing roughly east-west near the equator. The canoe's direction was aligned to both the rising and the setting pit at the same time rather than to particular stars marking the pits. The position of a pit may be determined

[4] Finney (1976b/1977) indicates that *Hokule'a*'s speed was at least 10 km/h on a course of 70–75° off true wind, while sailing in moderate-to-strong head winds.

[5] A period of optimum voyaging conditions may have prevailed between 450 and ~1200 A.D., when mild trade winds and possibly stronger, more frequent westerlies, may have occurred; strong trade winds and increased storms are hypothesized to have occurred during the Little Ice Age (15th–17th centuries), making long voyages hazardous (see citations in Finney 1977).

[6] A people of the island of Sulawesi, and found widely in the region, including the Indonesian archipelago.

not only by the star or stars rising from it, but also by its relationship along the horizon to other pits from which stars were rising. At the equator, navigators will observe these stars ascend vertically, but at any latitude, the diurnal movement will be away from the east point. Polaris, at the current epoch, always indicates the direction to north within a degree, although the north celestial pole has shifted significantly among the stars compared with past epochs because of precession (see §3.1.6). As recently as the 17th century, the separation of Polaris from the pole was sufficiently great that its altitude varied by several degrees during the night. This made the naked-eye estimate of latitude by means of Polaris's altitude alone somewhat more uncertain than at present. Similarly, this degree of variation in azimuth would have compromised the estimation of bearing, but this did not prevent the use of Polaris among some island groups.[7] Its use is certain in the Hawaiian group (Johnson and Mahelona 1975) and seems reasonably clear in the Carolines (Goodenough 1953; Gladwin 1970). In Tahiti, one of the star "pillars" that hold up the sky dome is said to be Polaris, invisible in Tahiti, even in the historically remote past (Lewis 1974, p. 143). Thus, the astronomy of Oceania is strongly dominated by the "voyaging stars."

Asterisms are still being used by more experienced navigators on sail-bearing craft of the Bugis. This is the case despite the widespread availability of the magnetic compass, because reading the latter requires frequent use of a flashlight during the night, whereas some of the useful asterisms are available on any clear night. The most common asterisms[8] in use are the following (Ammarell 1999, Ch. 4), beginning with those of the northern sky:

(1) *bintoéng balu Mandara'*, "Mandar widow-before-marriage" (α, β UMa)
(2) *bintoéng kappaka'é*, "ship" (α, β, γ, δ, ε, ζ, η UMa; β, γ UMi)
(3) *worong-porongngé bintoéng pitu*, "cluster of seven stars" (Pleiades)
(4) *bintoéng timoro'*, "eastern star" (α Aql)
(5) *bintoéng rakkalaé*, "plough stars" (α, β, γ, δ, ε, ζ, η Ori); the Belt stars (δ, ε, ζ) are also identified as *tanra tellué*, "sign of three"
(6) *bintoéng lambarué*, "skate stars" (Northern Scorpius: α, β, γ, δ, ε, ζ, μ, σ, τ Sco)
(7) *bintoéng balé mangngiweng*, "shark stars" (Southern Scorpius: η, θ, ι, κ, λ, ν Sco)
(8) *bintoéng balué*, "the widowed-before-marriage" (α, β Cen); also called *bintoéng sallatang*, "southern star"
(9) *bintoéng bola képpang*, "incomplete house stars" (the Southern Cross, α, β, γ, δ Cru; μ Cru)
(10) *tanra Bajau*, "the sign of the Bajau," the Bajau being sea gypsies who are found between the southern Phillipines and eastern Indonesia

The Bugis know well that stars cannot be followed through the night, and they make use of the bearings of rise and set as well as of culminations to determine sailing (or motoring) directions. The decision about a steering direction must take into account the wind and currents, as well as the desired direction of landfall. When sailing south, they make use of the brightest stars in the polar region, α and β Centauri; when sailing north, they make use of a similar pair, α and β Ursae Majoris in the Big Dipper. East or west can be determined by the positions of the "sign of three," the Belt stars of Orion, which are close to the celestial equator. Antares (α Sco) by itself is identified by them as the "lost Pleiad": *pitu*, "seven," is part of the name of the Pleiades; yet, only six are visible (§5.8.3); because the skate sets before the Pleiads rise and rises after they set, the skate is said to have stolen the brightest Pleiad for its tail, and so stealthily avoids them. When heading south, the absence of *bembé' é*, "goat" (the Coal Sack in Crux), outside the "incomplete house" (trying to get in, out of the rain, and sighted between squall clouds) is taken as a sign of calm weather ahead, a meteorological sign of which is a hazy sky. Ammarell recounts a widespread tale that the carpenter trying to fix the incomplete house (which has one post shorter than the other) can never do so because of the distracting charms of the woman next door, who was "'widowed' before her marriage." In addition to the stars, Venus can easily be seen when near maximum elongation, and it provides a beacon when all other stars fade from haze or light cloud. The Bugis star compass is shown in Figure 11.3, after Ammarell 1999.

The position of the Moon is a major tool of the navigator, both for position, and for tides (see Figure 11.4, which shows the use of the tilted crescent of the Moon as a seasonal indicator of direction). The Sun is used mainly for general E-W directional information, that is, the changing azimuths with season are not exploited, according to Ammarell (1999, p. 140); ocean swells are more relied on during the day, and the high altitude of the Sun during most of the day in the tropics makes it less useful.

Of observational instruments used in Polynesia, the most important was the sophisticated though technologically simple navigational gourd. Mahelona and Johnson (1975, p. 74) cite a Tuamotuan poem:

> Oh, my sacred calabash—
> Revealing the sacred wisdom of the stars

This gourd (*ipu*, calabash) must have been similar to the Hawaiian navigational gourds described by David Malo Kupihea, who learned about them when he was a small boy. Kupihea was born about 1872, the grandson of a navigator and head fisherman for the royal family. Kupihea wrote an account for Theodore Kelsey [~1950 but first published by Mahelona and Johnson 1975 (pp. 142–153)] claiming that he saw seven or eight of the gourds that were still in use in his childhood and were used on voyages lasting up to six months. According to this account, they were sometimes actual gourds, and at other times, wooden containers carved

[7] Ammarell (1999) notes that the bearings of the dozen or so asterisms used by the Bugis in the Sulawesi region are approximate only, with the bearings remembered only by the nearest wind compass direction. The group studied by Ammarell, the Bugis of Balobaloang (118° 524′. E, 6° 36′ S), a small island in the Sabalana Archipelago, could not use Polaris, which was below the horizon and did not use the pointer stars of the Big Dipper to find north, but rather the culmination of this pair of stars, the brightest such pair in the far northern sky.

[8] The Bugis word *bintoéng* is cognate with the Balinese *bintang*. These groups are related linguistically to the Polynesians.

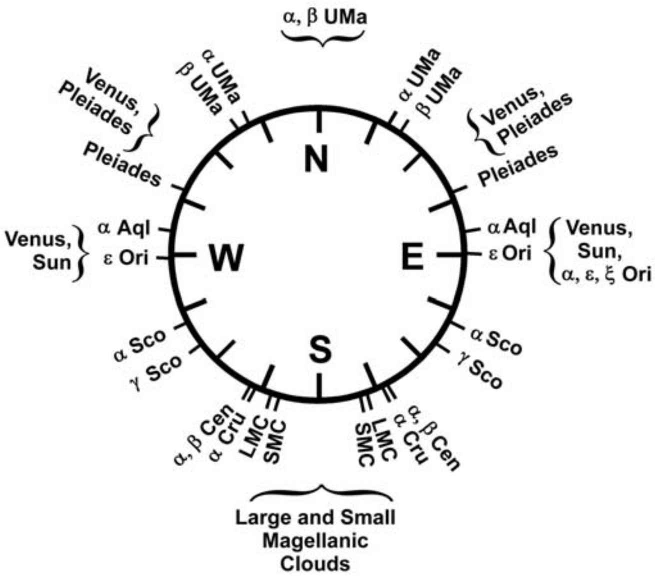

FIGURE 11.3. The Star Compass of the Bugis navigators of Sulawesi and the Indonesian archipelago. Drawing by Sharon Hanna, after Ammarell (1999).

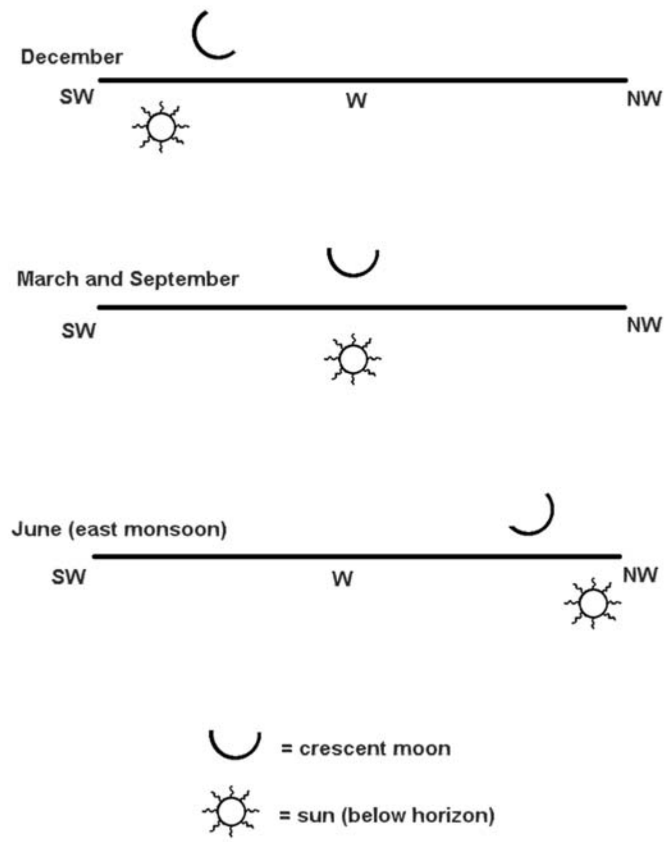

FIGURE 11.4. The use of the crescent moon as a seasonal direction indicator among the Bugis. Drawing by Sharon Hanna, after Ammarell (1999).

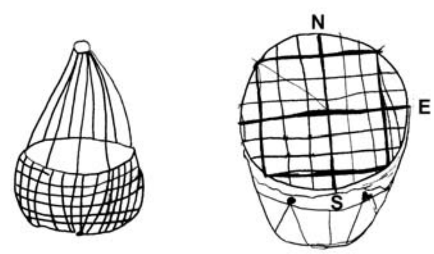

FIGURE 11.5. A navigational gourd as reported by the Hawaiian David Malo Kupihea: The cords presumably provided a grid of positions for the stars. Drawing by Sharon Hanna.

in the shape of a gourd. They were from 1.5 to 3 ft in diameter and usually about 4 to 6 ins deep. One diagram suggests a substantially deeper gourd (See Figure 11.5).

There were sighting holes from south to north for alignment on the Pole star and at right angles from west to east. The gourd was filled about 3/4 full of water, which served both to supply a level surface and to act as a mirror, reflecting the stars. Cords were stretched across the top of the gourd both parallel to the east-west sighting holes and at right angles to them, creating a series of about 36 squares of lines that were close analogs to our latitude and longitude lines, but shifting with the observer's position (and therefore more akin to an hour angle declination, or, more aptly, an azimuth-altitude grid). The junction knots of the cords all had names, so that they could be referred to easily. In an alternative version, cords were run at 45° angles to the north-south and east-west sighting lines. It is unfortunate that we do not have a full description of the use of this instrument, but the use of a horizontal reflecting surface does suggest its use as a device to measure relative azimuth. The use of such a gourd as a handheld navigational device would have at least one serious drawback, namely, its weight. The smallest of the containers indicated (~0.5 m diameter), 10 cm deep, 3/4 filled with water, would weigh close to 15 kg, with the larger gourds weighing much more. It is possible that such a device could be balanced on a point-like support, or held by more than one person, but neither solution is attested by any source.

A still earlier description of a navigation tool was given by Samuel Kamakau in 1865, but this "navigating gourd" more resembled a celestial globe. Lines were burned into the outside of a gourd, first from the North Star to the Southern Cross. Across this was burned a line for the celestial equator, called the "path of the spider" or "the road to (or of) the navel of the sky." Also crossing the hour circle were the "black shining road of Kane" and the "black shining road of Kanaloa."[9] Then stars were marked on, and finally

[9] Presumably the declination circles of the Tropic of Cancer and the Tropic of Capricorn, respectively.

planets, but it is not clear what positions would be assigned to the planets or why.

Of other possible instruments, we know archaeologically and ethnographically that Polynesians used concave mirrors, but there is no evidence known to us at the time of writing that these were used either for astronomy or for navigation. We also have important evidence for the use of stone pillars, often in conjunction with natural features of the landscape, to mark astronomical and calendrical features. Many processes that have been postulated hypothetically for European megalithic astronomy are directly attested in Polynesia. Our best information comes from Mangareva[10] and Hawaii, but there is every reason to suppose that they reflected a once widespread pattern. On Moloka'i, in the Hawaiian group, a phallic rock called *ka-ule-o-Nanahoa*, "the penis of Nanahoa" was used as a solstice marker. The cognate Micronesian term, *ul*, "penis," is a name of Aldebaran (α Tauri). Johnson and Mahelona (1975, p. 119) point out that the name *Nanahoa* is cognate with *Ngana-hoa*, applied to the wizard of the great legendary figure of *Rata*, who was said to float on the ocean as a calabash. The term *Ngana* is sometimes translated simply as "star," but seems actually to have been restricted to a specified subset of stars (perhaps 9; see Johnson and Mahelona 1975, pp. 62–65) of particular importance in navigation.

There is a fascinating, although somewhat confused, account of a set of five pillars in the Puna district of the island of Hawaii representing a voyager called Kumukahi and his four wives. The earliest information we have derives from an interview of Martha Warren Beckwith in 1914 with a local judge named Kalawe. Beckwith was later part of the staff of Vassar College, where Maude Makemson taught astronomy. Makemson (1938, p. 378) gives a brief acount of a *heaiu* in Puna used for making observations of the solstices, without mentioning Kumukahi. Mary Kawena (Wiggin) Pukui[11] was told by an individual named Kalewamakua about Kumukahi and his wives (Johnson and Mahelona 1975, p. 84; Beckwith 1970/1982, pp. 119–120; Pukui, Elbert, and Mookini 1974, p. 124). She and Beckwith each cite the other for portions of this information.

The eastern cape is named for Kumukahi, who is identified as a red pillar either "at the extreme end of the point" (ff. Beckwith 1970/1982) or "upland" from a pillar identifying one of his wives, where the Puna lighthouse is now located (Johnson and Mahelona 1975). The four (or possibly five, if Kumukahi is included) pillars are in a line from north to south, evenly spaced apart. The place is called "Ladder of the Sun" or "source of the sun," and the two outer wives push the sun back and forth from solstice to solstice. Aside from the geometry of the site, Kumukahi probably represents the equinoxes, for he is said to be incarnate in the plover, whose migrations in spring and fall are regarded as important seasonal markers. We have been unable to determine with certainty the present location of either Kumukahi or of his wives, other than the lighthouse site, although R. Johnson (1993, *private communications to EFM*) has described their approximate locations. James (1995, p. 64) describes the two wives as large *pohaku* (standing stones), many of which are found in the area. See Figure 11.6 for the flavor of the place.

In Mangareva, there were four observation points that were used in determining the solstices. In at least two cases, observations were made from flat stones. In two cases, the solstice was identified as the point where the Sun rose between two stones on a distant mountain. In at least one of these two cases, two long stones had been deliberately erected, close together, as markers. A stone was observed to be at the limit of the shadow cast by Mount Duff at the June (winter) solstice as observed from the observation point, *Te Rua-ra* (the pit of the Sun) at Ati-tuiti on the southern coast. In all cases, distant markers were used to achieve precision (Johnson and Mahelona 1975, pp. 83–84).

In Tonga, Maui is said to bear the Earth on his shoulders and earthquakes occur when he gets sleepy (Tregear 1891, *sub* Maui), whereas in Hawaii, *Maui* was said to be a name for a star near the Pleiades (Pukui and Elbert 1957, *sub* Maui). DHK thinks that the widespread myth of Maui snaring the Sun refers to the changing of the Sun's direction at the solstices. These ideas seem to be embodied in the great trilithon of coral slabs known as the *Haamonga-a-Maui* on Tonga. The name *Haamonga* refers to the weight-bearing pole with which Maui is said to have raised the sky, and it appears in Samoa and elsewhere in Polynesia as a name for Orion's Belt (Johnson and Mahelona 1975, pp. 75, 127, 135). The lintel of the trilithon is aligned to the rise point of an object with declination −24°.7. This can be compared with the declination of the December solstice Sun, −23°.4, in 1200 A.D., when its construction occurred in the reign of King Tu'i tatui, whose dates are based on a generational estimate, according to local tradition. On top of the *Haamonga-a-Maui* is a double zigzag design, 4 cm long, with axis aligned to the equinoxes and the two directions defined by the zigzag lines to the solstices, within 5°. The possibility of the solstitial alignments was noted by King Tau fa'a Tupo'u IV and checked under his direction in 1967 (Liller 1992, pp. 318–319; Lewis 1974, pp. 137, 139).

There is also evidence from Easter Island for equinoctial and solstitial alignments, discovered archeologically. Liller's (1989a) summary supersedes earlier work (Lee and Liller 1987) as well as discussions by Mulloy (1961, 1975), Ferdon (1961), and Carlyle Smith (1961), and incorporates his field work as well as unpublished work carried out by Mulloy in 1965. Liller's (1989a) study includes massive archeological evidence, careful statistical treatment, and the use of ethnographic information, mostly in the form of place names. Liller (1989a, p. S50) points out that the most important monuments on the island are at Hekii, with alignments to the equinox and the winter solstice, at Vinapu with alignments to the equinox and the summer solstice, and at Tongariki with a summer solstice alignment. Inland, an astronomically important site is *Ahu Huri a Urenga* (1989a, p. S31). This shows alignments to the equinoxes, to the rising

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[10] A small group of islands between Tahiti and Easter Island. The largest island, with an area of four square miles, gives its name to the group.

[11] Mrs. Pukui was a native of the Puna district; her mother came from a family of hereditary priestesses of the volcano goddess, Pele. She aided Beckwith (1932/1978) in translating Kepelino's *Traditions of Hawaii*.

and setting summer solstice Sun, to the rising and setting winter solstice Sun, and due north-south. Two of these alignments also matched local mountain peaks, and three additional ahus were in a direct east-west line with *Huri a Urenga*. Both at *Huri a Urenga* and at *Hekii* 2, the central platform is skewed relative to the base. These are the only two sites that show this type of construction. In the case of *Hekii* 2, the skewing of 13° makes the central platform align 1.7° south of the equinox sunrise (calculated for 1000 A.D., which is presumed to be close to the date of the monument). There seems to be a tendency for the *ahu*s to be aligned roughly with the coastline, which makes statistical appraisal difficult, but that is clearly irrelevant in this particular case.

The name of *Huri a Urenga* is also interesting for its parallels with Hawaii. *Huri* (Hawaiian *Huli*) is "turning point," and the name is involved in Hawaii with solstitial alignments. *Urenga* has the root *ure*, "penis," and the phallic monuments of Hawaiian fertility temples are associated with Kane (PP*Tane), who is associated in turn with the Tropic of Cancer.

One other Easter Island alignment should be mentioned. Malcolm Clark (according to Liller 1989a, p. S29) noticed that the name of the site *Ura-Uranga te Mahina* incorporates *mahina*, "moon," and that a line from the site to Poike passes over Rano Raraku (the quarry from which the famous statues came) and is the line of the most northerly rising of the full Moon. We add that Tregear (1891, *sub* Uranga) identifies the 5th Maori underworld as *Uranga-o-te-Ra*, and derives *uranga* from *u*-, "arrive," so that the Maori meaning would be something like "Arrival place of the Sun." Liller made no systematic investigation of possible lunar alignments. Liller's studies concentrate on solar alignments, although he mentions possible lunar alignments and the condition that Antares is a near-zenith star, so that the possibility of stellar alignments may need to be explored further.

Liller (1986) points out that there were five total or nearly total solar eclipses over Easter Island from 762 to 772 A.D. and suggests that they may have been a factor in the setting up of the great ceremonial centers. There had also been spectacular apparitions of Halley's Comet in 760 A.D., when it would have been seen with a magnitude ~–0.1, and in 837, when it would have appeared at a magnitude of –3.9 and with a tail stretching more than 90° across the sky. Earlier in 837, there had been another total solar eclipse. Liller suggests that these eclipses may be connected with equinoctial and solstitial alignments of the *ahu*s. Liller also points out representations of comets as petroglyphs near the ceremonial site of Orongo. Although not noted by Liller, it may be pertinent that the Maori said that one of their gods, Rongomai, a form of Rongo, had appeared in the shape of a comet or meteor (Tregear 1891, p. 425).

In Tahiti, Teuira Henry (1928/1971, p. 363) in her account of the birth of heavenly bodies wrote that "the chiefs of the skies . . . were royal personages . . . from the period of darkness, and they each had a star. They bore the names of those stars, and those names have been perpetuated in their temples in this world." This suggests that many temples were associated with particular stars and one may expect alignments, if any, with the "pit" from which that star arose. Among the Maori, we know of only one direct association between a star and a temple, namely, *Whaka-Ahu* (Castor) "appointed" to the temple called *Te-Hono-i-wairua*. In Hawaii, temples were generally associated with stars according to Makemson (1941, p. 148). Although we have no direct comparable evidence from elsewhere in Polynesia, the tremendous importance of the navigational stars and the deity names sometimes applied to them means that the possibility of stellar alignments should be kept in mind. A large number of potential and unique alignments makes a statistical treatment complex, if not impossible. What should not be assumed is that a particular stellar alignment applies to all monuments.

11.4. Islander Mythology and Astronomy[12]

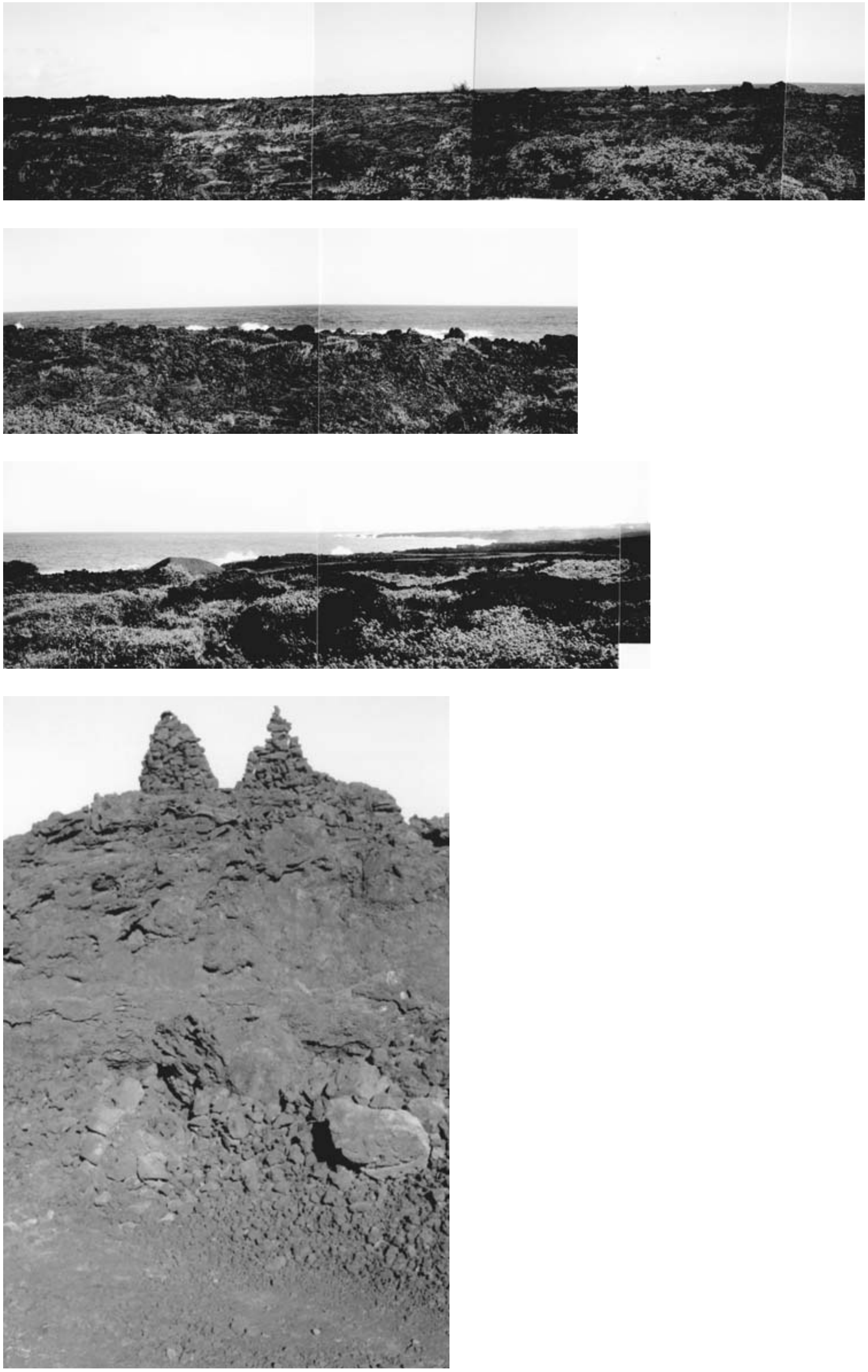
There is broad evidence from Polynesia that the relationship of movements of Sun, Moon, and stars to meteorology, seasonal changes, tidal effects on fishing and agriculture, and other natural phenomena was carefullly studied. Some of these associations are entirely acceptable in our society, whereas we regard others as unsupported allegations, or perhaps mere superstitions. Presumably, the Polynesians made no such distinctions. Some of the specifics of such associations were present in widely separated areas and were presumably old in the culture. For example. Makemson (1941, p. 168) points out that among the Maori, the nights of *Tane* and *Rongo* (named for the god of forests and the god of agriculture) were good times for planting sweet potatoes (a South American crop introduced prior to 1100 A.D. See Bellwood 1978, p. 395). From Hawaii, Kepelino (Beckwith, tr., 1932, p. 110) tells us that the equivalent nights of *Kane* and *Lono* (in their Hawaiian pronunciations) were good for planting (sweet) potatoes.

Among the oceanic cultures, there is clear evidence of personal astrology only from Hawaii. The native scholar David Kepelino (Beckwith, tr., 1932) gives personal characteristics for men and (somewhat different ones) for women born on particular days of the lunar month. Malo (1951) gives a similar set for persons according to the months in which they were born. Presumably, omens from the days and months moderated each other.

Thus, people born in the month *Hinaia-eleele* were said to be lazy, as were those born on the day named *Ole-ku-kahi*. Those who were born on the day *Ole-ku-lua*, however, were supposed to be good workers. Thus, in the first case, the laziness of the month would be reinforced, and in the second, counteracted.

A concept that is widespread in Polynesia (as in the Americas and Eurasia) is that of the layers of heavens and underworlds. An extremely enlightening drawing of these

[12] This section makes use of certain linguistic conventions and terminology. *PP* means *Proto-Polynesian*, referring to the reconstructed ancestral form of the languages of Polynesia. *UA* refers to *Uto-Aztecan*, an ancestral American Indian language, from which Aztec, among others, derives. An asterisk is used to mark a reconstruction of the earlier form of a word.



(a)

(b)

(c)

(d)

Figure 11.6. Views from Cape Kumukahi, the easternmost cape of the Hawaiian Islands: From here, the legendary chief for whom it is named, and his wives, surveyed and controlled the movements of the Sun. (a) to (c) Panoramic views sweeping from north to south along the coastline. (d) Twin *apu* (cultural shrine) at the cape. (e) Closeup of the southern *apu*. (f) Three views due to slight parallactic shifts in position, looking west from the twin apu at Cape Kumukahi, showing other apu, a *heiau* (temple)—in this case, a construct built into a lava formation. Lava flows have repeatedly devastated the Puna region of Hawaii. Photos by E.F. Milone.

was produced by Paiore, a Tuamotuan, in 1869 (see Figure 11.7).

Here, it is clear that "heavens" and "underworlds" are continuous in such a way that "highest heaven" and "lowest underworld" are conjoined. Concepts elsewhere may well have been very similar. Stimson (1928, 1933) argued that translators have consistently misunderstood the concepts of *po*, usually "night" or "darkness," and *rangi*, usually "sky" or "heaven." He thought that the Christian convert, Paiore, deliberately modified native views to make them more like

(e)

(f)

Figure 11.6. *Continued.*

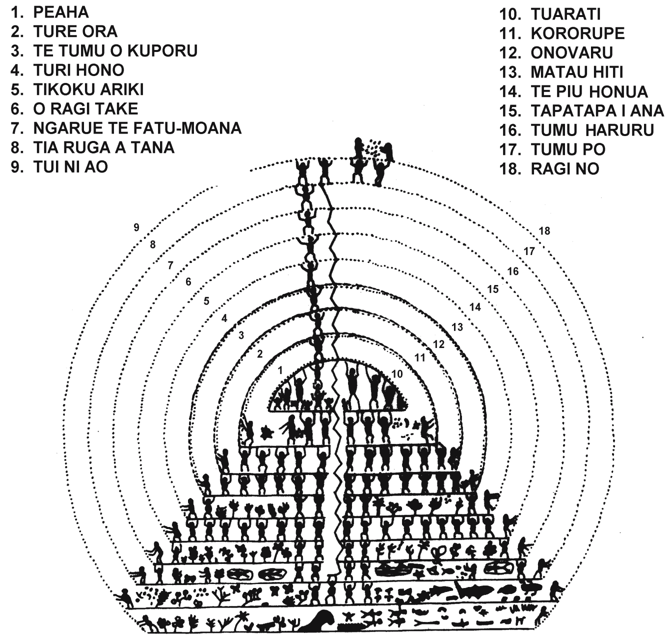


Figure 11.7. The layers of Heaven and of the Underworld, according to the Tuamotuan Paiore, ~1869. Drawing by Sharon Hanna and Sean Goldsmith.

his understanding of Christianity. Stimson thought that his informants were able to present older views more accurately. See Stimson for a comparison of their diagrams with Paiore's. Good summaries relating to heavens and underworlds may be found in Tregear 1891 (*sub* Kore, Hawaiki, Po, Reinga).

Kelley's claim (1957, 1990) that Uto-Aztecans from Mesoamerica somehow reached Polynesia and introduced the astronomical cult centering on *Tane*, the youthful Sun god, and his wife, *Sina*, the Moon goddess, relies heavily on linguistic evidence that would be inappropriate to consider in detail here.[13] However, it seems appropriate to consider some of the astronomical and calendrical data and interpretations. The myth of snaring the Sun, which was going too fast, and forcing it to go slower is widespread in Polynesia, and it is usually associated with the name of the "hero," Maui (see comments earlier in this section). It has normally been interpreted in modern Polynesian myths in terms of the east to west diurnal movement, but it is much more reasonable to think that the original intent was phrased in terms of movement along the horizon (§2.3.1). Maui caught it in a noose, PP **kolo*, apparently related to a Uto-Aztecan word for "circle," and also applied to halos around the Sun or the Moon. The inner halo is distant from the Sun by 22° (see §5.1.4), close to the maximum elongation[14] of Mercury, 23°, so that this angle is a good approximation for the arc length between Mercury and the Sun at sunset (for a greatest

[13] Much of this evidence is summarized in Kelley (1990), where further details and references may be found.

[14] See §§2.4.2, 2.4.3, and 3.1.5.

eastern elongation) or sunrise (for a greatest western elongation) during this event. Because 23.5° is the obliquity of the ecliptic, the angle is also an approximation to the bearing of either of the Tropics (Cancer or Capricorn) relative to the equinox rising or setting Sun. Thus, the halo seen at an equinox would appear to "noose" the Sun adequately, marking the solstitial limits, through which it may pass.

Maori mythology refers to two temples on Hikurangi mountain called *Koro-riwha-te-ao* and *Koro-riwha-te-po*. Maori *riwha* is "gapped," which has no obvious contextual meaning, but other Polynesian languages show "sloping" as a meaning for apparent cognates. This would give *Koro-sloping-towards-the-dawn* and *Koro-sloping-towards-the-night* and would, we suggest, nicely correspond to halos around the rising Sun. *Hikurangi* mountain would mean "tail of Heaven" in Polynesian, but Papago *Hikunavangu* is "Navel Mountain." Both were equated with the mountain where the people were saved from the flood. In Mangaia, *Ikurangi* or *Rangimotia*, "end-of-Heaven," where the people were saved from the flood, was said to be at the center of the universe—much more fitting for the Uto-Aztecan meaning. It is said by the Maoris that the bird of the Sun dwelt in its house, *Totoka*, on *Hikurangi* mountain. In Tahiti, the bird of *Tane*, the youthful Sun god, is *kura* (PP**kula*), a red parakeet; among the Uto-Aztecan *Tarahumaras*, *kura* is a parrot, and the *Huichol* identify a red parrot as the messenger of the Sun. Such a role is appropriate for Mercury, always back and forth near the Sun, and in Hawaii, *Hoku 'ula* (probably from PP **Fetu*, "star," despite the vowel irregularity, and **kula*) is a name of Mercury. The house *Totoka* may come from **toka*, "spider," a word shared by Polynesian and Uto-Aztecan, although not the usual word. In both Polynesia and Mesoamerica, it is said that heroes or "demons" passed back and forth from heaven to earth by a spider's thread. As in other areas, the Moon goddess as a weaver may have been personified as a spider, although direct evidence is lacking both in Polynesia and in Mesoamerica. However, all visible planetary movements fall closer to the ecliptic than the ±5° variation of the Moon (see §2.3.4). We suggest that this 10° range constitutes the bounds of the "house" of the "bird-of-the-Sun."

The outer halo at 46° is close to the maximum elongation of Venus, about 48°. The birth of *Ruatapu* from the top of the mountain may well be a reference to Venus seen where (but of course not when) a rainbow would appear.

It is also said that the canoe of Maui grounded on *Hikurangi* mountain, and that the canoe of Maui is sometimes associated with Orion's Belt. Orion's Belt is also associated with or identified as a turtle in both Mesoamerica and the Tuamotus (as well as Burma and China), and the birth of a hero from a turtle shell depicted on Maya pottery again probably refers to Venus. A name for Venus shared in Polynesia and Mesoamerica is **soli* (Aztec *xolotl*, "slave," a dog-headed god often identified as Venus or one of its phases; Pap. *holi*, "slave," both from UA **soli*- Tahitian *Hori-poipoi* translated as "dog of the morning," a name for the morning star—cf. Sam. *soli*, "to treat as a conquered person," both from PP **soli*).

DHK thinks that one form of planetary god is the Heron, a bird associated with death and with eating human souls in the form of fish, with similar associations in both Mesoamerica and Polynesia. The Heron is one of the figures who ran off with the Moon goddess, **Sina*, and his name appears in Polynesia as *Matuku* or *Kotuku*; apparently related forms in Uto-Aztecan suggest an earlier form **tuka*. In New Zealand, it was said that *Matuku* lived in *Rua-o-Ra*, "the pit of the Sun," which would be appropriate for a planetary deity. On Mangareva, *te Rua Ra* was the name of the observation post from which summer and winter solstices were observed. If Heron is to be identified as a planet, the motionless bird waiting for a fish seems most reminiscent of slow-moving Saturn, but no very good reason can be advanced for Saturn rather than for Jupiter or even Venus. Among the Maya, *Heron* is sometimes pictured with the incorporated head of a god (see Figure 15.2), identified by DHK as Saturn.

Among shared items with shared names is the **puwa* tree, the *Plumeria* or frangipani, a Mesoamerican plant. With the locative-gerundial ending -**nga*, shared by Uto-Aztecan and Polynesian, we have **Puanga*, a widely attested Polynesian name for Rigel, which also has the meaning "zenith" in New Zealand, where Rigel is far from the zenith at meridian transit (cf. §11.2). Among the Micronesians in the Caroline Islands, the sky is conceived of as a giant house, and the top beam of the house is represented as the path of Rigel. In such a scheme, cross-beams roughly represent an equivalent of latitude, and it seems notable that **teka*, "cross-beam," is another word shared by Uto-Aztecans and Polynesians (compare with Figure 11.2). Finally, DHK suggests that the relatively rapid movement of the Sun along the horizon near the equinoxes may be responsible for a reference to this as the "place of movement," UA/PP **oli* plus locative-gerundial **nga*. As in Mesoamerica, Mangaians recognized a series of Thirteen Lords of the Night, beginning with *Lono*, embodied in a conch shell (Gill 1876, pp. 95–96). The 6th of these Lords was Tane-Kio, said to have been enshrined in the planets Venus and Jupiter.

This sampling of mythical terms that also seem to have technical astronomical meanings, and that are shared by Uto-Aztecan and Polynesian, strongly indicates that much of the mythology of Polynesia may have had an astronomical interpretation. There is also a strong suggestion of a historical connection, which DHK has interpreted as a movement of Uto-Aztecans into the Pacific, probably in the early centuries A.D.

In any case, it seems probable that many words of myth once had a degree of technical astronomical meaning, and now are largely lost. Further analysis of the mythology may throw substantial light on both Mesoamerican and Polynesian astronomy. Polynesia also seems to have had a Sirius cult sharing many features with the cult of Sirius among the Dogons (§8.4).

Recent work on Hawaii has revealed much more detail about ancient Hawaiian culture and astronomy than was previously known. Consequently, the remainder of this section will concentrate on the Hawaiian islands. The Hawaiian temples are called *heiau*, sacred places. They were of stone, with walls several feet high. Some had a series of parallel walls and elevated platforms and terraces in several tiers. The most important had many houses, with wood and thatch of leaves or grass (Stokes 1919/1991, p. 27). Stokes makes three main points among generalizations. The first is that the temples varied in importance and function. The second is that location depended on the function. The third is that orientation had to do with the contour of land or shore, an interpretation that will be discussed later. The most important temples belonged to the king or chiefs. There, sacrifices of bananas, coconuts, pigs, and sometimes humans were performed. Human sacrifices, however, took place only in the most important of these, the *luakini*, which belonged to the king. They were found in or near villages. There were also many temples for the commoners. Agricultural temples (*heiau ipu o Lono*, "Temple of the Gourd of Lono") were between fields and villages. Fish temples (*heiau ko'a*) were at or near the beach. Temples "of the priestly caste" were at or near the priest's residence (Kamakau as summarized by Stokes 1919/1991, pp. 32–34). The orientation, Stokes (1919/1991, pp. 35–36) says,

> was controlled by the situation. If situated on the shore, the temple lay parallel or at right angles to the immediate shoreline (not the overall lay of the coast). If slightly inland, the orientation would seem to depend primarily on the contour of the ground and secondarily on the lay of the coast. . . . Farther inland, it would be only the contour of the ground which would be considered. I could find no evidence in the foundations of orientation to cardinal points. It is true that some of them did lie almost true north-south or east-west, but this was because the situation required it.

Stokes (p. 21) also notes that they were usually located in some sort of "commanding position" like the crest of a hill. This still begs the question of why they were sited where they were, especially in light of the comment that one of the purposes in setting up a temple was for "sailing to Kahiki" (Kamakau as summarized by Stokes 1919/1991, p. 33). Stokes's view does not preclude the possibility of alignments to individual stars. In fact, Makemson (1941, p. 148) asserts that the heiau were associated with particular stars and that "each community and family formerly had its own star with which its fortunes were immutably associated."

The *Ahu a 'Umi* heiau has been described by da Silva and Johnson (1982) as indicating extensive star alignments and as recreating a cosmological scheme. This heiau is located on the pass between Mauna Loa and southwest of Hualālei, a dormant volcano on the island of Hawaii. It is traditionally believed to have been built for King Umi, the first ruler of the entire island. The measurements of the base rectangle are close to a 3 : 4 ratio, suggesting interior Pythagorean triangles. Eight small cairns (A to H) surrounded the main platform; these fell in approximately paired oppositions. The line B–F is at right angles to the line D–H, and the point where they cross is also very close to the crossing point of A–E. Da Silva and Johnson postulate alignments to the June solstice sunrise and to the December solstice sunrise and sunset as well as stellar alignments, but all of these are dependent on their establishment of a geometrically determined central point for the complex. While we think their determination is a reasonable possibility, we do not think it well enough established to be certain of any of the alignments.

Although it has been clear for a long time that astronomy played a central role in navigation and calendrics in the Hawaiian group, that certain places were associated with astronomically determined rituals, and that astrology was important, our knowledge of details has been spotty and inadequate. Recently, Francis Warther (1991a/1991b; Warther and Meech 1993) has begun to show that unified evidence from several lines of investigation suggest that Hawaiian astronomy was both more sophisticated and more pervasive than anyone had previously thought. He has also demonstrated the probable presence of types of alignment that we could only recognize with the aid of written or oral tradition.

Warther has provided evidence that certain alignments of natural features of the environment were recognized by the Hawaiians as markers and regarded as important. He has shown that certain monuments either alone or in alignment with topographical features or other monuments coincided with astronomical alignments. He has used traditions associated with monuments and natural features, including various mythical associations. The names of such features are a form of traditional evidence, and translations of the names are often very revealing. He has provided translations of charts demonstrating astronomical meaning.

Among the interesting mythical-topographic traditions is that Maui stood on Oahu on Pu'ulanihuli Mountain, "the hill of the turning around of the sky," to snare the Sun over Haleakala Mountain, "the house of the Sun," on Maui. An observer standing on Pu'ulanihuli would see the December solstice Sun rising over Haleakala. Another hill on Oahu where Maui stood was called Heleakala, "snare of the Sun," and was in the district called Nanakuli Ahupua'a, "Star Dog of the mound of the Pig," the "Star Dog" unidentified, but the "Pig" probably Sirius. It is also said that Oahu and Kauai were once linked by Maui's fish-line (his hook is widely identified in Polynesia with Scorpio). A line between the two islands matches December solstice sunrise/June solstice sunset.

One of the most intriguing areas is the Wailua district on the east coast of Kauai. Here, Warther has drawn attention to three heiaus or sacred spaces. He thinks that he has correctly identified two large boulders as *Pohaku 'ele'ele*, "very black stones." The two are aligned at the base to the rising of the December solstice Sun. The Malae heiau is an elaborate stone building with a five to six proportion of the sides, aligned 14 arc-minutes east of north. There are unusual extensions of the walls at the corners. With this structure, the diagonals mark the solstices, which in turn creates a massive play of light and shadow. Referring to the walls as "east," "south," "west," and "north," despite the 14′ offset, the east and south walls will be lit at the December solstice sunrise; the south wall will be lit at mid-day; and the south and west walls will be lit at sunset. The north wall will remain in darkness. The projections at the corners can be used like gnomons, and the shadow projections along the east and west walls should allow mid-day and true north-south to be determined with high precision when both east and west walls are in complete darkness. At the June solstice sunrise, east and north walls will be lit, the south wall will remain in darkness, and the north and west walls will be lit at sunset. From the Malae heiau looking northwest to the sunset, the sun will drop into a notch on the otherwise even horizon in that direction.

Warther also draws attention to towers called *anu'u*. He says that these were 40 ft high and built with an opening to the ground that was illuminated only by the Sun at zenith passage. Unfortunately, he does not give his source for this statement.

Necker Island, the most northwesterly of the Hawaiian group, was uninhabited at the time the first Europeans reached it. However, the 41 acres of the island contained 33 heiaus. It was on the Tropic of Cancer in 900 A.D., and its Hawaiian name was Moku Mana Mana, "the island of great supernatural power."

Near the shore line of Cape Kumukahi (Puna, Hawaii), there is a *heiau*, the north and west parts of which are of a natural outcrop of *pahoehoe* lava, built on the east and south corner with slabs of weathered volcanic stones. Just west of this platform was a small cairn (*ahu*). At the shoreline, on a natural lava rock, east of at lighthouse, which narrowly missed destruction in a 1960 lava flow, two *ahu*s can be found. They are conical in shape, and ~3 m high (see Figures 11.6d–f). The space between them was slightly greater than were their diameters (about 2 m each) near the base. From this site, several of the principal terrain rises in the area are visible: the Kapoho crater; the partially natural *heiau*; and the Pu'u Kuki'i cone on which is located another *heiau*, which according to Johnson (private communication 1993), was constructed by the 15th-century ruler, King Umi. The relatively fragile appearance of the twin *ahu*s makes it appear unlikely that they could have survived without constant rebuilding. This and the other *ahu* near the partially natural *heiau* indicate a continuing tradition of maintenance, even if the modern purpose has more to do with the veneration of ancient practices and constructs than for any practical purpose. Modern *ahus* of all kinds are commonly constructed by young Hawaiians, natives and non-natives alike; their purposes are certainly multiple.

At this point, we voyage to the Americas.

12 Mesoamerica

12.1. Introduction

Mesoamerica is a name given by archaeologists to the area that is now southern Mexico, Belize, Guatemala, most of El Salvador, and parts of Honduras (Figure 12.1) and inhabited by people who shared many cultural traits in pre-Columbian times. Table 12.1 indicates the approximate chronology for the cultures of Mesoamerica. Much of the area was ruled by the Aztecs in the time immediately before the Spaniards arrived in 1519. The people spoke over 70 different languages at that time. The economic base was sophisticated farming, and there was a well-developed bronze technology. A few cities were bigger than those of ancient Egypt or the Near East. Elaborate hierarchies of political, religious, and economic personnel directed the societies. Astrology here had the same kind of importance as in many other cultures. The largest group were (and still are) the members of the Mayan language family, speaking over 20 languages.

The Maya Classic Period lasted about 600 years in the early centuries A.D., and many buildings and monuments were erected during this time, especially throughout the jungle zone, which was the heart of the Maya civilization. There seems to have been no metallurgy in use, and indeed, there are no native metals in the limestone-based region. Domestic animals were limited to the dog, turkey, and bee. Hunting and fishing maintained an important role in the economy. At the end of the Classic, a conservative estimate puts the Maya at about 20 million people (Wilhelmy 1981, pp. 405–408). Maya cities were large and sprawling aggregates, often improperly referred to as "ceremonial centres." Contemporary cities in highland Mexico show a much more formal city layout. Most communitites were under the domination of hereditary rulers who practiced polygamy and appear on monuments or in books garbed as deities. Blood offerings and sacrifices of plants, animals, and human beings were common. In both areas, astronomical–astrological–religious factors entered into the planning of sites.

Although we know little of observational techniques of Mesoamerican astronomers, it is apparent that various sighting devices were in use and there is some evidence that obsidian mirrors were used as observing instruments. See the possible Maya astronomer in Figure 12.2.

Astronomy not only entered into the planning of sites and the layout of buildings, but it also was recorded in books and inscriptions. In highland Mexico, the most important books for astronomical study are the *Borgia* codex, the exact origin of which is in dispute, and the *Vienna* codex, perhaps from the Mixtecs, but a number of others, such as the *Nuttall* (or *Zouche*) codex, also from the Mixtecs, contain some important data. From the Maya, the *Dresden* codex has very important materials, including tables of planetary motions. Tables for Venus and Mars are now generally accepted. There is also astronomical material in the *Paris* and *Madrid* codices. Another book, the authenticity of which is still somewhat in doubt, is the *Grolier* codex, which contains a Venus table. Most of the several hundred known and legible Mayan inscriptions provide at least some astronomical knowledge, particularly on the phases of the Moon. Some give substantial amounts of astronomical information. Our understanding of Mesoamerican astronomy is increasing rapidly, but it is hardly an exaggeration to say that we know nothing of the history of astronomy in the region. It is worth pointing out that we do not know the native names of the various books that have been mentioned (indeed, there is little to suggest that they had names). Their present names usually derive from the European cities to which they were taken after the Spanish conquest, or from collectors or scholars. The books are actually folded pages of animal skin or bark paper, covered with lime plaster and painted.

Susan Milbrath (1999) has attempted to synthesize what is known of modern Maya stories and rituals relating explicitly or implicitly to astronomical lore and calendrics. She then compares this material to the iconography of the classic Maya on monuments and ceramics and relates it to specifically astronomical iconography in the Mayan codices. She also attempts to recognize associations of iconography with

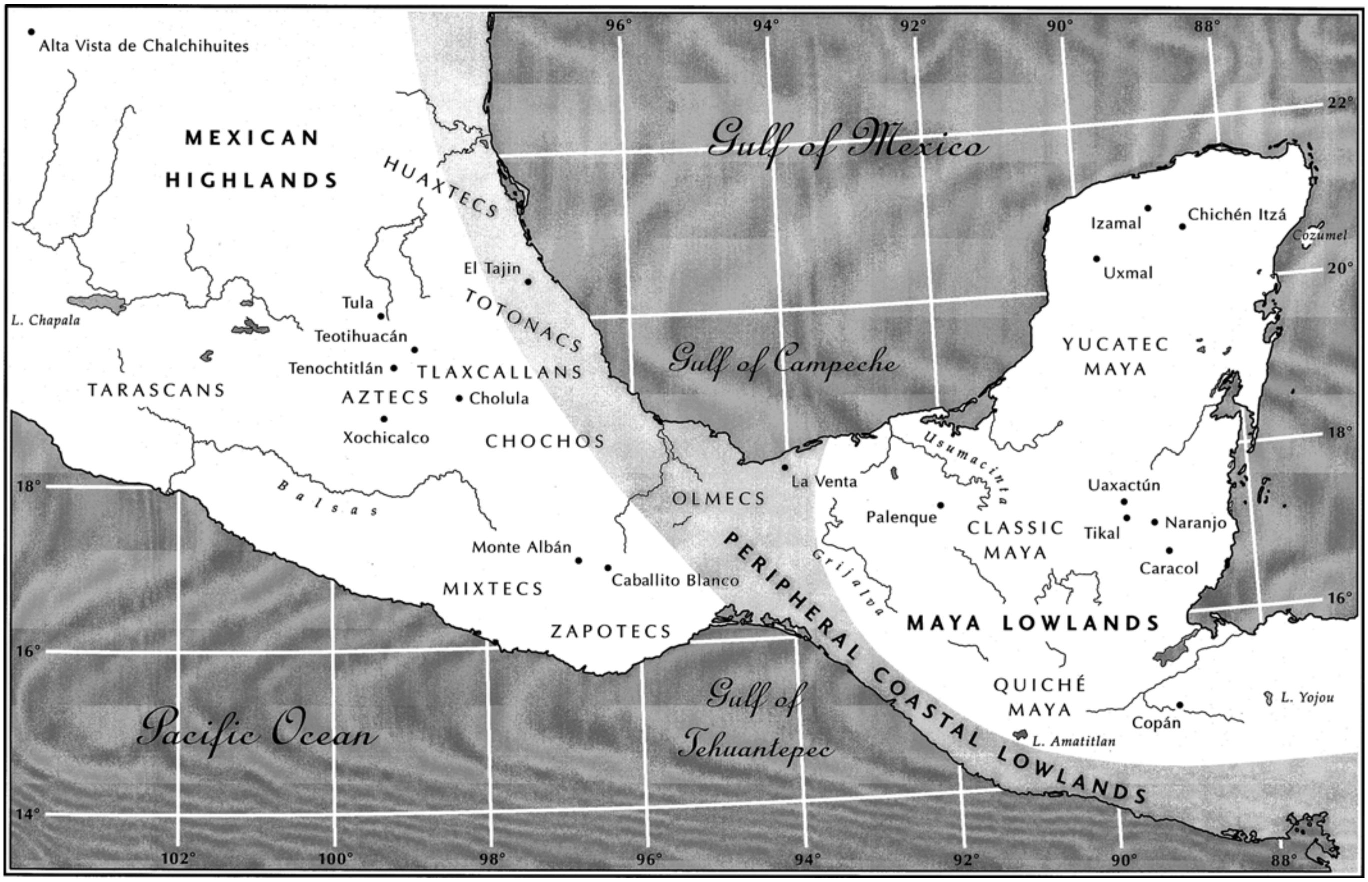


FIGURE 12.1. The Mesoamerica region, an area that is now southern Mexico, Belize, Guatemala, most of El Salvador, and parts of Honduras, was inhabited by people who shared many cultural traits in pre-Columbian times. Map kindly provided by David Mouritsen of Calgary.

real-time astronomical events. In all of these studies, she uses the 584283 correlation of the Maya calendar with our own (see Table 12.1 and §12.3 for the definition of the "correlation problem"). Milbrath has extensive discussions on Maya "constellations" and makes a serious effort to determine the mythical roles of planets and their identities as birds, animals, and gods. The approach integrates the evidence from folklore and iconography. The mythical imagery of Maya astronomy is better treated here than anywhere else. The calendrical evidence, however, is treated only minimally. The numerous illustrations are well chosen and helpful, but there are some curious flaws in the textual material. The most important of these is Milbrath's (1999, pp. 60–63) view that some kind of leap year intercalation was in effect in the post-Classic period, although this is inconsistent with the Thompson correlation, which she accepts. It is her view that the imagery of the Madrid Codex is seasonal and corresponds with the seasonal features of the Landa "year," to be discussed in §12.17.

A good view of where we now stand may be obtained in recent summaries by Thompson (1974), Aveni (1976), Lounsbury (1978), and Justeson (1989), with new interpretations by Bricker and Bricker (1983, 1986, 1989), by Kelley (1980, 1983, 1987, and 1989), and by S. Snow (1986). Kelley's

FIGURE 12.2. A dandy or an astronomer? A Jaina Island figurine, ff. P. Gendrop. Drawing by Sharon Hanna.

TABLE 12.1. Mesoamerican chronology.

Time frame	Settlements/cities		Comments
B.C.			
6000	Initial farming		Different in different areas
3000	First villages		Development of farming (corn, beans, squash, cotton); first pottery
1600	Olmec		Towns, monuments, major architecture; water control, dams
	Tlatilco		Writing?; bark beating
	Monte Alban		Development of urbanism
	Nakbe		
		7.16.0.0.0	Invention of full Mesoamerican calendar
		↑	
	Mirador	360 y	
A.D.		↑	Tropical year studies; zenith passages; alignments
		8.14.0.0.0	Emphasis on Venus and eclipses
	Teotihuacan	↑	
		600 y	(Classic Maya) Tables of mean planetary motion
	Xochicalco, Cacaxtla	│	
	Tula	│	Chichen Itza
		10.4.0.0.0	
(The length of the interval from 10.4.0.0.0 to 1240 A.D. constitutes the correlation problem)			
	Mixtec		
1240		Mayapan	
1428	Aztec		
1519			Spanish conquests

view that the correct correlation of the Mayan calendar with ours is unknown at present has been a factor in his acceptance of astronomical data incompatible with the widely accepted Thompson correlation. New historical evidence supports the Wells-Fuls correlation (see §12.3).

12.2. Structure of the Calendar and the Mayan Number System

Although both the year and lunations are recognized by most human groups around the world and recognition of stellar periodicities is not uncommon, the development or invention of really complex calendars is much more rare.

In Mesoamerica, such a calendar was invented, probably in the 1st or 2nd century A.D. Some components of that invention are still in use among Indian groups today. In its fullest form, among the Mayas, the calendar consisted of three main components: an era count (with one normal base and several alternatives), a 365-day year, and a 260-day period (sometimes called, with no strong basis, a *tzolkin*), functionally equivalent to the much shorter western week. Mayas and Mayanists normally put the era date first, followed by the 260-day date and the month date. These interlocking parts functioned beautifully to measure time precisely, accurately, and easily over as long a period as was desired. This basic function of a calendar was unmarred by any attempt to "correct" the calendar to make it conform to natural phenomena. The intercalary days or months that have wreaked such havoc with Eurasian attempts to measure time were completely ignored. The arguably impossible task of creating agreement among Sun, Moon, and stars was considered an irrelevant impediment to time measurement. Mesoamerican astronomers knew the length of the tropical year and various lunar and planetary periodicities with a very high degree of accuracy. Some of the time periods that they employ suggest attempts to measure such phenomena with a precision comparable to a calculation to five decimal places in our society. They did not, however, have our European and modern western preference for making adjustments to the measuring machine. Although evidence will be presented in §15.4.2 that the inventor of the calendar had a sophisticated knowledge of contemporary Eurasian calendar-making, this ability to recognize adherence to certain natural phenomena as a defect rather than a valuable goal makes it highly likely that the inventor was a native American (possibly, a *Chuh* speaker) rather than a Eurasian visiting a new environment.

The heart of the Mesoamerican system was the series of 260 days running endlessly as far into the past or the future as one wished to go, changeable only by the divine decree of a divine ruler or by a "war with heaven." This series consisted of 20 named days combined with 13 numbers (normally 1 to 13, although the *Azoyu* codices from Guerrero, Mexico, for an unknown reason, run from 2 to 14). The 20 named days in their Mayan and Aztec forms are listed in Table 12.2. Each series runs independently, with numbers repeating the entire series 20 times, the day names running from the 1st to the 20th for 13 times, before the number 1 is combined once again with the 1st day name and the combinations start again. Although the names differ in the many different languages of ancient Mesoamerica, they frequently embody similar or identical concepts. Both the

Table 12.2. Mesoamerican day names.

Aztec	English equivalent	Yucatec Maya
1. Cipactli	1. Crocodile	1. Imix
2. Ehecatl	2. Wind	2. Ik
3. Calli	3. House	3. Akbal
4. Cuetzpallin	4. Lizard	4. Kan
5. Coatl	5. Snake	5. Chicchan
6. Miquiztli	6. Death	6. Cimi
7. Mazatl	7. Deer	7. Manik
8. Tochtli	8. Rabbit	8. Lamat
9. Atl	9. Water	9. Muluc
10. Itzcuintli	10. Dog	10. Oc
11. Ozomatli	11. Monkey	11. Chuen
12. Malinalli	12. Twisted (a plant used for making brooms)	12. Eb
13. Acatl	13. Reed	13. Ben
14. Ocelotl	14. Jaguar	14. Ix
15. Quauhtli	15. Eagle	15. Men
16. Cozcaquauhtli	16. Vulture	16. Cib
17. Ollin	17. Earthquake	17. Caban
18. Tecpatl	18. Flint, flint knife	18. Etz'nab
19. Quiauitl	19. Rain	19. Cauac
20. Xochitl	20. Flower	20. Ahau

days and the numbers were associated with deities, and the deities were given calendar names. Kelley (1980) has argued that the calendar names were conceptualized as the birth of the deities and were counted from a single base and mark the astronomical identities of the deities. Illustrations of the 20 day names and their ruling deities from the central Mexican *Borgia* Codex are to be found in Figure 12.3.

The 365-day year (hereafter called the Mesoamerican year or My[1]) was broken into 18 named periods of 20 days each, and a nameless 5-day period (usually referred to by modern scholars as *uayeb*, one of many euphemisms used by the Mayas). The 20-day periods were called "moons" in many of the local languages and are called "months" in the modern literature, a term reflecting their functional correspondence with our months and perhaps their historical origin (Stewart 1984). The 18 Maya months are listed in Table 12.3. Due to a curious misconception among scholars, first corrected by Thompson (1950), a particular glyphic symbol that actually marks the day (or possibly evening) immediately preceding the 1st day of the month was construed as the "zero" of that month. Thompson showed that the true meaning of the glyph was something like "eve of"[2] and that the day written, for example, "*eve of* Uo" could also be written "*end of* Pop." We now know that the Mesoamerican year began with the 1st day of Pop and not with the incorrect "0 Pop" of earlier Mayanists. Unfortunately, this error is still common.

The relationship between the 260-day tzolkin and the months of the year is like our correlation of week-days and month-days, but more consistent. Because the intervals 20, 260, and 365 are all divisible by 5, only four of the 20 day names could begin the year. This was a source of endless confusion both for the Spaniards and for modern scholars because both the 260-day period and the 365-day period were each often referred to as "the calendar." The order of the day names and the way in which the day names were integrated with the positions in the months are indicated in Table 12.4, and an integrated list of Tzolkin and Haab cycles for a few years are given in Appendix D.

The beginning of the Maya 260-day "calendar" was *Hun Imix* ("One Crocodile" is a translation of the Aztec equivalent—see Table 12.2). Tedlock (1979) has shown that this beginning is no longer of any importance in calendar divination among the Quiche Maya time-keepers of Momostenango, but there is abundant evidence for its previous importance. The beginning of the 365-day "calendar" was the first of *Pop*. Earlier scholars, therefore, tried to fit the day 1 Crocodile to the first of Pop, and we have found that students often try to do the same despite warnings. It is impossible because the structure of the calendar allows "Crocodile" to fall only on the 4th, 9th, 14th, and 19th days of the months. The only days that could begin the Mesoamerican year during the Classic Period of Mayan history were *Akbal* (equivalent to "House"), *Lamat* ("Rabbit"), *Ben* ("Reed"), and *Etz'nab* ("Flint"). Any difference from this pattern is due to some sort of calendar change or reform. Among the colonial Maya, the following four days, viz., *Kan*, *Muluc*, *Ix*, and *Cauac*, had become the 1st of *Pop*. It is, however, possible that the days of the 260-day calendar began at one time of day and the days of the month began at a different time of day. This would account for a very small number of anomalous dates in the Mayan inscriptions and perhaps for that confusing use of the glyph that Thompson identified as "eve of."

In combining the day names with their positions in the month, it can be seen that any one day name can occur on only 73 days in the year (i.e., in four positions in each of the 18 months and once in *uayeb*). For example, 1 *Imix* may fall on 4 *Pop*, 9 *Pop*, 14 *Pop*, 19 *Pop*, on 4 *Uo*, 9 *Uo*, . . . , on 4

[1] The abbreviation *My* in this section will refer exclusively to "Mesoamerican years" and never to "Millions of years," a common astronomical reference.

[2] DHK: This is now known to mean "seating of."

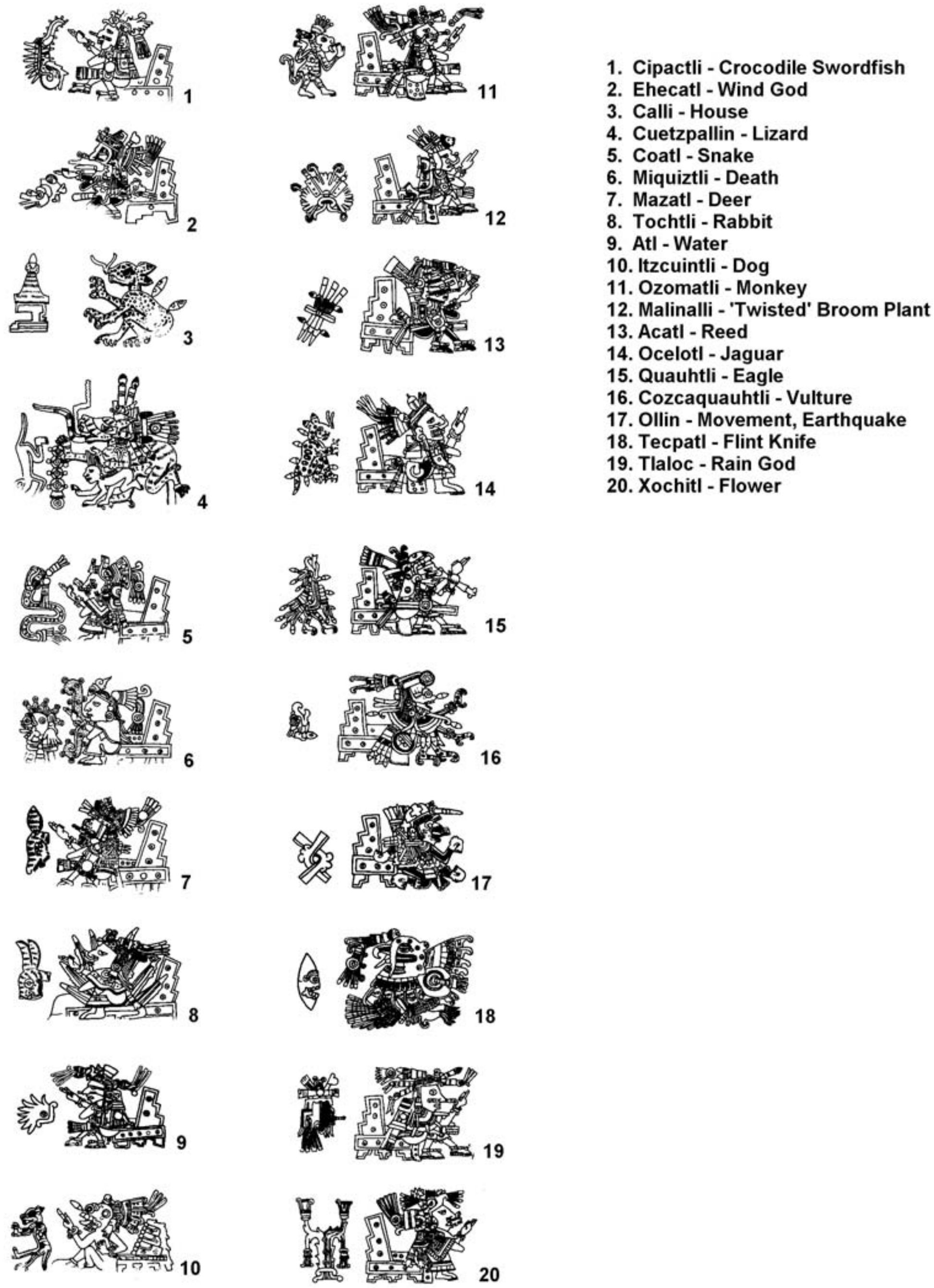


FIGURE 12.3. Central Mexican glyphs of the day names and the ruling deities of the days, from the *Borgia* codex. Drawing by Sean Goldsmith, ff. Caso.

Zip, . . . , and so on. It must occur in each of these positions before the combination of day name and month-position can recur, viz., after 73 × 260 = 18,980 days. The converse of the previous statement is that in any given month position, only four day names can appear and they must appear accompanied by each of the 13 numbers before the same day name can repeat with the same number in the same month position. This requires 4 × 13 × 365 = 18,980 days. This period is 52 Mesoamerican years (hereafter in this chapter, *My*) and is usually called the *calendar round* (abbreviated "*CR*") by modern scholars. Hence, any combination such as 7 Ix 2 Cumku can occur only *once* in 52 Mesoamerican years. This period was in use by most if not all of the groups in the area when the Spaniards arrived. In Mesoamerica today, most groups preserve only the 260-day cycle or only the 365-day cycle.

The existence of the 52-year cycle (CR) made it possible to name the year by a day falling in a specified position of the year. To the great confusion of modern scholars and perhaps the occasional confusion of the ancient Mesoamericans, different groups named the year by different day names, even though they agreed (within ±1 day) on what day was current. Hence, the beginning and ending points of the Maya year are different from those of the Mixtecs or Aztecs and probably different from many other groups. We know that different tribes had different deities, and it seems

Table 12.3. The months of the *Haab*: The 365-day Mayan year[a].

Month	Day running count: First	Last
Pop	1	20
Uo	21	40
Zip	41	60
Zotz	61	80
Tzec	81	100
Xul	101	120
Yaxkin	121	140
Mol	141	160
Chen	161	180
Yax	181	200
Zac	201	220
Ceh	221	240
Mac	241	260
Kankin	261	280
Muan	281	300
Pax	301	320
Kayab	321	340
Cumku	341	360
uayeb	361	365

[a] The 365-day year consists of 18 named months of 20 numbered days each and 1 "unlucky" period of 5 days. A *Haab* date is analogous to specifying a date and month in the Gregorian calendar; for example, the day 14 *Yaxkin* is followed by 15 *Yaxkin*. The 20th day of the month is designated "end" or "seating" (sometimes incorrectly translated as "zero"). Thus, 19 *Yaxkin* is followed by "end" *Yaxkin* (or "seating" *Mol*), which in turn is followed by 1 *Mol*.

Table 12.4. The Tzolkin[a] component of the Mayan calendar and the month positions of days.

Tzolkin (above) and									
1	*Imix*	2	*Ik*	3	*Akbal*	4	*Kan*	5	*Chicchan*
6	*Cimi*	7	*Manik*	8	*Lamat*	9	Muluc	10	*Oc*
11	*Chuen*	12	*Eb*	13	*Ben*	1	*Ix*	2	*Men*
3	*Cib*	4	*Caban*	5	*Etz'nab*	6	*Cauac*	7	*Ahau*
8	*Imix*	9	*Ik*	—					

Corresponding month positions (below)				
19	"End" or "seating"	1	2	3
4	5	6	7	8
9	10	11	12	13
14	15	16	17	18
19	"End" or "seating"	—	—	—

[a] The 260-day cycle (*Tzolkin*) consists of 20 day names, 13 numerals (read across, then down), each sequence continuously repeating. These sequences run simultaneously with the numbering of the days in each month, which are indicated below the Tzolkin. The month name stays the same, however, until the sequence of 20 numerals of month days is completed. Thus, the date 7 *Ahau* 18 *Zip* is followed by 8 *Imix* 19 *Zip* and then by 9 *Ik* "end" *Zip* (or 9 *Ik* "seating" Zotz). A spreadsheet sequence of a few years of combined *Tzolkin* and *Haab* cycles is given in the Appendix.

possible that each tribe named the year from the day of the festival of their god. With available data, this idea cannot be checked for most groups. The meshing of the 260-day cycle with that of the 365-day cycle has been likened to a meshing of gears, but such an analogue, although useful to us in a modern, industrialized society, should not be interpreted as

Table 12.5. The long count component of the Mayan calendar.

BB.KK.TT.UU.DD, where
DD ≡ *KINS* (days)
UU ≡ *UINAL* = 20 *KINS*
TT ≡ *TUN* = 18 *UINALS* = 360 KINS
KK ≡ *KATUN* = 20 *TUNS* = 360 UINALS = 7200 KINS
BB ≡ "BAKTUN" = 20 *KATUNS* = 400 TUNS = 7200 UINALS = 144,000 KINS

the way the Mayans thought of the interrelationship. The 52-year cycle was a *bundle* of years for the Mayas, and for the Aztecs, a *binding of the years*, a final gathering together of units of time like the tying of sheaves.

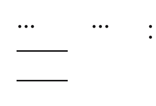
The third component of the Mesoamerican calendar, the *Long Count*, noted in Table 12.5, is known from a few very early monuments in the Olmec and Izapan styles and from the Mayas, but it is not part of the calendar in most other areas. It is a count from an era base, given in repeated intervals of time that have elapsed from a certain date in the remote past. This date was far remote even at the time of the earliest dated monuments. The periods of time normally used in this (or other) era counts were

(1) 144,000 days, usually called a "baktun" or Cycle and composed of 20 smaller units of 7200 days each;
(2) 7200 days, the *katun*, composed of 20 units of 360 days each;
(3) 360 days, the *tun*, composed of 18 units of 20 days each;
(4) 20 days, the *uinal*; and
(5) the day, or *kin*—the basic unit of the *long count*.

The term *baktun* does not come directly from the Maya, but it is a logical extension of the system names by scholars; we emphasize its artificial origin here and in Table 12.5 to make clear the distinction between it and the other names. Elsewhere in the text, the quotation marks will be omitted.

Longer units were occasionally used as well. The modern analog of this calendar component is the Julian Day Number. Now, we will describe the Mayan number system and its representation.

All numbers may be written with only three symbols: a dot for 1, a bar for 5, and a shell for 0. The shell marked the completion of a series, not of 10, as in our system, but of 20 (except in the second position, where 18 units completed the series). Hence, the statement 18 + 3 = 21 would be written as



In such a case, the *18* and *21* would normally be written in red, and the interval (*3*) in black. The place positions in a date of the Late Classic Period of the Mayas might be written as

9.19.19.17.19 6 Cauac 17 Zip.

If one day is added to this date, it becomes

10.0.0.0.0 7 Ahau 18 Zip.

This has been called a modified vigesimal system, in which 18 units of the 2nd position (from the right) become one unit of the 3rd position, but all other changes are of 20 units becoming 1 unit of the next position. It has also been argued that the last two units are not "really" part of the system but should be considered a separate count of days (Closs 1977). Although some mathematicians may be troubled by this irregularity, there is little practical difficulty in reading numbers, for the days are included in the count without differentiation and 359 days (written: 17.19) is always followed by 360 days (written: 1.0.0). Finally, the only calculations we have deal with calendrical matters; it has been suggested that the Mayas avoided this irregularity in other forms of counting, but there are no data to support this. The Mayan codices normally contain dates and intervals written in a pure place value system, but the monuments usually include glyphs for the names of the periods.

Historically, the most important era base was a date 4 Ahau 8 Cumku, which was both the zero date of a new era and the completion of 13 baktuns from a previous era base. This base was normally written

13.0.0.0.0 4 Ahau 8 Cumku.

For a long time, this was thought to mean that counts began over when they reached 13 cycles. This is untrue. It is more comparable to our practice when we say that the year 753 A.U.C. (era of the founding of Rome) was followed by the year 1 A.D. (of the Christian era), shifting from one era base to the other (cf. 4.1.5). No one would suggest that every time 753 is reached in an era count we start over:

In Figure 12.4, we show a date as it may appear in the inscriptions, written as *9* cycles or *baktun*s, *16 katun*s, *4 tun*s, *10 uinal*s, and *8 kin*s or days. Scholars usually transcribe this as 9.16.4.10.8. We also show this date as it may appear in the codices, written with a place value notation as

9.16.4.10.8 (12 *Lamat* 1 *Muan*)

FIGURE 12.4. A date, 9.16.4.10.8 12 *Lamat* 1 *Muan*, as it may be written in the inscriptions (left) or in the codices (right): The first part of the date is read, *9* cycles or baktuns, *16* katuns, *4* tuns, *10* uinals, and *8* kins or days. Drawing by D. Zborover.

Like all other dates, era bases such as 9 *Kan* 12 *Kayab* and 4 *Ahau* 8 *Cumku* recur every 52 years. Thus, for example, 9.9.16.0.0 4 Ahau 8 Cumku was a tun ending during the Maya Classic Period. Fifty-two Mesoamerican years later, it was 9.12.8.13.0 4 Ahau 8 Cumku. Such counts from the era base are normally referred to as Long Count dates. A parallel system has been called the *Short Count*. In its minimal form, this simply referred to an event as happening in a certain tun of a certain *katun* named for its ending day, for example, "in the 10th *tun* of (*katun*) 4 *Ahau*." Because *Ahau* can be preceded by any of 13 numbers, such a date will recur every 260 tuns (of 360 days each) in the katun order: 11 *Ahau*, 9 *Ahau*, 7 *Ahau*, 5 *Ahau*, 3 *Ahau*, 1 *Ahau*, 12 *Ahau*, 10 *Ahau*, 8 *Ahau*, 6 *Ahau*, 4 *Ahau*, 2 *Ahau*, 13 *Ahau*, 11 *Ahau*, 9 *Ahau*, and so on. Now, a full calendar round date recurs only at intervals of 52 Mesoamerican years (of 365 days each); so the 5th repetition of the calendar round will recur every 260 years ($5 \times 52 \times 365$) but will be off from the tun repetition ($13 \times 20 \times 360$) by 1300 days. Hence, a Short Count date, including the CR such as 6 *Cauac* 17 *Zip* in the 20th *tun* of *katun* 7 *Ahau*, implies the Long Count date 9.19.19.17.19 6 *Cauac* 17 *Zip* and will recur only after 18,980 *tuns*. This method of dating was used in inscriptions at Chichen Itza.

For a fuller discussion of how to calculate in Maya, see Sanchez (1961). This book shows how easy it is to do multiplication, division, addition, and subtraction using the Maya system, although some scholars have denied that the Maya used these simple procedures. There is, however, no evidence of the use of fractions. The Maya equivalent was to give calculations spanning a very long period of time. Whereas we may say that an average synodic period of Venus was 583.920 days, an equivalent Maya statement would be that 1000 Venus periods contained 583920 days. Unfortunately, working out Maya statements of this sort is not as simple as this example may suggest, for we usually have only the results of the calculations and these may include other factors such as reaching the nearest Venus date at a spring equinox or something of this sort.

12.3. The Correlation Problem

Because various versions of the Mesoamerican calendar have been recorded in regular use from the time of the first arrival of the Spaniards to the present time, it would seem to be a simple matter to determine what day of our calendar corresponds to a specified day of the Mesoamerican calendar. Indeed, the agreement in our sources for the colonial and modern period is such that we can say with assurance that JDN 2447893, 1 Jan 1990 (Gregorian), corresponds to a Mayan date: 11 Muluc 7 Kankin and to the equivalent Aztec date: 11 Water of the year 4 Rabbit, with a possible error of not more than ±1 day with respect to the colonial calendar. Unfortunately, the era base had ceased to be used before the Spaniards arrived; so the Long Count position is not known, and we do not know if any shift in the CR occurred. Determining the equivalence between our calendar and the classic Maya dates is the *correlation* problem. The solution to the problem is defined as the number of days that must be added to a particular Mayan Long Count date to equal the Julian Day Number (cf. §4.1.5). This interval is normally called the *correlation constant* and was occasionally referred to in the older literature as the *Ahau equation*. Over 30 correlations have been proposed in the past century, differing by over 1200 years, and many others have been considered. Most Mesoamericanists at the present time favor one or the other of the two solutions proposed by J. Eric Thompson. His first solution was 584,285, which seems to agree with data on eclipses and new moons as usually interpreted; later, he revised this by two days to 584,283, which agrees better with modern calendrical evidence but less well with astronomy. If there never has been a major calendar revision (and we have no direct evidence for such a major revision), the true correlation should be one of the two Thompson correlations or one deviating from 584,284 (±1 day) by some multiple of 18,980. These are called *continuity correlations*. In the Mesoamerican calendars still in use, 12 Kan 2 Pop (shifted in some cases to 1 Pop) was the equivalent of JDN 2440 328 ± 1 Apr. 16, 1969. In continuity correlations, this is a repetition at an undetermined number of CRs of 10.2.8.9.4 12 Kan 2 Pop, the date of the Initial Series Lintel at Chichen Itza, still in the Maya Late Classic Period. The archeological evidence and the historic evidence make it virtually impossible for this date to be later than 1200 A.D. Even the Diettrich correlation, which would put the date in 1189, or the Vaillant correlation No. 1, which would put it in 1187, seem unacceptably late to DHK. The correlation 660,205, now preferred by DHK, would put the Lintel in 1085. The widely accepted Thompson correlations would put the Lintel 208 years earlier. A considerable number of Mesoamerican lists and statements of the correlation of native day names with the Julian or Gregorian date may be found in Caso (1967). It is disconcerting to find highly competent scholars accepting both a pre-Columbian leap year and a Thompson calendar correlation for the Maya. Those two correlations are entirely based on the premise that there was no leap year and that the same system was in step from Michoacan to Yucatan and Guatemala and from the Classic Maya to the 20th century. For a full discussion of the correlation problem, see Kelley (1983, 1989), where it is suggested that there is evidence for a calendar reform of some sort in the 10th century and that there are at least 8–10 reasonably probable criteria that the Thompson correlations do not meet. They include a considerable number of astronomical interpretations that appear later in this book. Most of these are met by the correlation 663,310, proposed by Kelley (1983), but evidence on the Uaxactun alignment and its relationship to the inscriptions (cf. §12.21) suggests that this too is incorrect. A solution to the problem should bring the astronomical evidence into much clearer focus. A list of a number of correlations that have been proposed is found in Table 12.6. Bryan Wells and Adreas Fuls independently developed the correlation 660,208. This is a modification of the continuity correlation 660,205. Strong historical evidence indicates that these correlations (three days apart) give dates falling in the correct year.

12.4. The Old Ball Game at Yaxchilan

Although some dates at the Maya site of Coba give dates counted from an era base that seems to be back from the time of the monument by a 20-term interval, they are badly eroded and neither the period glyphs nor the context can be determined. At Yaxchilan, a Maya site on the Usumacinta river, a 13-term date incorporates the normal 5-term date of an initial series, although the normal era base would appear in this system at 13.0.0.0.0.0 rather than at 13.0.0.0.0. The glyphs used in the calculation are shown in Figure 12.5. We cannot read the Maya names for any period longer than the katun, but Mayanists have used the pseudo-Maya terms *baktun* for the 400-tun period, *pictun* for the 8000-tun period, *calabtun* for the 160,000-tun period, and *kinchiltun* for the 3,200,000-tun period. Variant forms of the glyphs for these periods are known from a number of inscriptions. No one has devised names for the glyphs of the longer periods known only from this Yaxchilan inscription. The longest period in this inscription refers to 10,240,000,000,000 tuns. The date is that of a ball game, played by the ruler of Yaxchilan, and the cosmic implications of ball games in Mesoamerica are clear in the illustration. The giant balls were put into play by rolling them down the steps of a pyramid. In the illustration, one can see a captive apparently bound to the ball. Among the subordinate figures in the scene are two dwarf-like "star-birds," marked by star glyphs on their wings. Aside from the tremendously remote era base, a number of dates in the text are separated by long intervals within the historic period. No one has yet thrown light on the context of these dates.

One of the factors involved may be lunar. The number 13 is associated with the Moon, as are extremely large parameters. The introduction to the *Dresden* (codex) eclipse table contains a series of thirteen *13*s. In the light of the Yaxchilan inscription, DHK would suggest that this is a date counted from the same base and going into the future. The interval from the base of the eclipse table,

9.16.4.10.8 12 Lamat 1 Muan to
13.13.13.13.13 4 Ben 1 Kankin,

is an interval of 3.17.9.3.5 (or 557,705 days). A modern calculation of 3218 eclipse half-years is 557,708.58 days. Now 18376 mean lunations (i.e., synodic months) are equal to $557{,}720.22^d$. Therefore, if we start at a lunar eclipse, after this interval we will have a solar eclipse, and vice versa.[3] The coincidence of the eclipse interval with such a numerologically important date may have provided important confirmation to the Maya of the validity of their systems.

[3] We do not know, of course, that an eclipse occured on the date at the base of the eclipse table. To clarify the intervals, the tabular interval is 557,705; the nearest eclipse half-year multiple is $557{,}708.58^d$; and the number of mean lunations is 557,720.22 days, 15 days or about half a lunar cycle later.

Table 12.6. Proposed Maya correlations.

In the correlation of	The Maya date 10.4.0.0.0 corresponded to:		Correlation constants of continuity correlations		Miscellaneous correlation constants	
		285 A.D.	356,523			
		337	375,503			
Joyce	378 A.D.					
Bowditch	379					
		389	*394,483			
		441	413,463			
		493	432,443			
		511			438,906	Willson preferred
		540			449,818	Bunge
		545	451,423			
		597	470,403			
Pio Perez	617					
De Rosny	624					
		630			482,699	Smiley preferred
Valentini	635					
		643			487,410	Owen
Brasseur	647					
		648			489,138	Makemson preferred
		649	*489,384	Spinden		
		672			497,879/8	Dinsmoor
		678			500,210	Smiley #2
		700			507,994	DHK
		701	508,363			
		748			525,698	DHK
		753	527,343			
		805	546,323			
		824			553,279	DHK
		857	565,303			
		893			578,585	Hochleitner
		909			584,280	Goodman
		909			584,281	Martinez
		909	*584,283/5	Thompson		
		910			585,789	Cook de Leonard
		920			588,466	Mukerji (Kali Yuga)
		920			588,626	Pogo
		936			594,250	Schove preferred
		961	603,263			
Sapper	963					
		977			609,417	DHK
		995			615,824	Schove #2
		1013	622,243			
		1025			626,927	Kreichgauer
		1065	641,223			
		1117	660,205			
		1117			660,208	Wells-Fuls
		1125			663,310	DHK preferred
		1155			674,265	Hochleitner
		1167			678,585	Aldana
		1168			679,108	Escalona Ramos
		1168	*679,183	Vaillant preferred		
Lehmann	1173					
		1222	698,164	Dittrich		
		1274	717,143			
		1324	736,123			
		1376	755,103			
		1428			774,078	Weitzel
		1428	*774,083	Vaillant #2		
Seler	1480					
		1532	812,043			
		1584 A.D.	831,023			
Forstemann	1607 A.D.					

* Denotes continuity correlations that also match the *katun* count.

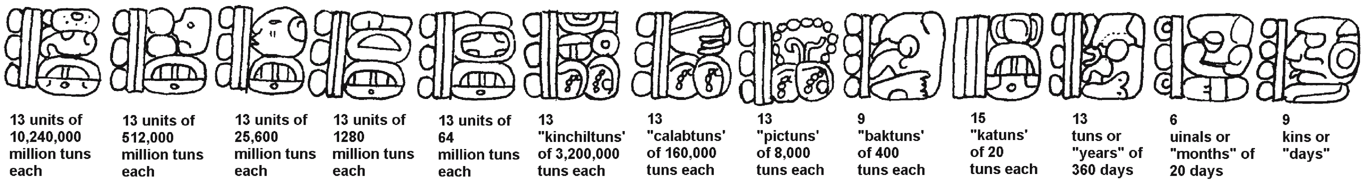


FIGURE 12.5. Period glyphs from the Yaxchilan ballcourt inscription, from Structure 33, Hieroglyphic Stairway 2, Step VII: It is the date of a cosmic ball game. Drawing by D. Zborover.

The interval 557,705 days is 1527 Mesoamerican years and 350 days. Because 1508 My (550,420 days) equals 1507 tropical years (550,420.00^d), the seasons would have occurred at nearly the same positions of the calendar at 9.16.4.10.8 and at 13.13.13.13.13. The date 4 *Ben* is associated with the World Ages (discussed briefly in §15.2).

12.5. Planetary Glyphs from Pacal's Coffin

Thomas Barthel was the first to recognize that seven of the symbols in the so-called "planetary band" on the coffin of Pacal, king of Palenque, were the symbols of the "seven planets" of the ancient world in their weekday order. The relevant inscription from the coffin is reproduced in Figure 12.6. The 1st glyph in the continuous band on the left appears to be the stylized head of the Sun god, although some have disputed this. The crescent Moon in 2nd position is unmistakable, as is the monster head that identifies the patron deity of the month Zip, the Mars deity repeatedly shown in the Dresden Mars table (cf. §12.6 and §12.8). The "star" glyph used for Venus appears in the 6th position. The remaining three glyphs (postulated as Mercury, Jupiter, and Saturn) require more discussion.

$1\frac{1}{2}$ mean synodic periods (cf. §2.4.4) of Mercury ($115.8^d + 57.9^d = 173.17^d$) correspond closely with half an eclipse year (173.31^d; see §5.2.2). The crossbands, in DHK's opinion, refer to a Mercury marker of the crossroads of Sun and Moon near an eclipse. It may be relevant that the cross is sometimes shown in Aztec sources as a symbol of *Quetzalcoatl*, whom Kelley has identified as Mercury. These items suggest that the crossbands may be associated, at least sometimes, with Mercury.

The last glyph in the series is the "night" glyph, also found as a day name, corresponding to Aztec "house." The Aztec god of this day is Tepeyollotl, "Heart of the Mountain," a lord of animals and a jaguar god of the underworld, thus, according to the arguments of Kelley (1980, pp. 522–524), corresponding with either Jupiter or Saturn. The great bird who appears as the pseudo-Sun in the Popol Vuh seems to correspond with the so-called "Principal Bird Deity" of Mayan and Izapan monuments, who is marked with the "night" glyph. The role as "pseudo-Sun" may refer to the Saturnian synodic period of 378 days, closest of the anciently known planetary periods (i.e., excluding Uranus, Neptune, and Pluto) to the tropical year. Kelley (1972) has argued previously that Tepeyollotl corresponded to the Hindu Prajapati, "Lord of Animals" (see §15.3.2.1), identified as a pseudo-Sun and as the planet Saturn. It could then be expected to find the "night" glyph representing Saturn. The remaining glyph appears in the 5th position, which is appropriate to Jupiter. The context afforded by the other six glyphs seems to make this identification nearly certain. The presence of the planets in their Old World weekday order on Pacal's coffin is one of the striking pieces of evidence that convinces DHK that much of Mesoamerican astronomy is derived in modified form from the Old World.

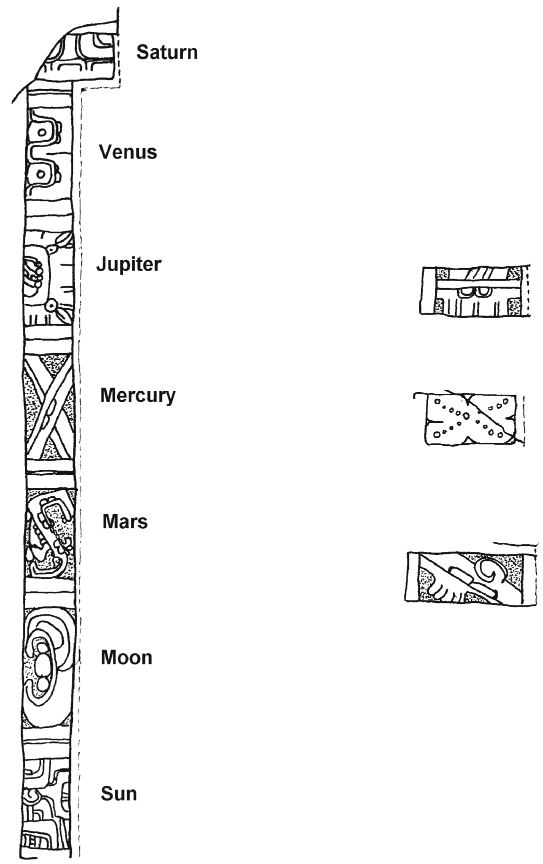


FIGURE 12.6. The "planetary band" glyphs from the top of the coffin of Pacal, ruler of Palenque, possibly representing planets in their weekday order, as originally postulated by Thomas Barthel: The 1st glyph may be the stylized head of the Sun god. The crescent Moon in 2nd position is unmistakable, as is the monster head that identifies the Mars deity of the Dresden Mars table. The "star" glyph used for Venus appears in the 6th position. The remaining three glyphs in the band and the three to the right are discussed in the text. Drawing by D. Zborover.

There are also three glyphs from the right side of the coffin lid shown to the right in Figure 12.6. These seem to be astronomical glyphs and may be associated with the multiple levels of Heaven.

12.6. Calendar Names of Gods and Planetary Identities

In parts of Mesoamerica, most or all of the deities seem to have had both proper names and calendar names that marked the date of their birth. Humans were also named in this way. In discussing calendar names and dates, we follow Long's (1926, p. 239) convention of citing dates with an ordinal number such as 13 Wind, 9 House, and so on, and names of humans or gods as Thirteen Wind, Nine House, and so on.

Seler (1902–1903/1960–1961, pp. 17–19) had argued that three dates in the mythical past at Palenque were the birth dates of three gods, who could be identified if the dates corresponded with their calendar names. The arguments and supporting dates for this view were amplified by DHK (Kelley 1965). It is now accepted that the dates refer to the births of three gods who were called the "Palenque Triad" by Berlin (1963) and designated "GI," "GII," and "GIII." The dates and births were recorded as:

1.18.5.3.2	9 Ik 15 Ceh	birth of GI — Venus
1.18.5.3.6	13 Cimi 19 Ceh	birth of GII — "Jaguar Baby"
1.18.5.4.0	1 Ahau 13 Mac	birth of GIII — (God K)

The general conclusion has been accepted but the details based on the calendar names have not. DHK argued that Nine Wind (9 *Ik*) was the name of Quetzalcoatl in central Mexico, the equivalent of Maya *Kukulcan*, widely identified as Venus. Among the Mixtecs, colonial sources said that there were two supernatural brothers, both named Nine Wind, children of One Deer. One Flower (1 Ahau) was the central Mexican name of *Cinteotl* (Corn God) and of *Xochipilli* (Flower Prince), a Sun god. The Quiche Maya equivalent, *Hun Hunahpu*, was the name of a decapitated god, whose head in the form of a gourd impregnated the young goddess who eventually gave birth to the twin heroes. The date 1 Ahau 13 Mac appears in the *Dresden* Venus table and seems to be associated with the tropical year. The least well documented of the triad is Thirteen Death (13 Cimi), a lord of the underworld, although here given the name of the "Jaguar Baby," one of the twins.

The only attempt to collect the known calendar names of the Mesoamerican deities is by Caso (1961, 1967). Sometimes the same calendar name was applied to completely different deities, and sometimes a single god had several different calendar names. Despite the obvious implications of chronological sequence in the array of calendar names, no one had attempted to determine any rationale for the names until Kelley (1980) did so. In that monograph, Kelley attempted to demonstrate that a large number (potentially all) of the calendar names were counted from a single base, 12.8.19.0.8 12 Lamat 1 Pop, a Maya New Year's day named by the equivalent of highland Mesoamerican 12 Rabbit. This base date falls approximately 216 years before the normal Maya era base at 13.0.0.0.0 4 Ahau 8 Cumku. The number of days from the base date to the date that supplied the calendar name often defined obvious astronomical intervals. Because the calendar names repeat after 260 days and nothing inherently indicates which repetition is significant, this introduces an element of doubt into the analysis. However, it was found that the deities were frequently lords of the month in which a particular repetition of their calendar name fell. This greatly reduces the probability of error. Kelley (1980) identified over 40 calendrically named deities as associated with particular astronomical intervals. Because all the identifications rest on the single hypothesis, all are strongly interlocked and the bulk of the identifications must be accepted or rejected as a unit, although some secondary identifications after several repetitions of the day name, are more dubious. In the years since the publication of that study, very few scholars have formally accepted or rejected the premises on which it rests. Because the identifications shed a mass of light on Mesoamerican astronomy and because they still seem to us compelling, most of the identifications are included here, together with some new evidence on the general hypothesis and on some of the identifications (see Table 12.7).

Table 12.7. Postulated astronomical identities of gods from calendar names.

Table 12.7(a). Planetary deities.

Planet name	Mean synodic period(s)	Calendar date and distance from base and notes on Madrid table	Names of Gods in the 260-day period	Deity associations of the months
Mercury	115.8774 (inferior conjunction)	115. 9 Ik 15 Xul Depiction of Quetzal-snake	Nine Wind Quetzalcoatl (Quetzal-snake)	end of Xul dedicated to Kukulcan (Quetzal snake)
		(172. 1 Cauac 12 Ch'en)	One Rain, Mixtec rain god	
	173.8161 ($1\frac{1}{2}$) (superior conjunction)	175. 4 Ik 15 Ch'en Depiction of Chac, Rain God	Four Wind Tlaloc-Quetzalcoatl	Ch'en = Tititl, magic to bring rain
		231. 8 Etz'nab 11 Ceh	Eight Flint Tlaloc-cihuatl (Rain god woman)	
	231.7548 (2) (inferior conjunction)	232. 9 Cauac 12 Ceh	Nine Rain Tlaloc	

Table 12.7. *Continued.*

Planet name	Mean synodic period(s)	Calendar date and distance from base and notes on Madrid table	Names of Gods in the 260-day period	Deity associations of the months
		Table 12.7(a). Planetary deities.		
	289.6935 ($2\frac{1}{2}$) (superior conjunction)	291. 3 Etz'nab 11 Muan	Three Flint. Mixtec goddess (Feathered Serpent) (wife of 293. Five Flower—Xolotl, i.e., Venus at inferior conjunction)	
	405.5709 ($3\frac{1}{2}$) (superior conjunction)	406. 1 Ben 1 Zip	One Reed Quetzalcoatl of Tullan (son of Mixcoatl, Jupiter, day 399)	
	463.5096 (4) (inferior conjunction)	465. 8 Eb 19 Zec Depiction of Chac, Rain God	Eight Twisted Chalchihuitlicue, Jade Skirt, sister or wife of Tlaloc	Zec = Tepeilhuitl, feast of Mountain Tlalocs
Saturn	378.09208	379. 13 Cimi 14 Pop	Thirteen Death Black God of the Underworld	Pop = Miccailhuitontli Water Lily Jaguar — Little Feast of the Dead, dedicated to Yacatecuhtli, Black God of Merchants
Jupiter	398.867	399. 7 Cimi 14 Uo	Seven Death Vucub Came, Lord of Death	Uo = Ue Miccailhuitl Knotted Jaguar God M. Black God — Great Feast of the Dead (death of Yacatecuhtli)
Venus	291.96083 ($\frac{1}{2}$) (inferior conjunction)	293. 5 Ahau 13 Muan	Five Flower Macuilxochitl, God of games and the ballgame — Name of Xolotl god of ball-game means "slave," dog-headed	
	(heliacal rising)	298. 10 Chicchan 18 Muan	(Base of 104-year solar cycle in which the 18 Muan dates will shift from heliacal rising to inferior conjunction, marked in *Madrid* as *haab-cuc*, "cycle of years")	
	583.92166 (superior conjunction)	583. 9 0c 18 Zac	Nine Dog Chantico Fire goddess, changed into a dog	
	2335.68664 (4) (superior conjunction) (shifts to approximate inferior conjunction 52 years later)	2338. 9 Chicchan 18 Mol	Nine Snake, one of the 5 major bases of the *Borgia* Venus table Xolotl	
	1167.84332 (2) (superior conjunction)	–1168. 1 Ahau 13 Muan	One Flower Hun Ahau, Lord of Underworld 1 Ahau, repetitious base of *Dresden* Venus table	
	17809.61063 ($30\frac{1}{2}$) (inferior conjunction at autumn equinox)	17813. 1 Ahau 13 Muan	One Flower Centeotl, corn god, Hunahpu	
Mars	779.936	781. 12 Lamat 11 Zip	(Twelve Rabbit) Cf. Sky peccary with 12 Lamat, *Dresden* p. 68a, cf. 12 Lamat dates at Mars intervals in *Dresden*	Zip = Ochpaniztli patron the sky peccary of *Dresden* 780-day table —"Mars beast" of Willson — mock battles of warriors cf. Huitzilpochtli Aztec war god, as youngest born of gods
		1561. 12 Lamat 1 Xul	Repetition close to a node passage, which would be followed by a solar eclipse at 4 Ben and preceded by a lunar eclipse on 2 Etz'nab (Flint Knife) (10 days earlier). Every alternate repetition of the Mars cycle will show a similar pattern for a very long interval. It is also close to $13\frac{1}{2}$ Mercury cycles. This may explain why Huitzilopochtli decapitates his sister the Moon and is a son of Tlaloc.	

Table 12.7. *Continued.*

Table 12.7(b). Lunar deities.

Node goddess		Old Moon goddess		Conjunction deities	New Moon goddess		Eclipsed Full-Moon goddess
173. 2 Ahau 13 Ch'en Two Flower, assistant pulque goddess				1. 12 Lamat 1 Pop			
174. 3 lmix 14 Ch'en Three Crocodile, pulque goddess		178. 7 Chicchan 18 Ch'en, Chicome Coatl, Seven Snake, Corn goddess—day of Cihuapipiltin	Ch'en, month of Moon goddess—Tititl, month of Ilamatecuhtli Old Princess—Cozcamiauh Jewel Ear of Corn—Cihuacoatl—Snake Woman	179. 8 Cimi 19 Ch'en marked with an eclipse glyph in *Madrid*			
↓ +173		↓ +148		↓ +148 +177			
		326. 12 Ben 6 Kayab Twelve Reed, Coatlicue, Snake skirt—148 days marked in *Madrid*			328. 1 Men 8 Kayab One Eagle Xochiquetzal	→ +13 goddess of Kayab young Moon goddess	341. 1 Lamat 1 Cumku One Rabbit Mayauel
		↓ +28					
347. 7 Ix 7 Cumku Seven Jaguar the gourd	*Cumku* means "Pot God" patron the eclipse dragon	354. 1 lmix 14 Cumku, One Crocodile Ilamatecuhtli	Cumku-Huehuetecuilhuitl, feast of death of Xilonen, young corn goddess and of Cihuacoatl	504. 8 Chuen 19 Yaxkin Eight Monkey—god of the Moon			↓ one Metonic cycle (6940 days)
↘		↓ +180 +177		↓ +180			
		711. 7 Etz'nab 6 Cumku, Seven Flint Chicomecoatl (*trecena* of Mayauel)		684. 6 Chuen 19 Pax Six Monkey Tecciztecatl, He of the Snail Shell Old Moon god with noosed peccary			
				3988. 8 Men 18 Kayab, eclipse at the *tritos* interval → +14	4002. 9 Muluc 12 Cumku (Xquic, Blood Woman?) (daughter of Vucub Came, Jupiter?)		
		3987. 7 Ix 17 Kayab ↘		6587. 7 lx 17 Pop eclipse at the *saros* interval			
		6586. 6 Ben 16 Pop Six Reed, Tlazolteotl					
				7266. 10 Ben 6 Mac → +15			7281. 12 Lamat 6 Cumku Xtabai. the hanged woman
		7265. 9 Eb 5 Mac Nine Twisted (Mixtec, = Tlazolteotl ff. Caso)		10218. 11 Chicchan 3 *Uayeb* Eleven Snake beheaded deity with opposum	god of *uayeb* is Opossum, Mam		
				11607. 9 lx 12 Muan (see text)			
				11961. 12 Lamat 1 Muan, Twelve Rabbit associated with old Moon god			

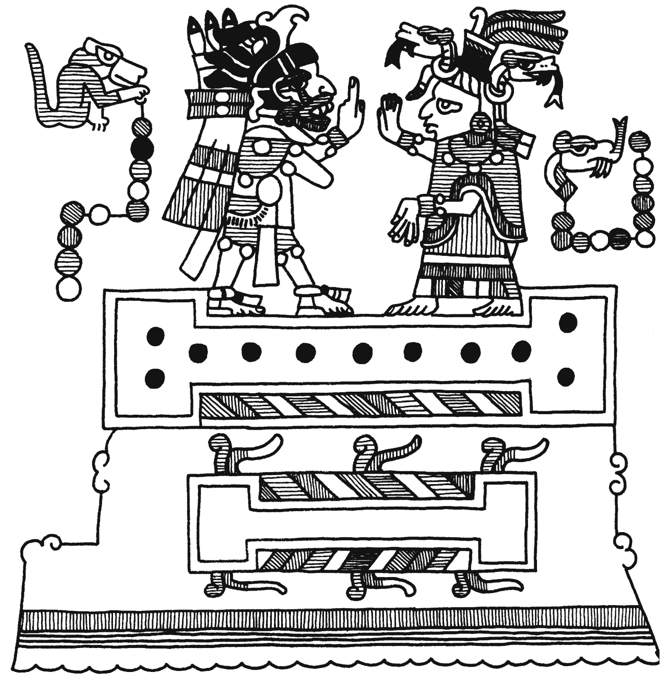
TABLE 12.7. *Continued.*

TABLE 12.7(c). Gods of equinoxes, solstices, and world ages.

Equinoxes and solstices	Aztec equivalent of Maya days	Maya New Year dates	Aztec Tezcatlipocas	Maya Bacabs	Madrid depiction	Solstices and equinoxes: Maya dates	World ages
Winter	12 House	–4745. 12 Akbal 1 Pop winter solstice					
	9 × 365					(12 × 365.24)	
	8 Rabbit	–1460. 8 Lamat 1 Pop					
Autumn	3 × 365					–1181.	12.8.16.13.7 1 Manik 20 Kankin (old god)
	11 House	–365. 11 Akbal 1 Pop				12.8.18.0.6 –362. 1 Cimi 4 Pop	13 days –1168. 12.8.15.14.0 1 Ahau 13 Muan (mean Venus conjunction)
Winter	365						(3 × 365)
	12 Rabbit	12.8.19.0.8 1. 12 Lamat 1 Pop				365 + 1	12.8.18.14.2 4 *Ik* 20 *Kankin* FOUR WIND (North—white)
Winter						5. (3 *Eb* 5 *Pop*)	
+89 90/89						+89	365 + 1 (2 × 91) 182
Spring			South Huitzilopochtli the Blue Tezcatlipoca	South Hobnil Chief of Bacabs the Yellow Bacab	young god	94. 1 *Imix* 14 *Zec* (beginning of *Madrid* table)	(52 × 365)
+93 94	365					+93	+3 days (97. 4 *Kan* 17 *Zec*) FOUR FIRE (South—yellow)
Summer			The Black Tezcatlipoca	East Cantzicnal the Red Bacab	mature Sun god	187. 3 Ix 7 Yax	
+94 92							+94 353. 12.9.0.0.0 13 Ahau 13 Cumku End of katun 13 Ahau
Autumn						+183	(281. 6 Lamat 1 Muan) (3 + 91) 273 (260 + 13)
+89 89/90			Quetzalcoatl the White Tezcatlipoca (old age)	North Zac Zini (Sac Cimi?) The White Bacab			+89 354. 12.9.0.0.1 1 Imix 14 Cumku First day of 260—day round and first day of katun 11 Ahau the katun of creation
	13 Reed	366. 13 Ben 1 Pop					
Winter	365		Xipe Totec the Red Tezcatlipoca	West Hozan Ek The Black Bacab	young god (birth of Sun)	370. 4 Caban 5 Pop	FOUR EARTHQUAKE (East—red)
Summer						+182	(2 × 91) 182
	1 Flint	731. 1 Etz'nab 1 Pop first new year's day after the birth of the Sun				552. 4 Cauac 7 Yax	FOUR RAIN (West—black) 17813. 1 Ahau 13 Muan the autumn equinox at or 1 day past the heliacal rising of Venus

Figure 12.7 shows drawings of some eclipse and planetary gods according to DHK's identifications. The match between astronomical intervals and intervals determined by day names is a good one and is strongly supported by iconographic parallels in the deity representations. The equation of the paired black gods, aged merchants, and warriors, with the slow-moving outer planets, Jupiter and Saturn, is iconographically appropriate. Mars, long equated with the monster who ruled the month *Zip*, has a period ending in the month *Zip*. *Xolotl*, equated by this evidence with Venus,

(a)

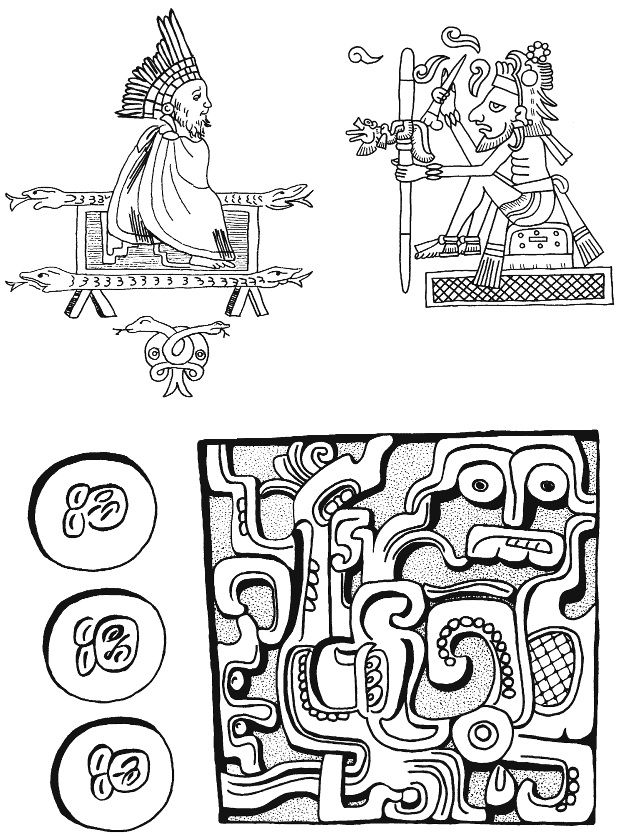


(b)

FIGURE 12.7. Drawings of some planetary and eclipse gods: (a) Two representations of a Moon goddess, Nine Reed. Drawings by Sharon Hanna. (b) A Venus god (Ten Lizard) and an eclipse goddess (Eleven Snake), ff. the *Vienna Codex*. Drawing by Sean Goldsmith.

has long been regarded in the more restricted sense as Venus when an evening star.

