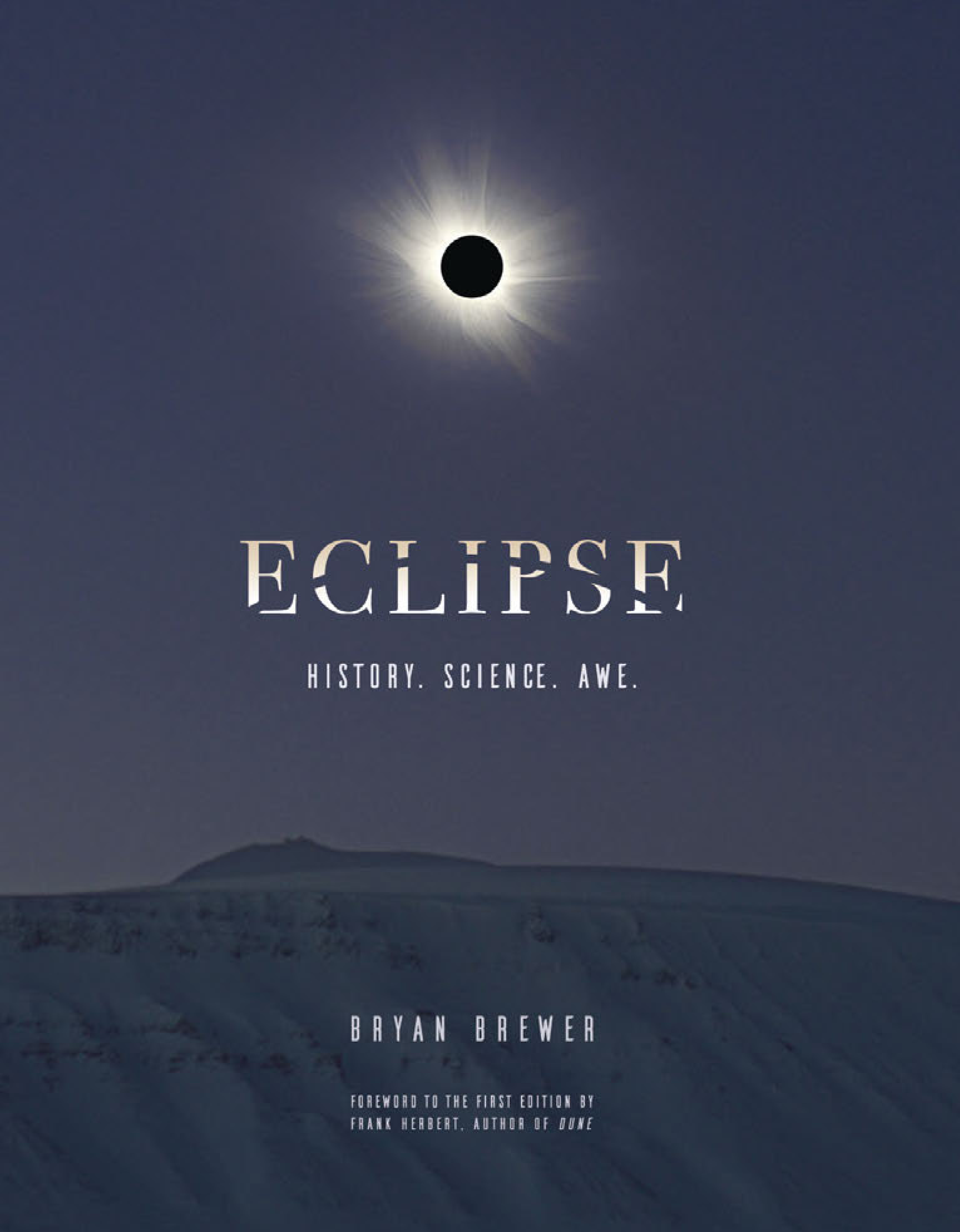

ECLIPSE

HISTORY. SCIENCE. AWE.

BRYAN BREWER

FOREWORD TO THE FIRST EDITION BY
FRANK HERBERT, AUTHOR OF *DUNE*

ECLIPSE

HISTORY. SCIENCE. AWE.

THIRD EDITION

BRYAN BREWER

earth view
SEATTLE WASHINGTON

ECLIPSE
Third Edition

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To my Grandson, Logan

See the world through the eyes of your inner child.
The eyes that sparkle in awe and amazement as they see
love, magic and mystery in the most ordinary things.

– Henna Sohail

TABLE OF CONTENTS

INTRODUCTION

CHAPTER 1

CHAPTER 2

CHAPTER 3

EPILOGUE

PREFACE

When people ask me how I first came to write *ECLIPSE*, I tell them it's a classic case of "I couldn't find a good book on the subject so I wrote one." In the late seventies I had the idea of organizing a reunion of some college classmates, and when I learned that a total solar eclipse was going to be visible in the Pacific Northwest on Feb. 26, 1979, I knew we all had to be there to celebrate this cosmic spectacle.

I started researching eclipses, and all of the books I found were either sorely outdated or far too technical. There was no popular treatment of the subject. So, as a fledgling writer, I wrote my first book, and published it several months before the event. I gave numerous press interviews and media appearances, and discovered how much I enjoyed helping people prepare for this "once-in-a-lifetime" experience.

I was fortunate to be at a viewing site on a hill in southern Washington where the winter clouds parted just before totality, and blessed us with a beautiful view of the corona. It was an awesome sight. It was an unforgettable experience. And it was over in just a matter of minutes. "Wow," I thought, "I want to see that again!" And I have, three times since then: Brazil (1994), the Caribbean (1998), and Germany (1999). Alas, I was clouded out in Hawaii (1991), for which I had issued the Second Edition of *ECLIPSE*.

Now in 2017 – as America prepares for its first coast-to-coast total solar eclipse in 99 years – I am especially excited to share my enthusiasm about the August 21, 2017 event. The vision of the Sun's corona is like nothing else in its ability to inspire a sense of awe. And in this edition of the book, I write about the new "science of awe" and how researchers are finding surprising benefits of this once-neglected emotion. (See "The Experience of Awe" at the end of Chapter 3.)

Throughout the years, so many people – too numerous to mention (or remember!) – have helped me with this book. I am especially grateful to the late Frank Herbert, who graciously wrote the Foreword to the First Edition. For this Third Edition, I would like to thank the following folks: Marc Williams, for his support and belief in this project; Fred Espenak, for his dedication to providing eclipse data to the world, and excellent photos for this book; Woody Sullivan, for his friendship and wise counsel; the design and production team (Greg, Adrienne, Michelle, Samantha, Michael, and others) for putting up with me as we have shepherded this book through to completion; Dennis Schatz, for his encouragement and review; and my sweetheart Diana Wiley, for her steadfast love, affection, and belief in me.

Bryan Brewer
Seattle, Washington
April 2017

FOREWORD

The starry heavens are as much yours to enjoy as they are an astronomer's, which is a basic message of this informative book by Bryan Brewer. When we look outward with awe and wonder at the marvels awaiting us in an unlimited universe, it is well to recall what he tells us here about the roots of our ancient fascination with the sky. Even if you are someone merely making a wish upon the vision of a bit of cosmic rock burning itself out in earth's atmosphere, you are in tune with that unbroken past.

Eclipses, those positive markers of our relative movement through the void, make a superb focal point for our outward vision. There is a direct line between Alan Shepard driving a golf ball across the Moon's surface and the Celtic stonemasons whose stellar observatory still stands on the Salisbury plain. From Stonehenge to that first landing on the Moon, the human statement is plain to read: If it moves, we want to know how and why.

When you stand in the shadow of those bluestone menhirs at Stonehenge to mark the moment of the summer solstice, it is not difficult to feel an affinity with those early astronomers. The archaeological evidence that this carefully arranged series of stone circles was also used to predict eclipses appears to be conclusive. They accomplished much with little beyond their own muscles and intellectual inspiration.

That is likely to be the view distant future generations will take when they consider today's accomplishments. We are always primitives where our own far-off descendants are concerned.

Let the computer-written ephemeris tell you then where and when the next eclipse will occur; that prediction is not different in kind from what the Celtic astronomers told their people.

It is, however, different in quality. It is doubtful that you will perform some esoteric ritual to force the dragon (or snake or worm) to disgorge the Sun.

Mysteries remain, though, and we remake our mythology with increasing frequency, partly because we are still creatures of this planet and caught by a racial compulsion to penetrate beyond the regions that we have already mapped.

I like to think of Bryan Brewer's book as a map of the influences and rhythms contained in eclipses. It is well to remember that more than half the Earth's human population still uses astrology as a guide in the making of decisions. There is a possibility that a kernel of truth remains at the core of this ancient belief. We are Earth creatures. It would be remarkable if the rhythms that influence this planet where we evolved produced no effects on our flesh comparable to the influences upon our religions and philosophies. When we look at the heavens, we look at a cosmic clock that has marked every evolutionary development upon this mundane surface. That clock is still ticking, as the eclipse reminds us.

Frank Herbert, author of *Dune*
(1920-1986)
Port Townsend, Washington
October 1978

INTRODUCTION

Into the Mouth of the Dragon

Above: *EYE SAFETY is critical. Don't look at the partial phases of the eclipse without approved eye protection, such as the commercially manufactured eclipse glasses shown above. During the brief moments of totality, however, it's OK to look directly at the solar corona without any eye protection and enjoy the beauty of this fleeting spectacle.*

It's Monday morning, August 21, 2017 — the day of the eclipse. You got up early to check the weather, and were glad to see a forecast for clear skies. You have been planning for this event for many months, and now the day has arrived. As you pause to gauge the anticipation of your friends and family who have gathered with you, you start to wonder if all the hype about the eclipse has been overblown. Just as you're asking yourself, "Is it all worth it?", you hear a shout of excitement.

"First contact! The eclipse has begun."

You rush over to where the eclipse viewer has been set up. People are looking at the image of the Sun projected onto a white surface. And sure enough, there on one side of the bright disk, a tiny bit of the Sun has been covered up. You also watch the Sun through your special "eclipse glasses" made with optical grade filter material. The Moon, slowly moving across the sky, is gradually blocking out more and more of the face of the Sun.

The timing of the eclipse was perfect, beginning within several seconds of the exact moment predicted for this location. Your group selected this site in central Oregon months ago. You wanted a place that is both near the center of the eclipse path (for maximum duration of totality) and has the best chances for clear skies. There hasn't been a total solar eclipse visible from the United States (except Hawaii and Alaska) for the last 38 years. And now, in a little less than an hour, all your plans and expectations will come to a climax in this once-in-a-lifetime event.

The feeling of excitement in the air begins to grow. Every few minutes you check the progress of the Moon inching across the image of the Sun. The Sun appears as a smaller and smaller crescent of light.

Above: *The partially eclipsed sun is photographed through broken cloud cover.*

For most of the hour after the beginning of the eclipse you barely notice the decrease in sunlight. But as the time approaches for the beginning of totality, the landscape turns quickly darker. A growing sense of uneasiness seems to stir up twinges of an unspoken, primitive fear in all those present to witness this event.

As the narrow crescent of sunlight starts to disappear, little specks of light hang on for a few seconds more. And then, the dark shadow of the Moon rushes over you at incredible speed. The sky is suddenly dark and the corona surrounding the Sun bursts into view.