Only *Nine Wind*, wind god and Feathered Serpent (Aztec *Quetzalcoatl*, Maya *Kukulcan*), is a surprise. Clear-cut, early colonial evidence identified *Quetzalcoatl* as the Morning Star, in terms that seem to refer to Venus. The interval of 114 days from 12 Lamat 1 Pop to 9 Ik 15 Xul refers equally clearly (in Kelley's view) to Mercury, which has a mean synodic period of 115.8+ days, and the mass of additional calendar names can also be fitted most easily to Mercury. Among the Mayas, the end of the month *Xul* was dedicated to *Kukulcan*. However, the fact that five Mercury rounds approximate roughly to one Venus round (5 days off) means that some equations can fit Venus as well. A Mixtec reference to *Nine Wind* as Twins, iconographic representations of a *Nine Wind* as a *Flint Knife* god identified with Venus, and Aztec references to *Quetzalcoatl* and *Xolotl* as twins suggest that we may be dealing here with a theological or political reinterpretation of *Quetzalcoatl*, transforming him from a god of peace and life identified with Mercury and dynastic ancestor of kings into a patron of warfare and the warlike kings of Tula, identified with Venus. New evidence, cited below, suggests that both identifications may be ancient. The Aztec god, *Tlahuizcalpantecuhtli*, "Lord of the House of Dawn," is represented as a giant flint knife and is associated with the days 9 Wind. A flint knife god is also associated with the day 3 Dog. 3 Dog precedes 9 Wind in the calendar by 32 days (modulo 260) and hence would represent 292 days or half a Venus synodic period. In the Mixtec Nuttall codex (pp. 14–22), there is an account of a woman named Three Flint Feathered Serpent who comes first from the Seven Caves and then from the temple of the Feathered Serpent, which has a mummy bundle identified as Nine Wind Flint Knife and is later often identified by a Venus staff in front of the temple. Three Flint gives birth to a daughter of the same name, then goes into a cave and emerges into a river ruled by the gods Four Death and Four Deer with their wives One Twisted and One Eagle. On the basis of dates associated with Four Death and Four Deer, DHK thinks that they are winter solstice gods. Then Three Flint and her husband, Five Flower, are shown sacrificing a white dog. After this, her children are shown and include a Nine Wind, but with the attributes of *Quetzalcoatl* rather than those of *Tlahuizcalpantecuhtli*. Either Three Flint or her daughter of the same name marries a man named Twelve Wind, who comes from above the star-marked sky band, and their children are involved in a repeated version of the War with Heaven. This Mixtec version should be compared in detail with Aztec accounts of *Tlahuizcalpantecuhtli* and with Iroquois accounts of the Flint Knife god, *Tawiskaron*, the evil twin of the Corn God. Floyd Lounsbury recognized that the Iroquois name is a borrowing from the prototype of *Tlahuizcalpantecuhtli*. The prototype of the Aztec name would have been **Tawiskalpan* + *Tecuhtli* ("lord"). The Iroquois had a white dog sacrifice at the time of the winter solstice in honor of *Tawiskaron's* twin brother, the Corn god (Lounsbury cited in Hall 1991; Lounsbury, personal communication to DHK). The Mixtec parallel was noted by DHK. Two representations from Nahua sources showing *Quetzalcoatl* as a bearded ruler appear in Figure 12.8 with a Maya depiction of the god in Feathered Serpent form.



(a)

(b)

Figure 12.8. The Feathered Serpent: (a) Two versions of *Quetzalcoatl* as a bearded ruler, from Nahua sources. (b) The Feathered Serpent god with "star" glyph and suffix, *na*, from a Classic Maya pot. Drawings by Sean Goldsmith.

In any case, the astronomical behavior of Venus and Mercury, the two inner planets, always close to the Sun, erratic in apparent movement, invisible for long periods, relatively swift moving, and having both inferior and superior conjunctions (§2.4.3), is enough to suggest that it is appropriate to regard them as twins. Long calculations going back to the birth (or rebirth) of the gods at Palenque seem to involve the Sun, Mercury, and Venus (see §12.7). In 2000, new work at Palenque revealed data on one of the later rulers of Palenque and recorded the birth of GI on 12.10.1.13.2 9 *Ik* 5 *Mol*. Mayanists have referred to this as an "elder" GI, but the "birth" of a planetary god is a repeating phenomenon. It now seems probable that the Mixtec brothers named Nine Wind were Mercury and Venus. The "Mercury" brother was born on 12.8.19.6.2. 9 *Ik* 15 *Xul* (114 days after the postulated base date 12.8.19.0.8 12 *Lamat* 1 *Pop*). Assuming that it was important to have a Nine Wind date that was at a Venus interval, the 1st one after 12 Lamat 1 Pop was 8174 days later at 12.10.1.13.2 9 *Ik* 5 *Mol* ($14 \times 583.92 = 8174.88$ days). A standard 584-day synodic period would yield 8176 days. This is important support for the concept that calendar names were counted from a single base date. DHK thinks that the "birth" term was unlikely to have been applied to superior conjunction, and DHK's hypothesis (shown in Table 12.7) that the 12 Lamat 1 Pop was a superior conjunction of Venus rather than an inferior conjunction now seems unlikely. The interval from 12.10.1.13.2 9 *Ik* 5 *Mol* to 1.18.5.3.2 9 Ik 15 Ceh is 2.8.3.8.0 (346,840 days). This is 593×583.92 days, with a remainder of 575.44 days. A difference of 8.5 days is about equal to a Mesoamerican interval of disappearance at inferior conjunction. DHK thinks that the 575-day interval may have been designed to represent an interval of reappearance at inferior conjunction to a disappearance at inferior conjunction; there is, however, no textual support for this view, and alternatively, a small error in the Maya calculation of the synodic period could account for the 8-day deficit.

Kelley's interpretation of the Madrid date as a calculating base before the Maya era is rejected by Robert Hall (1989–1993), who, however, accepts the basic idea. He suggests that 13 Ahau 13 Cumku was not the katun ending but a tun ending, 8.8.16.0.0, which was, in the 584,283 (Thompson) correlation, 12 April 412 Gregorian. There was no conjunction on 12 Lamat 1 Pop preceding, but there was one 12 days after that date on 11 *Ahau* 13 *Pop*, which was 9 May 411 A.D. This is the date of 1st zenith passage of the Sun at Tikal, and Sun-Moon-Venus-Jupiter and Saturn were all in conjunction and Mercury was nearby. DHK is willing to accept the possibility that back-calculations from a historic period conjunction were involved, but not that the reference in Madrid is to the 8.8.16.0.0 date.

Figure 12.9 shows a rollout drawing of the Vase of the Seven Gods with the CR date 4 *Ahau* 8 *Cumku*, which corresponds with the Maya era base (Coe 1973, pp. 106–109). The god most prominently featured on this pot (God 1 in the labeling of Coe 1973, pp. 106–109), identified as God L (in the notation of Schellas 1904), equated to Saturn by Kelley, is seated on a jaguar throne with a 9-sky glyph in his head-dress and with a bundle inscribed *cab*, "earth" (written phonetically), behind his back. Two other bundles are marked with "star-earth" glyphs and a prefix that suggests both the number 9 and the water prefix often found with "star-earth." Facing him are six other gods. Coe has labeled them as follows:

4	3	2	1
7	6	5	

Michael Closs (1979) has suggested that the gods represent different aspects of Venus. To DHK, it seems more likely that different aspects of Venus would be associated with different dates. Because all these gods are associated with the single date, it seems more probable that they represent different "planets" (in the Greek sense). God 2 has the same jaguar ear and markings as God L. This would seem to identify him with the figure called God M, the other black god with jaguar markings, identified previously (Table 12.7) as Jupiter. Gods 5 and 7 on this pot both show the headdress of the long-snouted monster normally worn by the Elder Heroes, and both have an *Ahau* headdress with what appears to be a number one prefixed. One *Ahau* (One Flower) is a name of several Mesoamerican gods, including a Sun god, a Venus god, and an underworld god; the Quichean equivalent, *Hun Hunahpu*, is the name of the father of the Hero Twins. Number 7 has the filed teeth

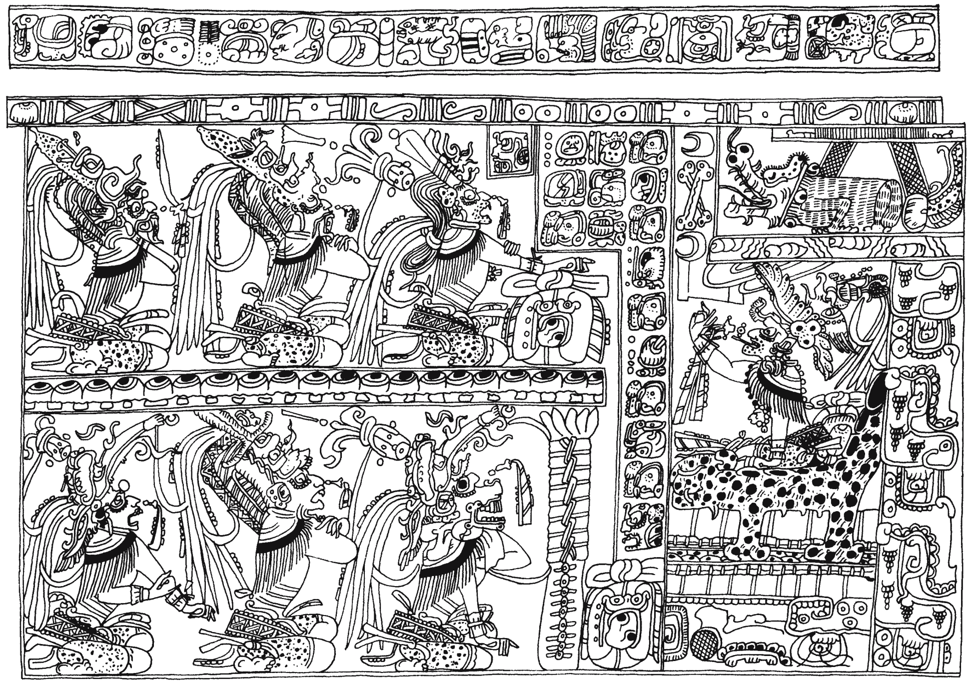


FIGURE 12.9. The Vase of the Seven Gods: God L is shown on his throne on the date 4 *Ahau* 8 *Cumku* (the Maya era base). Drawn by Sean Goldsmith.

characteristic of the Sun god, and number 5 has a monster head, reasonably similar to the dog-headed monster who appears as the Aztec Venus god. We will not here attempt to identify the remaining gods, but merely remark that the iconography suggests to Kelley that the era base was calculated as a mass conjunction. Our simulations running the *Visual Universe* (Parsec Software, Danville, Virginia) and Voyager, III, Carina Software, San Leandro, CA, computer packages show Venus and Mercury in near-conjunction and rising before the Sun, and Saturn setting just after the Sun as Jupiter and the Moon rise, and Mars is in the West, in the Thompson correlation, JDN 584,285, 7 Sept. 3114 B.C. (Julian calendar).

12.7. The *Dresden* Codex Venus Table

The most fully discussed and best known of all the literary material on astronomy from Mesoamerica is probably the Venus table of the *Dresden* codex. This is a table of mean motion covering 104 years. An introduction gives a calculation involving 12.19.13.16.0 1 *Ahau* 18 *Kayab* (a Ring Number) and a *later* date 9.9.9.16.0 1 *Ahau* 18 *Kayab*. In the interval of 1,366,560 days (72 CRs) represented by the difference between these dates, there is about a half-year shift, both of the tropical year and of the Venus synodic period.[4] The calculations in the Venus table show clearly that the Maya would have known that this was a gross error on both Venus and the Sun, and no one has yet suggested a good reason why they should count back to a base that they knew to be incorrect. Kelley (1976, p. 256) has suggested that the initial date was calculated as a rising of Venus (probably at or near one of the equinoxes or solstices) four days after inferior conjunction and that the table provided a constant measure of the amount by which observation was off from reality. At any given time, it would be easy to see how many days of error had accumulated in a given number of formal repetitions of the basic 584-day mean interval. Everyone else has assumed that the terminal date was fairly closely in step with reality. It has also been assumed that the introductory calculations were used to "reset" the (late) table base to new positions, but that the table was not adjusted.

Besides the introductory page, there are five additional pages, each containing the set of month names for a period of 584 days, with the month names repeating after 5×584 (2920), which equals 8×365. There is also a table of the 13 repetitions of the day names in each of the month positions. These are accompanied by glyphs for cardinal directions and glyphs for a series of 20 deities. Besides this, there are pictures of three sets of deities, associated with the different table positions. The month names mark intervals of 236 days, 90 days, 250 days, and 8 days.[5] It has been assumed that inferior conjunction lay in the middle of the 8-day period. Because of the asymmetry of the 236- and 250-day periods, the structural or mean superior conjunction is at day 52 of the 90-day period rather than at day 45. The 90-day period seems far too long for invisibility at superior conjunction but

[4] For the tropical year, modulo 365.24220 yields 3741 cycles and a remainder of 188.9299 days; for Venus, modulo 583.92166 yields 2340 cycles and a remainder of 183.3158 days.

[5] Modern rounded values are closer to 8, 263, 50, and 263 days for these synodic intervals (Gibbs 1977). Cf. §7.1.4.4 for their meanings.

was also used by the Babylonians (see §7.1) and is substantially less than that used in China (§10.1.4).

There are actually three sets of month names, the middle one beginning with 18 *Kayab*, corresponding to the introductory date, the top one with 13 *Mac*, and the bottom with 3 *Xul*. The date at 13 *Mac* and those on the same line on p. 46 are the only ones in the table that lack the past tense suffix, which, in Kelley's opinion, should imply that 13 *Mac* was the current date when the table was first written. It is widely assumed that 3 *Xul* and 13 *Mac* serve as correction positions for alternative table bases, but it seems equally likely that they were of primary importance in interlocking Venus with eclipses, as 1st suggested by Spinden (1928, pp. 44–45; 1930, pp. 91–92), and then amplified by Smiley (1961) and Kelley and Kerr (1973, pp. 182, 188). The minimal interval between a given name on 18 *Kayab* and the same day name on 13 *Mac* is 11,960 days, precisely the length of the eclipse table, as Spinden noted. The minimal interval between the same day name on 3 *Xul* and 18 *Kayab* is 9360 days, a major eclipse interval (the *Thix*, cf. §5.2.2) of particular Maya interest because it also restores the same day of the 260-day period. These figures mean that if there is an eclipse at or near any date in the 3 *Xul* line, there is a high probability that there will also be eclipses on the equivalent dates of the 18 *Kayab* and 13 *Mac* lines. These positions are diagrammed in Figure 12.10.

Spinden (1924, pp. 184, 193) was the first to draw attention to the relationship between the date 1.18.5.4.0 1 *Ahau* 13 *Mac* given at Palenque and now recognized as the birthdate of a Maya god, and 1 *Ahau* 13 *Mac*, a major base of the *Dresden* Venus tables. As Spinden pointed out, the next occurrence of the date 1 *Ahau* 13 *Mac* following 9.9.9.16.0 1 *Ahau* 18 *Kayab*, the primary base of the *Dresden* Venus table, is at 9.11.3.2.0 1 *Ahau* 13 *Mac*. We now know that this date fell within the lifetime of Chan Bahlum, ruler of Palenque, in whose reign the tablets relating to the birth of the gods were executed. The two dates 1 *Ahau* 13 *Mac* are separated by 2 × 1508 Mesoamerican years or 2 × 1507 tropical years, so that Maya calendar dates were at the same seasons for four years at both ends of the interval. The period of 1508 Mesoamerican years may be called the *great solar round*. It is surely no coincidence that 1.18.5.4.0 1 *Ahau* 13 *Mac* is half a great solar round after the four-year period in which the normal Maya era base (13.0.0.0.0 4 *Ahau* 8 *Cumku*) fell.

Stela C at Copan shows a similar back calculation to 10.19.14.17.0 6 *Ahau* 18 *Kayab*, one short Venus period of eight years before 11.0.3.1.0 1 *Ahau* 18 *Kayab*,[6] which is three great solar rounds before 9.9.9.16.0 1 *Ahau* 18 *Kayab*, the central base of the *Dresden* Venus table (slightly corrected from Spinden 1924, p. 174).

Figure 12.11 shows the emergence of various deities from a water lily vine with star glyphs, the two-headed serpent, the Bird of Heaven, and a brief text opening with a date 13 *Muluc* 8 *Zotz*. The principal god is identified in the text as One Ahau, the equivalent of Quiche Hun Hunahpu.

[6] These dates precede the usual era base at 13.0.0.0.0 4 *Ahau* 8 *Cumku*.

12.8. Venus, Star Wars, and the Rain and Corn Complex

The first attempt to do a formal statistical study of astronomical references in the Mayan inscriptions was done only recently by Aveni and Hotaling (1994, 1996). They used a carefully selected list of 98 dates, with the context of the dates described. This work relied partly on an unpublished list prepared by Bryan Wells, later substantially expanded. Unfortunately, they examined the data only in the framework of the astronomical information about the dates using the 584,283 (Thompson) correlation constant, which they regard (1994, p. S 25) as the only one that fits both astronomical and ethnohistoric data. They certainly show that there are peaks in Venus statements (their figure 3, p. S 36). They analyzed in terms of temporal "bins" of 20 days and 40 days, within the 584-day mean cycle, which give somewhat different results. Substantially smaller bins might have changed the results again. These distributional peaks would remain in any correlation, but in many correlations, they would be associated with other phenomena. There is some discussion of other planets and of multiple conjunctions, but the statistical analysis treats such phenomena as essentially ancillary to the Venus study. According to them, there were only two conjunctions of Mars, Jupiter, and Saturn during the Classic Period, one on 19–20 July 690 A.D. corresponding (in correlation 584283) to an event on **2 Cib 14 Mol** mentioned in the Palenque inscriptions. The other occurred in 828 A.D. Aveni and Hotaling have tried to use "real time" phenomena rather than "computational type" intervals (1994 p. S 48) and have assumed that only visible phenomena would have been of interest to the Maya. The second part of their paper is a very useful determination of parallel "almanacs" in the Dresden and Madrid codices. They emphasize the apparent relationship of Venus both to a rain-maize complex and to warfare. Their list of relevant dates includes both inscriptions containing the star/Venus glyphs and inscriptions accompanying rain-god-corn imagery.

The rain-maize relationships to Venus are discussed very fully by Ivan Šprajc (1993a, 1993b) in a comprehensive monograph, and John Carlson (1991) has an extended discussion emphasizing the Venus War complex. Šprajc's coverage of the literature is very helpful, and Carlson has uncovered many previously unnoted iconographic relationships. Šprajc shows that many Mesoamerican cultures associated Venus, expecially as evening star, with rain and that the northernmost extreme of Venus, as evening star in the eight-year cycle, always fell between May 1 and May 6. In many parts of Mesoamerica, this is a reasonably good approximation to the beginning of the rainy season. The southern extreme always fell between November 2 and November 7 and coincides well with the beginning of the dry season, often accompanied by cold weather. The extensive parallels that Šprajc cites make the existence of a cult associating Venus with rain, fertility, and corn seem certain. The association of the extreme northerly and southerly positions of the eight-year cycle of Venus with significant seasonal features provides an observable and regularly repeated linkage between Venus and farming. This interpretation

Line	Page 46				Page 47				Page 48				Page 49				Page 50			
	Cib	Cimi	Cib	Kan	Ahau	Oc	Ahau	Lamat	Kan	Ix	Kan	Eb	Lamat	Etz'nab	Lamat	Cib	Eb	Ik	Eb	Ahau
1	3	2	5	13	2	1	4	12	1	13	3	11	13	12	2	10	12	11	1	9
2	11	10	13	8	10	9	12	7	9	8	11	6	8	7	10	5	7	6	9	4
3	6	5	8	3	5	4	7	2	4	3	6	1	3	2	5	13	2	1	4	12
4	1	13	3	11	13	12	2	10	12	11	1	9	11	10	13	8	10	9	12	7
5	9	8	11	6	8	7	10	5	7	6	9	4	6	5	8	3	5	4	7	2
6	4	3	6	1	3	2	5	13	2	1	4	12	1	13	3	11	13	12	2	10
7	12	11	1	9	11	10	13	8	10	9	12	7	9	8	11	6	8	7	10	5
8	7	6	9	4	6	5	8	3	5	4	7	2	4	3	6	1	3	2	5	13
9	2	1	4	12	1	13	3	11	13	12	2	10	12	11	1	9	11	10	13	8
10	10	9	12	7	9	8	11	6	8	7	10	5	7	6	9	4	6	5	8	3
11	5	4	7	2	4	3	6	1	3	2	5	13	2	1	4	12	1	13	3	11
12	13	12	2	10	12	11	1	9	11	10	13	8	10	9	12	7	9	8	11	6
13	8	7	10	5	7	6	9	4	6	5	8	3	5	4	7	2	4	3	6	1
14	4	14	19	7	3	8	18	6	17	7	12	0	11	1	6	14	10	0	5	13
	Yaxkin	Zac	Zec	Xul	Cumku	Zotz'	Pax	Kayab	Yax	Muan	Ch'en	Yax	Zip	Mol	Uo	Uo	Kankin	Uayeb	Mac	Mac
16	N.	W.	S.	E.	N.	W.	S.	E.	N.	W.	S.	E.	N.	W.	S.	E.	N.	W.	S.	E.

17	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
18	Red ½	Red ½	Red ½	Red ½	Red	Red	Red	½	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus
19	236	326	576	584	820	910	1160	1168	1404	1494	1744	1752	1988	2078	2328	2336	2572	2662	2912	2920
20	9	19	4	12	3	13	18	6	2	7	17	5	16	6	11	19	15	0	10	18
	Zac	Muan	Yax	Yax	Zotz'	Mol	Uo	Zip	Muan	Pop	Mac	Kankin	Yaxkin	Ceh	Xul	Xul	Cumku	Zec	Kayab	Kayab
21	T	A	B	C	D	E	F	G	Winged	Winged	Winged	Winged	Winged	Winged	Winged	Winged		Winged	Winged	Winged
									Chuen	Chuen	Chuen	Chuen	Chuen	Chuen	Chuen	Chuen	Chuen	Chuen	Chuen	Chuen
22	Winged	Winged	Winged	Winged	—	—	—	—	H	I	J	K	L	M	N	O	P	Q	R	S
	Chuen	Chuen	Chuen	Chuen																
23	Red	Red	Red	Red	Red	Red	Red	Red	—	—	—	—	Red	Red	Red	Red	Red	Red	Red	Red
	Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus					Venus	Venus	Venus	Venus	Venus	Venus	Venus	Venus
24	E.	N.	W.	S.	E.	N.	W.	S.	E.	N.	W.	S.	E.	N.	W.	S.	E.	N.	W.	S.
25	19	4	14	2	13	3	8	16	7	17	2	10	6	16	1	9	0	10	15	3
	Kayab	Zotz'	Pax	Kayab	Yax	Muan	Ch'en	Ch'en	Zip	Yaxkin	Uo	Uo	Kankin	Cumku	Mac	Mac	Yaxkin	Zac	Zec	Xul
26	236	90	250	8	236	90	250	8	236	90	250	8	236	90	250	8	236	90	250	8

FIGURE 12.10. The structure of the *Dresden* Venus Table, with deity names. Glyphs drawn by Sean Goldsmith.

FIGURE 12.11. From a Maya pot: *Hun Hunahpu* and the other gods emerging from a water lily vine. There is a brief text that opens with the date 13 *Muluc* 8 *Zotz*. A two-headed serpent and the Bird of Heaven are also seen. Drawn by Sharon Hanna.

seems entirely acceptable to DHK. Šprajc further argues that the assocation of these ideas in a complex is an ancient feature of the mythology of Mesoamerican farming groups, extending perhaps as far back as the beginning of Mesoamerican agriculture. He recognizes that the association of Venus and warfare was very important from at least the Classic period onward, but regards it as a secondary development, associated with the rise of social hierarchies. Carlson, on the other hand, sees the relationship among rain, fertility, blood sacrifice, and warfare as natural and basic to even the earliest Venus iconography. Both of them tend to see such major deities as the Corn God, the Rain God, and the Merchant God as mere aspects of Venus—a view that was conventional with regard to the many deities mentioned in the Venus table of the *Dresden* codex. They also tend to see any use of star glyphs as referring to Venus. DHK acknowledges that "the star" was a term that might sometimes be applied to Venus but thinks that much of the iconographic evidence applies to other stars and planets, and that most of the major deities were separate from Venus, important as that planet was.

Among specific figures, a star scorpion deity is of interest. At Cacaxtla, a male figure with a star "kilt" and a scorpion tail is paired with a female figure with a star skirt, unfortunately, badly damaged. Carlson compares these with representations of Chaac, the Maya Rain God, with a scorpion tail and of the aged goddess of *Madrid* (p. 11a). He also shows a Maya plate depicting a scorpion-tailed man with arms and legs through the circles of a Maya star/Venus glyph (Carlson 1991, pp. 19–26 and 8a–k). They might also be compared with the Nahua myth of the ascetic Yappan, who after being seduced by the goddess *Xochiquetzal*, became a black scorpion and whose wife, *Tlahuitzin*, became a female red scorpion (Ruiz de Alarcon 1629/1984, ed. Andrews and Hassig, pp. 204–207).

Another figure tied into the Venus-rain-maize complex by both Carlson and Šprajc is the Star-Jaguar. Šprajc (1993a, pp. 42–43) draws attention to a carving from Chalcatzingo belonging to the Palangana Olmec phase, which shows felines, presumably jaguars, attacking people. One has an ear in the form of the Maya "star/Venus" and has symbols that have previously been interpreted as referring to maize and agricultural symbolism in general. The connection of these Chalcatzingo reliefs with various "star-jaguars" and "net-jaguars" at Teotihuacan seems very reasonable. As will be shown (§12.22), some Jaguar depictions at Teotihuacan refer to the Pleiades and, in DHK's opinion, to Jupiter. Carlson (1991, p. 43) discusses paintings of a toad and a turtle shown at Cacaxtla wearing jaguar skins and quotes with approval ideas that the Aztec Earth Mother originated as a "Jaguar-toad." "The toad sheds its skin in the spring," which Carlson associates with ritual flaying. Below the toad and the turtle are streams of water marked with half-stars, making both toad and turtle heavenly denizens.

An important component of the postulated Venus-war cult is the owl, depicted with the fertility goddess and with rain deities at Teotihuacan. The owl is directly associated with various conquests and sacrifices in the Maya area.

None of them discuss the identification of Venus as an iguana among the Cora nor the possible translation of the name of Itzamna, the Maya culture hero, as "Iguana House," although Šprajc does emphasize the many similarities between Quetzalcoatl as Venus and Itzamna. The Cora reference makes Iguana the morning star, and the owner of fire, which was stolen from him by Opossum (Munn 1984, p. 29).

12.9. The *Dresden* Codex Mars Table

In 1924, Robert Willson identified the middle sections of pages 43–45 of the *Dresden* codex as a table of the motions of the planet Mars. The table deals with multiples of 780 days, whereas the mean synodic period of Mars is 779.93651 days. However, because 780 days is a triple multiple of the basic 260-day *tzolkin* or *tonalpohualli* of Mesoamerica, many scholars have supposed this to be a simple coincidence. Eric Thompson, in particular, argued repeatedly that the subdivisions of the table were too small and too numerous to have any purpose in connection with planetary movements. As in other cases, he made no attempt to consider the implications of the Ring Number (*see* §12.10), which introduced the table and which lies 352 days before the usual Maya era base. Willson (1924, pp. 24–25 *et passim*) has pointed out that the interval from Mars's conjunction with the Sun to its first stationary point was about 352 days, followed by an interval of 76 days and then by a second interval of 352 days (see §§2.4.3, 7.1.4.4 for details of planetary configurations). The combined interval, 780 days, is the synodic period, with Mars returning to conjunction at the end of the interval. Because the table interval is 78 days, arranged 19-19-19-21, the Mars arrangement would have to be considered 351-78-351 days for the table to be a viable representation of Mars's motion. The nonuniform motion of both Earth and Mars (especially, the latter; see §2.4) due to their eccentric orbits will permit such variations to occur from year to year, as we note below. Willson's analysis would suggest that the Ring Number *3 Lamat* was at the second stationary point, and that the era base 4 Ahau 8 Cumku, was at or very near Mars's conjunction with the Sun. Neither Willson nor Thompson seemed to be aware, however, that Mars's actual motions are seldom close to its mean interval. Tabular almanac data reveal that deviations of successive Mars conjunctions from the mean are frequently as much as ±20 days. This may provide an explanation for the short intervals in the *3 Lamat* table, which so distressed Thompson.

In 1980, Kelley pointed out that his postulated 12 Lamat 1 Pop base for calculating the calendar names of the gods would put the name of the Mars god in the month Zip and that the deity of Zip was precisely the "sky peccary" who had been identified by Willson as Mars because of his appearance in the pages of the *Dresden* codex. More recently, V. and H. Bricker (1986) presented further arguments about the relationship of the Mars dates in the table with real-time events, using the 584,283 (the later Thompson) correlation. Although Kelley rejects this correlation, the arguments retain some validity when rephrased in more structural terms. On the basis of the Brickers' work, Justeson (1983, p. 25) has accepted the *3 Lamat* table as a Mars table.

12.10. *Dresden* Codex Ring Numbers

Throughout the *Dresden* codex, we find a series of Long Count dates starting at beginning dates before Maya zero (of the usual era), marked by a knot encircling the bottom numeral of the number, which gives the days before Maya zero. These are referred to as *Ring Number* dates and act as bases for later calculations. Such dates appear prefaced to many of the various almanacs and multiplication tables of the codex. A number leads forward from the early bases to a later base date of the early Classic Period (see Table 12.1). Table 12.8 gives the Ring Number (hereafter, *RN*) bases (ff. Satterthwaite 1964) as well as the Maya era base and the base of the eclipse table, which is eight days later than the Maya era base.

TABLE 12.8. Ring number bases from the *Dresden* codex.

−51419[d]	12.12.17.3.1	13 Imix 9 Uo
−2200	12.19.13.16.0	1 Ahau 18 Kayab (Venus)
−1646	12.19.15.7.14	9 lx 2 Ch'en (postulated Mercury, DHK)
−606	12.19.18.5.14	9 lx 7 Xul (postulated Mercury, DHK)
−511	12.19.18.10.9	13 Muluc 2 Zac
−456	12.19.18.13.4	3 Kan 17 Mac (Venus?)
−352	12.19.19.0.8	3 Lamat 1 uayeb (widely accepted, Mars)
−251	12.19.19.5.9	13 Muluc 7 Zec
−235	12.19.19.6.5	3 Chicchan 13 Xol
−208	12.19.19.7.12	4 Eb "eve of" Mol
−121	12.19.19.11.19	13 Cauac 7 Ceh
−86	12.19.19.13.14	9 lx 2 Kankin (postulated Mercury, DHK)
−30	12.19.19.16.10	13 Oc 18 Pax
−17	12.19.19.17.3	13 Akbal 11 Kayab
	13.0.0.0.0	4 Ahau 8 Cumku
+8	13.0.0.0.8	12 Lamat 16 Cumku (eclipse)

The nature of the *RN* bases has long been a subject of dispute. Most scholars have supposed that they involved astronomical calculations of some sort, but Eric Thompson thought that the tables with which they were associated were almanacs and more or less ignored the problem of the *RN*s and any probable meanings. Each of the places in the codex where the *RN*s are found is in a structurally similar situation (with the single exception of a group of 12 *RN*s on pages 71–73 of the codex). The *RN* is counted with respect to the Maya era base at 4 Ahau 18 Cumku and is followed by a distance number (or interval) that leads forward to a Classic Period date. This is followed by a multiplication table and then by a series of figures associated with a repeating *tzolkin* or longer period. This strong structural similarity is a good generic reason for supposing that the intellectual content is similar and likewise astronomical in the unidentified or dubiously identified cases.

The best starting point for an understanding of the *RN*s is the date 12.19.13.16.0 1 Ahau 18 Kayab, 2200 days before the Maya era. From this, the count goes forward to 9.9.9.16.0 1 *Ahau* 18 *Kayab*. The base of the accompanying table of Venus movements (Table 12.10) is a day 1 Ahau 18 Kayab, which may, theoretically, be either of these dates but has always been interpreted as the later of the two. The table covers 104 My and gives cumulative totals of a sequence of numbers: 584 (equal to 0), 236, 326, and 576, associated with *CR* dates in an unwavering 584-day cycle. These numbers refer to cumulative intervals of days (indicated by "Σ" in the list below) associated with the following Venus phenomena (see the discussions of general planetary phenomena in §§2.4.3, 5.4, 7.1.2.1, and 7.1.4.4):

(1) the zero point at heliacal rising four days after inferior conjunction;
(2) 236 days as morning star;
(3) 90-day disappearance around superior conjunction (Σ = 326);
(4) 250 days as evening star (Σ = 576); and
(5) 8-day disappearance following heliacal setting, around inferior conjunction (Σ = 584).

In the table, the *CR* date 3 Kan 17 Mac appears as a "standard" date of heliacal setting at "age" 576 and corresponds to the *RN* 12.19.18.13.4 13 Kan 17 Mac. Another *RN* base, 12.19.19.7.12 4 *Eb* 20 *Yaxkin* ("seating of" *Mol*), appears as day 240 of the cycle, 4 days after a standard 236-day interval, and a 4th *RN*, 12.19.19.11.19 13 Cauac 7 Ceh, appears as a day 327 of the cycle, 1 day after the standard 326. This strongly suggests that all four positions were involved in the calculation of the *RN*s and were being integrated with other phenomena. Over the period of 2079 days separating 1 *Ahau* 18 *Kayab* from 13 Cauac 7 Ceh, the accumulated error from use of the standard period of 584 days differs from that obtained from the use of the true synodic period (583.920$^+$ days) by <0.24$^+$ days. Hence, the positions involved may have been conceptualized as either true periods or cycles, or as both.

Of the other planetary phenomena involved in calculating these *RN* dates, the clearest refers to Mercury. The average synodic period of the planet is 115.87754 days. Counting from the earliest of the *RN*s, 12.12.17.3.1 13 *Imix* 9 *Uo* (at 51,419 days before the Maya era base), we find that the *RN* 12.19.19.13.14 9 Ix 2 Kankin has an *age*[7] of 115 days, almost exactly the same Mercury age as that of the base. We also find that *RN* 12.19.18.5.14 9 Ix 7 Xul has an "age" of 55.32 days, ≈ $\frac{1}{2}$ P_{syn}, hence, the mean interval from an inferior conjunction to a superior conjunction or vice versa, and that the *RN* 12.19.15.7.14 9 Ix 2 Ch'en has the same day name at an "age" of 61 days, only 3 days off from that previously discussed. The *RN* 12.19.19.16.10 13 Oc 18 Pax appears at 55 days, or 3 days off in the opposite direction. Finally, the date 12.19.19.7.12 4 Eb 20 Yaxkin, mentioned in connection with Venus, has a Mercury "age," reckoning from the earliest date, of 109 days, 6 or 7 days short of a complete cycle. Hence, of the 16 dates of the *RN* table, six occur at or close to intervals involving the true Mercury synodic period. Of the six dates, three are days 9 *Ix* from a single table of the codex, emphasizing that day, and another day, 4 *Eb*, is from a related and adjacent table. It may be more than a coincidence that the true average period of Mercury had shifted during the periods of the *RN*s approximately halfway around from a cyclical period counted with a round number of 116 days. Thus, the 109-day true average age of 4 Eb 20 Yaxkin would correspond to a cyclical "age" of 55 days; conversely, the true average "age" of 61 days at 9 Ix 9 Ch'en had a cyclical age of 9 days and the true average age of 58 days at 9 Ix 7 Xul would give a cyclical "age" of 5 days. The true average "age" of 55 days at 13 Oc 18 Pax has a cyclical "age" of 1 day.

The average sidereal period of Mercury is 87.96939 days, so that half a Mercury "year" is 44 days. The day 9 Ix 2 *Kankin*, already noted as being at a true average synodic "age" of 115 days from 13 Imix 9 Uo, was also a sidereal "age" of Mercury of 46 days. The *RN* dates 12.19.13.16.0 1 Ahau 18 Kayab, 12.19.19.0.8 3 Lamat 1 uayeb, and 13.0.0.0.0 4 Ahau 8 Cumku all have a sidereal "age" of 44 days, as reckoned from 13 *Imix* 9 *Uo*. These coincidences suggest to Kelley that both the synodic and sidereal periods of Mercury were involved, whether or not consciously formulated as such, in the construction of the *RN*s. This is congruent with other evidence from the 9 *Ix* tables and from the inscriptions.

Calculating the synodic period of Saturn at 378.09208 days, we find that the average "age" of Saturn at 13.0.0.0.0 4 Ahau 8 Cumku, counted from 12.12.17.3.1 13 Imix 9 Uo was 376 days. A cyclical count of exactly 378 days reached a point 11 days earlier. Put in terms of the table construction, if a Saturn "base" was desired and it was believed that 13.0.0.0.0 4 Ahau 8 Cumku was a Saturn base, a strictly cyclical base would have started 11 days after 13 Imix 9 Uo. Alone, this suggestion of a Saturn calculation does not offer much support to an interpretation of *RN*s in astronomical terms. If such an interpretation seems plausible on other grounds, one would certainly suspect Saturn interest here.

As our discussion in §12.7 on the *Dresden* Venus table points out, there is good reason to think that that table shows an interest in eclipses as well as an interest in Venus. Because the basic half eclipse year is 173.31 days, it is interesting to note that counting forward from 12.12.17.3.1 13 *Imix* 9 Uo to 12.19.19.11.19 13 Cauac 7 Ceh, it has an "age" of 171 days, and 12.19.13.16.0 1 Ahau 18 Kayab has an "age" of 172 days. Although Thompson (1950 p. 226) pointed out that the interval between the *RN* base 12.19.13.16.0 1 Ahau 18 Kayab and the table base 9.9.9.16.0 1 Ahau 18 Kayab involved a shift of about half a year both in the Tropical Year and in Venus's synodical phase or age (see §12.7), he did not extend this suggestion of a direct astronomical interest here to other *RN*s. Neither did he discuss why the Mayas should count back to a base off by about a half year from its later Venus position, although he supposed that the late end was in step with Venus's reality (if one applied certain corrections to the base). Willson (1924, p. 35) concluded that "all the planets appear with Ring Numbers and all Ring Numbers appear only with planetary tables." Without agreeing with all the details of his arguments, we think that the evidence supports his position.

12.11. The *Dresden* Codex Eclipse Table

The primary basis for our understanding of eclipses as viewed by the Mayas is the eclipse table of the *Dresden* codex. This consists of a series of 69 intervals, mostly of 177 days, some of 178 days, and 10 of 148 days, accompanied by cumulative totals and by a list of days reached by the intervals over a 3-day range for each interval. Each interval is accompanied by a very short text, largely undeciphered. The table is interrupted by 10 pictures, each following a rare interval of 148 days. Longer texts occur with pictures, frequently mentioning eclipses of both Sun and Moon. The Mayan astronomers seem to have been particularly interested in the months when the instant of new Moon shifts from the node enough so that there are successive eclipses of both Sun and Moon in a single month.[8] The glyphs for eclipses were first recognized in these texts. The pictures normally show deities who are associated with the dates. The total length of the table is 11960 days,

[7] The "age" of a given planet is counted in calendar days from a date given as "zero" without any *a priori* implication that a particular station (configuration) of the planet is involved. Any particular interval is counted in multiples of true mean synodic or sidereal periods with the remainder to the nearest whole day considered as the "age." Thus, the "age" is a given interval *modulo* some mean period. Astronomers often use the term "phase" instead. Cf. Table 2.9 for period data.

[8] Recall from §5.2.1 that eclipses occur when the Moon and Sun are within certain limits of a node—a crossover of the lunar orbit and the ecliptic. On rare occasions, an eclipse can occur within about a month of a previous one because the Sun moves slightly less than 30° over a synodic month and the major ecliptic limits can be as large as ±18.5° for partial solar eclipses.

which is a good cycle for the return of eclipses to the same place (in Table 5.4, Cycles 1 + 4). This interval also restores the same day of the 260-day cycle. The 11,960-day interval represents 32 tropical years (hereafter abbreviated simply as *Ty*) and 272 days, approximately 3/4 of a year. Table 12.9 shows a transcription of the positions of the eclipse table, counted from the base 9.16.4.10.8 12 Lamat 1 Muan with Long Count and month positions added and only the middle date of the 3-day range given.

Preceding the eclipse table proper are a number of calculations that can be used to reach true dates from the table dates (in DHK's interpretation) or to correct the table and furnish revised bases in a related but slightly different view (more widely held). The base parameter is defined by a date that is eight days after the Maya era base at (13/0).0.0.0.8 12 Lamat 16 Cumku, an apparent equivalent of the *Ring Numbers* of other tables (see Table 12.8) and by the previously mentioned 9.16.4.10.8 12 Lamat 1 Muan, an interval of 1,412,840 days.

Until recently, it has been generally assumed that such table bases as 9.16.4.10.8 12 Lamat 1 Muan as the base of the eclipse table or 9.9.9.16.0 1 Ahau 18 Kayab as the base of the Venus table were intended to reach real phenomena contemporary with the indicated dates. In the case of the eclipse table, this accorded so ill with the Thompson correlation that it was suggested that the table should be divorced from the Long Count base that immediately preceded it. A study of the placement of the 148-day intervals in the table by Teeple (1930) indicated that the base of the table should be within a day of a node passage of the Sun (probably the day after). In the Thompson correlation, this was far from being true for 9.16.4.10.8 12 Lamat 1 Muan, and it was suggested that the "real" base was an unmentioned day 12 *Lamat*, much later. Recently, Bricker and Bricker (1983) have suggested that the table is a "floating" ideal table, designed to be entered through various corrections, accepting 9.16.4.10.8 12 Lamat 1 Muan as the base of the table, but denying Teeple's structural argument (from the placement of the 148-day intervals) that the base was near the instant of a draconitic node passage. Kelley (1981, 1987) has developed new evidence that the table was a structural reality not originally designed to function at the table base. Kelley (1980) had suggested that the date 9.16.4.10.8 12 Lamat 1 Muan had originally been calculated as a Classic Period counterpart of a date 12.10.12.4.8 12 Lamat 1 Muan (before the normal Maya era base), which was exactly 11,960 days or one eclipse table length after 12.8.19.0.8 12 Lamat 1 Pop, a Maya New Year's day. The latter is the date from which, Kelley argued, the birth dates of the gods were calculated. This day, 12 *Lamat* or 12 Rabbit, was postulated by Caso as the name of an old Moon god of central Mexico, and supposed by Kelley to have been the eclipse cycle god. In Kelley (1980), no effort was made to determine the precise structural nature of the relationship between 12.10.12.4.8 12 Lamat 1 Muan and 9.16.4.10.8 12 Lamat 1 Muan. The possibility of the use of a formal table of 11,960 days, used without correction in order to measure the degree of variation of the real phenomena led to fuller examination of the dates. The least-common denominator of the 11,960-day cycle of eclipses and the 18,980-day calendar round is 873,080 days (46 calendar rounds or 73 eclipse table periods constituting 2392 Mesoamerican years). Such dates, counted from the presumed early base, occurred twice in the pre-Classic Period and then leaped the entire Classic Period (of about 600 years, missing about 12 dates 12 Lamat 1 Muan).

It was then realized that one other date in the table was a day 12 *Lamat* within the 3-day variation allowed by the table, at the important interval of 9360 days (in Table 5.4, Cycle $1 + 2 \times$ Cycle 2) reaching 12.11.18.4.8 12 Lamat 11 Mol. If one counted from this as the base by multiples of 11960 days and went forward to a 12 Lamat 1 Muan date, the first occurrence of such a date would have been at 3.14.19.6.8 12 Lamat 1 Muan. From this, one interval of 46 calendar rounds (as above) goes forward precisely to 9.16.4.10.8 12 Lamat 1 Muan (see Table 12.10).

This affords strong evidence supporting the placement of a "proto-base" by the Mayas at 12.10.12.4.8 12 Lamat 1 Muan and equally strong evidence that the late base of the eclipse table would have differed both on the true date of a draconitic node passage and on the correspondence with true lunations, depending on how much error the Mayas had in the parameters used in calculating the early base. In effect, this interpretation means that the eclipse table can offer no guidance in solving the correlation problem, except in that it suggests that other tables may have been structured in the same way.

The same calendar round date, 12 Lamat 1 Muan (±1 day), also has an important placement in real time in the intertribal *tzolkin* as an annular solar eclipse with path of centrality nearly across the Maya site of Copan, in Honduras, at J.D. 1 446 712, -752 (753 B.C.) November 18 (in the Julian Calendar), as given in Oppolzer. This was first pointed out by Spinden (1930, pp. 55–56). However, by more recent calculation, the track is markedly farther south. The implications of this date have not been considered adequately by anyone. Minimally, this implies either that the Mayas were already using the full calendar round in 753 B.C. and recording eclipses in it or that they were able to back-calculate eclipses with great accuracy and did so, using this date to place the intertribal tzolkin in step with real time. The latter could have been accomplished either at the time of invention (if there was no calendar correction) or at the time of a calendar correction if one did occur. It seems unlikely, although far from impossible, that the calendar was in use for more than 700 years (even in the Spinden correlation) with no use in a known inscription. At the same time, most Mayanists would be equally unwilling to admit that the Mayas could have retrodicted[9] a locally visible eclipse at the time of the inauguration of the calendar. It is even more unlikely that this is a structural reality of a purely accidental nature.

In the Spinden correlation, this date is 24 calendar rounds before 9.16.4.10.8, an interval of no known significance. In the Thompson correlations, the date would have been one day either before or after 5.19.15.11.8 12 Lamat 1 Muan, which is 29 *CR* before 9.16.4.10.8. In this interval, the

[9] This is an archeological term meaning the equivalent for the past to *predict* for the future. In this case, the term *back-calculate* is a clumsy equivalent.

TABLE 12.9. Potential dates of eclipses from the *Dresden* eclipse table.

Dresden lunar table: Calculated to middle line of table			Notes
0.	9.16.4.10.8	12 Lamat 1 Muan	
1.	9.16.5.1.5	7 Chicchan 13 Zec	
2.	9.16.5.10.2	2 Ik 10 Kankin	
3.	9.16.5.17.10	7 0c 13 Zip	Picture 1. Sky-in-hand; Yum Camil-x-sun half-darkened sun, moon
4.	9.16.6.8.7	2 Manik 10 Ceh	(3 Lamat 11 Ceh–star glyph)
5.	9.16.6.17.4	10 Kan 2 Zip	
6.	9.16.7.8.1	5 Imix 19 Zac	
7.	9.16.7.16.19	1 Cauac 12 Uo	
8.	9.16.8.7.16	9 Cib 9 Zac	
9.	9.16.8.16.13	4 Ben 1 Uo	
10.	9.16.9.7.10	12 0c 18 Yax	
11.	9.16.9.16.7	7 Manik 10 Pop	Cf. Copan St. N
12.	9.16.10.7.4	2 Kan 7 Yax	
13.	9.16.10.14.12	7 Eb 15 Kayab	Picture 2. Earth center; half dark sun, moon
14.	9.16.11.5.10	3 0c 8 Mol	
15.	9.16.11.14.7	11 Manik 5 Kayab	Cf. Copan Temple 11
16.	9.16.12.5.4.	6 Kan 17 Yaxkin	
17.	9.16.12.14.1	1 Imix 14 Pax	
18.	9.16.13.4.18	9 Etz'nab 6 Yaxkin	(Cf. Quirigua St. D, 8 Caban 5 Yaxkin; St. N 9.16.13.4.15 6 *Men* 3 *Yaxkin*)
19.	9.16.13.12.6	1 Cimi 14 Kankin	Picture 3. Earth center–half-dark sun, moon; six sky–*chac naab*
20.	9.16.14.3.3	9 Akbal 6 Zec	
21.	9.16.14.12.0	4 Ahau 3 Kankin	
22.	9.16.15.2.17	12 Caban 15 Zotz	
23.	9.16.15.11.15	8 Men 13 Mac	
24.	9.16.16.2.12	3 Eb 5 Zotz	
25.	9.16.16.11.9	11 Muluc 2 Mac	Rain–earth
26.	9.16.17.0.17	3 Caban 5 Uo.	Picture 4. Half-dark sun, moon; south; earth-center
27.	9.16.17.9.14	11 Ix 2 Zac	
28.	9.16.18.0.11	6 Chuen 14 Pop	
29.	9.16.18.9.9	2 Muluc 12 Yax	
30.	9.16.19.0.6	10 Cimi 4 Pop	(+2 = 12 Lamat)
31.	9.16.19.9.3	5 Akbal 1 Yax	–Death mannequin/sky-tun oc?/xul?
32.	9.17.0.0.0	13 Ahau 18 Cumku–new	–Copan Temples 11, 22a Alt. Z
33.	9.17.0.8.17	8 Caban 10 Ch'en	
34.	9.17.0.17.14	3 Ix 7 Cumku	
35.	9.17.1.8.11	11 Chuen 19 Mol	–Rain
36.	9.17.1.15.19	3 Cauac 7 Pax	Picture 5. Rain–reversal Sun Snake–x-sky–earth (verb)–housed Yum camil–his yellow sky (25 Dec., Spinden)
37.	9.17.2.6.17	12 Caban 20 Xul	
38.	9.17.2.15.14	7 Ix 17 Muan	
39.	9.17.3.6.11	2 Chuen 9 Xul	
40.	9.17.3.15.8	10 Lamat 6 Muan —rain	
41.	9.17.4.6.5	5 Chicchan 18 Zec	
42.	9.17.4.13.13	10 Ben 6 Mac.	Picture 6. Half-dark sun; *u ekel*; earth (verb); Hanging woman
43.	9.17.5.4.10	5 0c 18 Zip	
44.	9.17.5.13.7	13 Manik 15 Ceh	
45.	9.17.6.4.4	8 Kan 7 Zip	
46.	9.17.6.13.1	3 Imix 4 Ceh	
47.	9.17.7.3.18	11 Etz'nab 16 Uo	
48.	9.17.7.12.15	6 Men 13 Zac	
49.	9.17.8.2.3	11 Akbal 1 uayeb.	Picture 7. Earth (verb)–sky-in-hand
50.	9.17.8.11.0	6 Ahau 13 Ch'en	
51.	9.17.9.1.17	1 Caban 10 Cumku	
52.	9.17.9.10.15	10 Men 3 Ch'en	
53.	9.17.10.1.12	5 Eb 20 Kayab	20 Kayab = seating of Cumku, sometimes written "0 Cumku"
54.	9.17.10.10.9	13 Muluc 12 Mol	12 Lamat + 1 = 13 Muluc.
55.	9.17.11.1.6	8 Cimi 9 Kayab	–Sky
56.	9.17.11.10.3.	3 Akbal 1 Mol	
57.	9.17.12.1.0	11 Ahau 18 Pax	
58.	9.17.12.8.8	3 Lamat 1 Xul	Picture 8. (Ah) Cimil u cab (verb)–sky-in-hand 4 *haab* 4 (Vultures = suns, days??)
59.	9.17.12.17.5	11 Chicchan 18 Kankin	
60.	9.17.13.8.3	7 Akbal 11 Zec	

TABLE 12.9. *Continued.*

Dresden lunar table: Calculated to middle line of table			Notes
61.	9.17.13.17.0	2 Ahau 8 Kankin	
62.	9.17.14.7.17	10 Caban 20 Zotz	Sky New. 20 Zotz = end of Zotz = seating of Zec.
63.	9.17.14.16.14	5 Ix 17 Mac	
64.	9.17.15.7.11	13 Chuen 9 Zotz	
65.	9.17.15.14.19	5 Cauac 17 Zac–Two-legged Sky Ah Cimil.	Picture 9. Diving Star Glyph B–*kinil*
66.	9.17.16.5.10	13 Cib 9 Uo	
67.	9.17.16.14.13	8 Ben 6 Zac	
68.	9.17.17.5.10	3 0c 18 Pop	
69.	9.17.17.14.7	11 Manik 15 Yax (12 Lamat – 1)	Picture 10. Diving Star, picture and glyph. Royal throne. Half dark sun, moon. Sky-in-hand. *Ah ahpo tzu*
	9.17.17.14.9	13 Muluc 17 Yax–day after last in table	Next table section begins with 13 Muluc.

TABLE 12.10. Periodicities involving 12 *Lamat* 1 *Muan*.

12. 8.19. 0.8 12 Lamat 1 Pop
1.13. 4.0 +11960
12.10.12. 4.8 12. Lamat 1 Muan

+1. 6. 0. 0 (9360)
12. 11. 18. 4. 8 12 Lamat 11 Mol

+4.4.7.2.0
(32 × 18980)

+4. 3. 1. 2. 0 (50 × 11960)
3. 14. 19. 6. 8 12 Lamat 1 Muan

+6. 1. 5. 4.0 (= 873080)
(= 46 × 52 × 365)
(= 46 × 18980)
(= 73 × 46 × 260)
(= 73 × 11960)
5.11.17. 8.8 12 Lamat 1 Muan

+6. 1. 5. 4.0
11.13. 2.12.8 12 Lamat 1 Muan

N.B.: The dates arrived at have been referred to the era base 13.0.0.0.0 4 Ahau 8 Cumku. See p. 359.

+6. 1. 5. 4. 0
9. 16. 4. 10. 8 12 Lamat 1 Muan

difference between the Mesoamerican year and the tropical year cumulatively amounts to exactly one year i.e., 1508 My equal 1507 tropical years. This means that the Mayan year is back to the same season. The interval is also a moderately good eclipse interval (in the sense that there are nearly an integral number of nodal months—20,226.96—in this interval, and it is only 0.64 days more than 18,639 lunations by Spinden's correlation), and a very good Mercury interval (≈6257.01 synodic revolutions). Spinden (1930, p. 94) argued that the Venus cycle could be related to this formula, but the evidence of Maya calculations on this is lacking and the structural argument is too complex to be very convincing.

DHK does not think that the Thompson correlation is correct, but that calculation of this interval probably entered into the establishment of the CR as it was known in the colonial period (after the postulated calendar reform). The half-period of 29 CRs (otherwise emphasized at Palenque) is 275,210. Counted forward from the 753 B.C. date, this interval reaches JDN 1,721,922, May 14, 2 A.D. (Julian calendar), the day before a lunar eclipse and 16 days before a solar eclipse (Maya 3 Etz'nab 1 Muan).

Satterthwaite (1947) suggested that the Mayas evolved their eclipse system on a hit-or-miss cyclical basis without ever really understanding what they were doing. Because lunar eclipses are more widely visible than solar eclipses, it is possible that the Mayas worked out a theory based on lunar cycles and transferred it to solar eclipses. Although Satterthwaite's hypothesis is ingenious and persuasive in detail, it involves a combination of long periods of accurate record-keeping, mathematical sophistication in averaging, and minimal understanding. The general sophistication of Mayan astronomical concepts that seems to Kelley to be indicated in the sources is against this view. More recently, Smither (1986) has studied the distribution of both lunar and solar eclipses in Mesoamerica between A.D. 505 and 932 in an attempt to determine how eclipse prediction might have been achieved. He found that lunar eclipses would provide a readily recognizable pattern of repetition over 88 lunations (15 eclipse seasons, 10 tzolkin rounds or 7 Maya years, and 44 days). Smither (1986, p. 102) defined the area of investigation as that part of North America lying between 14° and 22° north lattitude. He defined a visible solar eclipse as one in which 50% or more of the Sun's surface was hidden. Of 1022 solar eclipses during the period investigated, 56 were visible in the area of interest. His published data deal with the period from 712 A.D. to 861 A.D., during which there were

13 total or annular eclipses, and 11 partial eclipses. During the same time period, there were 130 visible lunar eclipses—more than five times as many as the solar eclipses and visible from a given locality for much longer periods of time. Smither (1986, figure 2) compares these data with the eclipse table of the *Dresden* codex. His further contention that the positions of the five-lunar-month intervals in the codex would work better as predictors of lunar eclipses than of solar eclipses is valid but does not consider the fact that such intervals are necessarily times when it is more probable for a solar eclipse to fall in the same month as a lunar eclipse, which DHK thinks is probably the Maya interest. Smither's belief that lunar eclipses were intended leads him to propose a new correlation constant, 584,301, shifted 16 days from the Thompson constant, 584,285. This would imply that lunations throughout the Classic Period were counted from full moons, as Spinden argued. This does not seem to agree with DHK's postulates on the identities of lunar goddesses. Smither thinks that the table should have been adjusted every 52 years for most effective use, but does not explain the references in the introduction to the table to much longer intervals. Smither argues that the 52-year cycle and the 104-year cycle are evident as actual points where the 88 lunar month pattern "breaks."

Two suggestions have been made with respect to the interpretation of the pictures, which appear following 148-day intervals. The first view was that they marked locally visible eclipses. Willson (1924, pp. 9–16) checked the entire series of eclipses visible in Yucatan between 12 B.C. and 1520 A.D. and found that there was no series of 10 visible eclipses at the intervals shown in the codex. Indeed, Willson (1924, p. 15, fn. 1) points out that the interval between the 9th and 10th pictures is 708 days and that "no central eclipse visible in the tropics can be followed in 708 days by an eclipse whose shadow passes over tropical countries." Willson found four cases of seven visible eclipses at the intervals indicated, but no greater number of eclipses. He thought that the eclipses may be predicted eclipses, with errors up to 1/10 day, and found one series that included 10 eclipses that might have been predicted at the appropriate intervals. However, although not known in Willson's time, the verb accompanying the 5th picture has an affix that indicates that it refers to an event *in the past*. Because this indicates that it is unlikely that the text was directly designed to refer to the future, this makes it very unlikely that the pictures were intended to refer to visible eclipses.

The alternative explanation is that the pictures refer to a lunar month in which one may have found a lunar and a solar eclipse together. Because an interval of 148 days implies just such a condition, DHK thinks that Meinshausen (1913) was correct in making this suggestion. Indeed, the glyphs and details of the pictures seem to support this view. In particular, five of the pictures are accompanied by glyphs of both Sun and Moon, each in a curious frame, in which one is half-black, and another, half-white. These were accepted as "eclipse" glyphs by most early and present scholars, Eric Thompson's insistence that the frames indicate only "darkness" notwithstanding (such a view was consistent with Thompson's arguments that various "almanacs" were essentially agricultural with little or no astronomical content).

Severin (1981, p. 17) proposed that the "wings" of these symbols in their four variants marked the positions of the Sun—both white, summer solstice; both black, winter solstice; left white and right black, autumn equinox; left black and right white, spring equinox. This was part of his argument that the Maya knew and used calculations of precession over 26,000 years. Severin based his work on the *Paris* codex, where there is little chronological control. Closs (1983) shows that the forms in the *Dresden* eclipse table (not considered by Severin) are utterly inconsistent and would remain so whatever correlation is accepted and whatever base is accepted for the table, with the "autumn equinox" appearing in seven different months of the tropical year.

Teeple (1930, pp. 90–93) analyzed the sequence of intervals in the eclipse table and concluded that they do indeed refer to eclipse half-year intervals and that the instant of a solar node-crossing most probably occurred on the day before the 12 *Lamat* date which was the base of the table (see §5.2.1.1 for detailed discussion of the circumstances for eclipses to occur). The table is immediately preceded by the date 9.16.4.10.8 12 Lamat 1 Muan, which it is reasonable to suppose is the 12 *Lamat* date, the base of the table. However, neither the Thompson nor the Spinden correlations (which seemed most likely on historical grounds, at that time) put the instant of a node passage of the Sun even near this date; so various explanations were devised that removed the table by various amounts from its supposed base. Makemson (1943, pp. 187–188) argued that the three dates 9.16.4.10.8 12 Lamat 1 Muan, 9.16.4.11.3 1 Akbal 16 Muan (15 days later), and 9.16.4.11.18 3 Etz'nab 11 Pax (30 days after the first date), which appear just prior to the table depictions, could represent two solar eclipses flanking a lunar eclipse (or conceivably a solar between two lunar eclipses). In either case, a node passage of the Sun must be near the middle date. From the discrepancy between this node passage instant and that of Teeple, she argued that the 12 *Lamat* base of the table was different from 9.16.4.10.8 12 *Lamat* 1 *Muan* and that the table must belong to a substantially later date, corresponding to a different date of nodal crossing. However, she failed to point out that

(1) in the case of a lunar eclipse between two solar eclipses, one of the solar eclipses would be visible too far to the north for the Mayas to see it and the other would be too far south to be visible;
(2) two lunar eclipses with a solar eclipse between them could not be separated by more than 30 days; and
(3) there are actually four dates, not three, at the beginning of the table; the 4th seems out of place in this context, although reading is doubtful. In any case, the dates seem to be in two pairs, rather than a set of three and an extra date.

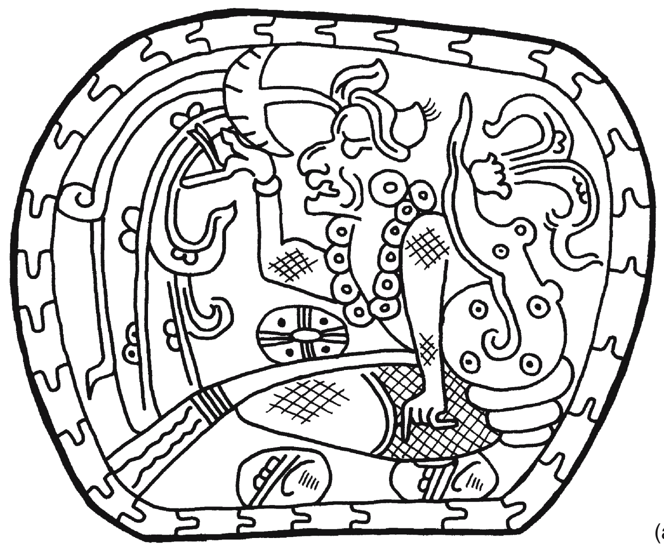
These circumstances would make it seem that the Makemson interpretation is unlikely and that the most straightforward interpretation would be that 9.16.4.10.8 12 Lamat 1 Muan was the table base, as Teeple thought, that it is very near an instant of solar node passage, and that the date is that of a new Moon. If so, the paired date 9.16.4.11.3 1 Akbal 16 Muan (15 d later) could serve as a base for calculating associated lunar eclipses, which would be in accord with the suggested interpretation of the pictures. However, that interpretation is incompatible with either the Thompson correlation or with the Spinden correlation, which once seemed the most likely competitor with the Thompson correlations. It was suggested earlier in this section that 9.16.4.10.8 12 Lamat 1 Muan was based on a formal cyclical recurrence of a date 12 Lamat 1 Muan back-calculated before the Maya era base, which would allow *any* correlation.

12.12. Calendar Names of Eclipse Deities

The base 12.8.19.0.8 12 *Lamat* 1 *Pop* defines a number of eclipse deities of five different classes (cf., Table 12.7b). Some are associated with a solar node passage, some with the night before conjunction (the old Moon), some with conjunction (the astronomers' new Moon—the "dark of the Moon" to farmers), some with first visibility, and some with full Moon. A few seem to be associated with eclipses that coincide with multiples of planetary periods from the base. The most striking and convincing of these deities is the old Moon god named by a full calendar round name as 12 *Lamat* 1 *Muan*, which was previously discussed. Among the Nahuas, the old Moon god was called *Tecciztecatl*, "He of the Snail Shell." Figure 12.12a shows a prototype of this god from Teotihuacan.

The deity names seem to display a pattern in which old Moon goddesses are associated either with the last visible old Moon or the dark of the Moon, and male deities are associated with the dark of the Moon (the astronomical new Moon); young goddesses are associated with the first visible new Moon, and other goddesses are associated with the full Moon. There are also goddesses associated with the moment of solar node passage, in the sense that they represent integer multiples of the interval 173.31 days. In most or all cases, these lunar deities seem to be associated with eclipse or eclipse season intervals rather than with more general lunar phenomena. The skull-headed goddesses of pulque, the intoxicating drink of Mesoamerica, with the Aztec calendar names Two Flower and Three Crocodile (corresponding to the Mayan Two *Ahau* and Three *Imix*), appear at days 173 and 174 from the base, apparently marking the solar node passage interval or the eclipse season of 173.31 days (see §5.2.2). The solar node passage 173 days later at 7 Jaguar (7 *Ix*) is known as the "magical name" of the gourd and is marked by the decapitated head of a god identified by Kelley (1980, pp. S34–S35) as a Sun god. This god is said to have been turned into a gourd in the 16th century Maya book of Guatemala called the *Popol Vuh*.[10]

The motif of decapitation in connection with eclipses recurs frequently. Because $3 \times 173.31^d = 519.93^d$ and $2 \times 260^d = 520^d$, the solar node passage will recur on the same day of the tzolkin for a long period of time. If the tzolkin day is repeated until it coincides nearly or exactly with a lunation, it then becomes the basis of an eclipse cycle. Thus, the original base 12 Lamat 1 Pop carried forward 11,960 days becomes 12 Lamat 1 Muan, the base of the major Mayan



(a)

(b)

FIGURE 12.12. (a) A prototype of the Nahua old Moon god, *Tecciztecatl*, "He of the Snail Shell," from Teotihuacan. Drawing by Sean Goldsmith. (b) The head of a Sun god growing on a gourd tree and another head already largely turned into a gourd, from a Mayan pot. Drawing by Sharon Hanna.

[10] A native term for "book of council." The term is used early within the book and was adopted by the early Mayanist Brasseur de Bourbourg (1861) as its name.

eclipse cycle, the *fox*.[11] The day *173*, 2 *Ahau* or 2 Flower, carried forward [173 + (40 × 260) = 10,573] becomes the base of the *inex* cycle, the most accurate of all short-range eclipse cycles. If *174*, 3 *Imix* (3 Crocodile) is carried forward until it coincides with an eclipse; it becomes the base of the cycle defined by 46 eclipse season intervals (7972.26 days) and 270 lunations (7973.26 days). 7 *Ix* (7 Jaguar) carried forward becomes the Saros cycle. The eclipse deities 2 Flower, 3 Crocodile, and 7 Jaguar are identified in Table 12.7b. More detail can be found in Kelley (1980/1987).

12.13. Eclipse References on Maya Pottery

A combination of the postulated 12 Lamat 1 Pop base with dates of mythicoastronomical events depicted on Maya pottery has allowed the recognition of a number of additional iconographic features associated with eclipses and has supported the postulated placement of the 12 Lamat 1 Pop base. Dates from these pots are shown in Table 12.11. The most clearcut example of these dates is given on the *Princeton 16* vase (Coe 1978, p. 108). Here, we see a pair of gods, one of whom is one of the monkey gods, identified by Coe (1977) as the gods of writing. On a sort of scroll attached to the body of one of these gods appear the numbers 12.15.12.7.1; if read as an Initial Series date before the Maya era base, this would be 3 Imix 19 Yax. This date is four eclipse table lengths of 11,960 days after 12.8.19.9.1, 3 Imix 14 Ch'en, the postulated naming date of Three Crocodile, the pulque goddess, mentioned in Table 12.7b as a goddess of draconitic node passage. Like that date, a mean lunation interval would suggest an eclipse three or four days later on 7 Snake or 8 Death. Moreover, the interval from 12.8.19.9.1 3 Imix 19 Yax to the normal Maya era base, 13.0.0.0.0 4 Ahau 8 Cumku, is 31,539 days, an important eclipse interval. This interval is, in fact, that which separates the Thompson correlation (584,285) from the second Schove correlation (615,824) (cf., Schove 1980). It may be considered to be composed of two intervals of 11,960 days plus 7619 days.

The date of the *Princeton 16* vase thus firmly ties the previously postulated 12.8.19.0.8 12 Lamat 1 Pop to the normal Maya era base. The buxom woman who appears associated with the rear head of the two-headed dragon is presumably some sort of Moon goddess, perhaps the goddess *Three Imix*. The rear head of the two-headed dragon is often shown with a Sun glyph and, for this reason, has often been directly associated with the Sun. However, this Sun glyph is often partly or completely cross-hatched, a normal way of indicating blackening or darkening in the inscriptions. The darkened Sun glyph appears at Palenque in a context in which DHK read it as "eclipse" (although this interpretation now seems unlikely) and partly on this basis, and partly on the basis of Eurasian parallels, he argued (Kelley 1972, pp. 56–57) that the rear head of the two-headed dragon stood for the descending draconitic node. Its presence on this pot would support that interpretation. Its further presence as a decapitated head being borne by the black god L is also in accord with that view, because decapitation seems to be a good iconographic marker of eclipses. The Muan owl flying about may be directly associated with the old black god with the pointed chin, for that is a form of the head of god L who frequently wears the Muan owl as a headdress. DHK regards him as the adult form of *Xbalanke*, who, as a youth, opposes the lords of the underworld and then takes their place to be opposed in turn by his youthful alter ego. His identity as Thirteen Death identifies him with Saturn (Table 12.7 and Kelley 1980, p. S18). This is verified for this pot by the fact that the interval of 48,013 days from 12.18.9.0.8 12 *Lamat* 1 *Pop* to 12.15.12.7.3 3 Imix 19 Yax is 5 days less than 127 mean synodic period intervals of Saturn, and these 127 Saturn intervals would coincide exactly with the mean eclipse interval of 48,013 days, resulting in an eclipse on 7 Snake or 8 Death.

There is still much to explain about the iconography of this beautiful pot, but there seems little doubt that eclipse imagery plays a central role. Table 12.11 shows the eclipse-related phenomena of the postulated 12 *Lamat* 1 *Pop* base, the protoeclipse table, the Dresden eclipse table, and a number of pots. The latter have been placed at what seem to be appropriate places in the "mythical time" realm between 12.8.19.0.8 12 Lamat 1 Pop and the Maya era. The *Princeton 1* vase (Figure 12.13; Coe 1978, pp. 16–21) carries the calendar round date 8 Caban 5 Ceh and a complex scene with a man about to be decapitated, watched by a lord and ladies.

Placed in its first possible position after 12.8.19.0.8, it becomes 12.11.5.34.17. Table 12.11 shows astronomical intervals near this date. The iconography corresponds absolutely. God L is marked by a Saturn conjunction. His five ladies are the sacrificial goddesses of the number 2; Coe suggests that they may correspond to the Aztec *Cihuateteo* whom DHK identified, in turn, as goddesses of the eclipse season interval. The rabbit scribe suggests by his book (*huun*) the number one (*hun*), and 1 *Lamat* or 1 Rabbit was the original lunar eclipse goddess. The executioners seem to be Venus and Mercury, and the victim is the young Sun god, *Hun Hunahpu*, or "one lord."

The decapitation motif with eclipses continues. On Princeton vase 4 (Figure 12.14), the twins demonstrate their prowess before the Lords of Death by cutting each other's heads off and then restoring them.

After doing this, they were asked by the lords to cut off and restore the lords' heads. The twins obligingly cut their heads off, but did not restore them. The date given with this scene is immediately after a mean solar eclipse (the 4th repetition of the eclipse cycle) and shows that *Xbalanke* here has been restored to life. Now the lord of death, here Jupiter, is about to come into conjunction with the Sun (i.e., be decapitated in his turn).

The association of ball games with eclipses is shown on the pots. The opposition of Deer (bearer of the sun in Mesoamerican mythology) and of a bird or birds, representative(s) of the lords of death, is frequent on Maya pots (including those without dates, not considered here). On one pot, Hummingbird is shown playing for the Lords of Death.

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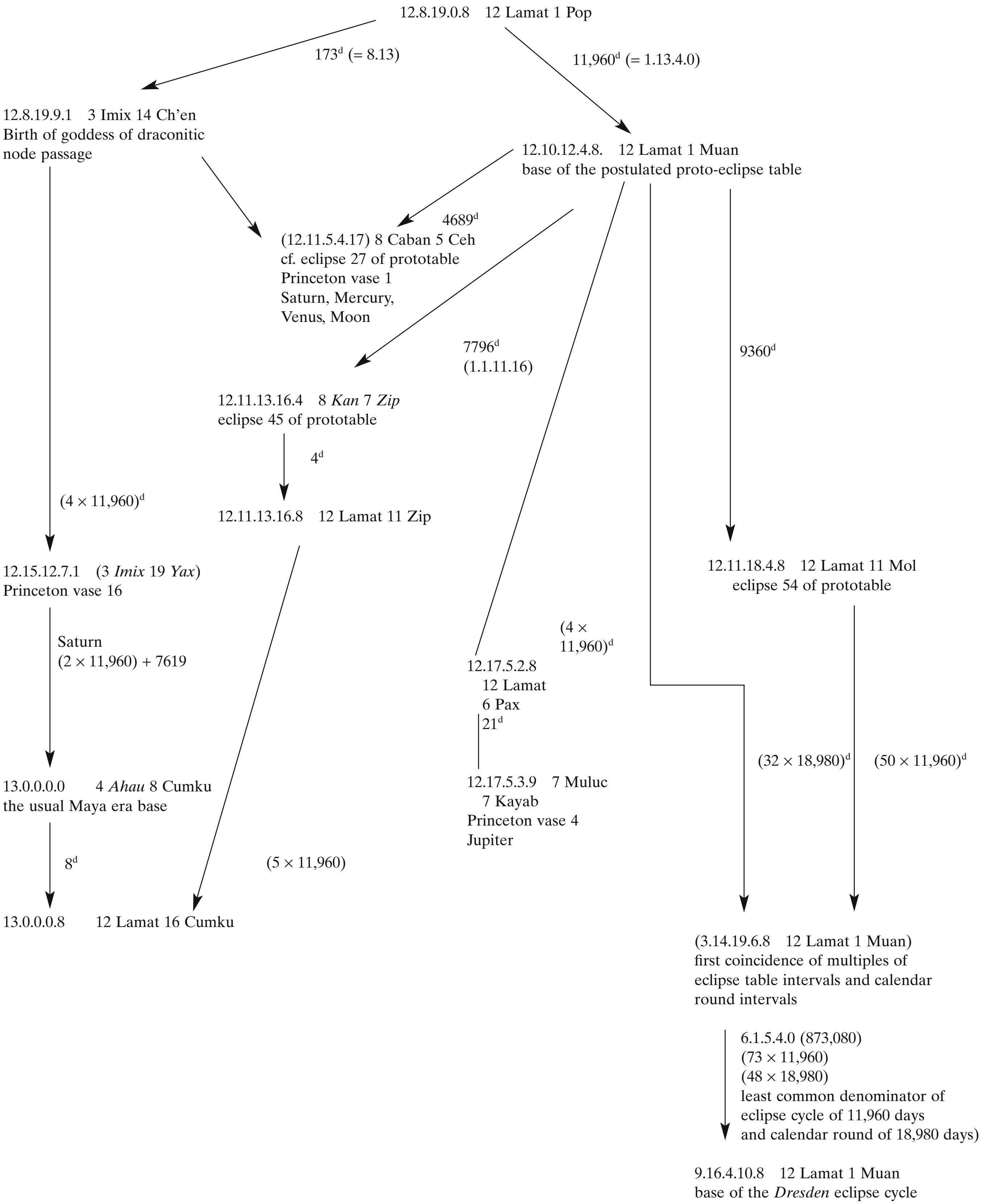
[11] See §5.2.2 for the eclipse cycles, §2.3.5 for lunar periods.

Table 12.11. Astronomical identifications of dates on Maya pottery.



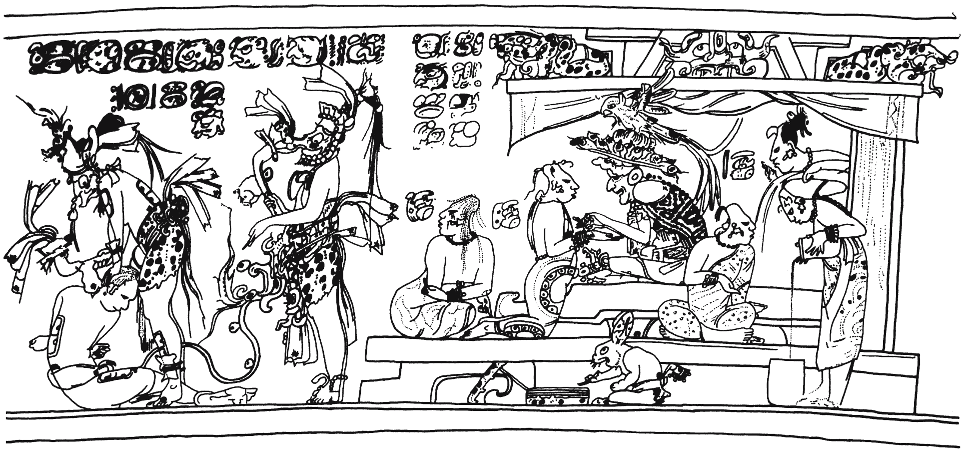


Figure 12.13. The Princeton 1 vase: God L is shown in the house of Jaguar Snakes with five Moon goddesses. Drawn by Sean Goldsmith.

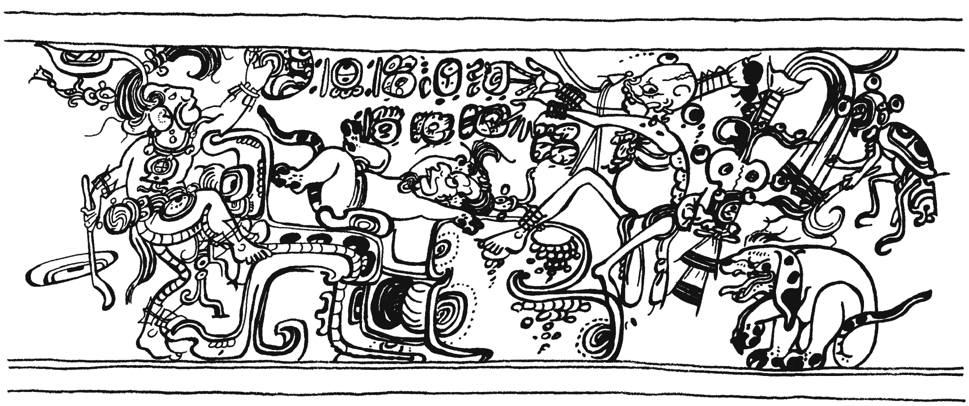


Figure 12.14. Princeton Vase 4: Decapitation at an eclipse. Drawn by Sean Goldsmith.

The interval suggests that he is a Mars deity. In Aztec culture, the hummingbird was associated with *Huitzilopochtli*, the war god, and a number of things suggest that *Huitzilopochtli* was a Mars deity, notably, that he is a youngest child and that he decapitates his sister, the Moon goddess.

12.14. New Fire Ceremonies in the *Vienna* Codex

In Mesoamerica, as in the southeastern United States and parts of the Old World, it was customary to put out all fires in an area, awaiting some calendrical or astronomical moment to pass. After an event had occurred, a new fire was kindled with much ceremony, and other fires throughout the land were lit from this *New Fire*.

Susan Snow (1986) did a careful study of the dates in the *Nuttall* and *Vienna* codices and was able to show that the Mixtec calendar, unlike the Aztec, was named for its beginning day, which corresponded to a day *6 Mac* of the Maya calendar as first recognized by Nowotny. For calculations with *Mixtec* dates, see Table 12.12. The 121st day of the Mixtec year corresponded to Maya 1*Pop*. The position of the days in the year is based on the intertribal *tzolkin*, checked by astronomical correspondences, and it corresponds to a Maya correlation 584,285, or any correlation constant that is different from this number by a multiple of 18,980. All dates are given in the Julian calendar, and all would be two days earlier in the year with 584,283. The table gives a complete 52-year cycle of named years. For example, Day 1 of Year 13 Rabbit would fall on a day 13 Rabbit equivalent to Maya 6 *Mac* and to the Julian date Sept. 28, 778. After 120 days, we arrive at Day 121, which would be day 3 Rabbit, equivalent to Maya 3 Lamat 1 Pop. Thus, this is the beginning of a new year in Maya, but not in Mixtec. The following Mixtec year was 1 Reed, equivalent to Sept. 28, 779. In the following 52-year cycle, 1 Reed fell on Sept. 15, 831. Because the Julian calendar year length is 365.25 days, the change in the Julian calendar date is indicated in place of the year for leap years. The table may be extended indefinitely. For convenience of later calculations, day 1Reed, New Year's day of the year 1 Reed, fell on June 29, 1143; June 16, 1195; June 3, 1247; May 21, 1299; May 8, 1351; April 25, 1403; April 12, 1455; March 30, 1507; and March 17, 1559. This calendar appears in the *Vienna* codex.

Table 12.12. The 52-year cycle of the Mixtec year with equivalent dates in the western calendar: The Mixtec year, prepared by David H. Kelley, ff. work of Susan Snow and D.H. Kelley. The Mixtec year was named for its beginning day, which corresponded to 6 *Mac* of the Maya calendar, as first recognized by Nowotny. The 121st day of the Mixtec year corresponded to Maya 1 *Pop*. The position of the days in the year is based on the intertribal *tzolkin*, checked by astronomical correspondences and corresponds to a Maya correlation 584,285, modulo 18,980. All dates are given in the Julian calendar, and all would be two days earlier in the year with 584,283. Day 1, 13 Rabbit (= 6 *Mac*) + 120 = day 121 = Maya 1 *Pop* 3 *Lamat* (3 Rabbit) (= Aztec year 1 Rabbit). The table may be extended indefinitely. For convenience of later calculation, day 1 Reed, New Year's day of the year 1 Reed, fell on: 29 June 1143; 16 June, 1195; 3 June, 1247; 21 May, 1299; 8 May, 1351; 25 April, 1403; 12 April, 1455; 30 March, 1507; 17 March, 1559. This calendar was used in the *Vienna* codex. The Mixtec years overlap years of the Tlaxcallan calendar with the same name and overlap years of the calendar in the *Borgia* codex. The Tlaxcallan years are named for their 360th day (i.e., the last day of the year excluding the five "extra" days), which was the end of the month *Panquetzaliztli* (the equivalent of Maya *Yaxkin*). This day is 260 days after 6 *Mac*, and hence, the Tlaxcallan calendar begins with *Atemoztli*, 105 days before the beginning of the Mixtec year. The year-namer of the *Borgia* codex is also in the 360th position, falling on the equivalent of 16 *Uo*, 520 days after the Mixtec year-namer.

13	Rabbit	778	830	882	934	986	1038	1090
1	Reed	779	831	883	935 20 Aug. 2062798	987	1039	1091
2	Flint	780 27 Sept.	832 14 Sept.	884 1 Sept.	936 19 Aug.	988 6 Aug.	1040 24 July	1092 11 July
3	House	781	833	885	937	989	1041	1093
4	Rabbit	782	834	886	938	990	1042	1094
5	Reed	783	835	887	939	991	1043	1095
6	Flint	26 Sept.	13 Sept.	31 Aug.	18 Aug.	5 Aug.	23 July	10 July
7	House	785	837	889	941	993	1045	1097
8	Rabbit	786	838	890	942	994	1046	1098
9	Reed	787	839	891	943	995	1047	1099
10	Flint	25 Sept.	12 Sept.	30 Aug.	17 Aug.	4 Aug.	22 July	9 July
11	House	789	841	893	945	997	1049	1101
12	Rabbit	790	842	894	946	998	1050	1102
13	Reed	791	843	895	947	999	1051	1103
1	Flint	24 Sept.	11 Sept.	29 Aug.	16 Aug.	3 Aug.	21 July	8 July
2	House	793	845	897	949	1001	1053	1105
3	Rabbit	794	846	898	950	1002	1054	1106
4	Reed	795	847	899	951	1003	1055	1107
5	Flint	23 Sept.	10 Sept.	28 Aug.	15 Aug.	2 Aug.	20 July	7 July
6	House	797	849	901	953	1005	1057	1109
7	Rabbit	798	850	902	954	1006	1058	1110
8	Reed	799	851	903	955	1007	1059	1111
9	Flint	22 Sept.	9 Sept.	27 Aug.	14 Aug.	1 Aug.	19 July	6 July
10	House	801	853	905	957	1009	1061	1113
11	Rabbit	802	854	906	958	1010	1062	1114
12	Reed	803	855	907	959	1011	1063	1115
13	Flint	21 Sept.	8 Sept.	26 Aug.	13 Aug.	31 July	18 July	5 July
1	House	805	857	909	961	1013	1065	1117
2	Rabbit	806	858	910	962	1014	1066	1118
3	Reed	807	859	911	963	1015	1067	1119
4	Flint	20 Sept.	7 Sept.	25 Aug.	12 Aug.	30 July	17 July	4 July
5	HOUSE	809	861	913	965	1017	1069	1121
6	RABBIT	810	862	914	966	1018	1070	1122
7	REED	811	863	915	967	1019	1071	1123
8	Flint	19 Sept.	6 Sept.	24 Aug.	11 Aug.	29 July	16 July	3 July
9	House	813	865	917	969	1021	1073	1125
10	Rabbit	814	866	918	970	1022	1074	1126
11	Reed	815	867	919	971	1023	1075	1127
12	Flint	18 Sept.	5 Sept.	23 Aug.	10 Aug.	28 July	15 July	2 July
13	House	817	869	921	973	1025	1077	1129
1	Rabbit	818	870	922	974	1026	1078	1130
2	Reed	819	871	923	975	1027	1079	1131
3	Flint	17 Sept.	4 Sept.	22 Aug.	9 Aug.	27 July	14 July	1 July
4	House	821	873	925	977	1029	1081	1133
5	Rabbit	822	874	926	978	1030	1082	1134
6	Reed	823	875	927	979	1031	1083	1135
7	Flint	16 Sept.	3 Sept.	21 Aug.	8 Aug.	26 July	13 July	30 June
8	House	825	877	929	981	1033	1085	1137
9	Rabbit	826	878	930	982	1034	1086	1138
10	Reed	827	879	931	983	1035	1087	1139
11	Flint	828 15 Sept.	880 2 Sept.	932 20 Aug.	984 7 Aug.	1036 25 July	1088 12 July	1140 29 June
12	House	829	881	933	985	1037	1089	1141
13	Rabbit	830	882	934	986	1038	1090	1142

The Tlaxcallan years overlapped Mixtec years of the same name. The Tlaxcallan year was named for its 360th day, a day 1 Reed, for example, the last of *Panquetzaliztli.*[12] After the insertion of the five "extra" days following *Panquetzaliztli*, the Tlaxcallan year began, again, with 1 *Atemoztli.*[13]

The year in the calendar of the *Borgia* codex, also named for its 360th day, was offset by 260 days from the Tlaxcallan calendar and year names overlapped, that is, were partially coincident with those of Mixtec years with the same name.

The *Vienna* shows in one section a series of 10 New Fire ceremonies. In 9 of these, the fire is being kindled by an individual, named by his calendar name, using a fire-drill. In the 10th case, the fire-drill is present but not being used. The year and day of the fire-kindling are given and are preceded by a date that is usually within the same CR but a number of years earlier. It has usually been assumed that the New Fires occurred in different CRs. However, Snow was able to show that a number of them showed patterned repetition of astronomical phenomena, especially lunar eclipses, and that they usually seemed to work best in the early 10th and late 9th centuries. This was an unexpected result. It seemed that the paired dates might be considered as formulae for calendrical patterns in astronomy. The details of this interpretation need much additional study.

The *Vienna* codex (p. 32) depicts the god *Nine Wind Ehecatl*, an aspect of *Quetzalcoatl*, drilling the first of the New Fires. He also appears with the 10th ceremony and in the latter case is associated with about 116 place names (in a few cases, it is uncertain if a glyph should be counted as a single place name or as more than one). With the same proviso, the total number of place names associated with the total of the other eight New Fires also seems to be 116. Because DHK has maintained that *Nine Wind Quetzalcoatl* was identified with the planet Mercury (see §12.6), the synodic period of which is ~116 days, this seems to be an indication of the extent to which astronomical (or astrological) ideas permeated political institutional theory.

Snow's study is useful in helping to identify the astronomical character of many of the figures associated with the New Fire ceremonies. Additional studies along the same lines will greatly benefit our knowledge of Mixtec astronomy.

There are other aspects of astronomy in the *Vienna* codex as well. Gordon Brotherston has maintained that the dates in the *Vienna* and other Mixtec codices are to be read continuously as dates in real time. Snow's evidence indicates that this is not true of the different New Fire ceremonies of the *Vienna*, but it does seem to be true of the long series of dates associated almost entirely with places in the *Vienna*. These constitute the first 122 dates. These dates are given in Table 12.13 prepared by Wells, Kelley, and Snow, with Mayan equivalents (in alternate spellings) in the 660,205 correlation. The most striking of these dates is date 8, the year 6 Rabbit day 7 Flower, which shows the god Nine Wind in heaven. This could be either 7 Ahau 18 Kayab or 7 Ahau 13 Ceh (260 days later). In the latter position, it is two days before 9 Ik 15 Ceh. DHK thinks that the 9 Wind, which appears beside the figure of the descending god, is both his calendar name and a chronological indicator that it was the date of his birth. In a structural sense, in the 52-year cycle, this is the same day as 1.18.5.3.2 9 Ik 15 Ceh, found at Palenque. With our present interpretation of the *Vienna* sequence, it seems also to be the same chronological placement in the Maya Long Count, whether in correlation 660,205 or in 660,208, preferred by Wells and Fuls (2000); see also Wells (1991) and Fuls (1999, 2000). See §12.20 for a further discussion of this correspondence. *Vienna* date 8 is one of several dates in this *Vienna* sequence that define important points in the Venus cycle. These dates are a strong indication that planetary computations are crucial to the understanding of this long sequence.

[12] At some earlier historical phase, this day 1 Reed had been the first of the following month, the equivalent of Maya 1 *Mol*.

[13] Corresponding to Maya 6 *Mol*.

12.15. The *Borgia* Codex and Eclipses

On pages 58 to 60 of the *Borgia Mexican* codex (from southern Mexico, perhaps Tlaxcalla or the Tehuacan valley) appear a series of 25 deities in pairs, accompanied by the numbers 2 to 26. The major commentary on this codex is by Edward Seler (1904/1980). Seler identifies the female figure in all these depictions as a version of the Moon goddess, *Xochiquetzal*. The scenes can be considered analogous to Mayan representations of the marriages of the Moon goddess. Occasionally, other figures appear with these pairs. Above each picture appears a small representation, usually of a half-Sun disk. These are shown in Figure 12.15.

Those shown with even numbers are usually half-covered with stars, whereas those with odd numbers do not show this. Seler (1904/1980) regards this as merely an alternation between day and night with deities associated both with hours of the day and night and with a series of 12 days and 13 nights, from which he derives a system of 26 hours, otherwise completely unattested. Seler quotes from Leon y Gama a statement that the trecenas represent the nightly movements of the Moon "from its first appearance after conjunction to a few days after full moon" (called Ixtozoliztli) "when it may be seen at night on the horizon," and a second period (called Cochiliztli) "when it may be seen in the day." How a 13-day period beginning with 1st visibility can extend a few days after full Moon is not clear to us, nor do we see how continuous periods of 13 days can be related to any genuine lunar phenomena. Seler, however, uses this passage to provide a deeper interpretation of the 25 pairs as a series of 26 nights. Alternatively, Mathews (private communication to Kelley 1991) has suggested that the numbers 2 to 26 refer to repetitions of the 260-day *tonalpohualli*, one of which, divided into 20 *trecenas* (or 13-day periods), occurs on pages 61–70 (which precede pages 58–60 due to the incorrect assumption that the codex was read from left to right) of the *Borgia* codex and contains two scenes that contain half-darkened Sun figures. It hardly seems likely, as Seler supposed, that two particular nightfalls would be especially marked in such a context. Seler also argued that the structure implies 12 pairs of day and night, and an isolated 13th night, and that the importance of that 13th night was such

TABLE 12.13. Vienna codex dates, read as real-time dates.

Number	Intervals	Era count	Day number	J. year	Mixtec year	Mixtec day	Tzolk'in	Haab	Second Haab	B	K	T	W	K	J. day
1	0	213,058	117.25	–2,322	5 Flint	5 Flint	5 Etz'nab	6 Mak	1 Mol	1	9	11	14	18	873,263
2	13,561	226,619	164	–2,285	3 House	7 Rain	7 Kawak	2 Pax	17 Yax	1	11	9	8	19	886,824
3	17,994	244,613	260.75	–2,235	13 Rabbit	9 Reed	9 Ben	6 Sip		1	13	19	8	13	904,818
4	408	245,021	303.5	–2,234	1 Reed	1 Crocodile	1 Imix	9 Sec		1	14	0	11	1	905,226
5	10,744	255,765	90	–2,205	5 House	7 Snake	7 Chikchan	8 Mak	3 Mol	1	15	10	8	5	915,970
6	16,251	272,016	270	–2,160	10 House	8 Vulture	8 Kib	14 Sotz'		1	17	15	10	16	932,221
7	66	272,082	336	–2,160	10 House	9 Wind	9 Ik'	20 Yaxk'in		1	17	15	14	2	932,287
8	3,378	275,460	61.5	–2,151	6 Rabbit	7 Flower	7 Ahaw	18 K'ayab	13 Keh	1	18	5	3	0	935,665
9	18,653	294,113	86.75	–2,100	6 Rabbit	5 Reed	5 Ben	11 K'ank'in	6 Ch'en	2	0	16	17	13	954,318
10	18,980	313,093	73.75	–2,048	6 Rabbit	5 Reed	5 Ben	11 K'ank'in	6 Ch'en	2	3	9	12	13	973,298
15	15,766	328,859	134	–2,005	10 House	2 Rain	2 Kawak	2 Kum'ku	17 Keh	2	5	13	8	19	989,064
11	14,156	343,015	45.25	–1,966	10 Flint	1 Eagle	1 Men	3 K'ank'in	18 Mol	2	7	12	14	15	1,003,220
16	8,802	351,817	81.25	–1,942	8 Flint	2 Earthquake	2 Kaban	5 Pax	20 Yax	2	8	17	4	17	1,012,022
12	13,081	364,898	13.25	–1,906	5 Flint	5 Flint	5 Etz'nab	6 Mak	1 Mol	2	10	13	10	18	1,025,103
13	5,475	370,373	9.5	–1,891	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	2	11	8	14	13	1,030,578
14	13,664	384,037	159.25	–1,854	5 Flint	8 Earthquake	8 Kaban	20 Wo		2	13	6	13	17	1,044,242
17	14,195	398,232	109.5	–1,815	5 Reed	7 Twisted	7 Eb	5 wayeb		2	15	6	3	12	1,058,437
18	9,470	407,702	83	–1,789	5 House	13 Wind	13 Ik'	6 Mak	1 Mol	2	16	12	9	2	1,067,907
19	631	408,333	348.75	–1,787	*7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	2	16	14	4	13	1,068,538
20	5,589	413,922	93.75	–1,772	9 Rabbit	6 Wind	6 Ik'	20 Kum'ku		2	17	9	14	2	1,074,127
21	1,919	415,841	186.5	–1,766	1 Reed	1 Crocodile	1 Imix	9 Sec		2	17	15	2	1	1,076,046
22	10,744	426,585	338.25	–1,737	5 House	7 Snake	7 Chikchan	8 Mak	3 Mol	2	19	4	17	5	1,086,790
23	6,277	432,862	40.75	–1,720	9 Rabbit	5 Wind	5 Ik'	20 Pax	15 Sac	3	0	2	7	2	1,093,067
24	795	433,657	105.25	–1,718	11 Flint	7 Earthquake	7 Kaban	20 Pohp		3	0	4	10	17	1,093,862
25	2,051	435,708	330	–1,712	4 Rabbit	4 Rabbit	4 Lamat	6 Mak	1 Mol	3	0	10	5	8	1,095,913
26	9,684	445,392	152.25	–1,686	4 Flint	3 Twisted	3 Eb	15 Sotz'		3	1	17	3	12	1,105,597
27	1,106	446,498	162.5	–1,683	7 Reed	4 Flint	4 Etz'nab	6 Sec		3	2	0	4	18	1,106,703
28	6,849	453,347	71.75	–1,664	13 Rabbit	2 Deer	2 Manik'	5 wayeb		3	2	19	5	7	1,113,552
29	454	453,801	160.5	–1,663	1 Reed	1 Crocodile	1 Imix	9 Sec		3	3	0	10	1	1,114,006
30	18,526	472,327	58.75	–1,612	13 Rabbit	2 Deer	2 Manik'	5 wayeb		3	5	12	0	7	1,132,532
31	17,292	489,619	184	–1,564	8 House	4 Rain	4 Kawak	6 Mak	17 Yaxk'in	3	8	0	0	19	1,149,824
32	1,745	491,364	102.75	–1,560	13 Rabbit	7 Lizard	7 K'an	17 Sip		3	8	4	16	4	1,151,569
33	10,668	502,032	178.5	–1,530	3 Reed	2 Twisted	2 Eb	20 Yaxk'in		3	9	14	9	12	1,162,237
34	18,901	520,933	86.5	–1,479	3 Reed	1 Rain	1 Kawak	7 Sec		3	12	7	0	13	1,181,138
35	8,788	529,721	108.5	–1,455	1 Reed	1 Crocodile	1 Imix	9 Sec		3	13	11	8	1	1,189,926
36	17,043	546,764	350	–1,408	9 Rabbit	1 Lizard	1 K'an	2 Kum'ku	17 Keh	3	15	18	14	4	1,206,969
37	15,964	562,728	243	–1,364	1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol	3	18	3	2	8	1,222,933
38	5,531	568,259	295.25	–1,349	3 House	7 Rain	7 Kawak	2 Pax	17 Yax	3	18	18	8	19	1,228,464
39	10,894	579,153	231.75	–1,319	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	4	0	8	13	13	1,239,358
40	18,707	597,860	311	–1,268	6 Rabbit	7 Flower	7 Ahaw	18 K'ayab	13 Keh	4	3	0	13	0	1,258,065
41	2,281	600,141	35.25	–1,262	12 Flint	13 Crocodile	13 Imix	4 Sotz'		4	3	7	1	1	1,260,346
42	13,418	613,559	304.25	–1,225	10 House	2 Rain	2 Kawak	2 Kum'ku	17 Keh	4	5	4	5	19	1,273,764
43	11,365	624,924	346.5	–1,194	2 Flint	5 Lizard	5 K'an	7 Wo		4	6	15	16	4	1,285,129
44	9,968	634,892	87.5	–1,167	3 Reed	2 Twisted	2 Eb	20 Yaxk'in		4	8	3	10	12	1,295,097
45	5,805	640,697	48.5	–1,151	6 Reed	9 Earthquake	9 Kaban	5 Xul		4	8	19	12	17	1,300,902
46	4,275	644,972	305.75	–1,139	5 Reed	7 Twisted	7 Eb	5 wayeb		4	9	11	10	12	1,305,177
47	15,943	660,915	177.75	–1,095	10 Reed	12 Eagle	12 Men	8 Mak	3 Mol	4	11	15	15	15	1,321,120
48	13,138	674,053	166.75	–1,060	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	4	13	12	6	13	1,334,258

Table 12.13. *Continued.*

Number	Intervals	Era count	Day number	J. year	Mixtec year	Mixtec day	Tzolk'in	Haab	Second Haab	B	K	T	W	K	J. day
49	2,062	676,115	37.25	–1,054	12 Flint	2 Eagle	2 Men	18 Xul		4	13	18	1	15	1,336,320
50	16,918	693,033	153.75	–1,008	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	4	16	5	1	13	1,353,238
51	7,508	700,541	356.75	–987	1 Reed	1 Crocodile	1 Imix	9 Sec		4	17	5	17	1	1,360,746
52	18,980	719,521	343.75	–935	1 Reed	1 Crocodile	1 Imix	9 Sec		4	19	18	12	1	1,379,726
53	18,980	738,501	330.75	–883	1 Reed	1 Crocodile	1 Imix	9 Sec		5	2	11	7	1	1,398,706
54	578	739,079	178.25	–881	3 House	7 Rain	7 Kawak	2 Pax	17 Yax	5	2	12	17	19	1,399,284
55	18,402	757,481	317.75	–831	1 Reed	1 Crocodile	1 Imix	9 Sec		5	5	4	2	1	1,417,686
56	5,866	763,347	339.75	–815	4 Reed	4 Deer	4 Manik'	15 Xul		5	6	0	7	7	1,423,552
57	5,606	768,953	101.75	–800	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	5	6	15	17	13	1,429,158
58	2,920	771,873	99.75	–792	2 Reed	2 Reed	2 Ben	6 Mak	1 Mol	5	7	4	1	13	1,432,078
59	16,229	788,102	257.75	–747	7 Reed	7 Wind	7 Ik'	10 Sip		5	9	9	3	2	1,448,307
60	18,180	806,282	175.25	–697	5 House	13 Wind	13 Ik'	5 Kum'ku	20 Keh	5	11	19	12	2	1,466,487
61	7,624	813,906	129	–677	13 Rabbit	6 Death	6 Kimi	4 Pax	19 Yax	5	13	0	15	6	1,474,111
62	6,512	820,418	66.5	–659	5 Flint	5 Flint	5 Etz'nab	6 Mak	1 Mol	5	13	18	16	18	1,480,623
63	4,747	825,165	65.25	–646	5 House	7 Snake	7 Chichan	8 Mak	3 Mol	5	14	12	2	5	1,485,370
64	8,236	833,401	265.75	–623	1 Reed	1 Crocodile	1 Imix	9 Sec		5	15	15	0	1	1,493,606
65	14,027	847,428	48	–585	1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol	5	17	13	17	8	1,507,633
66	13,262	860,690	161	–549	11 Rabbit	3 Dog	3 Ok	3 Pohp		5	19	10	14	10	1,520,895
67	3,163	863,853	36.75	–540	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	5	19	19	10	13	1,524,058
68	2,555	866,408	35	–533	1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol	6	0	6	12	8	1,526,613
69	10,819	877,227	261.75	–503	4 Reed	4 Deer	4 Manik'	15 Xul		6	1	16	13	7	1,537,432
70	8,161	885,388	22	–481	1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol	6	2	19	7	8	1,545,593
71	2,190	887,578	20.5	–475	7 Flint	7 Flint	7 Etz'nab	6 Mak	1 Mol	6	3	5	8	18	1,547,783
72	16,790	904,368	9	–429	1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol	6	5	12	2	8	1,564,573
73	3,287	907,655	8.75	–420	10 Reed	12 Eagle	12 Men	8 Mak	3 Mol	6	6	1	4	15	1,567,860
74	13,307	920,962	166.75	–384	7 Reed	7 Wind	7 Ik'	10 Sip		6	7	18	4	2	1,581,167
75	15,187	936,149	13.25	–342	10 House	11 Water	11 Muluk	12 Pax	7 Sac	6	10	0	7	9	1,596,354
76	13,603	949,752	102	–305	8 Rabbit	2 Twisted	2 Eb	5 Sip		6	11	18	3	12	1,609,957
77	19,115	968,867	224	–252	8 Rabbit	7 Deer	7 Manic	20 Yaxk'in		6	14	11	5	7	1,629,072
78	4,647	973,514	122.75	–240	8 Reed	13 Jaguar	13 lx	2 Sip		6	15	4	3	14	1,633,719
79	4,087	977,601	192	–228	6 Rabbit	5 Crocodile	5 Imix	14 Xul		6	15	15	10	1	1,637,806
80	14,003	991,604	315.5	–190	6 House	7 Lizard	7 K'an	7 Mak	2 Mol	6	17	14	8	4	1,651,809
81	8,029	999,633	309	–168	2 Reed	2 Reed	2 Ben	6 Mak	1 Mol	6	18	16	13	13	1,659,838
82	18,068	1,017,701	114.5	–119	12 Flint	13 Crocodile	13 Imix	4 Sotz'		7	1	6	17	1	1,677,906
83	2,772	1,020,473	329.75	–111	7 Flint	3 Reed	3 Ben	1 Muwan	16 Ch'en	7	1	14	11	13	1,680,678
84	2,728	1,023,201	135.75	–104	1 Reed	1 Crocodile	1 Imix	9 Sec		7	2	2	4	1	1,683,406
85	8,344	1,031,545	79	–81	11 Rabbit	12 Snake	12 Chikchan	18 Wo		7	3	5	7	5	1,691,750
86	11,615	1,043,160	6	–49	4 Rabbit	5 Flower	5 Ahaw	18 K'ayab	13 Keh	7	4	17	12	0	1,703,365
87	5,581	1,048,741	108.25	–34	6 House	9 Crocodile	9 Imix	19 Sotz'		7	5	13	3	1	1,708,946
88	693	1,049,434	70.75	–32	8 Reed	13 Jaguar	13 lx	2 Sip		7	5	15	1	14	1,709,639
89	11,727	1,061,161	109.75	0	1 Reed	1 Crocodile	1 Imix	9 Sec		7	7	7	12	1	1,721,366
90	11,472	1,072,633	259	32	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	7	8	19	9	13	1,732,838
91	18,980	1,091,613	246	84	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	7	11	12	4	13	1,751,818
92	7,111	1,098,724	52	103	13 Rabbit	7 Lizard	7 K'an	17 Sip		7	12	12	0	4	1,758,929
93	7,650	1,106,374	31.75	124	8 Reed	13 Jaguar	13 lx	2 Sip		7	13	13	4	14	1,766,579
94	9,567	1,115,941	102.25	150	8 House	12 Crocodile	12 Imix	19 Xul		7	14	19	15	1	1,776,146
95	9,443	1,125,384	48.75	176	8 Reed	4 Lizard	4 K'an	12 Sotz'		7	16	6	1	4	1,785,589
96	4,189	1,129,573	220	188	7 Reed	7 Reed	7 Ben	6 Mak	1 Mol	7	16	17	12	13	1,789,778

97	8,487	1,138,060	306.25	211	4	Rabbit	5	Flower	5	Ahaw	18	K'ayab	13	Keh	7	18	1	5	0	1,798,265
98	15,641	1,153,701	241.5	254	8	House	7	Crocodile	7	Imix	4	Muwan	19	Ch'en	8	0	4	13	1	1,813,906
99	2,360	1,156,061	44.75	260	1	Reed	1	Crocodile	1	Imix	9	Sec			8	0	11	5	1	1,816,266
100	7,283	1,163,344	22.75	280	8	Reed	4	Lizard	4	K'an	12	Sotz'			8	1	11	9	4	1,823,549
101	3,136	1,166,480	236.75	289	4	Flint	7	Flower	7	Ahaw	8	Muwan	3	Yax	8	2	0	4	0	1,826,685
102	3,973	1,170,453	192	300	2	Reed	2	Reed	2	Ben	6	Mak	1	Mol	8	2	11	4	13	1,830,658
103	16,060	1,186,513	181	344	7	Reed	7	Reed	7	Ben	6	Mak	1	Mol	8	4	15	15	13	1,846,718
104	9,230	1,195,743	279.75	369	6	Flint	7	House	7	Ak'bal	11	Kum'ku			8	6	1	9	3	1,855,948
105	19,288	1,215,031	209.5	422	7	House	3	Monkey	3	Chuwen	14	Muwan	9	Yax	8	8	15	1	11	1,875,236
106	9,866	1,224,897	213.75	449	8	Flint	2	Earthquake	2	Kaban	5	Pax	20	Yax	8	10	2	8	17	1,885,102
107	14,261	1,239,158	230	488	8	Reed	7	Dog	7	Ok	3	K'ayab	18	Sac	8	12	2	1	18	1,899,363
108	4,295	1,243,453	142	499	7	Reed	7	Reed	7	Ben	6	Mak	1	Mol	8	12	14	0	13	1,903,658
109	7,508	1,250,961	345	520	1	Reed	1	Crocodile	1	Imix	9	Sec			8	13	14	16	1	1,911,166
110	18,980	1,269,941	332	572	1	Reed	1	Crocodile	1	Imix	9	Sec			8	16	7	11	1	1,930,146
111	11,472	1,281,413	116	603	7	Reed	7	Reed	7	Ben	6	Mak	1	Mol	8	17	19	8	13	1,941,618
112	13,507	1,294,920	108.75	640	5	Flint	7	Flower	7	Ahaw	8	Mak	3	Mol	8	19	17	0	0	1,955,125
113	19,238	1,314,158	353.75	693	5	Flint	5	Flint	5	Etz'nak	6	Mak	1	Mol	9	2	10	7	18	1,974,363
114	12,983	1,327,141	187.75	729	1	Reed	1	Crocodile	1	Imix	9	Sec			9	4	6	9	1	1,987,346
115	11,641	1,338,782	140.75	760	7	Reed?	7	Wind	7	Ik'	10	Sip			9	5	18	15	2	1,998,987
116	18,263	1,357,045	141.25	810	5	House	5	Snake	5	Chikchan	3	Sotz'			9	8	9	10	5	2,017,250
117	3,468	1,360,513	322	820	2	Reed	2	Reed	2	Ben	6	Mak	1	Mol	9	8	19	3	13	2,020,718
118	2,723	1,363,236	123	827	9	Rabbit	8	Vulture	8	Kib	9	Sip			9	9	6	13	16	2,023,441
119	13,337	1,376,573	311	864	7	Reed	7	Reed	7	Ben	6	Mak	1	Mol	9	11	3	14	13	2,036,778
120	570	1,377,143	150.5	865	8	Flint	12	Earthquake	12	Kaban	20	Sotz'			9	11	5	7	3	2,037,348
121	19,015	1,396,158	172.5	918	8	Flint	8	Twisted	8	Eb	15	Xul			9	13	18	3	18	2,056,363
122	6,449	1,402,607	47	935	13	Rabbit	2	Deer	2	Manik'	5	wayeb			9	14	16	2	7	2,062,812
123	18,980	1,421,587	34	987	13	Rabbit	2	Deer	2	Manik'	5	wayeb			9	17	8	15	7	2,081,792
124	18,980	1,440,567	21	1039	13	Rabbit	2	Deer	2	Manik'	5	uayab			10	0	1	10	7	2,100,772
125					8	Flint	9	Crocodile	9	Imix	4	Sotz'								
126					9	Rabbit	5	Wind (?)	5	Ik'	20	Pax	15	Sac						
127					10	House	4	Snake	4	Chikchan	3	Sec								
128					*13	Rabbit	9	Reed	9	Ben	6	Sip								
129					7	Reed	4	Earthquake	4	Kaban	5	Yaxk'in								
130					13	Rabbit	7	Flower	7	Ahaw	18	Pax	13	Sac						
131					13	Rabbit	2	Deer	2	Manik'	5	wayeb								
132					6	Rabbit	3	Crocodile	3	Imix	14	Wo								
133					9	Rabbit	5	Wind	5	Ik'	20	Pax	15	Sac						
134					*13	Rabbit	2	Deer	2	Manik'	5	wayeb								
135					5	Reed	7	Twisted	7	Eb	5	wayeb								
136					3	House	1	Snake	1	Chikchan	8	Kum'ku	3	Mak						
137					9	Rabbit	5	Wind	5	Ik'	20	Pax	15	Sac						
138					5	Reed	7	Twisted	7	Eb	5	wayeb								
139					13	Rabbit	*2	Deer	2	Manik'	5	wayeb								
140					9	Rabbit	5	Wind	5	Ik'	20	Pax	15	Sac						
141					8	Reed	4	Lizard	4	K'an	12	Sotz'								
142					5	Flint	5	Flint	5	Etz'nab	6	Mak	1	Mol						
143					5	Flint	5	Flint	5	Etz'nab	6	Mak	1	Mol						
144					5	Flint	8	Earthquake	8	Kaban	20	Wo								
145					13	Rabbit	2	Deer	2	Manik'	5	wayeb								
146					13	Rabbit	2	Deer	2	Manik'	5	wayeb								
147					5	House	5	Snake	5	Chikchan	3	Sotz'								

TABLE 12.13. *Continued.*

Number	Intervals	Era count	Day number	J. year	Mixtec year	Mixtec day	Tzolk'in	Haab	Second Haab	B	K	T	W	K	J. day
148					8 House	4 Rain	4 Kawak	17 Yaxk'in							
149					13 Rabbit	7 Lizard	7 K'an	17 Sip							
150					3 Reed	2 Twisted	2 Eb	20 Yaxk'in							
151					7 Flint	1 Flower	1 Ahaw	3 Sec							
152					10 Flint	1 Eagle	1 Men	3 K'ank'in	18 Mol						
153					5 House	13 Wind	13 Ik'	5 Kum'ku	20 Keh						
154					9 Rabbit	1 Lizard	1 K'an	2 Kum'ku	17 Keh						
155					1 Reed	1 Crocodile	1 Imix	9 Sec							
156					7 Reed	4 Crocodile	4 Imix	14 K'ayab	9 Keh						
157					7 Reed	4 Deer	4 Manik'	20 Kum'ku							
158					5 Flint	5 Flint	5 Etz'nab	6 Mak	1 Mol						
159					5 Flint	7 Vulture	7 Kib	19 Wo							
160					7 Reed	4 Earthquake	4 Kaban	5 K'ank'in							
161					1 Reed	1 Crocodile	1 Imix	9 Sec							
162					7 Reed	6 Eagle	6 Men	3 Wo							
163					5 House	7 Snake	7 Chikchan	8 Mak	3 Mol						
164					5 House	9 Snake	9 Chikchan	8 K'ayab	3 Keh						
165					5 (Reed?)	8 Earthquake	8 Kaban	5 Xul							
166					6 Reed	7 Deer	7 Manik'	15 Mol							
167					10 Reed	12 Eagle	12 Men	8 Mak	3 Mol						
168					1 Reed	1 Crocodile	1 Imix	9 Sec							
169					2 House	10 Jaguar	10 lx	12 Wo							
170					1 Reed	1 Crocodile	1 Imix	9 Sec							
171					10 House	10 Lizard	10 K'an	2 Xul							
172					1 Reed	1 Crocodile	1 Imix	9 Sec							
173					7 Flint	1 Earthquake	1 Kaban	5 Pax							
174					5 House	7 Snake	7 Chikchan	5 Mak							
175	3,283				1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol						
176	10,819				4 Reed	4 Deer	4 Manik'	15 Xul							
177	8,161				1 Rabbit	1 Rabbit	1 Lamat	6 Mak	1 Mol						
178					8 Rabbit	2 Twisted	2 Eb	5 Pohp							
179					13 Rabbit	7 Lizard	7 K'an	17 Sip							
180					8 Flint	8 Twisted	8 Eb	5 Xul							

* Indicates reconstructed reading.