Above: *The "diamond ring" effect signals the beginning (and later the end) of totality (Aug. 11, 1999).*

Everything is silent. All eyes are held captive by this breathless spectacle in the sky. The irregular shape of the pearly white corona is spread behind the blackened Moon. Your eyes follow the wispy streamers of light extending out into the unreal darkness of the morning sky.

The sunlight from beyond the shadow casts a reddish glow near the horizon. You look around to notice how strangely things appear in the pale illumination of this eerie light. Birds have stopped singing; plants and animals react as if night has fallen. The sudden darkness seems to bring time and Nature to a quiet halt.

Precious seconds pass as you take in as much as you can of the beauty of these special two minutes in time. It is dark enough to see some stars and possibly a planet or two. Perhaps a few bright red solar prominences rise from the surface of the Sun, these arching flame-like eruptions punctuating the aura of light shining around the dark disk of the Moon. But one thing dominates the sky. The delicate corona – the halo of our Sun – shows its glory for these brief moments, giving you a vision never to be forgotten.

Above: *The delicate light of the solar corona is the crowning glory of the few minutes of totality (August 1, 2008).*

Above: *Thai statue of Rahu, one of two Hindu serpent deities that swallow the Sun causing eclipses. In Vedic astrology, Rahu is associated with the lunar ascending node. Ketu is associated with the descending node.*

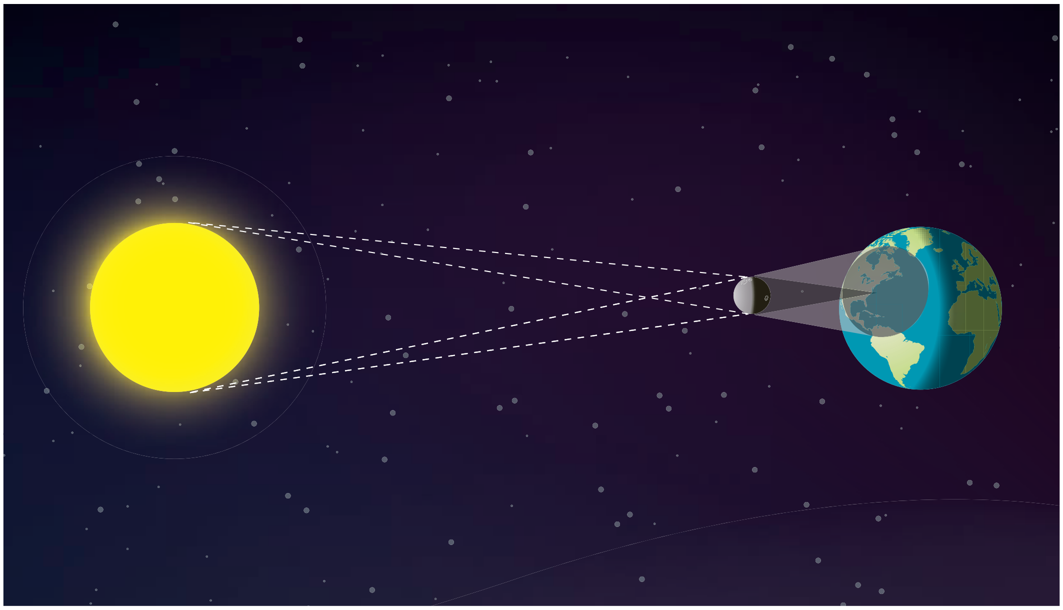
And then, as suddenly as it began, it's over. The shadow passes on and the sunlight returns. The excitement of totality is replaced by a soothing calm. No one talks much at first. As the Moon gradually uncovers more and more of the morning Sun, you are quiet. You want to savor the freshness of the experience, at a loss for words to explain it. Yet somewhere deep inside you have a feeling. An unexpected intimacy with the awesome and relentless forces of Nature has somehow become yours. And you sense that you may never feel quite the same again.

The darkening of the Sun in the middle of the day will always seem an unnatural event. Even today with our scientific understanding of the Earth and space, it still can't help but seem a little frightening to watch the Sun disappear and leave us shrouded in midday darkness. Fortunately, the Sun's "abandoning" of the sky during an eclipse is only temporary; daylight returns to reassure us just as it has done for eclipses throughout the ages. (The word "eclipse" comes from the Greek word meaning "abandonment.") But the Greeks were not the first civilization to leave us with a history of observing eclipses.

The ancient Chinese document Shu Ching contains the earliest record of a solar eclipse. Most historians agree that the date was October 22, 2134 BCE, when "the Sun and Moon did not meet harmoniously." The story goes that the two royal astronomers, Hsi and Ho, had neglected their duties and failed to predict the event. Widespread Oriental belief held that an eclipse was caused by an invisible dragon devouring the Sun. Great noise and commotion (drummers drumming, archers shooting arrows into the sky, and the like) were customarily produced to frighten away the dragon and restore daylight. When this eclipse took place, the emperor was caught unprepared. Even though the Sun returned, the angry ruler ordered the astronomers beheaded!

The people of many cultures have believed that an eclipse is an omen of some natural disaster or the downfall of a ruler. During eclipses in India people immerse themselves in water up to their necks, believing this act of worship will help the Sun and Moon defend themselves against the dragon. In Japan, the custom is to cover wells during an eclipse to prevent poison from dropping into them from the darkened sky. And as recently as the 19th century, the Chinese Imperial Navy fired its ceremonial guns during an eclipse to scare off the invisible dragon.

This ominous view of eclipses is not the only one. In Tahiti, for example, eclipses have been interpreted as the lovemaking of the Sun and the Moon. Even to this day, the Eskimos, Aleuts, and Tlingits of Arctic America believe an eclipse shows a divine providence: the Sun and the Moon temporarily leave their places in the sky and check to see that things are going all right on Earth. But regardless of the meaning given to them, eclipses will continue to occur, always obeying the regular timetables of celestial motions.



Left: *A solar eclipse occurs when the Moon passes directly in front of the Sun and casts its shadow on the surface of the Earth.*

BASIC ECLIPSE FACTS

The Moon travels in its orbit around the Earth once a month. An eclipse of the Sun (or solar eclipse) takes place whenever the new Moon, passing right between the Sun and the Earth, casts its shadow on our planet's surface. (This doesn't happen every month; usually the Moon passes slightly above or below the line between the Sun and the Earth.) From anywhere within the dark cone of the complete shadow, called the *umbra* (from Latin for "shade"), the Sun will appear in total eclipse. When viewed from the area covered by the larger cone of the *penumbra* (literally, "almost shade"), the Sun is seen in partial eclipse.

The partial phases of a solar eclipse are normally visible from a broad area of the Earth as wide as 5,000 miles. A total eclipse, on the other hand, can be seen only from a narrow band called "the path of totality." This path, sometimes as wide as 200 miles, covers only about one-half of one percent of the Earth's surface. And because there are fewer than 70 total eclipses per century, the chance to see one is for most of us a once-in-a-lifetime event.

It is remarkable that total solar eclipses even occur at all. They are possible because the Sun and the Moon appear from Earth to be about the same size in the sky. The Sun, whose diameter is 400 times that of the Moon, happens to be about 400 times as far away from the Earth. This condition permits the Moon to just barely cover up the Sun. In fact, if the Moon's diameter (2,160 miles) were just 140 miles less, it would not be large enough to ever completely cover the Sun: a total solar eclipse could never happen anywhere on Earth!

Fortunately they do occur. Once every year and a half (on the average) Nature permits someplace on Earth a view of the beautiful corona surrounding the Sun. For ancient people this spectacle of the sky must have had a forceful effect on their consciousness. From the beginnings of written history humankind has recorded eclipses and attempted to understand them. And now, recent investigations have pushed that history further back in time: the intelligent plan of an ancient stone monument, whose construction began as early as 2400 BCE, shows that it could have been used for eclipse predictions.

CHAPTER ONE

Eclipses Throughout the Ages

Above:
Stonehenge at sunset.

STONEHENGE: Eclipse Computer?

Every year on the first day of summer, the Sun rises at a point that is farther north than on any other day of the year. At the ruins of Stonehenge in England, this solstice sunrise appears on the horizon in direct alignment with the massive heel stone. This is the most outstanding feature of this ancient monument, built during the same era as the Great Pyramid of Egypt. There is little doubt that the builders of Stonehenge used it to mark this special day as the beginning of each year. By counting the number of days between these annual alignments, they could determine the length of the year. This could serve as a practical calendar to mark holidays and seasonal festivals and to ensure the timely planting and harvesting of crops.

But to predict eclipses, knowledge of two other cycles is required. One of these – the length of the lunar month – is easily determined. It is simply the number of days between one full Moon and the next. This cycle of 29½ days is marked at Stonehenge by two rings of 29 and 30 holes, which together average 29½. The other cycle, however, is of an altogether different character: it is a cycle of rotation of two invisible points in space. The evidence shows that the builders of Stonehenge probably discovered this cycle and could have used it to predict eclipses.

These two invisible points in space are called the lunar *nodes* (from the Latin for “knot”). They are the points where the Moon’s orbit, which is tilted at a slight angle, intersects the plane of the Earth’s orbit. It would have taken many decades of watching countless risings and settings of the Moon to figure out the cycle of the lunar nodes. This information – which must have been passed on from generation to generation – is preserved at Stonehenge. All the Moon alignments necessary for determining this cycle are marked by massive stones.

Above: *Aerial view of Stonehenge (2016).*

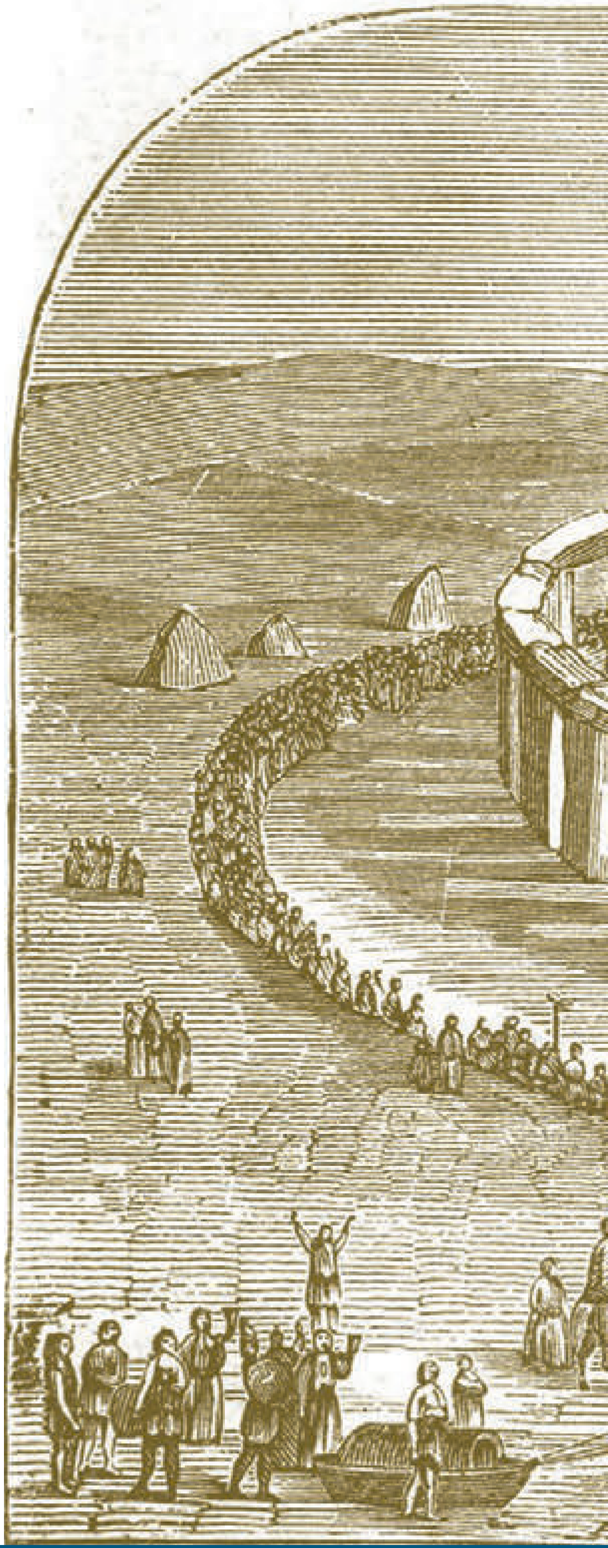
Who were these people who observed this subtle cycle even before the first metal tools were used by humankind? Some have suggested that Stonehenge was built by Druids, but we don't really know much about the builders. We do know that the actual motions of the Sun and the Moon are reflected in the structure of Stonehenge, and we can reason how it may have been used to keep track of these cycles. The number of stones or holes in the ground in the various rings around Stonehenge each represents a certain number of days or years in the cycles. By moving markers (such as stones) around a ring in time with the cycles, the positions of the Sun and Moon – and the two invisible points – can be tracked. (The details of this method are explained on pages 52-53.)