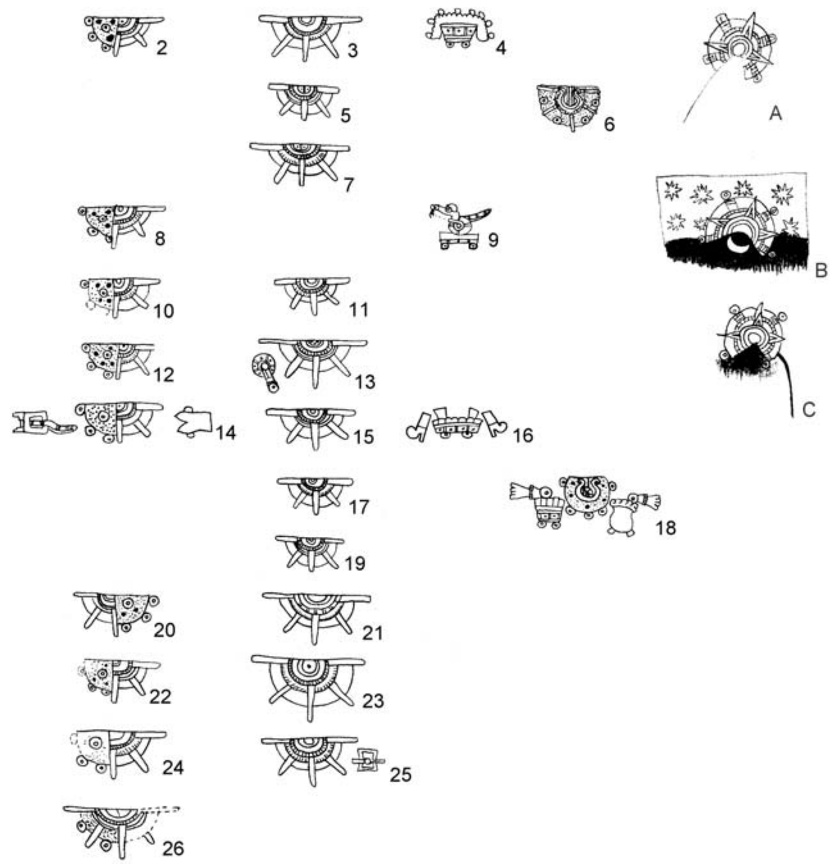


FIGURE 12.15. The possible eclipse symbols of the *Borgia* codex, in chronological sequence, compared with glyphs of known eclipses in the *Telleriano-Remensis* codex. Diagram by Sharon Hanna.

that the series had to start with 2—an argument that DHK finds completely unconvincing.

A more promising approach to interpretation is provided by the similarity of the depictions to those used by the Aztecs for eclipses. In the Aztec *Telleriano-Remensis* codex, eclipses are depicted, as shown in Figure 12.15, where *"A"* represents the eclipse for 1476, "B" that for 1496, and "C" that for 1507. The eclipse of 1496 is particularly interesting, because the stars are indicated as being visible. Note also that the Moon is depicted as a crescent, presumably to indicate only that the eclipsing body is the Moon. The *Borgia* codex sequence may represent a series of potential eclipses determined by the 520-day (double) tonalpohualli intervals. If so, the preceding 260-day tonalpohualli, which also contains these possible eclipse depictions, may somehow represent the missing 1st component. The two half-darkened suns are with the trecenas beginning 1 Jaguar (days 14–26) and 1 Twisted (days 92–104). However, if the table is repeated once, the 1 Jaguar sequence is 274–286 from the base; hence, days 97–104, are separated by 177 days or one normal eclipse interval, from days 274 to 281. The trecena associated with 1 Twisted is ruled by the goddess Mayauel (identified in Table 12.7b as an eclipse season goddess) facing a drinking companion. This depiction coincides completely in concept with the 25 pairs, and DHK thinks it should be considered the base of the series. Moreover, 1 Jaguar heads the trecena containing 9 Wind, the day of Quetzalcoatl, who is shown as the lord of this trecena. In the Madrid codex, 9 Wind is associated with the feathered serpent and with an eclipse glyph. DHK had supposed that the eclipse was particularly associated with another date in that column of the Madrid, but the presence of a half-darkened Sun here suggests that a more complex interpretation may ultimately be needed. Thus, the symbolism of the half-darkened Sun with stars, used among the Aztecs to denote eclipses, is here associated with possible eclipse intervals and with deities previously associated with eclipses.

Two *tonalpohualli* total 520 days and three eclipse half-years of 173.31 days total 519.93 days, so that if a *tonalpohualli* begins near an eclipse, all subsequent dates that are even multiples of 260 from the base will be near an eclipse also; moreover, no odd multiples of 260 can be near an eclipse, in agreement with the inferred pattern of Figure 12.15. The most notable support for this interpretation comes from the representation of the pair numbered *18*. Rather than the usual half-darkened Sun, this shows a Moon with a knife in it. If the number *18* connotes an interval equal to the number of 260-day periods, it represents an interval of 4680 days. Spinden (1930, p. 56) drew attention to this interval, which is equivalent to 13 Maya *tuns* ($13 \times 360^d = 4680^d$), as an ideal interval between a solar eclipse and a following lunar eclipse, which would fall on the same name day.

The reason for this circumstance is that 4680 days is nearly 27 eclipse half-years (from node to node, 4679.35 days), whereas the interval is close to $158\frac{1}{2}$ synodic months (4680.45 days, within 2 days of node passage). Thus, beginning at a new Moon, we arrive at a full Moon at the end of the interval, and if there is a solar eclipse at the beginning of the interval, there will be a lunar eclipse at the end of it. The knife in the Moon would be an appropriate metaphor for a lunar eclipse, also corresponding to the *Nuttall* codex representation of the knife with a goddess, presumably lunar (see §12.17).

The table is completed with the 25th pair (labeled "26"). Again, if *26* represents a sum of *tonalpohualli*s, it stands for an interval of 6760 days, or 18.508 tropical years, so that the remainder (185.6 days) is approximately the interval between opposing seasons, like that from spring to fall equinox. This creates a structure similar to the *Dresden* codex eclipse table, in which $11960^{d} = 32.745^{y} = 32^{y}\ 272.2^{d}$. The approximately three-quarters of a year remainder is like the interval between fall equinox and summer solstice. It is a matter for further investigation if the *Borgia* table was intended to function at a particular, specified date, or intended to be generalized. The absence of any day names in the table may suggest the latter. However, a *tonalpohualli* beginning on 1 Crocodile is found adjacent to the table, and it may have been intended to function as a not completely hidden zero and first repetition of the count, in which case, 1 Crocodile would have been the intended beginning point.

Among the Aztecs, the monstrous Tzitzimime descend threateningly from the sky at the time of eclipses and are said to control rains, water, thunder, and lightning. Their leader is Tzontemoc, "Head Down," an equivalent of Mictlan Tecuhtli, "Lord of Death," descending as a spider from the sky. Tezcatlipoca ("Smoking Mirror") is also said to have descended from the sky on a rope of spiderweb. The Tzitzimime were sometimes regarded as a single figure, sometimes as four (identified in that case with the supporters of the sky, whose failure caused the flood) and sometimes seven. In the month of Quecholli, the feast of Mixcoatl celebrated the descent of the following gods who were stars: Yacatecuhtli, Tlahuizcalpantecuhtli, Ce Acatl, Quetzalcoatl, Achitumetl, Zacopancalqui, Mixcoatl, and Tezcatlipoca. The calendar name Ce Acatl is usually assigned to Quetzalcoatl, and Tlahuizcalpantecuhtli, Lord of the House of Dawn, is a name often equated with Venus and with Quetzalcoatl. These statements suggest that all of these gods may have planetary identities and that their descent is on the spider rope (or path) (Thompson 1934, especially, pp. 228–230; Brundage 1979, pp. 62, 69), which in turn suggests that the spider web defines the band near the ecliptic in which the planets move.

12.16. The Birth of a God on a Maya Vase: Jaguar Baby

A four-sided vase of the Classic Period (Figure 12.16) is very like the *Dresden* codex in its format, size, combination of glyphic texts with illustrations, and even, in a generic way, content. It is very unlike depictions of codices on Classic Period ceramics, but so is the *Dresden* codex, and that surely had Classic Period predecessors. In a sense, this vase can be considered the earliest surviving Maya codex, short as it is. The iconography of this vase has been described in detail by

(a) (b) (c) (d)

Figure 12.16. A four-sided vase [K5113] of the Classic Period: Sides a, b, c, and d, respectively. Prints copyright Justin Kerr. Reproduced here with permission.

Karl Taube in Kerr (1994), with a somewhat different emphasis than is given here.

DHK suggests that the reading order is as indicated in the caption: *a*, *b*, *c*, *d*. The most compelling argument for this order is the presence of a two-headed red snake with white diamond markings the body of which extends over sides *a*, *b*, and *c*. On side *a*, the body of the snake descends from the head, extends along part of the base of side *b*, turns up, and has been cut apart with blood flowing or spurting from it. On side *c*, the body is shown at the same height of the vase where it was cut on side *b* and ascends into a second head.

The principal event of this vase is the birth of a god, shown emerging from the 2nd serpent head. His tremendously projecting lower jaw strongly suggests identity with god M. The birth glyph appears in the text above. In the scene are five old women wearing spindle-whorls in their hair, having deeply lined faces, and pendulous breasts. Four have visible jaguar ears, and the remaining one, whose ears are obscured, has an arm ending in a jaguar paw, as does the one reaching for the "baby." One of the five wears a death headdress. DHK thinks that they represent the five Moon goddesses of the west, but very different from the depictions in Figure 12.13. Another woman is mature and full-breasted, standing on a Chac head, crossed by blood spurting from the cut body of the snake. Very curiously, the nose of the Chac head is a human face in profile. The woman may well be a Full-Moon goddess. The final figure in the main scene is a male with a jaguar ear.

The 4th side shows two additional scenes, which seem to deal with offerings and rituals, possibly associated with birth. To DHK, they seem more likely to be a postscript to the birth scene than a prelude. God M has previously been identified as a planetary deity (see Table 12.7). Two-headed snakes often display planetary bands. All of these associations suggest that the subject matter of this vase is astronomical.

12.17. The Lords of Palenque

It is not surprising to find dates in mythical time or ritual events, such as New Fires, tied to astronomical phenomena. It is much more surprising to find the dates of birth and death, referring to apparently historic individuals, that show patterns of astronomical associations. Nonetheless, the dates of the rulers of Palenque show just such patterning. The close approximation of the 260-day tzolkin to the human gestation period means that it is not too difficult in a polygamous society to ensure with some probability that a child will be born near an appropriate date. It is, of course, possible to cut a person's life short, even if that person is a ruler, in a society in which human sacrifice is accepted as normal. It is more difficult to prolong a life to an appropriate date. Looking at the mass of Palenque dates, it is difficult to avoid the impression that the historical dates of the rulers have sometimes been substantially adjusted. See Kelley (1985, 1987) for further details. In Table 12.14, we show a pattern of eclipses associated with birth, accession, and death dates of rulers at Palenque. The interpretation of the Maya names of the rulers has been changed several times since this list was first prepared. They have not been updated here.

Table 12.14 shows eclipses in the 584,285 correlation and in the 663,310 correlation. Closely comparable eclipse patterns appear in the 615,824 (proposed by Schove 1977) and in the 660,208 correlation of Wells and Fuls. All of these correlations tend to pick up comparable eclipses with some minor variation; so they are reflecting a structural reality in the dates, even if none of these correlations is correct. Because the Schove correlation is based in part on some of the same premises about the planetary phenomena as the Thompson correlations, which were rejected in formulating the 663,310 correlation, the association of planetary phenomena with eclipses, which appears in correlation 663,310 and is certainly structurally present, is not found in correlation 584,285, 615,824, or 660,208. In general, correlation 663,310 first shows how Mercury phenomena may be associated with eclipses, then the Jupiter and Venus deities are brought into association with eclipses, and finally Mars and Saturn. The association of the calendar names of previously identified eclipse deities with calendar names and accession dates of Palenque rulers, the presence of the major eclipse intervals of the Mayas, and the regular procession of associations of eclipse phenomena with different planetary intervals all suggest that the dates of these rulers somehow mirror astronomy. In the case of the eclipse phenomena, this contention should be acceptable even to defenders of one or the other of the Thompson correlations. That is not true of associated planetary phenomena or tropical year phenomena, which nonetheless show similar patterns. In 663,310, note that all Mercury-Jupiter conjunctions are associated with individuals whose names indicate rain-god associations and that all individuals with such associations are associated with at least one Mercury-Jupiter conjunction. The accession of Pacal, "Shield," is associated with the accession of the Sky Peccary,[14] identified as Mars (§12.6, especially, Table 12.7) far in the past, and Pacal's birth is identified as a Mars conjunction. Note that the names that contain *kan*, "yellow," seem to be near tropical year stations.

It has been argued that the structural patterns that appear in these dates are present accidentally, and that all dates are bound to be near some astronomical phenomena. An examination of the distribution of dates in different correlations does not support such a contention (cf. Kelley 1983, especially Tables 6.5 and 6.6).

12.18. The Tropical Year in Mesoamerica

Interest in the tropical year (hereafter abbreviated *Ty*) is attested by the statement of Motolinia mentioning the equinoctial alignment of the temple of *Huitzilopochtli*, and in the first recognized alignment, at Uaxactun (both to be

[14] Linda Schele (personal communication) has argued that some aspects of the monster mentioned in this text differentiate it from the more common *Zip* monster.

TABLE 12.14. Pattern of eclipses associated with the rulers of Palenque.

Kelley date number	Historical event	Maya date	J.D. 663310	663310 events		J.D. 584285	584285 events
2	Accession Eleven Rabbit “Casper”	8.19.19.11.17 2 Earthquake 10 Xul (Xul month of Mercury)	1959181	E (Mercury as eclipse indicator?)	Sun 270° Mercury 264°	1880162	E – 1
3(a)	Birth “Manik” (Omitted by Aveni)	9.1.4.5.0 12 Flower 13 Zac	1968050	E + 4	Sun 7 Mercury 5	1889025	E + 33 (lunar + 18)
3(b)	Birth Five Flower Chaac I (Chaac Mercury name)	9.1.10.0.0 5 Flower 3 Zec (Five Flower Venus name)	1970110	E – 3	Mercury 252 Mars 69 (opposition)	1891085	E – 4
9	Accession Twelve Rabbit “Kan Xul” I	9.4.14.10.4 5 Lizard 12 Kayab	1993354	E	Sun 105 Jupiter 109 Venus 112	1914329	E + 29 (Lunar + 14)
10	Death Twelve Rabbit “Kan Xul” I (Animal glyph tied with a knot)	9.6.11.0.16 7 Vulture 4 Kayab (DHK has suggested that tying or binding refers to return to equinoxes or solstices)	2006486	E – 9 (lunar – 23)	Sun 89 Venus 60 Mars 62	1927461	E – 10 (total, Palenque)
13	Accession Eleven Snake Chan Bahlum I (Eleven Snake eclipse goddess) (Born on 13 Ch’en, day of node passage goddess) (Died on 3 Kayab, day of lunar eclipse goddess)	9.6.18.5.12 10 Twisted 20 Pop (0 Uo)	2009102	E + 9 (lunar – 6) Interval to next date of eclipse series, 11958 days, 2 days short of eclipse table interval	Sun 146 Venus 149	1930077	E + 8 (lunar – 8) (The interval between the birth and death of Eleven Snake is 21,320 days which can be construed as 11,960 days, the eclipse table length, plus 9360 a very good eclipse interval, although neither of these intervals is relevant to real time eclipses in either 663,310 or 584,285)

18	Accession "Aahc Kan" (Glyph like God N, Pawatun, cf. Az. Tecciztecatl a suggested lunar eclipse god)	9.8.11.9.10 8 Dog 18 Muan	2021060	E + 7 (lunar – 8)	Sun 55 Venus 60	1942035	E + 6
		(Note that Venus was near conjunction with the sun at both ends of the 11960 day period and that 3 other eclipse dates are near conjunctions of Venus and the sun)					
19	Death Pacal I (Interval from 19 helps define Venus-solar conjunctions near eclipses)	9.8.18.14.11 3 Monkey 4 uayeb	2023681 (lunar + 14)	E Sun 117 Mercury 120 Saturn 122	Jupiter 112 Venus 114	1944656 (lunar + 13)	E + 28
20	Death "Aahc Kan"	9.8.19.4.6 2 Death 14 Mol	2023836	E + 7 (lunar – 8)	Sun 271 (Jupiter 130, Saturn 122)	1944811	E + 6 (lunar – 9)
23	Birth Two Death "Great Eclipse" Chan Bahlum (9 Wind, primary Mercury name, is 59 days after 2 Death) (2 × 58 = 116)	9.10.2.6.6 2 Death 19 Zotz	2032156	E (Nearly total)	Sun 189, Venus 188 Mercury 172 Mars 172	1953131	E – 1
24	Death Bahlum Mo'o (Jaguar Macaw)	9.10.10.1.6 13 Cimi 4 Pax (Thirteen Death is the prime name of Saturn)	2034936	E + 3	Mars 137 Saturn 135 (Saturn 135 + 180 = 315; Jupiter 331)	1955911	E + 2
25	Birth Eleven Flower Yax T'ul (Great Rabbit) or "Kan Xul II")	9.10.11.17.0 11 Flower 8 Mac	2035610	E – 2	Sun 357 Mars 158 Saturn 162 (Interval from previous date helps define Mars-Saturn conjunctions near eclipses)	1956585	E – 3
	Dedication ceremony	9.11.2.1.11 9 Monkey 9 Mac	2039261	E	lunar + 2 Sun 356 solar – 12	1960236	E lunar + 1 solar – 14

discussed in §12.23). The structure of the *Dresden* eclipse table (§12.9) would fit calculations from the spring equinox to the winter solstice, and the sequence of 25 pairs of deities in the *Borgia* codex seems designed to go from spring equinox to fall equinox (see §12.15). The winter solstice calculations in the *Vienna* codex (§12.14) are equally important indicators of interest in the relationship of the Ty and the Mesoamerican calendar. The reference to the day *2 Deer* of the year *13 Rabbit* in the *Vienna* codex is paralleled by a reference to the same date as one of a series of Ty stations in the *Nuttall* codex (§12.19).

DHK thinks that comparable interest in the Ty is indicated by many Mayan calculations, especially a considerable number of long calculations that seem to refer to periods of 29 CR, or multiples thereof (e.g., $29 \times 18980 = 1508$ Mys ≈ 1507 Ty). The most convincing series of dates suggesting the count of the Ty is found in Palenque, where a count proceeds from the Mayan era base to 13.0.1.9.2 13 Ik tun Mol and then to three dates (discussed previously) associated with the birth of the gods at

(1) 1.18.5.3.2 9 *Ik* (Wind) 15 *Ceh*,
(2) 1.18.5.3.6 13 *Cimi* (Death) 19 *Ceh*, and
(3) 1.18.5.4.0 1 *Ahau* (Flower) 13 *Mac*.

The interval from 13 Ik *tun* Mol to 1 Ahau 13 Mac is $274{,}938^d$ = 752 Ty 276^d, the 276 days corresponding to an interval between spring equinox and winter solstice. In 753 Ty, the Maya year (365 days) will have advanced halfway around the tropical year (~182 days) because the accumulation of the excess of the tropical year over the Mesoamerican year (0.2422 days) in 753 Ty amounts to nearly half a Ty. The date 1.18.5.4.0 1 Ahau 13 Mac, in turn, is exactly twice 29 CR, or 3016 My = 3014 Ty before the date 9.11.3.2.0 1 Ahau 13 Mac, which fell in the 52nd year of Pacal, King of Palenque, during the lifetime of his son, *Chan Bahlum*, who erected monuments giving these dates. Thus, the births of the gods were assigned to Mayan years, in which the Mayan dates fall in the same tropical year positions they occupied when the monuments were erected, and halfway around the My from where they were at the beginning of the Mayan era. This circumstance was first pointed out by Bowditch and amplified by Spinden, who identified the base of the upper line of dates in the *Dresden* codex Venus table as 9.11.3.2.0 1 Ahau 13 Mac (see §12.7). This date, in turn, is 100 Ty 3.78^d before 9.16.4.10.8 12 Lamat 1 Muan, the eclipse table base. If 1 Ahau 13 Mac coincided with winter solstice, as the calculation would suggest, then 9.9.9.16.0 1 Ahau 18 Kayab, the base of the Venus table, would have been about 4 days after spring equinox. Of course, the two table bases could be brought in step if 1 Ahau 13 Mac were put 4 days off the solstice, but the calculation involving 1 Ahau 13 Mac seems to be directly involved with the tropical year, whereas 1 Ahau 18 Kayab and 12 Lamat 1 Muan are table bases for other phenomena that the Maya may have been trying to tie to the tropical year. See the discussion of the *Dresden* codex Serpent Numbers (§12.18), in which an interval of 20×29 CR (30,140 Ty) may be tied to the normal Mayan era base. Kelley (1983, pp. 180–181, Table 6.3) shows how various dates that may be tied to equinoxes and solstices appear in various correlations.

It seems difficult to think that these long calculations about the tropical year were tied to dates other than equinoxes or solstices, but it should be emphasized that no correlation that puts these dates near an equinox or solstice can also be in touch with the modern Mesoamerican calendar with any precision.[15] It is of interest to note that the two monuments at Uaxactun that furnish the sighting line for the famous equinoctial alignment at that site are as close to spring equinoxes as any Baktun date in the Classic period can be, if 9.11.3.2.0 is a winter solstice, and that they are separated by the minimum baktun interval, which can restore a date to nearly the same position in the tropical year.

There were, of course, substantial connections between the tropical year, the 365-day year, and the 360-day year. This is emphasized by the 5-day period at the end of the 365-day year, which is counted and yet somehow outside the year. The principal god associated with the year was the Sun god. The gods of the 5-day period outside the year, the uayeb, were opossums. They are equated with Mams, the ancestral gods and, in some areas, mountain gods. As an individual deity, Mam is sometimes regarded as evil, and sometimes as beneficent. The same ambiguity attends opossums and the four Bacabs with whom the opossums also seem sometimes to be associated (Kelley 1976, pp. 119, 177). In the *Mixtec* and *Borgia*-group codices, the opossum frequently accompanies the Moon goddess. For an extensive discussion of opossum myths, including associations with Venus, Jupiter, and the Moon, see Munn (1984).

12.19. The War Between the Gods: Calendar Reform

On page 4 of the *Nuttall* codex, there is a scene of "war in heaven" that seems to be tied both to a calendar change and to positions of the tropical year. The calendar dates referred to below are in the Julian calendar, rather than the retrodictive Gregorian dates often used in Mesoamerican studies.

Interpreted mythologically, it is a brief summary of a *Mixtec* version of the descent of *Hun Hunahpu* and *Vukub Hunahpu* to the ball court of the Lords of Death. Interpreted astronomically, it deals with solar data in relationship with data on Venus, but unrecognized factors are probably also involved. As calendrics, it deals with a one-day shift in the names of the gods, accompanied by functional changes. Because of the tremendous importance of the calendar names of the gods, this is depicted, in part, as a war between the gods of the old names and the gods of the new names. It may have other facets, not necessarily excluding historical interpretations.

Interpreted theologically, the most important facet is that the brothers are shown descending to the underworld after

[15] There are three possibilities, however, which are fairly close (see Kelley 1983, p. 183), although none of these has ever been seriously suggested as the correct correlation. Bryan Wells has spent a considerable amount of effort examining one of these (660,205) and convinced DHK that it is substantially more probable than any of those proposed by Thompson.

their death and cremation—something that certainly does not come out in the *Popol Vuh*.

We know that in the manuscripts of the *Borgia* codex group, Venus phenomena were marked by the series: Crocodile, Snake, Water, Reed, and Earthquake, corresponding to the Mayan days *Imix*, *Cicchan*, *Muluc*, *Ben*, and *Caban*, the set being shifted one day forward from the Mayan series in the *Dresden* Venus Table in which mean heliacal risings are associated with the days *Ahau*, *Kan*, *Lamat*, *Eb*, and *Cib*. Two of the Mayan Venus day names appear as Ring Number bases. 1 *Ahau* 18 *Kayab* appears at –2200 days, which represents a back-calculated heliacal rising in a formal 584-day table in DHK's interpretation; 3 *Kan* 17 *Mac* appears at –456, marking disappearance before inferior conjunction. 1 *Ahau* + 1^d = 2 *Imix* (2 Crocodile); 3 *Kan* + 1^d = 4 *Chicchan* (4 Snake). The principal attacking god appears in one scene as *Four Snake* and immediately thereafter appears with *two* calendar names: *Two Crocodile* and *Four Snake*, each one day after the names for the two calendar positions marked in the *Dresden* codex as *Ring Numbers*. As Kelley (1976, pp. 76–78) has pointed out, the characteristics of this god are those of the god shown in the *Dresden* codex Venus table (p. 49), although his astronomical function does not seem clearly defined there. The year *10 House* marked below the name *Four Snake* is that of the birth of *Four Snake* (more clearly specified as such in the *Vienna* codex). It is calculated as the equivalent of Mayan 4 *Chicchan* (3 *Zec*), JDN 2,052,050, 17 March 906, with the celestial longitudes of the Sun and Venus at 1° and 320°, respectively (see §2.3.3). Two dates are given in connection with the attack: days 7 Crocodile and 8 Wind of the year 12 Flint, JDN 2,057,526 and 2,057,527, 14 and 15 March 921. The celestial longitude of the Sun, $\lambda_\odot$, was 359° on 7 Crocodile and 0°, at the spring equinox, on 8 Wind. The next scene takes us forward to 12 Earthquake of the same year: 2057622, 18 June 921, with $\lambda_\odot$ = 91° (a day past summer solstice), and Venus in conjunction with Mercury at $\lambda_♀$ = 108°. An eagle named "One Jaguar" is being sacrificed. *Cihuacoatl*, "Snake Woman," widely regarded as a Moon goddess, is called "the Eagle Woman," and DHK suggests that the sacrifice represents a following eclipse; four days later, the date 3 Crocodile occurred, which DHK has suggested represents a node passage goddess, and the day after that was 4 Wind, 2,057,627, 23 June 921, the date of a lunar eclipse. This was followed 15 days later on 2,057,642 (6 Earthquake) by a solar eclipse.

The next scene shows the identities of the losers, the cremation of the bodies of *Seven Flower* and *Four Earthquake*. *Seven Flower* was the *Mixtec* equivalent of the name *Vukub Hunahpu*. *Four Earthquake* is identified repeatedly in our sources as a Sun god, particularly associated with the spring equinox in Duran. Figure 12.17 shows a drawing of *Four Earthquake* from the *Borgia* codex.

The Sun god is often shown with the red and white stripes of the diving gods. Another Sun god was *One Flower* (*Hun Ahau*, *Hun Hunahpu*). *Four Earthquake* here substitutes for *One Flower*, perhaps partly because *One Flower* seems also to have been a name for several other gods. Regrettably, the date shown in the printed version is 2 Earthquake of the year 6 Rabbit, probably an error, because dates within a single passage are normally in chronological order, and the following date is 13 Reed, identified with 934, but no 6 Rabbit falls between 921 and 934. Expanding by a 52-year cycle would remove either the earlier dates or the later ones from their positions at equinoxes and solstices.

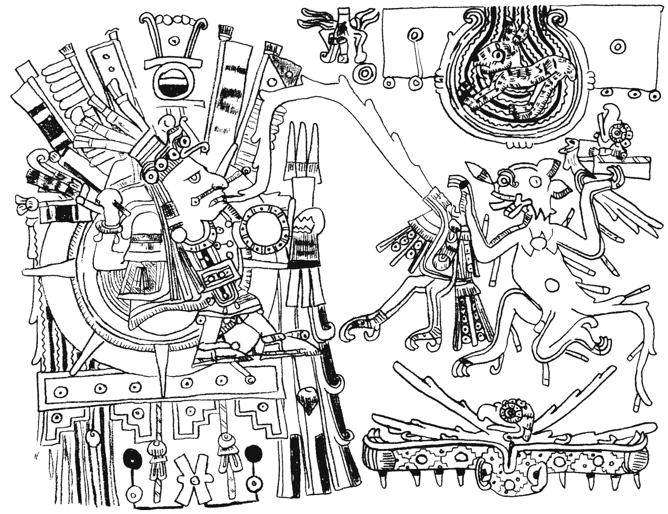


Figure 12.17. From the *Borgia* codex, Year 1 Reed, day 4 Earthquake, the Sun God on his throne: The event is interpreted as winter solstice, 936 A.D. Drawing by Sharon Hanna.

The final scene shows "Four Earthquake" and "Seven Flower," apparently none the worse for their cremation, seated at a ball-court marked with a skull, that is, presumably the ball-court of the Lords of Death. The date is 2 Deer, year 13 Rabbit, corresponding to Mayan 2 *Manik* 5 *uayeb*, the last day of a Mayan year, and to JDN 2,062,552, 17 December 934, with $\lambda_\odot$ = 271°. The day 2 Deer follows the day 1 Death, and the *Popul Vuh* tells how the younger brothers defeat the Lord of Hell called *One Death*. The same is apparently true of the elder brothers in some senses, despite the sad tales told of them; on the same CR date, 2 Deer of the year 13 Rabbit, in the *Vienna* codex, *One Flower* appears in the Sun disk as a Sun god. At any rate, some sort of equivalence seems to be indicated. The first date on the following page shows the year 1 Reed, the day 1 Crocodile, the well-known "mythical beginning" date. The date is JDN 2,063,006, 15 March 936, with the Sun at λ = 0, at spring equinox. Mercury was near conjunction with Saturn (λ = 344° and 348°, respectively).

Thus, we have close approximations to three spring equinoxes, one summer solstice, and one winter solstice, with one probably erroneous date, associated with red and white diving gods who are known to have Sun deity associations. On pp. 20–21, we find a similar scene of red and white diving gods in the year 12 Flint with the days 8 Wind (already considered) and 12 Flint (either the year naming day or 260 days later). The date may be JDN 2,057,583, 10 May 921. This was the date of a zenith passage of the Sun within the *Mixteca* and may be what this date indicates, but there seem to be no clear indications of the relevance of the date. The other date on the page is a repetition of 1 Reed 1 Crocodile.

The codex shows a figure named "Three Flint," accompanying a man named "Twelve Wind." Kelley (1980) has suggested that "Three Flint" was a name for Mercury. "Twelve Wind" holds the so-called "Venus staff" and has a loop over his nose, roughly corresponding to the so-called "cruller" of the Mayan Jaguar god; however, Kelley identified the latter with Jupiter, rather than with Saturn. DHK suggests the following relationships for the day names of some of the individuals of pp. 20–21. "One Death," of Sun Mountain, with a personal name derived from a decorated Sun disk with the previously mentioned winter solstice of JDN 2,062,551, 16 Dec. 934; her husband, "Four Crocodile," with the date JDN 2,063,646, 15 Dec. 937, three My later. "Four Crocodile's" personal name is "Blood-drinking Eagle." Although both Sun and Moon are sometimes identified as Eagles, it is the Sun who is said to need blood in order to move. Hence, the personal name equates "Four Crocodile" with the Sun. That "Four Crocodile" may equate with a winter solstice Sun is suggested also by his representation with two faces looking in opposite directions, Janus-fashion. On the preceding page of the manuscript, "Four House" and "Three Monkey" (identified in other manuscripts as Four Crocodile's great grandchildren) are shown being cremated wearing the red and white stripes particularly typical of Sun gods. The name of "Four House" also appears above a skyband with a Sun disk on p. 21. Their names may represent the following summer solstice and fall equinox: for 3 Monkey, JDN 2,063,828, 15 June 938, with $\lambda_{\odot} = 88°$; and for 4 House, JDN 2,063,920, 15 Sept 938, $\lambda_{\odot} = 177°$. There are, however, no year dates to verify these positions for *One Death*, *Four Crocodile*, *Three Monkey*, and *Four House*.

In the date 2 Earthquake 6 Rabbit, if one ignores the year 6 Rabbit as necessarily some sort of error, there is one day, 2 Earthquake, in this period that fits this pattern. This is JDN 2,061,642, 20 June 932, when $\lambda_{\odot} = 93°$ and $\lambda_{♀} = 92°$, three days past summer solstice and the day before conjunction. This was the year 10 Reed. If this was the scribe's intention, a calculation error seems more likely than one due to copying. This day 2 Earthquake corresponds to the Mayan 2 Caban 5 Yax and is the replacment for the preceding day, 1 Vulture (1 Cib 4 Yax). The *Dresden* codex Venus table shows 1 Cib 4 Yax as a station for mean disappearance, four days before inferior conjunction. This would thus be three days from mean position. The coincidence of month position offers some support for regarding this as intended.

There are two other dates that agree with this pattern, both iconographically and with respect to the associated dates. In the *Nuttall* codex (p. 9), there is a depiction of a Sun disk in a tree; below it is a naked woman in the water with a knife covering the genital area. The associated date is the day 13 Vulture of the year 12 Rabbit. DHK reads this date as 20 Jun 791 Julian (JDN 2,010,141), the date of a lunar eclipse with the Sun at ecliptic longitude $\lambda = 91°$, the day following summer solstice. It was also the date of a conjunction between Jupiter ($\lambda = 70°$) and Mercury. The only other occurrence of a Sun disk in a tree in the *Nuttall* codex is on p. 44 with the day 6 Snake of the year 6 Reed. In the chronology used here, it is 16 June 980 Julian (JDN 2,079,170) at the summer solstice with Venus at $\lambda = 92°$, and at new Moon.

A set of dates in the *Tulane* codex includes a repetition of one of the *Nuttall* CRs and several others associated with eclipses and the tropical year. The first and the last date are separated by twice the length of the *Dresden* eclipse table. The last date is that of a winter solstice between a solar and lunar eclipse, with a conjunction of Jupiter ($\lambda = 277°$), Mars ($\lambda = 278°$), and Mercury ($\lambda = 281°$) and another conjunction of Venus ($\lambda = 292°$) and Saturn ($\lambda = 296°$). See Table 12.15.

12.20. *Dresden* Codex Serpent Numbers

Table 12.16 shows the *Dresden* codex Serpent Numbers and accompanying short texts. They are transcribed following the work of Satterthwaite (1964) and of Schulz (1961). These numbers count from an era base 9 Kan 12 Kayab, and the interval from that base to the earliest date in the series is 12,381,728 days. The dates include the calendar round date 13 Akbal 1 Kankin at 4.6.9.15.12.19 from the base. Because this calendar round date occurs elsewhere in the *Dresden* codex at the Long Count (or Initial Series) date 10.6.10.6.3, Satterthwaite and Schulz assumed that the LC and the Serpent number date referred to the same day, which led to the LC dates shown in column 1 of Table 12.16. However, evidence of the tropical year, to be considered later in this section, strongly suggests a placement 104 My earlier, as shown in column 2. The analysis by Satterthwaite suggested one error in the Mayan scribe's recording (or calculating) of the month, one error in the month coefficient, and two errors each in two of the period notations. These are all marked in the table but not otherwise considered, as all of Satterthwaite's corrections seem certain.

To the best of our knowledge, there has been no serious scholarly consideration of what the long parameters mark. The days that appear here also appear in tables of 91 days and 117 days, and a Ring Number base at 13 Akbal 11 Kayab, 17 days before the normal Maya era base, seems to be tied in to these calculations. Deity and animal references and associated day names give us some help in interpretation, but details still largely elude us. Although the long parameters were presumably of most importance to the Mayas, the intervals between the resultant dates and their relationship to other dates in the codex can also aid in interpretation.

The evidence in favor of a revised placement comes particularly from the tropical year. The earliest date of the series would become 9.11.2.15.12 4 Eb 5 Ch'en. The long count is 1,376,232 days, which is exactly 3768 tropical years, so that 4 Eb 5 Ch'en would have the same position in the tropical year as the 4 Ahau 8 Cumku era base. The number seems to be composed of three additive components.[16] The first is 182 days, which goes almost halfway around the Mesoamerican year. The second is 275,210 days, which is exactly half of 29 calendar rounds (each CR being 52 My

[16] Of course, there are a large number of sets of three additive components that sum to this large number. The plausibility of this particular set, in context, is what is being argued here.

TABLE 12.15. Astronomically important dates from the *Nuttall* and *Tulane* codices.

Year	Day (Mixtec) and J.D.N.	Maya month equivalent	Julian date	Astronomical phenomena	Tulane codex			Vienna codex	
	Nuttall codex pp. 3–5								
10H	4 Snake 2052050	3 Zec	17 Mar. 906	☉ | ♀ 320 Near greatest elongation					
5H	8 Deer 2054992	5 Xul	6 April 914						
12F	7 Crocodile 2057526	4 Zec	14 Mar. 921	☉ 354					
	8 Wind 2057527	5 Zec	15 Mar. 921	☉ 360					
12F	12 Earthquake 2057622	20 Chen	18 June 921	☉ 91 ☿ 109 ♀ 108			14 Mesoamerican years		
[6 Ra	2 Earthquake Date mistaken?]		(23 June—lunar eclipse 4 Wind 8 July—solar eclipse)						
					6 Re	9 Earthquake 2060102	5 Xul	12 April 928 ☉ 18 ♃ 259 ♄ 262	Date 165
					7 F	1 Earthquake 2060562	(5 Pax or) 20 Yax	6 July 929 ☉ 108 ♂ 287 ♃ 287 in opposition	[solar 9 July lunar 24 July]
13 Ra	2 Deer 2062552	5 uayeb	17 Dec. 934	☉ 271	5 × 365				
1 Re	1 Crocodile 2063006	9 Zec	15 Mar. 936	☉ 360					Dates 28, 30, 122, 123, 124, 131, 134, 139, 145, 146
			(Between a lunar eclipse 2063002, 11 Mar. and a solar eclipse 25 Mar.)		5 Re	7 Twisted 2064377	5 uayeb	16 Dec. 939 ☉ 269 ☿ 248 ♃ 248	Dates 17, 46, 135, 138
					12 Re	7 Crocodile 2166466	14 Mac (or 9 Mol)	18 June 1219 ☉ 93 [partial solar 13 June lunar 29 June solar 13 July]	
					7 Re	7 Reed 2169378	6 Mac (or 1 Mol)	8 June 1227 ☉ 83 ♀ 82 ♂ 87	Dates 13, 19, 39, 48, 57, 67, 90, 91, 96, 103, 108, 111, 119,
					8 F	11 Flower 2169785	8 Muan	19 July 1228 (☉ 124) ☿ 149 ♀ 153	[lunar eclipse + 355 = 177 + 178 lunar eclipse-146]
				2 × 11960	9 H	8 Death (−1 = 7 Snake) 2170211	9 Cumku (or 4 Mac)	18 Sept. 1229 ☉ 183 ♀ 171 ♄ 357	
				Seven CR / 65½ years	10 Ra	7 Water 2170574	7 Cumku (or 2 Mac)	16 Sept. 1230 ☉ 180	
					3 Re	2 Wind (−1 = 1 Crocodile) 2187027	10 Pop	3 Oct. 1275 ☉ 197 ♄ 197	
					12 F	7 Crocodile 2190386	4 Zec	13 Dec. 1284 ☉ 270 ☿ 281 ♃ 277 ♂ 278 ♀ 292 ♄ 296	[solar eclipse 8 Dec. lunar eclipse 24 Dec.]

TABLE 12.16. *Dresden* codex serpent number bases and dates: Base of calculation is 9 Kan 12 Kayab. From this base, it is 4.6.9.15.12.19 to 13 Akbal 1 Kankin. Schulz and Satterthwaite believe this corresponds to the L.C. 10.6.10.6.3 13 Akbal 1 Kankin, attested elsewhere in *Dresden*. By this interpretation, 13.0.0.0.0 4 Ahau 8 Cumku, the base of the usual Maya era, becomes 3.16.3.5.6.16 4 Ahau 8 Cumku from the 9 Kan 12 Kayab base. The number 3.16.19.9.14.0 equals 584 CR, which would be 6 CR later. If this was accepted as equating with the base of the normal Mayan era, all Long Count positions in the tables below would be moved back by 6 CR. This is a reasonable possible alternative to the Satterthwaite placement. Smiley's attempt to move the dates in varying ways seems to me unrealistic; the dates must be moved as a block.

EA	4.5.19.13.12.8	4 Eb (5 Ch'en)	9.16.8.5.12	Black (5)		
	1. 0. 2.13		(7253)			
DA	4.6.0.13.15.1	3 Chicchan 18 Xul	9.17.8.8.5	Black (1)	Chac	
	6.16.9		(2489)			
EB	4.6.1.0.13.10	9 Ix (12 Zip)	9.17.15.6.14	Red (5)		
	9. 1.10		(3270)			
DH	4.6.1.9.15.0	3 Kan 17 Uo	9.18.4.8.4	Red (2)	Rabbit and (4)	Peccary
	1. 8.0		(520)			
DD	4.6.1.11. 5.0	3 Kan 12 Yax	9.18.5.16.4			
	6. 0.17.10		(43550)			
DE	4.6.7.12.4.10	3 Ix 7 Pax	10.4.6.15.14	Black (3)	Chac	
	2. 3.8.9		(15649)			
DG	4.6.9.15.12.19	13 Akbal 1 Kankin	10.6.10.6.3 (attested elsewhere)	Black (4)	Peccary	
	13.15.2		(4982)			
DC	4.6.10.9.10.1	3 Chicchan 13 Yaxkin	10.7.4.3.5			
	1.0.15.1		(7501)			
DF	4.6.11.10. 7.2	3 Cimi 14 Kayab	10.8.5.0.6	Red (3)	Black (2)	
	3. 0.13.19		(21879)			
DB	4.6.14.11.3.1	3 Chicchan 13 Pax	10.11.5.14.5	Red (1)		

[a] Items underlined above are here given correctly so that CR and SN count correspond, but are otherwise given in the *Dresden*.
[b] The *Dresden* table of multiples of 91 days uses dates 3 Chicchan, 3 Kan, 3 Cimi, 3 Ix, and 13 Akbal, emphasized above. 9 Ix is usually involved in Mercury calculations.
[c] N.B. *Dresden* R.N. base 12.19.19.17.3 13 Akbal 11 Kayab, 17 days before the usual Mayan era base, might tie in to these calculations.
[d] 3.16.3.5.6.16 (4 Ahau 8 Cunku) equals 10,967,536 days. Calculated at 365.25636, this is 17 days less than 30,027 sidereal years, or 34 days off from the 13 Akbal base above. DHK suspects calculations involving the precession of the equinoxes but proof is still lacking.
[e] The serpent number table of *Madrid*, pp. 18–20, has no discernible relationship to the *Dresden* dates, except possibly the 4 *Eb* date.

long). The third component consists of two intervals of 1508 My (each equal to 1507 Tropical years[17]). This period of 1508 My equals 29 CR, so that the same day of both the 260-day cycle and the 365-day Mesoamerican year return to the same seasonal position within the tropical year (in the context of earlier chapters, the same solar date). This placement, in turn, helps to explain the construction of the 9 *Kan* 12 *Kayab* base. The CR date 9 *Kan* 12 *Kayab*, which is closest to the Maya era base, is at 0.0.7.1.4 and is 7 My and 1 day (hence, exactly 7 Ty) after a date 13 *Akbal* 1 *Kayab*, a Ring Number date in the *Dresden* codex, some 17 days before the normal Mayan era base. With this placement, the 9 *Kan* 12 *Kayab* date, which is 7 tuns and 24 days after 4 *Ahau* 8 *Cumku* at the normal Maya era base, becomes 11,008,400 days after the 9 *Kan* 12 *Kayab* era base. This is an interval of 20×29 CR, or 30,160 My or 30,140 Ty. Given the Maya use of multiples of 20 in their mathematics and the use of $2\frac{1}{2}$ of these great tropical year intervals (of 29 CR) in reaching the earliest date of the Serpent Number series, it seems certain that the base is somehow involved with tropical year calculations. Why the normal Maya era base and the 9 *Kan* 12 *Kayab* base are offset by 17 days in the tropical year is unclear.

This previously unrecognized calculation is closely tied to the calculation of the birth of the gods at Palenque, discussed previously in §12.6. The total interval from the era base to 1.18.5.4.0 1 *Ahau* 13 *Mac* is 275480 days or 754 years and 87.532 days. It has been widely accepted that this 1 *Ahau* date was the birth date of a Mesoamerican god known in highland Guatemala as *Hun Hunahpu*, among the Aztecs as *Ce Xochitl* ("One Flower"), one of the Aztec names for the Sun god. The intervals suggest that the era base was at or near a fall equinox, that 0.0.1.9.2 13 *Ik* tun *Mol* was at or near a spring equinox, and that the Sun god was born at the winter solstice, the last being an appropriate and widely held view in other mythologies. The interval of 752 to 754 years is just the half-period of the 1508 Mayan year cycle under consideration. We have pointed out (ff. Spinden, §12.7) that the date 1.18.5.4.0 1 *Ahau* 13 *Mac* preceded the date 9.11.3.2.0 1 *Ahau* 13 *Mac* by two cycles of 29 calendar rounds. He also suggested that the latter date was the intended position of the 1 *Ahau* 13 *Mac* date, which appears in the *Dresden* Venus table. This view has been explicitly accepted both by Smiley (1961, pp. 237–238) and DHK, but implicitly rejected by most scholars who have worked on the

[17] This statement is precise enough for all practical purposes: The difference between 1508 My and 1507 Ty is 0.0046 days per 1507 years or $\approx 1^{d}/327{,}600^{y}$.

Venus table. The date 9.11.3.2.0 1 *Ahau* 13 *Mac* fell in the 52nd year of Pacal, ruler of Palenque, during the lifetime of his son, Chan Bahlum. These are the rulers associated with the tablets from the Temple of the Inscriptions, which give the birth dates of the gods. The date 9.11.3.2.0 1 *Ahau* 13 *Mac* is 88 days after 9.11.2.5.12 4 *Eb* 5 *Ch'en*, the Serpent Number date with which we started our discussion of serpent numbers and the tropical year earlier in this section. The 88-day interval is appropriate to go from a fall equinox to a winter solstice.

It should be pointed out that 1.18.5.4.0 1 *Ahau* 13 *Mac* is 280 days after 1.18.4.8.0 7 *Ahau* 18 *Kayab* and that the brothers Seven Ahau and One Ahau may well take their names from this structural relationship of the 18 *Kayab* and 13 *Mac* sections of the *Dresden* Venus table inscription. The nature of the relationship between One Ahau (Flower) as a Venus god and Nine Ik (Wind) as a Venus god is not clear at this time.

12.21. Caracol Stela 3

At the site of Caracol,[18] Belize, the Mayas erected a monument known to us as Caracol Stela 3 (see Figure 12.18). It contains a great deal of information about Mayan astronomy, integrated into the dynastic history of the site. Previous discussions of the astronomy of the monument are given in Kelley and Kerr (1973) and Kelley (1975, 1976, 1977a, 1983, 1990), but much remains to be learned, and more is now known of the glyphic context. The monument refers to two Caracol rulers, both of whose names incorporate star glyphs. The name of the first includes the glyph for god C, which Linda Schele (*private communication* to Kelley) has shown to be the head of a howler monkey (it was suggested some time ago that the head glyph of god C in the codices represented a monkey, but the evidence was far from clearcut). As shown previously, the god *Mixcoatl* and related Mayan gods are sometimes shown with monkey characteristics and Kelley has identified Mixcoatl with Jupiter. It is therefore interesting that in the Spinden correlation and in 663,310, suggested by Kelley, the birthdate assigned to "Monkey God Star" is a Jupiter conjunction. Kelley and Kerr (1973, p. 181) proposed that astronomical inscriptions among the Mayans might be recognized by any of five characteristics:

(1) The use of star glyphs, and other glyphs with previously defined astronomical associations, sometimes including Sun and Moon glyphs
(2) The use of a particular series of day names (DHK would now add month dates)
(3) The definition of known astronomical intervals by dates of a monument
(4) The calculation of dates with ranges far outside the historical period
(5) References to ceremonies or deities that normally recur in particular astronomical contexts

[18] Unrelated to the building of the same name in Chichen Itza, Yucatan, Mexico.

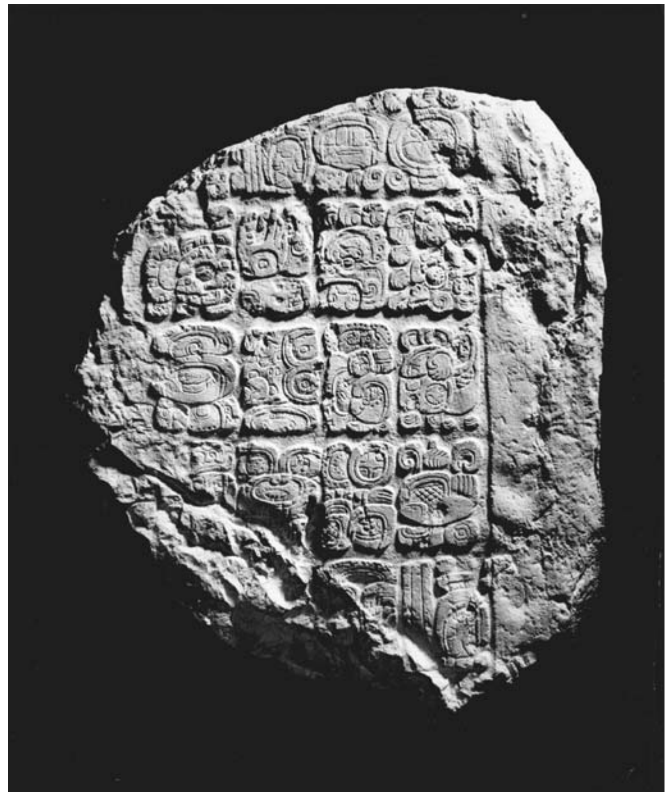


FIGURE 12.18. Stela 3 of Caracol, Belize, shows integration of Mayan astronomy and dynastic history. Photo by Peter Matthews and David H. Kelley.

Caracol Stela 3 shows star glyphs, repeated day names, repeated month dates, and known astronomical intervals. In 1973, that was enough to cause Kelley to reject a historical interpretation of the monument. Now, it seems clear that the monument is integrating historical and astronomical/astrological data.

The people of Caracol, under Monkey-God-Star, conquered neighboring Naranjo and commemorated the conquest by building a hieroglyphic stair there that gives many of the same dates commemorated at Caracol. The structural reality of the phenomena given by the intervals between dates given on the monument may be readily seen in Table 12.17, which shows the dates from Caracol Stela 3 with the equivalent Julian day numbers and phenomena in the Spinden and Kreichgauer correlations and in 663,310. Perhaps the most remarkable of these are the two Jupiter-Saturn conjunctions. However, there are also Jupiter-Sun, Venus-Jupiter, Venus-Mercury, Venus-Sun, Mars-Venus, Mars-Mercury, and Mars-Sun conjunctions. Some planetary intervals that do not appear associated with conjunctions in the Spinden or 663,310 correlations do appear as such in other correlations. This monument should eventually have a key role to play in the correct solution of the correlation problem and in showing Mayan knowledge of astronomy.

TABLE 12.17. Caracol Stela 3 dynastic history and astronomy.

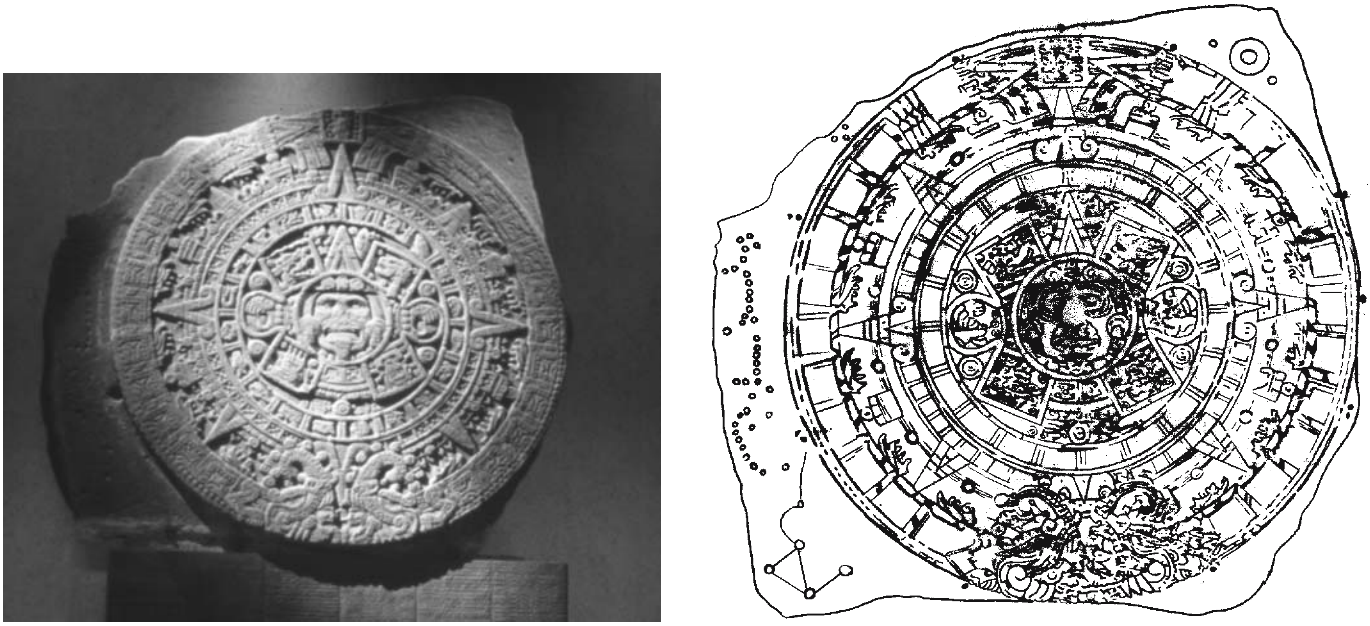
	Maya date: LC	CR	Decimal*	λ (Spinden 489384)	λ (Kreichgauer 626927)	λ (Kelley 663310)
1	9.6.12.4.16	5 Cib 14 Uo	1,343,616 2,304	☉ 93 ☿ 98 ♃ 99	☉ 304 ♀ 301	☉ 161 ☿ 163 ♃ 156
2	9.6.18.12.0	8 Ahau 8 Mol	1,345,920 4,408		☿ 37 ♀ 42	
3	9.7.10.16.8	9 Lamat 16 Ch'en	1,350,328 1,320			
4	9.7.14.10.8	3 Lamat 16 Uo	1,351,648 1,864	☉ 90 ♂ 89/ ☿ 116 ♀ 118		☉ 158 ♂ 153
5	9.7.19.13.12	8 Eb 15 Zotz	1,353,512 9,050	♃ 186 ♄ 184		♃ 243 ♄ 243
6	9.9.4.16.2[†]	10 Ik 5 uayeb	1,362,562 306	☉ 49 ☿ 47 ♂ 51	♃ 108 ♄ 108	☉ 116 ♂ 116
7	9.9.5.13.8	4 Lamat 6 Pax	1,362,868 1,377			
8	9.9.9.10.5	3 Chicchan 3 Ceh	1,364,245 155		☉ 114 ☿ 119 ♄ 113	♀ 291 ♂ 296
9	9.9.10.0.0	2 Ahau 13 Pop	1,364,400 1,164	☉ 60 ♀ 63	☿ 287 ♃ 287	
10	9.9.13.4.4	9 Kan 2 Zec	1,365,564 341	☉ 125 ♀ 127 ♃ 124/ ☿ 150 ♂ 152		☿ 218 ♂ 219/ ♀ 179 ♃ 181
11	9.9.14.3.5	12 Chicchan 18 Zip	1,365,905 1,249		☿ 330 ♀ 335	♀ 199 ♃ 199 ☿ 196
12	9.9.17.11.14[§]	13 Ix 12 Zac	1,367,154 449	♂ 273 ♄ 273		
13	9.9.18.16.3	7 Akbal 16 Muan	1,367,603 397	☿ 332 ♀ 332/ ♃ 293 ♄ 293	☉ 183 ☿ 186/ ♀ 193 ♃ 198/♂ 216 ♄ 220	♃ 356 ♄ 356
14	9.10.0.0.0	1 Ahau 8 Kayab	1,368,000 1,580	☿ 14 ♂ 17		♀ 84 ♂ 85
15	9.10.4.7.0	8 Ahau 3 Zec	1,369,580	☉ 123 ♂ 122/ ♀ 108 ♃ 103	☿ 235 ♃ 229 ♄ 234	♀ 158 ♃ 160

☉ Sun.
☿ Mercury.
♀ Venus.
♂ Mars.
♃ Jupiter.
♄ Saturn.
* Base 10 equivalents of Maya Long Count dates and (interlined) intervals between them.
† Calculated back from end date.
§ From parallel text of Naranjo Hieroglyphic Stairway.

12.22. Asterisms

Direct evidence for the identity of Mesoamerican asterisms is not extensive. The famed Aztec "calendar stone" was once set in the midst of a series of asterisms drawn in the ball-and-link convention, but only a few of these survive and we know of no convincing attempts to identify them. Figure 12.19 shows both a photograph, kindly provided by Prof. Angione, of the artifact as it appears in its current display case in Mexico City and a sketch that depicts the asterisms on the rim of the stone more fully than can be seen in the photo.

Sahagun also gives a few examples of Aztec ball-and-link asterisms. W. Lamb (1981) has uncovered a number of references in Mayan-Spanish dictionaries, but they are a meagre supply. From the few remaining codices, stelae, monuments, and other representations, however, we do have some idea of how Mesoamericans pictured certain asterisms. Coe (1975a) cites constellation references in an account of the admonition given Moctezuma Xocoyotzin on his election as emperor (Tezozomoc 1944) and sketches by the Spaniard Sahagun in the 1540s. The constellations include: *tianquitzli* ("Marketplace," the Pleiades; in Spanish, *las cabrillas*), *yohualitqui mamalhuaztli* ("Fire Drill," "the Keys of St. Peter," near Orion's Belt), *colotlixayac* or *citlalcolotl* ("Star Scorpion," identified as Scorpius), *xonecuilli* ("the Cross of St. James," which has the appearance of one of the Dippers), and *citlaltlachtli* ("Star Ballcourt," which looks somewhat like Gemini). The Christian names emerge from local Spanish, medieval usage. Aveni (1980) has a further discussion of these identifications and of individual star names in Mesoamerica. One of the most important "constellations" in Mesoamerica seems to have been the Pleiades. It was known as *tzab* ("rattlesnake rattle") among the Yucatec and Lacandone Maya. At the end of a 52-year calendar cycle, the Aztecs made special observations of the Pleiades at midnight. Following Bruce, Robles, and Ramos Chao (1971), Coe (1975a, p. 27) mentions the following modern Lacandone star names: "Big Woodpecker," Sirius;



(a) (b)

FIGURE 12.19. The Aztec "calendar stone," set in the midst of a series of asterisms drawn in the ball-and-link convention: (a) Photo by Dr. R. Angione. (b) Sketch, emphasizing the asterisms on the rim. Drawing by Rea Postolowski and Sharon Hanna.

"Woodpecker," Rigel; "Peccary," Orion's Belt; "Turtle," unidentified; "Red Dragonfly," Betelgeuse; and "Alligator," Ursa Minor.

Köhler (1984/1991) has collected material on the astromical knowledge of a number of communities in Mexico, with particular attention to the asterisms that seem to be at least similar to known Aztec asterisms. His data were obtained during the rainy season of 1982, and few were identified in the sky. Informants were Tzotzil, Mixe, Totonac, and Nahua. Köhler found that informants drew asterisms to correspond with their ideas about the stars, with little regard for visual accuracy, except at the most general level. He was able to identify "The many," as the Pleiades, also sometimes called "The sandal." The "Fire-drill" was the name of the Belt and Sword of Orion. The *Xonecuilli* was our Ursa Major. The Star-Scorpion has a variety of identifications, including: a small asterism near Corvus; Cassiopeia; and Scorpius. The Aztec "shooting star" had the same meaning as "shooting star" in English. Other asterisms remain unidentified.

By far the fullest account of the asterisms of any indigenous group in Mexico is that collected by Alessandro Lupo (1984/1991) from the Huaves of San Mateo del Mar, Oaxaca. Lupo was able to identify 17 asterisms and learned the names of 9 others, still astronomically unidentified. These are:

šikip	stars of the Pleiades	Pleiades	
mah¢oy	pelican	Aldebaran & Hyades	
roob	"bellows" [soplador]	Belt & Sword of Orion	nemeahmeay a wooden handle or hilt with a red macaw feather on the point (Huaves ff, A. Lupo 1984/91)
miwiil roob	"tail of the bellows"	Sirius	
ihkiaw okas (or mankwerna < span.)	"two stars" (two bulls?)	Castor & Pollux	
kinč	big crab	head of Hydra	
pilaw	little crab	γ, δ Cancri	
nepep	shooter (now, of a musket) once a blow gun??	"la hoz" of Leon sickle	
markesand	a sacred rectangular	trapecio del Cuervo	

(<Sp. marquesina)	object of wood and paper	
napïp	alacran scorpion	Scorpius, identical
šikwïw	deer (frontal view)	5 stars of Sagittarius
krus okas	cross stars	Cruz
Eskalera (stairway, ladder)	the ladder used by the "hangmen" to crucify Jesus	α, β Centauri
	[the sign "Jesus Nazarenus Rex Iudeorum"	γ, δ Centauri (one informant)]
krus nimeeč	Cross of the devil (el brazo "esta chueco")	Navio (3 Carinae 1 Velorum)
	if things are "not complete" they belong to the devil	
ndiïk	horned snake	Cassiopeia & Perseus
krus okas am Kalïy	cross stars of the north	Ursa minor [The Cross moves but the foot, Polaris, stays in place]
Pilmiïk	sea-horse	Ursa major +2 of Lynx, 1 of Leo
Huave "constellation"	names ff. A. Lupo 1984/91 "asterism"	astronomically unidentified
arch okas	three stars	
¢ol	heron	
kwak	spider	
lïw [Leo]	jaguar	
neoel	doll	
omal wakïš [<vaca]	head of the bull	
pišaw	duck	
wiïl	fox	
cïplïw	tarantula	

Several scholars, beginning with Spinden (1916), have suggested the existence of a series of asterisms analogous to our zodiac, especially as represented in the *Paris* codex and in an inscription at Chichen Itza. The *Paris* codex representations are marked with intervals of 168 units, presumed to be days. Although Spinden and many later scholars thought that these asterisms were next to each other, as depicted, Kelley argued that the associated interval of 168, if it did indicate days, suggested that adjacent representations were actually on nearly opposite sides of the sky. This view is supported by Justeson (1989, pp. 46–47) and by Lounsbury (cited therein).

It has been supposed by Thompson (1972, pp. 65–67) that the series of 20 deities that appear in the *Dresden* codex Venus table may have been associated with asterisms. The worst problem in connection with such an interpretation is the fact that the series of 20 deities appears twice in the table, shifted in relative position and thus associated with different intervals. Justeson (1989, p. 47) has calculated the relative sky positions of the deities in terms of their calendrical placements in the table in the upper of the two occurrences, and finds some similarities with the "zodiac" sequence. On the whole, the interpretation appears plausible.

Kelley's (1976, p. 87) illustration of a drawing of a cosmic diagram (sometimes called "cosmogram") from the *Fejervary-Mayer* codex was intended to suggest that the drawing may have some characteristics of a Mesoamerican sky map; the text, however, does not make such an interpretation clear, and there is no compelling evidence either to support or reject the idea.

Finally, Kelley (1989, p. 92) noted that the series of 20 drawings in the *Borgia* group of codices associated with the 13-day periods known to Americanists as *trecenas* (see §12.15), started with *Tonacatecuhtli*, identified as the "Milky Way." It is possible, however, that a more specific star grouping than what we call the "Milky Way" is intended. With one exception, the 20 *trecenas* show the same sequence of deities as the 20 day names. Eurasian parallels would suggest that day names were originally derived from the asterisms of the lunar mansions (Moran and Kelley 1969, especially, Fig. 19; and §15). Kelley further suggested that the 9 Lords of the Night and the 13 Lords of the Day also established sequences, counting in opposite directions from *Xiuhtecuhtli*

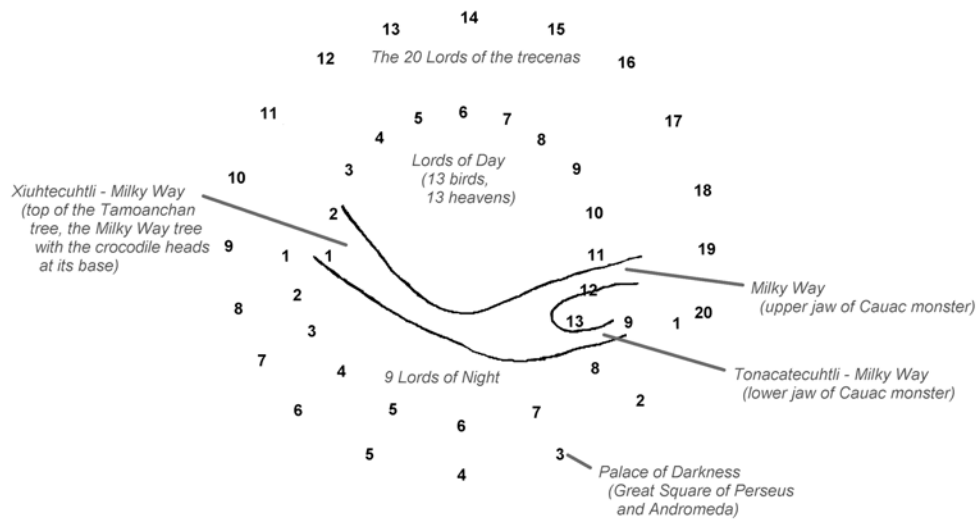


FIGURE 12.20. A sky diagram suggests the relationships of the sequences of the *Trecenas* and the Nine Lords of the Night to segments of the sky. Drawing by Sharon Hanna.

(Lord of Fire; see also §§13.3.3.1 and 15.3.2.1), associated with those just discussed. A diagram of the sky derived from the sequences is shown in Figure 12.20.

Bricker and Bricker (1992) have summarized the data on "zodiacal" constellations (ecliptic markers). Bricker and Bricker (1996) have made a major contribution to our knowledge of the glyphs associated with these constellations in a study of the throne inscription from the so-called Governor's Palace at Uxmal. They also infer a particular pattern of movements of Venus through these constellations as they identify them. They argue that constellations were treated in the iconography as horizon pairs. They found that the alignment between the Governor's Palace and Cehtzuc/Nohpat, to be discussed shortly, is a good reciprocal marker for Venus's northern P.M. and southern A.M. extreme positions, although not "perfect" for either (their study used dates between 880 and 934 A.D.). Examination for other correlations would be worthwhile. They found that a number of the glyphs of this inscription show a monster head with cross-bands in the mouth and iconographic traits allowing identification of the particular constellation.

12.23. Mesoamerican Alignments

Archaeoastronomical alignments have been known (by Europeans) to exist in Mesoamerica since Motolinia recorded in the 16th century that the Aztec ruler Montezuma found that the great temple of *Huitzilopochtli* was somewhat out of line with the rising of the Sun at the equinoxes and wished to correct this by tearing down the building and rebuilding it. The first recognition of such an alignment in an archaeological site in Mesoamerica was at Uaxactun, Guatemala, where alignments are associated with the rising of the Sun at the equinoxes and solstices.

Ricketson (1928), checking on a suggestion by the well-known archaeologist Frans Blom, recognized that the equinox rising Sun, viewed from *Temple EVII*, rose above the center of the central building (*EII*) on an eastern platform at the equinoxes and that the Sun rose at the outside corners of the other two buildings on the platform (*EI* and *EIII*) at the solstices. Temple *EVII* is a four-sided pyramid with stairways oriented to all cardinal directions. The equinox viewing line passes directly above the stelae in front of Temple *EVII*, which have the Long Count dates 8.16.0.0.0 3 *Ahau* 8 *Kankin* (ST 19) and 9.3.0.0.0 2 *Ahau* 18 *Muan* (ST 20), separated by seven katuns (140 tuns or 504,000 days—three days more than 138 Ty). This is the shortest possible interval at which two katun ending dates can return to approximately the same position in the tropical year. Although these dates are not equinoxes in any correlation that has yet been suggested, if the Palenque date 1 *Ahau* 13 *Mac* is a winter solstice date, as the structure of the associated dates suggests, then these dates occur 1 to 2 days before the spring equinox and 4 to 5 days before the spring equinox, respectively, the closest equinoctial positions of any katun ending for about 1000 years (Kelley 1986).

Perhaps the most striking equinox alignment in Mesoamerica is that of the Temple of *Kukulcan* (*Quetzalcoatl*) at Chichen Itza. Here, the serpent balustrades of the Temple, lit by the setting Sun, seem to come to life and wiggle down the stairs. This *hierophany*, or sacred appearance, has become a popular tourist attraction since first noticed by Arochi (1976), whose book, *La Piramide de Kukulcan*, deals primarily with this phenomenon. Although there is no obvious way to check it, it seems likely that the temple was originally built when the equinox coincided with a heliacal rising either of Mercury or of Venus (see §12.6 on the shift of the Feathered Serpent from Mercury to Venus).

Another remarkable visual phenomenon occurs in connection with the alignment of the axis of the Pyramid of the

Sun at Teotihuacan (Broda 2000, p. 424). As viewed from the west, the axis is directed 15°21′ S of east, and points to the (invisible!) Peak of Orizaba, the highest mountain in Mexico. At the winter solstice, a sun pillar appears above the peak, which is covered with an icefield, and presumably represents the vertical column above the Sun described in §5.1.4. The Pyramid of the Sun was the earliest major construction at the site, and this alignment is basic to the grid of the city and to many of the pecked circles, discussed below.

The person who did the most to determine possible astronomical alignments in Mesoamerica was Horst Hartung (1968, 1971, 1975, *inter alia*), frequently joined in later studies by Anthony Aveni (cf., especially Aveni and Hartung 1986). The study of major Mayan sites (Hartung 1971) is probably the most comprehensive attempt to examine the various ways in which astronomical alignments in Mesoamerica were incorporated into architectural patterns. Hartung's (1975) study is a summary of the major kinds of alignments discovered up to that time and their implications for Mesoamerican conceptions of the relationship between celestial and earthly affairs.

Among the classes of alignments pointed out by Hartung are lines marked across pecked designs, such as crosses or crosses within circles or circles; lines along the surface of a building; directions from corner to corner, especially of windows; directions from fixed observation points to structural markers such as the corners of buildings; and shafts, vertical or horizontal, through which the light of Sun, Moon, or stars might be observed at particular times. Stelae were sometimes used to mark alignments. The orientations of buildings, sometimes in sets, also served to draw attention to particular astronomically important directions. To these, we may add alignments designed to provide striking visual effects at particular times of the year.

The work of Aveni and Hartung (1986) is centered on the alignments[19] of archaeological sites and buildings of the Puuc area of Yucatan, with some comparative material from elsewhere in Mesoamerica. From the entire Mayan area, they examined over 96 sites and recorded over 200 alignments. Eighty-nine percent of these alignments fell east of north with maxima at 14′ E and 24′ E. In the Puuc area, 44 alignments from 33 sites showed the maximum at 14′, but not that at 24′. It seems reasonably clear that such figures are not a product of randomness. However, the degree of variation in these alignments is substantial.

It is perhaps not surprising in these circumstances that some of the exceptions to the general pattern provide some of the most clear-cut evidence of particular specifiable alignments. The best of all is that of the Governor's Palace at Uxmal (Figure 12.21), which looks toward a pyramid at Nohpat and the rising point of Venus at its southerly extreme.

Elaborate masks of Chac, the Rain God, so typical of the Puuc area, are numerous on the building and some of them are marked with the star or Venus glyph. An accompanying text contains a variant of the same glyph and a number of unusual glyphs that have been identified by the Brickers (1996) as constellation glyphs. Some of the Chac masks of the Governor's Palace are marked with a Venus glyph and the number 8. Aveni (1982, p. 15) and Aveni and Hartung (1986, p. 31) have suggested that this referred to the canonical eight days disappearance of Venus at inferior conjunction. The Brickers thought it was more likely in the context of the southerly and northerly extremes to refer to the eight-year cycle (§3.1.5). At the Adivino, or Pyramid of the Magician (Figure 12.22), the same combination appears, but this time there is a *kin*, or "day," glyph below the eight, thus, supporting Aveni. Strikingly, the characteristics of the two Venus glyphs are different.

A dispute has arisen between Aveni and Šprajc (see Šprajc 1990/1993a) over the question of whether the intent was to

FIGURE 12.21. The Palace of the Governor at Uxmal: From the top of the stairs, a line of sight leads to Nohpat and to a Venus horizon location. Photo courtesy of Dr. R. Angione.

FIGURE 12.22. The Pyramid of the Magician at Uxmal. Photo courtesy of Dr. R. Angione.

[19] Aveni and Hartung use the terms "alignment" for any measured direction and "orientation" for those alignments that they suppose were intended by the builders to coincide with particular phenomena.

create a southern sunrise alignment or a northern sunset alignment. Because the alignment is nearly reciprocal[20] and the Mayans must have known this, we assume that observers at Uxmal watched Venus rise over Nohpat, whereas observers at Nohpat and Cehtzuc watched Venus set, aligned with the Palace of the Governor. There is no reason we know to assume that these viewpoints are exclusive. A partly fallen pillar and a two-headed jaguar throne on top of a small square platform are also on the alignment to Nohpat. The throne could well have served as a fixed observing point to look in either direction.

At Palenque, the inner doorway of the Temple of the Cross is decorated with a bas-relief of the old black god of the underworld (God L), whom DHK has identified with Saturn. At winter solstice, the last rays of the setting Sun catch God L when all other scenes have faded into darkness. See §14.1 for parallels among the Kogi people of Colombia.

Broda (2000, pp. 414–415) discusses two examples of vertical tubes at Teotihuacan that were used to mark the zenith passage of the Sun. They are located in "caves" or tunnels used in the excavation of rock slabs for buildings. They are fully illuminated only at zenith passages, but some light enters these "caves" between April 30 and August 12, that is, for 105 days, followed by 260 days of darkness. Zenith passages occur at both Copan and Izapa on these very dates.

At Monte Alban ($\phi = 17°03'$ N) and Xochicalco (18°48′ N), there are vertical tubes penetrating deep into structures. These allow the direct rays of sunlight to penetrate to chambers below the bottoms of the tubes only on the two dates of zenith passage at each site, when the solar declination equals the site latitude. In these two sites, as at Teotihuacan, some light enters the chambers for the same 105-day period. Building P in Monte Alban contains the shaft among a flight of steps, visible from Building J, and aligned with a perpendicular to one face of building J, a five-sided structure (see Figure 12.23).

The section of Building J containing the steps leading down from this face is slightly skewed off this line, and a line perpendicular to the steps pointed to the rising azimuth of the star α Aurigae (Capella) in 250 B.C. The alignment was probably intentional because this star rose heliacally on one of the two dates of the calendar year in 250 B.C. (~May 12/13 according to The Sky, Red Shift, and Voyager III simulation software—see Figure 12.24)[21] when the Sun passed through the zenith. If this were indeed the case, the heliacal rising of Capella might have provided a warning to priests to prepare for that festive solar passage event, still celebrated today in the region. Voyager shows $h_{\alpha Aur} = +1.8°$, $h_{\odot} = -10.1°$ at 05:12 A.M., May 13.

However, our simulation shows a flat horizon; Capella would have arisen above building P, but as can be seen in Figure 12.23b and c, the horizon in this direction is certainly not flat. With increasing elevation of the actual horizon, the date of the heliacal rise of Capella would have to be later than for a flat horizon in order to keep the *arcus visionis* to $\geqslant 10°$ (cf., §3.1.5); that is, the Sun would need to have moved further eastward, away from Capella. This requirement throws some doubt on Capella as a harbinger of solar zenith passage at that epoch. Presumably, if the *arcus visionis* were determined to be smaller for this site (perhaps because the sky brightness was less than typical, the transparency of the atmophere higher making a star appear brighter—see §3.1), or if optical aids could have been used to observe Capella in a brightening sky, it might still have been possible. Additional investigation requires the determination of the elevation angle along the ridge of mountains on the visible horizon from the most likely observing site, presumably Building J, or some other place from which the alignments incorporated in Building J could have been used as a backsight. An alternative or additional use of the shaft may have been to note the instant of passage of the Pleiades through the zenith, which Aveni states (1980, p. 253) also occurred at Monte Alban at this time. Of course, such a passage would have occurred whenever the Pleiades could be seen, and when its declination matched the latitude of Building P, within the angular size subtended by the shaft on the sky (2° according to Aveni 1980). However, the simulation indicates that the various stars in the Pleiades had declinations between about ~14½° and slightly less than 15° in 250 B.C.; so the epoch of zenith passage was only beginning or about to begin at this time.

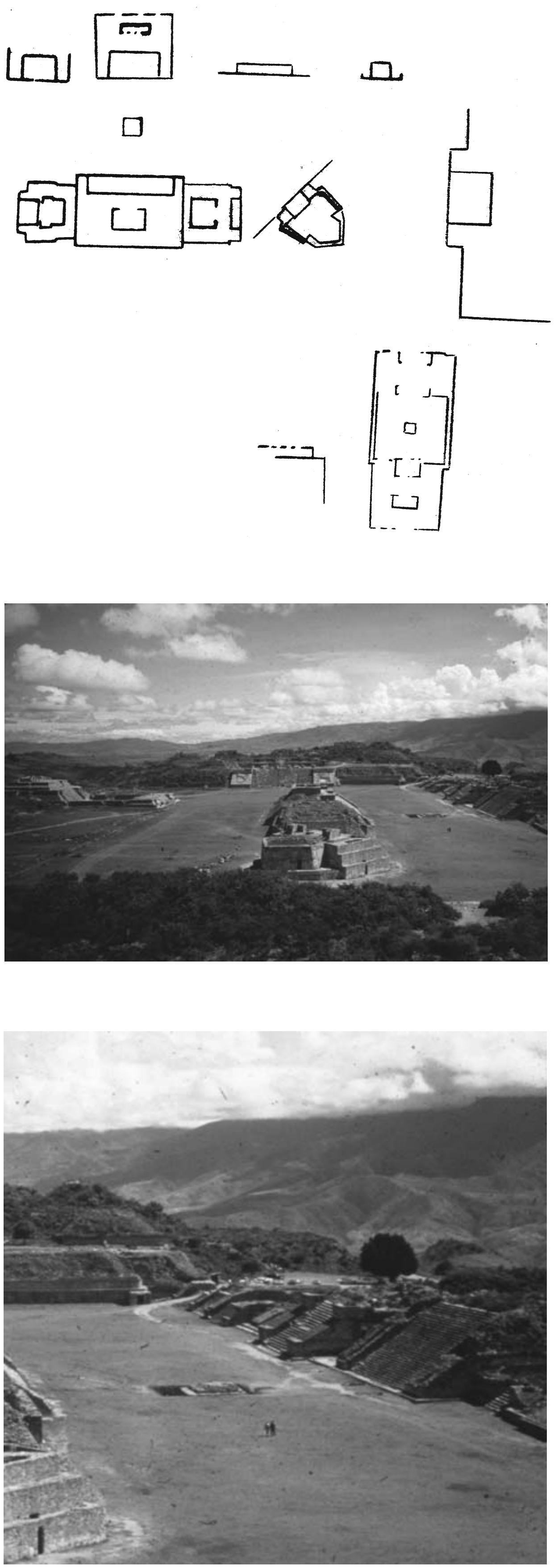
At the nearby site of Caballito Blanco, structure O is smaller but otherwise bears a strong resemblance to Building J at Monte Alban. Its alignments are not so clear, however. Whereas the V-shaped side of building J was aligned to the setting of the Southern Cross and α and β Centauri, the analogous point of Building O was directed to the setting of α Canis Majoris (Sirius), the brightest star in the sky. Its heliacal rising occurred just after summer solstice (The Sky and Voyager simulations suggest ~July 9), and its cosmical setting just before the winter solstice (~Dec.11), and its heliacal (acronychal) setting, ~May 21, in 250 B.C.

At Teotihuacan ($\phi = 19^{\circ}\!.68$), the zenith passage of the Sun coincided with the heliacal rising of the Pleiades about May 20 in 150 A.D., at about the time of the founding of the city (Aveni 1980, p. 225). Aveni notes that the Pleiades would have passed close to the zenith also, but this would have been far from the epoch when the coincidence was exact, that is, when the declination of the Pleiades was equal to the latitude. This circumstance took place many centuries later—at about 806 ± ~50 A.D., according to our calculation, depending on whether Alcyone, the brightest Pleiad, or another is selected, and the exact latitude of the ceremonial site from which the event was observed. Figure 12.25 demonstrates the proximity of 6 Pleiads to zenith passage, represented by the horizontal line through 0 (see Table 3.1 and §5.8.1 for the identities of the Pleiads and Figure 5.18 for their appearance in the sky).

The appearance of the Pleiades at or near the zenith may provide a partial explanation for a strange series of representations found painted on the floor of Portico 4 of a building at Tetitla within the Teotihuacan site. Jorge de Angulo

[20] Šprajc has found that the northern extreme during the 8th to 10th centuries A.D. was slightly greater than the southern extreme.

[21] Aveni 1980, pp. 256–257, gives ~May 2 as an approximate heliacal rise date; and his Table 11 would suggest ~May 8 for solar zenith passage. Thus, the harbinger appears to work fine. However, the dates of zenith passage and the apparent helicacal rise date as obtained from simulations are later, as noted above.



(a)

(b)

(c)

(1984) has shown that the 11 repeated diagrams on the floor constitute a giant version of the dots in each one of them and that they represent the 11 brightest stars of the Pleiades, drawn as a stylized jaguar. A jaguar in a knotted net is a very prominent feature of Teotihuacan iconography and seems to correspond to the knotted eye jaguar of the Mayas. Kelley (1980, p. S24) has suggested that the Aztec equivalent of this deity was *Mixcoatl* (literally, *Cloud Snake*) and that he was equated with Jupiter. Mixcoatl is said to have created 400 Chichimecs, in order that they might be killed by his children to obtain blood to feed the sun, and it is said that he himself became one of the 400 (Garibay 1965, ed. *Historia de los Mexicanos por sus pinturas*, pp. 36–37). They are also referred to as the 400 Mimixcoa,[22] killed by their sister, Itzpapalotl, the Obsidian Butterfly, and Brundage (1979, pp. 130–139) also equates them with the 400 Southerners, led by the goddess Coyolxauhqui. They are attacked and killed by their brother, Huitzilopochtli, who decapitated Coyolxauhqui and rolled her down Snake Mountain so that she broke in many pieces. The battle between Huitzilopochtli and the 400 Southerners is sometimes described as a midnight game in a ball-court. Brundage regards all the actors as figures in the sky—Coyolxauhqui as the moon, Mixcoatl perhaps as a version of Venus or the Sun—but he makes no attempt to interpret the story in an astronomically coherent fashion. Mixcoatl is also said to be the inventor of the intoxicating pulque, usually attributed to the Moon goddess, Mayauel, the associate of the Four Hundred Rabbits of drunkenness (Brundage 1979, pp.

[22] Plural of *Mixcoatl*. The number 400 may be significant in being both a Mesoamerican round number (20 × 20) and a close approximation to the number of days in the synodic period of Jupiter ($398^{\mathrm{d}}.9$).

◄

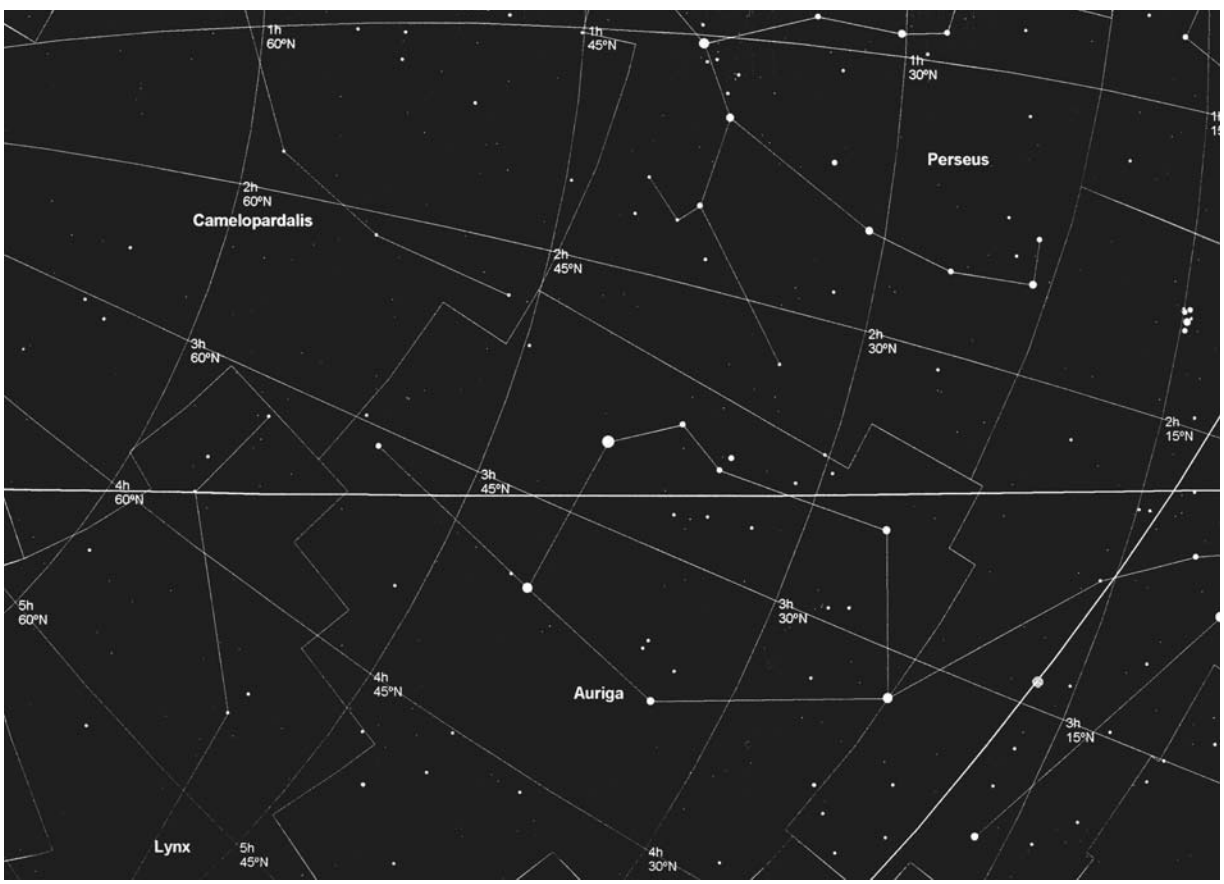
Figure 12.23. Monte Alban: (a) The plan view of the site. Drawing by Sharon Hanna. (b) Photographic overview—Building J is in the foreground. (c) A magnified view centered on Building P, which contains a vertical shaft among a flight of steps, possibly to mark the zenith passage of the Sun. Photo courtesy of Dr. R. Angione.

►

Figure 12.24. The simulations of the heliacal rise of Capella (α Aurigae) on the mornings (a) May 2 and (b) May 12, 250 b.c., at Monte Alban, Mexico, according to *Red Shift* (see Appendix A for details of the sky-simulation packages): The Sun is shown on the ecliptic and below the horizontal line representing the horizon. The distance of the Sun below the horizon should be between 10° and 25°, and the star heliacally rising should be high enough to overcome both the high extinction and the sky brightness close to the horizon, and, of course, elevated features on the horizon. The former circumstances should require at least a degree or two in the case of Capella; the latter, many degrees. Notice that Capella could not have risen heliacally as early as May 2.


Perseus
1h
15°N
2h
45°N
2h
30°N
2h
15°N
3h
45°N
Taurus
2h
0°
3h
30°N
4h
45°N
Auriga
3h
15°N
4h
30°N
3h
0°

(a)


1h
60°N
1h
45°N
1h
30°N
Perseus
2h
60°N
Camelopardalis
2h
45°N
2h
30°N
3h
60°N
2h
15°N
4h
60°N
3h
45°N
5h
60°N
3h
30°N
4h
45°N
Auriga
3h
15°N
Lynx
5h
45°N
4h
30°N

(b)

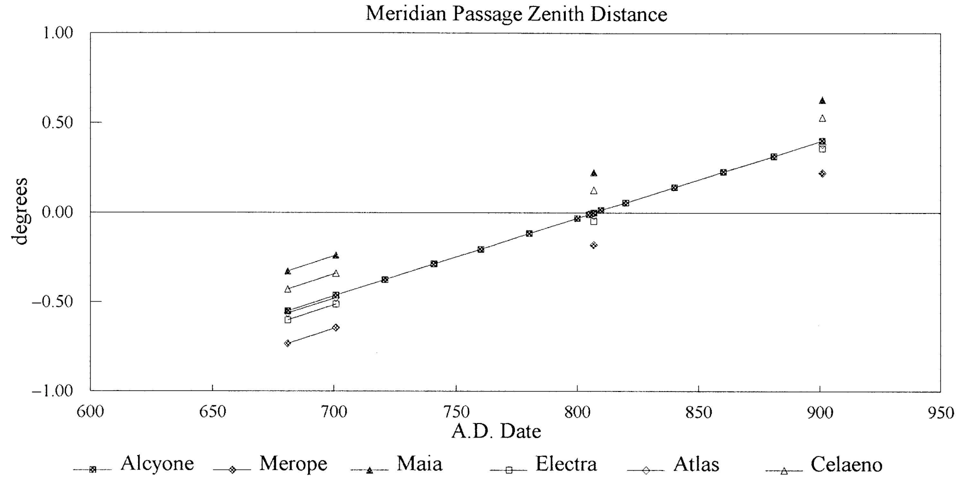


FIGURE 12.25. The zenith distance at a transit of six stars of the Pleiades at Teotihuacan (see Table 3.1 and §5.8.1 for the identity of the Pleiads and Figure 5.18 for their appearance in the sky) at Teotihuacan. Calculation and plot from a Lotus 1-2-3 spreadsheet by E.F. Milone.

158–159). In one account, it is said that Tezcatlipoca, a major Jaguar god, changed his name into Mixcoatl (Brundage, 1979, pp. 94–95).

A similar tale is told in the Guatemalan Mayan *Popol Vuh* that says that the 400 youths got drunk and were transferred to the sky. It adds that they became the Pleiades, thus, closing the circle and reenforcing the view that the knot jaguar was, somehow, identified both with Jupiter and the Pleiades (cf. Stewart 1978).

The reference to drunkenness suggests a connection with the goddesses of pulque and drunkenness, whose calendar names were *Two Flower* and *Three Crocodile*, identified as goddesses of the draconitic node passage at days 173 and 174 from Kelley's postulated base for calendar names of the gods (cf., Table 12.7). Here, we find a noteworthy coincidence, for the same two days appear 4332 and 4333 days from the base. The accumulated eclipse season interval is 4332.75+ days. The sidereal period of Jupiter is 4332.85$^-$ days. Moreover, the day 4331 is *1 Rain*. In the Mixtec codices, this is the name of one of the Rain Gods, and the name *Mixcoatl* (Cloud Snake) strongly suggests that rain was one aspect of the complex Jupiter god. See Table 12.14 where rain deity names of the lords of Palenque are associated with Jupiter-Mercury conjunctions.

These seem to be good reasons why the main streets of Teotihuacan should have been aligned to the Pleiades on the western horizon and why the line should have been marked with pecked crosses. Aveni and Gibbs (1976) have shown the wide distribution and ceremonial importance of such crosses. Broda (2000, p. 420) points out that there are now 46 pecked circles known from Teotihuacan alone. Aveni (2000, pp. 255–267) emphasizes the high degree of similarity among examples from sites as distant as Uaxactun and Teotihuacan. The similarity of pecked circles to calendrical cosmograms is striking.

The Mesoamericans attached exceptional importance to the passage of the Sun through the zenith, and undoubtedly charted the solar annual motion to and from its northern stationary point, the summer solstice. There is an astronomical complex probably designed to mark the Tropic of Cancer. It was built by Teotihuacanos who went North from their great city. If this was indeed their purpose, we have an indication of the accuracy with which the Teotihuacanos could measure the Tropic's location. The site is Alta Vista, Zacatecas, now located at longitude W103°28′.8, latitude +23°28′.8, a mere 2′.4 or 4.4 km N of the Tropic. Work on the site began between 350 and 550 A.D.; in 550 ± 100 A.D., the Tropic of Cancer would have been 9′.5 ± 0′.7 farther north than at present due to the decreasing obliquity of the ecliptic with time, and stood at a latitude of 23°38′.3 ± 0′.7, where the uncertainty in latitude derives from that in the date. The change of 9′.5 is equivalent to a length of 17.5 kilometers.[23] Thus, if the choice of location of Alta Vista for a solsticial zenith passage was deliberate, the error in establishing this site was ~8′, about a quarter of the angular diameter of the Sun.

There is independent evidence that this site was astronomically important: Alta Vista contains a number of impressive calendrical alignments. The roadway from the Sun Temple is struck by the rising Sun at the summer solstice. A line through the eastern and western corners of the Sun Temple points to the rising Sun behind the peak Picacho Montoso, 11 km E, at the equinoxes. Southward, at nearby Cerro Chapin, there are two pecked crosses, resembling those of Teotihuacan. The lines on these crosses point to the Sun rising behind the same Picacho Montoso, 13.75 km to the NE, at the summer solstice. Plate 5 (see the color insert) shows Sun rise beyond a pecked cross in this photo taken within a day of the summer solstice in 1999.

[23] The relationship between a degree of geodetic latitude and distance in meters along the surface of a triaxial ellipsoid approximating the Earth's surface is as follows:

$$1^\circ \doteq 111133.35 - 559.84\cos 2\phi - 0.000003519 \cos 4\phi \text{ meters},$$

where ϕ is the latitude at the midpoint of the arc. Thus, in the present example, the length of 1° corresponds to 110.752. km so that 1′ corresponds to 1.845. km.

FIGURE 12.26. The Caracol at Chichen Itza: Venus alignments have been suggested for the window jambs. (a) Front view of the monument. (b) Details of front stairs, showing stylobate structure. (c) Opening to the ruined tower. Photos by E.F. Milone.

(a)

(b)

(c)

As pointed out by Aveni (1980, pp. 232–233), the pecked crosses at Teotihuacan and at Cerro Chapin resemble a *patolli* board. The same calendrical and cosmological principles seem to be involved. Although this game is mentioned in early colonial sources on the Aztecs, details of play were not recorded. Remarkably, Alfonso Caso found the game still being played and was able to determine the rules. The integration of the game with Mesoamerican calendrics and cosmology is remarkably complete. The use of the numbers 13, 20, 260, and 4 in the calendar, in the game, and in surviving pecked crosses suggests that this was equally true in the Classic period at Teotihuacan and that the full Mesoamerican calendar was in use there, although we have no other direct evidence of it, save for two Caribbean shells with dates on them (see Caso 1967 and Langley 1986).

Although the marking of the extreme positions of the Sun appears frequently in alignments worldwide and the extreme positions of the Moon have been attested in a few rare cases, the Caracol Observatory at Chichen Itza (Figure 12.26) seems to be the only structure for which anyone has yet claimed alignments to the extreme rising points of Venus.

Astronomical observatory functions have been suggested for other Mesoamerican buildings, for example, the now-destroyed caracol of Paalmul opposite the island of Cozumel on the shore of eastern Yucatan (Mason 1927). The Paalmul conical tower resembled the Caracol at Chichen Itza. See Aveni (1980) for further discussion of this site.

This concludes our discussion of Mesoamerican astronomy. The ethnoastronomy of the rest of North America will be considered next.

13 America North of Mexico

We preface the discussion of the astronomy of pre-Columbian America north of the Rio Grande by a general overview of the cultures of the region. In North America north of Mexico, there was a wide diversity of cultures matching the ecological and linguistic variation. Kroeber's (1939) *Cultural and Natural Areas of Native North America* defined the major areas in ways that are still largely valid, although the descriptions have been described as too generalized, ignoring changes through time and local variation within the defined areas. When first recorded, about 50 language families and several hundred languages were spoken. We will mention only three of these families: the Algonquians, spread from the St. Laurence to Virginia and west into the Rocky Mountains; the Siouans, attested in Virginia, and Ohio as well as the mouth of the Mississippi and throughout the Great Plains; and the Uto-Aztecans, spread from northern California, throughout the Great Basin, onto the Plains and south all the way to Nicaragua.

Most of the tribes east of the Mississippi and south of a line somewhat north of the Great Lakes were agricultural, heavily dependent on corn, squash, and beans but also growing other crops, such as sunflowers. The degree of reliance on hunting, fishing, and gathering wild plants showed major local variation. Housing included many kinds of tents and sometimes long house frames covered with bark or skins. Clothing was mostly of skins.

In the Southwest (as defined by Kroeber), the tribes lived in adobe-walled apartment houses, forming villages. They grew a wide range of crops, with substantial use of irrigation. Clothing was often of cotton.

On the Great Plains, the historic cultures had acquired horses (originally introduced by the Spaniards in Latin America) and buffalo hunting was a major part of the subsistance base. Whale hunting was important in coastal areas in parts of California, the Northwest coast, and the Arctic. Gathering of plant foods and shell fish was also an important factor in many areas. Detailed descriptions of housing, clothing, weaponry, food preservation, and specialized features of technology can be found in Driver (1961/1969).

Our knowledge of the archeological background of these cultures and their development through time is constantly growing, and there are now a great many good summaries of regional archeology. There are also some widespread topical summaries mostly dealing with technological and economic evidence. Gordon Willey (1966) synthesized the material available at that time, and the general outlines retain substantial validity.

Comprehensive treatments of the astronomy of pre-Columbian America north of the Rio Grande are few. Williamson (1984) integrated contemporary beliefs of North American Indians, ethnographic evidence, and archeological data as they relate to astronomy and cosmology. Williamson and Farrer (1992) contains a series of important articles on similar topics but is less comprehensive. Dorcas Miller (1997) has written an important new work dealing largely with native North American constellations. For particular regions, the situation is better. Accordingly, we discuss each region in turn.

13.1. The Southwest

General works on the archaeoastronomy of the southwest are Malville and Putnam (1989) and Carlson and Judge (1987). In the southwestern United States, rituals, plantings and many daily activities are set, even today, in an astronomical framework, marked by the movements of the Sun, Moon, planets, and stars. Myths incorporating the movements of the heavenly bodies are still told in varying forms among the Pueblo groups, the Navahos, and other southwestern tribes. Sand paintings depict constellations as well as the Sun and Moon. Rock art in most of the area seems to incorporate astronomical information.

Boma Johnson (1996 private communication to DHK) has established three major points about many rock art areas:

(1) They were sacred areas to which pilgrimages were made and where people from different groups could meet safely even if they were normally enemies;
(2) They acted as junction points for trails, some of which Johnson has mapped, which often extended for great distances; and
(3) The symbol system used at such sites was comparable to and interpreted in similar ways among people who were widely separated, often with different languages and substantially different cultures.

For these reasons, symbols cross-cut tribal boundaries and conventional culture areas defined by archeologists and ethnographers. Moreover, there is continuity through time. These sites are still sacred to many today, and much can be learned about their interpretation by scholars who have some degree of acceptance by local Amerind groups.

From the Owens Valley in California to the Oklahoma panhandle to the east and Baja California to the south, the play of light and shadow was used to delimit the seasons and to determine the timing of festivals and rituals. Moreover, kinship groups were associated with asterisms and with calendrical divisions among the Yumans, the Papagos, and at least some of the plains Siouans. Preston and Preston (1987) in an examination of petroglyph sites from selected areas in Arizona found 18 Anasazi sites and one Hohokam site that showed obvious examples of "light daggers" striking designs at solstices and equinoxes (and occasionally at other times of year, particularly about 45 days before and after December solstice). In the 19 sites, there were 58 examples of solar markers. At three sites, there were markers for both solstices, equinoxes, and the 45 days before or after winter solstice all on a single rock face. Preston and Preston point out (ff. McCluskey 1977) that the Hopi Wuwuchim ceremony was marked by horizon observations 45 days before the winter solstice. They also found a number of sites at which the observer was apparently supposed to look from the petroglyph to a horizon marker. In many of these sites, this petroglyph was an eye within a circle or spiral. Hoskinson (1996, personal communication to DHK) has seen more than 30 sites where shaped shadows are cast on carved rock panels. These shadows hit significant designs, sometimes features designed as asterisms at solstices, equinoxes, and cross-quarter days. Over 10 sites are known where light enters a cave or shines on a particular design when the surroundings are darkened. Shadow casters varied from massive cliff edges or overhangs to tiny slivers of otherwise unnoticeable rock perched precariously amid many others. Although the objective of rock art has been specified by some of the most knowledgable individuals as making visible the inherent spirit of the rock, there are occasional sites where large pillars were moved into position to serve as gnomons or as shaped shadow casters at a particular date.