An eclipse can occur only when the Sun is close to being aligned with a node. By using Stonehenge to keep track of the position of the Sun and the nodes, these "danger periods" for eclipses can be predicted. A new (or full) Moon appearing during one of these periods would call for a special vigil to see if the solar (or lunar) eclipse would be visible from Stonehenge. (A lunar eclipse occurs when the full Moon is engulfed in the Earth's shadow; see pages 44-45.) A total solar eclipse would be a rarity. But the law of averages confirms that either a partial solar eclipse or a lunar eclipse can be seen (weather permitting) from the same point on the Earth about once every year.

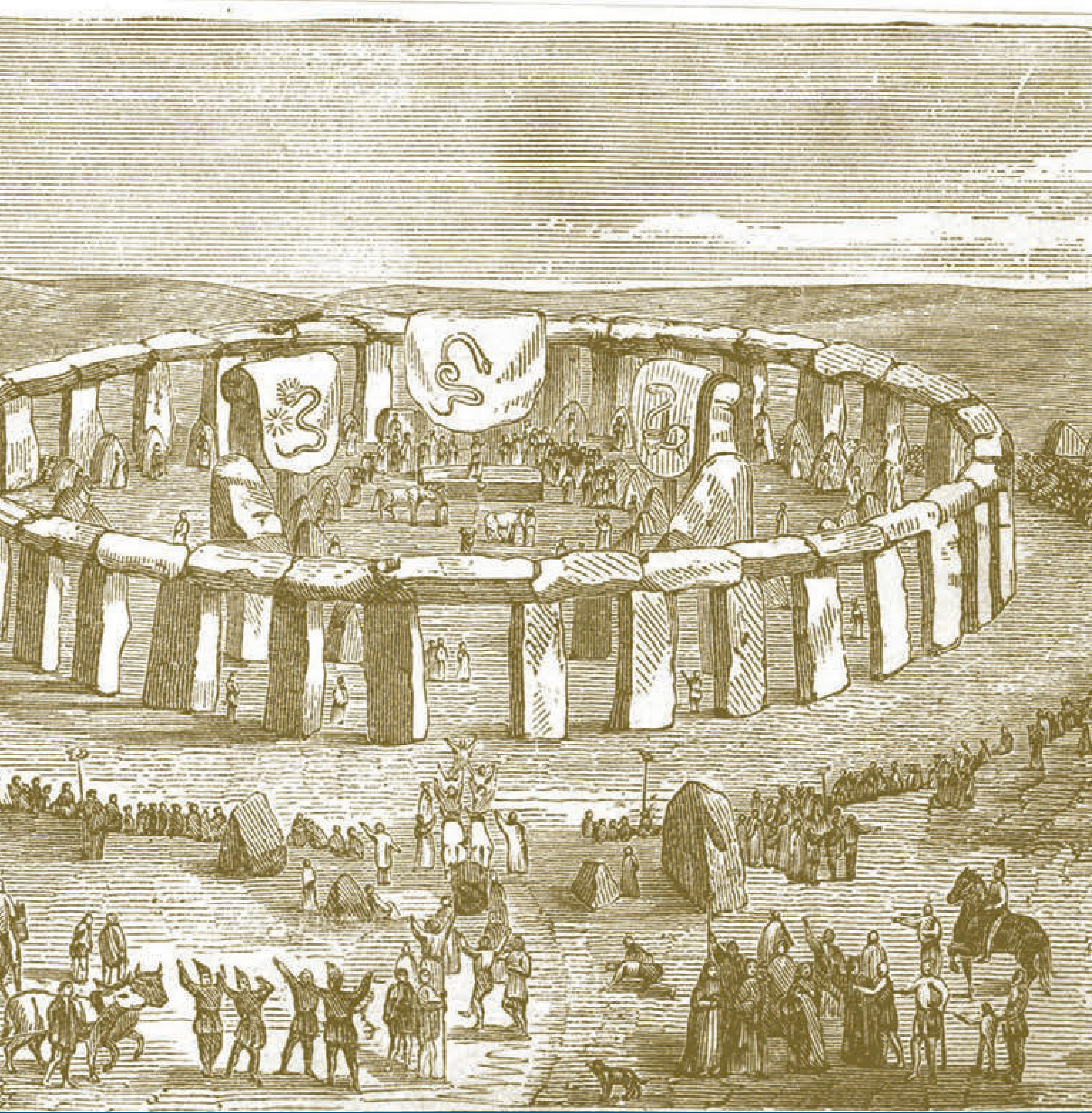
DRAGONS AND SERPENTS: Eclipse Symbols?

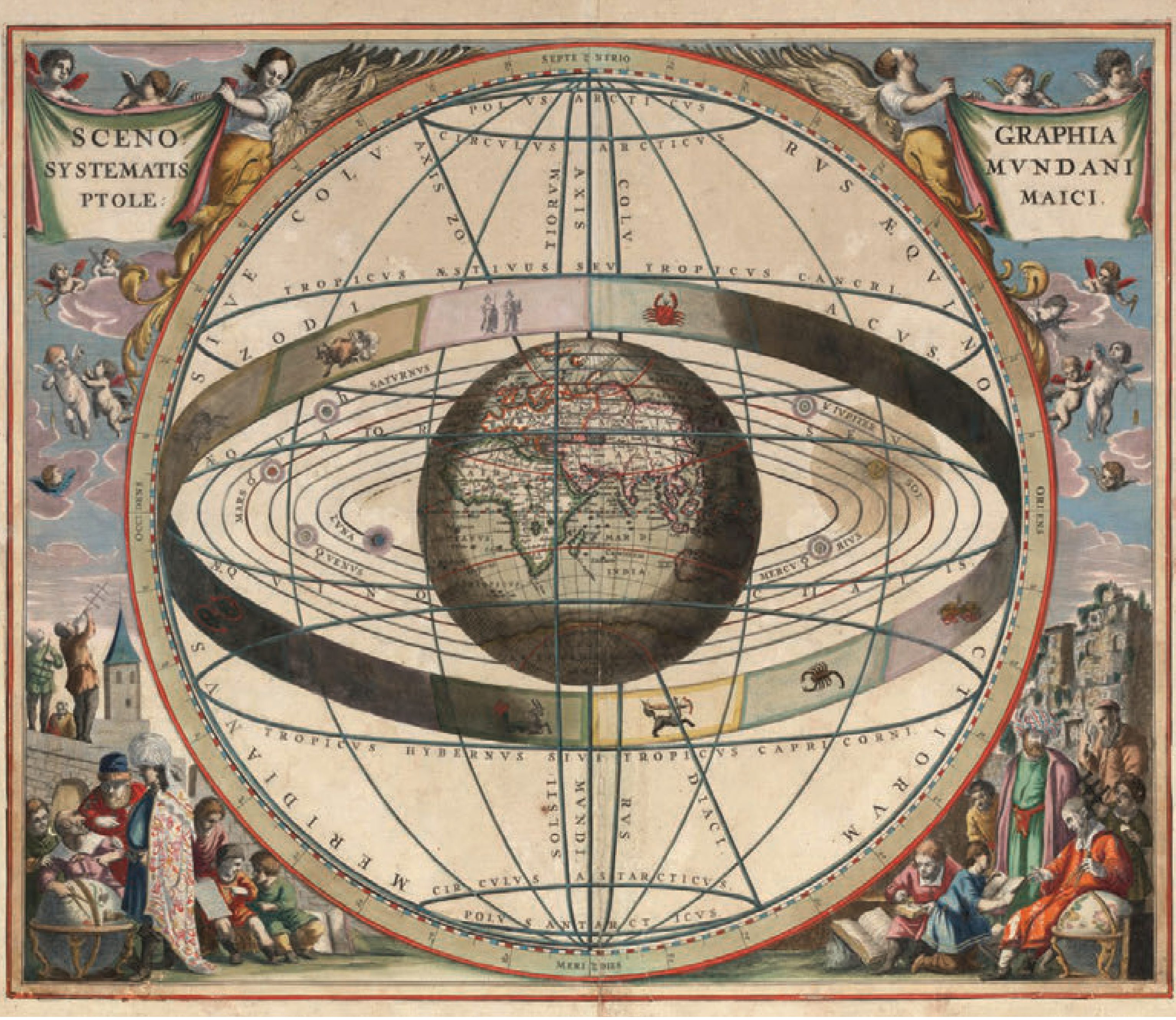
Why would eclipses have been so important to the ancient people of Stonehenge? Perhaps they considered the darkening of the Sun or the Moon a fearsome event – a celestial omen of doom or disaster. Many cultures have interpreted eclipses this way. But the sophistication of the astronomy of Stonehenge suggests that the builders had something different in mind. Their understanding of the solar and lunar cycles must have led to a high regard for the cosmic order. Eclipses may have been seen as affirmations of the regularity of these cycles. Or perhaps the unseen lunar nodes formed an element of their religion as invisible gods capable of eclipsing the brightest objects in the heavens.

The idea that Stonehenge may have been a center for some kind of worship has occurred to many. It is not hard to imagine Neolithic people gathering at a "sacred place" at "sacred times" (such as solstices, equinoxes, and eclipses) to reaffirm their religious beliefs through ritual practices. British antiquarian Dr. William Stukeley, who in 1740 was the first to note the summer solstice alignment at Stonehenge, advanced the notion that the monument was built by Druids to worship the serpent. He claimed that Stonehenge and similar stone circles had been serpent temples, which he called "Dracontia." Could this serpent symbolism be related to eclipses? Recall that the key to the occurrence of eclipses is the position of the lunar nodes. The length of time for the Moon to return to a node (about 27.2 days) astronomers call the *draconic month*. (Draco is the Latin word for "serpent" or "dragon.") Perhaps the mythical serpents of Stonehenge and the legendary dragon that eats the Sun are symbols of the same thing: the invisible presence in time and space that causes eclipses the Sun and the Moon.



Above: *Fanciful illustration of early Stonehenge celebration.*





Above: *Geocentric map of the solar system and zodiac from* Harmonia Macrocosmica *by Andreas Cellarius (1660).*

THE BIRTH OF ASTRONOMY

Whatever the reasons for Stonehenge, they are lost in time; the builders left no written records. During this same period (between 3000 BCE and 2000 BCE), the study of the heavens was developing as a written science in the Middle East. Astronomers in Babylonia and Assyria kept track of time by carefully observing the motions of the Sun and the Moon. They increased the accuracy of their measurements by recording the details of solar and lunar eclipses. As they studied this record of centuries of eclipses, a pattern of repetition began to emerge: eclipses tend to repeat themselves every 18 years, although they recur at different places on the globe. This eclipse cycle, called the *saros*, is used even to this day to make predictions. For example, the August 21, 2017, eclipse is included in saros series No. 145. On August 11, 1999, exactly 18 years and 11⅓ days earlier, a solar eclipse took place. Another solar eclipse will occur on September 2, 2035, again after 18 years and 11⅓ days. (See pages 50-51 for more details on the saros.)

The Babylonian discovery of the saros, important for eclipse predictions, is not the most famous of their contributions to astronomy. As early as 3000 BCE, they originated the division of the sky into the twelve signs of the zodiac, and the names they gave to each sign are still used. Today these names and symbols (the symbols are of unknown origin) are more familiar to the practice of astrology; but in ancient Babylonia, astronomy and astrology were inseparably connected.

Zodiac sign	**Symbol**	**Ancient "ruling planet"**	**Zodiac sign**	**Symbol**	**Ancient "ruling planet"**
Aries	♈	Mars	Libra	♎	Venus
Taurus	♉	Venus	Scorpio	♏	Mars
Gemini	♊	Mercury	Sagittarius	♐	Jupiter
Cancer	♋	Moon	Capricorn	♑	Saturn
Leo	♌	Sun	Aquarius	♒	Saturn
Virgo	♍	Mercury	Pisces	♓	Jupiter

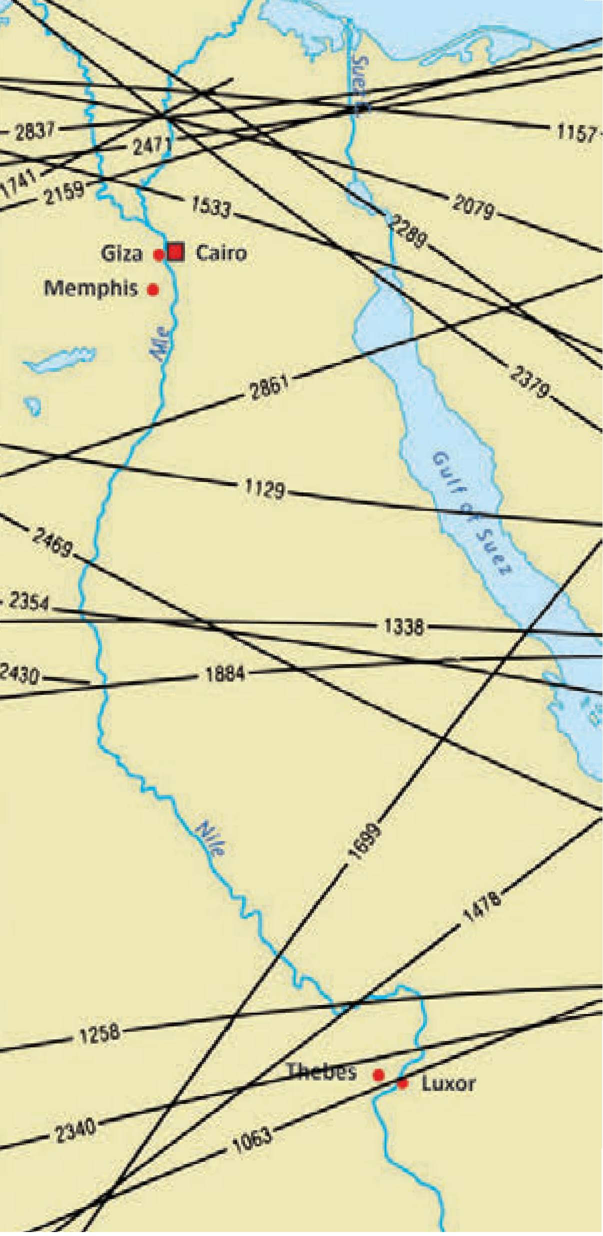
Above: *Detail of the Astronomical Clock in Palazzo Ducale, Venice, Italy.*

The religion of the Babylonians was based on the belief that earthly affairs were influenced by the motions of heavenly bodies. It was the duty of the astrologer-priests to keep watch on the skies and warn of any disasters that might be signaled. They developed an elaborate system of celestial omens to "divine" the future. It seems that the Babylonians were more interested in discerning meaning from the paths of the Sun, the Moon, and the planets across the background of the stars than in discovering the secrets of the physical world around them. They also believed that each sign of the zodiac was influenced by one of the "ruling planets," which imparted its qualities to events related to that sign.

The Babylonians also contributed to the establishment of the seven-day week. As the 12 signs of the zodiac related to the 12 lunar months in a year, the seven days in a week probably come from the quarter phases of the lunar month. Also, ancient astronomers/astrologers recognized seven planets (including the Sun and the Moon); they associated each planet, personified as a celestial deity, with a day of the week. The present names for the days of the week are derived from this same scheme, using Roman or Norse names for the planets and deities.

Above: *Celestial deities from which the names of the days of the week originated (celestial bodies are keyed by number to the illustration).*

Norse deity	**English name for the day of the week**	**Celestial body**	**Spanish name for the day of the week**
	Sunday 1	Sun	Domingo
	Monday 2	Moon	Lunes
Tiw (god of war)	Tuesday 3	Mars	Martes
Woden (chief god)	Wednesday 4	Mercury	Miércoles
Thor (god of thunder)	Thursday 5	Jupiter	Jueves
Freya (goddess of marriage)	Friday 6	Venus	Viernes
	Saturday 7	Saturn	Sábado



THE WINGED SUN OVER EGYPT

As the Babylonians were developing the science of astronomy, the ancient Egyptian civilization was flourishing. Pyramids, temples, and tombs attest to the high state of development of their art and technology. They measured the length of the year by observing the rising of Sirius, the brightest star in the sky. The Great Pyramid at Giza is aligned to the four points of the compass; it was built with a passageway in alignment with the star that was then the pole star, Alpha Draconis. There is no doubt that the Egyptians watched the heavens. The clear skies of the Nile Valley were ideally suited for celestial observation. Yet no one has found a single reference to an eclipse, either of the Sun or the Moon, in all of ancient Egyptian history.

This apparent gap in Egyptian astronomy has puzzled many historians. Was Egypt shortchanged on total solar eclipses? Far from it. The accompanying map shows all the paths of totality across the Nile Valley in the second and third millennia BCE. The solar corona was visible from somewhere in ancient Egypt during this period on an average of once every 75 years. It is hard to imagine that the spectacular recurrence of total solar eclipses could go unrecorded, especially by a culture that so worshipped the Sun.

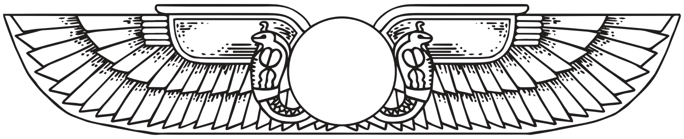
Perhaps the view of totality was preserved in symbolic form. The solar corona has a distinctive appearance during some eclipses. The size and shape of this halo around the Sun varies over a cycle of 11 years. (This is the sunspot cycle explained later in this chapter.) During the minimum phase of this cycle, the brightness of the corona is less intense, but extending to either side are long streamers of light. Because these equatorial streamers are so faint, they are difficult to photograph. Yet in clear skies they are plainly visible to the naked eye during an eclipse.

Above: *Central lines and years (all dates BCE) of total solar eclipse paths across ancient Egypt between the years 3000 BCE and 1000 BCE.*

**Total Solar Eclipses in the Nile Valley
3000 BCE – 1000 BCE**

23 Mar.	**2861** BCE	20 Apr.	**2044** BCE
19 Nov.	**2837** BCE	15 Sep.	**1884** BCE
1 Apr.	**2471** BCE	21 Dec.	**1741** BCE
2 Sep.	**2469** BCE	16 Apr.	**1699** BCE
25 Jul.	**2430** BCE	9 May	**1533** BCE
27 Oct.	**2379** BCE	1 Jun.	**1478** BCE
25 Jun.	**2354** BCE	14 May	**1338** BCE
23 Mar.	**2340** BCE	27 Jul.	**1258** BCE
20 Dec.	**2289** BCE	19 Aug.	**1157** BCE
29 Jun.	**2159** BCE	14 Feb.	**1129** BCE
11 Sep.	**2079** BCE	31 Jul.	**1063** BCE

It is not difficult to see the similarity between these eclipse streamers and the symbolic wings of the Egyptian Sun. The illustration on page 28 shows the corona as seen from the summit of Pikes Peak during the eclipse of July 29, 1878. The long equatorial streamers are well defined. The symbol below is the winged disk of the Sun; it was one of the earliest solar representations in Egypt. It appears above the entrances of many tombs and temples and is said to commemorate the victory of light over darkness. Sometimes the symbol includes the heads of two serpents and the horns of a goat, also solar symbols.



Could this view of the eclipsed Sun be the ancient source of this widespread symbol? English astronomer E. W. Maunder put it this way:

> *… there can be little doubt that the Sun was regarded partly as a symbol, partly as a manifestation of the unseen, unapproachable Divinity. Its light and heat, its power of calling into active exercise the mysterious forces of germination and ripening, and the universality of its influence, all seemed the fit expressions of the yet greater powers which belonged to the Invisible.*
>
> *What happened in a total solar eclipse? For a short time that which seemed so perfect a divine symbol was completely hidden. The light and heat, the two great forms of solar energy, were withdrawn, but something took their place. A mysterious light of mysterious form, unlike any other light, unlike any other single form, was seen in its place. Could they fail to see in this a closer, a more intimate revelation, a more exalted symbolism of the Divine Nature and Presence?*

– Knowledge, vol. XX, p. 9, January 1897

Above Left: *Drawing of the winged solar disk icon found throughout ancient Egyptian sites.*

Above: *An ancient Egyptian pectoral, or brooch hung around the neck and worn on the chest, showing the winged solar disk above the kneeling goddesses Isis and Nepthys in the solar barque (between circa 1300 BCE and circa 1200 BCE).*

Below: *Panoramic view of pyramids from the Giza Plateau.*

Above: *Illustration of a group of Chinese people observing a solar eclipse. The drawing shows the contrast between the curiosity of the astronomers on the right and the reverent behavior of the observers on the left.*

ECLIPSES IN HISTORY AND LITERATURE

Stonehenge, Babylonia, Egypt – each culture developed a unique approach to eclipses. But only the Babylonians discovered the long-range prediction cycle, the saros. An eclipse cycle can also be used to go backward in time. This technique has proven useful to historians in fixing exact dates of past events.

Numerous systems were used in ancient civilizations to keep track of the passage of time. Typically, routine happenings would be recorded as so many days, months, or years after some memorable event such as the crowning of a ruler, a natural catastrophe, or other momentous occasion. Often there would be no indication of exactly when the reference event took place. If an eclipse was described in the record of events, it could be compared with actual eclipses that were known to have happened near the time and place in question. If there were only one eclipse that fit the description, then the date could be fixed with certainty. Many historical chronologies have been verified or compared using this method.