Architectural alignments, spiral markers for positions of Sun and Moon, representations of the supernova of 1054, constellation drawings and depictions of heavenly supernaturals have all been claimed for this area with varying degrees of certainty. Astronomically interesting is the play of light and darkness relative to two spirals at Fajada Butte in Chaco Canyon, studied by Anna Sofaer and her colleagues (Sofaer et al. 1979a,b, 1982, 1986a; Sofaer and Sinclair 1987). Here at midday of the summer solstice, a dagger of light bisects the larger of two spirals. At the winter solstice, this spiral is framed by a line of light on each side. Finally, at the equinoxes, the smaller spiral is bisected by a light dagger. Such a combination of the play of light and shadow with symbols is far more convincing than are simple alignments without symbolic associations. It is also striking to find that a shadow cast by the Moon bisects the larger spiral at the northernmost position of the Moon in its 19-year cycle (see §2.3.5). However, as Carlson (1987) points out, the equinox and solstice alignments (which he accepts) fully determine the placement and size of the spirals; hence, the lunar alignment is unlikely to be intended. However, lunar interests are not unlikely.

Malville, Eddy, and Ambruster (1991) have shown that the Chacoan pueblo at Chimney Rock, Arizona, was associated with a full Moon at winter solstice (within the limits with which that could have been determined), which was also a northern standstill of the moon. They cite ethnographic evidence from Hopi and Zuni for the importance of lunar observations at winter solstice; at Zuni, the calendar was regulated by the relationship of full Moon and winter solstice. They also cite a Pueblo account of White Shell Woman (Moon) persuading the Sun to return north at winter solstice.

The tree-ring date for the initial construction of the site was 1076 A.D., and there was important renovation in 1093 A.D. There had been a solar eclipse (partial at Chimney Rock, total elsewhere in the southwest) on 7 March 1076. The full Moon rose between the Chimneys on 13 December 1076 (winter solstice occurred on 14 December 1076) and on 14 December 1095 (with winter solstice on 15/16 December 1095), both times at a northern standstill.

It has been suggested by Sofaer that the complexity of the patterns at Fajada Butte is such that the slabs may have been moved to their present positions. Although it is possible that there may have been some minimal adjusting of the slabs, the geology suggests that the slabs are very close to the position in which they broke away from their parent formation. The slabs have recently undergone slight shifting. The discovery of the Fajada Butte petroglyphs has led to widespread recognition of similar phenomena elsewhere in the Southwest.

Near Holly House, in Hovenweep National Monument, a petroglyph panel shows spirals, Sun symbols, and a depiction of a large serpent with a horn or feather on its head (Williamson, p. 94). A "streak" of light cuts across the left-hand spiral about 45 minutes after local sunrise on midsummer's day. Shortly thereafter, a second streak bisects the right-hand spiral and the two move toward each other, eventually creating a band of light across the entire panel. The use of the Anasazi triple concentric circle as a symbol for the Sun with the spirals helps to demonstrate that these spirals are, indeed, from the Anasazi group. Because nearby Anasazi structures at both Chaco Canyon and Hovenweep show astronomical alignments, it is reasonable to associate both petroglyph panels with the Anasazi.

The presence of the Feathered (?) Serpent at Hovenweep in association with summer solstice light markers suggests that some sort of planetary period of Mercury or Venus would be associated with the summer solstice at the contemporary date of the petroglyph panel. It seems to be widely accepted that the cult of the Feathered Serpent in the southwest is derived from Mesoamerica. In the Mayan area, at Chichen Itza, we see several representations of the Sun god, apparently personifying the Mayan people, standing opposite the Feathered Serpent (*Kukulcan* or *Quetzalcoatl*) accompanied by the Cloud Serpent (*Mixcoatl*), representing the invaders from the central Mexican highlands. In the great plaza of the city stands the *Castillo* or Temple of *Kukulcan*—a four-sided "pyramid" with stairways on each side of probably 91 steps each.[1] The solar connotation of these 364 or 365 steps is emphasized by the orientation to the cardinal points (different from the orientation of most other buildings at the site) and the remarkable light phenomena produced at the equinoxes by the giant serpents who align the stairways. The sinuous bodies of the serpents seem to writhe down the steps, as awe-inspiring a spectacle today as when the temple was first constructed.[2] Kelley (1980) has argued that the original Feathered Serpent of Mesoamerica (see §12.6) was identified with Mercury, but possibly already by Toltec times, this deity seems to have been identified with Venus. At the great Ballcourt to the northwest, scenes show the decapitated leader of one of the ball-teams, blood pouring out of his neck in the shape of snakes. The mural of the lower Temple of the Jaguars on the back of the ball court shows the Toltec ruler, *Quetzalcoatl*, wearing the full regalia of a ball player, with a ball in front of him, and a figure of a ruler in a Sun disk above—a scene of real rulers playing a game to replicate that of celestial bodies. The opposition of the Sun and Feathered Serpent, dramatized at Chichen Itza in so many different ways, continued to be enacted far to the north at Zuni, to at least the end of the last century, when it was recorded. The cult of the Feathered Serpent presumably appeared in the southwest with an astronomical identity either as Mercury or as Venus, which does not seem to have survived in any very clear form. The opposition to the Sun god may also be associated with the identification of the Sun, particularly at summer solstice, with the flaming red macaw. The cult associated with the latter seems to have been of considerable importance. At Casas Grandes, in Chihuahua, Di Peso (1974) discovered macaw breeding pens, and from this region, macaws were distributed widely in the Southwest. Hargrave (1970) found records of the discovery of the mummified bodies of macaws in southwestern sites, and the study of the age of macaws at death indicated a normal age of 11½ months, which strongly suggests that they were sacrificed in connection with ceremonies at the spring equinox. When these complex ideas reached the Southwest and how well the accompanying astronomy was understood are problems that need much more study.

At a number of sites in western North America, pictographs or petroglyphs show a crescent with a large star-

FIGURE 13.1. A rock cut overhang in Chaco Canyon, in the Four Corners area of the U.S. southwest, shows pictographs that may signify the outburst of the 1054 supernova: The artist would have needed a ladder to access and work on the overhang. Alternatively, a rope ladder suspended from above could have been used. Photo courtesy of Professor T.A. Clark.

like depiction. In some cases, the three concentric circles of the Anasazi Sun sign are nearby, It has been suggested that these may represent the crescent Moon within a couple of degrees of the Crab supernova (see §5.8.2) at the time of its greatest brilliance on the morning of July 5, 1054 A.D. Figure 13.1 shows the high roof of the overhang at Chaco Canyon, New Mexico, where a set of reddish-brown depictions is seen. Brandt et al. (1975) note that in absolute terms, the star lies to the south of the crescent and the lunar cusps point westward, but if the hand represents the Sun, there is approximate agreement in the relative placement of the Moon, Sun, and star elements (see Figure 5.20a for the Red Shift simulation of the scene in the sky at 4:40 A.M.). In addition, both the depiction nature of the Chaco Canyon pictographs and, more recently, the date of the event have been questioned.

At the Chaco Canyon site, a hand is shown with the other elements. On the basis of later Pueblo beliefs, it is held that the hand marks the site as sacred, but that is little help in this context, and possibly irrelevant. Among the Yuman tribes, Hand is a constellation used as a month marker. Florence Hawley Ellis (1975) summarizes the ethnographic data and concludes that the hand symbols as well as crescents and star symbols are all characteristic of Sun- and Moon-watching stations in the southwest. This carefully argued discussion throws some doubt on the supernova depiction interpretation of the Chaco Canyon and other area pictographs.

On the other hand, a Mimbres pot, from a culture that was flourishing at the time of the 1054 supernova, shows a lunar crescent in the shape of a rabbit (less realistically lunar than other examples). Next to it is a much smaller "sunlike" symbol with 23 rays. Chinese records of the supernova indicate that it was visible for 23 days. This numerical correspondence supports the view that the pot recorded the 1054 supernova.

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[1] The restoration of the structure is incomplete, and there is a possibility of error in the restoration so that it is by no means impossible that one of the stairways had 92 steps.

[2] See §12.23 for further description and discussion of this site.

Table 13.1. Apparent site-to-site alignments in the Chaco area.[a]

Site 1	Site 2	Azimuth line[b]	Astronomical alignments?[c]
New Alto	Pueblo Alto	90°.0	Equinox
Pueblo Bonito	Chetro Ketl	91°.5	Equinox
Penasco Blanco	Pueblo Bonito	124°.1 (180°–55°.9)	Lunar major SS S rise
	Pueblo del Arroyo	124°.2 (180°–55°.8)	Lunar major SS S rise
	Una Vida	123°.3 (180°–56°.7)	Lunar major SS S rise
	Kin Bineola	125°.0 (180°–55°.0)	Lunar major SS S rise
Una Vida	Chetro Ketl	128°.7 (180°–51°.3)	Lunar major SS S rise
	Pueblo Bonito	124°.2 (180°–55°.8)	Lunar major SS S rise
	Pueblo del Arroyo	124°.2 (180°–55°.8)	Lunar major SS Srise
	Kin Kletso	124°.2 (180°–55°.8)	Lunar major SS S rise
Chetro Ketl	Pueblo Pintado	110°.1 (180°–69°.9)	Lunar minor SS S rise
	Kin Bineola	69°.3	Lunar minor SS N rise
	Kin Kletso	110°.1 (180°–69°.9)	Lunar minor SS S rise
Pueblo del Arroyo	Hungo Pavi	110°.7 (180°–69°.3)	Lunar minor SS S rise
	Kin Bineola	67°.8	Lunar minor SS N rise
	Wijiji	114°.1 (180°–65°.9)	Lunar minor SS S rise
Pueblo Pintado	Pueblo Bonito	109°.7 (180°–70°.3)	Lunar minor SS S rise
	Penasco Blanco	111°.4 (180°–68°.6)	Lunar minor SS S rise
	Pueblo Alto	112°.0 (180°–68°.0)	Lunar minor SS S rise
	Kin Kletso	110°.1 (180°–69°.9)	Lunar minor SS S rise
Kin Kletso	Wijiji	115°.5 (180°–64°.5)	Lunar minor SS S rise
	Pueblo Alto	65°.8	Lunar minor SS N rise
	Hungo Pavi	114°.8 (180°–65°.2)	Lunar minor SS S rise

[a] From Sofaer (1997).
[b] No distinction is made between alignment directions *A* and *A* ± 180°, because explicit visibility information generally is not provided by Sofaer (1997). Thus, an alignment toward lunar major standstill northern rise could just as well represent an alignment toward lunar major standstill southern set.
[c] Abbreviations: "SS" = stand still; "N" = northern; "S" = southern.

Table 13.2. Apparent intrabuilding alignments in the Chaco area.[a]

Site	Feature	Azimuth line[b]	Astronomical aligns?[c]
Pueblo Alto	Back Wall	88°.9	Equinox
Pueblo Bonito west	Back Wall	90°.2	Equinox
Tsin Kletzin	Back Wall	89°	Equinox
Aztec	Back Wall	62°.5	Summer Solstice rise
Una Vida	Perpendicular to Back Wall	54°.8	Lunar major SS N rise
Penasco Blanco	Symmetry axis	126°.8 (180°–53°.2)	Lunar major SS S rise
Chetro Ketl	Back Wall	69°.6	Lunar minor SS N rise
Pueblo Pintado	Back Wall	69°.9	Lunar minor SS N rise
Salmon Ruin	Back Wall	65°.8	Lunar minor SS N rise
Pueblo del Arroyo	Main axis	114°.8 (180°–65°.2)	Lunar minor SS S rise
Kin Kletso	Main axis	114°.2 (180°–65°.8)	Lunar minor SS S rise

[a] From Sofaer (1997).
[b] No distinction is made between alignment directions *A* and *A* ± 180°, as per Table 13.1.
[c] Abbreviations as per Table 13.1. In addition to those shown, Sofaer (1997) suggests that a number of sites encompass angles along building diagonals that are suggestive of solar solstice azimuths and the complement (90 – *A*) of major or minor lunar standstills.

Sofaer (1997) summarizes the work done to date on the astronomical and cosmographic basis for the layout of the Chacoan sites, pueblos built between the early 9th and 12th centuries A.D. The Fajada Butte site has been associated directly with these Chacoan sites by the discovery of a road leading from the main area of the pueblos to that site. The symbolic representations indicating interest in equinoxes, solstices, and the major standstill of the Moon are now confirmed by low-precision alignments of (and between) individual buildings and sites. Aligned sites are often connected by major ceremonial roads. Fourteen important Chacoan sites have been examined as part of the Solstice Project, a conclusion of which is that the arrangement of structures within and between sites are determined by cosmological-astronomical principles. Examples of intersite alignments reported by Sofaer (1997) are summarized in Table 13.1, whereas alignments within buildings are listed in Table 13.2. Both sets of data are from Sofaer (1997). The most impor-

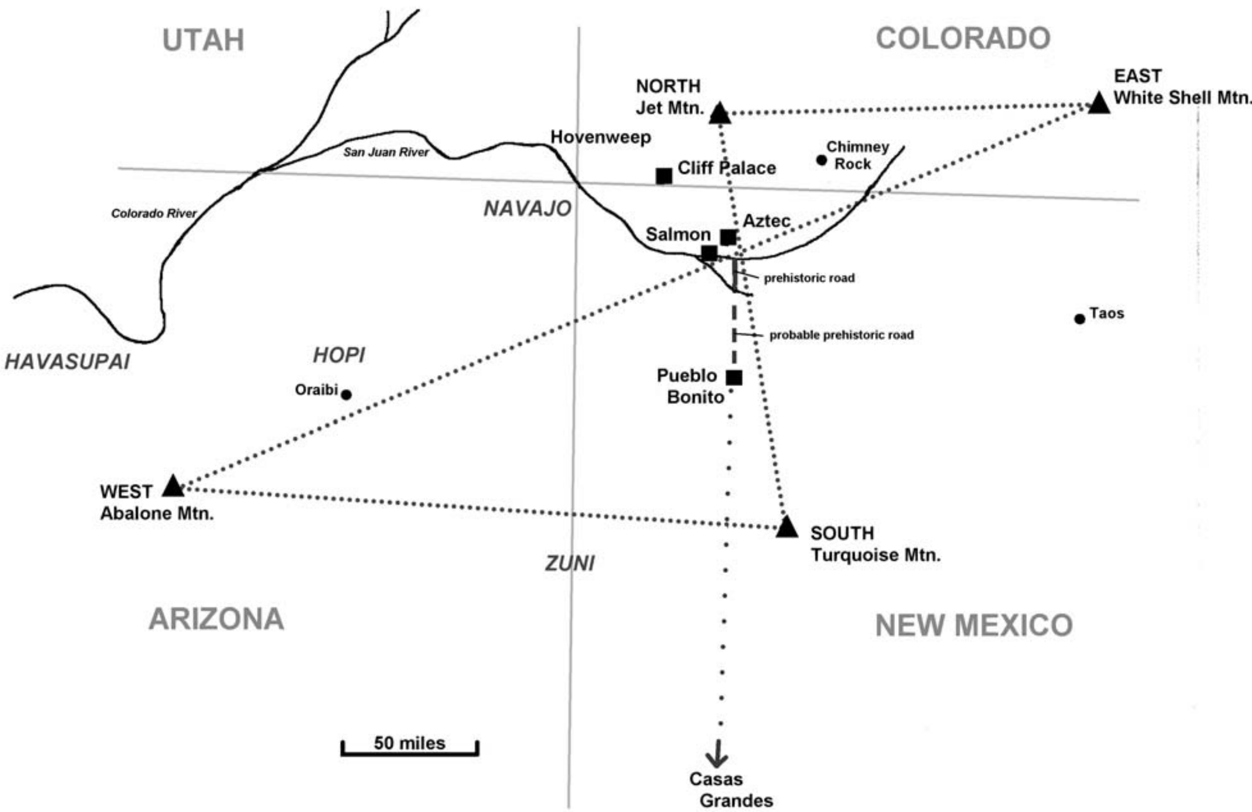


Figure 13.2. Map of the Chaco Canyon area in the Four Corners region of the U.S. southwest: Dotted lines connect four sacred mountains. Drawing by Sharon Hanna.

tant characteristic of these alignments is the repeated presence of reciprocal alignments, sometimes with structurally similar buildings. No natural features except the rising and setting of heavenly bodies or their movements along the horizon show such reciprocity. It is, however, possible that some of the alignments found refer to planets or fixed stars, rather than exclusively to solar and lunar measurements, and in places could be somewhat more precise than Sofaer now thinks. Many solar and lunar alignments (see §3.2.1 for a discussion of standstills) are claimed for various building facings and site-to-site directional lines, but it is not clear in the present summary on what basis the selection of alignment features had been made, or if horizon visibility permitted astronomical alignment along all the site-lines investigated. Firm conclusions about intentional alignments must await these and other technical details, concerning, for example, elevation information about backsights and foresights at individual sites, but the apparent wide-scale astronomical site-lines embodied in archeological placements are encouraging.

Chaco Canyon is in the heart of present-day Navaho country. Although the Navaho language is related to the Athapaskan languages of Canada, the people have adopted many of the customs and beliefs of their Yuman, Uto-Aztecan, and other Puebloan predecessors. Indeed, many of those people were incorporated into Navaho groups. Haile's (1947/1977) brief statements about their calendar indicate that it resembles Yuman calendars in that six months of the year were defined by the rising of particular stars. In these circumstances, it is probable that Navaho mythology and star lore are at least partially derived from Chacoan prototypes. It is therefore important that we have a fuller knowledge of Navaho asterisms and their relationship to mythology than we have for any other group in North America. Moreover, conventionalized star diagrams appear on ceremonial rattles and in sand paintings. The bounds of the area are marked by the four sacred mountains: White Shell Mountain (Mt. Blanco) to the east; Turquoise Mountain (Mt. Taylor) to the south; Abalone Mountain (Mt. Humphrey, San Francisco Peaks) to the west; and Jet Mountain (Mt. Hesperus) to the north. The relationships among the sites are shown in Figure 13.2.

A line drawn between Turquoise and Jet Mountains passes close to the late Chaco site of Aztec,[3] as does a line between White Shell and Abalone Mountains. The latter alignment is close to 69°, corresponding to the Chetro Ketl-Bineola alignment. Navaho asterisms are represented in

[3] The inappropriate name *Aztec* is a product of speculation about connections with Mexico when the site was first discovered. Even the late Chaco sites antedate Aztec culture by more than two centuries.

conventionalized ways but are important in the culture, appearing in sand-paintings, on gourd rattles, and in rock art. The most frequent portrayal of asterisms is in the sand-paintings used in healing ceremonies. The crucial factors in identifying Navaho asterisms seem to be the ceremonial context in which they appear, their position, and their shape. Some singers (who make the sand-paintings) seem to have tried to match the drawings of asterisms with their celestial counterparts in their orientation and in the number of visible stars, but others largely ignored such matters. The accounts of Navaho asterisms collected by Haile (1947/1977) include maps prepared by informants; designs on ceremonial rattles and sand-paintings; discussions of ceremonies associated either with particular asterisms or generically with stars; myths relating to figures identified with asterisms; and a little information on calenders. Haile was able to get the names of 37 asterisms, some of which are single stars. Attempts to determine more closely the astronomical identities of Navaho asterisms have been made by Chamberlain (1983) and Griffin-Pierce (1986). Interestingly, the Hero Twins give their names to asterisms, but are distinguished from them (Haile 1947/1977, p. 16). Perhaps, as heroes, they have planetary identities, although Haile contrasts their activities "on earth." A series of stars, used in some way as month markers from March to October, were regarded as feathers in the headdress of the Thunder Bird. Songs come from the sky people and "white thunder" songs come from the north. There was a contest over this between "white thunder" (presumably a form of the Thunder Bird) and "rock wren." The wren won (Haile 1947/1977, pp. 35–36). "Lightning" is another nearby asterism (Haile 1947/1977, pp. 9–10, 30). An interesting myth about Black God, Lord of Fire, says that he originally had the Pleiades on his ankle, then on his knees, then on his hip, and finally on his forehead, which is where they are shown in depictions of Black God (Haile 1947/1977, pp. 2–3). Other accounts indicate that Black God was once associated with the North Pole; he was replaced there by the red southern star, Coyote, and Black God went to the center (Haile 1947, p. 41). These transpositions are very difficult to understand.

A small asterism in the tail of Scorpio (Griffin-Pierce 1986) is called "Rabbit Tracks." Although we know of no Navaho evidence associating Rabbit and Moon, the idea is attested archeologically in the area. The tail of Scorpio, seen from this area, rises very close to the rising point of the Moon at its southern extremity. The same name is given to an asterism by the Chemehuevi in California (Hudson 1984, p. 53). According to Griffin-Pierce (1986), the nearby "Big Star" is Venus, but Haile says that it is "Big Black Star" (Haile 1947/1977, p. 8, #11). The Navaho star maps in Figure 13.3 show two asterisms with the shape usually assigned to "rabbit tracks," one in Scorpio, and the other "near" Ursa

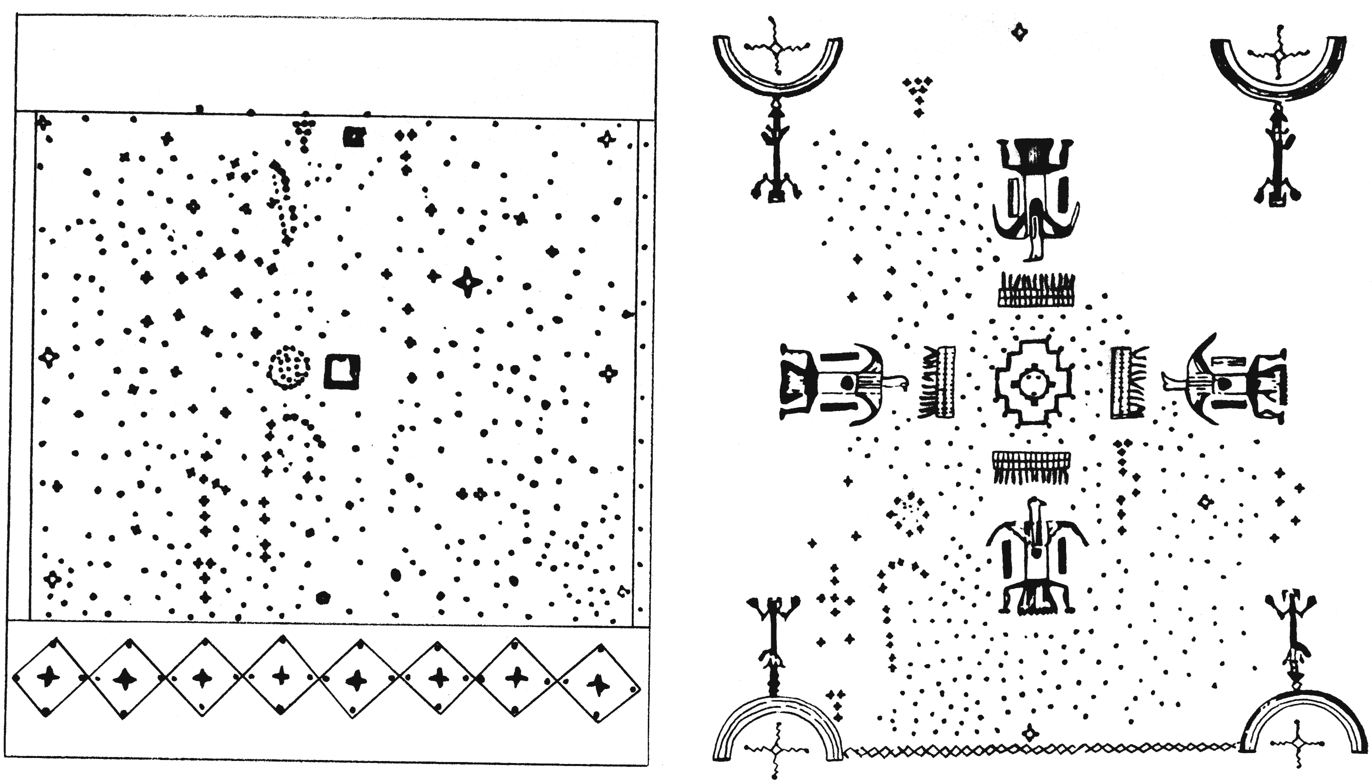


Figure 13.3. Two Navajo sky charts from sand-paintings. Drawings by Sharon Hanna.

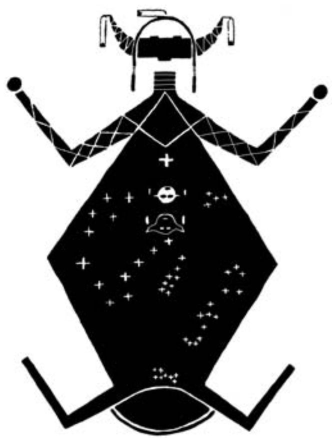


FIGURE 13.4. A sand-painting with asterisms, including the Big Dipper and the Pleiades, on the body of Father Sky. Drawing by Sharon Hanna.

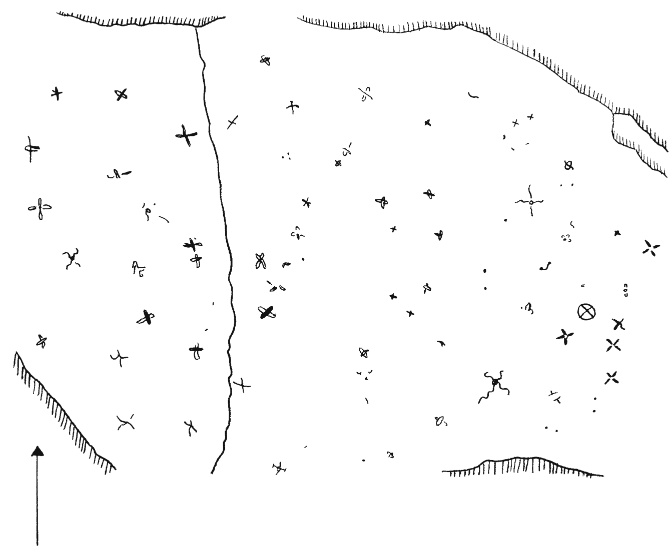


FIGURE 13.5. A possible Navajo star map on a rock wall. Drawing by Sharon Hanna.

Major. The latter may refer to Castor, Pollux, and two nearby stars. Castor is ~9°N of the (1950) ecliptic, and Pollux is ~6°N of the ecliptic. Because the Moon can vary ± 5° from the ecliptic, these stars could be reasonable markers for the northern major lunar standstill.

A sand-painting of Father Sky, bearing symbols of the Sun and Moon, and asterisms (including the Big Dipper, Polaris, Cassiopeia, and the Pleiades), is seen in Figure 13.4. In some representations, Father Sky is shown in intimate relations with Mother Earth.

Williamson (1984, pp. 170–171) says that some Navaho rock art also contains depictions of known Navaho asterisms, including "Rabbit Tracks," near Wijiji in Chaco Canyon and in Blanco Canyon. A possible star map on a rock wall in the Navaho territory is seen in Figure 13.5.

The Pima have a chant associated with the June solstice and the Saguaro "wine" ceremony. Hoskinson (1992) shows the astronomical nature of most of the references in the chant. "Running girls" is a reference both to the Pleiades and to prostitutes. "Houses of the Magicians" refers particularly to the solstices. The chant says directly that the Moon was lost to sight in the rising rays of the Sun; hence, that this was a new Moon. Hoskinson argues that "Bluebird," who "came running" with the "girls" is Venus. In other contexts, it is said that the supernatural "Bluebird" changes sex. The brilliant blue male bird is particularly prominent in June. Hoskinson maintains that these references indicate that Venus was the morning star at a new Moon at June solstice, and that the specificity of the references indicates a particular date in real time, not just generic characteristics of the "wine" ceremony. There is a further statement that the Sun was "tied" by "Grey Spider Magician" [i.e., at the Tropic of Cancer], but that Moon "rolls on" [presumably in this context to its northern standstill]. This may imply that Spider was at the center of a web and one of the outer strands caught the Sun. Hoskinson emphasizes the importance of the 251-year Venus cycle in attempting to determine the date for which the chant was created and gives a number of relevant calculations without actually specifying his preferred date. He does say that Venus usually has to be 35′ or more above the horizon to be visible in that area.

Tally counts using bars and dots have been recorded from Coahuila (Murray 1986).

One of these from Presa de la Mula, Coahuila, in northeastern Mexico, has a carefully done tally count that is divided by a grid of six horizontal lines and four vertical divisions. The resulting segments correspond very well with lunations. Murray's analysis suggests a sequence of (29, 28, 29, 28, 28), which he thinks involves an error. We would suggest that, instead, the invisible new Moon at conjunction was not included in the tally. Associated depictions include spear points and geometical figures reminiscent of the Yuman area to the west. Another tally count, using dots, comes from nearby Boca de Potrerillos, Nuevo Leon. It does not seem to be lunar.

Boma Johnson has investigated and mapped a number of geoglyphs created by clearing some areas of gravel and heaping up rocks in other areas. These were created by Yuman groups, and some are still used today for ceremonies. Johnson has had the benefit of discussing these geoglyphs with members of such groups. Some of the interpretations may be slightly influenced by the fact that informants today are often well aware of modern astronomical views, but the central features agree well with a wide range of other data. The most revealing with regard to the interrelationships of astronomy and cosmology is the Black Point Ceremonial Pathway site (Johnson 1992), which was used in initiation rituals (see Figure 13.6).

The Earth and the Pleiades are both shown as circles with pits in the center. The circles could agree equally well with Hudson's idea of the cosmos as three layers of flat circles or with the Juaneño allegation of a spherical earth. The pit in the Pleiades is supposed to represent the "emergence point" through which the ancestors came from the Pleiades to Earth and is conceptually connected to the earth pit. A path identified with the Milky Way cuts across the Earth circle. Sun and Moon are slightly removed from the Earth circle.

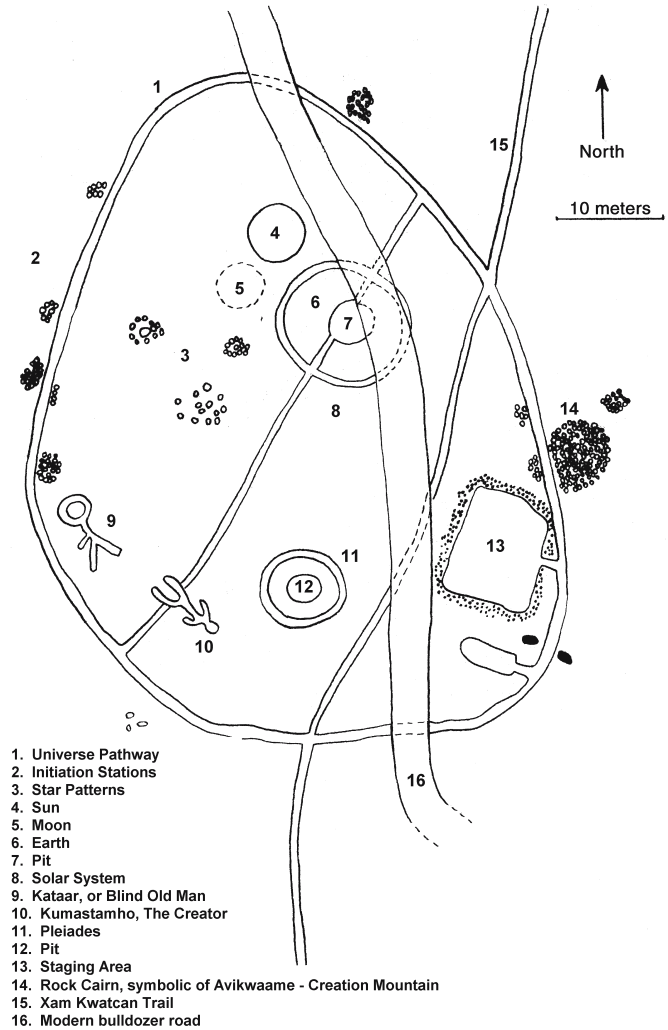


FIGURE 13.6. The Black Point Ceremonial Pathway shows interrelationships between astronomy and cosmology. Drawing by Sharon Hanna, after Johnson (1992).

As a cosmic diagram, this recalls the "ground paintings" of the Ipai (a nearby Yuman tribe to the west) (Hudson 1984, p. 54). These represent related conceptions, probably much later than the creation of the Black Point Ceremonial Pathway, but with substantially less probability of modern influence in the interpretations. The Creation Mountain at Black Point may correspond to one of four directional mountains in the Ipai ground painting (see Figure 13.7).

The Milky Way dividing the cosmic circle is very similar; the Pleiades, although present, are less emphasized in the Ipai versions. Altair to the Ipai was probably Buzzard, as it was to Tipai, Kamia, and Luiseño (neighbours on three sides), and to other Yuman groups. Among the Chumash, Buzzard was the chief of the land of the dead. If a similar concept was present here, Altair may correspond to Kumastamho in the Black Point Ceremonial Pathway.

The calendar system of the Yuman tribes of Arizona, California, and Mexico has been studied by Spier (1955), who examined the earlier literature and collected much new information. These tribes had a calendar in which six winter months (from about October to March probably) were named for stars or asterisms. Apparently the stars are given in the order of heliacal rising, but there are inconsistencies in the data that cannot yet be reconciled or interpreted with assurance. The six summer months were lunations that in some groups had the same names as the winter months and in other groups were nameless.

Among the Maricopa, the six month names were also the names of 6 of the 18 Maricopa sibs.[4] It is possible that the other 12 sibs were also named for asterisms. There are similarities to Mesoamerican 18 "month" calendars. The personal names of sib members reveal groupings of concepts that help to understand the cosmology. Thus, the x̥ipa sib is associated with coyote, fox, eagle, rain, clouds, opuntia cactus, cholla cactus, Moon, and wild gourd. We know that Moon in this area is often identified with Coyote. The equivalent month among the Seri was Jack-Rabbit, a known lunar animal in the Southwest. Probably the equivalent Mohave month is "Month of Fornication," and Coyote is known in this area as "Fornicator." The opuntia cactus was used for making an alcoholic drink, and Moon was associated among the Pinans with another alcoholic drink. "Coyote-carrying-a-pole" is one of the month names that Spier argues refers to an asterism that was part of Scorpio. The preceding month was associated with the Hand asterism, and the following month, "Buzzard," is associated with fire, a red or yellow beetle, and the Sun. Buzzard was apparently Altair, as it was elsewhere in California. An alternative name for Altair was "Cold's Cottonwood," which well illustrates the fact that a single star may have names involving widely different concepts. "Cold's Cottonwood" may imply an opposing "Heat's Cottonwood." North of the Yuman tribes, the Utes maintained that the sky was supported on two giant cottonwoods.

The Navaho calendar (discussed by Chamberlain 1983) was probably of the same sort. A Navaho "calendar stone" gives six months, beginning with October and associated with the sun followed by six months associated with the moon (ff. O'Bryan, cited in Chamberlain 1983). Although Chamberlain points out star markers for more than six months, it is not really clear that these are month names.

13.2. California and Baja California

Astronomy among the Indians of California is unusual for the degree of relationship between rock art and ethnographic information. The fact that the people were, until recently, hunter-gatherers, rather than agriculturists, is also unusual. Finally, much information was recorded when there was still more continuity in customs and beliefs than in many other areas of the world.

[4] A patrilineal inheritance group, such as a Scottish clan.

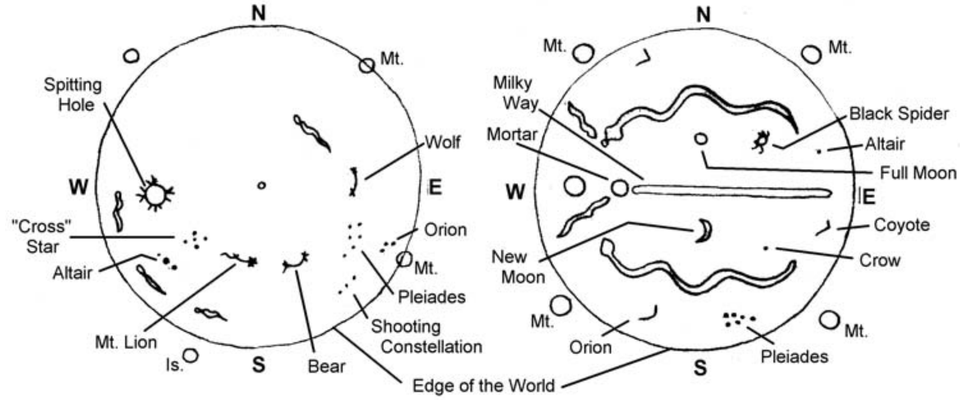


FIGURE 13.7. An Ipai ground painting of Earth and Sky shows four directional mountains, one of which may correspond to Creation Mountain at Black Point. Drawing by Sharon Hanna, after Hudson (1984).

The useful summary article of Hudson (1984) together with his work on the Chumash (Hudson and Underhay 1978) provides a wealth of helpful information. Hudson thought that information from California may throw light on the origins of astronomy among beginning agriculturalists, in marked reliance on the ahistorical concept of people in widely separated times and places going through comparable development stages. This version of social evolution assumes some sort of functional coherence among many diverse characteristics. Hudson rejects the idea that astronomical interpretations might have reached these complex hunter-gatherers from agriculturists or even urban dwellers during the several thousand years that the latter have been coexisting with their ancesters.

Although early information on astronomical and cosmological beliefs of the California Indians is scanty, Father Geronimo Boscana of the Mission at San Juan Capistrano from 1814 to 1826 recorded some relevant data from the Juaneño tribe (a partial translation is in Grant 1965, Appendix B). According to this account, Nocuma made the world, which was spherical in shape and rested in his hands. Laws and religious ceremonies were introduced by a god, variously called Ouiamot, Chinigchinich, and Tobet. He was painted red and black and came from the stars. The major ceremony was the annual sacrifice of a condor (known from other accounts to be considered a messenger to heaven). According to Hudson (1984, p. 44), Altair was identified by several southern California tribes as a buzzard (the condor was frequently regarded as a kind of buzzard).

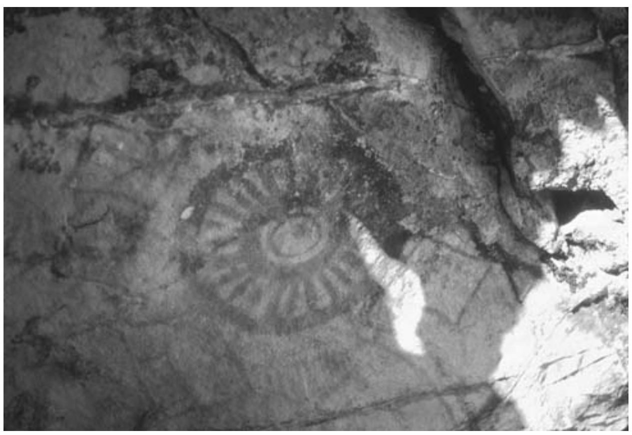
One of the problems in interpreting sketchy data is to differentiate astronomical knowledge from the way in which it is phrased. A group, or some members of it, may be well aware that Venus seen in the west as Evening Star is the same body as Venus seen in the east as Morning Star. However, that does not preclude using a different myth/analog for the two positions, which will make it immediately clear where Venus is. Similarly, the shifting tropical year positions of Venus in the eight-year cycle may be designated by different names with no intention to deny their ultimate identity. After all, when Venus ceases to be visible in the west, it is near a particular group of stars and when it reappears in the east, it is not far removed from the same group. Hudson's otherwise sophisticated analysis of the relationships of astronomy with myths and ceremonies never considers this kind of possibility.

At the time that Grant reproduced many of the rock paintings found in the Chumash area, very little was known of Chumash astronomy. Then it was found that J.P. Harrington had collected a mass of texts and interpretations from Chumash informants early in this century. The material was not collected from '*alchuklash*, "astronomers," but astronomy was so involved in all aspects of the society from the most practical to the timing of ceremonies that all members of the society understood some aspects of astronomy.

Chumash accounts of the winter solstice ceremonies indicate that people tended to stay indoors at this time of year, so that the Sun would not eat them (Hudson and Underhay 1978, pp. 62–63). We are told that two men, Rafael Solares and Joaquim Ayala, went into the mountains (in Santa Barbara county) at the time of the winter solstice to paint rock art (Hudson and Underhay, p. 58). The paẖa, or religious leader, became a "Sun-priest" at this time and his 12 assistants, the *antap*, were identified as rays of the Sun. On the second day of the ceremony, these 13 people set up a "Sun-stick" or pole about 3′ to 5′ (~1–2. m) high. At its top was an angled stone disk, painted "greenish" like a fresh sand dollar, with a red and black crescent for the moon. The ritual name for the sand dollar was *Chakwɨtɨ loka kakunupmawa*, "the shadow of the child of the winter solstice." Interestingly, the particular descriptions of the sand dollar in Chumash myth do not apply to a Californian species but correspond with one known farther south on the Mexican coast (Hoskinson 1983). The Sun-stick was ceremonially raised, and it was said "this is the pole symbolizing the center of the earth" (Hudson and Underhay 1978, pp. 63–65, 69). Such poles have been recovered archeologically, although sometimes the old pole was ceremonially burned. Some poles were feathered, with condor or eagle feathers above, and crow feathers below. The top feathers pointed east-west.

Although Hudson and Underhay have many interesting and plausible suggestions for the interpretation of Chumash myths and paintings, the interpretations are seldom decisive. We suggest that one area that is worth more attention is the study of turtle images in various degrees of stylization. They seem to be cosmic images, and the Chumash said that *Shaq*,

(a)



(c)

(b)

FIGURE 13.8. (a) A spiral pictograph illuminated by the Sun on January 10, therefore not long after winter solstice, at Burro Flats, California. (b) The ceiling of the Sapaksi cave, a small, south-facing, semi-elliptical sandstone cave located near the crest of the Sierra Madre Ridge in the Sisquoc Wilderness. (c) A sun dagger striking the ceiling of Sapaksi (House of The Sun) at the September equinox, 1982. Photo (a) by E.F. Milone. Photos (b) and (c) by Tom Hoskinson and Arlene Benson, respectively, reproduced by permission of the Slo'w Press.

"Turtle," was once chief of the land of the dead (Hudson and Underhay 1978, p. 153) (a role later held by "Condor"). The study of the road to the land of the dead by Hudson and Underhay (1978, pp. 119–121) suggests that the souls traveled westward along the Milky Way. After passing through the land of the Widows, the souls had to slip between clashing rocks (known as the Symplegades motif) after which two ravens plucked out the souls' eyes, which were replaced by poppies! Then these tortured souls met Scorpion Woman, "She who Thunders," *Malahshishinish*—Hudson and Underhay think in the neighborhood of Cygnus and Lyra.

More and more light plays in connection with paintings on rock faces or in caves are being recognized in the Chumash area (see Figure 13.8 and Plate 6, color insert) and elsewhere in the southwest. Eventually, it may be possible to distinguish iconographically between summer and winter solstices and perhaps to recognize equinox iconography as well. Both solsticial and equinox light plays have been seen at Sapaksi (House of the Sun) in the Sierra Madre ridge (Hoskinson 1985 and Figure 13.8b).

More generally, Hudson (1984, p. 21) says that it was attested that 16 groups determined the solstices by observation of the Sun on the horizon, that 10 used shadow-casters, and that others used sunlight on previously prepared marks or paintings. At that time, 11 archeological sites were known where one or more of these methods had been recognized. The importance of solstice determinations is reported for most California Indians. In several sites in California, a shadow bisects a spiral at sundown at a calendrically significant day. Kelley personally witnessed the summer solstice shadow play at sunset in the Paiute area. At the La Rumerosa site in Baja California, a pictograph panel is intricately lit by the winter solstice Sun about 20 minutes after local sunrise, the horns of a horned figure painted on the wall being the last to be lit. Other examples of spiral pictoglyphs on which shadow play can be found are those at Burro Flats (Plate 6 and Figure 13.8 are early morning views about two weeks after winter solstice) and at Agua Dolce Canyon in California.

A widespread California tale (Hudson 1984, pp. 17–18) says that (some of?) the Sky People were grouped into teams for gambling. Sun was the captain of one team (which included Evening Star), and Polaris was the captain of the other (which included Morning Star). Moon kept the score, and humans decided at the winter solstice who had been the winner that year. A contest between Sun (representing the ecliptic?) and Polaris (controlling the equator?) sounds like a precessional myth, but we would need to know how Moon kept score to be at all sure of this. Some of the California tribes kept records over long periods of time, but we have no knowledge of what information was kept. The Pomo (Hudson 1984, p. 62) kept bundles of sticks, 13 to a year. They had further bundles representing 8 years, 64 years (8 × 8), and 512 years (8 × 64). Hudson (1984, p. 58) discusses a rock record from Kerns County in the territory of the Tubatulabal (Uto-Aztecans) that he interprets as a solar record on the left referring to an eight-year period and a lunar record on the right. Comparative data will be needed to support such an interpretation.

Interest in eclipses is mentioned for a number of groups (Hudson 1984, p. 31). It is usually maintained that eclipses were caused by an animal eating the Sun or Moon—frequently Bear (a constellation) or Dog—sometimes Condor, Blue Jay, Coyote, or Raccoon. In a Yokuts account, Coyote moved along Sun's path and blocked it, coiling up with only his tail showing and getting burned. Given the widespread Southwestern equation of Coyote with Moon, this may be a more realistic description than is common. Coyote was also widely identified with Aldebaran. Hudson (1984, pp. 44–84) has notes on asterisms (arranged alphabetically by modern names) that reveal that many concepts were shared and many differentiated, entirely expectable in such a complex mosaic of groups speaking different languages, with major differences in economic patterns and very little political integration, even locally. The Pleiades frequently marked the beginning of the year; stellar markers for seasons and months were also common, but little is known of specifics. Buzzard is often Altair. Castor and Pollux were twins, a Boy and Girl in northeast California, holding a bow, and followed by a rabbit. The Belt of Orion was widely identified with mountain sheep, although the Yana (in northern California) thought that it was Coyote's arrow. The Chemehuevi thought that the Sword was an arrow shot by two hunters (Rigel and Betelgeuse) at the mountain sheep (the Belt). The Kamia (Yumans) identified the Belt as an antelope, a deer, and a mountain sheep (a view also attested for their relatives, the Maricopa, according to Spier 1955). Ursa Major is variously identified as a rabbit net or as seven boys (sometimes changed to geese). Polaris may have been equated with Wolf or Coyote in a number of groups. The star was of major ritual importance.

In rock art, the three mountain sheep of Orion are found with some frequency. Hudson gives other depictions in which he thinks a stellar identification is reasonably clear. It is unknown whether such representations are simply individual asterisms or whether they represent visually contiguous groups.

Gillespie (1998) presents a sophisticated analysis of a number of petroglyphs at the California archeological site INY272 in the Owens Valley. The area was at colonization (and still is) occupied by Paiutes, a Shoshonean group in the Uto-Aztecan language family. Modern Paiutes regard some of the petroglyphs as "important" and may repeck them, but at least some modern Paiutes do not think that their ancesters created the petroglyphs. Geometric forms in the Great Basin Curvilinear Abstract style are typical at the site and include a number of designs that seem to mark astronomical features. There are also some animal figures, especially mountain sheep. Six groups of petroglyphs are distinguishable by degree of patination and erosion. A line of petroglyphs of the same group as those under discussion was covered by a mud flow that formed a rind of $CaCO_3$. A ^{14}C date for this rind indicates an age of ~2100 years. The basis of this special application of the ^{14}C dating technique and factors causing uncertainties are discussed by Gillespie, who regards this as a minimal age.

13.3. Plains Indians

13.3.1. Caddoan Groups (Pawnee, Arikara, Caddo, and Wichita)

Among the Plains tribes, the Pawnees were a more sedentary group living in villages of earthen lodges and practicing some agriculture, although depending heavily on buffalo hunting. Their way of life certainly fits the general Plains pattern, but it has more similarities to Mesoamerica than that of other Plains groups. Most notably, they had a human sacrifice to the Morning Star by shooting arrows at a captive, usually a woman, fastened on a frame. The "Morning Star" in question seems usually to have been Mars, described as of red color, a star that moved across the sky and eventually joined the Evening Star (Venus) in the west, and made her his wife. The sacrifice is known to have been scheduled for 1827 April 11 and 1838 April 22 and in the spring of 1817. Possibly related ceremonies were held in 1902, 1906, and 1915. The two certain dates show no obvious astronomical relationships either to each other or to obviously important points of any planetary cycle (see an extensive discussion by Chamberlain 1982, pp. 73–80).

Wissler and Spinden (1916) wrote a classic paper suggesting that the Pawnee sacrifice was historically related to the comparable Aztec practice and probably derived from the Aztecs, perhaps between 1506 and 1519. We now know substantially more about the arrow (or spear) sacrifice in Mesoamerica. It is attested by graffiti from Tikal in the Mayan classic period, on at least two Mayan pots, and in various codices, notably, a scene in which the Mixtec king, Eight Deer, sacrifices his two maternal nephews, one by the

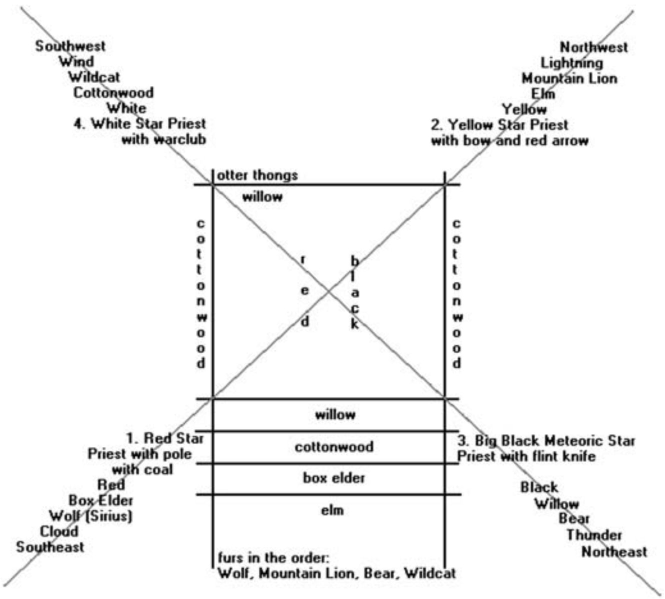


FIGURE 13.9. A diagram of the Pawnee scaffold and associated colors, directions, trees, animals, weather conditions, and weapons. Drawing by Sharon Hanna.

"gladiatorial conflict"[5] on the 19th of December 998,[6] and the other by the spear sacrifice eight days later. Two Cuicatec codices from southern Puebla show women sacrificed on a frame, which is precisely like the Pawnee descriptions with four cross-bars below and one above. Derivation from Mesoamerica seems increasingly likely with new information, but a direct Aztec derivation now seems much less likely. In most Mesoamerican depictions, the victim was spread-eagled on the scaffold, and it seems very likely that this was also the Pawnee practice, as it would fit Pawnee conceptions. Figure 13.9 shows a diagram of the Pawnee scaffold and associated colors, directions, trees, animals, weather conditions, and weapons.[7]

Von Del Chamberlain (1982, p. 68) points out additional similarities in the Aztec and Pawnee belief systems, but he thinks that these similarities are outweighed by the great difference between the Aztec and Pawnee cultures. Certainly, there is a great difference between Aztec and Pawnee culture, but this has little relevance to the origin of the ceremony; after all, borrowings from very different cultures are common in many parts of the world. Kelley's views on this matter have been strongly affected by a detailed comparison of the Mesoamerican and Pawnee sacrifices in a manuscript[8] by Joe Cason (~1954), which identified a large series of conceptual similarities in the two ceremonies that had not been noted previously. Chamberlain has argued that Mesoamerican cultures put more emphasis on the cardinal directions than on the cross-quarter points emphasized by the Pawnees, but both groups emphasized both, so this is a hard-to-judge question of degree. Moreover, the emphasis varied in different parts of Mesoamerica, and with respect to the year-beginning points and associated colors, highland Mexican groups may have emphasized the cross-quarter points. Symbolic colors and implicit directions are directly associated with the spear sacrifice in the *Nuttall* codex through a four-colored bar placed below the sacrifice. The colors differ widely in different parts of Mesoamerica, and so specific correlation with the Pawnee colors is not particularly significant. Both groups associated trees with directions, but again, the details are different (among the Mayans, the direction trees were simply named by their colors). Both Pawnees and Mesoamericans held important "New Fire" ceremonies, when all fires throughout the community were extinguished and new fires were started with torches lit from a newly built central fire (the Pawnees kept the firedrill for making the new fire in the sacred bundle of the Evening Star). Timing and social function were different between the Aztecs and Pawnees, but again, other Mesoamerican groups also seem to have held New Fire ceremonies under conditions different from those of the Aztecs.

Pawnee houses were regarded as both models of the universe and as observatories. At the center was a fireplace and the fire represented the Sun. In special ceremonies, the Pawnees built a clay model of a turtle and put the fire on the turtle's back. The Aztec *Xiuhtecuhtli* was the lord of fire, ruler of the year, the first of the Nine Lords of Night, equally the first of the Thirteen Lords of the Day, and was said to dwell at the center. His home seems to have been near Orion's belt, which, with the sword, seems to have been identified with the Aztec firedrill constellation. We are not told of the cosmic identity of the Pawnee turtle, but as the supporter of the fire/Sun, it must have had such an identity. Mayan evidence equates the turtle with Orion's belt. The Pawnees maintained that meteorites were a type of "fire turtle" (see especially Chamberlain 1982, pp. 144–145). The similarities persist.

It is mentioned that the Kikahahki Pawnee equated the Sun with a deer (Chamberlain 1982, p. 248), and accumulating evidence makes it clear that in Mesoamerica a deer

[5] This term is applied in Mesoamerica to a type of human sacrifice in which a captive was fastened to a rock by a rope and given wooden weapons set with paper instead of obsidian with which to defend himself against several properly armed warriors.

[6] According to Kelley chronology; in that of others: Dec. 6, 1050, in the Caso chronology and Nov. 23, 1102, in the Rabin chronology (cf. Kelley 1983).

[7] It should be noted that Murie (1981, p. 110) associates the "Big Black Meteoritic Star" with the willow and the "Yellow Star" with the elm, although they are reversed on his diagram on the same page. Weltfish (1965, p. 112) gives a comparable diagram, but has each tree shifted one position clockwise from Murie's position, if the willow is associated with the color black. According to Weltfish, the thongs used to tie on the scaffold were bear, mountain lion, wildcat, and wolf for the bottom poles and otter for the top pole. Murie (1981, p. 123) specifies that the animal skins were associated with the scaffold in the order: wolf, mountain lion, bear, and wildcat. The order of the poles that is given in the same way by Murie and Weltfish seems to be inconsistent with this ordering of associated animals. In any case, an association with astronomical ideas seems clear.

[8] Unfortunately never published and present disposition unknown.

appears sometimes as the bearer of the Sun[9] or on other occasions is identified with it. Orion's belt was also identified as three deer in northern, and probably also in central highland, Mexico. The Pawnees knew a constellation of three deer that seems to be Orion's Belt, although these could also be Belt, Sword, and Betelgeuse, or the Hyades (Chamberlain 1982, pp. 136–137).

The turtle–deer–fire–drill equations with Orion's belt should not be regarded as contradictions but as complementary relationships appropriate for different occasions. Chamberlain (1982, p. 68) points out that Morning Star (Mars) was a more important deity to the Pawnee than was Sun, who was merely his assistant, whereas Sun was the deity who generated the tremendous number of human sacrifices among the Aztecs. Again, we seem to be dealing more with a difference in emphasis than in concept. Indeed, Kelley (§12.12) has argued that the Aztec patron deity *Huitzilopochtli* was a form of Mars. The fact that the Sun was thought to give life and that life had to be given to the Sun in return was typical both of Mesoamerica and of the Pawnees. Although they did not sacrifice humans to the Sun, they did sacrifice dogs, which were then made into a stew and eaten (Murie 1981, pp. 163–164). Both dog sacrifices and the eating of dogs are typical in Mesoamerica (cf. particularly the *Nuttall* codex, p. 17). Eating dogs is rare in other parts of North America.

Another interesting parallel lies in the practice of associating goddesses with the west and gods with the east. This is supposed to be typical of the Pawnee, although they recognized that their "eastern" Morning Star, Mars, moved into the western sky and joined his (captured) bride, Venus, the "western" Evening Star. The western Moon goddess was certainly in no way restricted to the west. See Chamberlain (1982, p. 47 *et passim*) for further discussion. Among the Aztecs, the *Cihuateteo* or God-Women (patrons of childbirth) were assigned to the west (Brundage 1979, pp. 173–174).

All forms of ceremony seem to have been associated with sacred bundles, in Mesoamerica as among the Pawnee, but our knowledge of Mesoamerican bundles is much less. Some "cache deposits" in Mesoamerican tombs may represent such bundles. There are frequent representations of bundles on Mayan pottery, but some of them probably represent tribute rather than sacred objects.

Chamberlain (1982, p. 101) seeking visual clues to the identity of the star-gods had difficulty with the two deities "Black Star" and "Big Black Meteoritic Star." "Black Star" is identified by the Pawnees as Lord of the Animals. Among the Aztecs, this role was held by the black god, *Mixcoatl*; another black god, *Yacatecuhtli*, "Nose Lord," was lord of merchants. However, there is substantial overlap between them. Kelley (1980, pp. S22–S25) has identified these two black gods as Saturn and Jupiter, and he suspects that the Pawnee black god is probably Saturn as well. Chamberlain thought that the color-directional stars should more appropriately be identified with fixed stars. Although we cannot be certain, we do not think that identification as a planet necessarily precludes a parallel identification as a fixed star. Conceptual identities that are foreign to modern scientific enquiry were common in many groups.

Among the Pawnees, the celestial Sweat Bath was particularly associated with the "Black God" of animals and with healing ceremonies (Murie 1981, p. 158). Among the Aztecs, the sweat bath was euphemistically called *Xochicalco*, "Place of the House of Flowers." A terrestrial Xochicalco lies southwest of Cuernavaca in Mexico and plays an important role in mythology. A host of lesser sweat baths are known. The mythology of Xochicalco suggests correspondence with a celestial sweat bath, but we know of no direct documentation of this. In any case, the ceremonial importance of sweat baths is another feature common to Mesoamerica and the Pawnees (and, of course, many other cultures).

Chamberlain (1982, pp. 122–126) has drawn on unpublished material of Alice Fletcher that indicates that not only was the house a miniature cosmos, but also the layout of a series of 18 Pawnee villages was believed to replicate the astronomical relationships of 18 stars. Unfortunately, it has not been possible to check this material archeologically because the precise locations of the villages are not known and the sites may have been destroyed.

Murie (1981, p. 155) gives an interesting account of a ceremony known as the Twenty Day ceremony in Squash Vine Village. Then, a man from another village participated and asked permission to give it at his village. The other villages were given permission to use an adapted version, with 30 days instead of 20 and "could not use the star symbols, the mud woman, or the head of the water monster image." This account is remarkably illuminating as to the ways in which ceremonies must have changed with time, and with passage from one group of people to another, even within a reasonable homogeneous culture. At a more specific level, if we knew only of the derivative 30-day ceremony, it would simply suggest a lunar month, which might easily have arisen anywhere. The 20-day ceremony, however, is reminiscent of the 20-day intervals that Mesoamericanists call "months" and that separate the festival of one god or set of gods from another. Clearly much of such a 20-day period might be devoted to preparatory ceremonial. In Mesoamerica, there are 18 such periods in a year (plus five extra days, the unlucky "nameless days") (see §12.2). The apparent association of these 18 periods with asterisms is considered in §12.22. The combination among the Pawnees of a 20-day ceremony and 18 major stars is strongly reminiscent of the Mesoamerican calendar. Although nothing indicating the actual use of that calendar has been found north of Mesoamerica, we seem to have here two of the components in a different conceptual setting. Corresponding details provide good evidence of contact, even when other details are markedly different.

Another notable feature of Pawnee star lore is a star map, possibly the most accurate map by any indigenous group in the Americas. The map has been studied repeatedly, the most extensive published study being that of Von del Chamberlain. However, an unpublished study by Dee Beattie

[9] See the *Borgia* codex, p. 38, for the deer as the bearer of the Sun; among the Maya, see Thompson (1950, p. 230) for an example of the Sun disguising himself in a deer skin.

(1989) indicated that the degree of correspondence of star patterns on the map to actual stars in the sky was much greater than had been recognized previously. Chamberlain (1982, p. 205) points out that "the star patterns that appear on the chart are generally reversed from their actual appearance on the sky," that is, the map convention corresponds to our terrestrial maps, made to look down on, rather than to our celestial maps, made as if one was looking up at them. This is, then, analogous to those celestial spheres that depict the stars on the sky in a God's eye view, from outside. Beattie (1989, p. 21) suggests that the map was done in "segments depicted at different moments over extended time." She shows that inverted star charts of the west quadrant as viewed in early evening in July, the east quadrant in December, and the northwest quadrant in November, when inverted begin to resemble the Pawnee map much more closely. Beattie indicates that other apparent anomalies are due to the particular conventions of painting, which the map maker used. This, of course, hardly makes it more readable for us, but star knowledge was not democratically shared among many peoples, and the use of a map only portions of which provided correspondence with the sky at any one season supports the idea of hidden knowledge by a cadre of select star readers.

Beattie also claims, however, that the supernovae of 1572, 1054, 1006, and 393 are depicted. If this were true, it would suggest a tradition of map-making by Pawnee ancestors extending back to at least the 4th century, and maintained with an accuracy sufficient to identify them on current maps. Because the supernovae of 393 and 1006 were both located at a declination ~ –40°, their depiction raises some interesting problems. For an observer at latitude +50°, this area of the sky would barely be visible above the southern horizon and then only for a brief instant, although both altitude and duration of visibility during the night would improve at lower latitudes. The altitude question would be especially important for observations of the supernova of A.D. 323, because it had an estimated visual magnitude of only about –1 at greatest brilliance (see Table 5.8 and §3.1.2 for a discussion of the effect of altitude on visibility). The depiction of this region of the sky on Pawnee maps in itself is interesting, implying either borrowed knowledge or knowledge gained from more southern ancestors.

The *Skidi* or *Skiri* division of the Pawnee are the "Wolves," associated with the Wolf Star, Sirius. Chamberlain (1982, pp. 101–104, 128–129, 96) has suggested that Sirius is the "White Star" of the southwest but rejects Dorsey's statement that Wolf and Clouds are associated with White Star; instead, he favors Murie's view that they are associated with "Red Star," and indeed he suggests that the original Wolf Star might have been a Red Star, which, in terms of his identifications, would completely throw off the color-direction symbolism. In spite of Chamberlain's discussion, it seems to us that if Wolf and Clouds are associated with Red Star and Wolf Star is Sirius, then Sirius should also be Red Star. In fact, this is probably just one more example of the widespread view that Sirius was once red. It seems widely accepted by those who have studied the Pawnee that "Wolf Star" and "Fool Wolf" or "Wolf he is deceived" or "He Fooled the Wolf Star" all refer to Sirius. Kelley finds it incredible that "Wolf Star" and the opposing meanings should be accepted as identities. The usual explanation that the Wolves (Skidi) confused the star Sirius with the planet Mars seems utterly unlikely; the possibility of a nova or supernova depiction has not yet been investigated. Careful observers, particularly those interested in these two bodies, are not likely to have confused Sirius, already at this time white in color, and ~11° S of the ecliptic, with a red, wandering Mars, closer to the ecliptic.

The map-making tradition of the Pawnee seems to reflect a different pattern from that suggested by the evidence of Mesoamerican cultural influence. It may be related to reported Lakota star maps and a ceremonial tradition that appears to have its roots in the Plains possibly over 2000 years ago.

Besides those already mentioned, the Pawnee are reported (Chamberlain 1982) to have had the following asterisms:

(1) Two Swimming Ducks (in Scorpius)
(2) Two Loons (also in Scorpius?)
(3) Rabbit (Cassiopeia?)
(4) Bow (Delphinus)
(5) Real Snake (Scorpius)
(6) Chiefs in Council (Corona Borealis)
(7) Two Stretchers, with medicine man, Wife, Errand Man, and dog (Ursa Major and Ursa Minor with Alcor as the dog)

Waldo Wedel (1977) has shown that a series of archeological sites in central Kansas indicate probably deliberate astronomical alignments in a context similar to that of the Pawnee. The sites have been assigned to the Wichita, linguistically close relatives to the Pawnee, and roughly dated to the late 17th century. Relevant features have been revealed by excavations at the Tobias site (Wedel 1967). An ellipse has been dug surrounding four oblong basins that were dug into the ground around a large firepit. This pit was at some later point covered with a low mound. The ellipse had an approximate alignment to summer solstice sunrise and winter solstice sunset. The oblong basins were apparently the remains of semisubterranean houses aligned to the four cross-quarter points (rotated from the cardinal points by 45°). Excavations at two other nearby sites (the Paul Thompson site and the Hayes site) suggest a very similar layout, except that the two ellipses were aligned on each other and on the summer solstice sunset—winter solstice sunrise line. None of the alignments are of demonstrably high precision, undoubtedly due in part to destruction by plowing and erosion. The two lines intersected at 246 feet from the Tobias site and 2460 feet from the Paul Thompson site. The ratio of 1:10 is suggestive of deliberate intent, and it may bear some numerological speculation. If a unit of about 8.2 feet was used, the above distances would be 30 and 300 units, respectively, and Hayes site would have been south of the Paul Thompson site by about 781 units (6404.2 feet, compared with 6506 feet measured). The synodic period of Mars, an object important to their Pawnee relatives, is 780 days whereas, 30 is reasonably suggestive of a lunar period. This is probably stretching; however, it does seem reasonable to suppose that the positioning of these sites was deliberate and that the distances, as well as the directions, may have been conceptually important.

13.3.2. Siouans

Although it has been widely supposed that Siouan star lore has largely disappeared, a recent study by Goodman (1990) shows this is untrue, particularly for the Lakotas. Moreover, a combination of existing ceremonies, myths, and star lore suggests strongly that the roots of this tradition have been local for more than 2000 years. Goodman (1990, p. 2) writes,

> Members of our project have been interviewing Elders for the last eight years. Our purpose in gathering this knowledge is to create curriculum materials for Lakota students at the elementary, secondary, and college levels. Our goal is to give the stars back to the People, most especially, Lakota young people. Nevertheless, there is a willingness to share this knowledge with non-Indians, so that they (through learning how the Lakota experience the earth's sacredness) will be inspired to seek out and recover their own traditional ways of knowing the earth—not as dead matter spinning in empty space—but rather, as our very mother, a living and a holy being.

The subtitle of Goodman's work is *Studies in Lakota Stellar Theology*. A great deal of the material is a reconstruction, often based on combining materials from several informants. The end result is often convincing, but it should be borne in mind that the goals are far from the search for balanced alternatives so dear to conventional scholarship.

The two most striking features of this Siouan star lore are a one-for-one identification of a series of asterisms with geographic features of the Black Hills of South Dakota and Wyoming, and the fact that spring ceremonies were associated with the belief that the Sun had entered the asterism Dried Willow. This corresponds with stars of Aries and Triangulum. Because of the precession of the equinoxes (§3.1.6), the spring equinox would have been near Dried Willow between about 1500 B.C. and 200 B.C. The summer solstice is said to have occurred when the sun was in the Bear's Lodge, part of which was formed by Castor and Pollux and equated with the peak now called Devils Tower. This tower was an ancient site of the Sun Dance, performed near the time of the summer solstice. Charlotte Black Elk describes a three-month journey through the Black Hills, starting at the spring equinox at Dried Willow and traveling to the Bear's Lodge at the summer solstice, replicating the journey that the sun took over 2000 years ago (Goodman 1990, pp. 38–40). This was done by a group representing the Siouan confederacy. It was not always done every year, but occurred at least every 7th year, which was said to be marked by some planet. The most likely would seem to be Mercury.[10] The journey went through the positions of "the race course" or "sacred hoop," a circle of stars that was also identified as the base of the Sweat Bath. The fireplace of the Sweat Bath consists of five stars "above Regulus" (Goodman 1990, pp. 15, 23). This large asterism is, of course, reminiscent of the Pawnee, as is the identification of the Big Dipper with a stretcher carrying a dead man, accompanied by mourners (Goodman 1990, p. 22). The southern star in Orion's belt is a turtle (Goodman 1990, p. 38), and the familiar and widespread association repeatedly discussed elsewhere and nearby is *Pe Sla*, "the center," identified (*l.c.*) as the northern star of Orion's Belt but shown separately on the map (Goodman 1990, p. 29).

The way in which Earth was supposed to mirror the sky at a broad level was also involved in an identification of a tipi as a cosmic model, with the poles representing particular stars—a close parallel to the Pawnee earth lodge concept already discussed. In this context, the idea that the medicine wheels may represent both stellar imagery and the 28 poles of a medicine lodge seems entirely appropriate (see §6.3.1.1). This imagery apparently extended also to social organization. The Siouan groups had a series of clans, each of which had its appropriate seating place, an animal name, and an association with a particular star. Presumably, the animal names were also associated with asterisms. Most of them were divided into moieties of Sky People and Earth People.

A central feature of Lakota beliefs is a series of stories about the hero, Fallen Star, whose father was of the Sky People and mother was of the Earth People. He was the son-in-law of a chief who lost his arm (there is a parallel account in Mesoamerica). The chief's hand is an asterism formed by the Belt of Orion as the wrist, the Sword as the thumb, with Rigel marking the end of the index finger and β Eridani as the end of the little finger. How this corresponds to hand asterisms elsewhere is not clear, but the location is appropriate for the hand shown with depictions supposed to be of the supernova of 1054. One of the tasks of Fallen Star was to recover this lost arm for his father-in-law. It seems likely that Fallen Star is a planetary hero. It is interesting that he is said to have changed into a wren (Goodman 1990, p. 26), for this is reminiscent of European bird-lore (see §6.2.8), as well as Navaho accounts of the opponent of Thunder Bird. These isolated similarities may well be happenstance.

It is of substantial interest to note that stars may belong to more than one asterism and that the identity of an asterism may change according to the particular story of which it is part. These different conceptualizations seem to be perceived as complementary alternatives rather than as contradictory traditions.

One of the more remarkable items to emerge from Goodman's studies is the discovery that at least two Siouan star maps were in existence in the recent past (Goodman 1990, p. 18), although one of them vanished following the federal takeover at Wounded Knee in 1973. Unfortunately, neither map has been published; so we do not know how closely they resemble the Pawnee chart.

We have some important astronomical and cosmological information on other Siouans. Red Corn (William Matthews) of the Peace Moiety of the Osage (now in northern Oklahoma) provided a diagram (Figure 13.10) that shows planets, asterisms, world levels, and other notable features, including the Tunnel through which the ancestors emerged from the underworld.

[10] This interval is 7 years × 365 days/year = 2555 days, and can be compared with the interval of 22 synodic revolutions at 116 days/rev = 2552 days. More precise intervals are 7 × 365.2422 = 2556.70 for the solar interval and 22 × 115.88 = 2549.36 for the Mercury interval.

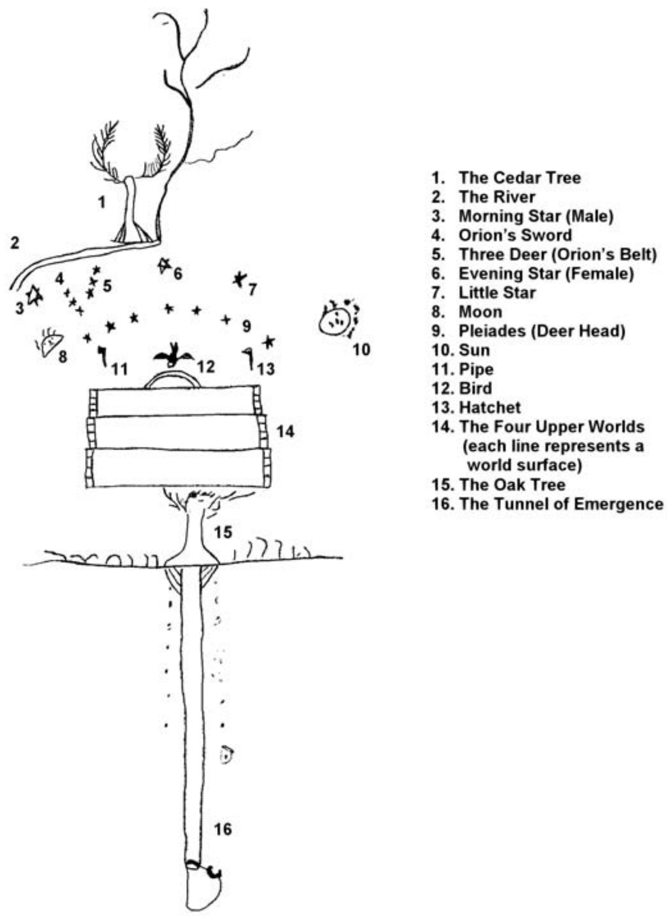


FIGURE 13.10. An Osage drawing of the cosmos. Drawing by Sharon Hanna.

From our viewpoint, this is puzzling, because the Osage say that their ancestors came from the stars (Miller 1997, pp. 33–34). Like other Siouans, they identified the Big Dipper as a funeral bier.

At present, little in the archeological record of the Siouans can be directly linked to astronomical ideas, but the extent to which earthly matters were regarded as a reflection of happenings in the sky suggests that eventually we should be able to recognize at least some linkages of this sort. A mass burial (with 12 individuals surrounding a central burial of an individual) in a tomb of the Hopewell culture, which Kelley suspects may be ancestral Siouan, may be an example of such linkages.

13.3.3. Hopewell, Cahokia, and Other Mound Builders

The excavation of two buried, gigantic Earth images of snakes (called the Kern effigies) has provided us with figures that are unmodified, unlike the badly damaged surface features. One of these is aligned (whether deliberately or not) on the winter solstice rising Sun, and the other on the summer solstice rising Sun. They belong to the Fort Ancient culture of ~1100–1200 A.D. See White (1987) for a fuller discussion.

An unusual duo of scholars, a philosopher, Horn, and a physicist, Hively, became interested in archaeoastronomy and have worked particularly on two Hopewellian sites, the Newark earthworks and the Highbank site (Hively and Horn 1982, 1984; Horn and Hively 1994). Each of these sites contains, with other features, an equilateral octagon joined by a short avenue with a circle. The size of the two circles is nearly identical (they measured 321.3 m for the Observatory circle at Newark and 320.6 m for the Highbank circle). However, the Newark octagon is substantially larger than is its counterpart at Highbank. At Newark, the octagon is generally northeast of the circle; at Highbank, it is southeast, rotated by about 90° (the azimuths of the connected avenues are 52°.0 at Newark, and 143°.3 at Highbank for a difference of 91°.3). At Newark, Hively and Horn found no evidence for any solar alignments, but massive evidence for alignments to lunar rise and set points at both the northern and southern maximum extreme positions and at both northern and southern minimal extreme positions (i.e., major and minor standstill lunar rise and set positions). Several of these alignments were repeated in different contexts and all together are convincing. Despite the change in orientation of the Highbank octagon, they found the same alignments were present there, although in different patterns. At Highbank, they also found alignments to the rise points of the Sun at both the winter solstice and the summer solstice. The two sites are about 60 miles apart, and Bradley Lepper has argued that the two areas are connected over much or all of the distance by an extremely straight road defined by two walls about a meter high and separated by somewhat less than 60 m. Over the most clearly defined part of its course, it has a bearing of 31° west of south, which Lepper has associated with the rising of Capella between about 100 B.C. and 100 A.D.—within the range of dates in which Hopewellian sites were constructed and therefore a reasonable but far from certain range of dates for these ruins.

Proposed archaeoastronomical alignments in earthworks of northern and eastern North America have been examined in some detail by James Marshall (1995 and references cited therein). Marshall has surveyed more than 220 sites (about half in Ohio) and collected data on 150 others. He shows that many earthworks are oriented (with as high precision as is possible without modern instruments) to the cardinal points but finds no evidence for any other alignments. Marshall presents evidence that complex geometric figures were sometimes replicated with high fidelity at different sites but with different orientations. Thus, the Hopewell period site at Newark, Ohio, with a center line azimuth of 52°.08, is a close replica of the Seip Work site in Ross Co., Ohio, with a center-line azimuth of 91°.40. Marshall has inferred that a unit of measure close to 57 m was in widespread use at sites throughout eastern North America. Marshall's work (1995) has shown that the maps published by Squier and Davis (1848) are seriously in error, in some cases by more than 30°; so that any claimed alignments based on Squier and Davis maps are, therefore, untrustworthy. They do not need additional discussion here. We are also in agreement with

Marshall's criticisms of the Cahokia "Woodhenge" interpretation. We do not share Marshall's belief that the sophisticated geometry of the sites precludes astronomical intent, but we do share his views that only accurately surveyed sites provide a basis for archaeoastronomical work and that similar sites should show comparable interests (although not necessarily identical alignments) in terms of astronomical interpretations.

Allegations that the Great Serpent Mound was built shortly after a specified locally visible eclipse are silly. The frequency of eclipses is greater than the precision of our dating techniques for these earthworks; so any earthwork was always built "shortly after" a local eclipse.

13.3.4. Colorado Area Sites

About a dozen sites with astronomical light and shadow play are known in the region of southeastern Colorado and Oklahoma. Claims that these sites, namely, those at the Purgatoire and Cimarron drainages in Colorado, have pre-Columbian European epigraphic information associated with them are highly controversial and will not be discussed here. DHK thinks that some of the information is in the form of tally marks. See Kelley (1990) for a brief summary of the decipherment problems and McGlone et al. (1993) for a critical review and additional references. In one case, a shadow passes across one mark a day for the 12 days preceding the fall equinox (or following the spring equinox) (McGlone, Leonard, and Barker 1999, Pl. 3, Figs. 63–64). Unfortunately, a number of these sites have been given names that incorporate built-in interpretations, which are unacceptable to most American archeologists. Examples are Sun Temple (for an area containing no constructions) and Anubis Cave (for a rock shelter with a canine figure illuminated briefly at the equinox sunset).

13.4. The Northwest

13.4.1. The Columbia Plateau Region

The rock art of the western coastal plains of the Columbia Plateau region has been discussed by Keyser (1992). This region extends from eastern British Columbia from the Fraser to the Alberta border and the states of Washington, Oregon, western Montana, and Idaho.

The presence of four-sided stars, rayed circles, and occasionally a concentric series of circles and a circle with a central dot suggest astronomical symbolism, but these forms are relatively rare in the region. The presence of shadow effects at any of these sites is not discussed and may deserve investigation in light of the importance such hierophanies seem to have had in the southwest.

Although little is discussed of the astronomical significance of the sites, the range of styles and their distributions in space and time make the summary a valuable one in gaining insights into the nature and purpose of the pictographs and petroglyphs in this area (see, especially, Keyser's Fig. 2). The presence of bows and arrows, which were introduced into the region ~500 A.D. or so, rather than atlatls, for example, provides for a relative dating; similarly, the introduction of the horse into the area in the late 17th century, ultimately from Spanish sources, dates depictions of horses. The presence of a face with large, ringed eye sockets and often toothy grin is associated with a death cult, which arose after postcontact diseases began to destroy large numbers of people. At least one of the figures is identified as that of the ogress *Tsagiglalal*, "She Who Watches"; as Keyser (1992, p. 101) reports the words of a Wishram woman shaman, "People grin like that when they are sick . . . when people look at you like that, you get sick." Keyser (1992, p. 102) suggests that because the power of the shamans to drive out evil spirits proved completely powerless against the new illnesses, the people developed a special guardian spirit to deal with their helplessness. As Keyser (1992) eloquently notes, "On the cliffs above their ancient villages, Tsagiglalal still watches—mute testimony to the agony of a vanished people."

13.4.2. The Pacific Northwest

Although in a Canadian context this region might better be called the "Pacific Southwest," we discuss the region from a North American viewpoint. There is ample evidence in the rich folklore and traditions of this area to indicate the integretation of astronomy into the lives of the people. This is clear from the work of Miller (1992) and Lévi-Strauss (tr. Modelski 1982).

Among the Kwakiutl of northeastern Vancouver Island and adjacent mainland of B.C., the year was divided into two parts: *bakus* (spring and summer) and *tsetseka* (fall and winter) (Lévi-Strauss 1982, p. 62). Their society changes dramatically from one period to the next: Proper names, songs, and musical styles change. In the *bakus* period, the secular ("profane") clan structure predominates. The clans were descended from people who came from the sky (Miller 1992). The entire *tsetseka* period is given over to rites performed by secret and religious societies (Seals, Cannibals, War Spirit, and Sparrows, the latter subdivided by ages into Puffins, Mallards, Killer Whales, and Whales). The higher ("superior") groups (Seals and Cannibals) are subdivided into three grades, each taking 12 years to pass through. Half of the group does not take part but are the "audience" for the rites and dances, often involving elaborate masks. The secret societies have parallel men and women organizations.

Among the Salish (in the southeastern part of Vancouver Island and the opposite mainland), the origin of the Swaihwe masks, used in many ceremonies, differs from island to mainland (Lévi-Strauss 1982, p. 30). On the island, the ancestor of the mask falls from the sky; in the mainland version, it comes from the sea.

Among the Quinault (a Salishan tribe in Washington), the old men had special seats where they observed sunrise and sunset, usually with respect to a designated tree or pole. The December solstice was named xa'Ltaanm, "come back, the sun," and the June solstice was observed but not named. Measurements were made with a marked horizontal stick on which the tree or pole cast its shadow (Miller 1992, pp. 194–195). Similar observing seats are reported to the north among the Tlingit and the Tsimshian. All Tsimshian groups sent representative astronomers to a sort of council at a high hill called Andemaul, "seat of native astronomers." They sat together in their fixed seats and discussed the meaning of particular portents as they were observed. All tribal members descended from the "Children of Heaven." The usual name for an astronomer among the Tsimshian was Gyemgat, "moon reader," and his primary objective was to determine how much food would be available in a particular season (Miller 1992, pp. 204–205).

Among the Wasco ("Chinook of the lower Columbia"), two brothers kill the Sun (a Sun that was unbearably hot for humans). The elder becomes the Sun, and the younger, the Moon. Ever since, the Sun is less hot and "the heavenly bodies alternated regularly in the sky" (Lévi-Strauss 1982, p. 113).

Some myths involve the son or daughter of the Sun. Among the Nimkish (Vancouver Island Kwakiutl), the first human to live on earth "after the deluge" had a son named "Giant" who married the Sun's daughter (Lévi-Strauss 1982, p. 78). The detailed myth has strong affinity with that of the Nootka.

There are many myths involving copper and the Sun. The Thompson (inland Salish) "make a character dressed in copper. . . . Th e son of the sun"—the same term used to refer to a beetle with bright bronze color (Lévi-Strauss 1982, p. 113). Among the Tlingit, a princess escaping from a grizzly bear finds a magic boat that takes her to the Sun. The Sun's sons fall in love with her, kill their present wife (a cannibal), and are accepted by the heroine. She bears a son and takes husbands and son back to her village, where she is abandoned (with her son) for allowing herself to be wooed by a villager. Some time later, the son finds "his father's" solid copper boat, cuts it up, and builds a house of copper that attracts a wife. Gifts to his father-in-law provide the Indian people with copper (Lévi-Strauss 1982, p. 119). Among the Menomini of the Great Lakes, the Sun stops at midday to contemplate the Earth through a long cylinder of copper (Lévi-Strauss 1982, p. 132).

According to Levi-Strauss (1982, p. 131ff), there is a widespread belief throughout North America that "the cylinder" has a role consisting of "capturing, fixing, and putting into direct communication terms that are very far apart." On the Pacific north coast, shamans have "soul catchers," often tubular shaped objects of ivory or carved wood. Among the Tlingit, the trickster, Raven, warned the Indians before leaving them that when he returned, anybody who looked at him with the naked eye would be turned to stone; henceforth, he would have to be looked at with a rolled-up leaf of skunk cabbage. It is reported that in 1786, the ships of the French explorer La Pérouse were examined by Tlingit through hastily made "telescopes"; they had misinterpreted the sails of the ships as the wings of the Raven. Among the Alaskan Inuit, large and bulging eyes are associated with piercing, or perhaps, night-penetrating vision. The shamans of Algonquin-speaking tribes in eastern Canada have "magic telescopes" of hollow juniper wood wrapped in white caribou skin and are said to enclose themselves in a white "shaking tent" designed like a cylinder to permit "an infinite view, far above and below" during trances. The Tucano of Vaupès (in South America) have a similar belief (Lévi-Strauss 1982, p. 133). Finally, the masks of the B.C. coast Indians show protruding eyes: *Swaihwe* masks with protruding bulges in place of eyes or *Dzonokwa* masks with eyes in deep set sockets (Lévi-Strauss 1982, p. 131). These descriptions are suggestive of some sort of viewing device. Any sort of tube might have been useful in viewing planets closer to the Sun.

In some cosmic myths, a hero rises to Heaven after spectacular exploits. Among the Tlaskenok of northwestern Vancouver Island, a hero kills an ogress who had kidnapped his brothers, resurrects his brothers, and rises to heaven (Lévi-Strauss 1982, p. 77). There are several varieties of this myth, which can have elaborate detail of the hero's exploits. According to Levi-Strauss, the several varieties of this myth involve the ascension of the hero into the sky to marry the daughter of the Sun. They all seem to involve two female protagonists: a subterranean creature (the ogress) representing darkness and the Sun's daughter, "a celestial creature whose home and ancestry all place her on the side of daylight" (Lévi-Strauss 1982, p. 79). Among the Tenaktak (inland Kwakiutl), the hero marries both the daughter of the ogress and the daughter of the Sun and Moon. In some versions, the wives remain enemies, and in others they are reconciled. Most have the hero attempting to return to Heaven with his second wife but falling to his death on the way. In one variation, he is brought back to life by the Sun, his father-in-law (Lévi-Strauss 1982, pp. 80, 81).

Among the Tlingit, a man is ashamed of his sister who had taken a lover. The brother drags her into the sky where he becomes the Moon and she becomes the Sun (Lévi-Strauss 1982, pp. 195, 203).

In other myths, origin of the Sun involves the theft of copper. Among the Cowlitz (inland Salish), the Sun (and rainbows) originate from a copper ring stolen by a boy who is either lame or covered with sores; among the Skokomish, that it was at first a copper hoop toy owned by "the rich," while the poor "had nothing to amuse themselves," but stolen, "it rises into the sky" where it can be enjoyed by all (Lévi-Strauss 1982, p. 114).

According to the Tlingit, at the beginning of time, "when darkness still reigned on earth," all animal species were undifferentiated. A culture hero stole and opened a box in which the Sun was "locked up." At the sight of its splendor, the animals dispersed in all directions, where they acquired their present characteristics as the environment dictated (Lévi-Strauss 1982, pp. 129, 130).

13.5. The Northeast

Floyd Lounsbury (cited in Hall 2000) has discovered that the Mesoamerican cult of the Morning Star spread to the Iroquois, probably through their Cherokee linguistic relatives. In any case, *Tawiskaron*, the name of the Iroquois Flint Knife god, and the related Cherokee form, are derived from the prototype of Aztec *Tlahuizcalpantecuhtli*.[11] According to

[11] Linguistically, the connection is: *tla* from earlier **ta*, *huiz* for phonetic *wis*, *cal* for phonetic *kal*, *pan*, a locative, also found as *an*, with *tecuhtli*, "lord," omitted.

the Iroquois, the Flint Knife god is the twin brother of the Corn god, who is the young Sun god associated with the New Year's ceremony following the winter solstice. At this time, the Iroquois sacrificed a white dog. A comparable myth is depicted in the *Nuttall* codex from the Mixtec area of southern Mexico (§12.6) ending with a white dog sacrifice. *Tlahuizcalpantecuhtli* in Nahua is literally "Lord of the Place of the House of Dawn." It is likely that Venus is intended, for the calendar names of *Tlahuizcalpantecuhtli* are Three Dog and Nine Wind, and it is 32 days from Three Dog to Nine Wind. If one adds one day-name cycle of 260 days, this becomes 292 days, which is the mean period of half a Venus synodic period. It may be presumed with considerable assurance that this cult spread north with corn agriculture before 1000 A.D. Versions of the myth of the Twin Star gods are widespread in North America, and it is probable that much astronomical knowledge and many ceremonies followed the same routes.

The relationship of Earth and sky in a cosmological and temporal sense is well shown in the Micmac myth of the Hunting of the Bear. The Micmacs are a Nova Scotian group and some of their astronomical stories were recorded more than a century ago by Stansbury Hagar, whose work is appraised by Dubé (1996). Modern Micmacs say that their people had names for all stars. There are six levels of existence: the world below the Earth, the world below the water, the Earth-world, the world of phantoms, the world above the Earth, and the world above the sky. The Beings who live in these worlds may take many different forms, from humans and animals to stars, winds, and mountains. Modern animals are transformed stars (Dubé 1996, p. 56). A Micmac song tells of the Milky Way as the singing stars, the fire-birds. The tale of the Hunting of the Bear identifies seven hunters (all birds) who chase the Bear (our Ursa Major, but not all the same stars). The hunters are identified with stars of the Handle of the Big Dipper and Bootes: Red-Winged Blackbird (Alioth), Titmouse (Mizar; Alcor is the pot in which the bear meat is eventually cooked by Titmouse), Gray Jay (Alkaid), Pigeon (Seginus), Blue Jay (Izar), Owl (Arcturus), and a red-feathered Owl (Mufrid). Red-Winged Blackbird, Titmouse, and Gray Jay are always visible from twilight in this area. The times of the appearance and disappearance of the hunters are tied to seasonal changes. In the Spring, the Bear emerges from its Den (Corona Borealis) and Titmouse announces its appearance and calls the other hunters to the chase. In myth, the Red-Winged Blackbird is often a messenger of Spring and is also associated with fire and heat, becoming a marker of summer. In mid-autumn, the Bear stands up on its hind legs to defend himself but is shot by Red-Winged Blackbird, who is then stained by the red blood of the Bear. Red-Winged Blackbird flew to a maple tree and blood dripped onto the tree. This is why maple trees turn red in autumn. Slow-moving Gray Jay arrived last but shared the meat anyhow.

Finally, we note the possibility of astronomical significance for structures in New England usually associated by archeologists with the colonial or post-colonial periods. One of these sites, at Morrill's Point, has been investigated by James Whittall (*private communication to Kelley*, 1992). There is no general acceptance that these sites were constructed in precontact times, however. The site is a series of stone walls constructed differently than known colonial walls, apparently laid out using Pythagorean triangles, with equinoctial and solstitial alignments. It is unassociated with any colonial buildings. Williamson (1984) has an extended discussion of the difficulties of appraising archaeoastronomical claims for some of the stone structures usually regarded as colonial.

13.6. The Arctic

The Arctic Islands were settled by the Aleut, and by 1000 A.D., their relatives, the *Inuit* ("people"), had extended from the Bering Sea to Greenland. Of course, the Eurasian Arctic was settled long before this, and the cultures along the Arctic circle are closely similar.

Notwithstanding the long periods of sunlight and twilight (nine months of the year!), bright aurorae, and frequent episodes of light snow and haze, there is a lively body of Inuit astronomical lore. Recent studies by John MacDonald (1998) provide for the first time a substantial summary of the astronomical interests of the Inuit and related groups. MacDonald received information from 28 named elders as well as citing many published studies.

MacDonald (1998, p. 14) points out that the Inuit have only 16 or 17 named constellations, or, more appropriately, asterisms, including ~33 individual stars among them. Groupings of stars are identified as inanimate objects and humans or animals as individual stars. The constellations among various groups are briefly summarized in Table 13.3, derived from MacDonald (1998) and sources cited therein. We have arranged them according to counterclockwise order around the pole. Of special interest are the names given to Sirius. One of these is "red fox and white fox," alternately trying to get down the same hole. Another is "flickering or pulsating" as a candle flame, which MacDonald associates, reasonably, with seeing effects. Although the "pulsating" and "red fox and white fox" designations invoke a strongly scintillating bright star near the horizon, the mysteries surrounding Sirius (cf. §5.8.4) permit an entirely different interpretation.

According to MacDonald, the Inuit did not really distinguish among the planets, which they referred to as *Ullursiaqjuat* ("great stars"). The singular of this word (*Ulluriaqjuat*) may have been applied to both morning and evening appearances of Venus, although other groups seem to have had separate designations for the two apparitions; for example, in Greenland, one of the names for Venus was *Seqernup maleruartâ*, "Sun's follower," appropriate only for its evening appearance.

The Igloolik Inuit name for the Milky Way, *Aviguti*, "divider," is simliar in West Greenland. In Labrador and Northern Quebec, it is *copput*, "Stripe" or "streak"; in the area of the Bering Strait, it is *copput*, "the track," made by Raven's snowshoes as he "walked across the sky"; among the Yup'ik Inuit, it is *Tanglurallet*, deriving from "snowshoe," and among the Norton Sound Inuit, it was recorded in the 1840s as *Tangukhuatlyat*, recorded as the name for the Milky

Table 13.3. Constellations among Arctic groups.

Inuit/alternatives	Meaning/significance	Asterism
Aagjuuk (I)[a]	"Arrow?"	α + γ Aql
Aassu(u)tit (G)	Constellation appearing on shortest day	″
Peggiyttyn (C)	Bringer of the New Year[b]	″
Akuttujuuk (I)	"Those placed far apart"; season indicator[c]	α + γ Ori
Akuttut (G)		″
Kingulliq (I)	"(Big) one behind" or "second one"	α Lyr (Vega)
A.gru.la.bwuk (A, E)		″
Sivulliq (I)	"One in front" (relative to Vega)	α Boo (Arcturus)
Sivulliik (I)	"Two in front"	α + η Boo
Kingulliq (I)	"One behind" (in reference to a legend)	β Ori (Rigel)
Nanurjuk (I)	"Having spirit of a polar bear"	α Tau (Aldebaran)
Qimmiit (I)	"Dogs" (attacking *Nanurjuk)*	Hyades
Sakiattiak (I)	"Breastbone"	Pleiades
Kaguyagat (I)	"Red fox"	″
Siqupsiqat (A)	"Shattered"	″
Qillugtussat (G)	"Baying dogs"	″
Nuutuittuq (I)	"Never moves"	α UMa (Polaris)
Qitirarjuk (CE)	"Spinal chord?"	″
Ursuutaattiaq (I)	"Sealskin oil container"	"W" of Cassiopeia
Pituaq (I)	"Lamp stand"	α + β + γ Cas (leading "V" of the "W")
Quturjuuk (I)	"Collarbones"; time indicator in late winter	α+β Gem + α+β Aur
Sikuliarsiujuittuq (I)	Legendary character: "the one who never goes onto the newly formed sea-ice"	α CMi (Procyon) ″
Singuuriq (I)	"Flickering" or "pulsating" as a candle flame	α CMa (Sirius)
I-gha-lum ki-mukh-ti (B)	"The Moon's dog"	″
Kajuqtuq Tiriganniaglu (N)	"Red fox and white fox"	″
Singoreq (R)	"Pulsating"	″
Ubluriakjuak/*Udluriaralu* (H)	"Big star"	″
Tukturjuit (I)	"Caribou"	Big Dipper
Ullaktut (I)	"Runners"	Orion's Belt
Qangiamariik (I)	"Nephews" or "nieces"	M42 (Orion Nebula)

[a] Code: *A* = Point Barrow, Alaska; *B* = Bering Strait; *CE* = Caribou Eskimo (Hudson Bay, NWT); *C* = Chukchi; *E* = East Greenland; *G* = Greenland; *H* = Hudson Bay; *I* = Igloolik, NWT; *Co* = Coppermine, NWT; *R* = Repulse Bay, NWT.
[b] First appearance on the NE horizon near the winter solstice.
[c] When seen in daytime, it is a sign that the days are getting longer.

Way. Among the Alaska Nunmaiut, it was a celestial river.

The spiraling motions of the Sun and Moon are celebrated in a myth remininscent of that of the Tlingit discussed earlier (§13.4). The sister is abused by her brother; she eventually catches him at it, and he chases her around in circles until they ascend to the sky, where she becomes the Sun and he the Moon.

This completes our survey of the astronomies of North and Central America. We next examine the astronomy of the cultures of South America.

14
South American Cultures

We preface the discussion of the astronomy of South American cultures by a general overview of those cultures. Humans were in South America already during the Pleistocene period. The ocean coasts and the great rivers of the Amazon drainage provided ready transport for rafts and dugout canoes. Availability of a great diversity of plants provided food, shelter, clothing, medicines, and poisons used in hunting and fishing. The technology of hunting and fishing also included atlatls, spears, clubs, blowguns, bolas, nets, fire-drives, and communal drives. The extensive knowledge of plants encouraged cultivation, and a primary emphasis on garden crops (including potatoes in the highlands, manioc and sweet potatoes in the lowlands) favored village settlements. Farming, including cotton and other fiber plants, preceded ceramics in much of South America, and there was some care and protection of trees, notably, the ceiba (for canoes), fig relatives (for bark-cloth), rubber trees (for such Amazonian inventions as syringes and rubber balls), and fruit trees. Domesticated animals included llamas, guinea pigs, and "Muscovy" ducks with dogs (ultimately of Old World origin) widespread. More than 1500 languages developed in over 70 language families, the greatest linguistic diversification of any area on Earth. This was accompanied by great variation in other aspects of culture. Warfare was endemic, varying from quick raids for trophies or loot to full-scale conquests accompanied by the displacement or enslavement of conquered populations. Head-hunting and cannibalism were normal accompaniments of warfare. High civilizations with fully urban populations and monumental architecture developed only in the Andean region, which was also the only area where metallurgy was developed. Although shamanism, with its emphasis on personal experience, was typical of the religions of South America, there were also true hierarchical priesthoods in the high culture areas. Some astronomical myths and observations seem to have been widespread, of which the most notable was the use of the Pleiades as a calendrical marker. The most comprehensive source on the native peoples of South America remains *The Handbook of South American Indians* of the Smithsonian Institution. A wide-ranging archeological coverage is provided by Willey (1971). The areas, archeological sites, and tribal groups that we discuss are indicated on Figure 14.1.

14.1. The Chibchan Groups of Colombia

A great deal of the most important ethnoastronomy familiar to us comes from what is now called Colombia. This area linked Mesoamerica, the Amazonian tropical forests, and the Andean civilizations. The area spans a considerable range of types of geography. Colombia had corn agriculture probably earlier than is known in Mesoamerica and certainly earlier than anywhere else in the Americas. The earliest known pottery in the New World also comes from northern Colombia (~4000 B.C., Oyuela-Caycedo 1986). Metallurgy in Colombia was technically well-developed already in the late centuries B.C. and included soldering, smelting, casting, alloying, and the lost-wax technique. The area was rich in gold, and precious jewels, notably emeralds, were numerous. Farming included a wide range of field crops, especially corn and many root crops, notably, manioc, yams, sweet potatoes, and potatoes. Agricultural terraces to control water flow and provide areas of arable land were common, and large irrigation canals and dams were built. Cotton was grown in the lowlands, and large looms were used for weaving. A number of Colombian groups built large public buildings, and there were some notable stone monuments. In some areas, there were paved roads and well-built stone bridges. Elite individuals were carried in litters. Little is known of water transport, but large rafts were sometimes used as were dugout canoes. Warfare was common, and there seem to have been complex hierarchies both in politics and in the religious structure. Many supernatural figures, cosmic concepts, and extensive sacrifices (from flowers to humans) are similar to Mesoamerica. They are also

FIGURE 14.1. Identifications of the archeological sites, peoples, and areas of South America, which we discuss. Drawing by Sharon Hanna.

integrated into a similar calendar system and involve astronomical knowledge that was probably developed as fully as among the Mayans but which still persists to an extent that is unparalleled anywhere in Mesoamerica.

The region known as the Sierra Nevada of Santa Marta rises abruptly from the Caribbean coast to more than 18,000 feet (5775 m); within that small area alone, there is tremendous climatic and geographic variation ranging from tropical jungles and semidesert to alpine meadows, windswept tundra, and snow-capped mountains. At the time of the Spanish conquest of Colombia, the Taironas, a Chibchan-speaking tribe, had conquered many of their neighbors and established political control over much of the Sierra Nevada. The Spanish often used the term Tairona for all the people of the area, and archeologists have applied it to the pre-Columbian remains in the Sierra Nevada region. To the modern day *Kogi* (sometimes spelled *Cogui*), of this region, the name Tairona may refer either to the ancient people in general or to a specific tribe that they distinguished from themselves in some contexts and regarded as their ancestors in other contexts. Here, we shall use *Tairona* for the pre-Columbian people and *Kogi* for the modern. The Sierra Madre region showing the locations of Kogi villages is shown in Figure 14.2.

Most of the relevant data on this group is derived from the work of Reichel-Dolmatoff, who has written a major monograph on the modern Kogi and done extensive archeological field work there and elsewhere in Colombia. In 1965, he published the only general study of Colombian archeology that has yet appeared. In some ways, the Kogi-Tairona seem to be the pivotal culture linking Mesoamerica, the Amazonian rain forest, and the Andean high civilizations. Reichel-Dolmatoff (1965, pp. 114–116, 157–158; 1975b, p. 233) emphasizes the many close parallels to Mesoamerican culture. It now seems likely that people were moving in both directions between Colombia and Mesoamerica. Many more details can be added to the comparisons suggested by Reichel-Dolmatoff, particularly in the areas of calendrics, astronomy, and religion.

The Tairona ceremonial building shown in Figure 14.3 has 18 levels: From a plaza level, two stairways ascend, each in two sets of five steps and a third set of seven, much shallower, steps. The archaeoastronomical significance of the 18 levels will be shown in our subsequent discussion of a modern Kogi temple.

The Kogi lived in the only urban area of pre-Hispanic Colombia; although there were no settlements larger than a

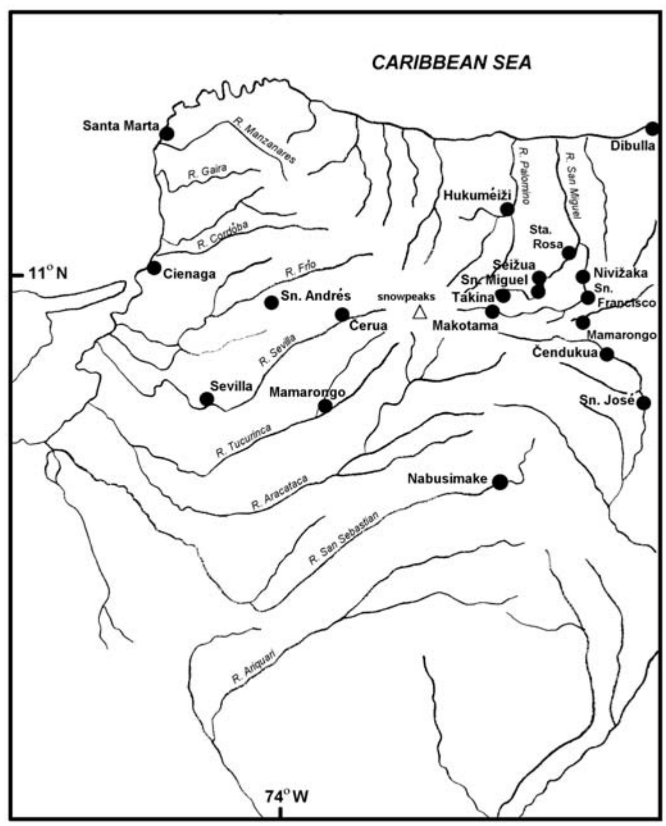


FIGURE 14.2. The Sierra Nevada region shows the locations of Kogi villages. Drawing by Sharon Hanna.

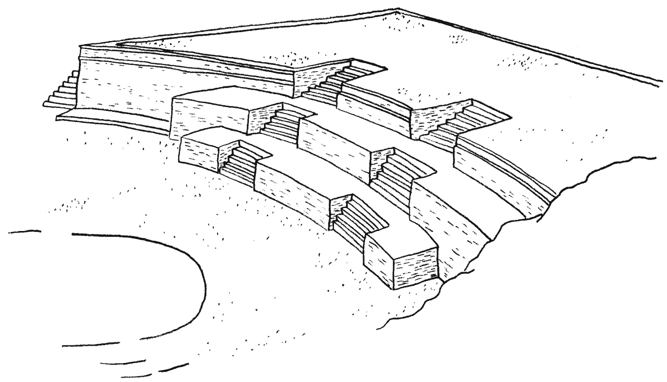


FIGURE 14.3. A Tairona ceremonial building has 18 levels of archaeoastronomical significance. Drawing by Sharon Hanna.

few thousand people, there were "large public works such as temples, agricultural terraces, irrigation, and paved roads" (Reichel-Dolmatoff 1965, p. 158). This is an area with practically every known sort of archaeoastronomy tied in to a still-living mythology. Moreover, the entire zone is conceptualized as a gigantic sky map. Among the observational practices known among the past or present-day Kogi (most of which are mentioned by Reichel-Dolmatoff 1982, pp. 177–178) are

(1) the use of stone alignments and stone circles;
(2) horizon markers;
(3) direct shadow and alignment observations that make use of a small stick-gnomon (to lay out Kogi temples);
(4) observations of light movements caused by the Sun in the day and Moon at night, on the floor of the temple, regulated by a removable cover over a central ceiling opening;
(5) observation locations (marked by stone seats);
(6) a ceramic tube probably for determining lunar and solar positions; and
(7) solar observations made with an obsidian mirror (the Sun is also regarded as a mirror).

The last observational practice appears to confirm what has long been suspected to have been done in Mesoamerica. There, a major Aztec deity was Tezcatlipoca, Smoking Mirror, and concave obsidian mirrors were in use (§12.15).

A major ceremonial center of the Kogi is Hukkumeiji, which is also the name of a principal Kogi lineage. The name comes from *uxan*, "palm tree," but the totem animal of the lineage is the jaguar. It is said that the Sun "lives in Hukkumeiji," and it is only there that equinox ceremonies are held. The Sun is called *Mama*, the usual Kogi term for "priest," and Preuss (1919/1993, Vol. I, p. 56) recorded a list of 55 priests of the jaguar family (some of whom are also called *maku*, ruler) who succeeded each other from father to son, from Seidjankua, who is a prominent figure in Kogi mythology, to Usaginmaku (Jacinto Garavito), who was living in 1914. A photograph of a Mama, Domingo Zalavata, taken in 1984 shows him seated on a stone seat of the sort used by priests throughout the Kogi territory for astronomical observations and for doing divination. Nearby cairns mark the graves of three earlier priests, and the main temple of Hukkumeiji is visible in the background. Although the genealogy of these jaguar priests makes it clear that inheritance was a major factor in the Kogi priesthood, it was entirely possible for individuals who had no priestly background to become priests if they were selected by a Mama. The training of a Kogi priest was long and arduous. At about three or four years of age, a child was removed from his family and went to live with a priest in a remote area. For the next nine years, he was not allowed to see any women, nor, indeed, many people of any sort. He awoke at dusk each day and spent nearly the entire night studying but was abed before sunrise as he was not allowed to see the Sun. He had a very restricted diet, the principal treat being occasional land snails. The novice was supposed to memorize myths, to study astronomy and local geography, to get a thorough knowledge of local traditions, and, in general, to become a very learned person, as the Kogi understood this attainment. After nine years, he was allowed to return briefly to his "home," at which time, he had to decide whether to stay for another nine years of study under similar conditions. The effectiveness of this training is demonstrated by a report[1] that when a portion of a myth recorded by Preuss in 1914 was read to a Mama in the 1980s, he recited the continuation of the myth, word for word, just as Preuss had recorded it. There has been acculturation during the nearly five centuries of domination by Spanish-speakers, but the isolated area and the tradition of special training has meant that modern Kogi knowledge of the astronomy of their pre-Columbian ancestors may be a good approximation to the ancient system, which seems to have been a sophisticated one and interwoven with all facets of their life and social organization. The preservation of Kogi knowledge was, no doubt, helped by their conviction (as reported) that Catholicism was simply a corrupted version of their own religion.

A Kogi Mama makes frequent use in ceremonies of objects made in Tairona times, claimed as heirlooms. They include such things as monolithic stone axes, gold plaques and figurines, a wide range of beads, and obsidian mirrors.