The earliest record of a solar eclipse comes from ancient China. The date of this eclipse, usually given as October 22, 2134 BCE, is not certain. Historians know the account was written sometime within a period of about two hundred years. During that time there were several total eclipses visible in China. The 2134 BCE eclipse is simply the best guess.

The date of an eclipse referred to in the Bible is known for certain: "'And on that day,' says the Lord God, 'I will make the Sun go down at noon, and darken the Earth in broad daylight'." (Amos 8:9) "That day" was June 15, 763 BCE. The date of this eclipse is confirmed by an Assyrian historical record known as the *Eponym Canon*. In Assyria, each year was named after a different ruling official and the year's events were recorded under that name in the *Canon*. Under the year corresponding to 763 BCE, a scribe at Nineveh recorded this eclipse and emphasized the importance of the event by drawing a line across the tablet. These ancient records have allowed historians to use eclipse data to improve the chronology of early Biblical times.

Left: *The winged solar disk icon in this Mesopotamian relief sculpture sits above an outline of the Tree of Life. This icon, which originated in Egypt, was later adopted by the astronomically inclined cultures of Assyria and Babylon, and is thought to represent a total solar eclipse.*

Right: *Battle between Lydians and Medes (585 BCE) halted by a total solar eclipse.*

WARS AND EARTHQUAKES

What is probably the most famous eclipse of ancient times ended a five-year war between the Lydians and the Medes. These two Middle Eastern armies were locked in battle when "the day was turned into night." The sight of this total solar eclipse (the date is fixed as May 28, 585 BCE) was startling enough to cause both nations to stop fighting at once. They agreed to a peace treaty and cemented the bond with a double marriage. The eclipse was predicted by Thales, the celebrated Greek astronomer and philosopher, but the prediction was probably not known to the warring nations.

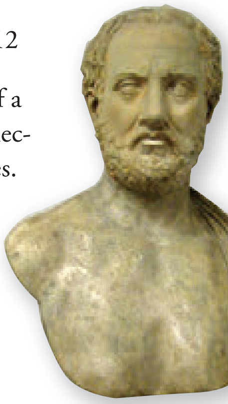
The lunar eclipse of August 27, 413 BCE, had a different effect on the outcome of a battle in the Peloponnesian War. The Athenians were ready to move their forces from Syracuse when the Moon was eclipsed. The soldiers and sailors were frightened by this celestial omen and were reluctant to leave. Their commander, Nicias, consulted the soothsayers and postponed the departure for twenty-seven days. This delay gave an advantage to their enemies, the Syracusans, who then defeated the entire Athenian fleet and army, and killed Nicias.

The spectacle of an eclipse, which had a powerful effect on decisions in battle, was equally impressive to ancient poets. A fragment of a lost poem by Archilochus contains the words:

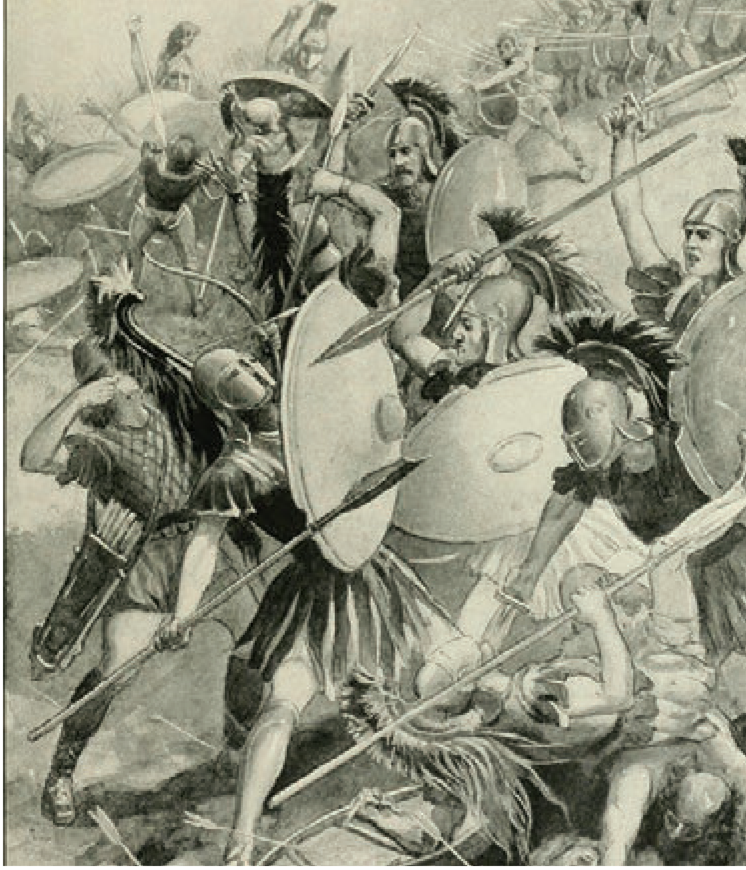
> *Nothing there is beyond hope, nothing that can be sworn impossible, nothing wonderful, since Zeus, father of the Olympians, made night from mid-day, hiding the light of the shining Sun, and sore fear came upon men.*

This has been identified as a description of the total solar eclipse of April 6, 648 BCE. Another eclipse reference (from the Bible) goes like this:

> *And I behold when he had opened the sixth seal, and lo, there was a great earthquake; and the Sun became black as sackcloth of hair, and the Moon became as blood.*
>
> – Revelation 6:12



This compelling passage is only one of a number of literary and historical connections between eclipses and earthquakes. The Greek historian Thucydides, in writing about the Peloponnesian War, remarked about "earthquakes and eclipses of the Sun which came to pass more frequently than had been remembered in former times."



Above: *A change in tactics – influenced by the interpretation of a lunar eclipse on August 27, 413 BCE – affected the outcome of a key battle in the Peloponnesian War between the Syracusans and Athenians.*

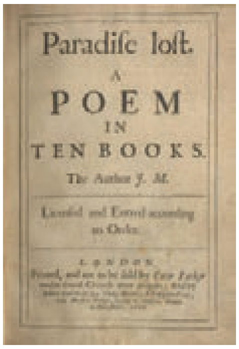
Left: *Bust of Greek historian Thucydides (460 BCE-395 BCE).*

Below: *Bust of Greek poet Archilochus (680 BCE-645 BCE).*

On another occasion he noted "... there was an eclipse of the Sun at the time of a new Moon, and in the early part of the same month an earthquake." Another Greek writer, Phlegon, reported the following events:

> *In the fourth year of the 202nd Olympiad, there was an eclipse of the Sun which was greater than any known before and in the sixth hour of the day it became night; so that stars appeared in the heaven; and a great earthquake that broke out in Bithynia destroyed the greatest part of Nicaea.*

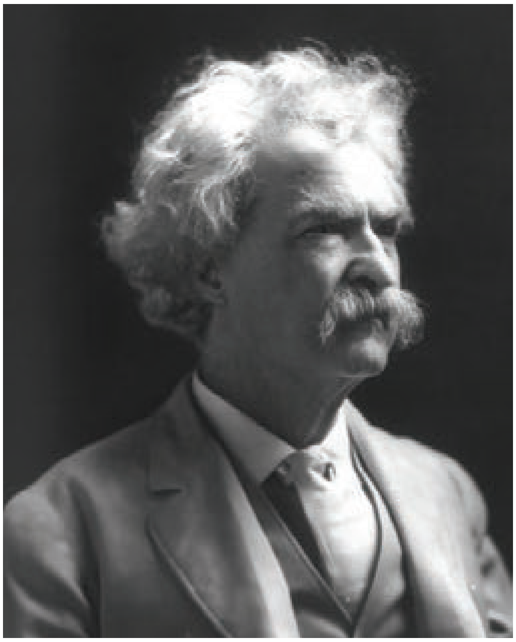
This interest in linking the two types of events by coincidence may have been attempts to derive some order out of the unpredictability of earthquakes, possibly a carryover from the celestial omens of the Babylonians. Oddly enough, this type of coincidence seems to persist. The earthquake in Iran on September 16, 1978, the most devastating one of that year and which killed more than 25,000 people, occurred just 3½ hours before a total lunar eclipse was visible there.



Paradiſe loſt.
A
POEM
IN
TEN BOOKS.
The Author J. M.

Licensed and Entred according
to Order.

LONDON



MYSTIFIED BY THE MOON

These kinds of ominous events have played important parts in human history. When English poet John Milton, in *Paradise Lost*, wrote these lines

> *As when the Sun, new risen,*
> *Looks through the horizontal misty air,*
> *Shorn of his beams, or from behind the Moon,*
> *In dim eclipse, disastrous twilight sheds*
> *On half the nations and with fear of change*
> *Perplexes monarchs*

he may have been thinking of Charlemagne's son, Emperor Louis the Pious. This European ruler was so "perplexed" by the five minutes of totality he witnessed during the eclipse of May 5, 840, that he died (some say of fright) shortly thereafter. The fighting for his throne ended three years later with the historic Treaty of Verdun, which divided Europe into the three major areas we know today as France, Germany, and Italy.

Solar eclipses perplexed the common people as well. Medieval historian Roger of Wendover reported on the total eclipse of May 14, 1230, which occurred early in the morning in Western Europe: "…and it became so dark that the labourers, who had commenced their morning's work, were obliged to leave it, and returned again to their beds to sleep; but in about an hour's time, to the astonishment of many, the Sun regained its usual brightness." This was during the Dark Ages when an understanding of eclipses was not common knowledge.

Mark Twain used this ignorance of eclipses as an element of the plot in *A Connecticut Yankee in King Arthur's Court*. The hero of the novel, Hank Morgan, is mysteriously transported backward in time to Medieval England. He finds himself about to be burned at the stake on a day when he knows a solar eclipse will occur. He "foretells" the event, claiming to have magical powers over the Sun. "The rim of black spread slowly into the Sun's disk,… the multitude groaned with horror to feel the cold uncanny night breezes… and see the stars come out…" Morgan promises to restore the daylight in exchange for his freedom. King Arthur agrees and, of course, the Sun returns. Twain gives the date of the eclipse as June 21, 528; this, however, is literary fiction. No such eclipse took place on or near that date.

Top Left: *Cover of* Paradise Lost*, which contains a passage describing the supposed ill effects of an eclipse.*

Top Right: *English poet John Milton (1608-1674), author of* Paradise Lost.

Middle: *Emperor Louis the Pious (778-840) is said to have died from fright a month after viewing a total solar eclipse on May 5, 840.*

Left: *Mark Twain (1835-1910), whose novel* A Connecticut Yankee in King Arthur's Court *features a plot device involving the prediction of total solar eclipse.*

Above: *Terrified Jamaicans plead with Columbus to restore the eclipsed Moon.*

A similar sort of deception was actually used by Christopher Columbus during his fourth voyage to the Americas. In 1503, he found himself stranded on the island of Jamaica, his ships damaged beyond repair and his provisions running low. At first he and his crew were able to get food from the natives in trade for baubles and trinkets. But as months passed without rescue, the Jamaicans finally refused to supply any more food. Faced with the prospect of starvation, the Italian explorer conceived an ingenious plan.

Columbus knew from his navigational tables that a total eclipse of the Moon would occur on February 29, 1504. He arranged a meeting with the natives that evening to coincide with the beginning of the eclipse. He announced that because God didn't like the way the natives were treating him and his crew, the Almighty had decided to remove the Moon as a sign of his displeasure! Columbus timed his theatrics precisely; no sooner had he proclaimed the Moon's disappearance than the Earth's shadow began to steal across the face of the full Moon.