Although Reichel-Dolmatoff has described the social organization relating humans to animals and animals to stars, the involvement of all of these with mythology, and with the construction of the temple as a model for the universe, he makes little use of that knowledge to expand his description of the Kogi calendar and astronomy. The Kogi temple consists of a rectangular framework, covered by a conical roof; temples are models of Earth, sky, and cosmos. It is said that the Earth is the spindle whorl of the Mother Goddess and that her spindle (which passes through ε Orionis) is the "central post" of the land of her children, which she marked off by a circle of thread from her spindle. The spindle thus corresponds to the gnomon and knotted cord used by the Kogi priests in laying out temples. The cord (*šubuli*) serves to maintain a strict canon of building. The priest directs the laying out of the temple, starting with the placement of a stake used as a gnomon. The cord is used to

[1] Oyuela-Caycedo (1986).

Table 14.1. Kogi gods and associations.[a]

Category					
Gods	Seokukui[b]	Seizhankua[b]	Kunchavitabueya[b]	Aldauhuiku	Mulkuexe
Animal form	Black deer	Metal-colored Peccary	White tapir	Red rabbit	—
Male lineage (Túxe)	Hukukui	Hánkwa	Kurča	Hukumeiži	None
Totem animal	Owl	Puma	Maktu, opposum	Nama, Nebbi, Jaguar	
Goddesses	Mitamsáma	Śivaldungaya	Nurlayatakán	Nunkályiyuxa	Haba Maukui Mother Toad
Female lineage (dáke)	Mitamdú	Hul-dáke	Nugé-nake	Śei-nake	
Totem animal	Snake	Deer	Armadillo	Peccary	
Domain	Air	Earth	Water	Fire	Invisible fire No visible hearth
Color	Black	"Metal"	White and blue-green	Red	Black
Other associations	Night	Squirrel	Canoe; rock crystals Kuišbangui, Lord of Thunder	Cotton, animals Sintana, the first man	Gold, corn, mist Night Sun
Village	Takina	Hukumeiźi (Palomino)	Noavaka or Sekarino	Mukañgalakue or Makotáma	
SS direction[c]	NE	NW	SW	SE	Center
FE direction[c]	SE	NE	NW	SW	
WS direction[c]	SW	SE	NE	NW	
SE direction[c]	NW	SW	SE	NE	
Basic direction associations	W (black)	S (reddish)	N (blue/green)	E (white)	

[a] Adapted from Reichel-Dolmatoff (1987, pp. 95, 104; 1950–1961, pp. 246–247).
[b] Alternative spellings from Reichel-Dolmatoff: Sehukúkui, Seižankua, Kunča vitabueya.
[c] SS = summer solstice; FE = fall equinox; WS = winter solstice; SE = spring equinox.

mark off circles where the posts are to be placed. There are four-post entrances to the east and to the west, marking the equinoctial alignment and two-post markers to the north and south. The idealized floor plan of a temple is conceived as a loom and as a map of the heavens and a map of local villages.

The first post to be set up is that in the NE, determined by the direction of the midmorning (nine o'clock local time) Sun at the summer solstice and approximately at the rising point of the Pleiades. Its location is determined from the use of a central stick both as a gnomon and as an anchor for a measuring rope. From this, the opposite post in the SW was laid out. The NW and SE posts were then established geometrically. Paired sets of posts were established at the perimeters at the cardinal points, and two interior posts at both the east and west sides were added to lay out the equinoctial lines. Two major structural posts were added near the center. This constituted 12 posts in the outer perimeter making 18 major structural members. Smaller poles were then placed around the circumference. In the idealized plan, these are NNE, 8; ENE, 7; ESE, 7; SSE, 6; SSW, 7; WSW, 8; WNW, 7; and NNW, 9, totaling 59. In addition, there was one small post between the major posts at the north point. Hence, the total number of posts in the perimeter is 72, the multiple of the two most sacred Kogi numbers, 9 and 8. Reichel-Dolmatoff did not comment on this number; so only an extended examination of present-day and archeological temples will reveal whether this was a deliberate feature of the plan or an accidental correspondence. The temple is constructed in five levels, which form a pyramid, and is supposed to have an invisible image below, in the underworld. The apex is a complex construction running in a transverse direction relative to the doorways, with projecting sticks. There are 90 sticks on the largest temple at Takina, dedicated to rituals concerning the conjunction of the Sun and the Moon. There are 44 sticks on the next largest, which possibly represent $1\frac{1}{2}$ synodic lunar months ($29\frac{1}{2} + 14\frac{3}{4} = 44\frac{1}{4}$).

Every temple represents the body of the Thunder God in some contexts but is identified as the uterus of the Mother Goddess in other contexts (Reichel-Dolmatoff 1975b, p. 211). Ancestral gods of named social groups are associated with fireplaces and entrance posts.

The ancestral gods determine the seating positions of the lineages (see Table 14.1). At the start of the year in June, Seokukui, ancestor of the Owls, the Lord of Air, of Night, of black things and of animals is at the primary position in the northeast; Seizhankua, ancestor of the Pumas, the Lord of Earth, of Plants, and of "metal-colored" things, is in the northwest; Kunchavitabueya, ancestor of the Opposums, the Lord of Water, associated with both white and blue-green objects, is in the southwest; and Aldauhuiku, ancestor of the Jaguars, the Lord of Fire, associated with red, is in the southeast. Puma, Opposum, and Jaguar are known to be month names that are identified as asterisms (see Table 14.2). Moreover, the Owls are associated with winter solstice ceremonies, and the Jaguars with equinox ceremonies. These connections and the great importance, generally, of astronomy suggest that these ancestral gods may be identified as planets. During a year, the position of the lineage groups, relative to the four major fireplaces, moves one position clockwise at each of the equinoxes and solstices, revolving

TABLE 14.2. Kogi months.

Months named from asterisms	Months	Wives of the Sun: Text 1	Wives of the Sun: Text 2
1. Uká Coatimundi (Pleiades)	4. Uxa (Pleiades)	1. Uxa	3. Uxa
2. Tami Tobacco container (Hyades)			
3. Seiku Scorpion (near Aldebaran)	6. Seiku	8. Seikú	6. Seiku, Scorpion (Scorpio)[c]
4. Huso Crab (in Taurus)	8. Husso ("Crucero")	9. Husso	4. Husso, Crab (Cancer)[c]
5. Neb-šiža Puma[a] (Orion's Belt)	1. Neb-siji (Orion's Sword)		
6. Neb-taši Blue jaguar (Orion's Sword)	9. Neb-tashi (Orion's Belt)	2. Neb-táshi	1. Neb-tashi
7. Nebbi Jaguar (Canis Major)	3. Nebbi		7. Nebbi, Jaguar
8. Nebbi-yéldyi Otter			
9. Tarbi (Takbi) Fer-de-lance (Eridanus)?	11. Takbi, snake (Scorpio or Ursa Major)	4. Takbi	C. Takbi, Snake
?. Neb-škiži abaxse Jaguarundi			
?. Wása Conepatus (skunk-like)			
?. Hibixa Mustela *sp.*			
?. Sinsi Mouse			
		3. Neb-skiji	2. Neb-Skiji, Big jaguar
	5. Nyui Mulúna		5. Mulduna, Miller
	12. Subalyi	10. Subalyi[b]	
	2. Enduksáma (Venus male)	6. Enduksáma	
		5. Abuchi-Atéima (Venus)	
		7. Saubaukua	A. Selda-Bauku, Eclipse goddess
			B. Mukui, Toad, vagina
	7. Seikuchi Nugi, Scorpion's tail		
	10. Maktu fox (actually opossum)		
	13. Nyúibi-Sija		
	14. Dji, Worm, penis		

[a] Literally "red jaguar."
[b] Or Subutuija.
[c] Identification with the European constellations Scorpio and Cancer is doubtful.

around the (invisible) fireplace at the center. The center position is ruled by the god Mulkuexe who is associated with the Night Sun and the underworld below the temple. No lineages are associated with the center. Although Reichel-Dolmatoff reconstructs a basic system of four male lineages and four associated female lineages, he also says that there were nine lineages from Hukkumeiji (Lords of Day) and nine others from Hukúkui (Lords of Night) (Reichel-Dolmatoff 1950–1951, p. 189). It seems likely that these 18 lineages were associated directly with the 18 20-day months. Specific social groups use identifying design marks in particular arrangements. In ancient Tairona iconography, some of the same marks are associated with specific deities and at least some seem to have specific astronomical connotations.

The Kogi calendar has been described by Reichel-Dolmatoff (1950–1951, pp. 254–255; 1975, especially pp. 223–230), and a great deal of relevant additional material is scattered through his publications. However, he emphasizes the secrecy of the calendrical information and the inadequacy of his own knowledge and understanding, which is underlined by major inconsistencies in his statements. It is clear that the Kogi recognized a series of 13 lunar months and a parallel series of 18 "months" of 20 days each, apparently used in counting divisions of the solar year. Both series seem to have been named from asterisms, and the known names and stellar identifications from four different lists are shown in Table 14.2. It will be seen that most of the names refer to animals. The identifications make it clear that the rising points of the asterisms mark successive horizon points of the ecliptic, and that the changes in the celestial latitude rather than celestial longitude of the Sun, are determining the calendrical sequence (cf. §2.3.1). The solar series apparently begins with the heliacal rise of the Pleiades in June, which led Reichel-Dolmatoff to assume, mistakenly, that the heliacal rise was the important factor for the other asterisms. He adds that nine "lunar months" were counted from the summer solstice to the winter solstice, but this is clearly an error for nine 20-day months. Possibly *su* ("lunar month" according to Reichel-Dolmatoff 1975b, p. 228) also serves as a name for the 20-day period. The same asterisms, although in a different order, may have marked the lunations. Reichel-Dolmatoff (1950–1951, Vol. II, pp. 28–30) gives two lists of the "wives" of the Sun, which he apparently did not recognize as month asterisms at that time. In 1975, he had recognized that the nine "concubines" of the Sun were the asterisms of the 20-day periods. Extra days were added to the basic 360 days when "the Sun was in his house," which was said to be at the spring equinox.[2] The equinox marked the beginning of the New Year. Perhaps this was true for Hukkumeiji, which was the only place where equinox ceremonies could be held, and not true for other sites, or perhaps the lunar year began with a new Moon at or following the spring equinox. An interesting artifact used by the Kogi priests to explain the relationships of the calendar to the astronomy is the *pispiska*, "that which revolves" (Figure 14.4).

Here, the path of the Sun is conceptualized as a spiral going out from a center (an equinoctial point of crossing) to two circles marking the Sun's path at the two solstices. The circle marking the summer solstice is called *Uxa* (identified as the Pleiades); the circle marking the winter solstice is presumably called *Takbi* (see Table 14.2).

The most important ceremonial site for the Kogi was Takina. Among the ceremonies celebrated at the winter solstice in Takina were rituals for the souls of the dead and a new fire ceremony. All fires in the community were extinguished at the time of solar eclipses, and new fires were started with fried fungi (Reichel-Dolmatoff 1975b, p. 219). It is probably significant that Takina is associated with the center (Kogi *muan*), that the fire god is associated with the center, and that the center is identified with the middle star of Orion's Belt. At Takina, a pottery tube, called a *seulu*, 15 cm in diameter and 30 cm in length was hung at the apex of one of the temples, about 30 to 40 ft (9 to 12 m) above the ground (Reichel-Dolmatoff 1975b, p. 227). Unfortunately, we have no details as to how this tube was used, although we are told that the apex had a NE to SW orientation. It is not known if the Kogi attempted to predict eclipses, but after the old Moon's disappearance, and appearance in the Underworld, Kogi priests spent much time trying to calculate the exact time when the Sun and Moon would "come together" in the "underworld."

The mask of *Heisei*, "Death," used in dances at the equinoxes in Hukkumeiji is described by Reichel-Dolmatoff (1950–1951, Vol. II, pp. 146–148). This shows an exaggerated lower jaw of a jaguar that is combined with a feather headdress in a semicircle, divided into six segments. The majority of the feathers are macaw plumes. The semicircle is said to represent the passage of the Sun between the solstices. Each feather represented a single day, and each one had a special name. Presumably, the six segments would each have about 30 feathers and thus would represent a lunar month or some formalized approximation to one. Reichel-Dolmatoff managed to collect only four of these names, an insuffficent number to determine if any recognizable structure is inherent in the naming. The presence of a series of named days apparently differentiated over more than 180 days is a very surprising feature of the calendar, although not discussed by Reichel-Dolmatoff in that context.

The Kogi insistence on multiple levels of reality and of different analogies/identities as appropriate for different situations extends to their astronomy. The loom and the floor of

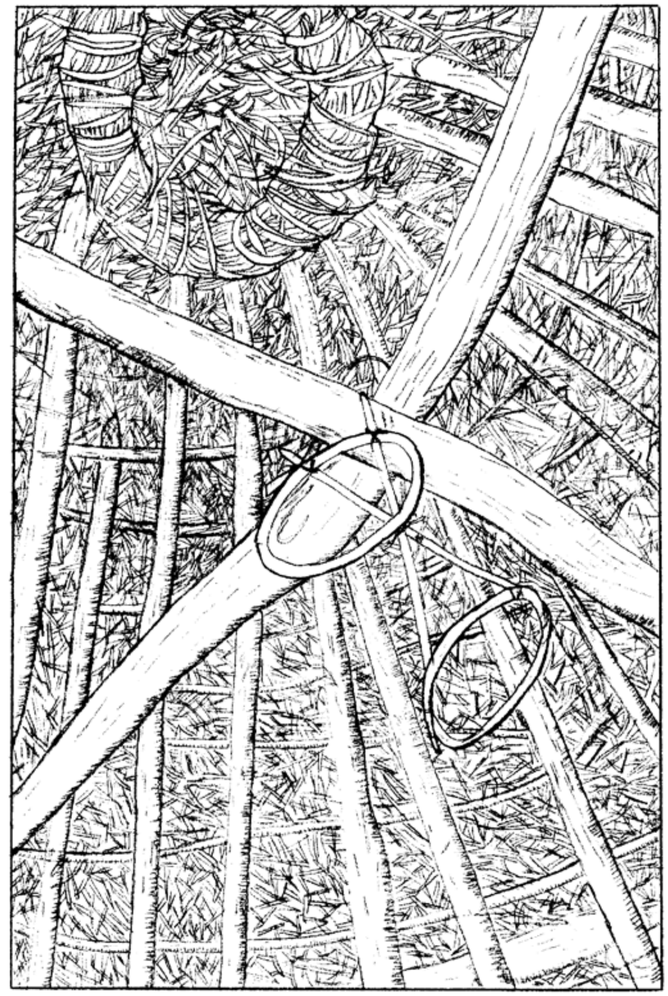


FIGURE 14.4. The *pispiska*, "that which revolves," an artifact used by the Kogi priests to explain the relationships of the calendar to the astronomy: The Sun's path is conceptualized as a spiral going out from a center (equinoctial crossing) to circles marking the Sun's diurnal path at the two solstices. The circle marking the summer solstice is called *Uxa* (identified as the Pleiades); the circle marking the winter solstice is presumably called *Takbi* (see Table 14.2). Drawing by Sharon Hanna.

[2] In March. See Figure 14.1: The equator runs through Ecuador, and so the Kogi are in the Northern hemisphere.

the Kogi temple on which Sun weaves light patterns supply a four-cornered Earth solidly in the center of the universe with the heavenly bodies revolving around it in the manner so aptly explained through the *pispiska*. The spindle whorl as "our world" suggests the analogy of a more or less globular Earth rotating on a central axis. Finally, the shifting of the lineages from one fireplace to another around the location of the central (hidden) fire of the Night Sun (the Sun in the Underworld) suggests that at least some Kogi had some sort of heliocentric interpretation in DHK's view.

A clay figure from the Tairona culture is very similar to the Heisei mask, with the same projecting feline snout, triangle band across the forehead, and great feathered head-dress (Reichel-Dolmatoff 1990, Plate 48). In a later study, Reichel-Dolmatoff (1988, pp. 152–153) discovered solstice imagery in a number of Tairona gold pieces, specifically comparing one of the objects with the Heisei mask. Reichel-Dolmatoff (1988, pp. 152–153) discusses the modern Kogi use of triangles, especially banded triangles with dots, to indicate poisonous snakes and argues that an identical design on the archeological pieces should have the same interpretation. Given the way in which the Kogi incorporated calendrical information into the modern Heisei mask, and into the temples and clothing, it seemed worthwhile to count some of the features of these gold figures. The round plaque showing a deity with jaguar-like canine teeth is surrounded by 28 triangles. Reichel-Dolmatoff (1988, Fig. 242) shows a human figure with a head-dress of 36 units, surmounted by 17 triangles and ending in what Reichel-Dolmatoff regards as two very stylized snake heads. Below the figure are 11 more triangles, thus again totaling 28. The 36 dots that end the head-dress units are supplemented by 9 more at each side, totaling 54 dots. The two projecting pieces at the bottom of the pectoral are each marked by two rows of dots, one of 10, one of 11, and the projecting pieces are separated by 12 dots. Hence, this section also sums[3] to 54. The fact that both 9 and 18 are important to the Kogi suggests that this repetition of 54 (3×18) may be important. Finally, Reichel-Dolmatoff (1992, Fig. 241) shows a pectoral with a figure that he identifies as a Sun god, borne on a litter. The edge is broken, but the regular spacing of the dots along it indicates that there must have been about 180 dots. Because Reichel-Dolmatoff identifies this scene as being a ritual celebrating the journey of the Sun from solstice to solstice and because the comparable mask of Heisei among the modern Kogi is said to have about 180 feathers to mark the same journey, it seems plausible to suppose that the dots were deliberately numbered. Such a hypothesis is presented here only as a suggestion to stimulate further examination of this material.

A few of the many striking astronomical-calendrical similarities between the Kogi and Mesoamerica, especially the Mayans, should be pointed out here:

(1) The structural similarities of the calendar include not only the 20-day months, but also the existence of a lengthy series of named days, and an emphasis on nine major time periods.
(2) The Mayan *Mams* ("grandparents," god-like ancestors who live inside the mountains) parallel the ancestral Kogi *Mamas*, who are also said to live inside the mountains.
(3) The Kogi name *Pispiska* may be related to Yucatec Maya *pis*, which is a prefix for numbers, particularly used for counting days, months, and years.
(4) The Kogi god *Duginavi* ("Elder Brother Jaguar") was serpent-footed and taught people agriculture that he learned from the "Thunder people." He was also said to have invented a device consisting of two crossed sticks on a base, called a *kankui* used to "measure the Sun" (Reichel-Dolmatoff 1987, p. 99). He was crucified on Orion's Belt (Reichel-Dolmatoff 1950–1951, Vol. II, pp. 36–38). He parallels the serpent-footed gods of Mesoamerica, Tezcatlipoca and the Maya God K, the latter associated with agriculture.
(5) The major Maya god called *Ah Bolon Tzacab*, "he of the Nine Lineages," is reminiscent of the Kogi emphasis on nine lineages derived from nine ancestors who arrived in nine canoes from the north, escaping from a world in flames (Reichel-Dolmatoff 1975b, p. 233).
(6) The old black god of the Kogi was *Seokukui*, Lord of Fire, ancestor of the Owl lineage at Takina, which was associated with the center point *muan* in Orion's Belt, and where New Fire ceremonies were held at the winter solstice. He parallels God L of the Mayans, an old black god who wears the *muan* owl head-dress. God L is represented at Palenque in such a way that his figure is illuminated by the last sunlight at the winter solstice. It may be noted that Aztec New Fire ceremonies, although held only at 52-year intervals, were also celebrated near winter solstice and that the Aztec Firedrill constellation was identified as the Belt and Sword of Orion.
(7) Kogi and Mayan month names show both semantic and phonetic parallels.

There are also parallels to the patron gods of the Mayan months (see Table 14.3).

These similarities seem even more indicative of direct cultural contact between the two areas than do the many others pointed out by Reichel-Dolmatoff. They suggest that the Kogi calendar may be a less-changed derivative of a prototype of the Mesoamerican calendar, which shows more clearly than any Mesoamerican evidence a direct connection with astronomy.

Thus, the Kogi provide a major source of ethnoastronomical information about pre-Columbian America, and the study of them may prove to be critical for understanding the spread of astronomical ideas.

Another Chibchan group, the Muiska Indians, now completely assimilated, had as their heartland a chain of flat-bottomed valleys running NE-SW, an axis toward June solstice sunrise. Reichel-Dolmatoff (1982, p. 178) considers them to be the most advanced culture of prehistoric Colombia. A "Temple of the Sun" was located at the NE end, whereas the "Temple of the Moon" was found at the SW end. Many columns and mountain foresight alignments are said to exist.

[3] The arithmetic is as follows: $[2 \times (10 + 11)] + 12 = 54$.

Table 14.3. Kogi and Maya months.

Kogi months	Maya months[a]
Mukui, toad[b]	*Uo*, *Bufo marinus*[b]
Vagina	
Wife of the Sun	
Wife of the god of the center	
(see *Mama*, item 2 in text list)	*Mam* (Cakchiquel Maya)[c]
Máktu, opossum	*Alauch*, little opossum (Tzeltal Maya)[d]
	Mucuch, big opossum (Tzeltal Maya)[d]
(see *Muan*, item 6 in text list)	*Muan*
Seiku, scorpion	*Tzec*[e], *Zec* (Sek)
Dji, worm	*Tzi* (Pokomchi Maya)[e]
Penis	
Enduksama, male Venus god	*Yax* (patron deity is the Venus god)
Husso, crab	*Tap* (Pokomchi Maya)[f]
Nebbi, jaguar	*Pop* (patron deity is the Jaguar)
Neb-tashi, blue-green jaguar	*Uo* (patron deity is the Water-lily Jaguar)

[a] Yucatec unless noted otherwise.
[b] The specific toad, *Bufo marinus*, in coastal regions. A Yucatec word for toad (and vagina) is *much*.
[c] Thompson (1950, p. 106). See discussion of *Mams* as Opossums (§12.17).
[d] Thompson (1950, p. 106).
[e] Tzotzil Maya *tzec*, "scorpion" (Thompson 1950, p. 77).
[f] *tap*, crab in Quiche Maya (Thompson 1950, p. 115).

14.2. Andean Civilization

A good general picture of Andean culture can be found in Moseley (1992). For Spanish speakers, there is the excellent summary of Bonavia (1991). Andean culture is dominated by the extreme geographic variation of the area. A narrow coastal plain, largely formed of desert sands, except where dissected by fertile river valleys, is bordered by the ocean to the west and two towering mountain ranges to the east. The more western and somewhat lower Sierra Negra overshadows the ocean, whereas the snow-capped Sierra Blanca rises behind. Still farther east, the mountains slope down to the Amazonian rain forest. In this inhospitable region, a scattered population of hunters and fishers gradually became more stable. Villages arose, particularly along the coast. From about 3500 B.C., domesticated cotton was used for fibers and various local plants began to be grown to supplement the food supply. Local potatoes, sweet potatoes, yams, beans, peanuts, and a wide variety of crops still little known outside the area were grown. In the coastal waters, there were fish in abundance. Seals and sea-lions also supplied meat in many areas. At a very different level, a wide range of shell fish was an important source of food. By about 3000 B.C., large ceremonial structures were being built. Guinea pigs were already domesticated at this early date. Ceramics were in use in Colombia and Ecuador by 4000 B.C., but did not reach Peru until about 1800 B.C. The ample mineral resources of the Andes were utilized to make a wide range of decorations, symbols of authority, and tools with a rapidly developed series of metallurgical techniques. The sophisticated technologies were accompanied by increasingly dense populations and hierarchical social structures. Along the coast, large rafts were used in fishing, trade, and warfare. Great irrigation canals, constructed in the early centuries A.D., were major engineering structures. Road building became increasingly important, culminating in the massive stone roads and bridges linking the Inca empire. Goods were transported by domesticated llamas, which also provided wool for textiles and, on special occasions, meat.

There have been six major studies, which, taken together, throw a great deal of actual and potential light on Andean astronomy and cosmology. They are those of Zuidema (1964 and later works), Urton (1981a, b), Sullivan (1996), Donnan (1976, 1978), Hocquenghem (1987), and Bauer and Dearborn (1995). Zuidema (1964) wrote on the archeological and literary evidence for *ceque* lines. Urton (1981a, b) is a study of the role of astronomy in the modern Quechua village of Misminay. Although the emphasis is on the modern community, Urton does not hesitate to go back and forth between modern practices and beliefs and those of Inca times. He also draws on comparative data from the tropical forests to aid in understanding his material. Sullivan (1996) partly on the basis of similar field work, but also on the basis of myths and statements recorded in Spanish colonial times, has attempted to identify the planets and to show that the Andean ideas about the world ages were based on precessional phenomena. He relies heavily for basic interpretations on Santillana and von Dechend (1969), but goes far beyond in attempting to identify what he calls "precessional events," which can be specifically and precisely tied down astronomically to particular dates. Sullivan also includes a great deal of comparative material from Mesoamerica. Hocquenghem (1987) has equated Moche iconography with Incan materials. Bauer and Dearborn (1995) is a major study of Incan astronomical materials.

14.2.1. Early Sites

The earliest presently known site in South America with clear astronomical properties is Cantogrande (77° 00′ 00″ W; 11°58′ 20″ S), between the Chillón and Rímac river valleys, and near Lima. Roselló (1997) reports on this remarkable site of the Early Formative (pre-ceramic) Period. The site has now been bulldozed by the inescapable advances first of irrigation farmers and later of builders. The site is a series of lines and more complex arrangements of boulders and smaller rocks, including trapezoids and a circle. Because many of the stones are large, the physical labor involved in creating the site must have been great.

Roselló thinks that the arrangements are purposeful and indicate solar and stellar alignments. The stellar alignments may be problematic, because the interpretation of which stars are involved prejudges the degree of precession required to make them fit. The solar alignments are less problematic and suggest both solsticial and equinoctial alignments, as well as a setting Sun alignment for the date of zenith passage.

His Line 41 (Roselló 1997, p. xviii) is associated with a shelter that Roselló thinks served as an observatory to lay out the lines. This had a ^{14}C date of 2545 ± 70 B.C. Roselló asserts that the obliquity is represented in these alignments and that the measurements are adequate to distinguish lines dating 500 years apart. An angle involving Line 41 is said to match the angle of the obliquity, $\varepsilon = 23°.98$ at ~2500 B.C. Roselló dates Line 56 of the site to ~3000 B.C., which would make it the earliest of these lines. Because the change in obliquity is only ~6′ in 500 years, this would imply a precision of both layout and measurement of better then 3′. This seems improbable to us, but the lines appear to be sufficiently long to make it possible. The dates so determined for the site are archeologically reasonable but not demonstrable because of the scarcity of datable associated materials.

The most striking feature discussed by Roselló is a "circle," defined by surviving arcs, Unit 42 of his map, which is 11.5 m in radius. His drawing suggests the former existence of five concentric circles defined by arc segments. The entire complex surrounds two nested squares, the sides and entrance of which define the E-W and thus the equinox directions. Southern and northern solstice set alignments are said to be defined by the edges of channels/canals and in the case of the southern alignment by an additional line of stones arising from within the inner square and extending nearly to the inner circle.

An important complex of the Cantogrande site is a trapezoid defined by pairs of lines bisected by a pair of parallel lines of stones. Roselló suggests that this was used for initiation ceremonies by a group divided into two moieties.

Even more controversial is Roselló's belief that certain lines (e.g., 51) are deliberate corrections of earlier lines (e.g., 52), which to him implies that they had detected stellar precession. The people involved would have recognized that they were doing this well before 2000 B.C. We reserve judgment on the issue because the measurements have not been verified by others and the interpretations are not necessary, even if sufficient.

The best-known early site is Chavin de Huantar, on the eastern slopes of the Andes (extensively discussed by Burger 1992). The architecture of the site is largely of stone and impressively monumental. In its later stages, several thousand people may have lived in the near vicinity. The site is at the convergence point of two major passes crossing the snow-capped Cordillera Blanca, and lying between the Huachecsa and Mosna Rivers, which flow down to the Marañon River and ultimately to the Amazon. The earliest architecture of the site was the Old Temple, built between ~850 and 700 B.C. This was built on top of the earliest construction of the site—an aqueduct bringing water from west to east. A stairway led up to a cruciform chamber inside a major temple. Where the arms of the cross met, the builders put a now famous monument called the *Lanzon* (Figure 14.5), which still stands today and is still bathed in light at the rising of the Sun at the December (summer) solstice.

In ancient times, when the structure was intact, the monument would have remained in darkness the rest of the year. The *Lanzon* is a depiction of an anthropomorphic figure with snakes as hair and a fanged mouth. The deity has been identified as a sky god or as a prototype of the Inca deity

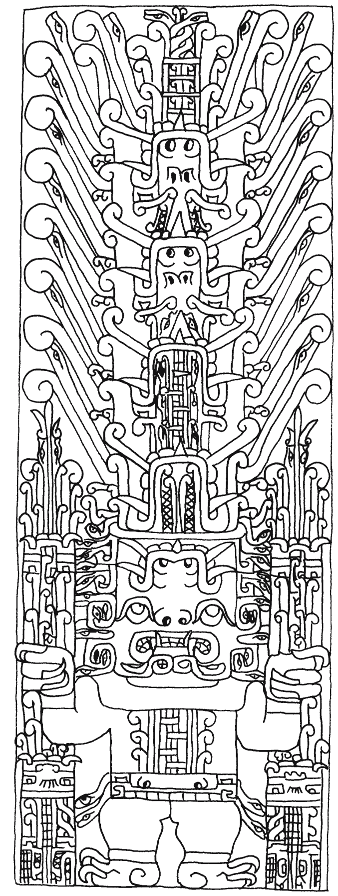


FIGURE 14.5. The *Lanzon* at Chavin de Huantar: In a cruciform chamber in a large temple, this monument was illuminated by the Sun at the December solstice. Drawing by Sean Goldsmith.

Viracocha[4] (Burger 1992, p. 150), not necessarily contradictory views.

The path of the aqueduct comes from the direction of the setting summer solstice Sun and goes to the direction of its rise. In accordance with later views, widespread in the Andes and in the Andean tropical forest, the aqueduct could symbolize the underground river, along which the Sun traveled to be born again in the East. This river was regarded as the continuation of the Milky Way. In a larger sense, the aqueduct might have symbolized the Pacific Ocean, to the west, where the Sun sank.

Chavin remained a major pilgrimage center for Andean groups until the Spanish conquest and even, to a certain extent, during the colonial period. Artistic motifs related to Chavin cult designs were widespread through Andean culture, and it was long supposed that these had been spread by Chavin "missionaries," creating a very early "Chavin horizon." We now know that monumental architecture, both in the highlands and on the coastal plain, predated Chavin by about 2000 years and that there are antecedents for some

[4] Among the Quechua, Viracocha is normally distinguished from the god Thunder, but the Quechua name *Tunapa Viracocha* identifies Viracocha with *Thunupa*, which is the Aymara name for the god of thunder and storms.

Table 14.4. Chronology of the Andean region.

3200 B.C.	Agriculture: Cotton, gourds Monumental architecture: Some corn Terracing	
2800 B.C.	Weaving, irrigation Clay friezes; stone sculpture	Cantogrande: Equinox and solstice alignments: Asterisms aligned?
2400 B.C.	Llamas, alpacas, guinea pigs domesticated Peanuts	
2000 B.C.	Ceramics Hammered gold	 Cupisnique
1600 B.C.		
1200 B.C.	Hammered copper	
800 B.C.		Chavin: Old Temple—Lanzón, light effect Star Woman and Caymans, Dec. solstice Moro de Eten: Light effect, Dec. solstice
400 B.C.	Developed metallurgy	Moche I, Nazca I
A.D. 1	Major aqueducts	Moche II, Nazca II, "Paracas" textile; eclipse calculation??
400 A.D.	Metal agricultural tools	Moche III, Nazca III, figures of asterisms and alignments Moche IV, Nazca IV
800 A.D.	650 A.D.: End of world age? Jupiter–Saturn grand conjunction; Quipus	Moche V, Nazca V Wari, Tiahuanaco, Akapana equinoctial alignments
1200 A.D.	Major fortifications; Chimu Pachacamac	Pacaritampo: equinoxes, solstices, light play Pachakuti Inca
1600 A.D.	Experimental crop-growing and breeding	Rumicucho, Ecuador; ceques, equinoxes, solstices, S. major standstill of moon

of the cult imagery on the coast. See Table 14.4 for a chart of the chronology. The Chavin cult included frequent representations of Jaguar, Anaconda, Harpy Eagle, and Cayman as well as occasional monkeys, all tropical forest animals. This led Donald Lathrap (1973, 1977) to postulate that the population of Chavin were ultimately of Amazonian derivation. However, there are also frequent representations of the Strombus (conch shell) and Spondylus (spiny oyster), and actual specimens were found in quantity in one of the galleries at Chavin. The nearest source for these is the Ecuadorean coast, and it can be obtained in quantity only by diving. The offering of conch shells as an item of tribute was of major importance right up to the time of the Spanish conquest. Conch shell trumpets were associated with major ceremonies, especially those involving the rulers. The Chavin cult seems to have involved ideas of the transformation of men into jaguars through the use of hallucinogens, especially the San Pedro cactus (containing mescaline), which is represented in Chavin art and in many later Andean cultures. A series of giant heads formerly tenoned into the walls of the Old Temple illustrate the transformation (Burger 1992, pp. 156–159). Given the solar alignment of the Old Temple, it does not seem too venturesome to suggest that the widespread later identification of the Sun as a jaguar was already present in Chavin belief. This association is further bolstered by the circumstance that a sound resembling both the roar of a (nocturnal) jaguar and thunder would have been produced by controlling the water running through the aqueduct in connection with air vents (Lumbreras, Gonzalez and Lietaer 1976). The roar would be an impressive component of a ceremony.

The Tello obelisk represents two great crocodilians or two aspects of a single supernatural (probably the Black Cayman). These have been defined at length by Lathrap (1973, 1977), who associates this cult with the bottle gourd (Lagenaria siceraria) and postulates that the gourd, cotton, various social practices, and the crocodilian cult arrived from Africa by sea in the late Pleistocene and spread throughout Amazonia, thence to Mesoamerica and the Andean region. Although this bold series of hypotheses has not been fully adopted by any one else, his application of Amazonian ideas to the Tello obelisk has been cited more favorably (Burger 1992, pp. 151–152). Specifically, Lathrap describes Cayman B as the Sky Cayman, female, associated on the monument with the origin of domesticated *aji* (peppers) and the bottle gourd. Both of these are house garden crops and above-ground plants. There are also two harpy eagles and a fish below one of them. The Sky Cayman, whom Lathrap refers to in his title as "Our Mother the Gourd," is responsible for rainfall. Cayman A, depicted as a male, is identified by Lathrap as "Our Father the Cayman," and associated by him with the underground and with surface water. Both a Strombus shell and a Spondylus are shown with Cayman A, who is depicted with probable peanuts and definite *achira* (Canna edulis) and manioc, the latter in front of his penis. These are all root crops and all field crops. It is noteworthy that like the cult animals, the crops are all from the tropical forest. Burger (1992) points out that the Trio tribe in Surinam say that agriculture was given to humans by a fish-woman, the wife of their culture hero and the daughter of a giant alligator, who got from him corn, sweet potatoes, cashew nuts, and manioc. The last was carried on his penis. The Trio are a long way in space and time from Chavin de Huantar, but the specificity of the comparison is striking. There is a widespread Amazonian myth that attributes the origins of agriculture to a star-woman (sometimes specifically the planet Jupiter), who comes down from the sky and is hidden by her mortal husband in a gourd. There are also myths of the origin of agriculture from a tree, identified in turn as the Milky Way (Levi-Strauss 1969, pp. 168, 246, 250). This brings us back to the aqueduct and to the Strombus and Spondylus shells associated with Cayman A and with the gallery near the round plaza.

A number of Chavin sculptures show figures wearing decapitated human heads hanging on their belts. In the Gallery of the Offerings, the skull of a middle-aged woman was found, surrounded by a circle of 40 milk teeth. The Gallery had a long corridor and nine chambers, apparently with specialized contents. A total of 800 broken pottery vessels had once contained a variety of goods and drink. Among the food remains were human bones, mostly broken and burnt, suggesting ritual cannibalism (such remains were not found in ordinary garbage dumps).

The site shows a strong emphasis on numbers—a 13-stepped stair inside the Old Temple, 6 steps down from there to the terrace level, then another 7 to the level of the Sunken Plaza, making 27 levels, corresponding to a sidereal lunar month. Bas-relief sculptures of seven jaguars on each side of the stairway make 14. The nine chambers of the Offering Gallery in the context of the death and rebirth of the Sun and of possible lunar associations may represent nine lunar months (265–266 days), the closest lunar approximation to the period from the equinox in March to the solstice in December (about 274 days).

Another impressive site, described by Carlos Elera (1986, Fig. 117), stands looking out over the sea at Moro de Eten in the Lambayeque Valley on the north Peruvian coast. The site dates from ~400 to 200 B.C. An ancient road leads to a cliff above the sea, passing a nearby pyramid. During most of the year, the road seems purposeless, but at the December solstice, the light of the setting Sun, reflecting on the waters, makes a brilliant golden extension of the road into the Pacific to the western horizon. The pyramid, just to the south, shares the same orientation.

14.2.2. Moche (Mochica)

On the north coast of Peru in the Moche valley and surrounding areas, flourished a rich culture that has been called both Mochica and Moche. There were large settlements, including some of the biggest temple mounds of the Americas. These also contained elaborate burials. Major irrigation works stretched for miles. Metal-working was well developed, and treasures in gold were buried with rulers, frequently dressed in costumes that identify them as personifications of deities. Murals showing mythical scenes have survived in considerable numbers. The pottery, both molded and painted, shows a tremendous range of subject matter that reveals a great deal about many aspects of Moche life. The culture is divided into five phases covering roughly the first seven centuries of the Christian era. Much of the material we will be considering comes from phase V (about 550–700 A.D.).

Donnan's (1976, 1978) work on Moche iconography established that at least the majority of Moche art (mostly pottery and some murals) could be considered as excerpts from a restricted series of basically religious scenes depicted in varying detail. He also maintained that even apparently secular depictions were actually extracted from larger religious scenes. Despite the importance of warfare to Moche conquest and expansion, he even argued that paintings of warfare represented something akin to Aztec "flower wars."[5]

Such conclusions cry out for some sort of systematic explanation and integration. This has been provided by Hocquenghem. She accepted Donnan's conclusions and suggested an astronomical-calendrical-ritual basis for them, closely related to Quechua ideas. She relied heavily but by no means exclusively on Zuidema and Urton for the latter. Hocquenghem went beyond Donnan by attempting to determine the number of "grand scenes" with precision and by pointing out that a "grand scene" may occur either with deity figures in animal form as actors, in which case, she regarded it as representing a myth, or with human actors, in which case, she regarded it as a ritual, re-enacting a myth. Her descriptive conclusion was that all scenes of Mochica art may be regarded as excerpts from a total of 18 grand scenes. The scenes can be put in a framework of the ceremonial year that corresponds remarkably well and in detail with the myths and ceremonial year of the Incas and with at least some modern beliefs and rituals. These include a number of parallels of highly specific items of an arbitrary nature (hence, unlikely to have arisen as convergent phenomena), and they include systemic parallels that can have only one or, sometimes, two placements as part of a system. Because Inca rituals incorporated nearly all aspects of daily life in one festival or another, these aspects of Mochica pottery can also be incorporated into the ceremonial year. If one accepts the basic argument, Donnan's conclusions are greatly reenforced.

Important stations of the ceremonial year were marked by three classes of astronomical phenomena: stellar, in the appearance, culmination, and disappearance of the Pleiades; solar, by equinoxes, solstices, and passage of the Sun through zenith and nadir; and lunar, by new and full Moon. However, although Hocquenghem interprets Moche iconography as entirely based on calendrical ritual, whose timing is astronomically based, she makes no attempt at astronomical interpretation beyond that which is explicit in some of her parallels, and in the identification of major figures of the iconography as Sun, Moon, and Thunder (including references to Thunder as a constellation). She seems to think that annually repetitive phenomena of the astronomical year are adequate to explain the material and apparently had no idea that the iconography may represent specific planetary actors or that World Ages, for example, may have specific astronomical referents. The latter possibilities are suggested by Sullivan's work on Inca astronomy and mythology. There may be some reconciliation of Hocquenghem's and Sullivan's views if ritual may be regarded as the compression into the span of a single year of celebrations of mythico-astronomical events that originally covered a substantial

[5] The "flower wars" involved conflicts carried out for the purpose of securing captives for sacrifice and were not economic in nature.

Table 14.5. Mochica grand themes.

Grand themes	Equivalent Quechua months and ceremonies	Correspondences in tropical/sidereal year
1. Flowers thrown in the air, "Purification"	1. Coya Raymi	Sept.: Dry season equinox
2. Union of Thunder and Moon(?) goddess; also Jaguar and Toad	400 warriors expel illness Ritual copulation	
3. Punishment, torture, place of execution		
4. Manufactures, weaving	2. Uma Raymi Weaving, ear-piercing	Oct.: Sun crosses zenith
5. Deer hunting, scenes associated with death	3. Aya marca Death God on litter	Nov.: Pleiades culmination
6. Dance of the dead		
7. Race	4. Capac Raymi, Ritual races Initiation rites Sacrifice of 500 children	 Dec.: Summer solstice
8. Offering and use of coca		
9. Combat: Capture of prisoners	5. Capac Camay *Flower war* at new moon	Jan.
10. War dance with rope	Multicolored rope dance	
11. Sacrifice	6. Hatun Pucuy	Feb.
12. Victims to guano Islands: Seal hunts	7. Pacha Pucuy	Mar.: Wet season equinox
13. Corpse preparation on guano islands		
14. Passage to the land of the dead sodomy, masturbation (cf. 5&6)		
15. Revolt of the artifacts	8. Ayrihua	Apr.: Disappearance of Pleiades
16. Gambling	Games of chance to help crops to grow	(Heliacal set of Pleiades)
17. Cultivated plants, masked dancers; toad with plants	9. Aymoray Offerings to Corn Mother (Santa Maria Sapo)	May
18. Bridge of cords (Spider Path to Heaven)	10. Huacaycuzqui or Inti Raymi Ritual race (cf. 7)	June: Heliacal rise of Pleiades, winter solstice
	11. Chahuahuay	July
cf. 9	12. Tarpuy	Aug.: Sun at nadir

number of years. If all of Mochica art is astronomical-ceremonial-mythical, it should be possible eventually to put astronomical constraints on the depictions and perhaps even obtain precise dates for some of them. Although our interpretations have sometimes been influenced by knowledge of comparative data from other cultures, we have usually tried to restrict our arguments to local data.

Unfortunately, in making her comparisons, Hocquenghem has treated the Inca months without allowing for the precession of the equinoxes. The rising of the Pleiades marks the beginning of the year now, as it probably did in Moche times, but this is a sidereal year. The tropical year has shifted relative to the sidereal, and so ceremonies relative to the equinoxes, solstices, zenith and nadir passages, and seasonal phenomena are no longer correlated with precisely the same stellar phenomena, although the shift has not been great since Mochica times.

Hocquenghem's interpretation is put into a particular theoretical framework of art history, largely derived from Panofsky (with some important changes), and into ideas about the relationship of forms of production, daily life, and the ceremonial calendar. The theoretical framework in which she couches her argument is not essential to her calendrical interpretations. In such an ambitious and remarkable analysis, one must expect that some details will be wrongly interpreted and others will be contentious. Hocquenghem makes a strong case for interpreting all scenes as consistently mythic/ritual, and this interpretation can survive even substantial changes of emphasis or detail. The greatest weakness of the interpretation is the supposition that scenes of daily life that played known roles in Inca ceremonial and calendrics also played comparable roles in the Mochica ceremonial year. If Hocquenghem is even approximately correct, the congruence of myth and ritual seems extraordinarily high compared with the situation in other cultures. Table 14.5 shows a list of Hocquenghem's "grand scenes" as she places them in the calendar year together with Incan parallels and the agricultural calendar. The seasons experienced by the Moche are as follows: hot and dry (Sep.–Dec.); warm and wet (Jan.–Mar.); cold and wet (Apr.–Jun.); and cold and dry (Jul.–Aug.). We will discuss here only the most striking parallels or those in which we have specific disagreements with her interpretations.

There are some indications that occasionally pots may even depict groups of scenes that include components of several grand themes. In such cases, the components should be treated separately. We think this may be true of three Moche pots depicting the burial of a woman in a step pyramid (Figure 14.6).

Her body is being lowered by animal-headed serpent-ropes held by Thunder and Iguana. On the viewer's left, on

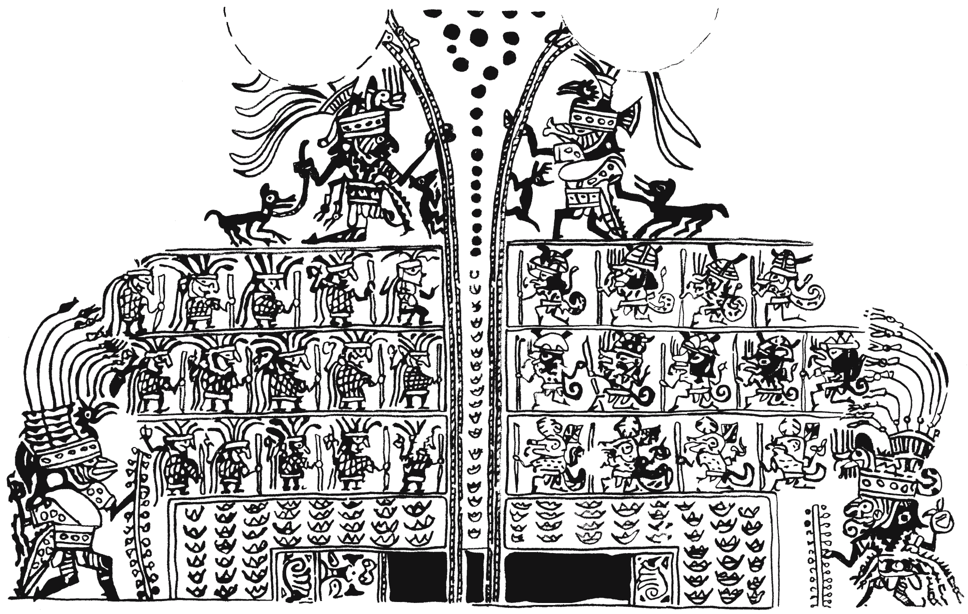


FIGURE 14.6. The burial of a woman in a step pyramid, amid possible astronomical themes: The woman may be the conceptual equivalent of Pleiades Old Woman of the Tukanoans and of Gourd Woman of the Kogi. From a Moche pot. Drawn by Sharon Hanna.

the top three courses of the pyramid, are human figures. On the viewer's right are animal figures, sometimes with some human traits. In the clearest of the drawings (Donnan 1978, Fig. 143), those of the bottom row have deer horns, those of the middle row have the "figure-8" markings characteristic of Moche jaguars, and those of the top row have long, fat tails that seem to have snake markings. These three kinds of animals immediately suggest the composite deer-snake-jaguar monster identified by Hocquenghem (1987, p. 213), with the *Amaru* associated with the world ages called *Pachacutis* and with the Moon (although the *Amaru* is sometimes identified with the two-headed Rainbow Snake). We shall return to the burial scene after considering other evidence of astronomical interest. On the other side of these pots is a complex scene with five major components. Four of the components are above and one below a dividing line composed of step-frets and war clubs on two of the pots, of step-frets and reversing triangles on the third pot. The components above the dividing line are

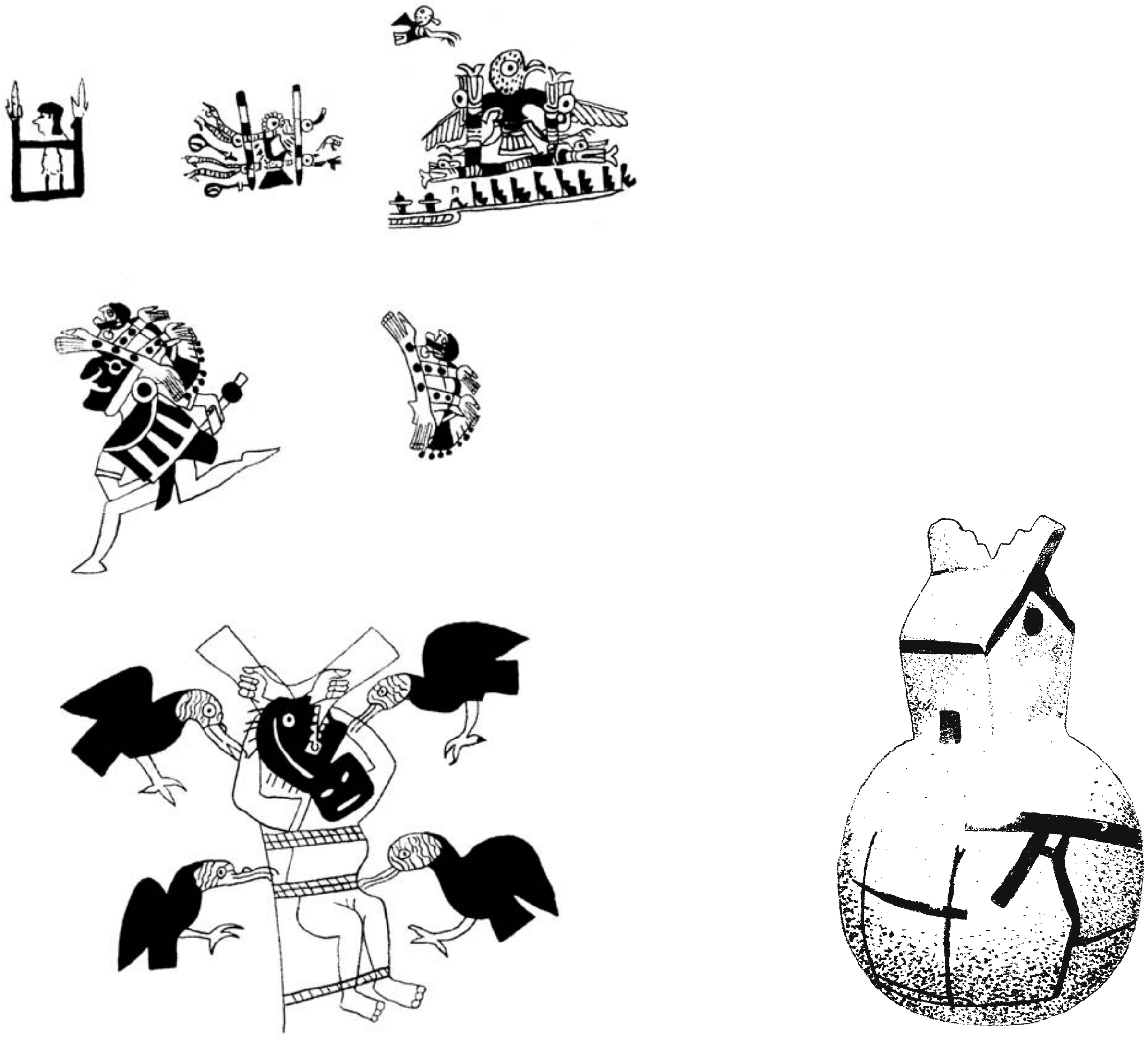
(1) a naked old woman surrounded by birds;
(2) Thunder and Iguana traveling toward the viewer's right;
(3) a vulture in a serpent frame, attacked by vultures; and
(4) a series of vultures on a rope (in one case a serpent-rope) being led (perhaps as dancers or captives) by a human figure.

Below the line is the so-called "presentation theme," which shows the bringing of offerings, including strombus shells, to a god or gods seated in a temple. This scene may include two llamas. In other versions, one of the llamas is accompanied by a baby llama. The llama mother and young form the best known of Andean asterisms (α and β Cen and the accompanying dark nebula) and the serpent frame is identified below as the Ladder or Orion's Belt. There is a reasonable possibility that the naked old woman[6] is the conceptual equivalent of Pleiades Old Woman of the Tukanoans and of Gourd Woman of the Kogi. We shall try to examine the most obviously astronomical themes on these three pots, first, and shall return to them after clarifying some of the components by examining related themes.

The figure of the vulture in a serpent frame attacked by other vultures closely parallels representations of a human figure in a similar serpent frame attacked by vultures. The serpent-frame with the captive on it is shown above a path marked by Greek frets leading to a temple whose top is marked by war clubs, the preferred weapon of the god Thunder. Occasionally, this is indicated by a line of step-frets on the right becoming a line of war clubs on the left. The serpent bars and heads (Figure 14.7a) correspond closely to the serpent heads, which mark the head of the figure usually accepted as the Sun god.

Donnan (1978, p. 95) points out the close correspondence of these depictions with the identification (by Calancha in the Moche area in the early colonial period) of the central star of Orion's Belt as a thief and suggests that the art may depict a thief—a secularization decidedly opposed to his general thesis. Urton (1982a, p. 240) discusses the myth more fully, noting that the thief is held by Pata (the two outer stars of the Belt) and attacked by vultures (other stars) under the direction of the new moon. Calancha's account is closely parallel to a Quechua statement (Urton 1981c/1988, p. 138, Fig. 44) that Orion's Belt with two adjacent stars formed a human figure that was also part of a ladder. Urton (1981c/1988, p. 130) says that *Chakana*, a Quechua name

[6] This old woman is a well-known figure in Moche Iconography. One eye is more or less diamond-shaped, and the other is rounded or oval. When clearly drawn, one hand has five fingers, and the other has four.



(a) (b)

Figure 14.7. (a) The god of Thieves attacked by vultures, possibly a depiction of a myth involving the central star of Orion's Belt as a captive. (b) A temple-topped pot with a serpent frame and another structure painted on its lower half. Drawings by Sharon Hanna.

of Orion's Belt, meant "ladder, bridge, cross-beam, lintel." Bauer and Dearborn (1995, pp. 127, 129) identify the serpent frame as Orion's Belt, which we accept. There is also a striking, although distant, parallel to the Kogi god, Duginavi,[7] crucified on Orion's Belt for adultery. If the "new Moon" reference is intended to suggest that the Moon was in the vicinity of Orion's Belt, it also implies the presence of the Sun and, hence, a date close to the December (summer) solstice. At Huarochiri, it was said that "There are three stars in a straight line. They call these the Condor, the Vulture, and the Falcon." Bauer and Dearborn (1995, p. 140) suggest that these are the Belt stars of Orion but regard that as highly speculative. Given the Moche depictions of a vulture sometimes replacing the human captive on the serpent frame, and Calancha's identification of the central star of Orion's Belt as the captive, it seems very likely that the

[7] Duginavi, "Elder Brother Jaguar," had sexual relations with Gourd Mother, whose animal form was the toad (see §14.2 for the description of Duginavi). There are Mochica pots showing a jaguar having sexual relationships with a toad marked with agricultural plants (Hocquenghem 1987, Fig. 15). Duginavi obtained agriculture from the Thunder People and introduced it to the Kogi. Urton (1981/1988, pp.98, 102) found several modern Quechua identifications of toad asterisms, most frequently, the Coal Sack (a dark nebula in Crux). The "Mouth of the Toad" was identified as the Hyades. Zuidema (1983, p. 253) in a discussion of the Thunder god and the goddess *Mamallqui Jirca*, "the plant of origin" suggests that she was identified with the asterism Toad and points out Brazilian myths in which Toad is the mother of the Twins and the wife of Jaguar. In Amazonia, the Twins are normally Sun and Moon. See below for an argument that the Moche "thief" in Orion's Belt was, in fact, the Thunder Twin.

FIGURE 14.8. The Thunder Twin in five scenes from a pot. Drawing by Sharon Hanna following Bourget.

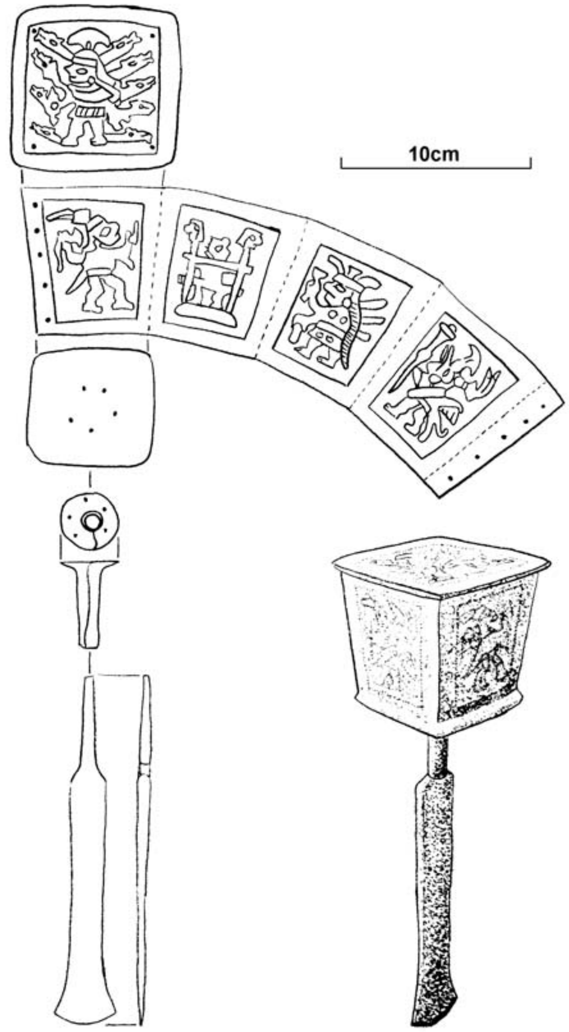


FIGURE 14.9. A *rattle* with representations of four seasonal "grand scenes." Drawing by Sharon Hanna.

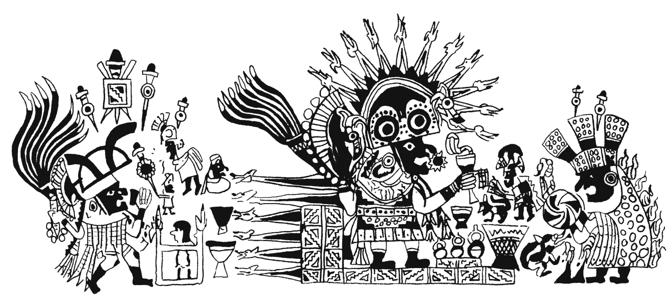


FIGURE 14.10. Gods with war clubs and the prisoner on the same serpent frame. Drawing by Sharon Hanna.

"three stars in a straight line" at Huarochiri are indeed the stars of Orion's Belt. Hocquenghem (1987, pp. 79–84) suggests, doubtfully, that the motif of the captive on the serpent frame may be associated with the Inca month of Uma Raymi and the zenith Sun in October. As we have pointed out, Calancha's statement implies that the mythical events shown are associated with the December solstice. Although Hocquenghem's specific interpretation here seems to be incorrect, the identification of an important set of motifs as specifically associated both with Orion's Belt and with a specific time of year gives strong support to her general interpretation. An important pot published by Bourget (1994, pp. 438–445) shows the Thunder Twin in five scenes, which form a circle (Figure 14.8). These may represent five successive grand scenes. Bourget argues that the scenes should be taken in order, and that they are connected with the poisonous and hallucinogenic properties of certain anthropomorphized fishes. One of these scenes shows the Thunder Twin as a captive held between two anthropomorphized birds, one apparently a vulture. The scene would be an appropriate preliminary to the depictions of the captive on the serpent frame attacked by vultures and strongly suggest that the captive is the Thunder Twin. On the opposite side of this pot is a scene that shows the Thunder Twin opposing the Lord of Fishes. See Figure 14.8. The captive on the serpent frame is also one of the motifs on a four-sided rattle (Figure 14.9), where it seems that each side may represent a different season or seasonal ritual. A prisoner in a serpent frame is also seen in Figure 14.10. What seems to be a similar rattle is seen in a painted scene of Figure 14.13, where it is part of the ritual equipment of a Sun god or Sun-god impersonator. This seems to be a minimal representation of the theme called "the Bridge of Cords" by Hocquenghem (Figure 14.11).

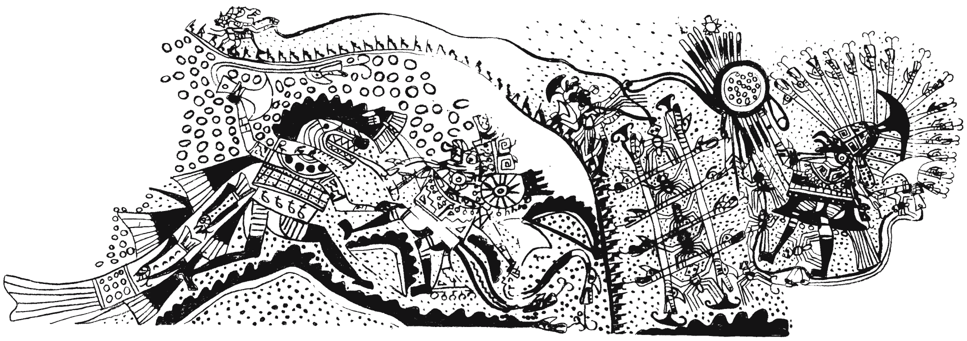


FIGURE 14.11. The "Bridge of Cords" or "The Spider Path to Heaven": Here, ascending and descending a spider ladder path may be references to planetary motions on the ecliptic. Drawing by Sharon Hanna.

(a) (b)

FIGURE 14.12. The Thunder Twin (two versions) with (a) shirt marked with step-frets and (b) elaborate serpent belt. Drawings by Sharon Hanna.

That theme also contains a serpent bar frame. Hocquenghem believes that this theme relates to the June solstice; this is appropriate if the captive motif (on the other side of the sky) refers to December solstice imagery. Here, a path marked by a series of serpent bars becomes a ladder, on which spiders are shown. In Mesoamerica and Polynesia, there are references to heroes and supernatural figures ascending to Heaven and descending from it on a spider path, which DHK has called "the Spider Path to Heaven." Kelley (1990, pp. 148–149) has argued that such figures are identified with the planets and that the "spider-path" is defined as the range over which the Moon, in spider form, can vary from the ecliptic (see §2.3.5 for lunar node regression effects). One of the figures that is shown here is the Thunder Twin, and Hocquenghem regards his climb up the spider path as his birth or rebirth. However, the Spider Path is here coincident with a ladder that probably represents a particular asterism. If the pot described by Bourget does encompass the whole sky, there should be two ladder asterisms: one at Orion's Belt and the other near Scorpio at the other end of the Milky Way.

The Thunder Twin (Figure 14.12), showing affinities both to Quechua *Viracocha* and to Quechua Thunder, is normally associated with war clubs (thunderbolts).

He often wears a stylized feline head-dress, sometimes showing figure-8 markings typical of Moche jaguars, and his shirt is often marked by a step-fret (sometimes called a Greek fret). His two-headed serpent belt is clearly the rainbow snake (cf., Carlson 1982), although Hocquenghem associates it also with the Milky Way, which modern Quechua identify as a "Night Rainbow." The Milky Way was also conceptualized among the Quechua as a giant river. Such an interpretation here is reinforced by the presence in the scene of a giant fish deity.

Thunder is known to be identified with a particular asterism (perhaps as a marker for the rainy season), but his presence in scene after scene associated with what seem to be a varied set of asterisms is much more appropriate for a planetary deity than for a deity identified with only one part of the sky. If we are correct in interpreting the Bourget pot as marking five successive stations around the sky, the Thunder twin, present in all of them, would almost have to be a planet. His association with agriculture is reminiscent of Amazonian stories of the origin of agriculture, sometimes by theft. Agriculture was normally considered to have been brought by Star Woman, sometimes identified as Jupiter (Levi-Strauss 1969, pp. 165–169, 250–251). In Quechua materials, the Thunder God is identified with Saturn. On presently available data, we prefer the identification of Thunder Twin with Saturn, but regard it as uncertain.

The Spider Path joins a second path that is marked by a series of step-frets. The serpent-bar path is attached to the Spider Ladder, and the two figures standing on the step-fret path are pulling the ladder toward themselves with ropes. An asterism attached to a celestial path and being pulled along relative to another celestial path is suggestive of a shifting of the equator relative to the ecliptic (namely, the precession). However, at the present time, there are too many apparent inconsistencies in our understanding of the Moche scenes to assert any interpretation of the paths with assurance. Either of the paths may be the ecliptic or segments of the ecliptic, and the role of Orion is difficult to understand. The successive horizon positions of the Sun could be conceptualized as a series of steps leading from the equinoxes to the solstices and back. If so, the step-fret would be a good marker for the shifting positions of the ecliptic on the horizon, or, perhaps, for the whole zone of declinations in which the planets move. In such a case, the step-fret may also define a zone of the sky corresponding to the tropical zone (the boundaries of the solar motion), or beyond, to the wider limits set by the meanderings of the planets, especially Venus. The change of the step-fret path into the war-club path may indicate the dominance of Thunder at the beginning of the rainy season. Both the serpent-bar path and the step-fret paths are associated with the Sun, perhaps with a particular emphasis on the step-fret at the equinoxes (the "Andean cross" of four joined step-frets pointing to the cardinal directions on the Akapana at Tiahuanaco will be discussed in §14.2.4). The serpent-bar path formed by depictions of the equivalent of solar rays could then represent the celestial equator.

The two-headed fox-snake as the litter-of-the-Sun is sometimes marked with a step-fret (Figure 14.13). The body of the two-headed fox-snake appears as a base on which seven deities and a dog are standing. The body is marked by a 52-unit step fret above, and the snake's belly is marked by 85 dots. An additional 13 dots appear on each leg, totaling 111. A similar figure without the step-fret serves as the image of the rainbow (Figure 14.14).

In the latter representations, the two fox heads represent points of the horizon, roughly separated by 90° of azimuth. The rolling topography and desert plants suggest that Figure 14.14a is an eastern rainbow. The wavy effect and apparent flat horizon at the bottom of Figure 14.14b suggest looking across the ocean to the west. The snake's body here assumes the form of a Sun-disk. By analogy, the animal heads of the step-fret depictions on the litter of the Sun may indicate separations of 90° in ecliptic longitude.

Another factor may have to do with the rainbows and halos. The rainbow is always centered opposite the Sun (see §5.1.3). Therefore, if the Moon is precisely at the center of a rainbow, this provides a remarkably good determination of the time of full Moon. A rainbow in the east arches 40°–42° from the anti-Sun direction (depending on wavelength), whereas Venus at greatest elongation is seen ~45°–47° from the Sun (see §2.4.3). Therefore, a rainbow seen near sunset provides a basis for a mythological association between the two phenomena. The Moche rainbow depictions seem to be of two varieties, possibly distinguishing rainbows in the east from those in the west. They appear with deities taking coca.

The Moche depiction of two corncobs with deity heads (Figure 14.15, taken from Hocquenghem 1987, Fig. 165) shows a close correspondence with the Quechua *Mamazara* (or sometimes *Saramama*, "Corn-Mother"). Mamazara is said to be a collective entity of two or more large or otherwise notable corn-cobs, dressed as "dolls" and worshipped in harvest ceremonies during the month Aymoray (Hocquenghem 1987, pp. 157–160). The corn-mother is identified as an asterism, that may be part of the Southern Cross, in a drawing by Pachacuti Yamqui Salcamayhua (reproduced in Bauer and Dearborn 1995, p. 119; cf., Figure 14.32). Zuidema (1983, p. 251) points out that *chu chu* means "twins," "twin corn-cobs" (a synonym for which is *Ayrihua*, a Quechua month name). These twins are said to be two

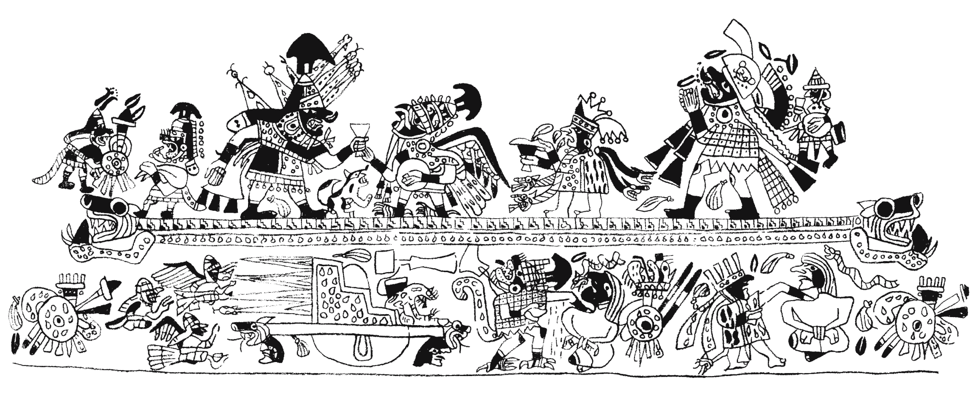
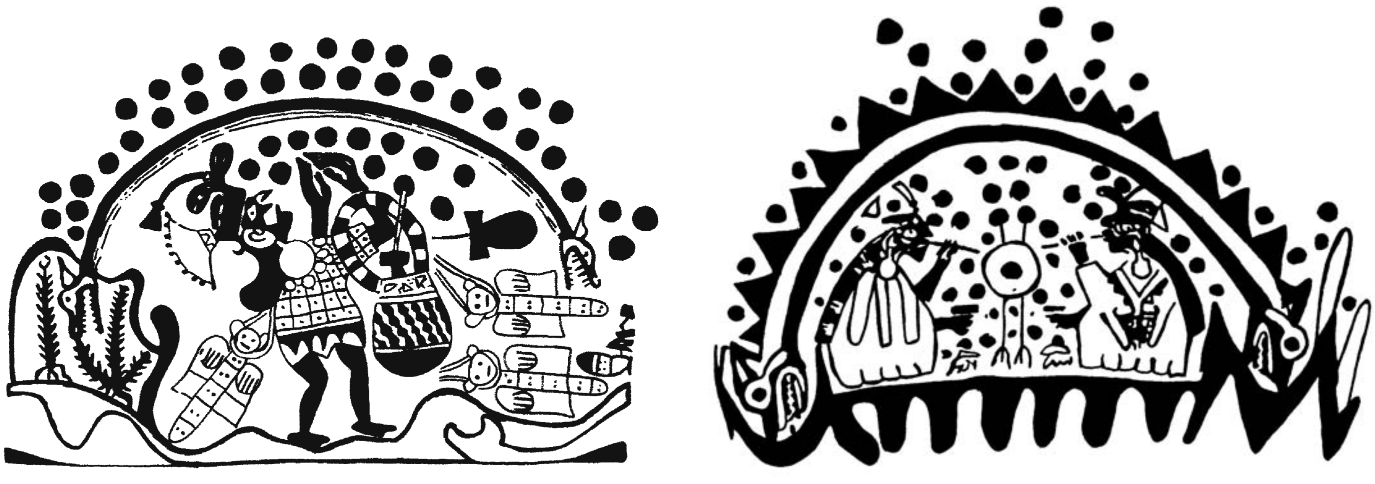


FIGURE 14.13. The two-headed fox snake as the litter-of-the-Sun. Drawing by Sharon Hanna.



(a) (b)

FIGURE 14.14. The two-headed fox snake as an image of the rainbow: (a) A possible "eastern rainbow" and (b) a possible western rainbow. Drawings by Sharon Hanna.

"small" stars near the Pleiades. Hocquenghem (1987, pp. 59, 157, Fig. 170d) points out that Moche toads appear marked with drawings of cultivated plants and that *Pachamama*, "Earth-Mother," also associated with harvest ceremonies, is identified by modern Quechua as Santa Maria Sapo ("Holy Mary Toad"). Zuidema (1983, p. 249) also points out that a Quechua myth about Mama Rayguana, the original owner of agricultural plants, lived at Atojhuarco, "the Hanged Fox" (see Figure 14.19), in which Fox may be identified as both a constellation and as the Moon.

A series of Quechua myths and rituals surround the mountain Anahuarque on one of the *ceque* lines from Cuzco (to be discussed later). Several of these may be directly tied to scenes of Moche iconography, as pointed out by Hocquenghem. Most strikingly, anthropomorphized beans appear in connection with two activities, both of which are associated by the Quechuas with Anahuarque. One is a game of chance, played with beans as counters (see Figure 14.16).

Among the Quechuas, this game was played as part of funeral rituals and is said to have been invented on top of

FIGURE 14.15. The Moche depiction of two corncobs with deity heads shows a close correspondence with the Quechua *Mamazara* (or sometimes *Saramama*, "Corn-Mother"). The corn-mother has been identified as an asterism, possibly part of the Southern Cross. Drawing by Sharon Hanna, from Hocquenghem 1987, Fig. 165.

FIGURE 14.16. Games of chance, played with beans as counters: Among the Quechuas, this game was played as part of funeral rituals and is said to have been invented on top of Anahuarque mountain. Drawing by Sharon Hanna.

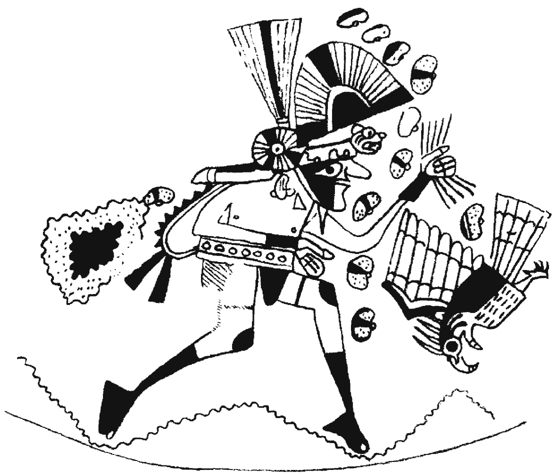


FIGURE 14.17. The other Moche "grand scene" involves anthropomorphized beans—a representation of races with beans carried by the racers (themselves sometimes anthropomorphized beans). Noble youths among the Incas raced from Anahuarque to Cuzco ($\phi = -13.52°$) as part of an initiation ritual at the time of the December solstice. Drawing by Sharon Hanna.

FIGURE 14.18. A Moche pot shows the Flood, indicated by large fish and sea-lions swimming past the shore, with the Revolt of the Artifacts: This myth tells how tools, weary of being abused by humans, arose against them at the time of a "five-day eclipse" of the Sun. Drawing by Sharon Hanna.

Anahuarque mountain. The other Moche "grand scene" is a representation of races with beans carried by the racers who are sometimes anthropomorphized beans (see Figure 14.17).

Noble youths among the Incas raced from Anahuarque to Cuzco ($\phi = -13.52°$) as part of an initiation ritual at the time of the December solstice. Anahuarque Mountain is said to be the ancestress of an Aymara group, the Uma, who performed a similar race in Uma Raymi (October). The alignment from Cuzco to Anahuarque is the line that marks the rise of the "eye of the llama" (Zuidema 1982a, pp. 218–220). Among the Quechua, the mountain Anahuarque is also identified as the place where the people were saved from the Flood (Zuidema 1982).

At Huarochiri, the llama is said to drink the waters of the Flood (in October) and hence to save the people. However, the people are also said to have been saved from the flood on a growing mountain. As the flood rose, the mountain rose. At the top of the mountain was Fox (a dark cloud "constellation" on the ecliptic). Urton discusses the alignment of the stellar Fox at Misminay and points out that foxes are supposed to be born only on December 25th, Christmas Day. The parallel of Fox with Uto-Aztecan Coyote, who saved the Papago from the Flood on a growing mountain is striking. Kelley knows of no Quechua association of Fox and Moon, but Moche iconography regularly associates Fox and Moon, and in northern Mexico, Coyote is sometimes identified as the Moon.

A Moche pot (Figure 14.18) shows the Flood, indicated by large fish, seals, and sea-lions swimming past the shore, with the Revolt of the Artifacts. This myth tells how tools, weary of being abused by humans, arose against them at the time of a "five-day eclipse" of the Sun.[8] Both Hocquenghem (1987, pp. 142–144) and Sullivan (1996, p. 221) associate this myth with a *Pachakuti*, or "earth-turning," the Quechua name for the end of a world age. Levi-Strauss (1969, p. 299) points out that similar myths are rare but geographically widespread in the Americas and are associated with solar eclipses among the Chiriguano and Tacana.

One pot (Figure 14.19) shows a fox within a recumbent crescent surrounded by eight-pointed stars and three other starburst-like symbols, which suggest a relationship between Moon and stars. A six-unit step-fret with steps to the right, attached to a CCW spiral, joins the head of the fox. An eight-unit step-fret with steps to the left, attached to a CW spiral, joins the foxes tail. The eight-pointed stars, which flank the crescent, may refer to planets or to planetary cycles. Finally, the starburst-like symbols consist of three quartered circles with bars and dots attached: 11 on the left, 9 in the middle, and 13 on the right.

Paired water craft appear on many pots (e.g., Figure 14.20). Deity figures stand on them. One of these figures is usually the Thunder Twin, and the other is Sun, often shown drinking from a cup. These opposing figures may represent the rainy and dry seasons, respectively. Figure 14.21 depicts a major god fishing from a boat (carried by birds) flying across the water.

An interesting theme on Moche pots is the depiction of flowers being thrown into the air from specially prepared implements resembling atlatls. There are always individuals present "decorated" with a step-fret. There is a Moche portrait vessel that seems to show one of these men with a step-fret head-dress.

Similar festivities are shown as part of the Quechua celebrations in the month Coya Raymi, the month of the Queen, which belongs to the Moon goddess. During this month, the Inca, personifying Sun, and his queen, personifying Moon, were carried on a litter with step-fret sides. In a depiction of these ceremonies, one of the warriors wears a garment with a step-fret design (Figure 14.22).

[8] Such a length for a solar eclipse of any variety, is, of course, impossible. See §5.2.1.1 for a discussion of eclipse lengths. It is conceivable that the Sun could be hidden for such a time by ash from extensive volcanic activity.

In this month, there was ritual coition in connection with fertility rites designed to increase the flow of irrigation water. The male partner was regarded as a water god and the female partner as the Earth goddess. Because the September equinox was in Coya Raymi and this was the month of the Queen as Moon, the sexual union of Sun and Moon (conjunction) was regarded as particularly important at this time. A complex Moche scene known from several vessels shows a deity (Sun god?) copulating with a woman, probably the Earth or Moon goddess. The goddess is portrayed as simultaneously giving birth to a tree with round fruits attached close to the trunk, in the manner of gourds. Monkeys are shown in the branches of the tree. In one version (Figure 14.23, from a later culture in the same area), a reversing double spiral with snakeheads appears above the heads of the couple. Both scene and spiral are appropriate for an equinox ceremony.

FIGURE 14.19. A Moche pot with a fox within a recumbent crescent surrounded by eight-pointed stars and three other starburst-like symbols suggests a relationship between the Moon and stars. Drawing by Sharon Hanna.

Such imagery in this context seems to us to be typical of conjunctions. Moche scenes relating to this scene fall into two categories, but the actors seem somewhat different from expectations. Sun and Earth(?) appear in the scene just discussed. In the second category, Thunder appears in the House of Thunder with a goddess not clearly identifiable, but associated with scenes of cooking, stirring, and the pouring of a liquid. This action could refer either to a cooking pot used in marriage ceremonies (Hocquenghem 1987, p. 76) or to making chicha (a corn-based alcoholic drink, which appears prominently associated with one of the fertility and irrigation myths cited by Hocquenghem 1987, p. 66). Disjointed parts of human bodies appear in one of these scenes and, on the basis of analogies elsewhere, are suggestive of a solar eclipse, perhaps at the time of a conjunction with the planet represented by Thunder.

Hocquenghem (1987, p. 185) points out that on the north coast of Peru, the iguana is said to have been transformed from a priest who was fascinated by the planet Venus. The statement may point to an identity between Venus and the

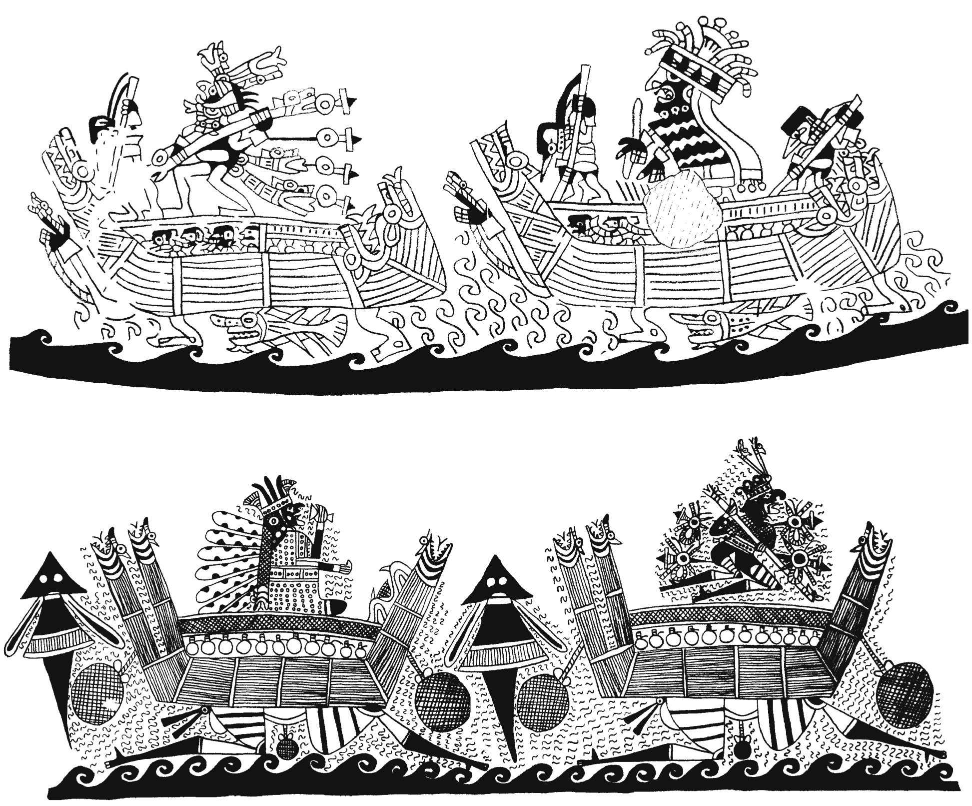


FIGURE 14.20. Paired water craft: From two Moche pots. Drawings by Sharon Hanna.

FIGURE 14.21. A fisher god on a flying (bird-borne) boat. Drawing by Sharon Hanna.

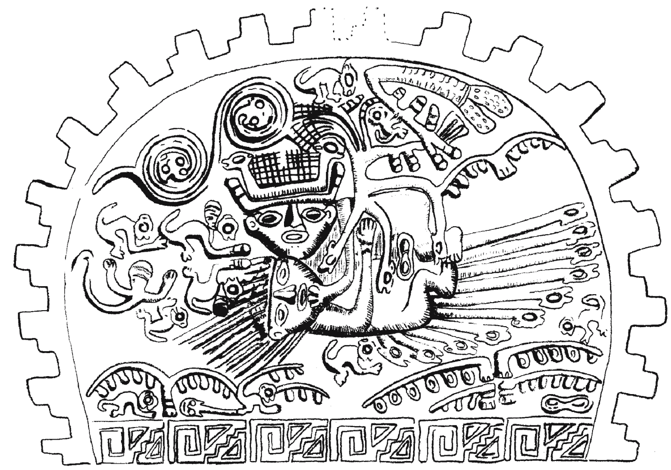


FIGURE 14.23. A Chimu representation of the birth of a tree. Drawing by Sharon Hanna.

FIGURE 14.22. Warriors at the Festival of Coya Raymí (Quechua): One of them has a step-fret design on his garment. Drawing by Sharon Hanna.

iguana during at least part of the Venus cycle. The frequent association of Iguana and Thunder indicates that Iguana is a planet.

On a number of Moche pots, women are depicted with long, unbound, or disheveled hair. As we shall point out, this is a characteristic of Venus among the Quechua. It is possible, if these depictions are of the planet Venus, that they represent an aspect of atmospheric refraction of this bright planet near the horizon (see §3.1.3 for a discussion of atmospheric refraction in the context of off-shore temperature inversions). One of the most notable of these pots show eight women weaving, with six other people, of whom two are receiving offerings (Figure 14.24).

One of the weavers has strikingly disheveled hair; another is distinguished by a woven cloak. Still another is seated above a fish. Hocquenghem (1987, p. 85) associates the scene with the Quechua month Uma Raymi (about October), in which there was a weaving ceremony. If this is indeed a calendrical astronomical scene, then the possible identification of one of the weavers with a planet may indicate that the other figures can be planetary, perhaps with different identities when rising and setting. In that case, there would be an interesting parallel with the Kogi concept of the heavenly bodies as weavers. Another motif shows a goddess with long hair that is draped over and hiding a mountain peak (Hocquenghem 1987, Figs. 185, 186; Donnan 1978, Figs. 146, 147, 149, 224–226). In one of these scenes, an anthropomorphized iguana appears below the mountain. This represents a difficulty for the view that both the goddess and Iguana represent Venus. As an alternative, Iguana as the priest fascinated by Venus may represent another planet.

We can now return to the pots with the burial scene (Figure 14.6 and similar depictions). In terms of parallel mythology elsewhere, the iconography of the burial of an old woman should represent a lunar eclipse. This identification in the Moche context will now be addressed. We have argued that the step-fret band may represent the ecliptic,

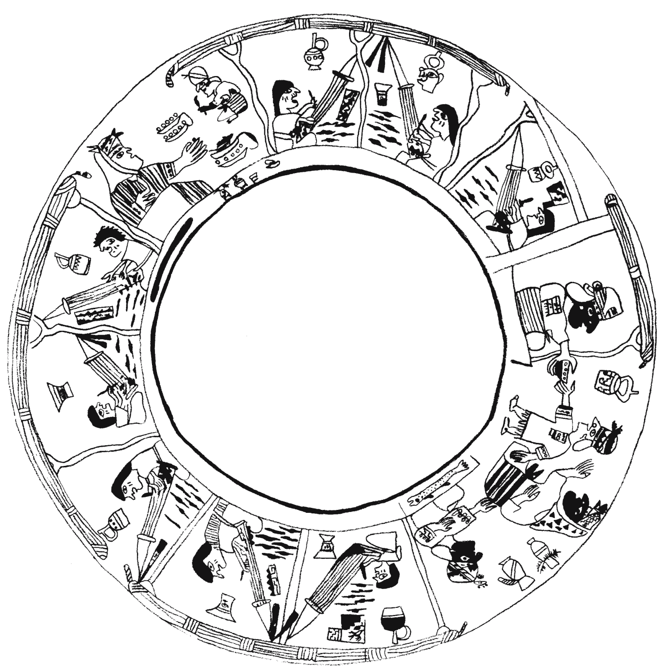


Figure 14.24. The Weavers, including Venus?, from a Moche pot. Drawing by Sharon Hanna.

that the serpent frame represents Orion's Belt, that Thunder is usually a planet (probably Saturn but possibly Jupiter), that Iguana may be Venus, and that the presentation scene is associated with the Dark Nebula Llama. We have also suggested the possibility that the naked old woman represents the Pleiades. If all or most of these identifications are correct, we would expect that the burial scene, too, represents an astronomical event associated with an archeologically attested burial and presumably accompanying ritual. If our extension of Bourget's interpretation of the "fishes" pot is correct, then the burial scene probably represents events opposite Orion's Belt in the sky. The use of serpent ropes by Thunder and Iguana suggests that the step-fret pyramid in which the burial occurs is divided vertically by the celestial equator or ecliptic rather than horizontally as on the other side. The burial of an old woman being lowered by serpent-ropes, and marked with a series of crescents, could represent a lunar eclipse. The crescents may represent actual artifacts in real burials, but this does not preclude their identification as indicators of lunar days or synodic/sidereal months. One of the burial scenes shows 13 crescents between the ropes, and two show 18 crescents. The crescents are similar to those used by a modern day Barasana shaman to represent months (Hugh-Jones 1982, Fig. 2), which in context may represent sidereal months. Thirteen sidereal lunar months are 354.9 days, and 12 synodic months are 354 days, twice the primary eclipse interval of 177 days (see §§5.2.2 and 12.11). Eighteen sidereal lunar months are 491.4 days, and 17 synodic months are 501.5 days, not an eclipse interval. Eighteen is suggestive both of Hocquenghem's Grand Scenes and of Kogi months. The crescents bear repeated but varying blips that may also have numerical meaning. There are also strombus shells present. If the strombus was associated with year beginnings, as suggested by Sullivan, they may indicate years. If the association is particularly with the spiral of the Sun between equinox and solstice, they could represent half-years. Unfortunately, although it is possible to find repetition in the numbers of various symbols, some of which approximate astronomical intervals, there is no pattern that is consistent enough to be convincing.

A remarkably instructive pot (Figure 14.25), published by Donnan (1976, pp. 22–23), shows 15 animals running in an upward spiral. At the bottom is a Fox-Snake, which should represent the ecliptic at an equinox or solstice point. The spiral suggests the path that the heavenly bodies follow along the ecliptic, whereas the 15 animals suggest the interval from new Moon to full Moon. If we assume that the stars were identified as lineage ancestors, as in Inca times, and that many stars were considered to be animals, the interpretation becomes even more likely. The presence of hexagons on the handle of this stirrup-spout bottle may be related to their ethnoastronomical usage among the Tukanoan groups where they are associated with Orion.

A number of distinguishing characteristics mark different kinds of individuals and animals. Runners normally have one of two frontal ornaments on their head-dresses, either circular or rectangular, which normally but not always alternate between successive runners. Among warriors, a distinction between factions is indicated by the use of rectangular or circular shields. Warriors are also distinguished by the kinds of weapons they used and by designs on their head-dresses, earplugs, or clothing. They may also be marked by distinctive facial painting or tattoos. The distinction between the two classes of warriors could correspond to the ceremonial battles between the "Upper" (*Hanan*) and "Lower" (*Hurin*) moieties. Moreover, we know that a common moiety division in many parts of the Amazonian rain forest is between Sky people and Earth people. The division may have paralleled an astronomical one. Possible astronomical divisions may include sunset and sunrise

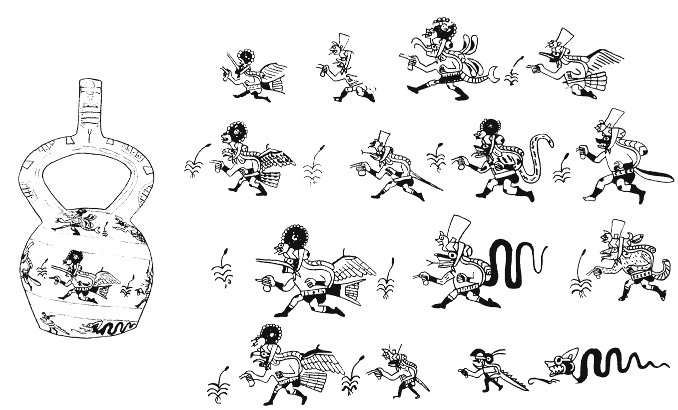


Figure 14.25. A Moche pot with 15 animals running in an upward spiral: At the bottom is a Fox-Snake, which may represent the ecliptic at an equinox or solstice point. Drawing by Sharon Hanna.

(east/west or night/day); north and south of the equator; north and south of the ecliptic; inside and outside the tropics; or within the boundaries of the Milky Way or outside of them. It is hard to see how to apply any of these divisions to the animal sequence of Figure 14.25, if it represents lunar movements over a 15-day interval.

Astronomical phenomena, if indeed present in Moche art, can be accepted only if the gods of the planets can be identified. Possible planetary figures in Moche art are as follows:

(1) The god with serpent rays surrounding his head is the Sun god.
(2) (a) The goddess with whom Sun and Thunder are frequently associated is probably Moon; however, not all female depictions are of the Moon.
(b) Calancha regarded Moon as male.
(c) Fox seems to be sometimes a form of Moon and sometimes an asterism or dark nebula figure.
(3) The god who wears the rainbow-serpent belt (apparently a god of agriculture) is the equivalent of the Quechua and Aymara Thunder God, probably either Saturn or Jupiter.
(4) The association of the Bean Lord with ritual races and with messengers seems to equate him with the Quechua messenger god, identified by the Anonymous Chronicler as Mercury.
(5) Hummingbird as a god has serpent rays like those of Sun and is particularly associated with warfare as is Mars among the Quechua, according to the Anonymous Chronicler. Therefore, he may be either a bird form of the Sun or Mars.
(6) (a) There is evidence that Iguana may be a form of Venus.
(b) The goddess with disheveled hair seems to correspond with the Quechua name of Venus.

In Moche art, we think there is clear evidence of World Ages, good evidence for extensive representations of constellations, strong suggestions of graphic symbols for the celestial equator and ecliptic, apparent planetary actors, possible depictions of effects of precessional changes, and eclipse imagery associated with solstices and equinoxes. It would seem desirable to study Moche astronomy in more detail.

From a late period in the same area, Sakai (1998) reports an interesting bowl (Figure 14.26), marked with a level and grid. This is the only pre-Columbian surveyor's tool (if that is indeed what it is) known from the Americas. It may have been used for building and performing astronomical observations. The way in which it may have been used is not known, but a plausible interpretation can be obtained from the figure.

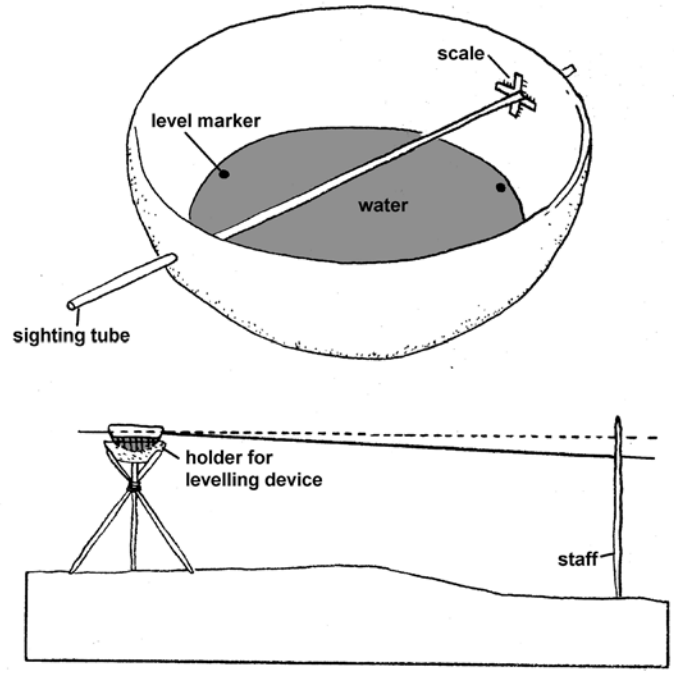


FIGURE 14.26. A pre-Columbian instrument, possibly used for surveying and astronomical observation. Drawing by Sharon Hanna.

14.2.3. Nazca[9] and the Geoglyphs

On the southern coast of Peru, there are a series of geometric and representational figures depicted on the desert plateau to the north of the Nazca Valley that have attracted much attention. Aveni (1990b) contains a good summary of data and interpretations to that time. We also draw attention to Kosok and Reiche (1947, 1949), Kosok (1965), the many works of Maria Reiche (especially, 1968), Hawkins (1969, 1973), Kern and Reiche (1974), Morrison (1978), Clarkson (1985), and van den Bergh (1992). Known technically as geoglyphs, these figures (sometimes hundreds of feet long) include about three dozen biomorphs (both plants and animals) and many geometric figures: trapezoids, triangles, rectangles, grids, curves, spirals, labyrinths, and many straight lines, the latter frequently radiating from points that have been called "line centers." There are also parallel straight lines and zigzags. Aveni (1990c, pp. 76–80) gives a list of most of the 62 line centers that his crew had mapped, giving the azimuths of the lines radiating from them and brief comments. The area investigated extends from ~14°40′ S to ~14°54′ S latitude. The locations and types of figures are illustrated in Figure 14.27.

The technique of creating the figures presumably involved some sort of geometric planning and then the clearing of the surface, probably by a substantial number of people sweeping the rocks away from an area. There has been no serious comprehensive examination of the geometry of the geoglyphs. It seems to be generally assumed that cords or ropes of some sort were used, and the use of some sort of template seems likely. Morrison (1978, p. 30) says that Maria Reiche had discovered a "model" for one of the figures, but we know of no details of this.

[9] Rowe (cf. Aveni 1990a, p. 3, fn. 2) has expressed a historically valid preference for "Nasca," but "Nazca" is solidly entrenched in the literature.

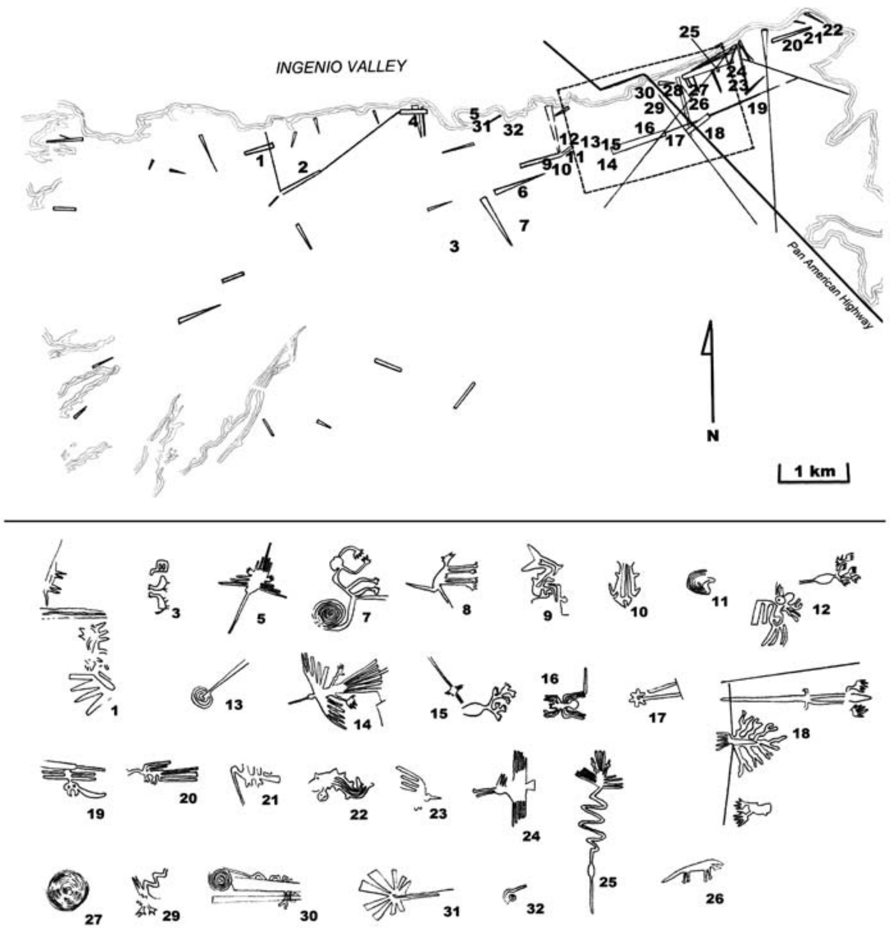
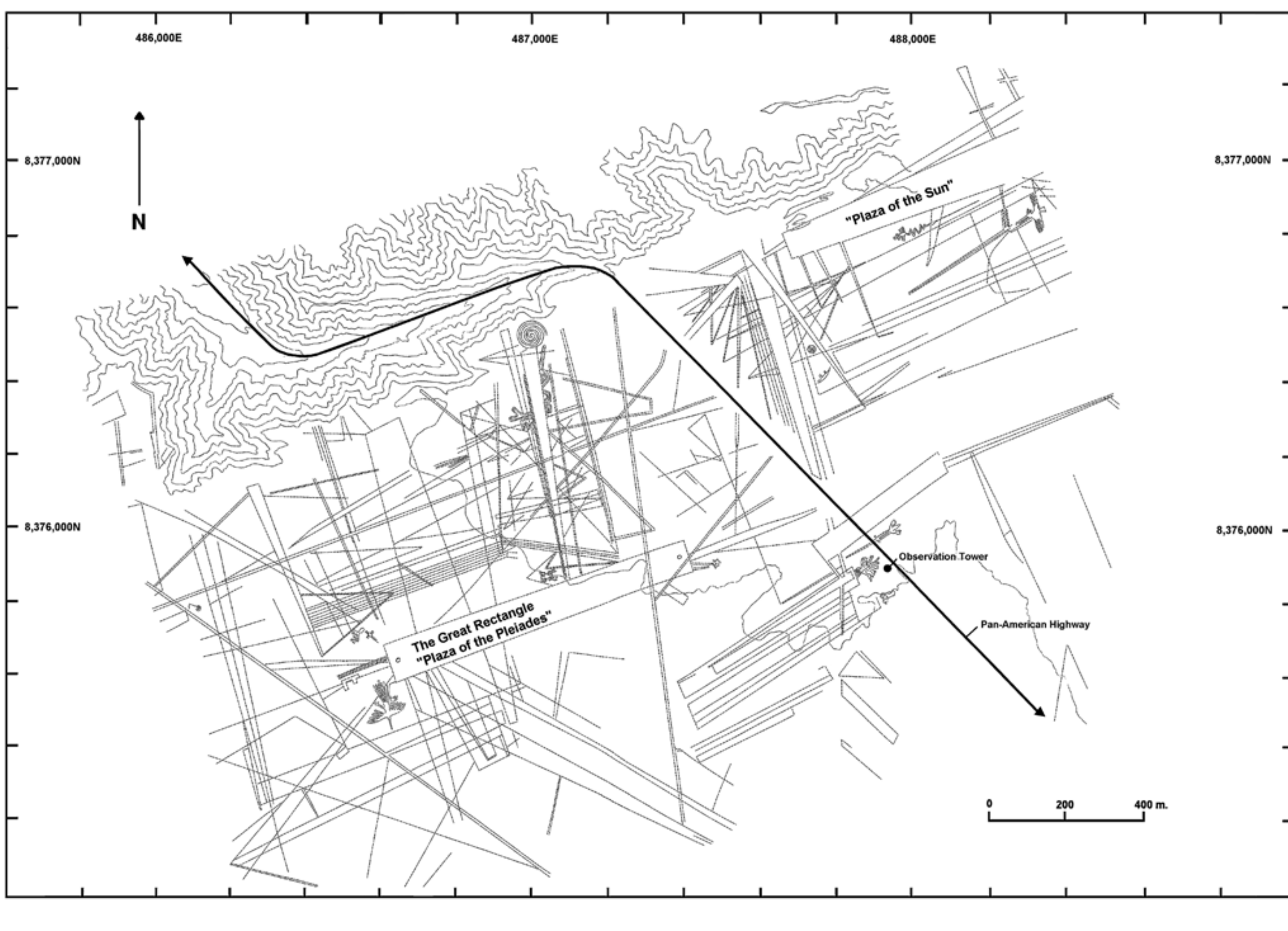


FIGURE 14.27. The types and locations of the terraglyph figures on the Nazca plains, Peru: These figures (sometimes hundreds of feet long) include about three dozen biomorphs (both plants and animals) and many geometric figures—trapezoids, triangles, rectangles, grids, curves, spirals, labyrinths, and many straight lines, the latter frequently radiating from points that have been called "line centers." There are also parallel straight lines and zigzags. Drawing by Sharon Hanna.



Geoglyphs are extremely difficult to date, although some sequencing can be detected when one figure overlies or cuts through another. A technique for measuring the amount of “desert varnish” that has formed since a figure was made has been developed by Dorn (see Clarkson 1990, pp. 167–168), but it is still not widely used or accepted. Clarkson’s (1990, pp. 142–143, 148–149, 152–153) maps show a clear relationship between line centers and archeological localities, which show a substantial correlation in the southeastern area from Nazca[10] times to the Spanish conquest, but associated in the northwest only from the Late Intermediate Period on (i.e., from about 1000 A.D.). There have been some attempts to date the biomorphic geoglyphs on the basis of style, particularly noting a generic similarity in subject matter to representations on Nazca pottery. The most striking of these is the shared motif of a killer whale holding a human trophy head. The presence of datable pottery sherds along some of the lines, particularly at the end points, provides evidence, albeit inconclusive, for dating the lines. The general congruence of the different kinds of evidence, which have no logical connection with each other, supports the suggested datings.

Aveni (1990b, p. 15) suggests that there have been five principal classes of explanation of the geoglyphs (ignoring such silly propositions as landing strips for alien spacecraft):

(1) The consistently most popular view has been that they were records or markers of astronomical or calendrical phenomena.
(2) One interpretation has centered on the alleged complexity of the geometry (neither adequately demonstrated nor analyzed, as Aveni points out). Laying out such forms would certainly have been an inexpensive way to teach builders what was needed to plan the construction of major edifices, such as temples.
(3) A central relationship to irrigation and agriculture involving alignments with respect to water courses would accord well with the local culture.
(4) It has also been suggested that the lines served as paths along which people walked, danced, or ran races, especially during rituals.
(5) Finally, the production of giant figures for the aesthetic appreciation of the gods has been suggested by some modern artists.

Aveni (1990b, p. 19) emphasizes that these interpretations are not mutually exclusive and, indeed, that other Andean evidence shows that lines may point equally to water sources or astronomical targets, both sacred, and may equally serve as paths for people performing rituals connected calendrically with the target area. Hawkins (1969, 1973, 1977) investigated the sites then known for potential alignments to the brightest 45 stars and those of the Pleiades, and the solar and lunar extremes; van den Bergh (1992) carried out a rigorous statistical analysis for common astronomical alignments among linear geoglyphs. Each of these investigations was essentially negative, showing no preference for alignments within 30° of the E-W points of the horizon. This effectively eliminates common alignments to the Sun, Moon, or planets. Hawkins’s analysis assumed bright astronomical targets, and ignored such “asterisms” as the dark clouds of the Milky Way. Aveni maintained that one of the problems with Hawkins’s approach to Nazca geoglyphs is, precisely, that Hawkins expected all lines or figures to show astronomical significance if the astronomical-calendrical hypothesis was valid. Aveni thought this to be unlikely even if Hawkins’s possible astronomical targets were well selected in terms of local astronomical thought (which he did not think they were). The van den Bergh work is based on a statistical consideration of the orientations of the lines, which largely eliminates the possibility of a common set of astronomical targets for all linear Nazca lines. This still leaves the possibility of separate alignments to specific, locally important astronomical targets by separate groups within the Nazca community, as well as the possibility of having different targets over the thousand years of the Nazca culture.