The natives were terrified. As the light of the Moon faded they pleaded with Columbus to restore it; they would give him all the food he wanted if he would bring back the Moon. Columbus told them he would have to retire to confer with God, which in this case was an hourglass timing the eclipse. Just before the end of the total phase he announced that God had pardoned them and would allow the Moon to return to its place in the sky. And as Columbus knew it would, the Moon reappeared. The grateful natives resumed the supply of food, and Columbus and his crew were eventually rescued and returned to Europe.

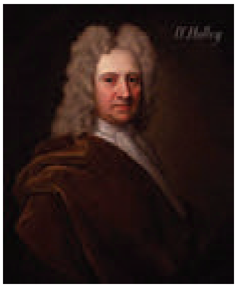
THE SCIENCE OF PREDICTION

Today's astronomers are able to predict the precise time and location of solar eclipses. With advance notice of the event and a higher level of scientific understanding among people, there is no need for anyone to be frightened by what should be a marvelous experience of the beauty of Nature. In fact, many people make plans to travel to locations in the path of the Moon's shadow just to witness the spectacle of a total solar eclipse. Astronomers at the U. S. Naval Observatory in Washington, D. C., and at NASA's Goddard Spaceflight Center process the data and publish predictions years in advance for all eclipses. According to the astronomers who maintain the computer programs for eclipses, the prediction of the path of totality is accurate to within one or two miles and the timing of the eclipse to within a few seconds.

Eclipse predictions have not always been that accurate. Stonehenge could be used to forecast the day of an eclipse, but not the specific time or place. The ancient Chinese, Babylonians, and Greeks made improvements, but it was not until the 17th century AD, after Copernicus had shown that the Sun is at the center of the solar system and Newton had formulated the laws of gravity, that eclipse predictions achieved modern accuracy. The actual motion of the Moon is fraught with numerous small disturbances and discrepancies. In 1693 British astronomer Edmond Halley (of comet fame) was the first to notice a small but steady change in the Moon's motion called *secular acceleration*. This simply means that the Moon is slowly gaining speed in its orbit. Modern astronomers use ancient eclipse records, some several thousand years old, to determine the value of this change.

Above: *Nicolaus Copernicus (1473-1543) posited the heliocentric model of the solar system, which laid the foundation for later eclipse prediction calculations.*

Below: *17th century astronomer Hevelius observing a solar eclipse by projection into a darkened room (from his* Machina Coelestis*, 1673).*



Left: *British astronomer Edmond Halley (1656-1742), in addition to making his famous comet prediction, contributed to the science of eclipse predictions.*

CANON

DER

FINSTERNISSE

VON

Hofrath Prof. TH. Ritter v. OPPOLZER,

HERAUSGEGEBEN VON DER

MATHEMATISCH-NATURWISSENSCHAFTLICHEN CLASSE

DER

KAISERLICHEN AKADEMIE DER WISSENSCHAFTEN

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LII. BAND IHRER DENKSCHRIFTEN.

MIT 160 TAFELN.

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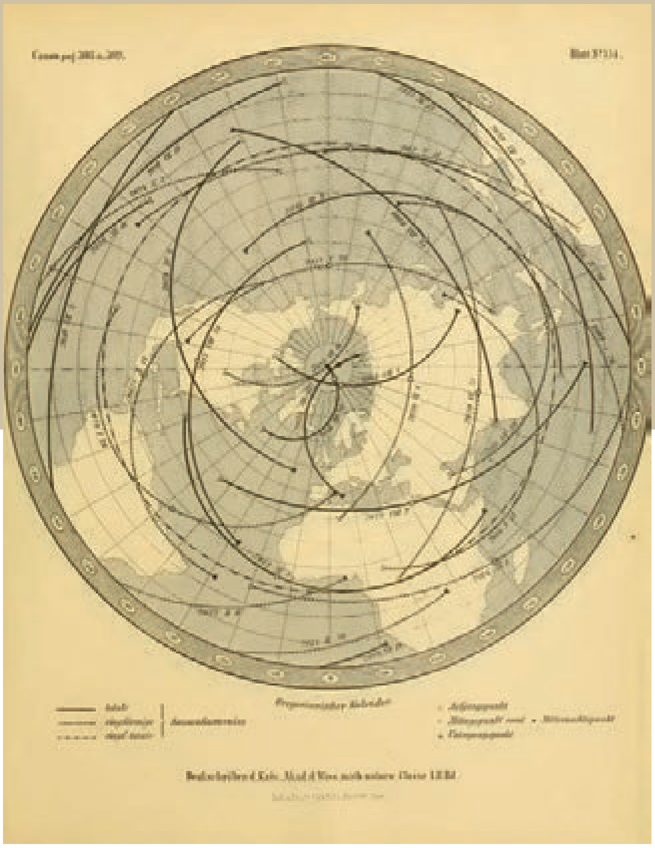
AUS DER KAISERLICH-KÖNIGLICHEN HOF- UND STAATSDRUCKEREI

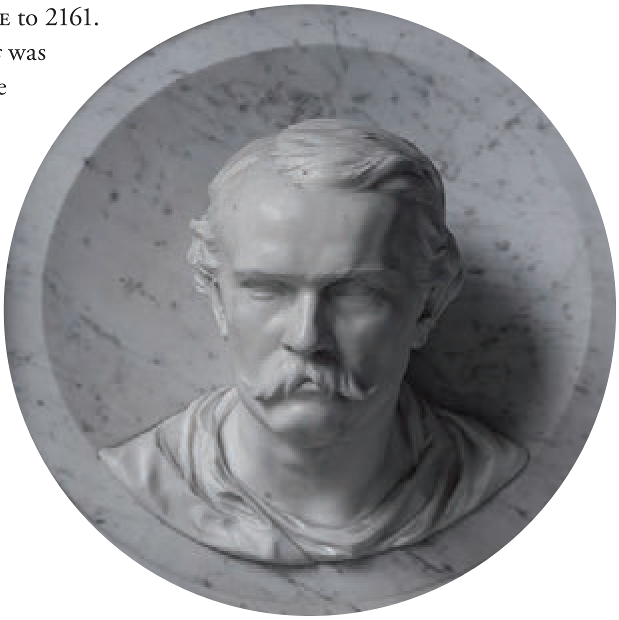
IN COMMISSION BEI KARL GEROLD'S SOHN.

1887.

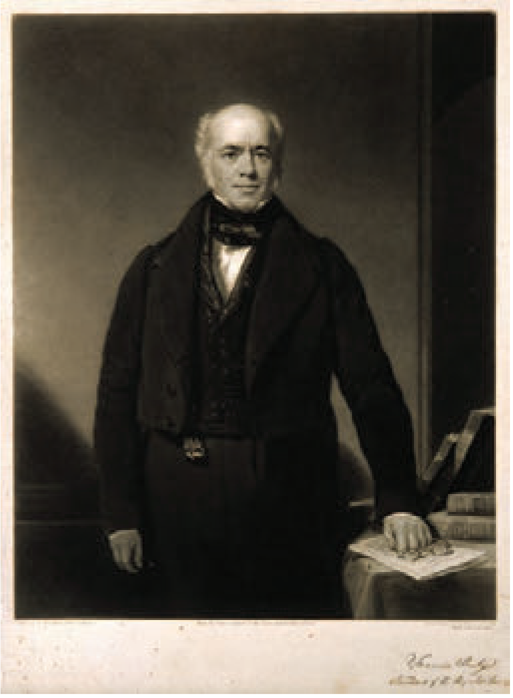


Above: *The cover and an inside page from Oppolzer's* Canon of Eclipses *(1887) provides details of all eclipses over a span of 34 centuries.*

In 1824 a great practical stride was made in eclipse predictions: Prussian astronomer Friedrich Bessel introduced a group of mathematical formulas that greatly simplified the calculation of the positions of the Sun, Moon, and Earth. These "Bessel functions," which are used even today, laid the foundation for a monumental book on eclipses. An Austrian astronomer named Theodor von Oppolzer organized the calculation of all eclipses from 1207 BCE to 2161. One year after his death in 1886, his *Canon of Eclipses* was published. It contains the details of the time and place for the 13,200 solar and lunar eclipses for those 34 centuries. Another Austrian astronomer, Friedrich Ginzel, used these data for historical research on eclipses. In 1899 he published his *Special Canon of Solar and Lunar Eclipses*, which shows the references in classical literature to all eclipses between 900 BCE and 600. Both of these works have been valuable tools for historians who use eclipses to verify dates in history.



Right: *Austrian astronomer Theodor von Oppolzer (1841-1886).*

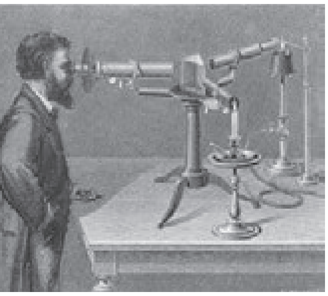


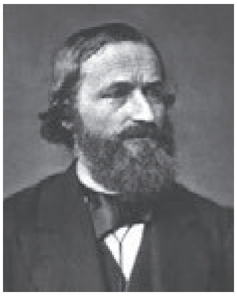
ECLIPSE EXPEDITIONS

Astronomers today travel to all parts of the globe to gather eclipse data, chasing the Moon's shadow wherever it happens to touch the Earth. This has not always been the case. It is only in the last two centuries or so that eclipse expeditions have been in vogue. A notable exception occurred for the total solar eclipse of October 27, 1780: Samuel Williams, professor at Harvard, led an eclipse expedition to Penobscot Bay, Maine. The exceptional part of the story is that this happened during the Revolutionary War and Penobscot Bay lay behind enemy lines. Fortunately, the British granted the party safe passage, citing the interest of science above political differences.

Until the middle of the nineteenth century, most of the scientific interest in eclipses concerned the precision of orbital motion. Astronomers used the data from eclipse observations to refine their knowledge of celestial mechanics, which in turn led to more accurate eclipse predictions. Little attention was paid to describing the visible phenomena of total solar eclipses.

This situation changed when the Moon's umbra crossed populated parts of Southern Europe on July 8, 1842. Those who observed totality on that day were rewarded with a magnificent view of the corona and prominences. Francis Baily, an English amateur astronomer, was the first to use the word "corona" as an astronomical term in describing this eclipse. Scientists were stirred to discover more about this halo of light and the "red flames" that appeared around the Moon. Luckily, the technology of photography was beginning to develop at that time. The first successful photograph of the corona was taken at the total eclipse in Northern Europe on July 28, 1851. Scientists in 1860 used eclipse photos taken in Spain to show that the solar prominences were definitely part of the Sun and not part of the Moon as some had believed.



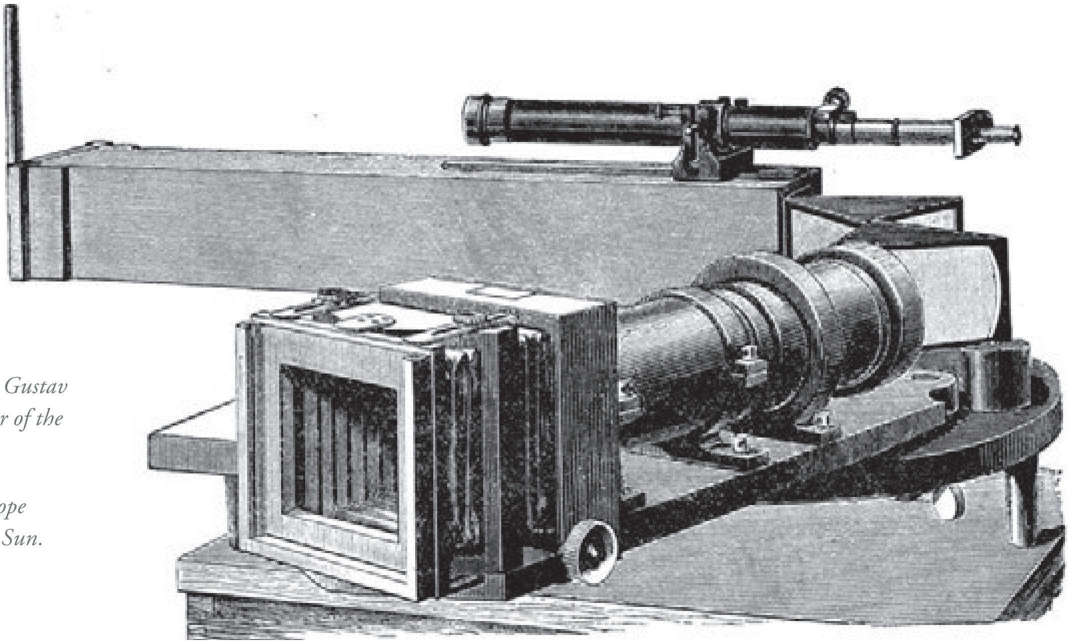


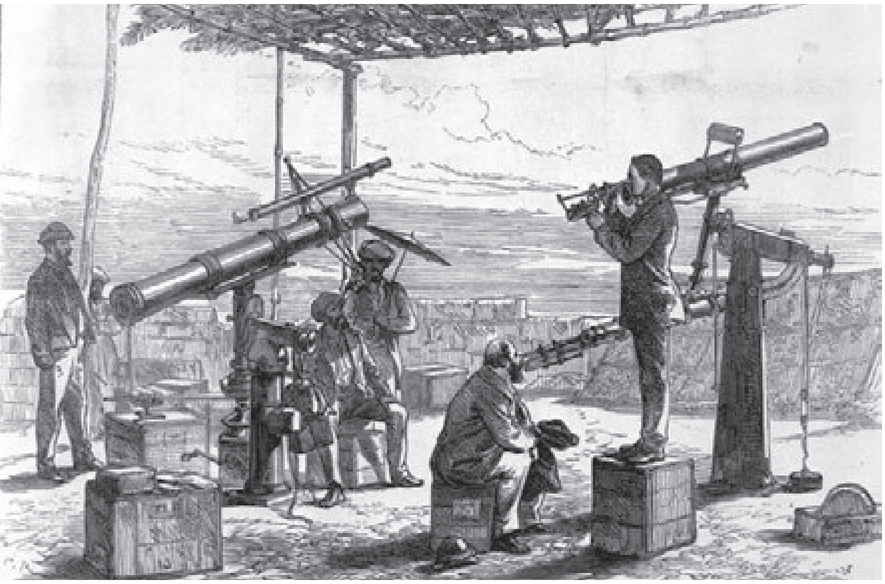
Top: *English astronomer Francis Baily (1774-1844) first drew attention to the pinpoints of light that disappear just before totality, today called Baily's Beads.*

Above Left: *Kirchoff peering through his spectroscope.*

Above Right: *German physicist Gustav Kirchoff (1824-1887), inventor of the spectroscope.*

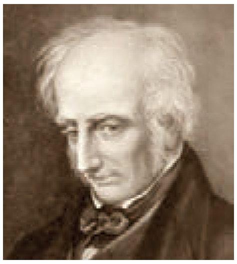
Right: *State of the art spectroscope (c. 1860) used for studying the Sun.*





About this time another breakthrough happened that opened entirely new avenues of investigation in solar physics. For many years scientists had noticed a number of thin dark lines in the rainbow spectrum of light from the Sun. In 1859, German physicist Gustav Kirchhoff accounted for their origin: the lines occurred because of the chemical elements present in the Sun. Since each element has its own distinctive set of lines, the chemical composition of the Sun could be derived from its spectrum. This new technique, called spectroscopy, was first applied to the eclipsed Sun on August 18, 1868. By this time, eclipse expeditions to remote areas of the globe were routine, and many traveled to India and Malaya to see this eclipse. British astronomer Norman Lockyer trained his spectroscope on the solar prominences and discovered a spectral line of a new chemical element. He named it helium (from Greek *helios*, the Sun); this familiar gas was not identified on the Earth until 1895. At the same eclipse, he and French astronomer Pierre Jules Janssen, each working independently, figured out a spectroscopic method for observing the prominences without an eclipse.

In the following ten years steady advances were made in the spectroscopy and photography of eclipses. Expeditions to America, the Mediterranean, India, South Africa, and Siam yielded new information about the composition of the Sun and the structure of the corona. These expeditions to remote areas presented many challenges to astronomers. Transporting large, sensitive telescopes and other instruments compounded the hardships of global travel in the nineteenth century. And once the observers were set up at a site within the path of totality, cloudy skies during the eclipse could defeat the purpose of the journey.



High on her speculative tower
Stood Science waiting for the hour
When Sol was destined to endure
That darkening of his radiant face
Which Superstition strove to chase,
Erewhile, with rites impure.

– Wordsworth, *The Eclipse of the Sun, 1820*

Top Left: *The expedition to India for the eclipse of December 12, 1871. These British astronomers (Norman Lockyer is seated at the left under the umbrella) made their observations from atop a tower at the old fort at Bekal.*

Top Right: *Sir Joseph Norman Lockyer (1836-1920), British astronomer who co-discovered the chemical element helium in the spectral lines of the Sun.*

Above: *A crowd of astonished natives gathered below the tower at Bekal. In their alarm at the sight of the disappearing Sun, they kindled a fire in preparation for a sacrifice. The astronomers, fearful the smoke would obscure their view, had the police stop the attempted fire-lighting.*

Left: *English poet William Wordsworth (1770-1850).*

THE SUNSPOT CONNECTION

None of these inconveniences deterred the scientists who traveled to Colorado and Wyoming for the total eclipse of July 29, 1878. The transcontinental railroad had been completed nine years earlier and astronomers were offered half-price fares for the trip from the East Coast. For a short period that summer, obscure towns in the West became centers of scientific activity. Famous astronomers from Europe and all over America turned out to see the eclipse in the clear skies of the Rocky Mountains. Even Thomas Edison (no astronomer himself) was there to test a new invention he claimed could measure the heat of the corona.

HARPER'S WEEKLY

A

JOURNAL OF CIVILIZATION

Vol. XXII.—No. 1130.] NEW YORK, SATURDAY, AUGUST 24, 1878.

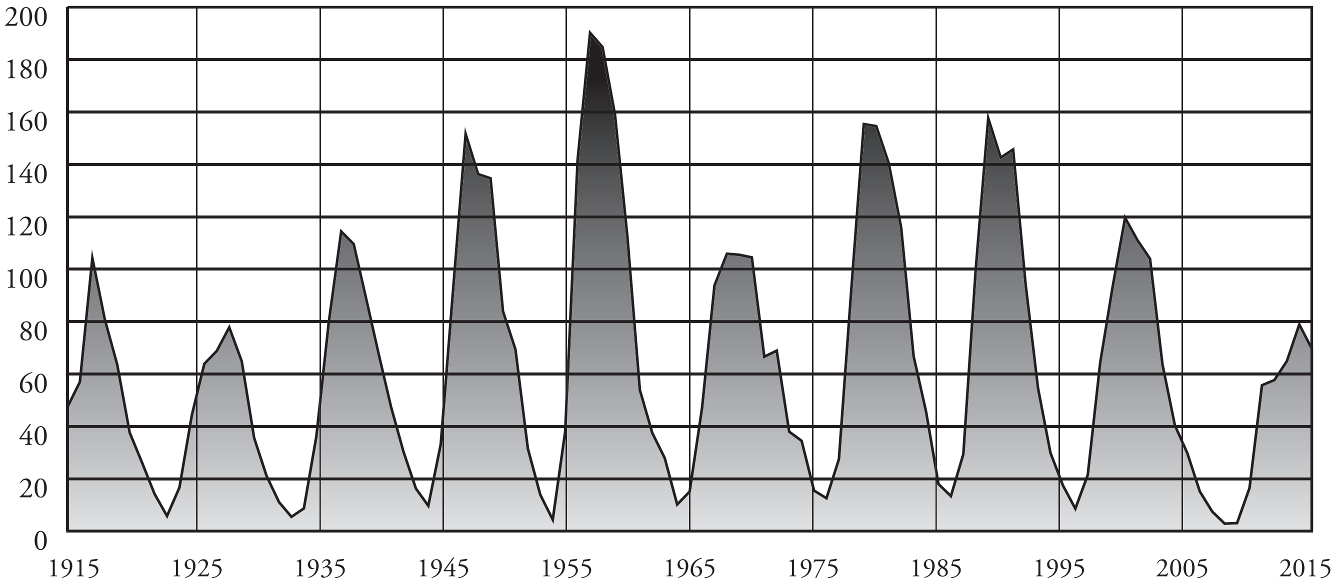
A group headed by Samuel P. Langley, later director of the Smithsonian Institution, climbed to the summit of Pikes Peak in Colorado to witness totality on that summer afternoon. The day before the eclipse was ominous; they experienced hail, rain, sleet, snow, and fog! But eclipse day was clear and their perseverance was rewarded by a startling sight: two coronal streamers extending in opposite directions as far as twelve diameters of the Sun. These streamers were much wider than had ever been seen before by scientists.

Although the 1878 corona was very wide, it was actually not as bright as those seen in 1870 and 1871. Astronomers began to suspect that the corona's shape and intensity were related to levels of activity on the Sun. One of the measures of solar activity is the occurrence of sunspots. These dark blotches appear on the Sun's surface, sometimes lasting for many weeks. Some years earlier Heinrich Schwabe, a German amateur astronomer, noted that the average number of sunspots per day varied in a regular cycle of approximately eleven years. Could this cycle be linked to the changing shape of the corona?