We now examine some of the proposals related to the biomorphs. The biomorphs are apparently limited to the northern part of the plateau. During the Nazca period, when most or all of the biomorphs were apparently produced, there is no overlap with the radial line centers, which, at that time, were probably limited to the southeastern part of the plateau. The biomorphs include plants, insects, spiders, fish, a pelican, and many other birds, such as a hummingbird, a condor, and a cormorant, a lizard or cayman, a killer whale, a dog or fox, and a monkey (Aveni 1990c, p. 99, fn. 28). Morrison (1978, p. 55) wrote, “If an animal figure fitted a constellation, and if a line that was part of the figure pointed directly to that constellation, then the astronomical interpretation could be taken as proven.” We think that this would be true only if by “fitted” one meant independent evidence for identification of a particular animal with a particular asterism and if it could be shown that different geoglyphs were conceptualized as parts of some larger astronomical or calendrical system. The most interesting item of this sort is the spider. This has been identified by Hawkins (1973, pp. 143–144) as the genus *Ricinulei*, an Amazonian spider. Maria Reiche (cited by Aveni, p. 18) said that the mark on the spider’s back pointed to Orion. As we have seen, the Kogi identified Spider as a goddess, who, like Toad, personified the center, which was, in turn, identified with the central star in Orion’s Belt. Hence, in this case, there is outside support, previously unknown, for Reiche’s interpretation. Reiche (Aveni 1990b) also thought that the hummingbird figure was aligned with the December solstice sunrise. Again, Hocquenghem’s Moche material shows hummingbirds marked by emblems that are probably symbols for key solar positions—not identified with the Sun god but accompanying him (cf., especially, Hocquenghem 1987, figs. 197, 202). Aveni (1990b) verifies Reiche’s alignment of the geometric figure associated with the Monkey as pointing to Benetnasch (Alkaid, η UMa) about 1000 A.D., rising in November at the beginning of the rainy season, but regards

[10] The Nazca culture is approximately contemporary with Moche.

any supposed resemblance of the stars of the Big Dipper and Canes Venatici to a monkey as "fanciful." A Moche depiction shows monkeys in the top of the "Tree of Life" accompanying a fertility scene of the copulation of the major god and a woman or goddess (Hocquenghem 1987, pp. 76–77; fig. 26). The scene is related by Hocquenghem to irrigation ceremonies and the beginning of the agricultural year. We know of no verified identification of Monkey and the Big Dipper, but such a suggestion was made for Mesoamerica long ago by Schellhas (1904, p. 20). Aveni points out that Hawkins thought that the spiral tail "might indicate a motion about the north pole." Aveni (Appendix I) points out some striking similarities of pattern with the Cantalloc spiral, including a general similarity of orientation, but does not mention that Reiche maintained that this geoglyph was also aligned on Ursa Major. Because monkeys are not native to the Nazca region, this figure, like the spider, may be derived from the Amazonian region. These remarks are not adequate for acceptance of Reiche's thesis, but they do provide some support for some of her ideas from iconographic evidence that Aveni thought was virtually lacking. With Aveni, we agree that Reiche's work needs fuller and more systematic presentation and "detailed critical assessment."

Hawkins's work was the first attempt to appraise the statistical probability that various geoglyphs matched astronomical possibilities. His final conclusion was that the number of alignments that he found was well within the limits of chance expectation, and therefore, there was no support for an interpretation of the lines as deliberately aligned on Sun, Moon, or stars whether for calendrical or astronomical purposes. One of the earliest results that Hawkins obtained was the determination that the two sides of a great trapezoid were aligned on the rising of the Pleiades in 610 ± 30 A.D., and he suggested to Morrison that the trapezoid might be called "The Plaza of the Pleiades" (Morrison 1978, p. 48). The name duly appears on Morrison's map, which is decidedly misleading, as Aveni (1990b, p. 21) points out, in the context of Hawkins's conclusion that such alignments were probably not deliberate. Morrison also refers to a trapezoid aligned on the rising Sun at the June solstice as "The Plaza of the Sun" and shows a parallel solsticial line crossing the outspread wings of the condor. Morrison also labels lines running due north-south.

The statistical analyses of Aveni (1990c) and of Ruggles (1990) were designed differently, but each used the massive data on line centers collected by Aveni. One of the striking features that emerged was that not one of the hundreds of lines mapped by the Aveni group led to a biomorphic figure. Partly for this reason, no attempt was made to consider the biomorphic geoglyphs nor, except when associated with line centers, the more complex geometric figures. In terms of published material, these are essentially new data and both the material and the analyses are more adequately published than in any previous work. One very striking characteristic discovered by Aveni is that straight lines tend to correlate either with water-flow direction or nearly perpendicular to water-flow directions to an extent that is unlikely to be due to chance (Aveni 1990c, p. 111).

However, lines also showed a higher than chance correlation with certain astronomical alignments, in both Aveni's and Ruggles's analyses. It should be kept in mind that Aveni's potential targets only partially overlapped those of Ruggles and that they used somewhat different criteria of reliability and different statistical techniques. Aveni (1990c, p. 98) found probably significant repeated alignments involving the zenith Sun, the Pleiades, α and β Centauri (or Canopus at nearly the same declination), Rigel, Capella, Regulus, and two of the lunar extremes.

Aveni thought that there was good support in the Andean literature for the deliberate nature of the alignments to the first four of these, and deliberate alignments to Rigel, Capella, and Arcturus seem probable for line center 11, which Aveni (1990c, p. 91) regarded as more likely to be astronomically oriented than any other line center.[11] It is interesting that line center 11 has a connecting line to the nearby line center 19, recorded by Ruggles as showing alignments within 1° of azimuth at "0 A.D." to the equinox setting Sun, the zenith passage rising Sun, the Pleiades heliacal set, and the Pleiades last dusk rise/first dawn set, a combination of events for which he found that "the nominal probability of this occurring by chance is less than 1 in 20,000." Line center 19 is very close to the Early Initial Period (Nazca) archeological locale number 1, and site 19 is near the archeological locale number 43, also of the Nazca period. Ruggles also found particularly interesting astronomical results at line center 45, which has 19 radial lines, of which 12 fall within 1° of a 'target' azimuth at 1000 A.D., three more fall within 2°, and three fall within 3° of his targets, giving a nominal probability level below 0.003. The site is close to the archeological locale 84 of the Late Intermediate Period, starting about 1000 A.D. There are no sites of preceding Middle Horizon (Wari) in the immediate vicinity. We find the congruence of the most probable archeological dates with the most probable astronomical dates impressive support for the view that as Ruggles (1990, p. 266) said, "at a few line centers astronomical considerations may have been an important, or even a prime, motivation in setting out the radial lines." Overall, although we accept Aveni's view that nonastronomical factors were important in laying out the geoglyphs, we think that there is good evidence that there were some deliberate astronomical alignments on the Nazca plateau.

New evidence of the astronomical interests of the Nazca peoples has recently been recognized. There is in the Brooklyn Museum a textile, reported, doubtfully, to come from the Paracas peninsula just north of the area of the Nazca figures. As we note below, however, an association with Nazca is likely. The textile is briefly described with a good set of line drawings by Martin (1991) and more fully by Haeberli (1996), who maintains that it is a calendar. The style and iconography of the textile indicate that it belongs to Nazca 2 (the second of the five chronological stages of

[11] Aveni states that line no. 4 aligns with the set point of Arcturus to within 1° in 500 A.D. with a best fit in 650 A.D. and that it rose heliacally within a day of the solar zenith passage at these dates. Line 11-1 aligned to the set of Rigel, and line 11-6 to the rise of Capella in 500 A.D., and solar events can be connected with these stars also.

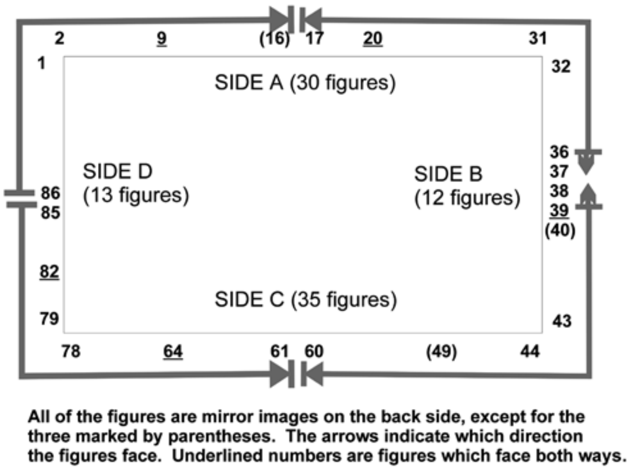


FIGURE 14.28. The schematic contents of a Nazca textile as described by Martin (1991) and Haeberli (1996), who maintains that it is a calendar. Drawing by Sharon Hanna.

Nazca—see Table 14.4). A diagram of the textile is shown in Figure 14.28 and the individual figures in Figure 14.29.

In the center of the textile are four rows of eight representations, each showing a full face view of the head of the "Oculate Being" (a head with rayed appendages). Such heads are associated elsewhere in the Andes with the Sun. Around the edges in the front are 90 'figures'.[12] On the reverse, there are mirror images of 87 of these "figures" and back views of three. For ease of reference, scholars identify the figures according to numbers assigned by d'Harcourt (1962), clockwise from the upper left. There is no firm evidence that the sequence was to be read clockwise, and the beginning point is structurally inappropriate in terms of the sequence of figures. The style of these figures seems to be closely related to textiles and ceramics of Nazca 2. Haeberli (1996, pp. 126–136) identifies 48 different figures, 29 of which appear only once and 19 of which are repeated from two to six times. Many of the figures are repeated in closely similar forms sharing comparable iconographic attributes, but many others show minor variations and substantially more lumping may be possible. The iconography of the figures emphasizes agricultural plants (45% are associated with plants and fruits [Haeberli 1996, p. 136]). Fish and water animals, important elsewhere in Nazca culture, are unimportant on this textile. The rivers of the Ica and Nazca valleys normally carry water at the present time for somewhat less than six months a year (Haeberli 1996, p. 136), mostly between late September and March. Patrick Carmichel (*private communcation*, 1996) informs us, on the basis of his field work, that the most crucial factor in Nazca agriculture is not rainfall but runoff from the Andes between January and March. Nearly all agricultural work is done from January to June. Curiously, from our viewpoint, the first work of the new agricultural season is the harvest of the crops planted in the previous May or June.

Martin (1991) says that there are "about 30" unique figures, plus repeating groups, very close to Haeberli's 29 and 19. The sides have been lettered clockwise A, B, C, D. The top, side A, has 30 figures, and the right end, side B, has 12; the bottom, side C, has 35, and side D has 13. In Haeberli's (1996, p. 139) interpretation, the 90 figures may refer to 3 months of 30 days each; that is, each representing one day, but the figures of sides B and D also refer to months. He thinks that side B represents 11 months of 30 days each and a "mnemonic indicator" for the 35 days of side C. He argues that side D represents 12 synodic lunar months (354 days) with a "mnemonic indicator" to treat the 11 larger figures of that end also as days to be added to these months to give a total of 365 days. This complicated and unclear double usage seems to us unconvincing. His primary argument, that repetitions of figures segment the sequence in ways that suggest deliberate intent and possible lunar interest, seems much more likely. The figure repeated as numbers 2, 32, 52, and 79, if read CW, would begin the sequences of side A (2), side B (32), and side D (79). If the sequence was read CCW, these figures would become the last members of those sides. A number of items on side A are repeated on sides C and D, and two items on side B are repeated on side D. All of this makes it likely that all sides are composed of the same kinds of units. This in turn may mean that the mirror image figures on the back are also the same kind of units, but that the three figures that show back views of figures on the front are to be omitted. If the units are counted as days, we would have $90 + 87 = 177$ days, which is a mean interval of six synodic months and the most frequent eclipse interval. Although we do not think that the identification of units as days is fully demonstrated, for the purposes of developing hypotheses, in the remainder of this section, we treat them as such.

The sequential ordering of the figures is puzzling. Four quadrants are defined by the directions indicated by the feet of the figures (Figure 14.28). Feet face in both directions on figures 9, 20, 39, 64, and 82. On side D, figures 85 and 86 face away from each other; figures 86 to 1 on side D and 2 to 16 on side A form an upper left quadrant of 21 figures. These meet an upper right quadrant of 21 figures (17–37), in which the feet of figures 36 to 17 face toward the figures of the upper left. However, figure 37 faces away from the other figures of the upper right quadrant and toward figure 38. In the lower right quadrant of 23 figures (38–60), figures 39–60 have feet oriented toward the center, except for figure 38. Finally, the lower left quadrant contains 25 figures (85–61) with figure 61 facing 60. In essence, all four quadrants face toward the center, except for figures 37 and 38 which seem to suggest a division into upper and lower halves. None of the directional feet orientations seem to indicate continuous movement around the entire textile either CW or CCW, but the arrangements pointed out by Haeberli do suggest a continuous sequence. Neither is there any indication of how the 90 figures on the front are to be related to the corresponding 87 figures on the back. This would seem to be difficult to understand either in terms of weather or astronomy, because no three-month period could be followed by another that is so closely similar. DHK thinks, therefore, that the primary purpose of the images was to extend the

[12] Some of the "figures" are scenes: a man leading a llama, three anthropomorphs standing together, a cat associated with a tree, and others.

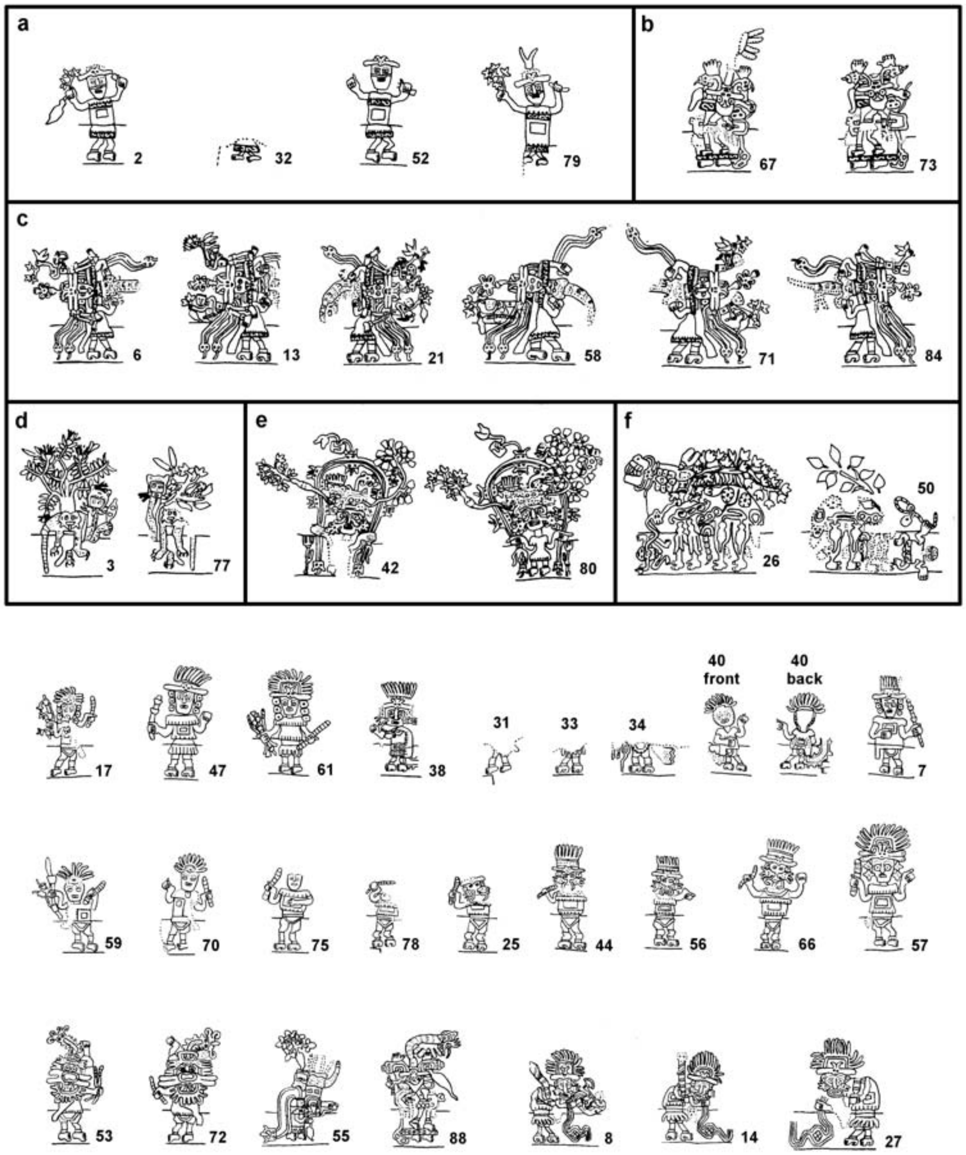


FIGURE 14.29. Individual images from the "Paracas" textile. Drawings by Sharon Hanna.

numerical frame in which ritual or astronomical events could be placed. In later Andean times, the chronology of the agricultural season was primarily determined by the Moon. The 177 days of the textile suggests that it has a major lunar component. The 32 virtually identical heads in the center of the front of the textile should also be meaningful. If they are solar representations, one would expect them to represent either days or years. If the diverse figures of the border represent a continuous sequence of days, it seems unlikely that the figures of the center should also be days. If they represent years, then the association with the 177-day eclipse interval immediately suggests the Mayan eclipse cycle of 11,960 days, roughly $32\frac{3}{4}$ years (the *Fox*; see §§5.2.2, 12.11, 12.12). If we have a period of 177 days representing the agricultural season, it should begin near the December (summer) solstice with the melt water from the Andes. In this textile, there are three different sets of iconographically defined figures marked with a repeated S-shape. The figures of one such set (2, 32, 52, and 79) are positioned so that one figure is at the beginning/ending point for three of the four sides. We have argued that S-shaped designs elsewhere seem to have the function of marking intervals, and DHK regards that as a possibility in this textile. Another set of figures appears at positions 67 and 73. For present purposes, however, the most interesting set (figures 6, 13, 21, 58, 71, and 84) consists of representations of a humanoid figure with serpents emerging from the head (as hair?). The humanoid figure is holding a smaller figure that in turn is holding a plant and possibly a bow and arrow. The main figure is shown devouring an animal, identified as a feline by

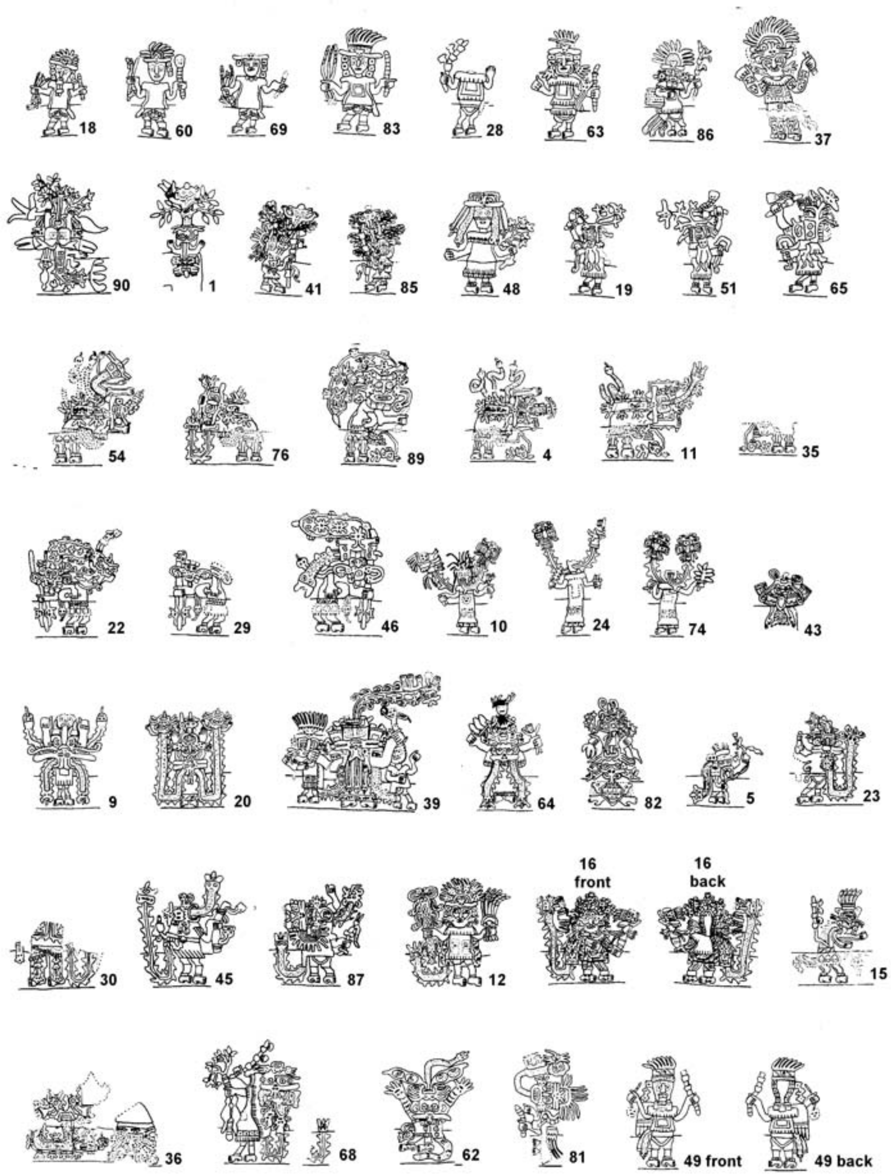


FIGURE 14.29. *Continued.*

Martin (1991). We have discussed feline imagery associated with the Sun and occasionally other figures among the Moche. A deity eating a feline seems iconographically reasonable as an eclipse reference. Six such representations could easily signify a series of locally visible eclipses in a *Fox* cycle. In Mayan tables, the entire 11,960 day sequence is represented. If such a sequence was compressed into the frame of a single year (or half-year), the resulting record may resemble the Nazca textile. The compression may be accomplished through the placement of distinctive figures at critical intervals in the sequences marking a remainder in days from the 1st eclipse of the series. In making such a calculation of remainders, one would need to subtract integral numbers of years. In later Andean cultures, both the 360-day and 365-day years were in use. A modern calculation suggests that the intervals on the textile are appropriately close to eclipse intervals in the *Fox* if calculated with a 360-day year, but no such similarity occurs with the 365-day year. However, a complete match with any particular eclipse series has not been found within the assumed dates of the Nazca culture.

Another iconographic set of figures shows a cat with a tree (figures 3 and 77). Again, the feline association may be solar. The interval of 74 between the figures may be significant also. Assuming that the 32 central "Suns" represent 32 years, the slippage of the 360-day year relative to the tropical year would be ~163 days in 31 years ($31 \times 5.25 = 162.75$). In the figures sequence, the addition of 74 to 90 yields 164, an extra day added possibly to compensate for the slippage in a quarter of a year. Thus, the similar figures may be markers of the positions of an equinox (probably the March equinox) or a solstice (probably the December solstice) from cycle to cycle. If, as previously indicated, the beginning of the 90-figure sequence coincided with the onset of the rainy season in Nazca, then the December (summer) solstice would appear near the beginning of the sequence on the reverse face of the textile. DHK would suggest that figure 2 marks the Spring (September) equinox of the starting year and that figure 3 is to be understood as figure 3 of the reverse, marking the 92nd day in the solar calendar.

A fifth iconographic set (figures 42 and 80) shows a figure with a feline head-dress and holding an arch ending in what DHK thinks are animal heads (but which Martin interprets as vegetation); he interprets the arch as a rainbow snake. Stemming from the arch and head-dress are agricultural plants. Iconographically, these characteristics closely parallel those of the Moche Thunder Twin,[13] although the artistic style is utterly distinct. The interval noted by the two positions is 38; this interval is approximated by taking the difference between the synodic period of Jupiter and subtracting the length of the 360-day year. Indeed, the Maya may have used 398 days for this period (see §12.22). Thus, one may suggest comparable and consistent interpretations of eclipse phenomena, the tropical year, and Jupiter relative to a calendar year of 360 days.

The two llamas of this textile (26, 50) could have a celestial connotation because llamas in the Andean tradition were widely identified with a dark cloud figure near the Milky Way associated with rain and fertility. The llamas of the textile are associated with crop plants, and these in turn with fertility. In Quechua belief, the next dark cloud figure to the llama is the fox, and it is, therefore, interesting that one of three figures wearing fox skins, according to Martin (1991), is in position 51, next to one of the llamas.

More recently, Darrell Gundrum (2000) has also studied this textile. He maintains that a single set may be read in two directions (A to B and back to A, with B counted only once). This enables him to suggest longer intervals within the course of a year. He also suggests that figures on the ends of the textiles represent the synodic lunar month (on one end) and the sidereal lunar months (on the other), and he identifies the llama on the textile as the dark cloud constellation known to the Incas as "the llama." These are interesting possibilities, but the identification of some figures as days and others as months makes it much harder to determine how repetitions of figures should be interpreted. However, Gundrum specifies iconographic associations marking his shifts, and if other such textiles are discovered, his interpretations may become checkable.

For the first time in the Andean region, we have a series of representations in which iconographic details of different kinds of (probably) supernatural figures are placed in a numerical context. If the suggestions made here for the interpretation of this textile are correct, then the astronomy it contains is surprisingly complex and observationally sophisticated. If similar interpretations can be made for other figures of the textile, that will be the best support we are likely to obtain. However, it may eventually be possible to relate some of the figures to Nazca alignments (on the basis of similar iconography) or to quipus (on the basis of shared numerical features). In any case, the possibilities are exciting.

14.2.4. Tiahuanaco (Tiwanaku)

At ~4000 m (more than 13,000 ft) above sea level near Lake Titicaca on the high plains of Bolivia stands the monumental site of Tiahuanaco. The majority of the local people speak one of three Aymara languages (distantly related to Quechua), but an important minority speak Uru or the closely related Chipaya. The now extinct Puquina language was once fairly common in the area. Kolata (1993, pp. 33–35, 66–69) suggests that all of these languages were important in the Tiwanaku state. The Aymara name for the site was Taypikala, "the stone in the center," because it was near the center of the world (Kolata 1993, p. 8). Building at the site probably began in the late centuries B.C., but the massive influence of Tiahuanaco-related culture throughout the Andean region occurred during the Middle Horizon. We now know that this influence was mediated through the conquests of Huari (Wari), which many scholars regard as the first major conquest state in the Andes. Huari arose in opposition to Tiahuanaco, but shared many features with it. The site of Tiahuanaco is surrounded by a moat, within which lived a dense population. The general orientation of the site is to a fairly precise east-west line. Massive buildings and religious sculptures are common throughout the site.

Tiahuanaco has probably been the subject of more fantasy than has any other archeological site in the Americas, although hardly surpassing the native belief that the Sun, Moon, and stars were created at Tiahuanaco (Kolata 1993, pp. 5–6). Much of this fantasy has depended on the archaeoastronomical calculations of Arthur Posnansky (1914, 1945–1947/1957), who maintained that the monuments had been erected when the obliquity of the ecliptic, ε was $23°8'48''$, which he said indicated a date of 15,000 B.C. The interest of the technical procedure and the sorry example of misused archaeoastronomical evidence make this work worth mentioning as a cautionary tale. The date depends on several crucial factors. We accept that the variation in ε is known, at least on shorter time scales (see §4.4, especially equation 4.22); but even if an extrapolated value for ε were sufficiently accurate, the assumptions that monuments were aligned to particular solar phenomena to such accuracy and that the accuracy of the alignments could be maintained to seconds of arc over 170 centuries are highly questionable. Although we would not dispute the possibility of solar alignments at the site, we note also that many of the monuments were completely unexcavated in Posnansky's time.

Finally, Posnansky assumed that the back- and foresights were relatively stable. We are willing to accept some instability, but Posnansky, curiously, argued that Tiahuanaco had

[13] Associated with either Jupiter or Saturn (see previous section for the argument).

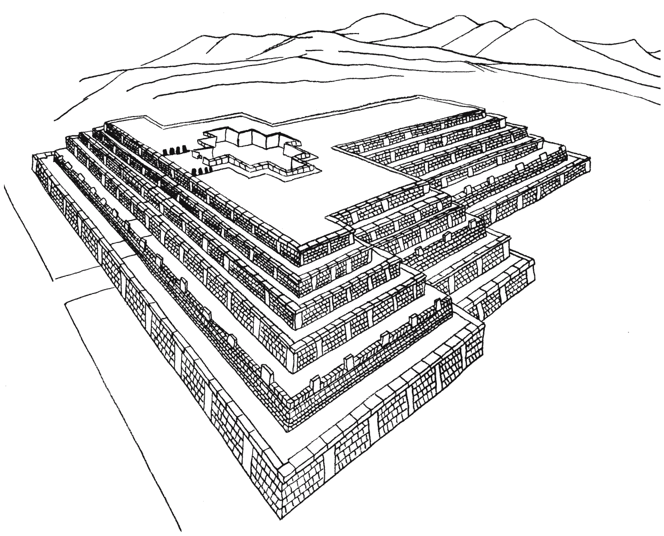


FIGURE 14.30. The Akapana monument at Tiahuanaco (Taypikala). Drawing by Sharon Hanna, after J. Escalante, in Kolata 1993.

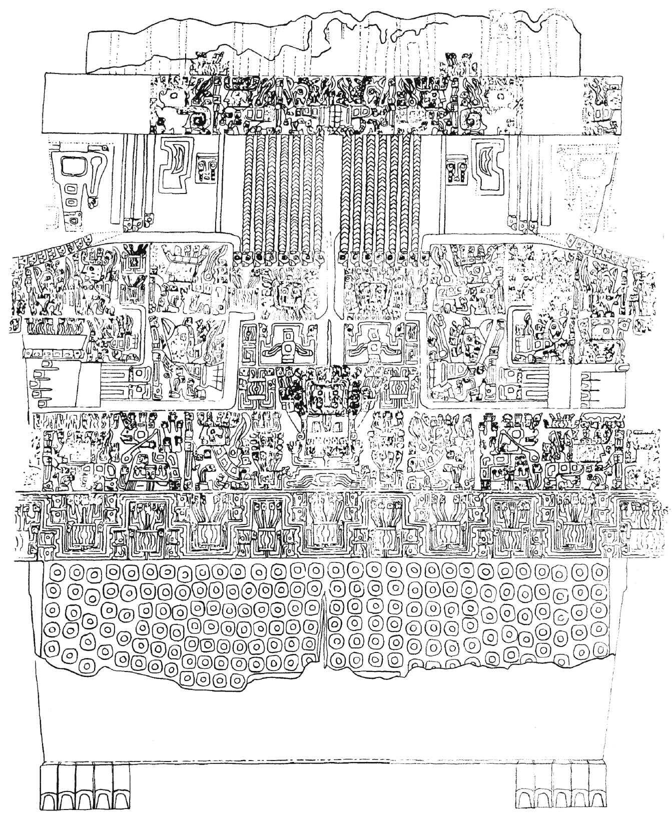


FIGURE 14.31. The Bennett Stela of Tiahuanaco, Bolivia: Zuidema interprets the iconography calendrically. He suggests that the 177 dots on the "skirt" of the major deity figure represent days, measuring six lunar months. Drawing by Sharon Hanna.

been uplifted from sea level since the site was first occupied. How this could be done without disturbing the alignments on which his date was determined was, apparently, not seen as a difficulty.

Most of the reliable archaeoastronomical information from Tiahuanaco deals with the Akapana monument (Kolata 1993, pp. 104–129. See Figure 14.30). The basic shape is that of a step-fret (which has also been described as "half of an Andean cross"), with the "tail" to the west. Six stages rest on a large basal terrace and a sunken court on top of the pyramid is in the shape of a full "Andean cross." During the rainy season, this filled with water that was carried to ground level through an intricate series of stone-lined drains, alternately buried in the pyramid and flowing on the surface of the terraces. The structure is aligned to the equinox, and there were stairways both on the east and the west sides. At some point, the drainage channels ceased to work, and subsequently a series of offerings were made at various points around Akapana, probably in the early 7th century A.D. (Kolata 1993, pp. 122–124, 133). Hundreds of broken polychrome ceramic vessels were found in one cache. These contained a dominant motif of decapitated human heads. Elsewhere, the archeologists found 21 human burials (mixed with llama bones), 18 of which lacked skulls. Several others lacked lower limbs or parts of the spinal column. The bones lack cut marks, which led Kolata to infer that they had not been sacrificed or butchered at the time of death. However, Sullivan (1996, pp. 391–393) points out that modern Indians have a technique of killing and butchering llamas, in which great emphasis is placed on not harming the bones and in which the same parts of the body are often removed. There seems to have been some equivalence of human and llama sacrifice. Everyone accepts a substantial integration of ritual and religious practices with astronomically determined calendrical rituals, but there is little agreement on details.

The "Gateway of the Sun," found in the Kalasasaya temple, has been repeatedly interpreted as a calendar, but none of the analyses is convincing in detail. The great monolithic gateway centers on the figure of a god with solar snake rays around his head, holding two staves. He is regarded as a prototype of Thunupa, the Aymara weather god ruling thunder and lightning, the equivalent of Thunder of the Moche ceramics and of Illapa or Viracocha of the Incas. The god is accompanied by three rows of eight winged anthropomorphic beings in profile, on each side, totaling 48 in all.[14] Below these figures, a 4th frieze shows 15 unidentified images in peculiar serpentine frames, alternating above and below.

Zuidema (1983) has offered a calendrical interpretation of the iconography of the Bennett Stela (Figure 14.31). He suggests that the 177 dots on the "skirt" of the major deity figure represent days, measuring six lunar months. This

[14] We see 40 human-headed and 8 bird-headed beings; cf., Sullivan (1996, Fig. 10.2).

seems to us reasonable, particularly considering that this is the most important eclipse interval. Moreover, the dots are arranged in a curious abacus-like way, suggestive of arithmetical calculations rather than directly of astronomy. There are 5 lines of 5 dots, 3 lines of 6 dots, 3 lines of 7 dots plus a line with only 6 dots, but extending to the 7th position, and 4 lines of 6 dots on one side, totaling 94 and, on the other side, 8 rows of 6 dots and 7 rows of 5 dots, totaling 83. The subtotal of 94 suggests a rough calculation of a quarter of a year. The monument also shows 12 human-headed figures, with solar snake rays, 2 llama-headed figures, 8 bird-headed figures, and 3 unidentified animal-headed figures, generically, 13 animal heads (possibly connected with lunar months) and 12 human heads (possibly representing solar months). The monument shows agricultural plants and hallucinogenic cacti along with the human and animal-headed figures, and Kolata thinks that it represents a deliberate balance between llama pastoralists and agriculturalists.

Our knowledge of the calendar and astronomy of Huari is very limited, but Anders (1986) thought that the layout of Azangaro, a Huari site, indicated that it was a ceremonial center, deliberately planned to incorporate cosmological and calendrical principles. The site is walled and laid out in three major divisions, with 13 large courtyards in the northernmost section and five smaller courtyards. To the southeast, in the central division, a long central corridor is flanked by 20 rows of rooms on each side, separated by corridors. Some of the corridors were blocked by cross-walls. Nineteen of the rows contain eight rooms on each side. The 20th row has eighteen small rooms on each side. A conduit for water ran below the central corridor, and subsidiary conduits are found in the SW section of the central division. The southern division had three very large subdivisions containing architectural structures that are irregular compared with the other divisions. This complex seems to have been the living quarters of the ruling elite. A final architectural complex at the gate controlled access. There was also a shaft tomb burial, apparently associated with one of the water conduits. The water-damaged skeleton was probably that of a woman.

Anders postulated that the eight rooms in a row represent the days of an eight-day "week," that each was associated with a particular day of the year, and that each was assigned as temporary quarters to a particular individual or group responsible for rituals associated with that day or with longer intervals incorporating that day. She attempted to match the material with aspects of Zuidema's reconstruction of the Inca calendar (see §14.2.5) and even tried to assign particular rooms to the equivalents of particular days of specified Inca months. We do not find the latter endeavor convincing, but there does seem to be an emphasis on the numbers 8, 13, 18, 40, 360, and 361, which matches other Huari evidence. The water channels running beneath the site, the associated (presumed) female burial, and the emphasis on 13 and 18 (2×9) are all reminiscent of Chavin. The alignment is, unfortunately, given only in terms of magnetic north, but it is clearly SE-NW in general terms. It would be interesting to know how closely it resembles Chavin in that regard.

A surviving Huari textile with two identical panels has been interpreted by several scholars as a calendar (originally by Lommel 1967; most fully by Zuidema 1982a, pp. 221–225).[15] Anders (1986, III, pp. 867–868) discusses features shared with Azangaro. In each panel, there are 36 columns of 10 circles each. There are 3 columns of circles above each of 12 deity/human figures. Below the 12 figures are 61 front-facing heads, giving 73 heads in all. The circles are color-coded—five different colors created by their placements—45 diagonal lines of circles. From these, one can recognize patterns of 5×72 and 8×45. Taken together, these suggest a 360-day calendar arranged in 12 months of 30-days each with probable subunits of 8 and 10 days. Zuidema suggested that the human figures and heads represented 5 days each, creating a parallel reference to a 365-day year. Even if they only represent 1 day each, the figures and heads would represent a definite and often-used fraction, viz., one-fifth, of a 365-day year. In this widely accepted calendrical interpretation, the doubling of the panels refers to a two-year interval.

Conklin (1982) has drawn attention to a number of quipus from the Huari horizon. These quipus consist of a main cord with subsidiary pendant cords, wrapped with colored threads. The cords and threads indicate numerical values both by position and by color and seem to use binary, base 5, and base 10 notations. Both the color coding and the use of units of 5 and 10 support the previously proposed interpretation of the Huari textile.

14.2.5. The Incas

The Incan empire in existence at the time of the Spanish conquest stretched for most of the length of western South America, from Colombia in the North to central Chile in the South. It was efficiently administered by a bureaucracy answerable to "the Inca," who claimed descent from the Sun. The Incas were a Quechua-speaking people, a language still spoken by Indians in the area.

There are no generally accepted written documents from the Inca period, but there are five classes of evidence concerning their interest in and recording of astronomical phenomena. First, a considerable amount of material was recorded in colonial sources after the Spanish introduced writing, both by Spaniards and Quechuas. Second, there is also much information to be obtained from modern Quechuas, who still make extensive use of astronomical observations. Third, iconographic representations are sometimes useful. Fourth, quipus were a complex series of knotted strings used for counting. Finally, *ceques*, which have been claimed to be directional lines of sight running from the capital city of the ancient empire, Cuzco ($\phi = -13.5°$), have been interpreted astronomically.

Quipus were used to record information about chronicles and genealogies, taxes and tribute (with census and treasury

[15] Unfortunately, the previously cited discussion by Kolata (1993, p. 135) confuses details taken from the analysis of this textile with Zuidema's study of textiles depicted on figures of the Gateway of the Sun, the Bennett Stela, and the Ponce Stela.

information), legal records, and astronomy (Murra 1975, pp. 243–254; Conklin 1982, p. 261). Depictions of a secretary, a treasurer, and an astrologer, all of whom are using quipus, are shown by Guaman Poma (Zuidema 1982, p. 232; Bauer and Dearborn 1995, pp. 57–58). Nordenskiold (1925) analyzed a number of quipus that he thought contained astronomical data. The Ashers (1972) analyzed the numerical content of over 400 quipus but were not convinced that any were astronomical. The major problem in attempting to interpret quipus is that we can recognize the contents only from the numbers recorded, but if we select only those in which the numbers match our astronomical expectations, we may be picking out accidental correspondences. This is the reason why Nordenskiold's interpretations are usually rejected. Zuidema (1989) interprets a particular quipu as calendrical, which he claims replicates the organization of days into higher groupings of time periods.

Zuidema has written extensively on the ceque lines and associated *huacas*, or shrines, and has worked closely with Anthony Aveni in attempting to locate still existing huacas. They postulate observation points in the city of Cuzco, from which the ceque lines could have been used to indicate directions of risings and settings of Sun, Moon, and stars (Zuidema 1977, p. 233). Cristobal de Molina and Juan Polo de Ondegardo specifically say that the ceques were used to observe astronomical events on the horizon and that huacas were used for counting in the calendar, each huaca representing a single day (Zuidema 1977, p. 220). The chroniclers specify that were 328 huacas on 41 (or 40) ceque lines divided among the four world quarters so that there were nine ceques incorporating three groups of three huacas each in three of the quarters and two groups of seven ceques in the fourth quarter. Zuidema maintains that this number was calendrically important for two reasons. First, it was composed of 12 sidereal lunar months ($12 \times 27\frac{1}{3} = 328$); second, it is the interval from June 9 (the first heliacal rise of the Pleiades) to May 3 ("some two weeks after their last heliacal set of the evening" [Zuidema 1983, p. 235]). The association would be more convincing if the two phenomena coincided exactly. Zuidema (1982a, p. 208) also points out that the 41 lines, multiplied by 8 (the number of days in an Andean week) also yields 328 days. Zuidema (1977, p. 229) discusses the evidence for such a week. He does not point out that the Spaniards habitually referred to their seven-day week as *ocho dias*, "eight days," and this may well be the basis for the attribution to the Incas. Guaman Poma mentions that one of the duties of a calendar expert was to know the date of Sunday, which may refer to an indigenous seven-day week. Bauer and Dearborn (1995, pp. 64–65) express strong doubts about Zuidema's views, but they are mistaken in thinking that no other group used sidereal lunar months[16] calendrically. Zuidema (1977, p. 247) also emphasizes that there are three repetitions of groups of huacas totaling 73 each. He regards these as references to a 73-day interval forming $\frac{1}{5}$ of a solar year. He also argues that they are useful in the Venus cycle ($8 \times 73 = 584$) in what he calls the "double-sidereal lunar year" ($328 + 329 = 657 = 9 \times 73$). Finally, Zuidema (1977, p. 230) asserts that the Incas used a 16-year period possibly related to Venus ($16 \times 365 = 5840 = 10 \times 584$).

Zuidema and Aveni thought that the *ceques* of Cuzco blended observational horizon information with religious and societal organization. Zuidema's analysis of the social implications of the ceques is based on a statement of the Anonymous Chronicler (quoted by Zuidema 1977, p. 239):

> [Pachakuti Inca] divided the population of Cuzco into 12 parts and ordered that each part would take up the name of its month and of the occupation carried out then, and that at the beginning of its month, the group would come out on the central plaza, announcing its month, and playing trumpets in order that everybody would know.

From Cobo, Zuidema received further information that each of these groups was responsible for caring for three ceque lines and that each group was associated with a *sucanca*, or horizon pillar, marking the months. See the extended discussion of Bauer and Dearborn (1995, p. 35), who think that one of the best accounts of these pillars is that of the Anonymous Chronicler. Apparently, the sucancas were sometimes counted as huacas and sometimes distinguished from them. Ten of the 12 groups are named for the first 10 rulers in the genealogy of the Incas, from whom they claimed descent. Two were named for groups that had been absorbed into the Inca empire (Zuidema 1964, *passim*). One of the latter was the Uma or Oma (Aymara "water"), who claimed descent from *Mama Anahuarque*, the goddess identified with Anahuarque Mountain. Zuidema (1977, pp. 239–240; 1982, pp. 220–221) associates them with the month Uma Raymi (roughly October) and with the ceque Anahuarque, both of which seem reasonable. However, some doubt is cast on this attribution, because the town Uma (modern San Jeronimo) is not in the direction of the Anahuarque ceque, as seen from Cuzco. This is still the best correspondence between the general statement of the Anonymous Chronicler and specific details.

The premise that the ceques are fairly straight lines has controlled the archeological identification of particular huacas, except where contrary evidence is particularly strong. However, Bauer and Dearborn (1995, Ch. 4) have shown that the premise is wrong and that any astronomical explanation must be substantially more complicated than those that have been proposed. Actually, ceque lines join huacas, but the huacas associated with particular ceque lines do not lie in a straight line (Bauer and Dearborn, Map 6), and the azimuths of the individual huacas as viewed from Coricancha may vary more than 30°. In the case of the alleged Pleiades rise line, none of the certainly identified huacas lies within 10° of the true Pleiades rise line with respect to the observed horizon, and there is no direct statement in any of the colonial literature that ceque lines or individual huacas were aligned on sidereal risings. In addition, many huacas of a single (not necessarily straight) line are not intervisible, and in some cases, the terminal huaca is either invisible or not on the horizon as viewed from Cuzco.

[16] We note that the term "sidereal month" is sometimes used to denote intervals that may approximate the length of the month, but do not, in fact, involve the Moon. Thus, for example, the Kogi 20-day "sidereal months."

These objections are strong enough to make the particular astronomical interpretation proposed by Zuidema and Aveni seem unlikely. Nonetheless, the idea that particular huacas have some sort of astronomical identification or association seems strongly supported by the literature. If they somehow map celestial points, no one has yet convincingly demonstrated how they do so.

Several sources clearly indicate some kind of relationship between asterisms, sacred places, lineage groups, and animals. Although Andeanists have payed little attention to planets, other than Venus, there are also some indications of important planetary deities. The earliest extensive account is that of Cobo[17] (deriving from the now lost report of Juan Polo de Ondegardo, ~1559, published in abstract form in 1585):

> They thought that there was a patron in heaven for each of the animals and birds that provide for their preservation and increase. This function was attibuted to several constellations and stars. And they thought that all of these patrons came from that group of small stars commonly known as the Pleiades, which these Indians called Collca. . . .
>
> All herders respected and made sacrifices to the constellation called Lira by the astronomers and known to the Indians as Urcuchillay. . . .
>
> They took great care in worshiping another star called Machacuay. They thought that this star watched over snakes, serpents, and vipers. . . .
>
> In short, they identified a star in the sky for every species of animal and for this reason they worshiped many stars, and made sacrifices to them. Here are the names of some of the other stars: Topotoraca, Chacana, Mirco, Mamana, Miquiquiray, Quiantopa, and others. In fact, they had names for all the stars of the first magnitude, the morning and evening star [Venus] and the most noteworthy signs and planets.

A still more explicit account is that of the Anonymous Chronicler (writing ~1570, according to John Rowe 1980, p. 74), who gives Quechua names and characteristics for the planets. At that time, there were still people living who had been adults at the time of the Spanish conquest. This testimony is important in the astronomical interpretations of Sullivan (1996). According to the source, as translated by Sullivan:

> To other stars, like various signs of the zodiac, they gave various duties to care for, guard, and sustain; some in relation to the flocks, others for the lions, others for the serpents, other for plants, and so on for all things.
>
> Then some groups said that in each one of these gods, or stars, there existed the ideals and models of those living beings whose welfare was their responsibility; and so they said that such and such a star had the shape of a lamb [i.e., llama], because it was its duty to protect and conserve sheep [llamas].
>
> [Venus, called *Chasca*, "tangled or disheveled hair"] . . . casts dewdrops upon the earth when she shakes her hair."
>
> They called Jupiter *Pirua*, stating, first of all, that the great *Illa Tecce* [Wiracocha] had ordained that this planet be the lord and guardian of the empire and provinces of Peru and of its republic and lands; and therefore they sacrificed to this planet. They entrusted to this god their granaries, treasure, and stores.
>
> To [the planet] Mercury—*Catu illa*—is given responsibility over matters pertaining to merchants, travellers, and messengers.
>
> Mars is *Aucayoc*, "he with enemies".
>
> Saturn is *Haucha*, 'fierce', [responsible for] carnage, pestilence, and famine, and for lightning and thunder; and they say he had a staff, which, along with his bows and arrows, he used to punish and thrash mankind for its misdeeds.

It is interesting to note that *illa*, part of the Quechua name of Mercury and mentioned in the account of Jupiter, means "male twin."

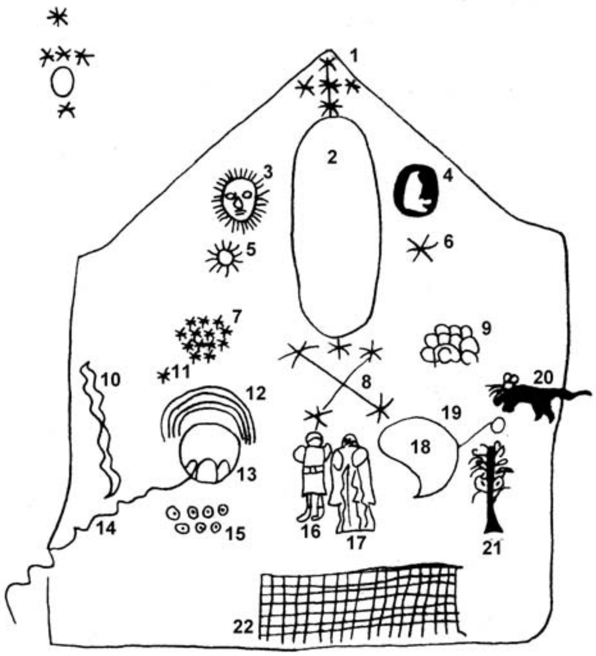
It has been claimed that some of these descriptions are too European to be valid for the pre-Hispanic Quechuas, and therefore, the entire testimony is suspect. However, most historians hold that it is a mistake in principle to reject the explicit testimony of a usually well-informed source unless it is directly contradicted by another well-informed source. No one has challenged the Andean accounts of the World Ages, which we discuss shortly, despite their generic similarity to certain European accounts.

Perhaps our fullest representation of the relationship of temples, gods, planets, asterisms, weather, and general cosmology among the Quechuas is the diagram of Pachacuti Yamqui Salcamayhua, with annotations in Spanish, Quechua, and Aymara (Figure 14.32). It is very important evidence for understanding how to interpret astronomical myths not only among the Quechuas, but also among the Andean peoples generally.

Zuidema (1964, pp. 94, 219, 227–231, 235) has some interesting remarks on the Peruvian accounts of the World Ages (Pachakutis) or Suns. There are possible astronomical implications in this concept. The alternate name, Sun, suggests a basis in solar phenomena. According to Molina, there were four past ages, each ended by a different kind of catastrophe, and the Incas were living in the fifth age. A reference to four past ages, called *runa* ("people") is given by Guaman Poma de Ayala. The first, *Uariviracocharuna*, associated with the god Viracocha, lasted 800 years; the second, *Uariruna*, lasted 1300 years; the third, *Purunruna*, lasted 1100 years; and the fourth, *Aucaruna* ("warriors"), lasted 2100 years. A very full account is given by Montesinos, who defined an *Intip* ("Sun"), as 1000 years and a *Pachacuti* as 500 years. He gave a full list of rulers, covering all the Suns and gave the name Pachacuti to nine rulers, each of whom lived at the end of one half-Sun and the beginning of another. The historic Pachacuti Inca is usually supposed to have begun his reign in 1438, and Zuidema asserts that 938 may have been the mythical onset of the reign of Manco Capac, the "first" Inca. The date is curiously close to the beginning date of the Mixtecs, day 1 Crocodile year 1 Reed, calculated by DHK as the spring equinox of 936 A.D. (cf., 12.18). Apparently, Montesinos's beginning point for the first age was 4500 years prior to Pachacuti IX (9×500). Calculated from 1438, the beginning date would have been –3062 (3061 B.C.). It is interesting that the last three World Ages of Guaman Poma also total 4500 years.

The interpretations of Andean myths as astronomical events, put forward by Sullivan (1996), are even more controversial than are those of Zuidema and Aveni. Sullivan

[17] Cobo, Book 13, Ch.6, 1653 ed., tr. Hamilton 1990, pp. 30–31, cited by Bauer and Dearborn 1995, pp. 104–105.



1. Orion's belt, Rigel (herder), Betelgeuse (herder)	1. Orcorara, tres estrellas todas yquales
2. Viracocha	2. Viracocha Pachayachachi
3. Sun	3. Inti
4. Moon	4. qilla
5. Grandfather Venus, Morning Star	5. Lucero Chasca Coyllur Achachi Urari
6. Grandmother Venus, Evening Star	6. Choqui chinchay apachi Ururi
7. Stars of Summer	7. Nuchu Verano
8. Southern Cross	8. Saramama, Chacana en general
9. Clouds, hail, wind and mist of winter	9. Nube, pocoy, inbierno
10. Lightning	10. Rayo chuquiyila e yllapa
11. A and B Centauri	11. Catachillay
12. Rainbow	12. Arco del cielo
13. The world or the earth	13. El mundo o la tierra
14. Pilcomayo River	14. Pillcomayo
15. Eyes of abundance, Pleiades	15. Los ojosymaymana nacraycu napnauin
16. Man	16. Hombre
17. Woman	17. Mujer
18. Mother Sea	18. Mama cocha
19. Pot of coca	19. Pucyo co
20. Hail or black cat	20. Granisso O chuqui chinchay
21. Mallqui, Young tree	21. Arbol mallqui
22. Terraces of storehouses	22. Collca pata y la casa estaba toda parada con planchas de oro, llamada Cori cancho uaci

FIGURE 14.32. The cosmological map of Pachacuti, Yamqui Salcamayhua. Drawing by Sharon Hanna.

maintains that Andean mythology is historically related in unspecified ways to Old World mythology and that mythology embodies and presents astronomical data. The basic interpretation and many of the details derive from de Santillana and von Dechend (briefly discussed in §6.4). However, Sullivan brings forward a substantial body of data on the astronomical identities of Incan gods, which is partially independent of his other interpretations, and he proposes specific real astronomical events related to particular myths, which allow the origin of those myths to be placed chronologically. Many regard his evidence of associations as mere coincidence, but the claims and associated visual effects are equally dramatic and deserve a hearing, regardless of his problematic attempt to tie in these effects with native recognition of the effects of precession.

Sullivan's (1996, pp. 39–43) most important archeoastronomical claim is the identification of a myth of the destruction of the world by a flood with the June (winter) solstice of 650 A.D. The date was originally calculated on the basis of a statement that he understood to indicate a heliacal rising of the Pleiades in the month before the June solstice. The flood was said to have been predicted by a male llama, *urcuchillay*, the name also of an Andean constellation, partly corresponding to Lyra, including Vega. Sullivan (1996, p. 18) drew attention to the Quechua name *paqo*, both for "male alpaca" (a llama relative) and for "shaman" (the modern *paqos* being authorities on astronomy). Sullivan suggested that perhaps "llama" in this context should be understood as priest-astronomer. In any case, he thought that the male llama (Vega), serving as a paranatellon (see §3.2.2) for the female Dark Cloud Llama, was looking across at the Pleiades.[18] In fact, Vega and the Dark Cloud were setting as the Pleiades rose in 650 A.D. In a planetarium simulation set for 650 A.D., Sullivan found that "the Milky Way had ceased to rise heliacally at the June solstice for the first time in more than 800 years." The flood tale also told of the animals crowding up the mountain as the waters rose higher, and that the Fox got his tail wet. Again, "Fox" is a Dark Cloud that follows the Dark Cloud Llama close-on. According to Sullivan, when the planetarium simulation showed Fox at the December solstice of 650, he had risen above the horizon except for the end of his tail. There was one final piece of supporting evidence, dealing with the Inca ruler Pachakuti and his vision of the god Viracocha. The name of Pachakuti Inca strongly suggests that he lived at the end of a World Age (*Pachakuti*). Sullivan (1996, pp. 285–286) argued that an alleged meeting of Viracocha and the emperor Pachakuti symbolized an "encounter" between Jupiter and Saturn. It is generally thought that Pachakuti became emperor in A.D. 1438 and that his reign began with seven years of drought. Sullivan asserted that the vision followed the drought. In fact, Jupiter and Saturn were in conjunction in 1444, 40 Jupiter-Saturn conjunctions after their conjunction in 650 A.D. Sullivan's (1996, pp. 129–131) interpretations of the statements about Pachakuti Inca and about flood myths led him to think that in 650 A.D. there should have been a Jupiter-Saturn conjunction with the following characteristics:

(1) located in the eastern edge of the Milky Way in Gemini,
(2) at the June solstice,
(3) at sunset, and
(4) at or near the northwest horizon.

Tuckerman's Tables demonstrated to Sullivan that these conditions did hold.

If *Catu illa* is Mercury and associated with messengers, DHK thinks that he should be associated with the ritual races, which have been discussed, and with the Bean Lord of Mochica pottery. The concept that Mercury is a messenger between the Sun and other heavenly bodies is widespread, but the Bean Lord does not suggest classical conceptions of Mercury. According to Hocquenghem (1987, p. 206), *Catuilla* was one of the three major names of the god Thunder in the Andes. Nothing else suggests that the Bean Lord was the primary god of Thunder in the Andes.

[18] This parallels the actual behavior of the male llama, standing apart from the herd, and observing the surroundings for possible danger.

Other gods are also associated with war clubs, and even thunderbolts. Mercury in the Old World seems to be associated only rarely with warfare, and Hermes's theft of the clouds is the only story connecting him even marginally with Thunder. The testimony of the Anonymous Chronicler instead identifies Saturn as the Thunder God.

Turning now from the colonial Quechua, the first comprehensive attempt to study astronomical conceptions in a modern Quechua community was by Urton (1981). He was able to demonstrate remarkable continuites between early colonial references to Inca astronomy and the existing astronomical lore and to show that the latter explains much that was obscure in our colonial sources. Perhaps the most notable discovery was that everybody in the community, including children, had a substantial knowledge of observational astronomy. The people regarded astronomical information as crucial in determining when to plant certain crops—a generalization frequently made by astronomers (and occasionally challenged by archeologists) but better demonstrated here than anywhere else known to us. Unfortunately, Urton was unable to get nearly as much information about the knowledge held by the women, except for intimations that they were better informed than were the men about lunar phases and movements. He found relatively little information about planets, which may be an indication that knowledge of planetary movements was considered a more specialized topic. Urton emphasizes the great importance of Dark Cloud (nebula) figures (called, misleadingly, "constellations").[19] These figures are called *pachatierra* or *pachatira* (from the Quechua *pacha*, "earth," and Spanish *tierra*, "earth") and are usually animals or, more rarely, plants. They are in striking contrast to asterisms (which Urton calls "star-to-star constellations"), which are normally geometric figures such as crosses or architectural representations, notably, granaries. There is some syncretism with Catholicism, especially in the identification of one of the cross asterisms as *cruz calvario* (Spanish for "the cross of Calvary").

The Milky Way plays a central role in astronomical observations at Mismanay as the "River of the Sky" controlling water. It is identified as a "nocturnal rainbow." The extreme orientations of the Milky Way in the sky determine the alignment of the crossroads (northeast-southwest and northwest-southeast) that meet in the center of Mismanay. This curious pattern emphasizes that alignments to a celestial feature may have more than one orientation. These directions are also correlated with the solstices (Urton 1981, p. 62), in the sense that the rise/set points of the solsticial Sun coincide more or less with the sweep of the Milky Way across the horizon. The Milky Way is believed to be a continuation of the Vilcanoto River, and this river was said to be the path taken by Viracocha. Interestingly, the direction of water flow is an important factor in topographical alignments, but it is conceptually related to the flow of the heavenly river, and so is also part of an astronomical framework in Quechua thought.

The solstices are important celestial markers, especially the "northern" (i.e., winter) solstice, which is more directly tied to the agricultural cycle because it marks the beginning of planting season. The "center" is also important and seems sometimes to refer to the specific horizon location where the zenith Sun[20] rises/sets, but it generally refers to a segment of the sky rather than to a specific point or line (Urton 1981c, pp. 72–77). Urton did not get any direct information relating to the "nadir Sun" or "anti-zenith Sun,"[21] although he points out that it might have been determined using the full Moon. Urton is able to show a substantial correlation between the seasonal activities of particular animals and the rising times of Dark Clouds or asterisms named for those animals. He also points to some striking alleged associations, most particularly, the view that foxes are normally born on December 25 and the place of their birth is the mountainous area at the setting point of the June solstice Sun. It is very striking that the Sun "enters" the Dark Cloud Fox at the time of the December solstice (Urton 1981c, pp. 188–189). Urton (1981c, p. 211) points out that Sullivan's data from Quechua communities in northern Bolivia and southern Peru agree with his data from near Cuzco, helping to show that the identifications were widespread and supporting their Inca derivation.

An important site near Ollantaytambo in the Vilcanota drainage has been called Pacaritampo[22] (Ellorieta and Ellorieta 1992, 1996a, 1996b). It is an extremely large earthmound of unusual shape (roughly pyramidal). The shape was apparently designed to mark the equinoxes and both solstices; so the sides are at curious angles visually. The site is in a high Andean valley, surrounded by mountains, so that all solar alignments are dependent both on the movements of the Sun and its relationships to the local topography. The height of the different levels on the west side is such that the rising Sun at the summer (December) solstice creates ten sharply bounded areas of sunshine on that side, whereas the rest of the valley remains in morning twilight. On the winter (June) solstice, a much less noticable band of light marks one edge of the structure. The light of the rising Sun at each equinox aligns with the southwest corner. See Plate 7, in the color insert, courtesy of William Sullivan. Other sites in the vicinity also show interesting plays of light and shadow at the solstices.

There is also archaeoastronomical evidence from the northern Incan empire. Zborover (1996) discusses both historical and archeological data associated with a Quechua solar observatory deliberately established on the equator by the Incas, with possible local prototypes. Juan de Velasco, although writing substantially after the Spanish conquest, described two temples in Quito (probably of the pre-Inca period, associated with the Caranquis), one for the Sun and another for the Moon and stars. He said that two tall columns on the sides of the door of the temple of the Sun were used as gnomons to mark the solstices. There were 12 smaller gnomons around the temple plaza, the shadows

[19] Kelley suggests "nonstellations" may be more apt.

[20] The Sun at the date when it passes through the zenith.

[21] The Sun at the date when it passes through the nadir.

[22] A name that is also given to a site south of Cuzco.

of which marked the beginnings of the (solar) months. Velasco[23] says that the temple was "very well known for its adjacent astronomical observatories, to which their kings were very devoted."

Zborover thinks that the site of Cochasqui (6 km north of the equator) was a prototype of the temples in Quito. At Cochasqui, there are a number of structures, including two round platforms, each with two double channels with bearings ($A \approx 4°$ and ~30° for channels of one platform and ~8° and ~40° for the other), whose purpose is presently undetermined.

There are sets of three socket holes associated with these channels. In one of them, one of a set of three short stone pillars (all of which had been removed but later replaced on the basis of good archeological evidence) cast a shadow on one of the others very near the June solstice. The report deals with preliminary examinations not yet checked as fully as is desirable; the archeological context is certainly pre-Inca, perhaps by several centuries, but the archeology is also inadequately known at this time. Zborover suggests that the carefully leveled and hard-baked channels were used to hold water, which could act as a mirror for stellar observations.

Zborover also describes (private communication to DHK, 2000) a group of three round platforms with irregularly spaced radial markings on their surfaces in the Rumicucho area of Ecuador, very close to the equator. Among these lines, some coincide with equinoxes and solstices; another seems to mark the May 9/August 4 alignment attested near Cuzco. There is also a line at $A = 118°6'$ that coincides with the southern lunar major standstill maximum and points toward the top of Catequilla mountain. The name Catequilla means "he who follows the moon," which is strong support for regarding that alignment as deliberate. There is potentially a substantial amount of information to be gained from further studies in the Quito region.

14.3. Other South American Cultures

With a few exceptions, our increasing knowledge of the astronomy of tropical forest tribes is largely restricted to constellation names, to the relationship of stellar patterns and social organization, and to a series of explicitly stellar myths. The *Bororo* Indians of the Brazilian and Bolivian tropical savannahs occupied an area between 14° and 19°S and 51–59° W (see Fabian 1982 for a full discussion). Formerly, they were reported to be one of the largest and most powerful groups in South America. In the 1980s, there were approximately 500 of them left, concentrated mostly in the five villages in the eastern half of their former domain. The sources of our information about the Bororo are Salesian missionaries. The Bororo celebrated the heliacal rising of the Pleiades, which they called the A*kiri-doge*, because this astronomical event marked the onset of the dry season. Among the celebrations were fire-leaping ceremonies: the "Burning the feet of the Pleiades" to slow them down so that the dry season would last longer. They also noted carefully the motions of the Sun (*Meri*) and Moon (Ari) who were considered brothers. *Meri* was able to resurrect himself once a year, and could resurrect *Ari*, which he did many times during the year. The travels (*Meri-doge*) of these two brothers involved meetings with a series of animals, suggestive of the zodiac. The animals encountered were Jaguar, Ocelot, Suçuaruna (a third type of cat), Caracari Eagle, Royal Eagle, Great Eagle, Little Eagle, Heron, Parakeets, Monkeys, and Cayman. There is a possible break in the sequence between Jaguar and Ocelot and again between Heron and Parakeets. The eagles are described as having fledglings and, thus, vulnerable to capture. Recognized constellations included the Pleiades, Orion's belt, the Southern Cross, Pavo (which they too described as a bird), and several "dark constellations," including our Coal Sack, and *Pari*, a running emu. In architecture, the village structure consisted of concentric rings of houses, the sectors of which were, in theory, administered by eight matrilineal and matrilocal clans divided into north and south moieties. Paths among them suggest the *ceques* of Cuzco.

Another people whose myths and rituals show a substantial interest in astronomy is the Sherente (Levi-Strauss 1969, pp. 75, 168, 194, 199–202, 216–217, 250–251) of present-day east-central Brazil (~−9° latitude). The Sherente, like the Bororo, speak a language of the Ge family. Again, like the Bororo, they were divided into eight kin groups in two moieties. Their encampments and villages were arranged so that the eight groups were located in a fixed pattern, the northern moiety associated with the Moon and the southern moiety associated with the Sun. However, unlike the Bororo, the kin groups were patrilineal and patrilocal, and the village entrance was in the west. Their year began with the heliacal rising of the Pleiades in June and was said to consist of 13 lunar months (if so, these must be sidereal rather than synodic months). The year was divided into a dry season of four months (June to September) and a rainy season of nine months (September to May). Tree cutting occurred in June and July; burning and planting occurred in August and September.

A major culture hero of the Sherente is Asare (Rigel) of the Sun moiety, a half-brother of the many brothers called Sururu (Pleiades) of the Moon moiety. According to the myth, Asare was very thirsty and unable to slake his thirst from palm nuts. The Sururu brothers, however, dug a well from which water gushed forth. Asare tried to drink all of it but failed; it became the sea. He then had to swim across it to retrieve an arrow. On the way, he was attacked by a cayman, the master of water, but escaped. This happened twice more, and finally, the cayman was killed by Asare's uncle, the skunk-like *Conepatus*. Asare is a principal figure in a ritual against drought, designed to appease the Sun. The Sherente erect a pole 10 m high and 40 cm in diameter that was called "the Road to the Sky." Most of the young men of the village, separated into their moiety groups, are obliged to climb it after other activities and three weeks of fasting. All fires in the community must be extinguished. The climbers are given small amounts of water by a group of old men who are called Asare. These old men fast for only five days. The first man to reach the top of the pole must be a member of the Kuze or "fire" kin group. This group also includes the *mutum* bird (curassow), who was the most

[23] Translated from Zborover 1996, p. 2.

important figure in the Sherente myth of the theft of fire from Jaguar. The Kuze climber carries with him some fibres that he asks Sun to set afire. The way in which this is accomplished is unclear, but he climbs down with burning fibres, which are then used to start new fires throughout the community. The last climber is given a message from Asare (Rigel) saying that Sun is pleased with them and will allow rains to fall. Then, an impersonator of Mars, a member of the Moon moiety, offers the climbers a drink of stale, dirty water in a cup decorated with feathers. They refuse it and are offered clear water by impersonators of Jupiter and Venus, who are members of the Sun moiety. The clear water is offered in gourd vessels (*Lagenaria* decorated with cotton, and *Crescentia*). Such a ritual may suggest the possibility of a near-conjunction of Venus, Jupiter, and Mars. The association with Rigel is unclear, but it may be related to the circumstance that Rigel transits close to the zenith in this region (when the latitude and the declination of the transiting object are the same). Because the declination changes with precession, however, both latitude of the site and the date are important. Rigel's declination has been increasing (to less negative values) and is now ~–8° (it was within ½° of –9° from ~1200 to ~1700 A.D.). Parallels in Mesoamerica, among the Kogi, in Moche culture, and among the Quechua, put Jaguar as Lord of Fire as the central star of Orion's Belt. Among the Sherente, fire has been stolen from Jaguar by Mutum. As the ancestor of the fire kin group, Mutum is associated with Asare (Rigel). In 1450 A.D., about three weeks after the September equinox, the Sun would pass through zenith. According to the *Visible Universe* software package, around October 8, when the Sun is at the zenith of a site at latitude –9°, Rigel would have crossed the zenith two to three hours before sunrise, thus, not providing a strong marker for the event. However, Rigel would have transited the meridian at sunrise three weeks before the September equinox (~August 27); thus, if the symmetry of the dates were considered, such a pairing of events might have been made.

Jupiter and Venus also appear in myths. It is said that Jupiter, a woman, came down to Earth, presumably descending in the west, and married a man, who kept her hidden in a gourd. Then she took him to the sky, where he was horrified to discover that all her relatives were cannibals and fled back to Earth. When he died, he went back to Jupiter and became a star. Although Jupiter is identified as a female, and associated with a gourd, Venus appears in Sherente myth as an ulcerated and impoverished male, who was badly treated by all the humans whom he met except Wainkaura. Therefore, he warned Wainkaura that a flood was coming and had him kill a dove. From the body of the dove, Venus made a boat in which Wainkaura and his family were saved.

The Sherente say that they received corn (maize) from a rat, but there are no celestial components in the story. However, a nearby Ge group, the Apinaye (Levi-Strauss 1969, p. 165), tell the story of Star Woman coming from the sky and being hidden in a gourd. They say that she first appeared as a frog and brought sweet potatoes and yams. Later, she transformed herself into an opossum (parallel in this and other stories to a rat) and showed people a maize tree. She also taught people basketmaking. A careful reconstruction of the prototype of these Ge stories would be extremely interesting. It is just possible that more direct evidence of astronomical knowledge and beliefs may yet be obtained among these groups. Also in Brazil, but much less well studied, the *Tupinamba* Indians of the coast had an extensive list of named stars and constellations.

In 1930, in a study of Brazilian inscriptions, Bernardo Ramos published a 19th-century drawing of a carved rock from Pedra Lavrada, Paraiba, Brazil (near the Brazilian coast), which seems to be a star map. Ramos "read" the various components of the diagram as "Greek letters" giving the names of the constellations of the zodiac. This bizarre effort need not detain us here, but the drawing is reproduced in Figure 14.33 with two local inscriptions. Some of the drawings look like asterisms, drawn in the ball-and-link style. We have not been able to identify any of the asterisms with assurance. Some of the signs may signify planets. If they can be identified, it may be possible to date the panel.

In Colombia, there were many native tribes, some of which still exist in substantive number. The Tukanoan group is composed of six tribes, some of which may not intermarry. Three intermarrying tribes are the Desana, Tukano proper, and Pira Tapuya. Others are the Barasana, the Karapana, and the Tuyuka. Moieties exist also within tribes.

The Desana tribe inhabits the equatorial rainforests of the northwestern Amazon, and as of the early 1980s (Reichel-

FIGURE 14.33. A 19th-century drawing of a carved rock from Pedra Lavrada, Paraiba, Brazil (near the Brazilian coast), published by Bernardo Ramos, which seems to be a star map with two local inscriptions: See text for details. Drawing by Sharon Hanna.

Dolmatoff 1982, from which this summary is taken), a few thousand still existed. One of the principal myths of this tribe was the Search for the Center—the spot where a vertical shaft carried by a hero casts no shadow. The spot on Earth corresponding to this center is a place called *Nyi*, marked by a large boulder covered with petroglyphs, which lies on the equator. This thus marks the place where the equinox Sun is overhead at noon. The area around this center has its counterpart in space and can be recognized in the stars. The area is roughly hexagonal, and the celestial counterpart has as its center the star ε Orionis, in Orion's belt (see Appendix B, Figure B.1), with Castor + Pollux, Procyon, Canopus, Achernar, τ^3 Eridani, and Capella forming the vertices of the hexagon. The beliefs are reflected in the architecture: The longhouses of the tribe have a hexagonal shape. In the imagery of the shamans, Orion is conceived to be a hunter, walking over the Milky Way, among other interpretations. According to Reichel-Dolmatoff (1982, p. 176), in the NW Amazon region, in the thought of the shamans, "there exists a close relationship between astronomical observations, cosmological speculations, and drug-induced trance states."

Another Tukanoan tribe, the Barasanas, consider themselves Earth People, and are permitted to intermarry only with the Sky People (Tatuyo) and Water People (Bará). See Hugh-Jones (1982) for an informative summary. In the creation myths of the Barasana, the Primal Sun created the Universe People: Sun, sky, Moon, and stars. The first beings died (but later returned to life, immortal), and in the process, humans were created. A dualism pervades the culture: The dead in this world become alive in the underworld, where it is day when this world is in darkness. The annual and daily movements of the Sun are linked: The Sun (*muhihu*) and his children, the stars (*nyokoa*), revolve around the Earth each day (east to west in the sky; west to east in the underworld river). Day and night are linked metaphorically with dry and wet seasons. Stars are said to return to the east as flocks of migratory birds (whose passage is connected to the heliacal setting of particular constellations). The Pleiades are said to return as bobolinks, Orion's Belt and sword as small, black, seed-eating birds. The stars and constellations are listed in sequential order and tied to the seasons. Most lie along the Milky Way, which is cut in two by the ecliptic: the "New Path" (*mama ma*), which runs SE to NW, and currently precedes the "Old Path" (*buku ma*), which runs NE to SW (see Figure 14.34).

The New Path begins at what a shaman identifies as the "Star Thing" (*nyokoaro*) or Star Woman, the Pleiades, which appears on the eastern horizon at dusk in November, marking the end of the rainy season. The eight stars that the Barasana number the Pleiades are Star Woman's fire sticks, banded in red and black stripes. The red bands are said to symbolize the fires of a cleared midden site, at the start of the dry season, whereas the black bands represent the charcoal after the fire goes out, and the rainy season's overcast skies. Following the Pleiades, there are fruit fences, a fish rack, a red ant (Betelgeuse), fish, otters, and adze; there is then a "star path" followed by the Old Path. In contrast to the New Path, this segment is marked by dangerous creatures,

> Poisonous Spider, Scorpion, Caterpillar Jaguar, Poisonous Snake, Headless One (a headless corpse of an eagle), Vulture, Corpse Bundle,

characteristic of the dangers of the rain forest in the wet season. In Barasana mythology, *Wekomi*, the headless eagle is the father-in-law of Venus the Morning Star (*busuri nyoko*) and of Venus the Evening Star (*nyamikarima*). He was beheaded by his daughter, "Star Snake" (*nyoko anya*). Table 14.6 lists the constellations and the identifications when these are known. The star paths separating the Old and New Paths are associated with egrets and forest fruits and help to mark the transition between the wet and dry seasons.

Ritual events are similar to those of the Desana described above. The main initiation ritual takes place at the end of the dry season, marked by the Pleiades low on the western horizon at dusk, and the Sun at the March equinox. The ceremony unites the Barasana with their ancestors, a condition

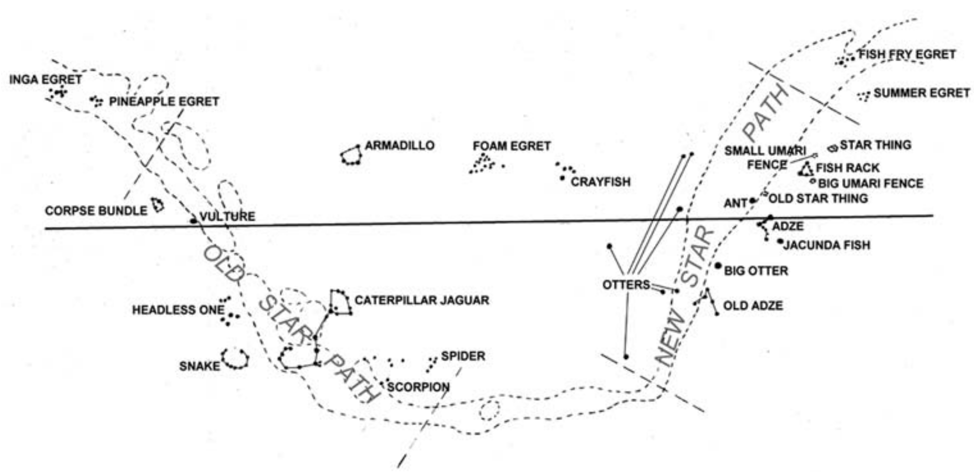


FIGURE 14.34. Barasana constellations. Drawing by Sharon Hanna.

Table 14.6. Barasana constellations, ff. S. Hugh-Jones, 1982.

The New Path

1. nyokoaro, "Star Thing" (or Star Woman): Controls the seasons and agriculture; Pleiades
2. wamʉ saniro kīhika, "Small Umarí Fruit Fence"; near the Hyades
3. wai kasabo, "Fish-smoking Rack"; Hyades triangle
4. wamʉ saniro haigʉ, "Large Umarí Fruit Fence"; the other side of the Hyades from 2.
5. nyokoaro bʉkʉrā, "Old Star Thing"; Orion's Head (?)
6. mekahiamʉ, "Leaf-cutter Ant"; Betelgeuse, α Orionis
7. siorʉhʉ, "Adze"; Belt and Sword of Orion
8. muha buhua, "Jacundá Fish"; Rigel, β Orionis
9. timi haigʉ (Maha hesaʉ), "Big Otter"; Sirius, α Canis Majoris
10. siorʉhʉ bʉkʉra, "Old Adze"; Canis Maior (?)
11. wania timia (ria timia), "The Small Otters"; Procyon, Castor, Pollux, Canis Minor, Gemini and others, each star a separate otter
12. rasikamʉ, "Crayfish"; Leo (?)

The Old Path

13. bʉhʉ, "Poisonous Spider"; Centaurus (?)
14. kotibaha, "Scorpion"; Centaurus or Lupus (?)
15. īya yai, "Caterpillar Jaguar"; Scorpius (+)
16. anya, "Poisonous Snake"; Corona Australis (usually)
17. rihoa mangʉ, "The Headless Corpse" of the eagle, wekomi
18. yuka, "Vulture": Announced the time of warfare; Altair, α Aquilae
19. masa hoti, "Corpse Bundle" (the body of Star Woman, killed by wasps); Delphinus
20. hamo, "Armadillo"; Corona Borealis

noted in the chants; instruments said to be the bones of ancestors are assembled (symbolically recovered from the underworld) and played. At midnight, sacred flutes are played by men, who, dressed as the Sun, move along the east-west axis of the house, which, like that of the Desana, is shaped like the cosmos.

From the Wayana of Surinam and French Guiana, Magaña (1987) has collected an extensive series of native names for asterisms, with some information on the calendar and an extensive collection of myths, only a few of which have explicit astronomical associations. The identification of asterisms is much more detailed and explicit than has been common and Magaña has noted differences between different informants. It seems to be agreed that the year begins with the dry season and is associated with the heliacal rising of the Pleiades or the Hyades or Orion. The year is divided into 12 months, each named and marked by an asterism. The observations are done at sunset. Some of the months are named from asterisms that are culminating at sunset, whereas others are named from asterisms that are rising at sunset. His Table I shows information on the calendar asterisms from Coudreau 1893 (Magaña 1987, p. 48). Figure 14.35 shows the identified Wayana asterisms.

14.4. Caribbean Archaeoastronomy

The study of Caribbean archaeoastronomy is still in its initial phases. Much of the work has been done by Robiou Lamarche (1985), whose summary is followed here.

The Caribbean Islands were peopled by groups from South America, principally Arawakan and Cariban speakers. Robiou has attempted a synthesis of the mythology with local ecology, astronomically marked seasonal events, and with astronomical alignments, especially of plazas and ballcourts among the Taino. Taino mythology was recorded by friar Ramon Pane in 1498, the earliest recorded work on the beliefs of any tribe in the Americas. Robiou has suggested that three mythological themes may be associated with astronomy on the basis of comparisons with South American myths. The myth of weeping children, abandoned by their mothers, and changed into frogs is, he thinks, to be associated with the Pleiades. In the Taino version, the mothers of the children are carried off by the hero, Guahayona, in his canoe. At the start of his voyage, Guahayona drowned his brother-in-law, Anacacuya. Robiou accepts a translation of Anacacuya as "Central Spirit" or "Star of the Centre," which he equates with the Pole Star and with hurricanes as well with the Quiche god *Hurakan*, who is also identified with the "Centre of the Sky" according to Robiou. Guahayona ended his voyage at the mythical island of Guanin, the name for a gold-copper alloy, for a crescent-shaped ornament made from it and for the planet Venus (Robiou Lamarche 1992, p. 66).

Another myth (Robiou Lamarche 1990, p. 163) tells of the killing of *Yayael*, son of *Yaya*, the supreme being, because of his rebellion against his father. His bones were put in a gourd, from which all fishes originated. When the gourd was tipped over by two pairs of twins, the water that poured out of the gourd became the ocean. Then, a turtle was created on the shoulder of the twin, Deminan (Robiou Lamarche 1990, p. 167). Parallel South American myths of the origin of fishes suggest to Robiou that this myth should be associated with Orion.

Robiou (1990, p. 166) describes a number of sites that he thinks indicate sophisticated solar observations. The most clearcut of these is at Bajuro de los Cerezos, where a line of standing stones is oriented to the winter solstice. At

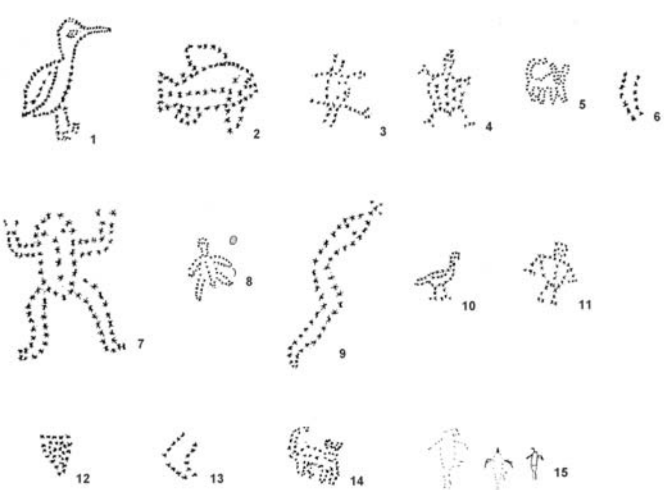


Figure 14.35. The asterisms of the Wayana of Surinam and French Guiana. Drawing by Sharon Hanna.

Chacuey, among many other features, is an ellipsoidal plaza. A line from the western entrance to the eastern entrance marks the rising of the winter solstice Sun. The reciprocal line of summer solstice sunset is marked by a cairn. Outside the ellipse, two parallel causeways, running toward the Chacuey River, are aligned with equinox sunrises and sunsets. Equinox alignments are also found at Plaza M, Cajuana, and at the principal plaza at the site of Tibes. At the present time, there has been no systematic study of site alignments, nor any statistical appraisal, but these preliminary results seem congruent with what we know of Amazonian tribes in their homelands.

Robiou Lamarche (1992, p. 167) finishes by suggesting the use of an agricultural calendar, associated with the frog, rains, and the Moon, and based on the movements of the Pleiades; a separate solar year is associated with the turtle, the theft of fire, the creation of fishes, and Orion. All of this is far from demonstrated but is an interesting attempt to unify diverse kinds of evidence.

This concludes our treatment of the native and pretelescopic astronomy of all the separate culture areas. We now explore the purposes of ancient astronomy.

15
The Descent of the Gods and the Purposes of Ancient Astronomy

The central themes of archaeoastronomy are the relationships that people have seen between themselves and the heavens and the ways in which these relationships have been reflected in archeological remains. The related study of ancient astronomy needs to be integrated with all available relevant information on myths and religious practices in as clear a cultural context as possible. In many cases, myths provide a descriptive account of astronomical processes or events, related to behavioral patterns of the particular group. We have found that the purposes of ancient astronomy tend to fall in the general areas of calendrics, navigation, and astrology. In this section, we draw attention to notable similarities and differences among cultures around the world and offer some interpretations of the patterns we recognize. The major difficulties of interpretation lie in deciding what material is relevant. If we try to interpret a myth astronomically when it had no astronomical referent, we distort both the myth and our perception of the culture. If a myth has a deliberate astronomical component and we do not study it, we lose culturally important information. Similarly, we know that many cultures created structures with deliberately incorporated astronomical alignments, sometimes with a high degree of precision, and sometimes loosely. We also know that there is great variation in the degree of interest in such alignments in different cultures, and that there are a tremendous number of possible alignments. Some cultures and individuals have little interest in alignments that are crucially important in other cultures. Again, we run the contrasting risks of perceiving alignments that never had any cultural existence, and of missing information that was of major cultural importance. The cultural treatment of numbers presents a comparable problem. Schaefer (1997) has provided a long list of "astronomical" numbers, which suggests that scholars can "create astronomy" from essentially random numbers. Yet we know cultures in which simple dots are representations of gods with astronomical functions, and carefully counted. Because cultures differ from each other, judgments on such problems need to be made for specific cases. In the following material, we point out some problems and offer some possible solutions.

15.1. Cultural Suppositions Regarding Life on Other Worlds

The concept of intelligent life on other worlds has been widespread in many cultures around the world. The Dogon account of being taught useful skills by fish-men from Sirius (see §8.4) is more specific than are most such accounts but is otherwise typical. Heroes pass back and forth between this world and the star worlds with ease. In South American belief, Star Woman came from the sky, taught people agriculture, and returned to the sky. Many groups in both North and South America are divided into moieties of Sky People and Earth People, and in many cases, it is believed that the ancestors of Sky People came from the stars (see §§§13.3.2, 14.2.2, and 14.3). Even where there are no moieties, lineages or even whole tribes may claim that their ancestors came from the sky. It was an Ojibway claim that Indians descended from the Moon on a web spun by a giant spider (Conway 1992, pp. 241–242). Some Yumans of Arizona and California say that their ancestors came from the Pleiades. In Polynesia, specific, named ancestors of existing families are alleged to have gone back and forth between the land of the Sky People, Earth, and the underworld. When these lands are described, they are usually very much like Earth. Occasionally, their inhabitants have special characteristics, such as the Dogon fish-men, but more frequently, celestial dwellers are virtually indistinguishable from humans except for their superior knowledge. One could say that Mercury (as Apollo in Greece, Woden in northern Europe, Budha in India, and probably Quetzalcoatl in Mexico) was a dynastic ancestor.

The idea of the heavens as the source and destiny of the soul was widespread in the ancient world. Buddhist concepts of the journey of the soul after death include various dangers that it must face—a treacherous river that must be crossed, a giant dog, a pair of rocks that clash together, among others. At the close of the 19th century, Edward B. Tylor (1894, 1896) argued that these ideas were so similar to those of the Aztecs and other peoples of Mexico that Buddhist ideas must have spread to the New World. He suggested a possible origin from India (particularly because of the resemblance between the Indian cosmological game *pachisi*, and the Aztec *patolli*). Since then, detailed parallels have also been discovered in Oceania and in other parts of the Americas, with some particularly striking examples in California. Although we know of no culture in which these dangers are systematically associated with asterisms, many of them seem to be identifiable in the sky.

Also in Buddhism, one finds multiple heavens and hells, the transformation of the soul of the dead into moths or butterflies, and rebirth (sometimes as a human, sometimes as an animal). Dualistic concepts of good and evil are used to reinforce ethical values of the society. Many of these beliefs are also found in Oceania and Mesoamerica.

In the Mediterranean, the descent of the soul to Earth was felt by some to be fraught with dangers from evil planets and by others to be either a morally neutral or a positive experience, in which traits were acquired from planetary beings en route (Scott 1991, Ch. 6). These ideas carried over into the Christian era, particularly among the gnostics. Variants of the ideas were held also by Philo, among the Jews, and Clement [d. 216] of Alexandria, among the Christians (Scott 1991, especially, pp. 107–109). Philo basically believed that the planets and stars were creations of God and were used by him and, in all cases, were dependent on him. On the other hand, Philo considered the astral bodies to be higher forms of creation, and astral worship by pagans was part of a divine plan to move them toward religious truth (Scott 1991, p. 72). Both Philo and Clement were strong opponents of astrology, in the sense that they considered astral bodies not to be causative agents, but both considered the stars as newsbearers of things to come (Scott 1991, p. 105). Dodds (1965, p. 15) thinks that the κοσμοκράτωρες ("cosmocratores"), "rulers of the darkness of this world" of Ephesians 6:12), is a reference to these planetary powers. The Christian theologian Origen [Alexandria, ~184–254], Clement's student, regarded the Sun, Moon, and stars as creations of God and, as such, were considered good and unlikely to be the sources of evil among people.[1] Clement had believed that the stars and planets played an important role in the universe, but Origen carried the ideas further. He envisioned a prior creation in which creatures suffered moral lapses to various degrees: The worst was the devil and his angels; then humans, somewhat less degraded; the only slightly lapsed principalities and powers (including celestial bodies); and the unlapsed angels. The present world was created in order for the fallen to be redeemed; into this world the *Logos*, the second person of God, was sent to provide the means for salvation. Through repeated rebirths, individuals would have opportunities to grow in grace and become closer to God, whereas sinners would sink lower and undergo regression at later births. At the close of this world and age, a new world and a new age would be created—an effective restoration of the original and perfect condition of the universe. As a necessary consequence of the infinite mercy of God, no soul could be lost in this process, and would ultimately be redeemed. Thus, creation is tripartite, and in our present world, all of creation is in a constant state of flux. The brilliance, sweep, and enormous optimism of Origen's vision in a time of severe persecution of Christians is all the more amazing.

Another well-known, but less illustrious figure who discussed the multiplicity of worlds was Giordano Bruno [1548–1600]. Bruno took Dominican orders, renounced them, and traveled extensively throughout Europe. He believed that the universe is the manifestation of God himself, and that God is the soul of the universe. He was a Copernican, and he believed that the stars were distant suns, and the centers of many worlds, each in need of salvation and grace. He was arrested by the Inquisition in Venice, and as a lapsed priest who denied the efficacy of prayer, and for other offenses (but not necessarily his astronomical ideas), he was imprisoned for seven years and then burned at the stake.

15.2. Astronomy in Mythology and Ancient Religion

This topic has been dealt with, in varying detail, in sections of previous chapters, but nowhere comprehensively. Here, we attempt a more general summary. As we have examined these ancient astronomies and the associated beliefs, we have found widespread similarities embedded in strikingly different cultural matrices. DHK thinks that the similarities are far greater than would be found by a random assortment of phenomena linked only by happenstance. To the extent that such similarities are arbitrary features, representing particular historical associations, their presence in distinct cultures suggest past contacts. However, we have increasingly found that similarities that, at first, seemed utterly arbitrary and inconsistent have an understandable common basis in human thought processes. Anthropologists have called the spread of ideas from one culture to another "diffusion," and the commonality of symbolism, "the psychic unity of mankind," that is, the separate, independent development of comparable ideas. The two interpretations have usually been opposed, but the ideas that will spread most easily are precisely those that embody new combinations of basically appealing "natural" symbols. For present purposes, it seems desirable to draw attention to some of the most striking parallels that we have noted without trying to specify what combination of normal human thinking processes and historical or ahistorical contacts between

[1] In his Commentary on Matthew (tr. by Patrick in Menzies 1896, p. 478), written between 246 and 248, Origen says about lunacy that "the great light in Heaven which was appointed "to rule by night" . . . has no power to originate such a disorder among men." And, citing Jeremiah (Lamentations iii:38), "Out of the mouth of the Lord shall come things noble and good", Origen asserts that "no star was formed by the God of the universe to work evil."

groups could have produced the similarities. Whatever the causes of specific similarities, the material presented here supports the view that interest in abstract data and the intellectual capacity to use such data are normal in all human groups. In summary, we pose the threefold question: Are such ideas accidental correspondences, do they represent ideas that recur repeatedly because of the inevitable connotations of symbolic systems, or, finally, are they vestiges of historical contacts? In many cases, detailed appraisal would be inappropriate, and sometimes it is difficult to find a plausible explanatory hypothesis. We have admitted some cases of this sort.

Perhaps the interpretation of mythology that has been most influential in anthropology (including archaeology) is that of Levi-Strauss, who examines the structure of myths. He uses three basic terms to characterize myths (Levi-Strauss 1969, p. 199):

(1) *Armature*, "a combination of properties that remain invariant in two or several myths"
(2) *Code*, "the pattern of functions ascribed by each myth to these properties"
(3) *Message*, "the subject matter of an individual myth"

A great deal of his presentation is devoted to an analogy between myth and music that presupposes that the reader has a detailed knowledge of modern music and of the history and theory of music. Levi-Strauss claims that the structures of music and of myth are dependent on the same basic properties of the human brain and particularly on binary oppositions. In terms of archaeoastronomy, his most interesting conclusion is that a considerable number of myths incorporate an astronomical "code" that is hidden behind surface "messages" that have no astronomical content. Unfortunately, his "astronomy" is merely a statement of structural oppositions about astronomy, such as a widespread contrast between "organized" Orion and "chaotic" Pleiades. He makes no attempt either to reconstruct mythical prototypes or to determine whether astronomical events or processes are being described. He sometimes concludes that widespread similarities among myths (of which he has striking knowledge) are due to similar structural patterning rather than to historical contacts (Levi-Strauss 1969, pp. 226–239). At other times, he writes as if certain widespread stories, particularly parallels between South American and North American myths, are due to the dissemination of a story with changes. Moreover, he usually seems to assume that only the "message" was conscious on the part of storytellers. He maintains that myth has meaning only in the sense that a symphony does, resonating, as it were, in the soul of the listener.

Precession is the basis for all myths of disorder and the ending of world ages according to Thomas Worthen (1991), largely a follower of Levi-Strauss in his techniques of myth analysis. He also depended heavily on Dumezil, particularly for his study of the "ambrosia" cycle of myths dealing with the sacred drink of the gods. Worthen (1991, p. 157) departs markedly from Levi-Strauss by maintaining that observable astronomical events were conceptualized in myths in a coherent way by observers who knew very well what they were saying. Worthen's data, myth constructions, and conclusions are very similar to Santillana and Dechend (1969), although they are hardly mentioned.

Worthen (1991, p. 171) accepts that Hipparchos was the first to make a serious technical effort to determine the rate of precession. He distinguishes this from the knowledge that "a continuous nondirunal [sic], nonseasonal motion alters the stars' positions relative to the equator." Both should be distinguished from simple recognition of the fact that stellar markers for the equinoxes and poles are no longer functioning. For the latter position, he presents evidence that some find substantial. In light of the dismal knowledge of precession exhibited by astronomers after Hipparchos[2] [due, in no small extent, to Ptolemy whose lower value for the precession gave rise to the notion of trepidation (see §7.3 and §7.7)], it is most unlikely that any appreciation of the true nature of precession would have permeated the consciousness of other groups of people; the commonly cited but very slowly changing pole location among the stars and circumpolar constellations, notwithstanding. The effects of precession on the positions of star groups relative to the equinoxes encapsulated in myth and poetry could be recognized as changing with time. Such recognition does not necessarily imply any sophisticated appreciation of the nature of precession.

There are other, more direct, objections to Worthen's position as well. His dependence on structuralism leads him to say that "If something is like another in one way, it is like it in every way, even though some of those ways may not be immediately apparent." This seems to DHK utterly contrary to his knowledge of comparative mythology. The way in which Worthen (1991, pp. 94–95) makes things alike "in every way" may be seen in his attempt to equate all cultivated plants, fire, vultures, hummingbirds, jaguars, and rodents because they are all amphibian! Apparently, the differences that most of us would see in such a varied list are to be considered merely superficial. Worthen's knowledge of the Indo-European languages and of comparative linguistics is such that some of his linguistic interpretations are worthwhile contributions and much of his analysis is more sober than the previous citations might suggest. However, he has no hesitation in suggesting that Vedic myths antedate 4500 B.C., and he thinks that the full nakshatra system in India with the so-called junction stars was in use at that time (Worthen 1991, pp. 218–222).

Among the rare studies that attempt to show how convergent myths may derive from parallel observations of real phenomena, rather than merely asserting it, the study of the opossum by Munn (1984) is outstanding. The opossum's habit of pretending to be dead and then appearing very much alive made it a natural symbol of rebirth, just as the Moon wastes away, "dies," and is reborn again. Its immunity to snake bite and ability to survive even after very rough treatment reenforced the theme that opossums did not die. Its nocturnal habits make it a natural companion for the Moon and stars, its fondness for corn fields associates it with agriculture, and its fiercely protective attitude toward its young make it a fitting associate of Mother Moon and Mother Earth. Babies

[2] With the important exception of *al-Battani* (see §7.4).

are born 13 days after conception, and the mother has 13 teats. Although Munn does not explicitly point it out, the number 13 creates a parallel with the Moon in years that have an intercalary month. The bare tail is widely associated with loss of original hair by burning, which leads naturally to the Mesoamerican identification of opossum as the "man" who stole fire for people; the pouch is sometimes identified as a burnt out area created by the burning coals that the animal stole. South American myths of a Star Woman (sometimes identified as Jupiter, although this is not mentioned by Munn) who becomes an Opossum and helps men to get corn agriculture may be associated with the opossum's fondness for corn as a food and cornfields as a habitat. If one is to argue that parallel myths throughout the world arise independently, studies like this one of Munn's are essential. One also needs to ask whether the celestial analogies are basic to a widely transmitted story or are independently "tacked on" to animal stories that originally had no celestial component, and if "tacked on," whether that was done in observationally and psychologically similar ways. On present evidence, a legitimate argument could be presented for either view. Formal reconstructions of prototypes of related tales to determine whether this increases or decreases similarities with other areas seems to DHK a highly desirable way to approach these problems.

The most comprehensive studies of myth in a worldwide context are those of Joseph Campbell (especially, 1959, 1962, 1964, 1988, 1989). Despite his preliminary work explaining widespread mythic parallels in terms of Jungian archetypes, Campbell seems to have been more and more convinced that many similarities in myths around the world were due to movements of peoples and ideas. His magnificently illustrated *Historical Atlas of World Mythology* is actually a culture history of the world with an emphasis on belief systems. Perhaps his most basic point is that all existing belief systems are transformations and adaptations of earlier systems with patterns traceable in broad outlines from the Palaeolithic to the present. Plant distributions and artifact distributions often show congruences with patterns of myth distribution, and they show no respect for conventional cultural boundaries, although he is entirely willing to accept concepts of cultural matrices. For purposes of archaeoastronomy, his approach to culture history helps to furnish a context for parallels in astronomical beliefs and practices. However, at least in the volumes that have so far been published, there is little direct mention of the role of astronomy in myth except for some very broad generalizations.

To our knowledge, the only attempt to treat myths as astronomical systems on a worldwide basis is that of Santillana and Dechend (1969). They proposed that most mythic motifs incorporate descriptions of astronomical phenomena, including, but not limited to, descriptions of precession in terms of catastrophes. Their procedure is to present comparative motifs from many areas, not to demonstrate historical relationships, which are assumed, but to illuminate the prototypical meaning of the motifs. They maintain that many mythic motifs are analogical and once had a technical meaning as astronomy. Iconographic similarities are likewise constructed as historical derivations of diffused knowledge about astronomy and examined for the light they throw on the meanings of myth. There is no formal attempt to arrange motifs according to chronology nor, in most cases, to specify particular cultures that share groups of motifs or interpretations. To the extent that Santillana and Dechend are correct, massive reinterpretations of mythology are needed. We have not attempted the detailed study of their work that would be necessary to make a fully informed judgment about the extent to which their ideas might be justified. Some of their ideas parallel interpretations put forth by DHK in his unpublished Ph.D. dissertation (1957), and he has been influenced by some of their ideas in subsequent studies of comparative mythology.

Among many scholars who have worked on mythology and religion, the works of Erwin Goodenough seem particularly important for three reasons. First, his massive work on early Jewish art and its relationships provides extensive information on the use of astronomical and astrological symbolism in Greco-Roman Judaism. Second, he has proposed a consistent theory of the interrelationships of religion, iconography, and astronomy. Third, DHK has noted certain striking similarities between Gnostic (Egypto-Judaic) symbols described by Goodenough and religious symbols in Mesoamerican art that he thinks need explanation (discussed below). The rest of this section examines them.

To most interested scholars, the presence of representational art in synagogues was unexpected. In the same milieu, the presence of pagan symbolic art, including the signs of the zodiac and the Sun God in his chariot, was in strong opposition to the position of the rabbis in Talmudic literature. Indeed, Goodenough pointed out that the most common representations in the synagogues were precisely the elements against which the rabbis fulminated most strongly. Goodenough contrasted "normative" Judaism as it had been set forth by later Jewish scholars with a more Hellenized and mystical "other" Judaism. The latter incorporated widespread pagan concepts of sacraments associated with concepts of resurrection and important elements of Egyptian gnosticism. However, to Goodenough, this other Judaism consistently used pagan symbols that had fixed and relatively unchanging interpretations, which were consonant with Jewish ideas of deity. He tried to determine the meaning of these symbols by a combination of Freudian and Jungian psychology, with a liberal dash of his intuition. In literature, this mystical movement was represented primarily by the works of Philo Judaeaus. The most important physical remnants of this Judaism were magical amulets and charms. Christian murals suggested to him the prior existence of then unknown Jewish murals, and he emphasized the use of Greco-Roman symbols in Jewish tombs, especially symbols connected with the life-giving wine of Dionysos. Subsequent archeological work has amply confirmed the remarkable degree of Hellenization present in many synagogues and other monuments of Judaism, but there seems to be no evidence to support the basic thesis of a two-way split in Judaism. Instead, "normative" Judaism seems to have been much more eclectic and locally varied than anyone had supposed (cf. Shanks 1979, especially, pp. 152–158).

Goodenough (1953–1968, Vol. 2, p. 201) quotes a charm that mixed Greek, Egyptian, and Jewish concepts in addressing Eros, said to sit upon the lotus "enthroned" as a croco-

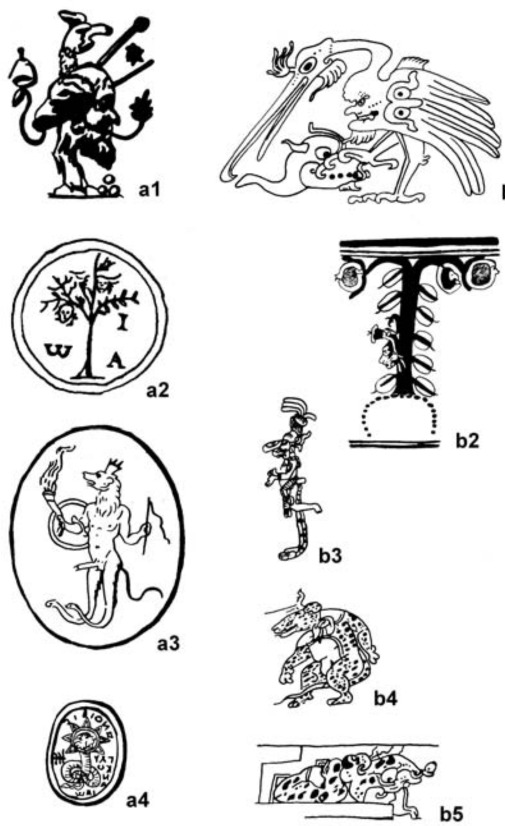


FIGURE 15.1. Comparisons of astronomical and astrological symbolism in amulets of Greco-Roman Judaism (a1 to a4) with Mesoamerican representations from pottery and monuments (b1 to b5). Drawings by Sharon Hanna.

dile and "to the south" of a winged serpent. Goodenough (1953–1968, Vol. 2, p. 215) maintained that "Symbols could not have been put publicly into the synagogues and cemeteries of the period unless they had already won such widespread tolerance among Jews as the literature of Judaism has never suggested." He goes on to claim that amulets and charms such as the one to Eros were the primary mechanism by which pagan symbols were adopted. This is apparently still an acceptable position. However, Morton Smith, a strong admirer but also critic of Goodenough, concluded that several of Goodenough's crucial positions were mistaken. Widespread "sacramental paganism" did not exist, and many of Goodenough's equations of different symbols were based on the premise that it did exist. At the level of comparative detail, many of his insights have been widely accepted.

From time to time, scholars have emphasized the striking difference between the Mediterranean and Mayan concepts of religion. It seems worthwhile to emphasize that there are also striking similarities clustering both geographically and conceptually. Although DHK has no hypothesis at present to explain similarities between a gnostic form of Judaism and Mesoamerica, he thinks that the similarities might easily be missed by other scholars and that they deserve attention, and, hopefully, explanation. In Figure 15.1, there are a few parallel items that would seem unusual wherever they were found, all associated with the deity name Iao.

Many of the Egypto-Judaic representations come from protective amulets. The more sophisticated possessors of such amulets might well have explained that they were not intended to represent the deity but only to symbolize some aspects of this power. DHK is particularly struck by the strange idea of incorporating a bearded human head with a prominent nose as the breast of a bird (Goodenough 1953–1968, Fig. 1086; see Figure 15.1a1 and b1). Beards are rare in Mesoamerica, and representations of human heads were offensive to many Jews; yet, they appear in similar figures in both areas. The Judaic amulet shows a rooster, and the Mesoamerican examples depict water birds (probably stylized herons), but we know of no similar depictions from anywhere else in the world. In Mesoamerica, the heads are accompanied by star glyphs in some cases and resemble those of known deities (cf., Figure 15.2). The six-pointed star of David with the Egypto-Judaic representation may also embody a planetary reference. It is noteworthy that among the Egyptians, Heron (*bak*) was a planetary name. The Mayan for heron is also *bak*.

Another resemblance is found in the so-called anguipedes, or serpent-footed gods (Figure 15.1a3 and b3). In the Mediterranean, such figures are often labeled *Iao* (*Iaw*) or *Abrasax*, Hebrew names given to God. DHK thinks that *Iao* seems to be a syncretism of Hebrew *Yahweh* with Egyptian ideas of a supreme creator, himself a syncretism of ancient Egyptian concepts with Hellenized Greek ideas. Abrasax is an artificial name, and the numerical values of the letters add to 365, which suggests solar symbolism. Goodenough (1953–1968, p. 251) writes, "We have already seen the name Iao attached to a considerable variety of forms, and we shall see it with many more, none of which need to be taken to stand for a likeness of Yahweh, or should be so taken in any direct sense. On the other hand, a complete denial of the reference of Iao to the God of the Jews, or to God in any sense, such as Ganschinietz has made, seems to me just as misleading." Goodenough is suggesting syncretistic identification of Yahweh with the Egypto-Judaic deity, of whom all other deities were manifestations. Both the rooster head and the lion head found on anguiped representations are also

FIGURE 15.2. Bird breasts in the form of bearded human heads representing star deities: Representations on a Mayan vase (Kerr 1991), K5082. Copyright, Justin Kerr. Reproduced with permission.

typically associated with solar symbolism across much of Eurasia. The lion-headed anguiped holding a shield and a torch resembles the Mayan god *Ah Bolon Tzacab*, "he of many generations," usually depicted with a single serpent-foot and a torch in his forehead, inset in a mirror. His Aztec counterpart, *Tezcatlipoca*, was associated with a smoking mirror (and we have argued for a solar role for him). In the latter case, his foot was lost to a crocodile, and he was replaced sometimes with a serpent and sometimes with a smoking mirror. The smoking mirror is associated in turn with New Fire ceremonies and the winter solstice. Although other gods with serpent feet are known, notably, the Greek *Boreas* and the Kogi *Duginavi*, the torch attributes seem to be restricted to Iao and to Ah Bolon Tzacab. Another representation labeled Iao shows a tree, the fruits of which are human heads (Figure 15.1a2). In Mesoamerica, the equivalent heads appear as gourds (Figure 15.1b2) and seem to represent the decapitated Sun god and, we have argued, solar eclipses. The calendar name of the decapitated god was *Hun Ahau*, literally "One Lord." Finally, a snake with a lions's head set with solar rays is also labeled Iao and finds a parallel in the Jaguar-Sun and in a jaguar-headed snake from Mesoamerica (Figure 15.1a4, b4, and b5).

All of the scholars we have discussed in §15.1 recognize major relationships between religion and social order. To the extent that a perceived concept of the heavens serves as the pattern for social relationships, any change in the way that Heaven is ordered may be regarded as a mandate for change in social relationships. Thus, evidence for a necessary change in governance in China was found in "unpredicted" eclipses, and other disturbing heavenly phenomena and changes in dynasties and in religious paradigms in the Near East were attributed to or associated with Jupiter-Saturn conjunctions by a number of Arabic scholars.

15.2.1. Conjunctions of Planetary Gods and Deified Kings

Associations between stellar entities and rulers have been widespread in both time and space. The 1st century B.C. kingdom of Commagene (in what is now a region in south-central Turkey) provides fine examples of such associations in its *hierothesia* or cult-monuments.[3] Commagene was strategically placed: It was at the crossroads of Hellenistic and Persian cultures and kingdoms. Cappadocia lay to the north and west; Cilicia and the Mediterranean, to the southwest; Armenia and Parthia, to the east, across the Euphrates River; and Seleucid-held Syria and Palestine, to the south. The region was continually traversed by traders as well as armies because of its control of favored crossing places of the Euphrates. It's lands were fertile, and the kingdom prospered. In late antiquity, it was renowned as the most prosperous of all the kingdoms owing allegiance to Rome. This small and prosperous kingdom was not, however, destined to be long-lived.

The regional satrap Ptolemaios (~163–~130 B.C.) led a successful revolt from the Seleucid Empire around 163 B.C. and consolidated the kingdom for his son, Samos (~130–100 B.C.), who constructed a 4-m tall rock relief of himself at Gerger, overlooking the Euphrates River, on which the kingdom bordered (Sullivan 1972, pp. 732–798; 1990, pp. 59–62 and Stemma 5). Samos maintained good relations with the Seleucids by securing as wife for Mithradates, his son, a daughter of the Seleucid king Antiochus VII Grypus [r. 125–96 B.C.]. Her name was Laodice Thea Philadelphos ("She who loves her brothers"); the marriage was celebrated not long before 96 B.C., when her father died. Mithradates I Kallinikos [r. ~100–~70 B.C.] ruled over a kingdom that lay between the Hellenistic, and increasingly Romanized, world to the west and that of Persia to the east. Not surprisingly, the kingdom became highly syncretized, blending Hellenic and Persian culture and religion, as the name Mithradates ("Gift of Mithra"), with its Persian deity and Greek form, demonstrates.

The associations between the gods and Commagene's 1st century (B.C.) kings Mithradates I [r. ~100–~70 B.C.], his son Antiochus I (Theos) [r. 70–36 B.C.], and his grandson Mithradates II [r. ~36–20 B.C.] have been explored through monuments constructed by these kings. Discussions of Commagene monuments have been given by Goell and Dörner (1956), Waldmann (1973), van der Waerden (1974), Dörner (1987), Beck (1998, 1999), and Sanders (1996).

One of the more impressive monuments is that built by Antiochus I at Nemrud Daği (or Dag), just west of Gerger on the Euphrates; it consists of three terraced complexes placed around a 50-m tumulus on one of the highest peaks in the Taurus range, and a prominent landmark in the region. The east and west terraces have colossal statues of gods seated on thrones, and a separate series of panels that show meetings between the gods and Antiochus. The *Nomos* or Holy Edict, the Greek text inscription on the back of the bases of the thrones on both the east and the west terraces, begins, in part, as follows:

IA-1 The great king Antiochos Theos [god] Dikaios Epiphanes, friend of the Romans and Hellenes, Son of King Mithradates Kallinikos and of Queen Laodice Thea [goddess] Philadelphia, . . . records at the bases of the holy thrones, in imperishable letters, . . . words—for all time.

11 I believed that for us humans piety is not only the most secure of all possessions, but also the sweetest joy and even this judgement had as its source my lucky power as well as blessed custom. Throughout my life I have been standing before the citizens of my realm as one who took piety as his truest defence and his incomparable bliss. Hence, when, against all expectation, I escaped great dangers, I became the Lord over my hopeless situation and passed through it to reach an age rich in years.

IB-24 When I undertook paternal rule, I declared from my god-fearing soul that my throne and kingdom would be a hospitable resting place for all the gods. The representations of their forms, depicted in the most diverse manner—in the fashion of the ancient art of Persia and Greece—the fortunate lineage of my family—handed down to us. I honored them with sacrifices and festivals, as has been the custom since ancient times, and the general practice of mankind.

[3] Sanders (1996, p. 91) describes a *hierothesion* as a "common consecrated seat" or "dwelling place" of all of the gods. As far as is known, the word actually appears only at Commagene (see the *Nomos* translation, below).

I also discovered, through due consideration, a suitable way to manifest these honors.

53 So I have erected, as you see, these true and esteemed likenesses of the gods: that of Zeus Oromasdes, that of Apollo Mithras Helios Hermes, that of Artagnes Herakles Ares, and of the all-sustaining (goddess) Kommagene of my homeland.

(Translated by EFM from the Greek and German translation in Waldmann 1973, pp. 63–77; bracketed comments added by present authors.) Note the interesting blend of Greek and Persian names: Zeus [Jupiter] Oromasdes [Ahura Mazda]; Apollo Mithras Helios Hermes [Mercury]; Artagnes (or Verethragna [abstract expression of Victory]) Heracles Ares [Mars]. The inscriptions indicate that the monument celebrates meetings among the gods with Antiochus, depicted on equal terms with them; this is hardly surprising because one of his titles is *Theos*, god, but the acceptance by the pantheon seems to be what is being celebrated on the panels of both terraces.

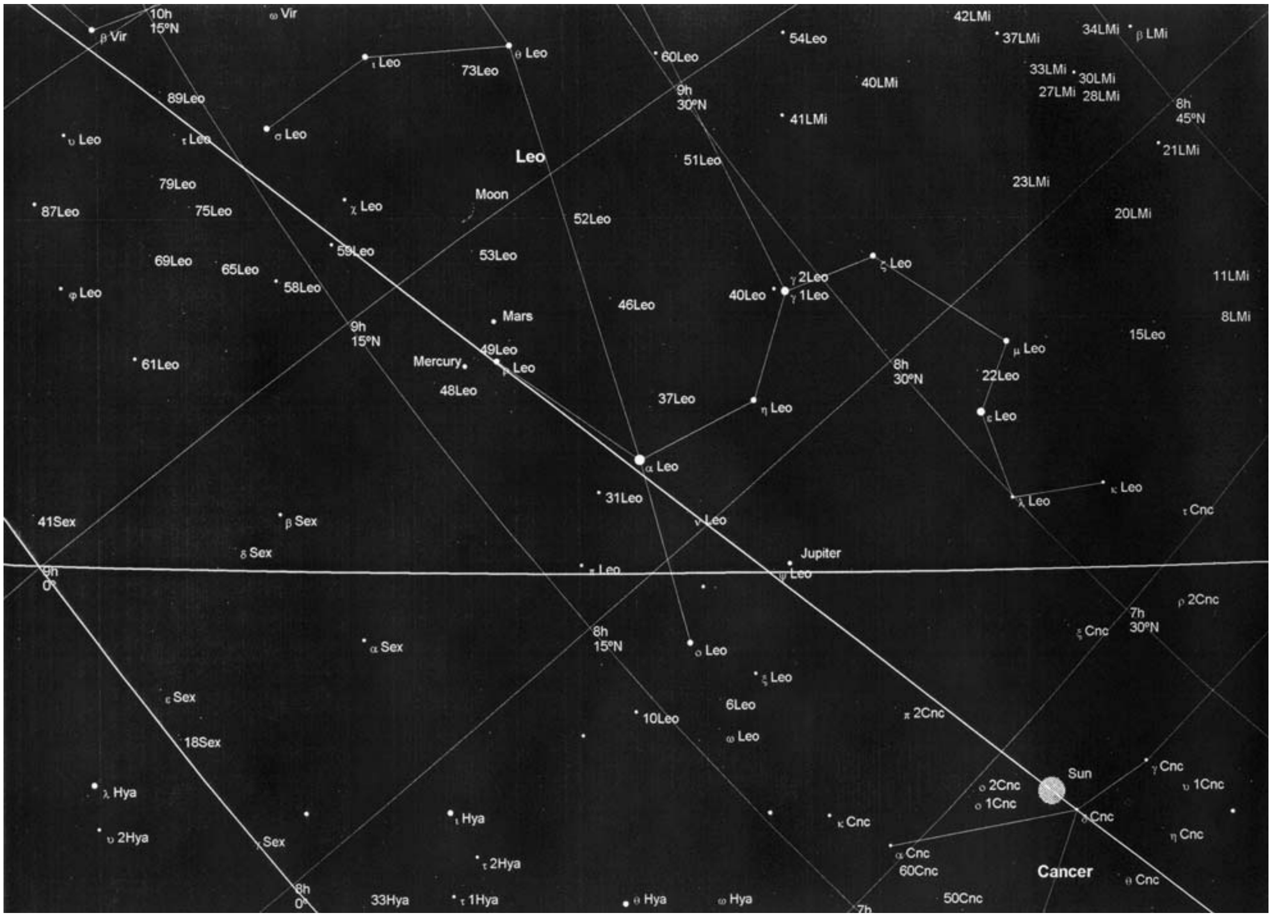
The west terrace contains a line of five 8-m-high statues of forward-facing god figures flanked by a pair of eagle and lion figures at either end. Adjacent to the line of god figures is a shorter line of smaller figures. These too are flanked by forward-facing eagles and lions, again with the lions on the outside. The whole scene is identified with a series of planetary conjunctions. Three panels in this smaller line of figures show the king clasping hands with each god in turn. King Antiochus wears a *kitaris* (the pointed tiara of the Armenian kings, who under the Orontid dynasty, once controlled the area). He is shown meeting and greeting Mithra-Apollo, characterized by the Phrygian cap and other Persian dress, and by a rayed halo. Another panel shows the meeting between Antiochus and Ares; the 3rd panel is fragmented, but presumably depicts the meeting between Antiochus and Zeus.

A 4th panel in the smaller line of figures is the so-called "lion horoscope," shown in Figure 15.3. The body is shown bearing the stars of the constellation Leo, and although the placement of all the stars is not fully accurate (see Figure 15.4), the triangle involving Denebola is roughly correct, and the brightest star, on the breast of the lion above an incumbent crescent Moon, is presumably α Leo, *Regulus*, sometimes known as *Cor Leone*, "heart of the Lion." Three bright stars above Leo's back are labeled with the names of the three planetary gods of the Nomos inscription, but with their astronomical descriptions: Πυρόεις 'Ηρακλ[έους] ('Fiery planet of Heracles'), Mars; Στίλβων 'Απόλλωνος ("Gleaming planet of Apollo"), Mercury; and Φαέθων Διός ("Radiant planet of Zeus"), Jupiter. That the lion wears a crescent Moon around its neck, and that planets appear above its back, suggests a horoscope, or at least one or more conjunctions in Leo of these objects and makes the panel an astrological record of historical importance. Interpreting the king as the star *Regulus*,[4] and the three stars as those of the planetary gods, the lion horoscope dates the conjunction of these three planets. Paul Lehmann investigated all conjunctions in which these planets appeared in Leo in the exact order indicated by their labels and found only one date that would fit this description: July 17, 98 B.C. (reported in Humann and Puchstein 1883/1890, pp. 329–333). If this is a birth horoscope, it contradicts what Antiochus says about his date of birth in the *Nomos* inscription (16 Audnaios, a month equivalent to December/January, but the Sun is far from Leo at this time of year and yet the presence of Mercury in Leo indicates that the Sun must be near). If interpreted as a coronation date (11 Loos, equivalent to July), the horoscope creates severe chronological problems. This analysis, moreover, ignores the crescent Moon on the lion, and there is the question of the Sun, which is not explicitly indicated on the lion. It is true that both Helios and Apollo were also associated with the Sun, but Hermes would appear to indicate Mercury alone, and there is no association of the equivalent Persian Sun deity, Ahura Mazda, with the planet Mercury. Iconographically, the Sun is unlikely to be represented by a bright star; a Sun disk was in use in Persia.

In about 1958, an astronomical analysis was done by O. Neugebauer at the request of Theresa Goell, whose work on Nemrud Daği is summarized in Sanders (1996). Neugebauer noted that none of the three planets was more than 3° from the Sun on the 98 B.C. date (yet the Sun was not represented on the horoscope). He therefore abandoned the assumption

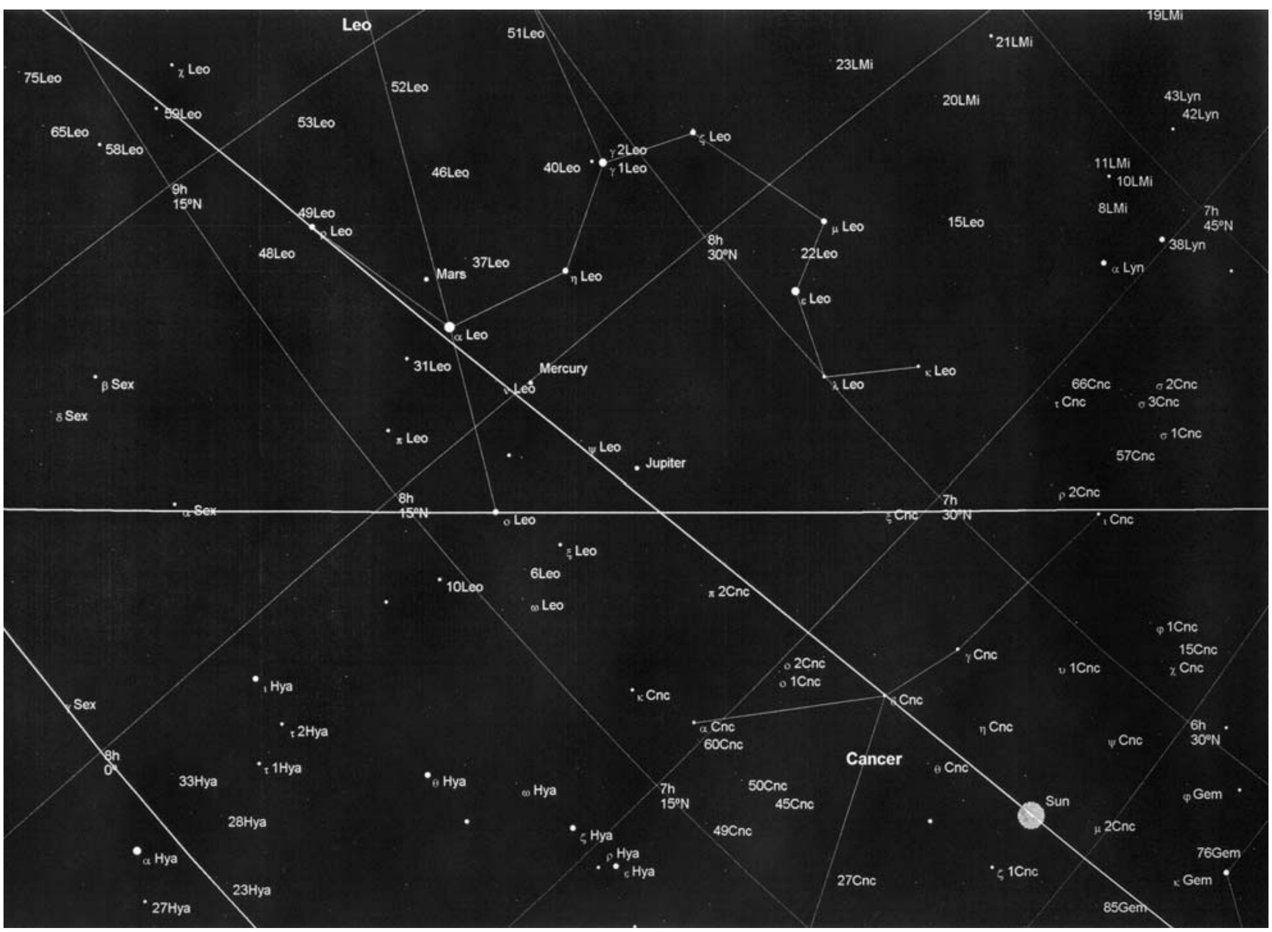
FIGURE 15.3. The so-called "lion horoscope," from the 4th panel in the smaller line of figures on the west terrace of Nemrud Dag: The body is shown bearing the stars of the constellation Leo, although the placement of all the stars is not fully accurate (see Figure 15.4). The bright star on the breast of the lion above an incumbent crescent Moon is presumably α Leo, *Cor Leone*, "heart of the Lion." Three bright stars above Leo's back are labeled with the names of three planetary gods: Mars, Mercury, and Jupiter. Staatliche Museen zu Berlin photograph reproduced from Humann and Puchstein [Fig. XL, Vol. II (Plates), 1883/1890] by D. Stone.

[4] A diminutive form of the Latin *Rex*, the name meant "king" throughout most of the region: It was called βασιλίσκος (basiliskos) in Greece; Sharru, "the king," in Babylonia; Amil-gal-ur, "king of the celestial sphere," in Akkadia; *Miyan*, "star of the center" or "the central one," in Persia; and *Maghā*, "the Mighty," in India.



10h
15ºN
ω Vir
β Vir
ι Leo
θ Leo
73Leo
60Leo
54Leo
42LMi
37LMi
34LMi
β LMi
33LMi
30LMi
27LMi
28LMi
40LMi
9h
30ºN
8h
45ºN
89Leo
σ Leo
41LMi
υ Leo
τ Leo
Leo
51Leo
21LMi
23LMi
79Leo
87Leo
75Leo
χ Leo
Moon
52Leo
20LMi
69Leo
65Leo
59Leo
53Leo
ζ Leo
γ 2Leo
γ 1Leo
40Leo
58Leo
φ Leo
46Leo
11LMi
8LMi
Mars
9h
15ºN
49Leo
ρ Leo
Mercury
48Leo
61Leo
μ Leo
15Leo
8h
30ºN
22Leo
37Leo
η Leo
ε Leo
α Leo
31Leo
κ Leo
λ Leo
τ Cnc
41Sex
β Sex
ν Leo
δ Sex
Jupiter
π Leo
ψ Leo
9h
0º
ρ 2Cnc
7h
30ºN
ξ Cnc
8h
15ºN
α Sex
ο Leo
ξ Leo
ε Sex
6Leo
π 2Cnc
10Leo
ω Leo
18Sex
Sun
γ Cnc
λ Hya
ο 2Cnc
υ 1Cnc
ο 1Cnc
ι Hya
κ Cnc
δ Cnc
η Cnc
υ 2Hya
γ Sex
α Cnc
60Cnc
τ 2Hya
Cancer
θ Cnc
8h
0º
33Hya
τ 1Hya
θ Hya
ω Hya
7h
50Cnc

(a)



Leo
51Leo
19LMi
21LMi
75Leo
χ Leo
23LMi
52Leo
20LMi
43Lyn
42Lyn
59Leo
53Leo
65Leo
58Leo
ζ Leo
γ 2Leo
γ 1Leo
40Leo
46Leo
11LMi
10LMi
9h
15ºN
49Leo
ρ Leo
8LMi
7h
45ºN
μ Leo
15Leo
8h
30ºN
48Leo
22Leo
38Lyn
37Leo
Mars
η Leo
α Lyn
ε Leo
α Leo
31Leo
Mercury
κ Leo
λ Leo
β Sex
ν Leo
66Cnc
σ 2Cnc
τ Cnc
σ 3Cnc
δ Sex
π Leo
σ 1Cnc
ψ Leo
Jupiter
57Cnc
8h
15ºN
7h
30ºN
ρ 2Cnc
α Sex
ο Leo
ξ Cnc
ι Cnc
ξ Leo
6Leo
10Leo
ω Leo
π 2Cnc
φ 1Cnc
15Cnc
ο 2Cnc
ο 1Cnc
γ Cnc
υ 1Cnc
χ Cnc
ι Hya
γ Sex
κ Cnc
δ Cnc
α Cnc
τ 2Hya
60Cnc
η Cnc
ψ Cnc
6h
30ºN
8h
0º
τ 1Hya
Cancer
33Hya
θ Hya
θ Cnc
ω Hya
7h
15ºN
50Cnc
45Cnc
φ Gem
28Hya
Sun
ζ Hya
49Cnc
μ 2Cnc
ρ Hya
α Hya
ε Hya
76Gem
ζ 1Cnc
κ Gem
27Cnc
27Hya
23Hya
85Gem

(b)

that the order of the planets was exactly rendered on the lion horoscope, and instead, he examined all conjunctions within a historically plausible interval (120 to 35 B.C.). As pointed out by Neugebauer and van Hoesen (1959, p. 15) and summarized by Goell in Sanders (1996, Vol. I, pp. 87–91), the planetary positions were probably calculated rather than observed, but the precision with which such positions could be calculated in the 1st century B.C., would not have permitted sufficiently precise placements of either Mercury or Mars to ensure the accuracy of the labeled order. The date obtained by Neugebauer was July 7, 62 B.C., which modern software programs confirm. This would seem to be the date of Antiochus's coronation; indeed, Loos 10 was approximately July 4 (Ginzel 1906–1914, 3, 19). However, the usually reliable historian Cassius Dio [3rd century A.D.] indicates that Antiochus was already king by 69 B.C., and again the chronology is disrupted. Antiochus is mentioned by Dio because of his support of the Armenian king, Tigranes I the Great, against Rome, in the Third Mithradatic War. Following the successful conclusion of the war by Pompey, Antiochus was symbolically, although not literally, dragged through Rome in the triumphal procession. Diplomatically turning an enemy, Pompey confirmed Antiochus as king in a reorganization of the region in 64 B.C. Neugebauer suggested that because Antiochus mentions his friendship with the Romans in the Nomos, this act of confirmation was the likely occasion for the erection of the monument. Goell disagreed with this conclusion, however, arguing that it was scarcely likely that a defeat and humiliation could be the basis for such a work.

We agree with Neugebauer that this was the date of commemoration, but we believe that the date of erection must have been later than this, and that the event although probably calculated could have been driven by the impact of the observational event as well. The conjunction of two of the three planets in Leo could well have been seen after sundown, on July, 7, 62 B.C., (as Figure 15.4a indicates) and Jupiter's position known from observations carried out a week or so earlier, when it could have been seen approaching acronychal setting (see §2.4.3). Figure 15.4b shows the sky as it would have appeared on June 28, 62 B.C., at nearly the same configuration, but without the Moon. Tuman (1984) prefers Feb. 4–5, 55 B.C. The commemoration could have been realized only after Antiochus's regime was secure and his reconciliation with Rome in 64 B.C. could have provided that security. Antiochus's immediate forebears had preserved their kingdom through a series of diplomatic moves, which, when successful, would have demonstrated to them that the gods had approved. The comment in the Nomos that he had come through difficulties against all odds suggests that Antiochus was supremely grateful to the gods for the perservation of his crown and kingdom. The conjunction would have seemed a sign of divine favor, and he could well conclude from the heavenly display that the gods did consider him as an equal. This is as sound a basis for the apotheosis theory of the monument as one may find.

The detailed instructions for religious ceremonies and festivals that are included in the Nomos further states that henceforth, in Commagene, all the gods would continue to find a hospitable dwelling place. Antiochus's expressed piety and gratefulness for his fortunate circumstance and life can certainly be regarded as genuine, but it also served a kind of deistic political purpose; after all, if the kingdom should fall and the dynasty swept away, who would ensure this hierothesion "for all time?" This implies great confidence on the part of Antiochus that his apotheosis was, in fact, real, but it undoubtedly reflects also Antiochus's preoccupation with diplomatic maneuverings that were so essential to the little kingdom's survival. But, was the lion used previously?

Another relief, from Arsameia on the Nymphaios [a site near to but not at Nemrud Dag (Hinnells 1973/1985, p. 24)], shows Antiochus's father, Mithradates I Kallinikos, greeting Verethragna-Herakles [Jupiter], who is shown in stylized Greek fashion, naked but for a lion skin and carrying a large club. This site was developed by Mithradates, but Antiochus is known to have developed it further. Evidently, this monument, too, was erected to commemorate the apotheosis of a king as well as a dynasty and, by implication, the harmonization of dynasty and kingdom with the gods.

Whereas the Antiochan monument involved a massive conjunction that would have been difficult, although not impossible, to see because of the proximity of the Sun, another monument commemorated a series of conjunctions and astronomical alignments that would have been brilliantly visible over an interval of about a year. Antiochus's son, Mithradates II [r. ~36–20 B.C.] erected a monument ~30 km to the southwest, at Karakus. This one consisted of a 21-m-high mound around which were erected three sets of columnar pillars arranged in a triangle centered on the mound. One of the pillars on the west side of the mound is surmounted by a lion, and another by relief images of the king and his sister; the sole (remaining) pillar to the south side has an eagle, and those on the east side included one with an ox (the other pillar is standing empty). Given the approximate dates of Mithradates's reign, it is certain that Leo set behind the monument group that included the lion; when this occurred at sunset, the constellation Aquila would have transited the meridian and thus appear to be above the

◀

FIGURE 15.4. The recreation of the "lion horoscope" sky: (a) July 7, 62 B.C., at dusk. Mercury, Mars, Jupiter, and the Moon are located in Leo. The horizon is made transparent in this Red Shift plot to show the Sun below the horizon. The Moon is a narrow crescent located just above Mars. Note that the Sun is not at the required *arcus visionis* (h below ~−10°) to permit easy visibility for the planets, and yet Jupiter is about to set. This indicates that the lion horoscope circumstances were probably computed rather than based on observations on this date, although two of the three planets could have been seen and the position of Jupiter inferred (by its position days earlier, when it could have been seen setting acronychally). (b) The sky as it would have appeared on June 28, 62 B.C., at dusk, at nearly the same configuration as in Figure 15.3 but without the Moon. Simulations by E.F. Milone with the Red Shift and Voyager software package with essential details confirmed with JPL ephemerides kindly provided by E.M. Standish.

south statue near midnight, and, finally, near dawn, Taurus would rise over the eastern monuments that included the ox. Roger Beck has suggested additionally that a series of year-long conjunctions around 27 to 26 B.C. was commemorated in these monuments.

Beck, indeed, brilliantly demonstrated these phenomena in a public lecture in the Digistar Discovery Dome at the Calgary Science Centre on Oct. 17, 1997, by having the sky programmed as it would have appeared on the suggested dates. The planet Venus initiated a series of planetary conjunctions with Regulus, and the planets Mars, Jupiter, and Saturn, also appeared in conjunctions with Regulus, and sometimes with each other. Seen near opposition, the grouping of the giant planets would have permitted Saturn to be in conjunction with Regulus three times, and the "great conjunction"—between Jupiter and Saturn—occurred in this interval as well. Venus concluded the series in evening twilight. The association of Antiochis (the sister of Antiochus) with Venus is suggestive because the column relief displays Antiochis taking leave of her brother. The dynastic tree produced by Sullivan (1990, Stemma 5) shows another brother, Antiochus II, as deceased in 29 B.C.

Beck suggested further that these events spurred the rise of a new dynastic cult in the Middle East. It is interesting that such events should have been commemorated as they were shortly before the Christian era. Beck (1999) calls attention to the similarity of the Karakus figures with the description of the "four living creatures" of the Book of Revelation (4:6–9): "And before the throne there was a sea of glass like unto crystal; and in the midst of the throne, and round about the throne, were four beasts full of eyes before and behind. And the first beast was like a lion, and the second beast like a calf, and the third beast had a face as a man, and the fourth beast was like a flying eagle. . . ." (King James version). Arndt and Gingrich (1957, p. 530) also indicate "young bull or ox" for "calf," (μόσχῳ, mos-choi). As Beck again notes, correspondence with constellation figures is strongly suspected, even if no firm identification is agreed upon (Beck 1999; Malina 1995). Now we discuss perhaps the most famous of all associations between cosmic events and the birth of a king, the Star of Bethlehem.

15.2.2. The Star of Bethlehem

Here, we discuss one of the better known astronomical references in religion—the Christmas star. In the time when stars were considered angels, this particular story, unattested outside of the Gospels of the New Testament, nevertheless has a cohesiveness that suggests possible astronomical interpretations.

The New Testament records the familiar Christmas story in Matthew[5] ii:1–12:

[1]Now when Jesus was born in Bethlehem of Judea in the days of Herod the King, behold, wise men from the East came to Jerusalem, saying, [2]Where is he who has been born king of the Jews? For we have seen his star in the East and have come to worship him." [3]When Herod the king heard this, he was troubled, and all Jerusalem with him; [4]and assembling all the chief priests and scribes of the people, he inquired of them where the Christ was to be born. [5]They told him, "In Bethlehem of Judea; for so it is written by the prophet:

> [6]And you, O Bethlehem, in the land of Judah,
> are by no means least among the rulers of Judah;
> for from you shall come a ruler
> who will govern my people Israel."

[7]Then Herod summoned the wise men secretly and ascertained from them what time the star appeared; [8]and he sent them to Bethlehem, saying, "Go and search diligently for the child, and when you have found him bring me word, that I too may come and worship him." [9]When they had heard the king they went their way; and lo, the star which they had seen in the East went before them, till it came to rest over the place where the child was. [10]When they saw the star, they rejoiced exceedingly with great joy [11]and going into the house they saw the child with Mary his mother, and they fell down and worshiped him. Then, opening their treasures, they offered him gifts, gold and frankincense and myrrh. [12]And being warned in a dream not to return to Herod, they departed to their own country by another way.

This verbal depiction of the Christmas star has become a familiar and integral component of the annual celebration. The eyes of faith do not require astronomical confirmation, but it is interesting that the details provided in the Gospel accounts do permit astronomical interpretations. The interpretations have been numerous, as the extensive bibliography by Ruth Freitag (1979) indicates, and they continue to appear, year after year.

Consider the details as they are laid out in Matthew. The "wise men" are μαγοi, "magi," in the Greek, a word that carries connotations of astrology. They are traditionally regarded as Zoroastrian priests, whose duties would have included interpretations of astronomical events and of dreams. The statement, "We have seen his star in the East," has been the source of some controversy, because it has been claimed (Hughes 1976; Molnar 1999) that the form used for "in the East," εν τη ανατολη, has a special, astronomical meaning with astrological significance. The meaning in an astrological or astronomical context is that of "heliacal rising," the first rising of the season to be seen—just before dawn—and does not mean more generally "in the East part of the sky," for which the plural, ανατολαi, is used. In addition, Hughes (1976) interprets the passage as indicating an acronychal rising—a rising after sunset. However, we do not really know if the intent of the writer was astrological, and from the lexicons (Lampe 1961; Liddell and Scott 1940), it is evident that the phrase can equally well mean "in the East" meaning a geographic area. If this was the intent, the passage may be telling us nothing more than that the star appeared to the magi before they began their journey somewhere "in the East," probably Persia. Hughes (1976) argues that the magi were unlikely to use this expression to refer to their country; he, of course, may be correct, but the true meaning of the phrase is still uncertain.

We are told that Herod was king in Jerusalem, which places the event before mid-March, 4 B.C., when many scholars believe that he died—a few days after a lunar eclipse, according to Josephus (93 A.D., Whiston tr., p. 365). A lunar

[5] *The Holy Bible*, Revised Standard Version. Collins: New York, 1973.

eclipse did occur on Mar. 12–13, 4 B.C., although Edwards (1972) has argued that Josephus's chronology pointed to another lunar eclipse—that of Jan. 9–10, 1 B.C., which would imply a correspondingly later date for Herod's demise. The star was not so brilliant or marked that Herod had seen it, or if he had seen it, recognized its importance. Kings may not have needed to be astrologers, but in the narrative, at least, Herod was uninformed. Molnar's (1999, p. 16) explanation, that this was the case because Jews did not practice astrology, we find unconvincing. For one thing, although it may not have been sanctioned officially by the priests, there is ample evidence of its importance even to the extent of details on the High Priest's robe (cf. 7.1.2.2), and, for another, Herod had been educated at Rome and was thoroughly Hellenized, a circumstance that did not endear him to a sizable number of his subjects. Additionally, the account implies that he appreciated the significance of the star once the Wise Men had mentioned it to him. In the first instance, though, the significance that the star held for the magi had to be different from its significance for Herod's advisors. This suggests to us that the Wise Men were talking about a phenomenon that was not strictly interpretable within the omens of either Jewish or Hellenistic astrology.

We are next told that when the magi left the palace, the star "went before them" and it "stood over" the place where the child lay. They "rejoiced greatly" when they saw it; so seemingly it had not been continually visible to them since they left their homeland. Thus, it would be a strange reaction for astrologers to have to a recurrent planetary phenomenon involving a single planet or even a conjunction of two planets. In any case, we have either two distinct events or a recurrent phenomenon. The possibilities are

(1) none—the narrative being a literary invention for the purpose of identifying the birth of a king with heavenly signs;
(2) a comet, which could be seen prior to and following perihelion passage;
(3) a variable star, most likely one or more novae or supernovae;
(4) a planetary conjunction—either a two- or three-planet conjunction;
(5) at least for one of the events, an exploding bolide; and, finally,
(6) a unique or rare event or combination of events, which believers could well call a miracle.

Concerning the first possibility, there is the oracle of Balaam the son of Be'or, given in Numbers 24:17:

> . . . a star shall come forth out of Jacob,
> and a scepter shall rise out of Israel. . . .

which provides a purpose for including the narrative of a Christmas star. In early Christian times, the magi were regarded as the intellectual heirs of Balaam, as is illustrated by paintings in the catacombs (Lindsay 1971, p. 231). The star is not mentioned in the other Gospels, but it is mentioned in the apochryphal *Protoevangelium* of James, where there is a description of a star so bright that it caused other stars to dim to invisibility. Although stars are not explicitly mentioned, it is not impossible that the angelic visitation in Luke 2:8–15,

> [8]And in that region there were shepherds out in the field, keeping watch over their flock by night. [9]And an angel of the Lord appeared to them, and the glory of the Lord shone around them, and they were filled with fear.

is a reference to a bright and perhaps transient object. Yet in neither source is there explicit mention of the fulfillment of a prophecy regarding a celestial event; this would seem to be a strange omission if evidence of prophetic fulfillment was the purpose for inclusion of the narrative. The depiction of the star in connection with the symbol of the Good Shepherd, the earliest Christian depiction on tombs, would testify to the power of the Christmas star symbolism to the early church. A note by Beehler (1980), discussed in an astronomical context by Hoffleit (1984), purports to provide just such a linkage. Beehler suggested that the fruits hanging from trees in a catacomb painting represent a sky map, which provides a record of the Star of Bethlehem. She claims that the map suggests approximate coordinates ($\alpha = 20^h$, $\delta = -20°$) for the "nativity" star. A person standing next to a rotated image of a mother and child allegedly points to this fruit/star. Beehler claims that this object is the only one that does not match known stars in the vicinity. She further argues that the name of the deceased, Priscilla, was the same Priscilla mentioned in the New Testament (Acts 18:2, 18, 26; Rom. 16:3; I Cor. 16:19; II Tim. 4:19). The Priscilla mentioned in the New Testamant was married to a man named Aquila (originally from Pontus); they were exiled from Italy because of an edict by Claudius banning Jews from Rome in 49 A.D. They subsequently converted to Christianity and, with Paul, were active in the early Church by about 52 A.D. In attributing astronomical knowledge to Aquila, however, Beehler appears to conflate this Aquila with another, also from Pontus, who was active in the mid-2nd century A.D., and who apostatized to Judaism because of opposition to his astrology. The latter Aquila was instrumental in providing a new version of the Old Testament in Greek (more acceptable to the Jewish establishment of the time than that which had been used previously by Christians and Jews alike), a work dated to ~140 A.D., and is clearly a later figure. It is unlikely (but not impossible—as we note below) that the tomb has anything to do with this Aquila because there is no reason why an apostate would wish to be connected with Christian symbolism. There is no evidence that the Aquila mentioned in Acts knew astronomy or astrology, let alone practiced it. There are other problems with the claim as well, which create doubt that the scene represents the Christmas star and the nativity:

(1) The relative locations do not agree with the stars of the summer sky in any consistent way (although one has to concede that a subjective depiction from memory could be faulty, especially given the difficult conditions in the catacombs in which the artist would have had to work).
(2) The relative sizes of the fruit do not agree with the brightnesses of the stars as identified by Beehler.
(3) The figures are unclear, and it can be argued that the "pointing" figure is rather in a gesture of adoration. The figure of the child does not appear to be that of a newborn infant; and, finally, neither image appears to be connected with the fruit trees at all, which,

however, frame the more traditional scene of the Good Shepherd.

Therefore, in our opinion, there is neither credible evidence for an astronomical depiction in this scene nor any convincing basis for supposing that there should be one. However, there are arguments on the other side of the issue. Hoffleit 1984; (private communication to EFM, 1998) points out that if the stars were intended to be disguised as apples, the relative sizes need not be indicators of stellar brightness. Moreover, if the later Aquila was, as is sometimes alleged, the grandson of Aquila and Priscilla, he might have executed the imagery prior to leaving Christianity as an act of devotion to his grandmother, whether or not he was a devout Christian at the time of commission. As an astrologer, he could have been motivated to do the scene. Thus, the identification, although neither fully demonstrated nor convincing, is not greatly implausible, and in fact is made somewhat more plausible by the discovery of McIvor (1998; reviewed by Hoffleit), discussed later.

In his work, *Against Celsus* (Book I, Chaps. LVIII-LX; tr. Crombie, in Roberts and Donaldson/Coxe, repr. 1994, pp. 422–423), the early Christian theologian Origen takes the Star to be a "new star," by which he means an object, "such as" a comet,[6] newly visible in any of the heavens. The qualification is required by the wording of the Balaam prophecy, which Origen cites "with respect to comets there is no prophecy in circulation to the effect that such and such a comet was to arise in connection with a particular kingdom or a particular time; but with respect to the appearance of a star at the birth of Jesus there is a prophecy of Balaam recorded by Moses" [Book I, Ch. LIX]. Halley's comet was visible between Aug. 26 and Oct. 20, 12 B.C. (Marsden 1993, p. 38), which is earlier than most scholars would accept for Jesus's birth. If Joseph's enrollment did take place, and there is evidence cited by Hughes (1976) that a census for Roman taxation purposes was ordered for 8 B.C., then Comet Halley was too early. Ho's (1962) catalog of Chinese comets indicates that a comet appeared in 10 B.C. ("During the third year of the Yuan-Yen reign period a comet was seen at *Shê-Thi* and *Ta-Chio*"), but it is mentioned in only one source, *Thung Chien Kang Mu*. Ho (1962) also records comets for the years 5 B.C. and 4 B.C., but in neither case is there any indication of movement. The 5 B.C. object appeared in the Chinese constellation *Chhien-Niu* (the ninth lunar mansion) sometime in the interval Mar. 10 to Apr. 7, 5 B.C., and was visible for 70 days. The other "ominous star" appeared in Aquila in April 4 B.C., but it was described as a *po-hsing* ("sparkling star"), one that radiates in all directions and so may be without a tail, making it a possible nova.[7] The latter object is also recorded as a *po* ("sparkling") object in the *Chronicle of Silla*, in Korea.

Stephenson and Clark (1978, Table 3.1) provide a list of novae visible in pretelescopic times, and they include among them the Chinese *hui-hsing* or "broom-star" type object of 5 B.C., cited above, at position $\alpha = 20^h20^m$, $\delta = -15°$, in eastern Capricorn near β Cap. The term "broom-star" is often used to describe tailed comets, but Stephenson and Clark (1978, p. 63ff) note that the Chinese records are sometimes inconsistent and include this object in their list of novae because there is no mention of any motion. Clark and Stephenson (1977) suggest that this object, whatever it was, represents an independent sighting of the Star of Bethlehem.

A more recent study (McIvor 1998) argues again for supernovae—but with a twist. There is a binary pulsar: PSR1913 + 16 (the designation gives its coordinates in RA and DEC), which implies two supernovae events. McIvor argues that successive supernovae may have appeared in 4 B.C., when he thinks the Magi had their 1st sighting, and again in 2 B.C., after they left Herod's palace. No pulsars have been detected in the locations given in the annals for the objects of 5 B.C. in *Chhien-Niu* (in eastern Capricorn), and of 4 B.C. in *Ho Ku* (Altair and its flanking stars, in Aquila). The double pulsar, is, however, some 12° northwest of Altair, near the Chinese constellation of Tso-chi (in Sagitta). If the location given in the annals for the the 4 B.C. event is in error, the identification is plausible, if not demonstrated.

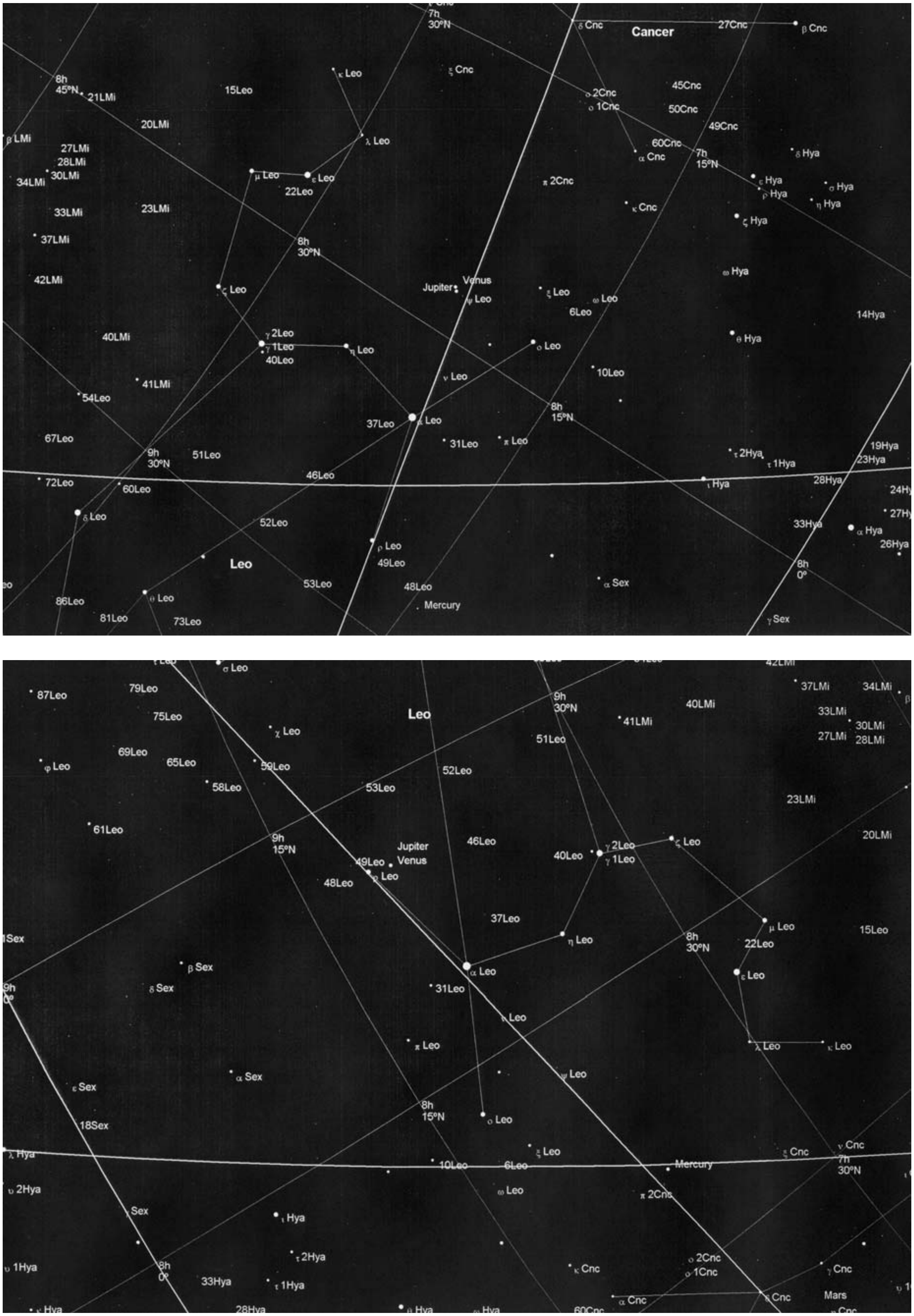
Configurations of planets were important astrologically. If more than one "star" was involved, however, Matthew's account must be faulty. Hughes (1976, 1977) argues that Matthew was writing in κοινη or popular Greek, and he was merely following Old Testament tradition in referring to the phenomenon as *a* star (ἀστήρ) instead of stars (ἀστέρος) or planets (πλάνητες ἀστέρες or ἀστέρες πλανῆτας—see §2.4.1). Sinnott (1968) selected six conjunctions that would have been spectacular as viewed from the Middle East; the criteria were that the planets must be ≤12 arcminutes apart and be >15° from the Sun. Two conjunctions of Venus and Jupiter were particularly noteworthy in this list. The first was visible in the dawn sky in Leo on August 12, 3 B.C., when they were 12 arc-minutes apart. See Figure 15.5a for a simulation of this first event.

The second was visible in the evening sky of June 17, 2 B.C., when they were less than 4 arc-minutes apart and would have seemed to fuse into a single bright star over Judea, to the west. See Figure 15.5b, for a simulation of this second event. The dates appear to be too late, however, unless the familiar Christian era base (from the work of Dionysius Exiguus in 525 A.D.) turns out to be nearly correct.

There were other sets of conjunctions also. Every 120 years, Jupiter and Saturn undergo a set of three conjunctions

[6] Origen writes that "The star which was seen in the east we consider to be a new star, unlike any of the well-known planetary bodies, either those in the firmament above or those among the lower orbs, but partaking of the nature of those celestial bodies which appear at times, such as comets, or those meteors which resemble beams of wood, or beards, or wine jars, or any of those other names by which the Greeks are accustomed to describe their varying appearances" [Book 1, Ch. LVIII]. He argues [see §5.5] that such "comets" can portend *good* as well as *evil* events, and therefore would be appropriate to mark the birth of Christ: "If, then, at the commencement of new dynasties, or on occasion of other important events, there arises a comet so called, or any other similar celestial body, why should it be matter of wonder that at the birth of Him who was to introduce a new doctrine to the human race, and to make known his teaching not only to Jews, but also to Greeks, and to many of the barbarous nations besides, a star should have arisen?" [Book 1, Ch. LIX].

[7] However, Comet Halley in the apparition of 12 B.C. is also described as a *po* comet, although it is clearly described as having a tail and moving among the stars (see §5.5).



(a)

(b)

FIGURE 15.5. Simulations of two conjunctions of Venus and Jupiter that are particularly noteworthy candidates for the Star of Bethlehem: (a) The first is seen in Leo in the pre-dawn sky on August 12, 3 B.C., at Baghdad. (b) The second conjunction is seen on June 17, 2 B.C., in the evening sky at Bethlehem, when the planets would have fused into a single brilliant point of light. Simulations by E.F. Milone with the Red Shift software package.

(a "triple conjunction") over an interval of about six months. Kepler is known to have viewed a close conjunction between Jupiter and Saturn in 1603–1604 (joined, in Spring 1604, by Mars). The significance of such conjunctions for Mideastern astrologers is that Jupiter was associated with the ruler of the world, and Saturn with the Jewish people, hence, a conjunction at a particular instant of history. On May 29, Sep. 29, and on Dec. 4, 7 B.C., conjunctions took place in Pisces, which in Kepler's time and in the Middle Ages was astrologically associated with the Jews. However, Molnar (1999, pp. 27–30), among others, argues persuasively that this association between the Jews and Pisces was not held at the dawn of the Christian era, and that Judea, as part of a more general region, was at that time astrologically held to be governed by Aries.

Correct or not, the predominant view today is that conjunctions were somehow involved, at least among those who regard the Christmas Star event as historical. As we have noted, the conjunction interpretation was opposed by Origen, who moreover derided Celsus for confusing the magi with Chaldeans (whose interest in conjunctions was and is well attested), and thereby expecting the magi to be interested in conjunctions [*Against Celsus*, Book I, Ch. LVIII (see Roberts and Donaldson/Coxe, repr. 1994)]. Molnar (1999) ignores the point of this distinction and assumes that the magi held Hellenistic astrological views (whereas Herod and his court did not, thus, explaining their apparent ignorance of the "star"). He also argues that the magi were most likely impelled to Jerusalem by an occultation or appulse of Jupiter by the Moon in Aries, an astrologically powerful configuration. His interpretation depends strongly on his view that the Jews did not practice Hellenistic astrology, despite Herod's background and strong associations with Rome, but that the magi did. If, as is commonly thought, the magi were Zoroastrian priests, however, their religion, extant well before Alexander's invasion (see Ch. 9.2), might have resisted Hellenism better than had Herod's cosmopolitan court. If this were the case, Molnar's case could be inverted, and Herod's ignorance of a nonstandard Hellenistic astrology interpretation given to the star by the magi becomes perfectly reasonable!

The possibility of a meteoritic event has been widely discounted because of the apparent extended aspect of the occurrence. However, the accounts in Luke and the Protoevangelium make better sense if the event described in Bethlehem was that of an exploding bolide. The account in Luke refers to a speaking angel, and a heavenly multitude that could be interpreted as an audible explosion and fragmentation. The fireball could well "go before" the magi and seem, in an azimuth sense, to go "over" the place where the child lay. The explanations need not be exclusive: if a conjunction got them on their way, a bolide could have provided the magi with their endpoint once they were at Bethlehem. If the account in James is correct, two bolides are required. A similar suggestion but involving a comet instead of bolides was made by Humphreys (1991, 1992). Molnar's (1999) explanation for the apparent reappearance of the star as given in Matthew involves the stationary points and retrograde motion of Jupiter when at opposition. The phrase "went before them" is interpreted to mean that Jupiter is moving in the same direction as the diurnal motion of the stars, westward (i.e., in retrograde motion). The phrase, "and stood over" the place where Jesus lay, Molnar interprets as a reference to one of the two stationary points flanking Jupiter's opposition (see discussions of the planetary configurations in the early chapters). If correctly interpreted, this provides a limit on the interval between the heliacal rising of Jupiter (his interpretation of εν τη ανατολη) and Jupiter's opposition, namely, about six months. Molnar's most propitious date is Apr. 17, 6 B.C., which would date the movement of the magi from Jerusalem to Bethlehem to the end of October 6 B.C. As we have noted, however, there are problems with the various assumptions that lead to this scenario, not the least of which is the supposition that Matthew is using astrological terms in their technical meanings. We find this interpretation forced and unconvincing, but it is certainly not ruled out.

Finally, there is the prospect that none of these explanations is appropriate but that the phenomenon was in fact unique and of a kind not knowingly seen since it occurred in Bethlehem nearly two millennia ago. Science is notoriously ill equipped to study phenomena that are not recurrent because the usual checks on hypotheses cannot be applied. As far as some scientists are concerned, such an event could well qualify as a miracle. Perhaps more palatable to modern consciousness, although not necessarily any more correct, is the possibility of combinations of the phenomena that we have discussed, for example, an appulse or conjunction for the first sighting and a nova, comet, or bolide for the second.

This concludes our brief examination of examples of apotheosis, celestial omens, and related ideas. We next turn to cosmological and cosmographic frameworks and concepts around the world as we explore other aims of ancient astronomy.

15.3. Cosmogonies and Cosmologies

15.3.1. Indian Cosmology

Buddhist Sumeru cosmology derived from 5th-century B.C. Jain cosmology. In this construction, Mt. Sumeru rose from the center of a disk-shaped Earth. It was situated somewhere in the Himalayas and had nine levels, the first eight of which successively rose from craters containing seas. The planets were propelled by a wind to revolve around Mt. Sumeru in concentric paths. One of these planets was the Sun, which rose in the Himalayas, passed over India in the day, and returned in the evening.

From India, this cosmology spread into China, and later, Japan. There is an illustration of the orbits of the Moon and Sun in each of the four seasons from a Chinese translation of an Indian source written ~450 A.D. (Nakayama 1969, p. 207). In Japan, the Hoshi Mandala—a cosmographic sketch—was transmitted from India in about the 8th century. The diagram has at its center the Buddha on the summit of Mt. Sumeru. Surrounding him are the seven stars of the Big Dipper (upper part), and below him are the nine luminaries: The Sun, Moon, five (other) planets, and two additional, unseen planets, Rahu and Ketu. In the 3rd circle are the 12 houses (a zodiac), and beyond these are the 28 mansions. Japanese Buddhists continued to defend this cosmology against western astronomical ideas until close to the end of the 19th century.

15.3.2. Cosmic Comparisons

15.3.2.1. The Cosmic Turtle

From Mesopotamia to Ireland and Africa, we have the intellectual domination in astronomical thought of geometrically based concepts of the zodiac, well symbolized by the astrolabe; cf. §3.3. These ideas eventually penetrated India and ultimately China, Japan, and other Asian areas. However, in those areas, they never entirely replaced the elaborate complex of ideas surrounding the turtle as cosmic supporter of the universe, accompanying a more arithmetical concept of astronomy. These ideas were found in Tibet, China, Korea, Japan, India and the derivative southeast Asian cultures, New Guinea, Polynesia, Mesoamerica, and most of northern North America. The distribution is essentially continuous. Whether South America is part of this complex is not determinable on evidence known to us. The oldest archaeological evidence for such beliefs is from China, and tradition there associates the appearance of a cosmic turtle with a story of a great flood.

The concept of the cosmic turtle was treated by Schuster and Carpenter (1988, III, pp. 63ff), who established much of the distribution and discussed many associated traits. There is, however, no systematic discussion of which traits co-occur in different areas nor of possible meanings of the associated tales and concepts. They mention no astronomical references to the turtle except for the *axis mundi* insofar as that can be considered astronomical. It is their belief that the distribution in Asia, Oceania, and North America indicates a spread in "extreme antiquity" (long before the Vedas). This idea is not supported by any direct evidence but is more acceptable to many anthropologists than is the view that the ideas spread widely in more recent times. DHK will try to show that some fairly sophisticated astronomical ideas are involved in these conceptions, which are unlikely to be earlier than the 3rd millennium B.C. They also contain arbitrary components that are unlikely to have arisen independently in different areas.

Although many conceptions associated with cosmic turtles are widely attested, the representations fall into subgroupings, none of which give a complete representation of the imagery even in a single area. The major components in the cosmic turtle imagery include

(1) association with one or two snakes, often wrapped around the turtle;
(2) the snakes are sometimes dragon-like, and one of them may be five- or seven-headed;
(3) a pillar or tree or lotus on the turtle's carapace (the snakes are sometimes wrapped around this pillar);
(4) the snake used as a rotator of the pole to stir the Sea of Milk (Milky Way);
(5) opposing "teams" of "gods" and "demons" pulling on the snake;
(6) a god, born from the carapace or from the lotus;
(7) symbols of Sun and Moon, close by;
(8) representations of asterisms, particularly the 28 lunar mansions and the 12 zodiacal signs;
(9) an associated god in dance position;
(10) magic squares, especially those of 3 and 5;
(11) identification of Orion's Belt as part of the turtle;
(12) association with a fire god;
(13) association with drilling of New Fire; and
(14) orientation to the cardinal directions.

Other components, some important for interpretation, are not yet widely attested; we discuss some of these in the context of Angkor Wat.

The cosmic turtle may be put into an archaeoastronomical context, most fully at Angkor Wat in the work of Eleanor Mannikka (1996). Mannikka's study presents massive amounts of new data and interpretations related to that site, accompanied by many impressive photographs, diagrams, and maps. She gives detailed information (Mannikka 1996, pp. 17–19) on her calculation of a precise value (0.43545 m) of the *cubit*, used in planning the site. This is somewhat different from the value (0.4345 m) deduced by Stencil et al. (1976), on the basis of their measurements discussed in §9.3.1. DHK thinks that the resulting values she obtains provide convincing evidence that there was high precision in measurement and that her value is a good approximation to the actual unit, however laid out.

The site is located at 13°.43 N latitude, and "13.41 cubits is a basic module in the second gallery, devoted to Brahmā, who is 'situated' at the north celestial pole" (Mannikka 1996, p. 19). The same unit appears in the central sanctuary, also devoted to Brahmā, and in the area known as the "preau cruciforme."

Mannikka (1996, p. 190) makes an interesting argument that a series of deity representations in the third gallery of the NW pavilion (east wing, north wall) constitute a planetary sequence. On the left pillar, the Sun and Moon sit in their respective chariots drawn by horses. Above, various gods are depicted mounted on their animal steeds in a procession facing to the right. Mannikka identifies them with their steeds, from left to right, as follows:

(1) Ketu	"Comet"	Lion
(2) Agni	Saturn	Rhinoceros
(3) Yama	"God of the south"	Buffalo
(4) Indra	Jupiter	Elephant
(5) Kubera	Venus	Horse
(6) Skanda	Mars	Peacock
(7) Varuṇa	Mercury	Hamsa
(8) Nirṛti	"God of the southwest"	Yakṣa

Note Mannikka's identification of Ketu as "comet" rather than the usual descending node, which she regards as an incorrect interpretation (she also regards the interpretation of Rahu as the ascending node similarly). She argues that the sequence represents the rising order of the planets (with two directional deities added) for the 24th–29th of July, 1131. She simply dismisses Ketu's position at the head of the list, where we would have expected it to refer either to a comet (as per her interpretation) or to an eclipse.

Mannikka's planetary identifications are not all certain, and the two directional gods seem unnecessary, but this sort of attempt to tie iconography to specifiable astronomical events seems to us desirable.

The difference between Mannikka's value for the cubit and that of Stencil et al. (1976) does not make an effective difference in the values the latter found for the World Ages, with lengths in cubits indicating years. Mannikka has specified general rules for measuring different components, and she was able to find evidence for measurements referring to the World Ages in parts of the complex where they had not been recognized by Stencil et al. (1976), thus, strengthening the case that these correspondences are deliberate. She also points out (Mannikka 1996, p. 51) that the Khmers believed that a perfect ruler could bring about a change from the deplorable conditions of the Kali-Yuga and institute the beginning of a new World Age. She maintains that Sūryavarman II was attempting to do this with the Angkor Wat temple complex. She is able to integrate the locations of the implicit references to the different World Ages with her analysis of the mythical and political themes of the sculptural complexes.

Mannikka's study of the "Churning of the Sea of Milk" shows that the iconography, the visual alignments (e.g., the Sun rising over the central tower), and the measurements are different ways of emphasizing the same phenomena (including equinox and solstice alignments). There are two depictions of the "Churning of the Sea of Milk" at Angkor Wat, but we will emphasize the main one. The pole of the churn, here Mt. Mandara, at the center of the composition, rests on the back of Kūrma, the king of the "tortoises",[8] wearing a crown. He is surrounded by parts of crocodiles and fish destroyed in the churning (Mannikka 1996, fig. 2.21, p. 49). In front of the mountain, we see Vishnu in a central role. To the left are 91 *asuras* (sometimes called "demons") pulling the body of the five-headed snake, *Vasuki*, toward the south. To the right are 88 *devas* (sometimes called "gods") pulling to the north. A single *deva* is leaping above the central pivot. The king of the *devas* is a monkey-headed figure, identified as *Sugriva*, holding on to the tail of *Vasuki*. At the other end, *Bali* appears as king of the *asuras*, holding the crowned heads of *Vasuki*. Lighting effects emphasize Vishnu, Kūrma, and the Churn at equinox sunrises. *Sugriva* is marked out at the summer solstice and *Bali* at the winter solstice, but in a somewhat different manner from Vishnu. The contrast between 88 *devas* and 91 *asuras* clearly suggests the inequality of the seasons. However, a check of the inequality of the seasons at ~1000 A.D. indicates that the intervals would be more appropriate if the *devas* and *asuras* were reversed (see Table 2.3, §2.3.1). A parallel phenomenon is the alignment as viewed from the extreme west edge of the site, from the west end of the bridge across the moat surrounding the site to the south end gateway of the western entrances where the Sun rises at the winter solstice. Because the site is aligned east-west and is symmetrical, the Sun would rise behind the north end gateway at the summer solstice. From the juncture of the causeway and the bridge, the Sun rises directly above the central tower at the equinoxes.

Mannikka emphasizes repeatedly the importance of the 28 lunar mansions. Together with the four directional gods, the gods of these mansions make up the major set of 32 deities (when Brahmā is added, this gives 33. See §§9.1.1, 9.1.3, 9.3, 9.3.2 for the significance of this number).

Mannikka (1996, p. 33) points out that the "tortoise" Kūrma was one of the incarnations (avatars) of Vishnu and is described as "half a globe." She also emphasizes (pp. 36–37) that Varahamihira refers to the Earth as a "ball" in the "starry sphere" and identifies the *asuras* with the South Pole and the *devas* with Mt. Sumeru or Meru as the North Pole. She says that Khmers tended to identify Meru with Mt. Mandara (Mannikka 1996, Ch. 2, fn. 8, p. 305), but she maintains that "Meru *is* the north-south axis of the world and Mandara is not." Mandara is said to be the mountain that was "uprooted and brought to the shores of the Sea of Milk to serve as the churning pivot." In the context that Mannikka has shown, it would seem that the uprooting of Mt. Mandara should have an astronomical significance. It would also seem that the identification of Mandara and Meru might be related to the Khmer contention that Sūryavarman II was inaugurating a new World Age—a return to the conditions before the uprooting of Mandara at the beginning of the Kali-Yuga era.

Whatever significance this scene may have had for other cultures, its representation seems to be extraordinarily widespread.

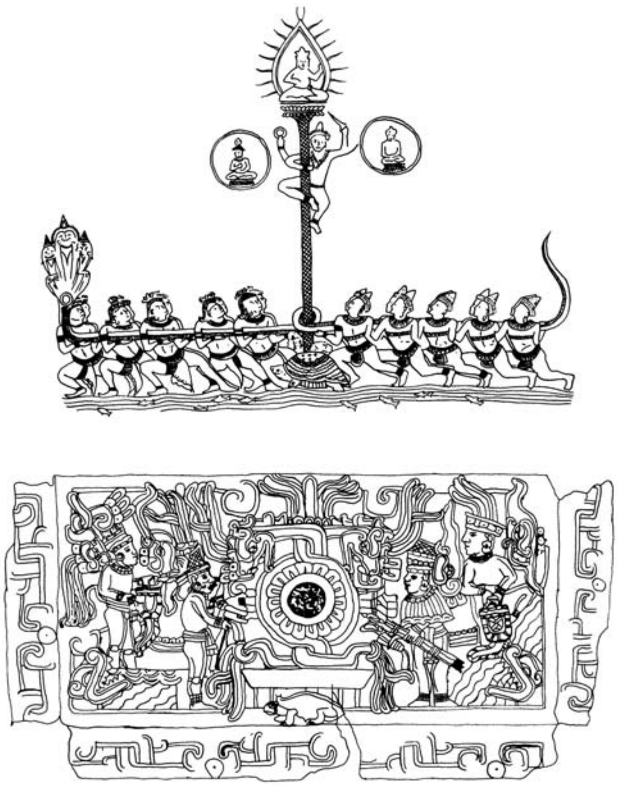
In Figure 15.6a, we have Schuster's version of the churning from the SW pavilion at Angkor Wat. He shows a gigantic pole as a lotus surmounted by a deity figure (Brahmā) and with a dancing four-armed deity figure (Vishnu) on the pole. Sun and Moon appear on either side. A five-headed serpent is being used to turn the churn, tugged in opposite directions by gods and demons.

In a Totonac version (Figure 15.6b), the pole (in this case, a flower stem) is shown in plan rather than in elevation view, with the turtle seen in profile in front of the structure. The snakes are intertwined around the pole. On some Mayan pots, the snakes are replaced by water lilies, a Mesoamerican approximation to the lotus.[9] This Totonac depiction was regarded as a war standard (Ringle, Gallareta Negrón, and Bey 1998), which seems to DHK unlikely. This is the site with the Pyramid of the [365] Niches, certainly suggesting the importance of solar phenomena there. Schuster and Carpenter (1988, Vol. III, pp. 74–75), compared the "Sea of Milk" at Angkor Wat with the highland Mexican representations of Mayauel, goddess of the milky drink, pulque, seated on a turtle.

A very elaborate Balinese version shows *Tintiya*, their highest god, in dance position above a turtle. The turtle is

[8] Although evidently somewhat more aquatic than that term normally connotes.

[9] See Rands (1953) for a detailed comparison of the artistic representations of Mayan water lilies and the Indian lotus. Rands regarded the similarities as independently developed.



(a)

(b)

FIGURE 15.6. (a) A version of the Cosmic Churn from Angkor Wat, with the pole as a lotus surmounted by a deity and with a dancing four-armed deity figure on the pole: Sun and Moon appear on either side. A five-headed serpent is being used to turn the churn, tugged in opposite directions by gods and demons. (b) A Totonac version from Structure 4, El Tajin, Mexico, shows the pole (in this case, a flower stem) in plan rather than in elevation view, with the turtle seen in profile in front of the structure. Two feathered snakes are intertwined around the pole. Drawings by Sean Goldsmith.

bound by two snakes that are looped together in an elaborate and intricate manner (see Figure 15.7a). The binding snakes prevent the turtle, as fulcrum of the world pillar, from causing earthquakes (Schuster and Carpenter 1988, Vol. III, p. 225). The pillar is curiously missing. The turtle from India in Figure 15.7b shows an emphasis on eight directions in four sets, as can be argued also for the Balinese and Batak representations of Figure 15.7. The Batak turtle (Figure 15.7c) shows an elaborate cosmogram apparently marking the cardinal and the intercardinal points as two squares, one superimposed on the other. Two snakes encircle the entire scene, and a ladder appears between their tails. According to Schuster and Carpenter (1988, Vol. III, p. 78), "this ladder symbolizes, often simultaneously, a sacrificial pole, Tree of Trees, and Ladder of Ascension." They point out (p. 66) that the Samsam tribe on the "Siamese-Malayan" border places a turtle diagram under a house post when it is being built, thus, replicating the Cosmic Pole on the Cosmic Turtle.

In a Mayan picture (Figure 15.8a) from the *Madrid* Codex, gods hold the body of a snake that passes over an elevated structure on which the turtle appears to be precariously perched. Hieroglyphs of the Sun and Moon appear on the body of the snake. A Mayan painting at Bonampak shows a turtle with three "star" hieroglyphs on its back (Figure 15.8b). Given colonial Mayan identifications of the turtle with Orion's Belt, it seems highly likely that this was intended here.

A version of the churning of the Sea of Milk from India is shown in Figure 15.9. Here, the demons appear animal-headed, on the right, holding the heads of Vasuki. Sun, Moon, and Lotus appear below the turtle with a number of other figures, many known in other contexts as asterisms. That may be what is intended here.

Turning now to cosmic turtles in other contexts, Figure 15.10a shows the Indian turtle as world supporter, with the cobra wrapped around its neck. The layers of heaven and earth are clearly shown with supporting elephants all surmounted by a pyramid. The same ideas, in very different form, are incorporated in the Tibetan turtle (Figure 15.10b). This shows one turtle within another. The inner turtle has the magic square of 9 on its plastron and is surrounded by the 12 animals of the rat zodiac. Outside of these are the

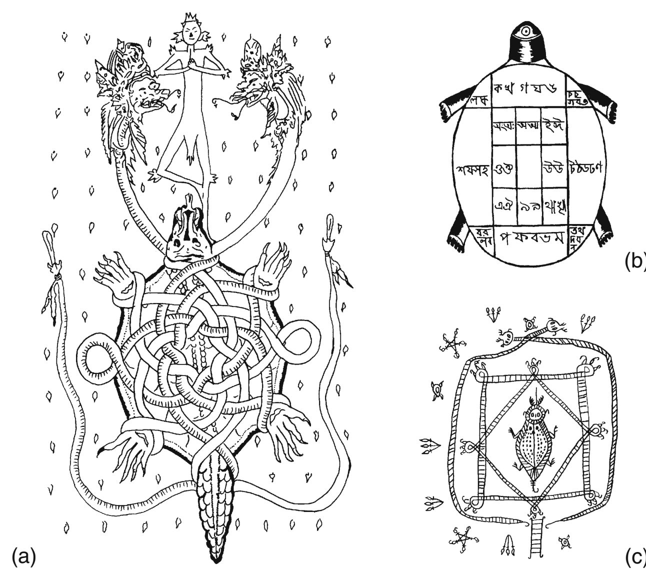
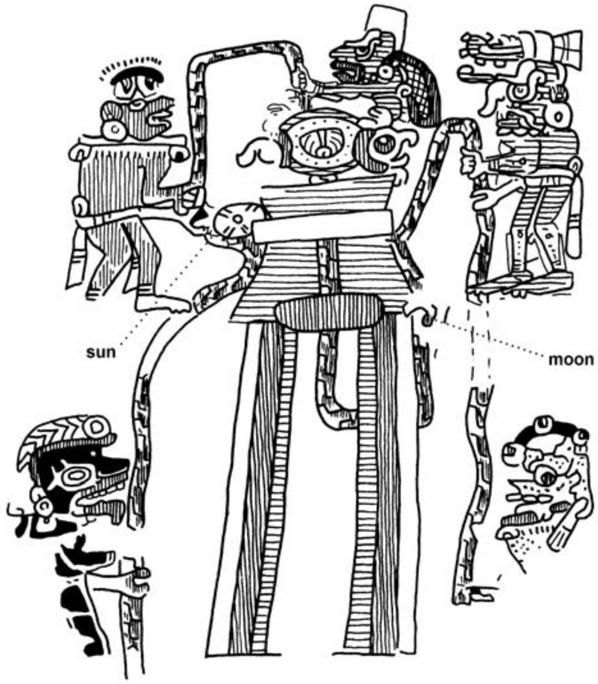
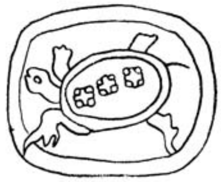


FIGURE 15.7. (a) From Bali, we have a depiction of two serpents elaborately intertwined around the turtle. Between the serpent heads is a phallic figure in dancing pose, like that of Figure 15.6a. (b) A turtle from India with written numbers indicating an interest in directions in sets of four. (c) A Batak turtle as an elaborate cosmogram: It is shown surrounded by a directional frame, snakes, and ladder. Drawings (a) and (b) by Sean Goldsmith and (c) by Sharon Hanna.



(a)



(b)

FIGURE 15.8. (a) In a Mayan picture from the *Madrid* Codex, gods hold the body of a snake that passes over an elevated structure on which the turtle appears to be precariously perched. Hieroglyphs of the Sun and Moon appear on the body of the snake. (b) A Mayan painting at Bonampak shows a turtle with three "star" hieroglyphs on its back, probably Orion's Belt. Drawings (a) by Sean Goldsmith and (b) by Sharon Hanna.

eight Chinese trigrams and various other symbols, and finally, the outside turtle and associated directions.

Another similar example is shown in Figure 15.11, where the two turtles are somewhat separated from each other, and the Tibetan symbols for the planets descend from the turtle's tail.

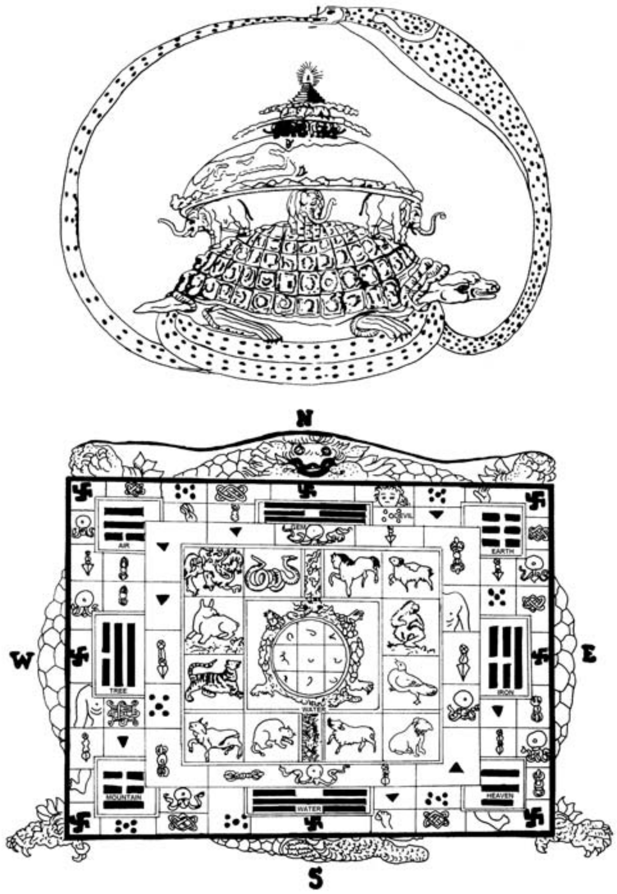
The Assyrian "charm" in Figure 15.12 has many interesting features that tend to tie it in to the Tibetan cosmic turtles. In a general way, the appearance is similar. Both were used in averting evil. The symbols of the planets and of the Pleiades appear across the top, and they may be seen on Tibetan turtles. There are 12 animal-headed people depicted on the Assyrian amulet, in addition to two "fish-men" and a man lying on a bed or bier. The active posture of the individual shown in the two-headed boat, as well as the association with a river, create a degree of parallelism with some of the scenes of the Churning of the Sea of Milk. The Tibetan representations usually include the 12 animals of the "rat zodiac."

In southern India, housewives make elaborate sand paintings called *kolams* (Bayiri 1967–1992). These are placed on the threshholds of houses during certain festivals. They are designed to ward off evil. They include "tortoise" designs, some of which are easily recognizable, whereas others seem to have no representational identity at all. The date of the Assyrian amulet is much earlier than is any turtle representation from Tibet or India, but there could well be some sort of prototypical relationship.

The earliest iconographic representations of cosmic turtles come from China, where the turtle and an associated snake are identified as seven asterisms of the 28 lunar mansions (Figure 10.9), which represent one of the four great directional animals (cf., Figures 10.5 and 10.6). Figure 15.13 is a later example.

In China, when the great mythological flood subsided, a turtle appeared. On its underside were cosmic symbols and a pattern of 9 numbers (three on a side—see the lower part of Figure 15.14a) revealing, according to the belief, the first magic number square ever known (the horse in the upper part of the figure also bears a magic square). Another more realistic appearing turtle is seen in Figure 15.14b. In medieval European belief, the magic square of 3 was asso-

FIGURE 15.9. In India, the demons in the Cosmic Churn depiction appear animal-headed. Here, Sun, Moon, and Lotus appear below the turtle. Drawing by Sean Goldsmith.



(a)

(b)

FIGURE 15.10. (a) The Indian turtle as world supporter, with the cobra wrapped around its neck. Drawing by Sharon Hanna. (b) The same ideas incorporated in this Tibetan turtle as in (a) but in very different form involving magic squares and one turtle within another. Drawing by Sean Goldsmith.

ciated with Saturn. Saturn as a slow-moving[10] turtle seems appropriate at any time or in any culture, but we do not seem to have a direct Saturn-turtle association in either place, although it is found in India.

The magic square[11] of 5 is indirectly associated with the turtle. We have noted that the magic square of 5 is regarded in India as a representation of sky and Earth together, and we have just seen that the turtle is there regarded as the supporter of sky and Earth. In Mesoamerica, the so-called Kan cross (Figure 15.15) substitutes in the lunar series for a compound Earth-sky glyph and is frequently shown on the backs of depictions of turtles on Mayan pottery (Figure 15.16a), although the glyph of the Sun may also appear there. In India, odd numbers represent sky and even numbers, Earth.

These pots show a hero being born from the turtle's back and an associated water lily representation (the New World equivalent of the lotus). In India, the numbers of the central cross, representing Heaven, add to 117, and the numbers of the four corners, representing Earth, add to 52. The sum of numbers in any column, row, or along a diagonal of the magic square of 5 is 65. The number 65 is also reached by summing five chess moves of a knight. These numbers are very important in Mesoamerican divinatory tables.

In Thailand, many cosmic turtles have designs that include number patterns. See Schuster and Carpenter (1988, Vol. III, figs. 49–54, p. 77). The inscriptions on the turtle from India in Figure 15.7b are also numbers. On Malekula Island in the New Hebrides, cosmic turtles with intricate designs are found in diagrams and sand paintings. They are similar to the Thai turtle designs.

In the New World, the Algonquins maintained that the Earth was supported by a turtle. Plate 8 (see color insert) shows a modern cosmic turtle created by Christine Sioui Wawanaloath. This is an artistic rendering of various symbols of American Indian groups, based partly on sacred traditional Algonquin drawings to which she has access and partly on her perceptions and intuitions. Schuster and Carpenter (1988, Vol. III, p. 66) mention that the Delawares

FIGURE 15.11. A Tibetan plaque of the Cosmic Turtle bearing the magic square, trigrams, and Oriental or "rat" zodiac: A second turtle is shown to the lower left. Photo by Jerry Newlands of a metal plaque given to D.H. Kelley by Hugh Moran.

[10] See Table 2.9 and §§2.3.5 and 2.4 for the physical basis for this motion.
[11] See also §9.1.2.1.

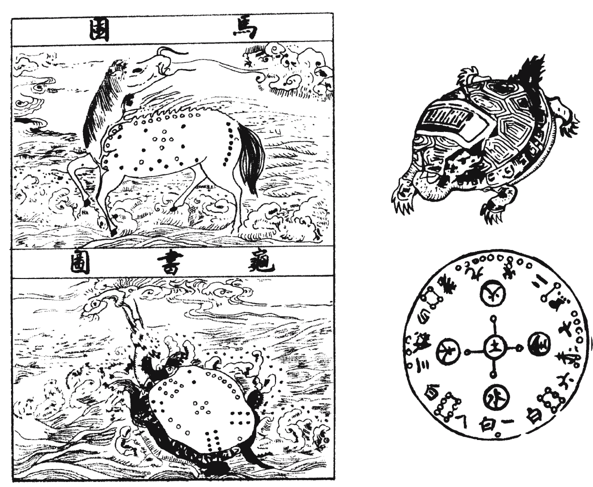
FIGURE 15.12. An Assyrian amulet in the form of a turtle-like "monster" with stellar symbolism. Drawing by Rea Postolowski.

(of the Algonquian language family) say that the turtle "brought forth the world and from the turtle's back sprang a tree that reached to Heaven." Among the Iroquois of New York, it was thought that the Earth rested on the back of a snapping turtle.

Among the Chumash, in California, we also have representations of a cosmic turtle. Mimbres pottery from the southwest United States shows a turtle with a checkerboard pattern on its back and two fish-tails, compared by Santillana and Dechend (1969, pp. 434–435) with the field between the two fishes of Pisces.

The Pawnee directly associate the cosmic turtle with the firepit at the center of the lodge, and among the Aztecs, the fire god, *Xiuhtecuhtli*, "Lord of the Year," is associated with the firedrill, identified as Orion's Belt. *Xiuhtecuhtli* is also said to live at the navel[12] of the World or Sky. *Hiku-navangu*

FIGURE 15.13. An example of the cosmic turtle and snake, as one of the four great directional deities, along with the dragon, bird, and tiger, each representing seven lunar mansions: See also Figures 10.5, 10.6, and 10.9. Drawing by Sean Goldsmith.



(a) (b)

FIGURE 15.14. (a) (lower) The turtle that appeared after the "Great Flood" in China. On its plastron are cosmic symbols and a pattern of 9 numbers, according to belief, the first magic number square ever known. (b) A realistic turtle with plastron (lower) bearing a magic square and directions. Drawn by Sharon Hanna.

[12] Aztec *xictli* from the Uto-Aztecan **siku*.

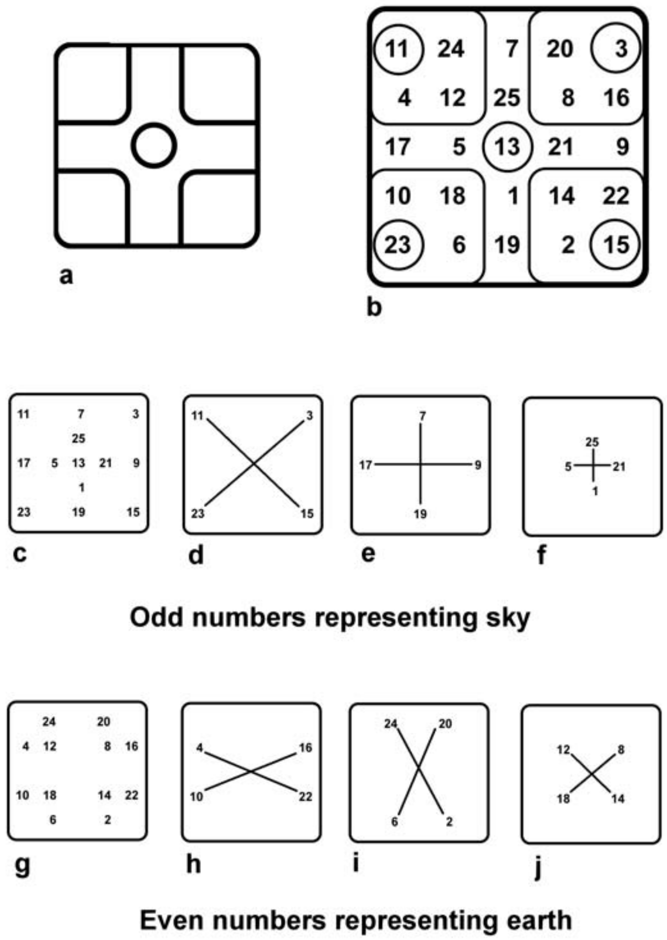


FIGURE 15.15. (a) The kan cross of Mesoamerica and (b) with the magic square of 5 superimposed. (c) to (f) Odd numbers of the magic square of five and sums of elements to produce the number 52. (g) to (j) Even numbers of the magic square of five and sums of elements to produce the number 52. Drawings by Sharon Hanna.

(Papago "Navel Mountain" from the Uto-Aztecan **siku*) is said to be where Coyote saved the Red Ant people from the Flood, because the mountain grew as the flood came up. In New Zealand, Maui was associated with a flood. When it subsided, his canoe landed on Hiku-rangi ("Tail of Heaven") mountain. His canoe is identified with the stars of Orion's Belt. Although *hiku* (from *PP *siku*) meant "tail" in Polynesian, in Rarotonga, it was said that Ikurangi Mountain was at the center of the universe, corresponding with the Uto-Aztecan meaning, navel. The correspondence suggests a borrowing. Maui is widely known in Polynesia for such feats as the theft of fire and the trapping of the sun-bird. Rarely, he appears as a fire god. In Oceania, the turtle boy is said in Tuamotuan myth to have become Orion's Belt, and some representations of turtles from Easter Island seem to show cosmic traits.

Medicine wheels show some characteristics, tying them into this complex. Some have been described as turtle effigies, such as the one from Minton (cf., Figure 6.39), and there is a strong possibility that the Majorville Medicine Wheel originally had 28 spokes. These have been associated with the 28 poles of a medicine lodge, itself considered as a replica of the cosmos.

The conception of a world-supporting turtle is presumably connected in some manner with the presence of the turtle as a constellation—Orion's Belt in China, in Burma, in the Tuamotus, and in Mesoamerica. In Greece, the lyre of Apollo is said to have been made from a turtle shell and placed in the heavens as the constellation Lyra. In Cambodia, the turtle is in a "catasteric" or roughly opposite position from Orion's belt, in Scorpius or Sagittarius.

All of the turtles we have been considering seem to represent considerably more important roles in mythology and cosmology than DHK would have expected. They support the world (or a mountain, or the universe) from India to eastern North America. Their identification with Orion's Belt in China, Burma, the Tuamotus, and the Mayan area is, equally, an association with the Milky Way. The latter association is also directly found in the accounts of the Churning of the Sea of Milk. An interesting subset of turtle representations seem to be found in sand paintings, charms against evil, and healing rituals. These range from gigantic Tibetan mandalas through South Indian *kolams* and Thai

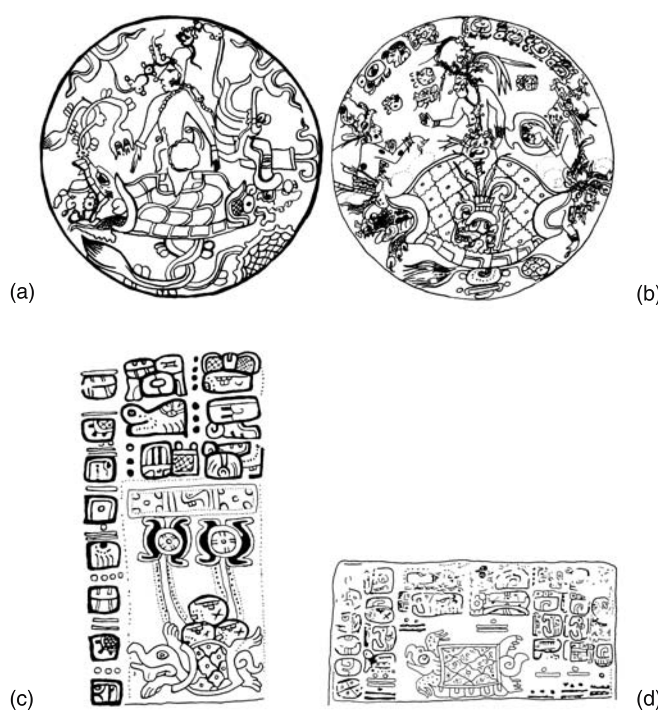


FIGURE 15.16. (a) and (b) Two Mayan pots each show a turtle from whose shell a god is being born. Drawings by Sharon Hanna. (c) A representation from the *Madrid* Codex shows the turtle with solar eclipse symbols and a sign that has been interpreted as the three hearth stones of a cosmic firepit. (d) Also from the *Madrid* Codex, a calendrical table referring to the turtle. (c) and (d) drawn by Sean Goldsmith.

numerological turtles to the relatively plain designs of the New Hebrides. Navaho sand paintings are like that group, except that they lack the turtle emphasis. Many of the sand paintings of all groups emphasize astronomy and cosmology.

Frequent associations directly with the equinoxes or with the cardinal directions or with spring and fall festivals are to be found in all major subareas. New Fire ceremonies at the equinoxes extend substantially beyond attested distributions of cosmic turtles but are often directly correlated. The turtle often appears at the base of a tree, sometimes identified as the Milky Way and sometimes as a polar axis. The polar axis in turn can be identified as a churning pivot, a spindle whorl, or a firedrill. The shifting of the axis is directly associated with World Ages in India and Mesoamerica. These features seem to DHK to indicate the former presence of a consistent complex of ideas partially preserved in many different areas.

15.3.2.2. Celestial Watercraft

The identification of Orion's Belt as a watercraft was found in Egypt as the ship of Horus; a similar identification was made in India and Burma. Among the Mayans, Chac appears paddling a canoe and the six circles of this representation look surprisingly like the Belt-and-Sword of Orion.

15.3.2.3. Celestial Deer and Sheep

In India, Saturn was identified as Prajapati, "Lord of Animals," the patron deity of the lunar mansion, Rohini. The lunar mansions were his daughters. He was said to have assumed the form of a giant stag in order to rape his daughter, Rohini, the roe deer. However, in the process, he was transfixed to the sky by an arrow (the stars of Orion's Belt) shot by *Lubdahka*, "Deer Slayer" (Sirius). In Mesopotamia, the Arrow Point (Sirius) was aimed at Orion's Belt (Walker 1996/1997) [from the Bow, *ban*; although this is not mentioned in Walker]. In Egypt, Satet, the archer goddess, associated with Sirius, is shown on the Dendera round zodiac shooting at the Sothis Cow (Sirius). In China, the Emperor shot the bow (the same stars as in Babylon) at Sirius, the wolf (Santillana and Dechend 1969). Petroglyphs from Sears Point, Arizona, show an archer shooting at a three-star diagram that is almost certainly Orion's Belt and that is illuminated by the winter solstice Sun.

In the southwestern United States, native groups show many ideas parallel to those of Mesoamerica. The degree to which these are due to the influence of Mesoamerica, particularly traders, is disputed. Macaws were imported into the southwest and were sacrificed at the spring equinox and rubber balls reached the Hohokam who built large ball-courts like those of Mesoamerica. Mimbres pottery is particularly full of depictions that seem like illustrations of Mesoamerican myths, including especially representations that correspond in detail to Mayan Twin myths (Marc Thompson 1999). Other representations in Mimbres pottery suggest connections much farther afield. The Mimbres "rabbit in the moon" reflects those of Mesoamerica, India, China, and Syria. Wicke (1984) has argued for the derivation of this imagery in Mesoamerica from China. Other similarities include the zodiacal Goat-fish and the turtle-checkerboard-fish pattern equated by Santillana and Dechend with Pisces and the Mesopotamian "field." In northern California, the Yana identify the Belt as "Coyote's Arrow" (Hudson 1984, p. 48). The Belt stars are identified as deer among the Tepehuanes of Mexico, and the Belt-and Sword formed the deer stars of the Skiri Pawnee. The Kamia of California regarded the Belt stars as an antelope, a deer, and a mountain sheep (Hudson 1984, p. 49). In Mesoamerica, the deer is the bearer of the Sun in the *Borgia* codex group just as the turtle has the Sun glyph on his back among the Mayans. Analogously, the Belt stars are sheep in Arabia and among the Uto-Aztecan tribes of the Great Basin. We seem to have cross-cutting imagery in which different symbols refer to the same objects in different contexts and where a single symbol may also have different referents, probably even in a single culture.

The idea of the fire god at the center of the "universe" taken to be the planetary system seems natural enough in a heliocentric view (in which the Sun would represent the central fire), but less natural otherwise. Unless in many cultures this concept repeatedly prefigures the heliocentric system, it suggests common cultural derivation. DHK has argued strongly that the ideas incorporated in the newly invented Mayan calendar derived from northern India, and that such ideas were subsequently spread to Polynesia, accompanied by Uto-Aztecan vocabulary, mythology, and calendar ideas.

It has been supposed since Wissler and Spinden's (1916) study of the Morning Star sacrifice among the Pawnees that this Plains Indian group incorporated Mesoamerican ideas into their astronomy. As noted above and in §13.5, Lounsbury has recognized that the Twariskaron Morning Star cult among the Iroquoian tribes of New York and southern Canada involves direct borrowing from the Nahua prototype of Aztec *Tlahuiscalpantecuhtli*, Lord of the House of Dawn, the god depicted as Flint Knife and identified with Venus as Morning Star. Next, we consider one of the basic purposes of archaeoastronomy—calendars—and examine possible historical and structural relationships around the world.

15.4. Calendars and the Spread of Astronomical Ideas

Calendrical systems are usually associated with astronomical phenomena. Sometimes the association is little more than a recognition of a pattern of seasonal variations coupled with the shorter repetitions of change in the lunar cycle. Many other calendars are formulated with elaborate and precise correlations with specified astronomical events. Because formal calendar systems normally incorporate both astronomical information and religious ideas in a highly

TABLE 15.1. Lunar mansion variants.

Nakṣatra	Nakṣatra depictions	Xiu	Xiu meaning
Aśvini	Horse head	Lou	Bond (blade)
Bharani	Vulva	Wei	Stomach
Krttika	Razor, flame	Mao	Abundance (the Pleiades)
Rohini (Hyades)	Wagon, carriage	Bi	Net (Hyades)
Mrgaśiras	Animal head[a]	Zi[b]	Beak
Ardra	Gem, blood drop, saw	Shen	Warrior
Punarvasu	House, bow, balance	Jing	Well
Pusya	Arrow, pencil	Gui	Ghost or cloud
Aślesa	Tail, flag, serpent	Liu	Willow
Magha	House, wall, beak	Xing or Qi Xing = seven stars	Star
Purva-Phalguni	Bed, rat, fig tree	Zhang	String of a bow
Uttara-Phalguni	Bed, sword, fig tree	Yi or I	Wings
Hasta	Hand	Chen	Chariot part
Citra	Pearl, flower, sabre	Jiao	Horn
Svati	Bead, saffron, wedge	Kang	Neck
Viśakha	Wreath	Di	Root or paw
Anradha	Snake, string	Fang	House[c]
Jyestha	Boar head, tusk, earring	Xin	Heart
Mula	Lion tail, couch, scorpion	Wei	Tail
Purva-Asadha	Couch, elephant, tail	Ji	Winnow basket
Uttara-Asadha	Elephant tusk, lion	Dou	Southern dipper
Ŝravana	Arrow, yoke, Vishnu 3 footsteps	Niu	Ox
Dhanistha (Sravistha)	Drum, bird cage	Nü	Woman, girl
Ŝatabhisaj	Circle of jewels or stars, flower, seeds	Xu	Emptiness or darkness
		Wei	Dangerous cliff or rooftop
Purva-Bhadrapada	Two-faced image, couch, pond, cot legs	Shi or Ying Shi = encampment	House
Uttara-Bhadrapada	Couch, pond, beam, cot legs	Pi	Wall
Revati	Drum, fish, ship	Kui	Sandal, leg
(Abhijit = α Lyr)[d]	Triangle, ox head		

[a] Variants are Antelope head, cat's paw, gazelle's head, wild beast head, deer, turtle, and coconut (the last three from a Burmese source).
[b] Yi et al. (1986, p. 30) cite *bie* or "river turtle" as an alternative mansion but one based on a confusion in the literature with "river turtle" in CrA.
[c] Or Dragon's breast.
[d] Some sources include Vega as an additional nakṣatra, making 28.

structured framework, it is often possible to reconstruct a common prototype of related systems as is done in linguistics. Such reconstructions require the reexamination of masses of data and analysis of structural characteristics, especially sequences. Detailed presentation of unpublished studies is inappropriate here, but it is worthwhile to summarize some important cases of the spread of astronomical ideas embodied in calendrical contexts. In the discussions that follow, we omit some important calendrical features, particularly structural characteristics, such as the 365-day "astronomer's" year, the 361-day Jupiter year, the 360-day "counting year," and the 354-day "lunar year."

15.4.1. The Lunar Mansions: Africa and Eurasia

The movement of the Moon among the stars requires that the Moon traverse a different region each night for the ~$27\frac{1}{3}$ days of its sidereal period. In an anthropomorphic sense, it spends each night in a different house or mansion. In India, China, and Arabia, a system of 28 asterisms was used to mark the movements of the Moon. The term lunar mansions has been used as an English equivalent applying equally to the Hindu system of *nakṣatra*, the Chinese system of *xiu* (Wade-Giles *hsiu*), the Arabic system of *menazil*, and many derivative systems. These asterisms were sometimes substantially removed from either the ecliptic or the equator and were of very different widths. The geometric relationships of the stars composing them were of more importance than were their brightnesses. In India and China, the entire sky was divided into a series of 28 segments named after these asterisms. The boundaries between these segments are marked by *junction stars* in India and by *determining stars* in China.

Table 15.1 lists the names of the lunar mansions and their probable meanings. Table 15.2 gives the component stars of the mansions. Table 15.3 lists the junction (*Yogatara*) stars of the naksatras and the determining stars for the xiu. Identifications and English transliterations of the nakṣatra are from Subbarayappa and Sarma (1985, pp. 30 and 101) among other sources. The identifications of Needham (Ronan 1981, pp. 96ff) and transliterations and identifications of Yi et al. (1986) were used for the xiu. The xiu were associated with particular circumpolar stars, such as those of our Big Dipper, which were always visible at night and thus

TABLE 15.2. Stars of the lunar mansions.

(No.) Naksatra	Composition	(No.) Xiu	Composition	Arab mansion	Composition
(27) Aśvini	β, γ Ari	(16) Lou	β, γ, α Ari	(1) aš-šaraâni / al-nah	γ Ari
(28) Bharani	35, 39, 41 Ari	(17) Wei	35, 39, 41 Ari	(2) al-butain	35, 39, 41 (or ε, δ, ρ^3) Ari
(1) Krttika	Pleiades	(18) Mao	η Tau	(3) at-turaijâ	η Tau [Pleiades]
(2) Rohini	Hyades +	(19) Bi	α, θ, γ, δ, σ, λ, ε Tau	(4) al-dabarân	α, θ, γ, δ, σ, λ, ε Tau
(3) Mrgaśiras	Head of Orion	(20) Zi[a]	λ, ϕ^1, ϕ^2 Ori	(5) al-hak'a	λ, ϕ^1, ϕ^2 Ori
(4) Ardra	α Ori	(21) Shen	δ, ε, ζ, α, γ, κ, β Ori	(6) al-han'a	ξ, γ (η, μ, ν) Gem
(5) Punarvasu	α, β Gem	(22) Jing	ε, δ, ζ, λ, ξ, ν, μ Gem	(7) ad-dirâ'u	α, β Gem
(6) Pusya	belly of Crab	(23) Gui	γ, δ, θ Cnc	(8) an-nara	γ, δ Cnc + Praesepe
(7) Aślesa	head of Hydra	(24) Liu	η, σ, δ, ε, ρ, ζ, ω, θ Hya	(9) at-tarf	[lions's eye] ξ Cnc + λ Leo +
(8) Magha	α Leo, sickle +η, γ, ζ Leo	(25) Xing or Qi Xing	α, ι Hya +	(10) al-gabha	[lion's star] α, η, ζ, μ, ε Leo (theSickle)
(9) Purva-Phalguni	δ, θ (rump of) Leo	(26) Zhang	κ, ν, λ, μ, ϕ Hya +	(11) àz-zubra	[lion's mane] δ, θ Leo
(10) Uttara-Phalguni	β, 43 (tail of) Leo	(27) Yi or I	22 *s in Crt, Hya	(12) as-sarfa	[turning point] β Leo
(11) Hasta	Corvus	(28) Chen	β, δ, γ, ε Crv	(13) al'awwâ	β, η, γ, δ, ε Vir
(12) Citra	α Vir	(1) Jiao	α (+ζ?) Vir	(14) as-simâk	α Vir
(13) Svati	α Boo	(2) Kang	λ, κ, ι (+ν?) Vir	(15) al-ghafr	λ, κ (+ι?) Vir
(14) Viśakha	α, β Lib claws of Scorpio	(3) Di	α, β, ι, γ Lib	(16) az-zubâny	α, β Lib
(15) Anuradha	β, δ, π Sco	(4) Fang	β, δ, π, ρ Sco	(17) al-iklîl	β, δ, π Sco
(16) Jyestha	σ, α, ι Sco heart of Scorpio	(5) Xin	σ, α, τ Sco	(18) al-kalb	[scorpion's heart] α Sco
(17) Mula	tail of Scorpio	(6) Wei	λ, υ/ε, ζ, η, θ, ι, κ Sco	(19) aš-shaula	[scorpion's tail] λ, ν Sco
(18) Purvasadha	bow of Sag	(7) Ji	δ, ε, γ, η Sag	(20) an-na'âjim	δ, ε/γ, η/σ, ζ, ϕ, τ Sag
(19) Uttarasadha	σ, ζ, ϕ, τ Sag (left shoulder of Sag)	(8) Dou	σ, ζ, τ, ϕ Sag	(21) al-baldāh	empty space def. by π Sag & other faint *s
(20) Abhijit	α Lyr[d]	(9) Niu	α, β, ν, π, ρ, o Cap	(22) sa'd ad-dâbih	α, β Cap
(21) Ŝravana	α, β, γ Aql	(10) Nü	ε, μ, ν Aqr +	(23) sa'd bula'	εμν Aqr
(22) Dhanistha	α, β, γ, δ Del	(11) Xu	β, ξ Aqr	(24) sa'd as-su'ûd	β, ξ Aqr
(23) Ŝatabhisaj	λ Aqr + 99 others	(12) Wei	α Aqr; θ, ε Peg	(25) sa'd al-ahbija	α or π; γ, ζ, η Aqr
(24) Purva Bhadrapada	α, β Peg	(13) Shi or Ying Shi	α, β Peg	(26) al-fargh al-awwal	α, β Peg
(25) Uttara-Bhadrapada	γ Peg, α And	(14) Pi	γ Peg, α And	(27) al-fargh-altânî	γ Peg, α And
(26) Revati	ζ Psc + 31 other *s	(15) Kui	ζ And, ψ-ν Psc (≥16*s)	(28) batn al-hût	β And (or β And + 15 *s in And and Psc)

[a] Yi et al. (1986, p. 30) cite *bie* or "river turtle" as an alternative mansion but one based on a confusion in the literature with "river turtle" in CrA.
[b] Later sources exclude Vega as nakṣatra, making 27.

could relate the whole system of xiu. The *menazil* transliterations are from Ginzel (1906) and the identifications from that source and from Moran and Kelley (1969).

Systems closely based on the Chinese were used in Japan and Korea. The Indian system was adopted in Tibet from which it passed to Mongolia and was also present throughout southern India and southeast Asia. The Hindu system was also adopted by medieval Jewish scholars, from which it spread to Christian Europe—a striking exception to the usual pattern of Arab influence. The Arab version went wherever Islam went, including deep into Africa, where an interesting Hausa version can be found. The earlier relationships among these systems, and with the Greco-Coptic system and an Iranian system, are much more obscure. A small minority of scholars interested in the lunar mansions maintains that the Chinese and Indian traditions, at least, arose independently, but it is generally thought that all the systems have a common origin. The strongest support for this view lies in shared asterisms, particularly those of 5th and 6th magnitude stars and asterisms, such as Vega, that were far removed from either ecliptic or equator. There are also a few correspondences in nomenclature; the most clearcut example is that of Antares, known as the "heart" of the Scorpion in the Arab system, of the Dragon in the Chinese system. The Chinese lunar mansion *niu*, "ox," (originally, Vega) agrees with "ox" as the representation (although not the name) of the first Jain lunar mansion (Vega). An important structural characteristic is the existence of paired mansions, particularly those of the Great Square (involving α and β Peg in one mansion and α And and γ Peg in another), in the Greco-Coptic, Arab, Sogdian, Hindu, Jain, and Chinese lists.

There is, unfortunately, no fully adequate evidence of the place of origin and only roundabout and inconclusive

TABLE 15.3. Junction and determining stars of the lunar mansions.

Naksatra	Junction star	Xiu	Determining star
(27) Aśvini	β Ari	Lou	β Ari
(28) Bharani	41 Ari	Wei	41 Ari
(1) Krttika	η Ari	Mao	η Tau
(2) Rohini	α Tau	Bi	ε Tau
(3) Mrgaśiras	λ Ori	Zi	λ Ori
(4) Ardra	α Ori	Shen	ε Ori[a]
(5) Punarvasu	β Gem	Jing	μ Gem
(6) Pusya	σ Cnc	Gui	Θ Cnc
(7) Aślesa	α Cnc	Liu	δ Hya
(8) Magha	α Leo	Xing or Qi Xing	α Hya
(9) Purva-Phalguni	δ Leo	Zhang	μ Hya
(10) Uttara-Phalguni	β Leo	Yi or I	α Crt
(11) Hasta	δ Crv	Chen	γ Crv
(12) Citra	α Vir	Jiao	α Vir
(13) Svati	α Boo	Kang	κ Vir
(14) Viśakha	α Lib	Di	α^2 Lib
(15) Anradha	δ Sco	Fang	π Sco
(16) Jyestha	α Sco	Xin	σ Sco
(17) Mula	λ Sco	Wei	μ Sco
(18) Purvasadha	δ Sag	Ji	γ Sag
(19) Uttarasadha	α Sag	Dou	ϕ Sag
(20) Abhijit[b]		Niu	β Cap
(21) Ŝravana	α Aql		
(22) Dhanistha	β Del	Nü	ε Aqr
(23) Ŝatabhisaj	λ Aqr	Xu	β Aqr
(24) Purva Bhadrapada	α Peg	Wei	α Aqr
		Shi or Ying Shi	α Peg
(25) Uttara-Bhadrapada	γ Peg	Pi	γ Peg
(26) Revati	ζ Psc	Kui	η And

[a] One of the three stars in Orion's Belt: δ, ε, and ζ Ori.
[b] Originally Vega. Later sources exclude Vega as naksatra, making 27.

evidence of the time of origin. The fullest summary to date is the Ph.D. dissertation of Joe D. Stewart (1974), upon which this discussion leans heavily. All 28 lunar mansions are directly attested in India in the *Atharvaveda*, usually dated on structural grounds to about the 8th century B.C. In China, the full series appears on a box (discovered in archeological excavations in 1978), dating from about 433 B.C. An Arabian series is mentioned (as the Menazil) in the Koran; the full list appears soon thereafter. A Greco-Coptic series is in a later copy of a 5th-century manuscript, which DHK thinks may represent a 4th tradition. It has long been supposed by competent scholars that the system originated in Mesopotamia, but there is no trace of such a system in Sumer, Babylon, or Assyria, and the local constellation series of Mesopotamia seems distinct. We have discussed Parpola's evidence, which indicates indirectly that the people of the Harappan culture of the Indus Valley were Dravidian speakers and that they probably already used the lunar mansions by ~2400 B.C. (see §9.1.1). We have also mentioned Pang's argument that the system was in use in China by ~2000 B.C. (see §10.1.2). The beginning points of various lists of lunar mansions vary greatly. In China, the first mansion was *Jiao* (or *Chiao*), Spica. Among the Jains alone, there were *four* versions with different beginning points. Elsewhere in India, the unequal-width, 28-mansion system is attested in the earliest source; this system usually begins with *Krittika*, the Pleiades. In contrast, the equal-width, 27-mansion system begins with *Asvini* in Aries. The difference between the two is partly comparable to that between the zodiacal constellations and the zodiacal signs. The 28-mansion Arab system, likewise, begins with *al butain*, the equivalent of *Asvini*. The Suchow planisphere describes the celestial equator as the "red road," "which encircles the heart of Heaven, and is used to record the degrees of the twenty-eight xiu" (§10.1.7; Rufus and Tien 1945, p. 3). The chart (cf., Figure 10.7) reveals the xiu marked off in a radial pattern emanating from the imperial precinct surrounding the north celestial pole. Hence, the Moon's movement, more or less along the ecliptic, was recorded in the Chinese equivalent of equatorial degrees. A similar practice seems to have been true in India.

There is a Mongolian version of the system of lunar mansions that derives from northern India, with some added Chinese characteristics. Despite the massive movements of conquest by Mongols and related groups,[13] there are few if any indications of influences other than Indian and Chinese in Mongolian (or, more generally, Turkic) astronomical knowledge or astrological ideas. Among the Mongols, one possibly indigenous or early Indian practice, although unattested in India, is the sacrifice of an animal associated with a lunar mansion to the deity of that mansion.

15.4.2. The Lunar Mansions: Two Disputed Extensions

Besides this tremendous spread across Eurasia and Africa, according to DHK, there is a strong body of evidence that a version from northern India reached Mesoamerica (probably Guatemala) and became a component in the invention of the Mesoamerican calendar, perhaps in the 2nd century A.D. The invention of the Mesoamerican calendar seems to have involved components from at least four different Asian systems, combined to create an interlocking system of repetitive elements in a 18,980-day cycle, tied to an era base (see §12.2). One of the parts of this system is a list of 20 days. These include animal names that correspond in sequence and largely in position with a recontructed list of the prototype of the Indian-SE Asian-Chinese 28-animal list, omitting the domesticated animals of the latter list. These correspondences suggest that the 20-day sequence of Mesoamerica is a deliberate modification of a 28-lunar mansion series (Kelley 1960; Moran and Kelley 1969; Stewart 1974). DHK has also argued that a version of this Mesoamerican calendar spread into the Pacific and was further modified to become the Eastern Polynesian system of nights of the noon. For a fuller discussion of Kelley's unorthodox opinions both on the invention of the Mesoamerican calendar and on Mesoamerican chronology, see §12.3.

15.4.3. The Zodiac and Its Symbols

A Babylonian list of 18 asterisms along the ecliptic seems to foreshadow the zodiac in some ways, although these asterisms were said to mark the path of the Moon rather than that of the Sun. The first stage in the development of the zodiac proper was the definition of a series of constellations more or less bordering the ecliptic that could be used to mark the seasonal variation in the movements of the Sun. Nine of the constellations forming the zodiac were first created in Mesopotamia, where they seem to have been in use from well before 2000 B.C. We do not know when they were first set apart as a series of approximate monthly divisions of the ecliptic, but some recognition of the regularity of seasonal changes in which asterisms were visible at particularly times of the day must have been a prerequisite for any serious study of astronomy. Direct evidence of a formal list of 12 constellations is surprisingly late (about the 6th century B.C.). A list of "Normal Stars," used as reference objects to measure the positions of planets, and which dates from around the 4th century B.C. or earlier, is shown in Table 7.5 (based on Hunger and Sachs 1988, p. 17). The positions are given for 601 B.C. See §7.1.3 for further details.

The first appearance of the zodiacal signs seems to have been in an astronomical "diary" for the year 418–417 B.C. (Lindsay 1971, p. 38). The earliest Greek evidence is in the next generation. Lindsay (1971, p. 68) points out that the paranatellons (cf. §3.2.2) of Aratos (derived from Eudoxos [b. ~408 B.C.]) imply the signs of the zodiac rather than the constellations and that they are accurate for the latitude of Babylon.

The signs of the zodiac appear in India, first with borrowed Greek names, and then with translated names, probably by the 2nd century A.D. The appearance of the Twins as a male and female pair suggests the Egyptian version of the zodiac. Characteristically, Aquarius, the water-bearer, became a simple pot. Capricorn, the goat-fish, was replaced by its Indian equivalent, the *makara* or crocodile, and then by increasingly complex composite monsters. From India, the zodiac spread into southeast Asia, where there was additional replacement of the zodiacal signs by other equivalent constellations. An Indian version had been introduced into China by Buddhists by the 8th century A.D., when personal astrology seems to have entered China. The zodiac appears with the lunar mansions on tomb ceilings in China from about this date.

The zodiac spread rapidly into Africa, primarily with Islamic traders and invaders. In some parts of Africa, the symbols of the zodiac became entirely divorced from astronomy, becoming little more than decoration. Similar developments happened in western Europe and are typical of modern astrology worldwide.

During the Hellenic period, the Egyptian decans became 10° subdivisions of the zodiacal signs. These were assigned to the guardianship of 36 minor deities. Descriptions and images of these became attached to Latin astrological treatises and were widespread in the European tradition. They also reached India before 300 A.D. according to a detailed study of the Indian sources and their Greco-Latin cognates by Pingree (1963b).

15.4.4. Old World and North American Parallels

D. Miller (1997) shows some widespread identifications of asterisms among North American tribes, a number of which have Old World parallels, only a few with the zodiac. Some of these identifications may be colonial borrowings from European cultures (Spanish, French, Dutch, or English) but that seems unlikely in many places. The identification of Ursa Major as a bear (largely in Algonquian groups but also in the Plateau) seems involved in chieftainship and ceremonials to an extent unlikely for recent borrowings. The view that Ursa Major is a funeral bier (among Siouans and Inuit) is also found among Arabs, but is not widespread. Aquila as a buzzard is attested in California and probably in the Southwest. Gemini appear as Twins to the Blackfoot and in the Plateau (where, as in Asia, they are a boy and a girl). Corvus in the Subarctic is identified as Raven-Carrying-the-Sun,

[13] Such as the Huns under Attila, who reached as far west as France.

reflecting the association with Sun as crow or raven from Ireland to China. Orion's Belt appears as a watercraft in the Pacific Northwest and the Plateau, corresponding to Maui's Canoe in Polynesia, probably to a similar idea in Mesoamerica, and to Horus's Boat in Egypt. Recent Polynesian contact seems possible as an explanation of this similarity, but the identification as a canoe is not found in Hawaii or the nearer parts of Polynesia. Mountain Sheep as the identification of Orion's Belt is typical of Yumans and Uto-Aztecans in the Great Basin and California, who also often regard it as an arrow. The arrow identification appears in India, where it pierces the giant stag Orion, and Sheep as a name for Orion's Belt is known in Arabia. In India, three deer are identified with the Belt, as they are sometimes in California and the Southwest. Sirius as a dog or wolf appears in astronomy among the Alaskan Inuit (as the Moon Dog), among the Seri of the Southwest, among the Osage, and among the Cherokee—a very broad but clearly incomplete distribution. Miller lists only the Maricopa (in the Southwest) for the identification as Scorpius as a scorpion, despite its prominence in western astrology, perhaps as an indication that there has not been recent borrowing. An asterism, Scorpion Woman, is known from the Chumash, apparently part of Lyra. In Mesoamerica, there were probably two different asterisms called Scorpion, and Scorpion Woman seems to have been an additional asterism. One of these was identified with Scorpius.

15.4.5. The Seven- and Nine-Day Planetary Weeks

Seven-day groupings may have been present as quarters of the 28-day lunar mansion sequence or for other reasons at a fairly early date. This is suggested, for example, by the seven days of creation of the Hebrew Bible or the seven fires of Agni in Indian Vedic texts. However, the existence of a series of seven days directly associated with the planets in a fixed sequence is first clearly attested (in the Mediterranean) in the last century B.C. The sequence was Saturn, Sun, Moon, Mars, Mercury, Jupiter, and Venus. The structural reasons for the sequence were discussed in §4.1.3, and the order of the days of the week was illustrated in Figure 4.11. Their associated deities are given in Table 2.7, and a comprehensive survey of the names of the week is to be found in F.G. Richards (1998). Even in Mesoamerica, what seems to be the same arbitrary sequence of the planets appears on the lid of Pacal's coffin (see §12.5).

The image of the Sun as a charioteer (or driven by a charioteer) spread throughout the Mediterranean world, even to such unlikely places as the Beth-Shan synagogue. Presumably, the image derives from the regular pattern of movement in a chariot race, rather than from irregular movements of, say, engaged war chariots. Increasingly, there was a feedback effect from the creation of ever more elaborate racecourses designed as cosmic images. During the Byzantine period, astrological images seemed to dominate the design of hippodromes (Lindsay 1971, pp. 239–243). All planets were conceived at least by the 4th or 5th century A.D. to be drawn in chariots.

Indian planetary diagrams also show the planets in chariots drawn by animals (by no means always horses) and in China, the mythical Hsi-Ho (cf., §10.1.2) was sometimes regarded as the charioteer of the Sun and sometimes as the mother of the Sun (Needham 1959, p. 188).

When the seven-day week spread to India, it was adopted both in the seven-day form found elsewhere and in a unique nine-day form, incorporating two additional postulated invisible planets, *Rahu* and *Ketu*. The introduction of these additional planets, conceived as the causes of eclipses, implies a slightly more scientific interpretation than does an older view, in which eclipses were caused by a giant dragon whose head was called *Rahu* and tail was called (perhaps later) *Ketu*. Still later, they were interpreted as the ascending and descending nodes of the lunar orbit. In creating the nine-day week, the days Rahu and Ketu were simply added on to the normal sequence of the seven-day planetary week, although this nullified the mathematical basis on which the seven-day sequence had been constructed (see §4.1.3).

This nine-day week, with the seven-day week, was introduced to China in a translation of an early Indian Buddhist text and became a regular feature of Chinese calendrics. Despite its invention in India, the nine-day week never seems to have achieved the importance in India that it did in China.

15.4.6. The Animal Cycles

Here, we will consider only the series of 12 animals of the so-called "rat zodiac" (also called the "Oriental zodiac"), tied to the 12-year Jupiter cycle, the related cycles of 27/28 animals of the lunar mansions and the cycle of 36 animals. The earliest attested 28-animal list is Greco-Egyptian of about the 4th century A.D. (Weinstock 1950), which seems from very fragmentary evidence to have Greek prototypes several centuries earlier. The southeast Asian lists form a subgroup together, fairly closely related to the Hindu sequences. In China, the entire list of 12 animals is incorporated in sequence in the list of 28 animals and the latter, in turn, in the 36 animal sequence (with some minor variations). Variations of the 12-animal sequence are found at the present time from Japan to Turkey[14] to name the years.

Investigations by Joe D. Stewart and David Humiston Kelley suggest that one of these animal lists was incorporated in the construction of the Mesoamerican calendar. Independent work by David Byron Kelley reached a parallel conclusion with some differences. There was also a great deal of earlier work reaching back as far as Alexander von Humboldt. For extensive discussion, see Stewart (1974). Only in Burma and Cambodia are the animal lists directly identified as the names of asterisms; so these remarks seem adequate for the present study.

[14] And now, indeed, in groups of Asian origin throughout the world.

15.5. Comparative Navigational Practices

The importance of the stars in navigation is attested in all seafaring cultures. The use of the rising or setting points of stars as horizon markers seems to be universal in all such groups where we have adequate data. This involved a *de facto* recognition of latitude, not necessarily formally conceptualized. The ecliptic as the path of the Sun, and the broader surrounding path of the Moon and planets, both seem to have been recognized widely and probably universally by seafarers. The limits of the path of the Sun at the Tropics of Cancer and Capricorn usually seem to have been formalized. Evidence of a conceptualization of the equator is also widespread. The conception of longitude was formally recognized in all areas influenced either by China or by the Hellenistic culture. Techniques of determining the actual longitude of a particular place, whether on land or sea, were limited to direct measures of distance on land or very rough estimates of distance traveled on the sea and to the technique of simultaneous observation of lunar eclipses from different places. Pingree thinks that this technique is the only one that could have been used to get the difference in longitude of Alexandria and Ujjain with the precision with which it is given in the *Panchasiddhantika* (see §9.1.3). Islamic mariners made extensive use of this technique in creating maps, but some of the errors are larger than would be expected. See §4.1.1.2 for the relationship between longitude and time, and Harley and Woodward (1994) for a fuller discussion of problems in determining longitude.

15.6. Astrology and the Purposes of Archaeoastronomy

In the early period of Mesopotamian history, various deities were identified with celestial objects, particularly the planets, or "wanderers" as the Greeks called them, moving against the pattern of the fixed stars in ways that seemed strange and unpredictable. The assumption that these erratic movements were due to the self-determination of the bodies seems to have been made at an early date. It was likewise assumed that Sun, Moon, Venus, and others were interested in human affairs and interfered with them. As long as such movements were considered self-motivated and largely unpredictable, it was possible to assume that the planets were gods, intervening capriciously in human affairs, influenced by offerings and prayers. As careful observation began to make the movements of these "gods" more predictable, a mechanistic view of their activities became possible. From this, astrology arose as an essentially antireligious reaction against the view that the gods interfered in human activities. Astrologers did not go so far as to deny the effects of the heavenly bodies, but instead insisted that they were predictable and universal. The attitude of many of these early astrologers had more science in it than was acceptable to the religious establishments of their time. Lindsay (1971) is the fullest summary we have seen of the development of astrological conceptions and the changing role that they had in the Mediterranean society from about the 6th century B.C. to about 300 A.D. He emphasizes that the only consistent opponents of astrology were the Epicurean philosophers and that the Stoics tended to be the strongest defenders of astrology. Politically, only Julius Caesar among the Roman emperors seems to have scoffed at astrology. His successor, Augustus, was a believer in astrology; symbols associated with his birth were imprinted on coins. The major differentiation among groups of astrologers seems to have been between those who believed that astrological factors merely influenced human actions, allowing some room for free will, and those who thought that astrological determinations were inevitably followed by the appropriate result. The latter may have believed either that stars or planets directly caused the result or that the astral bodies merely supplied omens of a higher "fate." The differences in astrological beliefs were partially crosscut by two opposing views: that the stars were "divine intelligences," in Cicero's words; or that they were parts of an essentially rigid mechanism.

Politicians,[15] or at least the historians who reported their deeds, frequently held the view that the stars influenced behavior. We have discussed at length the importance of such views in many cultures. Nevertheless, there were many civic and canon laws[16] against astrology, which indicates that belief in it was widespread. The reasons to discourage such belief are not difficult to fathom. It was treasonable, for instance, to ask an astrologer the date of death of an emperor. Fatalistic acceptance of what was deemed an inevitable defeat in battle would have to be avoided at all costs.

Astrology has traditionally dealt with the belief that the movements of the planets influence events on Earth. The belief is still with us, and it seems to be as popular as ever. Personal astrology, examples of which are found in most newspapers under "horoscopes," operates under the assumption that the planetary configurations at the time of the birth of an individual in some way determine that individual's prospects and fate. Most newspaper horoscopes refer only to the astrological signs associated with birthdates and not to the circumstances of any particular year of birth. These can be considered primitive forms of horoscopes; the casting of more elaborate types has been carried out since the 5th century B.C. or earlier in Mesopotamia. The heliocentric advocate and pioneer of modern astronomy, Johannes Kepler, cast horoscopes for the generals of the Holy Roman Empire as part of his duties as Imperial Math-

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[15] Among modern heads of state, former U.S. president Ronald Reagan seems to have taken advice from an astrologer. Of course, royalty has traditionally done so.

[16] Canon XXXVI of the Synod held in Laodicea (in Phrygia Pacatiana) sometime between 343 and 381 A.D., for example, states in part that "They who are of the priesthood, or of the clergy, shall not be magicians, enchanters, mathematicians, or astrologers." The 12th-century Byzantine historian and commmentator on the canons, Joannes Zonaras, argued that the "science of mathematics or astronomy" were "not at all hereby forbidden to the clergy" but only the "excess and abuse of that science" (Percival 1899, p. 151).

ematician. Today, most respectable scientists take a dim view of such activity, and astrology has come to be the arch representative of pseudoscience. Given the "prophecies" of the newspaper "horoscopes," one could infer that the same specific actions will occur to all of the many millions of people born under each of the 12 signs. What makes this appealing? Perhaps astrology appeals to those who feel helpless before the complexities of modern science and society because they see astrology as an outside force that affects the most powerful individuals as much as themselves. The weak, therefore, are relieved of some degree of responsibility for their actions.

At the beginning of the 2nd century, many scholars were still attacking astrology vigorously. By the end of the 2nd century, it had been so widely accepted that only its nature was any longer a subject of lively intellectual debate. This seems to have been due to the influence of Ptolemy's *Tetrabiblos*. Although the authorship of the Tetrabiblos has occasionally been challenged by modern scholars, Boll's (1894) defence has generally been accepted. Ptolemy's astrology was based on concepts of physical causation and empiricism and is probabilistic rather than deterministic. He argued that generic effects on the environment are both more far reaching and more easily determinable than are effects on individuals, using the example of the effects of the "planets" Sun and Moon emphasizing differences in different geographic areas of the effects of heat and tides. These influence human behavior both racially and individually. However, multicausational results are determined by the whole environment, including astrological events, modified by individual heredity (as we would phrase it) and the sociocultural trained behavior within the particular society. Ptolemy thought that some events, such as fatal illnesses, were so clearly indicated as to be inevitable, whereas others were merely probable and could be avoided through luck or foreknowledge, leaving room for a judicious use of free will. For specific effects, he appealed sometimes to theory, and sometimes to recorded experience in known situations. He discussed at length the conflict between an astrology based on the signs of the zodiac and one based on the equivalent constellations. His influential opinion favoring the use of the signs may have been the principal factor making this a dead issue for nearly all astrologers until the 20th century, when it again became a central point of disagreement. Finally, he deplored the fact that incompetence among astrologers caused damage to the whole field among critical thinkers. This presentation answered the majority of objections, which could have been made against astrology at that time. Now we consider present-day objections to astrology, and whether it should continue to be studied at all.

There are such abundant reasons for modern readers to be sceptical about astrology that the enlightened reader may be surprised to see them enumerated here. Yet, the continued popularity of the subject indicates an important need to do so. At the end of the 20th century, it has been said, there were ten times as many people studying astrology as there were studying astronomy. Clearly, astrology speaks to the human psyche in some persuasive way. So, are there any plausible bases for astrology?

The appearance of the sky and the objects in it have certainly influenced human behavior. Moreover, physical and physiological changes can occur simply as a result of photons of light striking the eye. The psychological effects of the appearances of astronomical, meteorological, geological, and other phenomena on human behavior are palpable, but even if there were demonstrated to be a correlation between human behavior and the seasons,[17] the influences of planets have never been demonstrated satisfactorily. The reactions therefore range from using the stars for navigation to enjoying a romantic interlude under the stars. Hence, astrologers could argue, the planets do have influences of some kind on people. We must be willing to concede that the very visibility of a phenomenon means it exerts an influence on its human observer, but presumably this is not the kind of compelling influence for which personal astrologers would like to argue.

Now let us consider arguments against astrology. First, determinative and prescriptive planetary or astral astrologies are without any known physical basis. The relative gravitational forces of each planet are indeed negligible on the Earth, as the reader can readily verify by comparing the ratio of the mass of a planet to the square of its distance from Earth to the same ratio for the Sun, $M_\odot/r_\odot^2$ (where $M_\odot$ is the mass of the Sun and $r_\odot$ is its distance from Earth), remembering that the most massive planet is Jupiter with a mass of only $\sim 0.001 M_\odot$. The tidal forces (which are proportional to $1/r^3$) caused by the other planets on the Earth are so minuscule compared with the dominant tidal effects of the much nearer Moon and very much more massive Sun that, to our knowledge, the tide-raising forces of the planets have not yet been verifiably detected at the Earth's surface. Electromagnetic field effects also go as the inverse square of the distance and are similarly unimportant. The empirical effects of magnetic fields have also been investigated. In "The Jupiter Effect," Gribbin and Plagemann (1974) argued that correlations existed between the position of Jupiter and the number of Sunspots (connected to the 11-year cycle on the Sun) and the frequency of earthquakes. That there are links between the solar cycle and terrestrial weather patterns continues to be argued because of the complexity of the problem, but the connection between planetary positions and earthquakes has been thoroughly examined and found not to be significant. Consequently, the Gribbin-Plagemann thesis has been refuted, and its authors have retracted it. The only influences that are unmistakable are due to the radiation of the Sun and the tidal influences of the Sun and Moon. Thus, there is a lack of a clear mechanism to effect the planetary influences. In an ancient context, such a response was not available and the planetary influence thesis had to be countered on other, principally empirical grounds. It was on these grounds that Augustine, among others, attacked astrology.

Second, the arguments that certain human behaviors or dispositions toward behavior are correlated with

[17] It is not beyond the realm of possibility that someone experiencing rainy, cold, or other conditions for the first few months of life would be inclined to look at life differently than would someone else experiencing contrasting conditions. However, as far as we know, there are no data to substantiate this idea.

positionings of particular planets are entirely unverified, Ptolemy's defence notwithstanding. The complexity of human behavior makes it extremely difficult to correlate human activity in any simple way with astronomical phenomena.[18] Indeed, most scientists argue that there is no basis for any such correlation with planetary phenomena. Studies have been cited (Bok and Jerome 1975) that claim that there is no statistical difference in the "average" destiny of persons born at certain times of the year (although rival claims are sometimes advanced). A great deal of literature contrasts the greatly different lives and fortunes of people born at the same hour of the same day. An early example is that of St. Augustine [354–430] in the *Confessions*, in which the fates of two persons—one rich and one poor—born on the same day are compared. The results in this case are exactly what one would predict: a mean and miserable life for the slave, and a prosperous and happy life for the wealthy person. Because such circumstances occur frequently given our planet's huge population, the conclusion that horoscopic astrology is determinative, is, in fact, being refuted continually, even if Ptolemy would not have regarded this as refutation, and, inevitably, exceptions arise.

Third, a major point of criticism has been the attitude of astrologers toward their subject matter. For example, astronomy, as a modern science, is characterized by constantly changing views as new data challenge old ideas and cause their alteration. Most astrologers have preferred to deal with a fixed set of rules, and their efforts, as such, have been directed not toward revealing the true nature and structures of the cosmos, but in trying to divine signs for human beings in the motions of the planets.

Finally, horoscope and individual predictions can be dangerous if they are accepted as guides for personal actions because a belief in their efficacy can limit one's actions when flexibility may be required. They can even be catastrophic, when, for example, they are accepted and acted on by heads of governments.

Nevertheless, although it is useless as a guide to modern living, astrology as a historical topic is far from worthless, because, as we have demonstrated, astrological concerns provided motivation for much officially sanctioned study of the sky in antiquity and even more recently.

Historically, astrology may have arisen from logical considerations. One of the seven classical planets of antiquity has a very strong effect on humanity and on all life on earth, viz., the Sun. More prosaically, the Sun provided time and calendar information through its movement across the sky and its rise and set points along the horizon. The Moon's light has been useful, particularly at high-latitude locations, in winter, and its behavior in the sky with respect to the tides is important for sailing coastal waters. The many myths associated with the Sun and Moon around the world underscore both their symbolic and physical significance. The planets, especially Venus, had important calendrical influences, and the stars provided time, calendar, and navigational aid. But even in its historical context, many leading figures recognized astrology as unreliable in regard to predictions and encouraging escape from responsibility and legitimate action that the circumstances of life continuously demand.

Of course, we are mistaken if we believe that those who carried out observational and calculational astronomy of the past because of nonmodern motivation were less observant, intelligent, or sane than are their modern counterparts. They included, after all, such prominent astronomers as Claudius Ptolemy and Johannes Kepler, and indeed many astronomers in between. They were merely steeped in the presuppositions of their times, just as we are in ours. Their work continues to have value, despite the nature of their astrological beliefs or activities, because of the careful attention they brought to their astronomical work.

Much of the ancient world believed that the stars revealed the destinies of the great. We do not have to share that belief to recognize the impact that it has had not only on the monuments people have left behind, but also on their lives and, ultimately, on ours.

More broadly, whether astronomically related ideas were spread largely by diffusion across cultures, or arose by parallel but independent processes, the many similarities we have explored imply a deep resonance between cosmic themes and human thought, and the expression of this resonance from culture to culture may be the most profound purpose to archaeoastronomy.

[18] It is interesting to point out, however, that if a people of a certain country, in Southeast Asia, say, were to be at war with a western power, and if their activities were in any way guided by astrological predictions, the western military authorities would ignore the astrology of its adversaries to its peril.

Appendices

Appendix A
Archaeoastronomy Tools

A.1. Introduction

There are a number of useful sources of information as well as devices and software packages that are very useful for work in archaeoastronomy. We merely list a few of them here.

The first five chapters and appendices A–D of the laboratory manual by Schlosser et al. (1991/1994), *Challenges of Astronomy: Hands-On Experiments for the Sky and Laboratory* (New York: Springer), are especially suitable for archaeoastronomy students.

A.2. Spherical Astronomy Aids

(1) Green, R.M. 1985. *Spherical Astronomy* (Cambridge: University Press), includes discussions of relativistic effects.
(2) Smart, W.M., *Spherical Astronomy*, revised by Green, R.M. (1977), and still the best general discussions of spherical astronomy.
(3) Woolard and Clemence (1966) *Spherical Astronomy* (New York: Academic Press), contains useful formulas and discussions beyond those discussed here.
(4) *Astronomical Almanac* (annual) (Washington: Superintendent of Documents); (London: Her Majesty's Stationery Office), contains numerous tables and information.

A.3. Computational and Sky Simulation Software

We include a selected number of software packages with which we are familiar and have used to varying degrees in this work. For up-to-date and more complete lists, we recommend the software review pages linked to the Sky & Telescope website as well as recent reviews in that magazine before any purchase is made.

Sources of useful programs include:

(1) Standish, E.M. JPL Planetary and Lunar Ephemerides on CD-ROM. Available on-line and from Willmann-Bell, Richmond, VA.
(2) Bretagnon, P., and Simon, J.-L. 1986. *Planetary Programs and Tables from –4000 to +2800*. (Richmond: Willmann-Bell).
(3) Duffett-Smith, P. 1985/1990. *Astronomy with your Personal Computer*. (Cambridge: Cambridge Univ. Press); and 1996. *Easy PC Astronomy* (Cambridge: the Press Syndicate of the University of Cambridge).

The first work contains algorithms and FORTRAN subroutines to provide rectangular coordinates of the Sun, Moon, and nine planets. Three sets of ephemerides are provided: *DE 200* (includes nutation but not librations, and covers the interval 1599 Dec. 9 to 2169 Mar. 31); *DE 405* (includes both nutation and librations, for the interval 1599 Dec. 9 to 2201 Feb. 20); and *DE 406*, the "New JPL Long Ephemeris" (includes neither nutation nor librations, but covers the interval –3000 Feb. 23 to +3000 May 6).

The second work contains programs containing algorithms and formulae for computing azimuths, altitudes, and other practical quantities. Corrections for refraction and extinction are included. "Easy PC Astronomy" offers a script language for calculations.

(4) Montenbruck, O. 1989. *Practical Ephemeris Calculations*. (New York: Springer).
(5) Montenbruck, O., and Pfleger, T. 1991. *Astronomy on the Personal Computer*. (New York: Springer).

Some of the self-contained computer software programs available at present include:

(1) *Distant Suns* (PC) (RomTech, Inc., 2945 McMillan Avenue, Sanhui, Obispo, California, 93401-6767 U.S.).
This software package produces all sky and horizon

views, but our printed charts sometimes bear a spurious anti-ecliptic that does not appear on screen or even in the preview screen, possibly an unmasked view of the far side of the sphere. The program is best used for contemporary sky simulations; avoid negative Gregorian dates.

(2) Guide 8.0 (PC) (Project Pluto, 168 Ridge Road, Bowdoinham, Maine, 04008).

This software makes excellent deep sky prints for astronomical observations. We have not used it much for archaeoastronomy, but others have. The star positions incorporate corrections for proper motions as well as for precession. We have been successful in receiving timely responses to our emails from "Project Pluto" (Bill Gray), in sharp contrast to the lack of responses from most star chart or planetarium software vendors.

(3) *Redshift: Multimedia Astronomy* (PC) (Maris Multimedia Ltd., 99 Mansell St., London E1 8AX, England).

This package is one of the most versatile we have found. We tested it on the lunar eclipse of Aug. 9, 2403 B.C. (Julian Calendar), calculated by Schoch (1927) for Babylon, and found it to show the total umbral eclipse on this date. There are conjunction and eclipse finders for specified years or ranges of years. Movies of such events can be played, and many modes of viewing the sky are available.

(4) *Starry Night* (PC) (Sienna Software, 411 Richmond St. East, Suite 303, Toronto, Ontario, M5A, 3S5, Canada).

Starry Night is said to produce some of the most visually stunning results. Many prefer this software package, but we have not had opportunity to use it.

(5) *Superstar* (PC).

This software package contains solar system objects, stars from the Smithsonian Astrophysical Observatory, Variable stars from the General Catalogue of Variable Stars, clusters, nebulae, and galaxies, all to relatively faint limits (specifiable). This package is good for calling up star charts, but we did not find it particularly friendly, and obtaining hard copy charts from its screens can be a nightmare.

(6) *TheSky* (PC) (The Sky Astronomy Software for Windows, available through the Astronomical Soc. of the Pacific, San Francisco, CA).

This software package provides nice views of the sky at various time in the past and for everywhere on Earth, and, by a selection of "filters," various planets, Sun, Moon, stars, clusters, galaxies, and nebulae can be included. There is a slight bias toward equatorial charts; fields have to be rotated to present horizon views (although both sets of grids are available). There is no ecliptic system of coordinates either in text information or charting available, other than the ecliptic depiction itself (this shortcoming is shared by many of the packages). All charts can be printed as needed. This program is best run on contemporary sky simulations.

(7) *Visible Universe* (PC) (Parsec Software, 1949 Blair Loop Road, Danville, VA. 24541).

This software package provides views of sky from any geographical location from any date in the distant past to the future. Solar system objects, stars from the Bright Star Catalogue, brighter clusters, nebulae, and galaxies are included. Time lapse images can produce a dynamic recreation of events. For example, the simulation of the blood-red eclipsed Moon rising above the Heelstone at Stonehenge on Dec. 22, 1471 B.C. is breathtaking. We are unsure if the current package is being maintained.

(8) *Voyager* (MacIntosh) [Carina Software, San Leandro, CA]

This package can provide all sky views and display horizon views from any epoch; it contains the brighter stars, the planets, Sun, and Moon. The graphic screens as well as text can be output to printers. Voyager has consistently been hailed as one of the best packages available. As far as we have been able to tell, however, the company does not respond to email. The PC version of this software package is available in Voyager III. This program appears to be reliable for ancient sky simulations, but one should be cautious when using any program for historical work if the corrections for ΔT, due to Earth's variable rotation, treatment of precession, or calendar implementation are not explicitly described.

A.4. Planetary Positions

(1) The Tuckerman Tables.
Tuckerman, Bryant. 1962. *Planetary, Lunar, and Solar Positions 601 B.C. to A.D. 1 at Five-Day and Ten-Day Intervals* (Philadelphia: The American Philosophical Society). The Amer. Phil. Soc. Memoirs, No. 56.
Tuckerman, Bryant. 1964. *Planetary, Lunar, and Solar Positions A.D. 2 to A.D. 1649 at Five-Day and Ten-Day Intervals* (Philadelphia: The American Philosophical Society). The Amer. Phil. Soc. Memoirs, No. 59.

In these two volumes, Tuckerman uses improved theories and ephemerides and attention to roundoff error to present the geocentric ecliptic longitude and latitude positions of the naked-eye planets for an important segment of history; as a check, he compares them to the earlier work of P.V. Neugebauer (1914, 1929) and investigates the differences between them. See the Introduction to the 1962 volume for a discussion of error. He gives estimated uncertainties in celestial longitude (p. 12) of 0.011°, 0.016°, 0.006°, 0.016°, 0.025°, 0.155°, 0.22° for Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the Moon, respectively; but also see Stephenson and Houlden (1981) for a discussion of the precision and Houlden and Stephenson (1986) for a discussion of the accuracy and for corrections, which can amount to as much as 0.7° (for longitudes of Mars), when Stephenson's positions are compared with those provided by numerical integration techniques. The positions of the Moon, Mercury, and Venus are given at 5-day intervals, and those of the Sun and outer planets at 10-day intervals.

(2) Supplement to the Tuckerman Tables.
Houlden, M.A., and Stephenson, F.R. 1986. A *Supplement to the Tuckerman Tables.* (Philadelphia: The American Philosphical Society). The Amer. Phil. Soc. Memoirs, No. 170.

This is an important update to the Tuckerman tables for the longitude positions of the outer planets for the full interval 601 B.C. to 1649 A.D. Tables are explicitly given for Mars, and graphs of the corrections are given for Jupiter and Saturn. The predicted brightnesses of all naked-eye planets in magnitude measure are also tabulated.

(3) Stahlman, W., and Gingerich, O. 1963. *Solar and Planetary Longitudes for Years –2500 to +2000 by Ten-Day Intervals*. (Madison: Univ. of Wisconsin Press).
(4) United States Naval Observatory almanacs (and corresponding sources in other countries).

The positions of planets can be calculated for modern epochs to good precision by software packages such as the "Floppy Almanac" and the annual Astronomical Almanac, available from the U.S. Government Printing Office, Superintendent of Documents, Mail Stop: SSOP, Washington, D.C. 20402-9328. Certain astronomy supply houses also carry them.

(5) Orbital calculations can be carried out given observations, or given the elements of an orbit, predicted positions can be computed. Several resources are available:
   (a) Schlosser et al. (1991/1994) have a section on celestial mechanics in which planetary positions can be calculated; tables are provided as shortcuts. Ch. 14 and App. E are suitable for finding approximate positions of planets.
   (b) Danby, J.M.A. 1988. *Fundamentals of Celestial Mechanics*, 2nd ed. (Richmond: Willmann-Bell, Inc.) available with floppy disks containing celestial mechanics programs.
   (c) Boulet, D. 1992. *Methods of Orbit Determination for the Micro Computer*. (Richmond: Willmann-Bell, Inc.) with optional program listings in BASIC.

A.5. Miscellaneous Tables

(1) Meeus, J. 1983a. *Astronomical Tables of the Sun, Moon, and Planets* (Richmond: Willmann-Bell, Inc.), is a collection of interesting and sometimes useful tables. It also contains programs for scientific calculators (HP-67, HP-41C, TI-59). Especially relevant to archaeoastronomy are the tables for the Oppositions of Mars, Jupiter, and Saturn from year 0, the conjunctions of Venus from 0 to 2500; the transits of Venus from 1 to 300 and of Mercury from 1 to 600; the dates of the onsets of the seasons from 1 to 3000.
(2) Goldstine, H.H. 1973. *New and Full Moons 1001 B.C. to A.D. 1651*. (Philadelphia: The American Philosophical Society). The Amer. Phil. Soc. Memoirs, No. 94. This work is another of those inspired by Otto Neugebauer to modernize and make more convenient the study of early science. It provides the times of full and new moons as observed at Baghdad, regarded as approximately equivalent to ancient Babylon. The tables employ a terrestrial longitude correction of $+3^h00^m$ to Greenwich (therefore, for Greenwich time, –3:00 should be applied), and provide the geocentric (not topocentric) lunar longitude at each instant.

Appendix B
Modern Star Charts

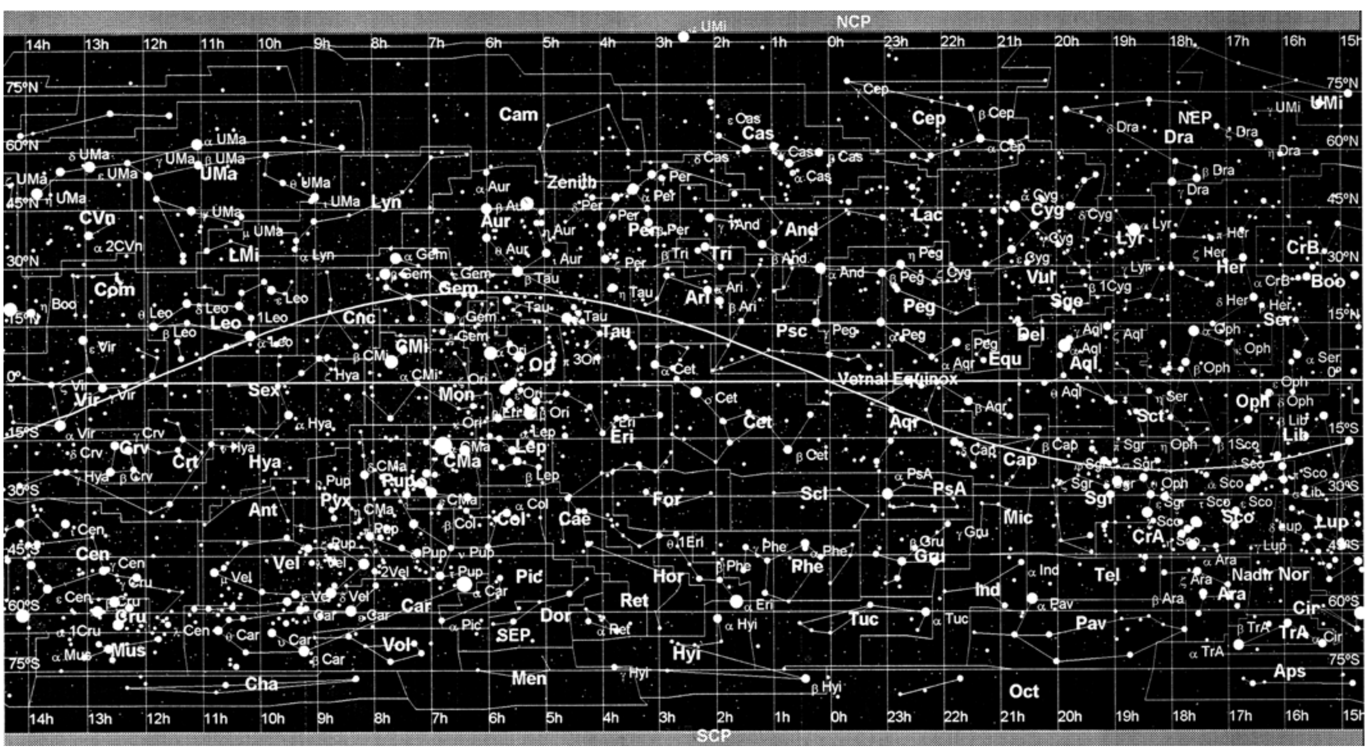
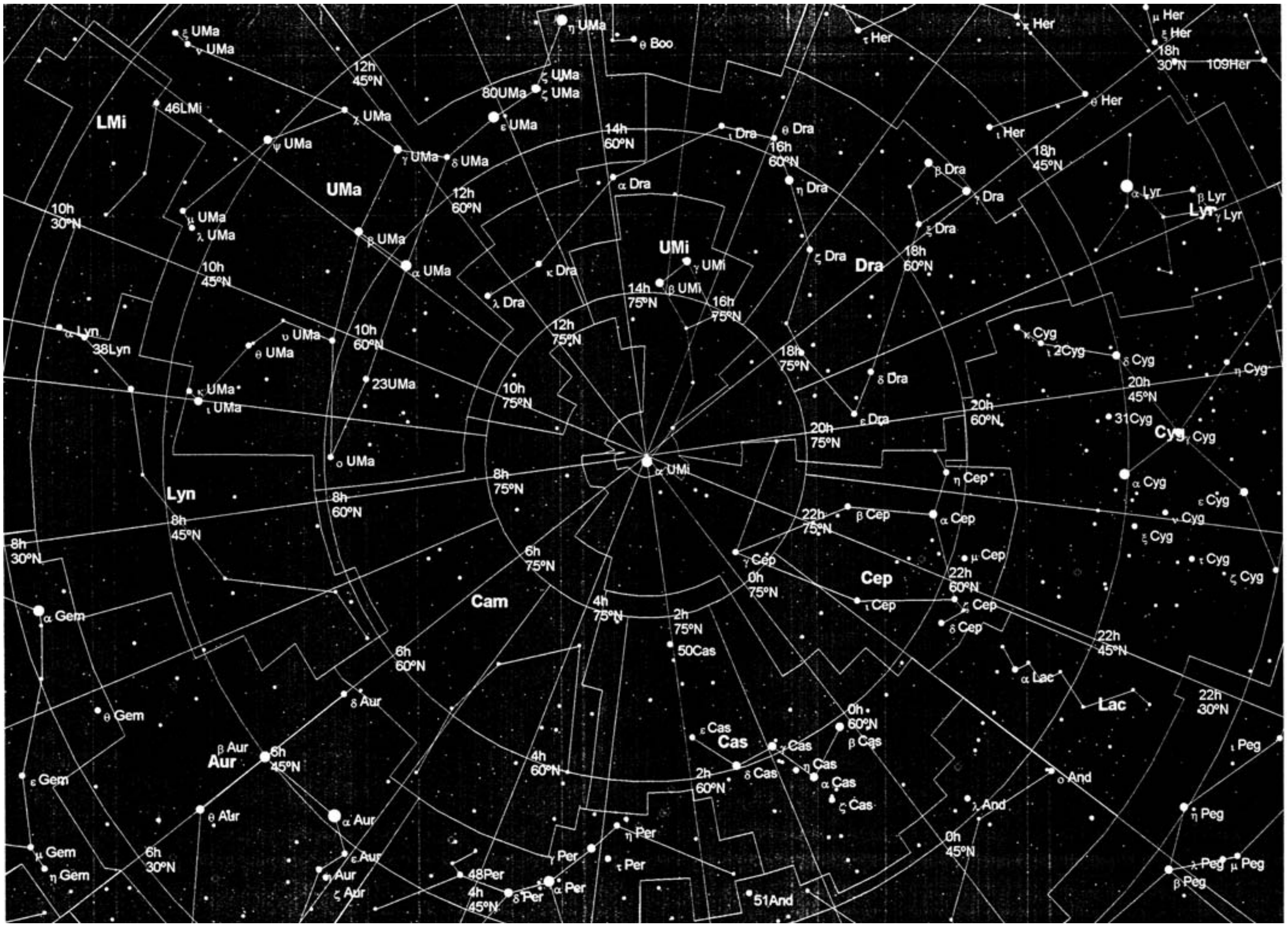
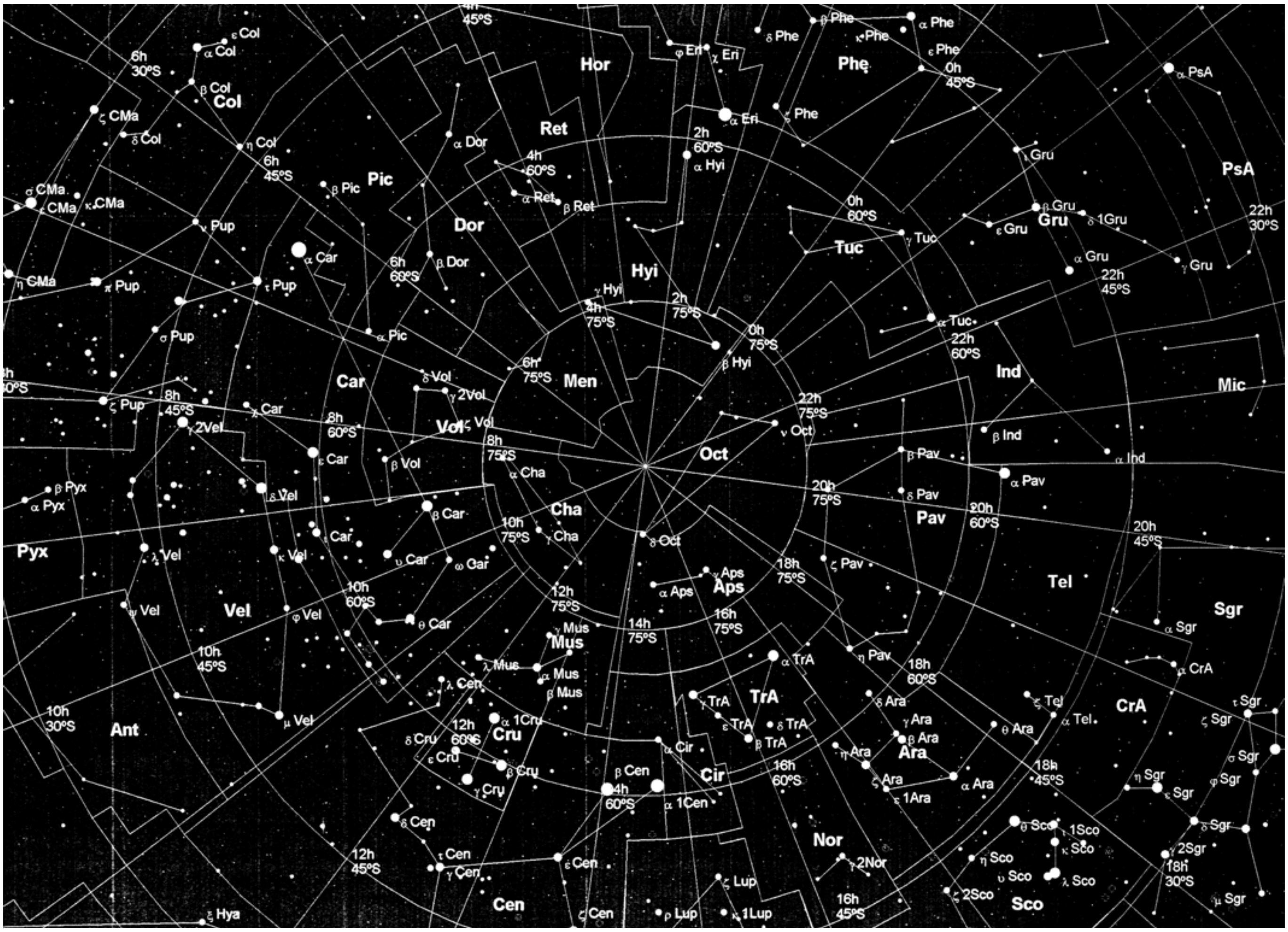


FIGURE B.1. The sky in the equatorial system of coordinates: Note the ecliptic, a sinusoid crossing the celestial equator at 0^h, going north, and at 12^h, going south. The equinox of 2000.0 is shown, along with the (α, δ) grid. The labels are Bayer designations for naked-eye stars and shortened Latin names for the constellations. The north and south ecliptic poles (*NEP*, *SEP*) are also indicated. Produced by E.F. Milone with Red-Shift software.



(a)

FIGURE B.2. The northern (a) and southern (b) polar regions of the equatorial system, equinox 2000.0: The poles mark 90° north and south declination, respectively. The labels are Bayer designations for naked-eye stars and shortened Latin names for the constellations. Produced by E.F. Milone with RedShift software.



(b)

FIGURE B.2. *Continued.*

Appendix C
Sample Exercises and Problems

§2

(1) Compute the maximum altitude achieved by the Sun during the year at sites with latitude = 90°, 66.7°, and $23\frac{1}{2}$°.
(2) Calculate the maximum azimuth of the setting summer solstice Sun at sites with latitude = 51° and 32°.
(3) Calculate the maximum elongation of (a) Mercury and (b) Venus as seen from the Earth; use mean distances from the Sun for all planets.
(4) Calculate the hour angle and declination for an object at azimuth 120° and altitude 50° at a site with latitude = 45°.
(5) Do the calculation in Question 4 for a site with latitude –45°, and comment on the required convention for treating Southern Hemisphere site calculations.
(6) Compute the right ascension and declination for an object with celestial longitude 75° and celestial latitude 5°.
(7) Calculate the arc distance between two objects on the sky separated by 45° of right ascension and 20° of declination.
(8) At a certain observatory, Orion's Belt is observed to rise parallel to the horizon. From star charts and spherical astronomy, determine the latitude of the site.
(9) Calculate the difference (a) in azimuth and (b) the difference in hour angle for two objects on the ecliptic, one at 0° and the other at +10°.
(10) At a certain site a 1- or 2-day-old crescent Moon is observed to have its horns pointing up, directly away from the horizon. If the date is Sept. 21, what is the latitude of the site?

§3

(1) Calculate the hour angles of the onset of civil and astronomical evening twilight at a) the equator and b) a latitude of 51°N. [See §3.1.2.5 and (2.5).]
(2) Compute the refraction and the observed altitude under standard atmospheric pressure and temperature conditions for objects at the following altitudes [see §3.1.3 and (3.16)]: $h = 30°$, $h = 45°$, $h = 60°$, and $h = 90°$.
(3) Calculate the expected (algebraically) maximum altitude of the Sun at midwinter from Novaya Zemlya [see §3.1.3 and (3.16)].
(4) Calculate the effective magnitude of a cluster of 50,000 stars of average magnitude 16 [see §3.1.2.4.5 and reasoning behind (3.13)].
(5) Calculate the apparent azimuth of sunrise at midsummer at a site with latitude = 51°. Assume $dz = \frac{1}{2}°$ [see §3.1.3 and (2.1)].
(6) Taking refraction into account, what is the algebraically smallest latitude at which the phenomenon of the "midnight Sun" can be observed?
(7) From the precessional pole charts (Figures 3.9 and 3.10), which of the first magnitude stars were circumpolar (a) at Giza (Cairo will do!) at 2500 B.C. and (b) at Callanish, 1500 B.C.?

§4

(1) Calculate the angle between the shadows' edges of a vertical gnomon cast by the Sun at 12 and 1 P.M. local solar time for a flat sundial.
(2) Calculate the length of the solar shadow at noon at a site with latitude 45° for such a sundial at (a) summer solstice and at (b) winter solstice.
(3) Calculate the length of daylight for Alexandria in winter and sunlight, correcting for expected mean refraction and the semidiameter of the Sun.
(4) Determine the length of astronomical twilight for Alexandria (as per Question 3).
(5) Compute the altitude of Thuban (alpha Draconis) at 2500 B.C. at Giza (Cairo will do!) at upper culmination.

(6) Derive the mean length of the synodic month from that of the mean sidereal month length and the sidereal year length.
(7) Derive the length of the tropical year from the sidereal year and the precession rate.
(8) Calculate the length of a "seasonal hour" at winter solstice at (a) Rome and at (b) Karnak.
(9) Calculate the length of a "seasonal hour" at summer solstice at (a) Rome and at (b) Karnak.

§5

(1) Determine the maximum altitude of a sundog for a setting/rising Sun.
(2) Compute the maximum altitude of the primary and secondary rainbows of the rising/setting Sun.
(3) Compare the azimuths of the rainbows of Question 2 for a setting summer solstice Sun at latitudes = 20° and 60°.
(4) Calculate the brightness required for the Crab Nebula supernova to be visible in the daytime.
(5) Estimate the energy produced by the impact of a 50-km-diameter comet on the forward (Eastern) limb of the Moon. Assume maximum possible velocity of impact.
(6) Estimate the brightness of the impact described in Question 5 for an observer on Earth. Explicitly list and discuss all assumptions.
(7) Discuss the *arcus visionis* needed to see a first magnitude star when it is (a) 1° and (b) 10° above the astronomical horizon above the Sun.

§§6–15

(1) Demonstrate the correctness of the statement in fn. 4 of §6 concerning the identical equations derived for the Southern Hemipshere.
(2) Calculate the amplitudes of the rising/setting Sun at (a) Stonehenge and at (b) Tenochtitlan for appropriate epochs.
(3) Calculate the extreme amplitudes of the rising/setting Moon at (a) Stonehenge and at (b) Callanish.
(4) Compute (a) the Julian day number and (b) the back-calculated Gregorian date of October 31, 1517.
(5) Determine the date of Easter for the current year (stating the criteria and whose criteria they are).
(6) Discuss the importance and limitations of the probability approach to deciding the "reality" of astronomical alignments.
(7) A commonly discussed problem is how the pyramids could have been aligned as accurately as they apparently are. List and discuss several astronomically based schemes for doing so.
(8) Compute by interpolation (from the data given in Table 2.3) the expected lengths of the seasons for the epoch of the construction of Angkor Wat (§§9.3 and 15.3.2). Can you think of an alternative interpretation for the numbers of *asuras* and *devas*?
(9) Suppose you have an eroded Maya monument of which you can read:

#.17.5.3.# #Ix #Zip

Give the correct reading of the Long Count and the Calendar Round.
(10) Suppose you infer from a myth that Jupiter, Saturn, and Venus were "close together" in the sky in the constellation Gemini. Define "close together," and calculate the approximate dates when this would have been true in the past 3000 years.
(11) Suppose a painting in a cave depicts a deity whom you have identified as Saturn and is illuminated at the winter solstice. What inferences would you consider legitimate as to the astronomical conditions when the painting was created? About how often would those conditions repeat?
(12) On what days of the retrodicted Gregorian year would zenith passage of the Sun occur at latitude 21°15′N?

Appendix D
Mayan Calendar Progression: A Sample

To see progression by days (kins), read across all columns (dates 1–20). To see progression by months (Uinals), read down.

1				2				3				4				5			
1	Imix	19	Uo	2	Ik	end of	Uo	3	Akbal	1	Zip	4	Kan	2	Zip	5	Chicchan	3	Zip
8	Imix	19	Zip	9	Ik	end of	Zip	10	Akbal	1	Zotz	11	Kan	2	Zotz	12	Chicchan	3	Zotz
2	Imix	19	Zotz	3	Ik	end of	Zotz	4	Akbal	1	Tzec	5	Kan	2	Tzec	6	Chicchan	3	Tzec
9	Imix	19	Tzec	10	Ik	end of	Tzec	11	Akbal	1	Xul	12	Kan	2	Xul	13	Chicchan	3	Xul
3	Imix	19	Xul	4	Ik	end of	Xul	5	Akbal	1	Yaxkin	6	Kan	2	Yaxkin	7	Chicchan	3	Yaxkin
10	Imix	19	Yaxkin	11	Ik	end of	Yaxkin	12	Akbal	1	Mol	13	Kan	2	Mol	1	Chicchan	3	Mol
4	Imix	19	Mol	5	Ik	end of	Mol	6	Akbal	1	Chen	7	Kan	2	Chen	8	Chicchan	3	Chen
11	Imix	19	Chen	12	Ik	end of	Chen	13	Akbal	1	Yax	1	Kan	2	Yax	2	Chicchan	3	Yax
5	Imix	19	Yax	6	Ik	end of	Yax	7	Akbal	1	Zac	8	Kan	2	Zac	9	Chicchan	3	Zac
12	Imix	19	Zac	13	Ik	end of	Zac	1	Akbal	1	Ceh	2	Kan	2	Ceh	3	Chicchan	3	Ceh
6	Imix	19	Ceh	7	Ik	end of	Ceh	8	Akbal	1	Mac	9	Kan	2	Mac	10	Chicchan	3	Mac
13	Imix	19	Mac	1	Ik	end of	Mac	2	Akbal	1	Kankin	3	Kan	2	Kankin	4	Chicchan	3	Kankin
7	Imix	19	Kankin	8	Ik	end of	Kankin	9	Akbal	1	Muan	10	Kan	2	Muan	11	Chicchan	3	Muan
1	Imix	19	Muan	2	Ik	end of	Muan	3	Akbal	1	Pax	4	Kan	2	Pax	5	Chicchan	3	Pax
8	Imix	19	Pax	9	Ik	end of	Pax	10	Akbal	1	Kayab	11	Kan	2	Kayab	12	Chicchan	3	Kayab
2	Imix	19	Kayab	3	Ik	end of	Kayab	4	Akbal	1	Cumku	5	Kan	2	Cumku	6	Chicchan	3	Cumku
9	Imix	19	Cumku	10	Ik	end of	Cumku	11	Akbal	1	uayeb	12	Kan	2	uayeb	13	Chicchan	3	uayeb
3	Imix	14	Pop	4	Ik	15	Pop	5	Akbal	16	Pop	6	Kan	17	Pop	7	Chicchan	18	Pop
10	Imix	14	Uo	11	Ik	15	Uo	12	Akbal	16	Uo	13	Kan	17	Uo	1	Chicchan	18	Uo
4	Imix	14	Zip	5	Ik	15	Zip	6	Akbal	16	Zip	7	Kan	17	Zip	8	Chicchan	18	Zip
11	Imix	14	Zotz	12	Ik	15	Zotz	13	Akbal	16	Zotz	1	Kan	17	Zotz	2	Chicchan	18	Zotz
5	Imix	14	Tzec	6	Ik	15	Tzec	7	Akbal	16	Tzec	8	Kan	17	Tzec	9	Chicchan	18	Tzec
12	Imix	14	Xul	13	Ik	15	Xul	1	Akbal	16	Xul	2	Kan	17	Xul	3	Chicchan	18	Xul
6	Imix	14	Yaxkin	7	Ik	15	Yaxkin	8	Akbal	16	Yaxkin	9	Kan	17	Yaxkin	10	Chicchan	18	Yaxkin
13	Imix	14	Mol	1	Ik	15	Mol	2	Akbal	16	Mol	3	Kan	17	Mol	4	Chicchan	18	Mol
7	Imix	14	Chen	8	Ik	15	Chen	9	Akbal	16	Chen	10	Kan	17	Chen	11	Chicchan	18	Chen
1	Imix	14	Yax	2	Ik	15	Yax	3	Akbal	16	Yax	4	Kan	17	Yax	5	Chicchan	18	Yax
8	Imix	14	Zac	9	Ik	15	Zac	10	Akbal	16	Zac	11	Kan	17	Zac	12	Chicchan	18	Zac
2	Imix	14	Ceh	3	Ik	15	Ceh	4	Akbal	16	Ceh	5	Kan	17	Ceh	6	Chicchan	18	Ceh
9	Imix	14	Mac	10	Ik	15	Mac	11	Akbal	16	Mac	12	Kan	17	Mac	13	Chicchan	18	Mac
3	Imix	14	Kankin	4	Ik	15	Kankin	5	Akbal	16	Kankin	6	Kan	17	Kankin	7	Chicchan	18	Kankin
10	Imix	14	Muan	11	Ik	15	Muan	12	Akbal	16	Muan	13	Kan	17	Muan	1	Chicchan	18	Muan
4	Imix	14	Pax	5	Ik	15	Pax	6	Akbal	16	Pax	7	Kan	17	Pax	8	Chicchan	18	Pax
11	Imix	14	Kayab	12	Ik	15	Kayab	13	Akbal	16	Kayab	1	Kan	17	Kayab	2	Chicchan	18	Kayab
5	Imix	14	Cumku	6	Ik	15	Cumku	7	Akbal	16	Cumku	8	Kan	17	Cumku	9	Chicchan	18	Cumku
12	Imix	9	Pop	13	Ik	10	Pop	1	Akbal	11	Pop	2	Kan	12	Pop	3	Chicchan	13	Pop
6	Imix	9	Uo	7	Ik	10	Uo	8	Akbal	11	Uo	9	Kan	12	Uo	10	Chicchan	13	Uo
13	Imix	9	Zip	1	Ik	10	Zip	2	Akbal	11	Zip	3	Kan	12	Zip	4	Chicchan	13	Zip
7	Imix	9	Zotz	8	Ik	10	Zotz	9	Akbal	11	Zotz	10	Kan	12	Zotz	11	Chicchan	13	Zotz
1	Imix	9	Tzec	2	Ik	10	Tzec	3	Akbal	11	Tzec	4	Kan	12	Tzec	5	Chicchan	13	Tzec
8	Imix	9	Xul	9	Ik	10	Xul	10	Akbal	11	Xul	11	Kan	12	Xul	12	Chicchan	13	Xul
2	Imix	9	Yaxkin	3	Ik	10	Yaxkin	4	Akbal	11	Yaxkin	5	Kan	12	Yaxkin	6	Chicchan	13	Yaxkin
9	Imix	9	Mol	10	Ik	10	Mol	11	Akbal	11	Mol	12	Kan	12	Mol	13	Chicchan	13	Mol
3	Imix	9	Chen	4	Ik	10	Chen	5	Akbal	11	Chen	6	Kan	12	Chen	7	Chicchan	13	Chen
10	Imix	9	Yax	11	Ik	10	Yax	12	Akbal	11	Yax	13	Kan	12	Yax	1	Chicchan	13	Yax
4	Imix	9	Zac	5	Ik	10	Zac	6	Akbal	11	Zac	7	Kan	12	Zac	8	Chicchan	13	Zac
11	Imix	9	Ceh	12	Ik	10	Ceh	13	Akbal	11	Ceh	1	Kan	12	Ceh	2	Chicchan	13	Ceh
5	Imix	9	Mac	6	Ik	10	Mac	7	Akbal	11	Mac	8	Kan	12	Mac	9	Chicchan	13	Mac
12	Imix	9	Kankin	13	Ik	10	Kankin	1	Akbal	11	Kankin	2	Kan	12	Kankin	3	Chicchan	13	Kankin
6	Imix	9	Muan	7	Ik	10	Muan	8	Akbal	11	Muan	9	Kan	12	Muan	10	Chicchan	13	Muan
13	Imix	9	Pax	1	Ik	10	Pax	2	Akbal	11	Pax	3	Kan	12	Pax	4	Chicchan	13	Pax
7	Imix	9	Kayab	8	Ik	10	Kayab	9	Akbal	11	Kayab	10	Kan	12	Kayab	11	Chicchan	13	Kayab
1	Imix	9	Cumku	2	Ik	10	Cumku	3	Akbal	11	Cumku	4	Kan	12	Cumku	5	Chicchan	13	Cumku
8	Imix	4	Pop	9	Ik	5	Pop	10	Akbal	6	Pop	11	Kan	7	Pop	12	Chicchan	8	Pop
2	Imix	4	Uo	3	Ik	5	Uo	4	Akbal	6	Uo	5	Kan	7	Uo	6	Chicchan	8	Uo
9	Imix	4	Zip	10	Ik	5	Zip	11	Akbal	6	Zip	12	Kan	7	Zip	13	Chicchan	8	Zip
3	Imix	4	Zotz	4	Ik	5	Zotz	5	Akbal	6	Zotz	6	Kan	7	Zotz	7	Chicchan	8	Zotz
10	Imix	4	Tzec	11	Ik	5	Tzec	12	Akbal	6	Tzec	13	Kan	7	Tzec	1	Chicchan	8	Tzec
4	Imix	4	Xul	5	Ik	5	Xul	6	Akbal	6	Xul	7	Kan	7	Xul	8	Chicchan	8	Xul
11	Imix	4	Yaxkin	12	Ik	5	Yaxkin	13	Akbal	6	Yaxkin	1	Kan	7	Yaxkin	2	Chicchan	8	Yaxkin
5	Imix	4	Mol	6	Ik	5	Mol	7	Akbal	6	Mol	8	Kan	7	Mol	9	Chicchan	8	Mol
12	Imix	4	Chen	13	Ik	5	Chen	1	Akbal	6	Chen	2	Kan	7	Chen	3	Chicchan	8	Chen
6	Imix	4	Yax	7	Ik	5	Yax	8	Akbal	6	Yax	9	Kan	7	Yax	10	Chicchan	8	Yax
13	Imix	4	Zac	1	Ik	5	Zac	2	Akbal	6	Zac	3	Kan	7	Zac	4	Chicchan	8	Zac

6				7					8				9				10			
6	Cimi	4	Zip	7	Manik		5	Zip	8	Lamat	6	Zip	9	Muluc	7	Zip	10	Oc	8	Zip
13	Cimi	4	Zotz	1	Manik		5	Zotz	2	Lamat	6	Zotz	3	Muluc	7	Zotz	4	Oc	8	Zotz
7	Cimi	4	Tzec	8	Manik		5	Tzec	9	Lamat	6	Tzec	10	Muluc	7	Tzec	11	Oc	8	Tzec
1	Cimi	4	Xul	2	Manik		5	Xul	3	Lamat	6	Xul	4	Muluc	7	Xul	5	Oc	8	Xul
8	Cimi	4	Yaxkin	9	Manik		5	Yaxkin	10	Lamat	6	Yaxkin	11	Muluc	7	Yaxkin	12	Oc	8	Yaxkin
2	Cimi	4	Mol	3	Manik		5	Mol	4	Lamat	6	Mol	5	Muluc	7	Mol	6	Oc	8	Mol
9	Cimi	4	Chen	10	Manik		5	Chen	11	Lamat	6	Chen	12	Muluc	7	Chen	13	Oc	8	Chen
3	Cimi	4	Yax	4	Manik		5	Yax	5	Lamat	6	Yax	6	Muluc	7	Yax	7	Oc	8	Yax
10	Cimi	4	Zac	11	Manik		5	Zac	12	Lamat	6	Zac	13	Muluc	7	Zac	1	Oc	8	Zac
4	Cimi	4	Ceh	5	Manik		5	Ceh	6	Lamat	6	Ceh	7	Muluc	7	Ceh	8	Oc	8	Ceh
11	Cimi	4	Mac	12	Manik		5	Mac	13	Lamat	6	Mac	1	Muluc	7	Mac	2	Oc	8	Mac
5	Cimi	4	Kankin	6	Manik		5	Kankin	7	Lamat	6	Kankin	8	Muluc	7	Kankin	9	Oc	8	Kankin
12	Cimi	4	Muan	13	Manik		5	Muan	1	Lamat	6	Muan	2	Muluc	7	Muan	3	Oc	8	Muan
6	Cimi	4	Pax	7	Manik		5	Pax	8	Lamat	6	Pax	9	Muluc	7	Pax	10	Oc	8	Pax
13	Cimi	4	Kayab	1	Manik		5	Kayab	2	Lamat	6	Kayab	3	Muluc	7	Kayab	4	Oc	8	Kayab
7	Cimi	4	Cumku	8	Manik		5	Cumku	9	Lamat	6	Cumku	10	Muluc	7	Cumku	11	Oc	8	Cumku
1	Cimi	4	uayeb	2	Manik		5	uayeb	3	Lamat	1	Pop	4	Muluc	2	Pop	5	Oc	3	Pop
8	Cimi	19	Pop	9	Manik	end of		Pop	10	Lamat	1	Uo	11	Muluc	2	Uo	12	Oc	3	Uo
2	Cimi	19	Uo	3	Manik	end of		Uo	4	Lamat	1	Zip	5	Muluc	2	Zip	6	Oc	3	Zip
9	Cimi	19	Zip	10	Manik	end of		Zip	11	Lamat	1	Zotz	12	Muluc	2	Zotz	13	Oc	3	Zotz
3	Cimi	19	Zotz	4	Manik	end of		Zotz	5	Lamat	1	Tzec	6	Muluc	2	Tzec	7	Oc	3	Tzec
10	Cimi	19	Tzec	11	Manik	end of		Tzec	12	Lamat	1	Xul	13	Muluc	2	Xul	1	Oc	3	Xul
4	Cimi	19	Xul	5	Manik	end of		Xul	6	Lamat	1	Yaxkin	7	Muluc	2	Yaxkin	8	Oc	3	Yaxkin
11	Cimi	19	Yaxkin	12	Manik	end of		Yaxkin	13	Lamat	1	Mol	1	Muluc	2	Mol	2	Oc	3	Mol
5	Cimi	19	Mol	6	Manik	end of		Mol	7	Lamat	1	Chen	8	Muluc	2	Chen	9	Oc	3	Chen
12	Cimi	19	Chen	13	Manik	end of		Chen	1	Lamat	1	Yax	2	Muluc	2	Yax	3	Oc	3	Yax
6	Cimi	19	Yax	7	Manik	end of		Yax	8	Lamat	1	Zac	9	Muluc	2	Zac	10	Oc	3	Zac
13	Cimi	19	Zac	1	Manik	end of		Zac	2	Lamat	1	Ceh	3	Muluc	2	Ceh	4	Oc	3	Ceh
7	Cimi	19	Ceh	8	Manik	end of		Ceh	9	Lamat	1	Mac	10	Muluc	2	Mac	11	Oc	3	Mac
1	Cimi	19	Mac	2	Manik	end of		Mac	3	Lamat	1	Kankin	4	Muluc	2	Kankin	5	Oc	3	Kankin
8	Cimi	19	Kankin	9	Manik	end of		Kankin	10	Lamat	1	Muan	11	Muluc	2	Muan	12	Oc	3	Muan
2	Cimi	19	Muan	3	Manik	end of		Muan	4	Lamat	1	Pax	5	Muluc	2	Pax	6	Oc	3	Pax
9	Cimi	19	Pax	10	Manik	end of		Pax	11	Lamat	1	Kayab	12	Muluc	2	Kayab	13	Oc	3	Kayab
3	Cimi	19	Kayab	4	Manik	end of		Kayab	5	Lamat	1	Cumku	6	Muluc	2	Cumku	7	Oc	3	Cumku
10	Cimi	19	Cumku	11	Manik	end of		Cumku	12	Lamat	1	uayeb	13	Muluc	2	uayeb	1	Oc	3	uayeb
12	Cimi	14	Pop	5	Manik		15	Pop	6	Lamat	16	Pop	7	Muluc	17	Pop	8	Oc	18	Pop
4	Cimi	14	Uo	12	Manik		15	Uo	13	Lamat	16	Uo	1	Muluc	17	Uo	2	Oc	18	Uo
11	Cimi	14	Zip	6	Manik		15	Zip	7	Lamat	16	Zip	8	Muluc	17	Zip	9	Oc	18	Zip
5	Cimi	14	Zotz	13	Manik		15	Zotz	1	Lamat	16	Zotz	2	Muluc	17	Zotz	3	Oc	18	Zotz
6	Cimi	14	Tzec	7	Manik		15	Tzec	8	Lamat	16	Tzec	9	Muluc	17	Tzec	10	Oc	18	Tzec
13	Cimi	14	Xul	1	Manik		15	Xul	2	Lamat	16	Xul	3	Muluc	17	Xul	4	Oc	18	Xul
7	Cimi	14	Yaxkin	8	Manik		15	Yaxkin	9	Lamat	16	Yaxkin	10	Muluc	17	Yaxkin	11	Oc	18	Yaxkin
1	Cimi	14	Mol	2	Manik		15	Mol	3	Lamat	16	Mol	4	Muluc	17	Mol	5	Oc	18	Mol
8	Cimi	14	Chen	9	Manik		15	Chen	10	Lamat	16	Chen	11	Muluc	17	Chen	12	Oc	18	Chen
2	Cimi	14	Yax	3	Manik		15	Yax	4	Lamat	16	Yax	5	Muluc	17	Yax	6	Oc	18	Yax
9	Cimi	14	Zac	10	Manik		15	Zac	11	Lamat	16	Zac	12	Muluc	17	Zac	13	Oc	18	Zac
3	Cimi	14	Ceh	4	Manik		15	Ceh	5	Lamat	16	Ceh	6	Muluc	17	Ceh	7	Oc	18	Ceh
10	Cimi	14	Mac	11	Manik		15	Mac	12	Lamat	16	Mac	13	Muluc	17	Mac	1	Oc	18	Mac
4	Cimi	14	Kankin	5	Manik		15	Kankin	6	Lamat	16	Kankin	7	Muluc	17	Kankin	8	Oc	18	Kankin
11	Cimi	14	Muan	12	Manik		15	Muan	13	Lamat	16	Muan	1	Muluc	17	Muan	2	Oc	18	Muan
5	Cimi	14	Pax	6	Manik		15	Pax	7	Lamat	16	Pax	8	Muluc	17	Pax	9	Oc	18	Pax
12	Cimi	14	Kayab	13	Manik		15	Kayab	1	Lamat	16	Kayab	2	Muluc	17	Kayab	3	Oc	18	Kayab
6	Cimi	14	Cumku	7	Manik		15	Cumku	8	Lamat	16	Cumku	9	Muluc	17	Cumku	10	Oc	18	Cumku
13	Cimi	9	Pop	1	Manik		10	Pop	2	Lamat	11	Pop	3	Muluc	12	Pop	4	Oc	13	Pop
7	Cimi	9	Uo	8	Manik		10	Uo	9	Lamat	11	Uo	10	Muluc	12	Uo	11	Oc	13	Uo
1	Cimi	9	Zip	2	Manik		10	Zip	3	Lamat	11	Zip	4	Muluc	12	Zip	5	Oc	13	Zip
8	Cimi	9	Zotz	9	Manik		10	Zotz	10	Lamat	11	Zotz	11	Muluc	12	Zotz	12	Oc	13	Zotz
2	Cimi	9	Tzec	3	Manik		10	Tzec	4	Lamat	11	Tzec	5	Muluc	12	Tzec	6	Oc	13	Tzec
9	Cimi	9	Xul	10	Manik		10	Xul	11	Lamat	11	Xul	12	Muluc	12	Xul	13	Oc	13	Xul
3	Cimi	9	Yaxkin	4	Manik		10	Yaxkin	5	Lamat	11	Yaxkin	6	Muluc	12	Yaxkin	7	Oc	13	Yaxkin
10	Cimi	9	Mol	11	Manik		10	Mol	12	Lamat	11	Mol	13	Muluc	12	Mol	1	Oc	13	Mol
4	Cimi	9	Chen	5	Manik		10	Chen	6	Lamat	11	Chen	7	Muluc	12	Chen	8	Oc	13	Chen
11	Cimi	9	Yax	12	Manik		10	Yax	13	Lamat	11	Yax	1	Muluc	12	Yax	2	Oc	13	Yax
5	Cimi	9	Zac	6	Manik		10	Zac	7	Lamat	11	Zac	8	Muluc	12	Zac	9	Oc	13	Zac

11				12					13				14				15			
11	Chuen	9	Zip	12	Eb		10	Zip	13	Ben	11	Zip	1	Ix	12	Zip	2	Men	13	Zip
5	Chuen	9	Zotz	6	Eb		10	Zotz	7	Ben	11	Zotz	8	Ix	12	Zotz	9	Men	13	Zotz
12	Chuen	9	Tzec	13	Eb		10	Tzec	1	Ben	11	Tzec	2	Ix	12	Tzec	3	Men	13	Tzec
6	Chuen	9	Xul	7	Eb		10	Xul	8	Ben	11	Xul	9	Ix	12	Xul	10	Men	13	Xul
13	Chuen	9	Yaxkin	1	Eb		10	Yaxkin	2	Ben	11	Yaxkin	3	Ix	12	Yaxkin	4	Men	13	Yaxkin
7	Chuen	9	Mol	8	Eb		10	Mol	9	Ben	11	Mol	10	Ix	12	Mol	11	Men	13	Mol
1	Chuen	9	Chen	2	Eb		10	Chen	3	Ben	11	Chen	4	Ix	12	Chen	5	Men	13	Chen
8	Chuen	9	Yax	9	Eb		10	Yax	10	Ben	11	Yax	11	Ix	12	Yax	12	Men	13	Yax
2	Chuen	9	Zac	3	Eb		10	Zac	4	Ben	11	Zac	5	Ix	12	Zac	6	Men	13	Zac
9	Chuen	9	Ceh	10	Eb		10	Ceh	11	Ben	11	Ceh	12	Ix	12	Ceh	13	Men	13	Ceh
3	Chuen	9	Mac	4	Eb		10	Mac	5	Ben	11	Mac	6	Ix	12	Mac	7	Men	13	Mac
10	Chuen	9	Kankin	11	Eb		10	Kankin	12	Ben	11	Kankin	13	Ix	12	Kankin	1	Men	13	Kankin
4	Chuen	9	Muan	5	Eb		10	Muan	6	Ben	11	Muan	7	Ix	12	Muan	8	Men	13	Muan
11	Chuen	9	Pax	12	Eb		10	Pax	13	Ben	11	Pax	1	Ix	12	Pax	2	Men	13	Pax
5	Chuen	9	Kayab	6	Eb		10	Kayab	7	Ben	11	Kayab	8	Ix	12	Kayab	9	Men	13	Kayab
12	Chuen	9	Cumku	13	Eb		10	Cumku	1	Ben	11	Cumku	2	Ix	12	Cumku	3	Men	13	Cumku
6	Chuen	4	Pop	7	Eb		5	Pop	8	Ben	6	Pop	9	Ix	7	Pop	10	Men	8	Pop
13	Chuen	4	Uo	1	Eb		5	Uo	2	Ben	6	Uo	3	Ix	7	Uo	4	Men	8	Uo
7	Chuen	4	Zip	8	Eb		5	Zip	9	Ben	6	Zip	10	Ix	7	Zip	11	Men	8	Zip
1	Chuen	4	Zotz	2	Eb		5	Zotz	3	Ben	6	Zotz	4	Ix	7	Zotz	5	Men	8	Zotz
8	Chuen	4	Tzec	9	Eb		5	Tzec	10	Ben	6	Tzec	11	Ix	7	Tzec	12	Men	8	Tzec
2	Chuen	4	Xul	3	Eb		5	Xul	4	Ben	6	Xul	5	Ix	7	Xul	6	Men	8	Xul
9	Chuen	4	Yaxkin	10	Eb		5	Yaxkin	11	Ben	6	Yaxkin	12	Ix	7	Yaxkin	13	Men	8	Yaxkin
3	Chuen	4	Mol	4	Eb		5	Mol	5	Ben	6	Mol	6	Ix	7	Mol	7	Men	8	Mol
10	Chuen	4	Chen	11	Eb		5	Chen	12	Ben	6	Chen	13	Ix	7	Chen	1	Men	8	Chen
4	Chuen	4	Yax	5	Eb		5	Yax	6	Ben	6	Yax	7	Ix	7	Yax	8	Men	8	Yax
11	Chuen	4	Zac	12	Eb		5	Zac	13	Ben	6	Zac	1	Ix	7	Zac	2	Men	8	Zac
5	Chuen	4	Ceh	6	Eb		5	Ceh	7	Ben	6	Ceh	8	Ix	7	Ceh	9	Men	8	Ceh
12	Chuen	4	Mac	13	Eb		5	Mac	1	Ben	6	Mac	2	Ix	7	Mac	3	Men	8	Mac
6	Chuen	4	Kankin	7	Eb		5	Kankin	8	Ben	6	Kankin	9	Ix	7	Kankin	10	Men	8	Kankin
13	Chuen	4	Muan	1	Eb		5	Muan	2	Ben	6	Muan	3	Ix	7	Muan	4	Men	8	Muan
7	Chuen	4	Pax	8	Eb		5	Pax	9	Ben	6	Pax	10	Ix	7	Pax	11	Men	8	Pax
1	Chuen	4	Kayab	2	Eb		5	Kayab	3	Ben	6	Kayab	4	Ix	7	Kayab	5	Men	8	Kayab
8	Chuen	4	Cumku	9	Eb		5	Cumku	10	Ben	6	Cumku	11	Ix	7	Cumku	12	Men	8	Cumku
2	Chuen	4	uayeb	3	Eb		5	uayeb	4	Ben	1	Pop	5	Ix	2	Pop	6	Men	3	Pop
9	Chuen	19	Pop	10	Eb	end of		Pop	11	Ben	1	Uo	12	Ix	2	Uo	13	Men	3	Uo
3	Chuen	19	Uo	4	Eb	end of		Uo	5	Ben	1	Zip	6	Ix	2	Zip	7	Men	3	Zip
10	Chuen	19	Zip	11	Eb	end of		Zip	12	Ben	1	Zotz	13	Ix	2	Zotz	1	Men	3	Zotz
4	Chuen	19	Zotz	5	Eb	end of		Zotz	6	Ben	1	Tzec	7	Ix	2	Tzec	8	Men	3	Tzec
11	Chuen	19	Tzec	12	Eb	end of		Tzec	13	Ben	1	Xul	1	Ix	2	Xul	2	Men	3	Xul
5	Chuen	19	Xul	6	Eb	end of		Xul	7	Ben	1	Yaxkin	8	Ix	2	Yaxkin	9	Men	3	Yaxkin
12	Chuen	19	Yaxkin	13	Eb	end of		Yaxkin	1	Ben	1	Mol	2	Ix	2	Mol	3	Men	3	Mol
6	Chuen	19	Mol	7	Eb	end of		Mol	8	Ben	1	Chen	9	Ix	2	Chen	10	Men	3	Chen
13	Chuen	19	Chen	1	Eb	end of		Chen	2	Ben	1	Yax	3	Ix	2	Yax	4	Men	3	Yax
7	Chuen	19	Yax	8	Eb	end of		Yax	9	Ben	1	Zac	10	Ix	2	Zac	11	Men	3	Zac
1	Chuen	19	Zac	2	Eb	end of		Zac	3	Ben	1	Ceh	4	Ix	2	Ceh	5	Men	3	Ceh
8	Chuen	19	Ceh	9	Eb	end of		Ceh	10	Ben	1	Mac	11	Ix	2	Mac	12	Men	3	Mac
2	Chuen	19	Mac	3	Eb	end of		Mac	4	Ben	1	Kankin	5	Ix	2	Kankin	6	Men	3	Kankin
9	Chuen	19	Kankin	10	Eb	end of		Kankin	11	Ben	1	Muan	12	Ix	2	Muan	13	Men	3	Muan
3	Chuen	19	Muan	4	Eb	end of		Muan	5	Ben	1	Pax	6	Ix	2	Pax	7	Men	3	Pax
10	Chuen	19	Pax	11	Eb	end of		Pax	12	Ben	1	Kayab	13	Ix	2	Kayab	1	Men	3	Kayab
4	Chuen	19	Kayab	5	Eb	end of		Kayab	6	Ben	1	Cumku	7	Ix	2	Cumku	8	Men	3	Cumku
11	Chuen	19	Cumku	12	Eb	end of		Cumku	13	Ben	1	uayeb	1	Ix	2	uayeb	2	Men	3	uayeb
5	Chuen	14	Pop	6	Eb		15	Pop	7	Ben	16	Pop	8	Ix	17	Pop	9	Men	18	Pop
12	Chuen	14	Uo	13	Eb		15	Uo	1	Ben	16	Uo	2	Ix	17	Uo	3	Men	18	Uo
6	Chuen	14	Zip	7	Eb		15	Zip	8	Ben	16	Zip	9	Ix	17	Zip	10	Men	18	Zip
13	Chuen	14	Zotz	1	Eb		15	Zotz	2	Ben	16	Zotz	3	Ix	17	Zotz	4	Men	18	Zotz
7	Chuen	14	Tzec	8	Eb		15	Tzec	9	Ben	16	Tzec	10	Ix	17	Tzec	11	Men	18	Tzec
1	Chuen	14	Xul	2	Eb		15	Xul	3	Ben	16	Xul	4	Ix	17	Xul	5	Men	18	Xul
8	Chuen	14	Yaxkin	9	Eb		15	Yaxkin	10	Ben	16	Yaxkin	11	Ix	17	Yaxkin	12	Men	18	Yaxkin
2	Chuen	14	Mol	3	Eb		15	Mol	4	Ben	16	Mol	5	Ix	17	Mol	6	Men	18	Mol
9	Chuen	14	Chen	10	Eb		15	Chen	11	Ben	16	Chen	12	Ix	17	Chen	13	Men	18	Chen
3	Chuen	14	Yax	4	Eb		15	Yax	5	Ben	16	Yax	6	Ix	17	Yax	7	Men	18	Yax
10	Chuen	14	Zac	11	Eb		15	Zac	12	Ben	16	Zac	13	Ix	17	Zac	1	Men	18	Zac

16				17				18				19				20			
3	Cib	14	Zip	4	Caban	15	Zip	5	Etz'nab	16	Zip	6	Cauac	17	Zip	7	Ahau	18	Zip
10	Cib	14	Zotz	11	Caban	15	Zotz	12	Etz'nab	16	Zotz	13	Cauac	17	Zotz	1	Ahau	18	Zotz
4	Cib	14	Tzec	5	Caban	15	Tzec	6	Etz'nab	16	Tzec	7	Cauac	17	Tzec	8	Ahau	18	Tzec
11	Cib	14	Xul	12	Caban	15	Xul	13	Etz'nab	16	Xul	1	Cauac	17	Xul	2	Ahau	18	Xul
5	Cib	14	Yaxkin	6	Caban	15	Yaxkin	7	Etz'nab	16	Yaxkin	8	Cauac	17	Yaxkin	9	Ahau	18	Yaxkin
12	Cib	14	Mol	13	Caban	15	Mol	1	Etz'nab	16	Mol	2	Cauac	17	Mol	3	Ahau	18	Mol
6	Cib	14	Chen	7	Caban	15	Chen	8	Etz'nab	16	Chen	9	Cauac	17	Chen	10	Ahau	18	Chen
13	Cib	14	Yax	1	Caban	15	Yax	2	Etz'nab	16	Yax	3	Cauac	17	Yax	4	Ahau	18	Yax
7	Cib	14	Zac	8	Caban	15	Zac	9	Etz'nab	16	Zac	10	Cauac	17	Zac	11	Ahau	18	Zac
1	Cib	14	Ceh	2	Caban	15	Ceh	3	Etz'nab	16	Ceh	4	Cauac	17	Ceh	5	Ahau	18	Ceh
8	Cib	14	Mac	9	Caban	15	Mac	10	Etz'nab	16	Mac	11	Cauac	17	Mac	12	Ahau	18	Mac
2	Cib	14	Kankin	3	Caban	15	Kankin	4	Etz'nab	16	Kankin	5	Cauac	17	Kankin	6	Ahau	18	Kankin
9	Cib	14	Muan	10	Caban	15	Muan	11	Etz'nab	16	Muan	12	Cauac	17	Muan	13	Ahau	18	Muan
3	Cib	14	Pax	4	Caban	15	Pax	5	Etz'nab	16	Pax	6	Cauac	17	Pax	7	Ahau	18	Pax
10	Cib	14	Kayab	11	Caban	15	Kayab	12	Etz'nab	16	Kayab	13	Cauac	17	Kayab	1	Ahau	18	Kayab
4	Cib	14	Cumku	5	Caban	15	Cumku	6	Etz'nab	16	Cumku	7	Cauac	17	Cumku	8	Ahau	18	Cumku
11	Cib	9	Pop	12	Caban	10	Pop	13	Etz'nab	11	Pop	1	Cauac	12	Pop	2	Ahau	13	Pop
5	Cib	9	Uo	6	Caban	10	Uo	7	Etz'nab	11	Uo	8	Cauac	12	Uo	9	Ahau	13	Uo
12	Cib	9	Zip	13	Caban	10	Zip	1	Etz'nab	11	Zip	2	Cauac	12	Zip	3	Ahau	13	Zip
6	Cib	9	Zotz	7	Caban	10	Zotz	8	Etz'nab	11	Zotz	9	Cauac	12	Zotz	10	Ahau	13	Zotz
13	Cib	9	Tzec	1	Caban	10	Tzec	2	Etz'nab	11	Tzec	3	Cauac	12	Tzec	4	Ahau	13	Tzec
7	Cib	9	Xul	8	Caban	10	Xul	9	Etz'nab	11	Xul	10	Cauac	12	Xul	11	Ahau	13	Xul
1	Cib	9	Yaxkin	2	Caban	10	Yaxkin	3	Etz'nab	11	Yaxkin	4	Cauac	12	Yaxkin	5	Ahau	13	Yaxkin
8	Cib	9	Mol	9	Caban	10	Mol	10	Etz'nab	11	Mol	11	Cauac	12	Mol	12	Ahau	13	Mol
2	Cib	9	Chen	3	Caban	10	Chen	4	Etz'nab	11	Chen	5	Cauac	12	Chen	6	Ahau	13	Chen
9	Cib	9	Yax	10	Caban	10	Yax	11	Etz'nab	11	Yax	12	Cauac	12	Yax	13	Ahau	13	Yax
3	Cib	9	Zac	4	Caban	10	Zac	5	Etz'nab	11	Zac	6	Cauac	12	Zac	7	Ahau	13	Zac
10	Cib	9	Ceh	11	Caban	10	Ceh	12	Etz'nab	11	Ceh	13	Cauac	12	Ceh	1	Ahau	13	Ceh
4	Cib	9	Mac	5	Caban	10	Mac	6	Etz'nab	11	Mac	7	Cauac	12	Mac	8	Ahau	13	Mac
11	Cib	9	Kankin	12	Caban	10	Kankin	13	Etz'nab	11	Kankin	1	Cauac	12	Kankin	2	Ahau	13	Kankin
5	Cib	9	Muan	6	Caban	10	Muan	7	Etz'nab	11	Muan	8	Cauac	12	Muan	9	Ahau	13	Muan
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13	Cib	9	Cumku	1	Caban	10	Cumku	2	Etz'nab	11	Cumku	3	Cauac	12	Cumku	4	Ahau	13	Cumku
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13	Cib	4	Mac	1	Caban	5	Mac	2	Etz'nab	6	Mac	3	Cauac	7	Mac	4	Ahau	8	Mac
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3	Cib	4	uayeb	4	Caban	5	uayeb	5	Etz'nab	1	Pop	6	Cauac	2	Pop	7	Ahau	3	Pop
10	Cib	19	Pop	11	Caban	end of	Pop	12	Etz'nab	1	Uo	13	Cauac	2	Uo	1	Ahau	3	Uo
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13	Cib	19	Yaxkin	1	Caban	end of	Yaxkin	2	Etz'nab	1	Mol	3	Cauac	2	Mol	4	Ahau	3	Mol
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1				2					3				4				5			
7	Imix	4	Ceh	8	Ik		5	Ceh	9	Akbal	6	Ceh	10	Kan	7	Ceh	11	Chicchan	8	Ceh
1	Imix	4	Mac	2	Ik		5	Mac	3	Akbal	6	Mac	4	Kan	7	Mac	5	Chicchan	8	Mac
8	Imix	4	Kankin	9	Ik		5	Kankin	10	Akbal	6	Kankin	11	Kan	7	Kankin	12	Chicchan	8	Kankin
2	Imix	4	Muan	3	Ik		5	Muan	4	Akbal	6	Muan	5	Kan	7	Muan	6	Chicchan	8	Muan
9	Imix	4	Pax	10	Ik		5	Pax	11	Akbal	6	Pax	12	Kan	7	Pax	13	Chicchan	8	Pax
3	Imix	4	Kayab	4	Ik		5	Kayab	5	Akbal	6	Kayab	6	Kan	7	Kayab	7	Chicchan	8	Kayab
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4	Imix	4	uayeb	5	Ik		5	uayeb	6	Akbal	1	Pop	7	Kan	2	Pop	8	Chicchan	3	Pop
11	Imix	19	Pop	12	Ik	end of		Pop	13	Akbal	1	Uo	1	Kan	2	Uo	2	Chicchan	3	Uo
5	Imix	19	Uo	6	Ik	end of		Uo	7	Akbal	1	Zip	8	Kan	2	Zip	9	Chicchan	3	Zip
12	Imix	19	Zip	13	Ik	end of		Zip	1	Akbal	1	Zotz	2	Kan	2	Zotz	3	Chicchan	3	Zotz
6	Imix	19	Zotz	7	Ik	end of		Zotz	8	Akbal	1	Tzec	9	Kan	2	Tzec	10	Chicchan	3	Tzec
13	Imix	19	Tzec	1	Ik	end of		Tzec	2	Akbal	1	Xul	3	Kan	2	Xul	4	Chicchan	3	Xul
7	Imix	19	Xul	8	Ik	end of		Xul	9	Akbal	1	Yaxkin	10	Kan	2	Yaxkin	11	Chicchan	3	Yaxkin
1	Imix	19	Yaxkin	2	Ik	end of		Yaxkin	3	Akbal	1	Mol	4	Kan	2	Mol	5	Chicchan	3	Mol
8	Imix	19	Mol	9	Ik	end of		Mol	10	Akbal	1	Chen	11	Kan	2	Chen	12	Chicchan	3	Chen
2	Imix	19	Chen	3	Ik	end of		Chen	4	Akbal	1	Yax	5	Kan	2	Yax	6	Chicchan	3	Yax
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3	Imix	19	Zac	4	Ik	end of		Zac	5	Akbal	1	Ceh	6	Kan	2	Ceh	7	Chicchan	3	Ceh
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11	Imix	19	Kankin	12	Ik	end of		Kankin	13	Akbal	1	Muan	1	Kan	2	Muan	2	Chicchan	3	Muan
5	Imix	19	Muan	6	Ik	end of		Muan	7	Akbal	1	Pax	8	Kan	2	Pax	9	Chicchan	3	Pax
12	Imix	19	Pax	13	Ik	end of		Pax	1	Akbal	1	Kayab	2	Kan	2	Kayab	3	Chicchan	3	Kayab
6	Imix	19	Kayab	7	Ik	end of		Kayab	8	Akbal	1	Cumku	9	Kan	2	Cumku	10	Chicchan	3	Cumku
13	Imix	19	Cumku	1	Ik	end of		Cumku	2	Akbal	1	uayeb	3	Kan	2	uayeb	4	Chicchan	3	uayeb
7	Imix	14	Pop	8	Ik		15	Pop	9	Akbal	16	Pop	10	Kan	17	Pop	11	Chicchan	18	Pop
1	Imix	14	Uo																	

6				7					8				9				10			
12	Cimi	9	Ceh	13	Manik		10	Ceh	1	Lamat	11	Ceh	2	Muluc	12	Ceh	3	Oc	13	Ceh
6	Cimi	9	Mac	7	Manik		10	Mac	8	Lamat	11	Mac	9	Muluc	12	Mac	10	Oc	13	Mac
13	Cimi	9	Kankin	1	Manik		10	Kankin	2	Lamat	11	Kankin	3	Muluc	12	Kankin	4	Oc	13	Kankin
7	Cimi	9	Muan	8	Manik		10	Muan	9	Lamat	11	Muan	10	Muluc	12	Muan	11	Oc	13	Muan
1	Cimi	9	Pax	2	Manik		10	Pax	3	Lamat	11	Pax	4	Muluc	12	Pax	5	Oc	13	Pax
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2	Cimi	9	Cumku	3	Manik		10	Cumku	4	Lamat	11	Cumku	5	Muluc	12	Cumku	6	Oc	13	Cumku
9	Cimi	4	Pop	10	Manik		5	Pop	11	Lamat	6	Pop	12	Muluc	7	Pop	13	Oc	8	Pop
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5	Cimi	4	Xul	6	Manik		5	Xul	7	Lamat	6	Xul	8	Muluc	7	Xul	9	Oc	8	Xul
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13	Cimi	4	Chen	1	Manik		5	Chen	2	Lamat	6	Chen	3	Muluc	7	Chen	4	Oc	8	Chen
7	Cimi	4	Yax	8	Manik		5	Yax	9	Lamat	6	Yax	10	Muluc	7	Yax	11	Oc	8	Yax
1	Cimi	4	Zac	2	Manik		5	Zac	3	Lamat	6	Zac	4	Muluc	7	Zac	5	Oc	8	Zac
8	Cimi	4	Ceh	9	Manik		5	Ceh	10	Lamat	6	Ceh	11	Muluc	7	Ceh	12	Oc	8	Ceh
2	Cimi	4	Mac	3	Manik		5	Mac	4	Lamat	6	Mac	5	Muluc	7	Mac	6	Oc	8	Mac
9	Cimi	4	Kankin	10	Manik		5	Kankin	11	Lamat	6	Kankin	12	Muluc	7	Kankin	13	Oc	8	Kankin
3	Cimi	4	Muan	4	Manik		5	Muan	5	Lamat	6	Muan	6	Muluc	7	Muan	7	Oc	8	Muan
10	Cimi	4	Pax	11	Manik		5	Pax	12	Lamat	6	Pax	13	Muluc	7	Pax	1	Oc	8	Pax
4	Cimi	4	Kayab	5	Manik		5	Kayab	6	Lamat	6	Kayab	7	Muluc	7	Kayab	8	Oc	8	Kayab
11	Cimi	4	Cumku	12	Manik		5	Cumku	13	Lamat	6	Cumku	1	Muluc	7	Cumku	2	Oc	8	Cumku
5	Cimi	4	uayeb	6	Manik		5	uayeb	7	Lamat	1	Pop	8	Muluc	2	Pop	9	Oc	3	Pop
12	Cimi	19	Pop	13	Manik	end of		Pop	1	Lamat	1	Uo	2	Muluc	2	Uo	3	Oc	3	Uo

11				12				13				14				15			
4	Chuen	14	Ceh	5	Eb	15	Ceh	6	Ben	16	Ceh	7	Ix	17	Ceh	8	Men	18	Ceh
11	Chuen	14	Mac	12	Eb	15	Mac	13	Ben	16	Mac	1	Ix	17	Mac	2	Men	18	Mac
5	Chuen	14	Kankin	6	Eb	15	Kankin	7	Ben	16	Kankin	8	Ix	17	Kankin	9	Men	18	Kankin
12	Chuen	14	Muan	13	Eb	15	Muan	1	Ben	16	Muan	2	Ix	17	Muan	3	Men	18	Muan
6	Chuen	14	Pax	7	Eb	15	Pax	8	Ben	16	Pax	9	Ix	17	Pax	10	Men	18	Pax
13	Chuen	14	Kayab	1	Eb	15	Kayab	2	Ben	16	Kayab	3	Ix	17	Kayab	4	Men	18	Kayab
7	Chuen	14	Cumku	8	Eb	15	Cumku	9	Ben	16	Cumku	10	Ix	17	Cumku	11	Men	18	Cumku
1	Chuen	9	Pop	2	Eb	10	Pop	3	Ben	11	Pop	4	Ix	12	Pop	5	Men	13	Pop
8	Chuen	9	Uo	9	Eb	10	Uo	10	Ben	11	Uo	11	Ix	12	Uo	12	Men	13	Uo
2	Chuen	9	Zip	3	Eb	10	Zip	4	Ben	11	Zip	5	Ix	12	Zip	6	Men	13	Zip
9	Chuen	9	Zotz	10	Eb	10	Zotz	11	Ben	11	Zotz	12	Ix	12	Zotz	13	Men	13	Zotz
3	Chuen	9	Tzec	4	Eb	10	Tzec	5	Ben	11	Tzec	6	Ix	12	Tzec	7	Men	13	Tzec
10	Chuen	9	Xul	11	Eb	10	Xul	12	Ben	11	Xul	13	Ix	12	Xul	1	Men	13	Xul
4	Chuen	9	Yaxkin	5	Eb	10	Yaxkin	6	Ben	11	Yaxkin	7	Ix	12	Yaxkin	8	Men	13	Yaxkin
11	Chuen	9	Mol	12	Eb	10	Mol	13	Ben	11	Mol	1	Ix	12	Mol	2	Men	13	Mol
5	Chuen	9	Chen	6	Eb	10	Chen	7	Ben	11	Chen	8	Ix	12	Chen	9	Men	13	Chen
12	Chuen	9	Yax	13	Eb	10	Yax	1	Ben	11	Yax	2	Ix	12	Yax	3	Men	13	Yax
6	Chuen	9	Zac	7	Eb	10	Zac	8	Ben	11	Zac	9	Ix	12	Zac	10	Men	13	Zac
13	Chuen	9	Ceh	1	Eb	10	Ceh	2	Ben	11	Ceh	3	Ix	12	Ceh	4	Men	13	Ceh
7	Chuen	9	Mac	8	Eb	10	Mac	9	Ben	11	Mac	10	Ix	12	Mac	11	Men	13	Mac
1	Chuen	9	Kankin	2	Eb	10	Kankin	3	Ben	11	Kankin	4	Ix	12	Kankin	5	Men	13	Kankin
8	Chuen	9	Muan	9	Eb	10	Muan	10	Ben	11	Muan	11	Ix	12	Muan	12	Men	13	Muan
2	Chuen	9	Pax	3	Eb	10	Pax	4	Ben	11	Pax	5	Ix	12	Pax	6	Men	13	Pax
9	Chuen	9	Kayab	10	Eb	10	Kayab	11	Ben	11	Kayab	12	Ix	12	Kayab	13	Men	13	Kayab
3	Chuen	9	Cumku	4	Eb	10	Cumku	5	Ben	11	Cumku	6	Ix	12	Cumku	7	Men	13	Cumku
10	Chuen	4	Pop	11	Eb	5	Pop	12	Ben	6	Pop	13	Ix	7	Pop	1	Men	8	Pop
4	Chuen	4	Uo	5	Eb	5	Uo	6	Ben	6	Uo	7	Ix	7	Uo	8	Men	8	Uo

16				17				18				19				20			
9	Cib	19	Ceh	10	Caban	end of	Ceh	11	Etz'nab	1	Mac	12	Cauac	2	Mac	13	Ahau	3	Mac
3	Cib	19	Mac	4	Caban	end of	Mac	5	Etz'nab	1	Kankin	6	Cauac	2	Kankin	7	Ahau	3	Kankin
10	Cib	19	Kankin	11	Caban	end of	Kankin	12	Etz'nab	1	Muan	13	Cauac	2	Muan	1	Ahau	3	Muan
4	Cib	19	Muan	5	Caban	end of	Muan	6	Etz'nab	1	Pax	7	Cauac	2	Pax	8	Ahau	3	Pax
11	Cib	19	Pax	12	Caban	end of	Pax	13	Etz'nab	1	Kayab	1	Cauac	2	Kayab	2	Ahau	3	Kayab
5	Cib	19	Kayab	6	Caban	end of	Kayab	7	Etz'nab	1	Cumku	8	Cauac	2	Cumku	9	Ahau	3	Cumku
12	Cib	19	Cumku	13	Caban	end of	Cumku	1	Etz'nab	1	uayeb	2	Cauac	2	uayeb	3	Ahau	3	uayeb
6	Cib	14	Pop	7	Caban	15	Pop	8	Etz'nab	16	Pop	9	Cauac	17	Pop	10	Ahau	18	Pop
13	Cib	14	Uo	1	Caban	15	Uo	2	Etz'nab	16	Uo	3	Cauac	17	Uo	4	Ahau	18	Uo
7	Cib	14	Zip	8	Caban	15	Zip	9	Etz'nab	16	Zip	10	Cauac	17	Zip	11	Ahau	18	Zip
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2	Cib	14	Xul	3	Caban	15	Xul	4	Etz'nab	16	Xul	5	Cauac	17	Xul	6	Ahau	18	Xul
9	Cib	14	Yaxkin	10	Caban	15	Yaxkin	11	Etz'nab	16	Yaxkin	12	Cauac	17	Yaxkin	13	Ahau	18	Yaxkin
3	Cib	14	Mol	4	Caban	15	Mol	5	Etz'nab	16	Mol	6	Cauac	17	Mol	7	Ahau	18	Mol
10	Cib	14	Chen	11	Caban	15	Chen	12	Etz'nab	16	Chen	13	Cauac	17	Chen	1	Ahau	18	Chen
4	Cib	14	Yax	5	Caban	15	Yax	6	Etz'nab	16	Yax	7	Cauac	17	Yax	8	Ahau	18	Yax
11	Cib	14	Zac	12	Caban	15	Zac	13	Etz'nab	16	Zac	1	Cauac	17	Zac	2	Ahau	18	Zac
5	Cib	14	Ceh	6	Caban	15	Ceh	7	Etz'nab	16	Ceh	8	Cauac	17	Ceh	9	Ahau	18	Ceh
12	Cib	14	Mac	13	Caban	15	Mac	1	Etz'nab	16	Mac	2	Cauac	17	Mac	3	Ahau	18	Mac
6	Cib	14	Kankin	7	Caban	15	Kankin	8	Etz'nab	16	Kankin	9	Cauac	17	Kankin	10	Ahau	18	Kankin
13	Cib	14	Muan	1	Caban	15	Muan	2	Etz'nab	16	Muan	3	Cauac	17	Muan	4	Ahau	18	Muan
7	Cib	14	Pax	8	Caban	15	Pax	9	Etz'nab	16	Pax	10	Cauac	17	Pax	11	Ahau	18	Pax
1	Cib	14	Kayab	2	Caban	15	Kayab	3	Etz'nab	16	Kayab	4	Cauac	17	Kayab	5	Ahau	18	Kayab
8	Cib	14	Cumku	9	Caban	15	Cumku	10	Etz'nab	16	Cumku	11	Cauac	17	Cumku	12	Ahau	18	Cumku
2	Cib	9	Pop	3	Caban	10	Pop	4	Etz'nab	11	Pop	5	Cauac	12	Pop	6	Ahau	13	Pop
9	Cib	9	Uo	10	Caban	10	Uo	11	Etz'nab	11	Uo	12	Cauac	12	Uo	13	Ahau	13	Uo

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Index

Plate 1. (Ch. 8) A view to the east along the approach to the entrance of the temple of Amun-Re at Meroe far to the south: The picture, taken the day before the winter solstice, clearly shows that Amun-Re's temple was oriented to the winter solstice sunrise, interesting support for the view that the similar alignments at Karnak were intentional. Photo by J. Robertson.

Plate 2. (Ch. 9) Persepolis, the capitol of Darius I: The columns of the royal palace are aligned so that the shadows of each row of columns strikes the next row at the summer solstice. Photo by W. Dutz for D.H. Kelley.

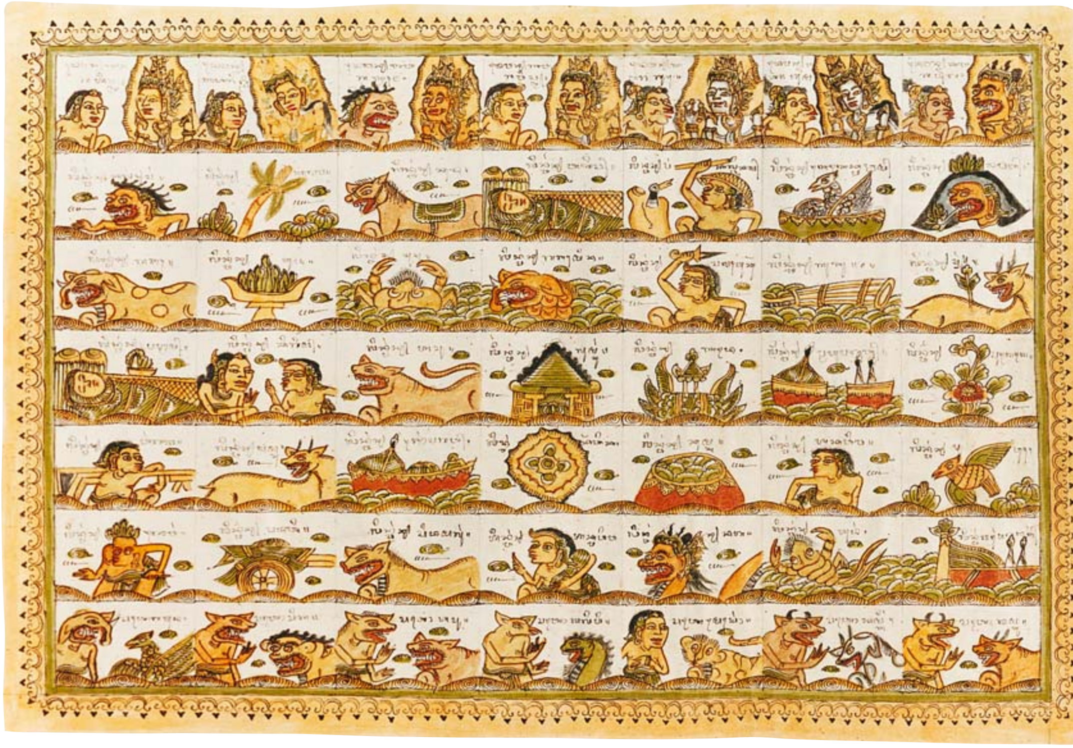

Plate 3. (Ch. 9) A *pelelintangan*, a diagram to show the fortune associated with a 35-day sequence created by the combination of the 7-day week and the 5-day week: The diagram has 49 divisions, the seven across the top associated with the seven days of the week, each showing, ideally, a god, a tree, a bird, a shadow puppet character, and an animal, each associated with a particular day and a particular planet. Across the bottom are seven animals, identified as heads of a seven-headed demon and associated with the days of the 7-day week. Courtesy, Norman Totten.

Plate 4. (Ch. 10) The most complex mandala we have seen is that of Garbhadata or Taizoukai mandala published with a preliminary commentary by Nishiyama (1999). This Chinese Buddhist mandala is said to have been brought to Japan from China in 806 A.D. Over 300 deities seem to be represented. The ruling deities of the 28 lunar mansions appear, as do the nine planetary lords and the 12 signs of the zodiac. A comet (*ketu*) and meteor (*Nirghataketu*) are also represented, generically (recall that in India *Ketu* is a deity, one of the nine planets). Original in Toji Temple, Kyoto, Japan. Photograph by Dr. G. Newlands of a silk cloth version produced by Fukagawa Fudou, courtesy, M. Nishiyama.

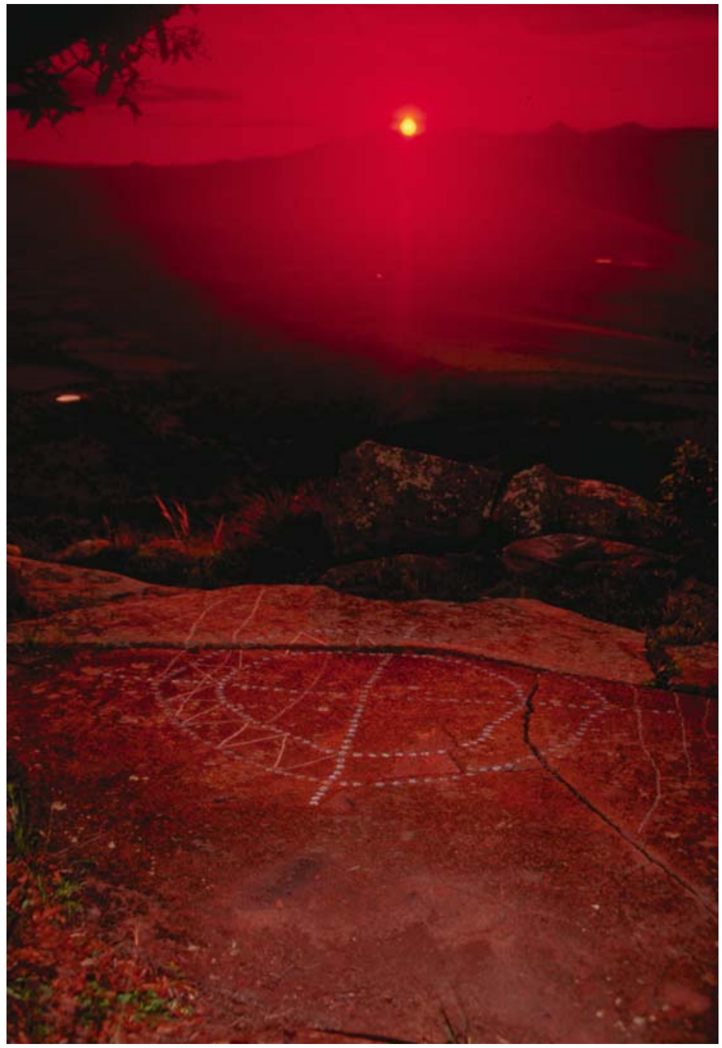

Plate 5. (Ch. 12) The roadway from the Sun Temple, Alta Vista, struck by the rising Sun, taken at the pecked cross overlooking the site within one day of summer solstice, 2000. Photo by Daniel Zborover for D.H. Kelley.

Plate 6. (Ch. 13) Shadow-play spiral painting at Burro Flats, California, approximately two weeks after winter solstice. Photo by E.F. Milone.

Plate 7. (Ch. 14) Ollantaytambo view at June solstice. Photo courtesy of William Sullivan.

Plate 8. (Ch. 15) "This is dawn": A copy of the original artwork with a modern cosmic turtle, by Christine Sioui Wawanaloath. This is an artistic rendering of various symbols of American Indian groups, based partly on sacred traditional Algonquin drawings to which she has access and partly on her perceptions and intuitions. Courtesy of the artist, Christine Sioui Wawanoloath.