Top Left: *Group that traveled to Sumatra to view the total solar eclipse of May 18, 1901.*

Top Right: *Samuel P. Langley (1834-1906), American astronomer and aviation pioneer, led an eclipse expedition to Pikes Peak, Colorado in 1878.*

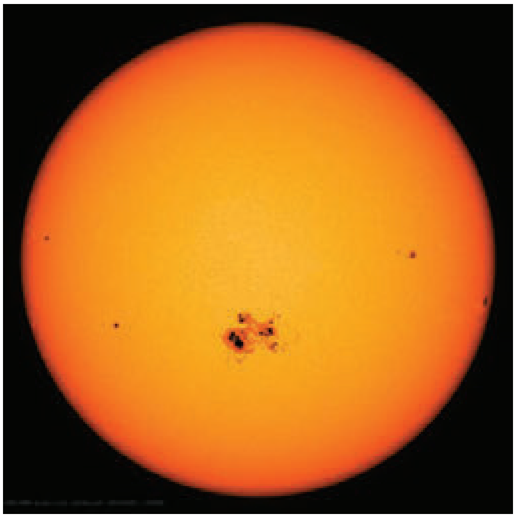
Left: *Harper's Weekly cover page depicting total solar eclipse seen by astronomers at Pikes Peak, Colorado on July 29, 1878.*



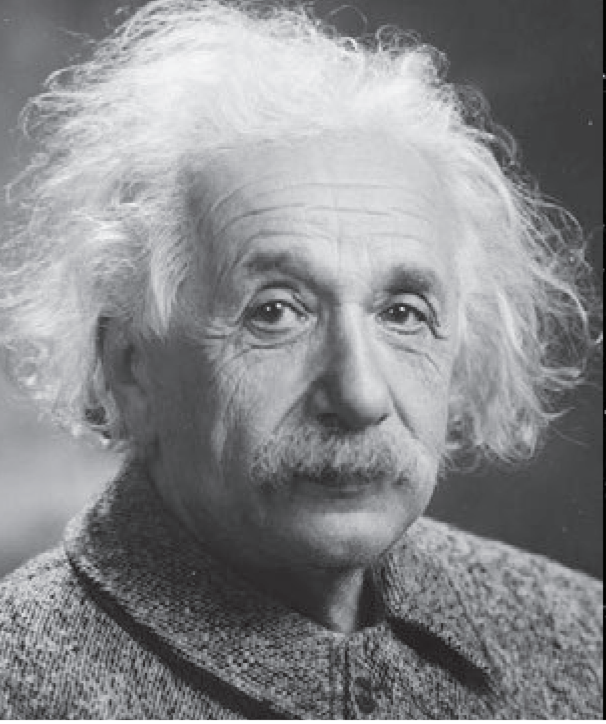
Above: *Graph of yearly sunspot numbers.*

Observations of the corona over the following decades proved this theory correct. An eclipse that occurs near a low point in the sunspot cycle (as in 1878) reveals a corona that is dimmer than normal but that shows a more detailed structure. The coronal “halo” seen surrounding the black disk of the Moon is somewhat compressed. The long *equatorial streamers* may be seen stretching out from either side of the Sun. Finely detailed *polar plumes* of light curve above and below the dark disk in the sky. Near sunspot maximum (as in 2017), the appearance is just the opposite. The plumes and streamers are less pronounced, but the coronal glow around the Sun is brighter and more expanded. Eclipses occurring at intermediate stages of the cycle exhibit some combination of features of both types.

The 1878 eclipse also marked the height of the search for the elusive planet “Vulcan.” This was the name given to a small object reportedly seen near the Sun on several occasions; some scientists thought it was a planet that up to then had escaped detection. The calculation of small irregularities in the orbit of Mercury supported this theory. Just 30 years earlier Neptune had been discovered in a similar manner. Astronomers were hoping that the clear skies and the blacked-out Sun would reveal the planet in their telescopes during the eclipse. But it didn't happen. One astronomer did announce he had discovered Vulcan, but he was later proved wrong. It turns out that the discrepancies in Mercury's orbit are fully accounted for by Einstein's theory of relativity.



Below: *A gigantic sunspot – almost 80,000 miles across -- can be seen on the lower center of this image of the Sun (Oct. 23, 2014).*



Top Left: *Albert Einstein (1879-1955), German-born physicist who developed the theory of relativity and received the 1921 Nobel Prize in Physics.*

Top Right: *A portion of the Milky Way galaxy.*

Above: *Bending of starlight as observed during an eclipse.*

ECLIPSES AND EINSTEIN'S THEORY OF RELATIVITY

Because the Sun's light is shielded during an eclipse, some of the brighter stars and planets can be seen in the darkened sky. This fact has enabled astronomers to test part of the theory of relativity. According to Einstein, who proposed the theory in 1915, rays of light should be deflected by a gravitational field. In particular, starlight passing near the Sun should be bent slightly toward the Sun. The only time when stars near the Sun are visible is during a total solar eclipse.

Scientists put the theory to test during eclipse expeditions to Brazil in 1919 and to Australia in 1922. Photographs of stars near the Sun during these eclipses were compared to photographs taken of the same stars several months later when the Sun, in another part of the sky, would have no effect. The difference in position of the stars showed that Einstein was correct. Eclipses became the first tool to crack the door of experimental proof on one of the most profound scientific ideas about the universe.

Scientists at these "relativity eclipses" were blessed with clear skies. The excitement generated by this new theory led to great plans for observation of totality on September 10, 1923. The path would graze Southern California at a favorable time of year. Forecasters predicted a 90% chance of clear skies. But as fate would have it, the day was overcast and the clouds spoiled all the planned observations.

A year and a half later there was little hope of good weather for the total eclipse in the Northeast United States. Yet many places in the path of totality in New York and Connecticut experienced clear skies on January 24, 1925. Millions of people witnessed the eclipse. The southern edge of the path crossed right through New York City. This situation provided a unique opportunity to determine the precise location of the edge of totality during an eclipse.

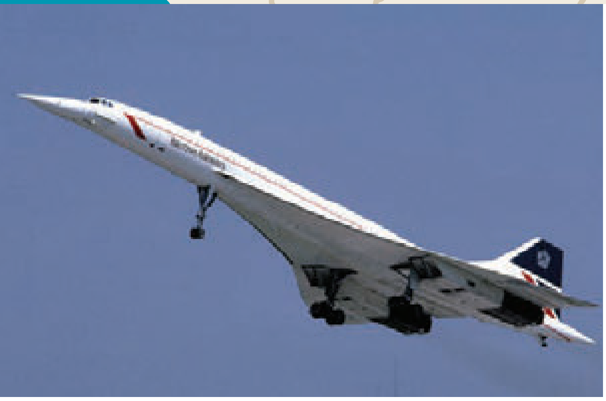
Astronomers knew beforehand that the edge of the Moon's shadow would pass over Riverside Drive in New York City somewhere between 83rd and 110th Streets. To be on the safe side, observers were positioned at every intersection between 72nd and 135th Streets. They were instructed to report whether they had seen the corona (total phase) or only a crescent of the Sun (partial phase). The results were definite: the edge of the umbra passed between 95th and 97th Streets, yielding an accuracy of several hundred feet for a shadow cast a distance of over 200,000 miles.

Left: *Observers on Jan. 24, 1925 confirmed that the southern edge of the path of totality crossed Riverside Drive in Manhattan at 96th Street.*

Above: *View of totality and the Moon's shadow from an aircraft flying at 32,000 feet altitude (July 20, 1990).*

CHASING THE MOON'S SHADOW

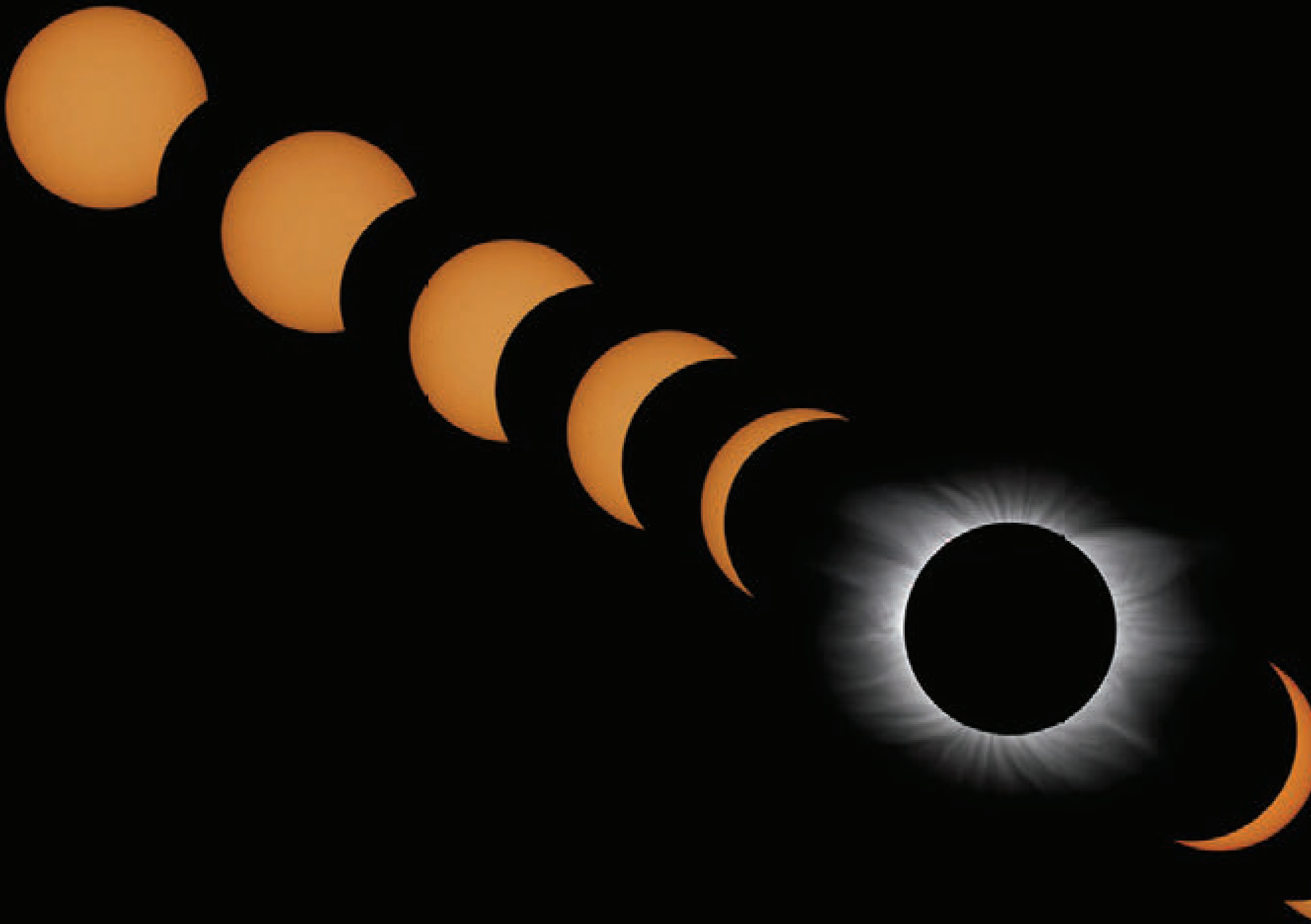
In recent years, great technological advances have occurred in many types of instruments used to gather scientific data during eclipses. Much of this increased sensitivity is lost, however, because of distortion by the lower atmosphere. More accurate data can be gathered at higher elevations, but eclipse paths don't often pass over convenient mountaintops. The modern astronomer's solution has been to take to the air. Three distinct advantages have resulted from the use of "flying observatories" in the past few decades. First, flying above the clouds ensures that bad weather will not spoil the occasion. Second, the clarity of the atmosphere at high altitudes provides better results. And third, because an aircraft can fly in the direction the shadow is moving, the effective duration of totality can be lengthened. On June 30, 1973, scientists aboard the supersonic aircraft *Concorde 001* flew in the Moon's shadow across Africa for 74 minutes – ten times longer than an eclipse can ever be observed from the ground.



But the story doesn't end there. The study of the Sun is also reaching into space. Observations of the solar corona from orbiting spacecraft have expanded our understanding of the Sun into areas previously unexplored. This increase in solar knowledge coincides with a growing public awareness of the Sun as the primal source of energy for our planet. A total solar eclipse provides a magnificent opportunity to personally appreciate the source of life-giving energy at the center of our solar system. The next part of this book explains what happens during an eclipse and how these events are repeated in time and space.

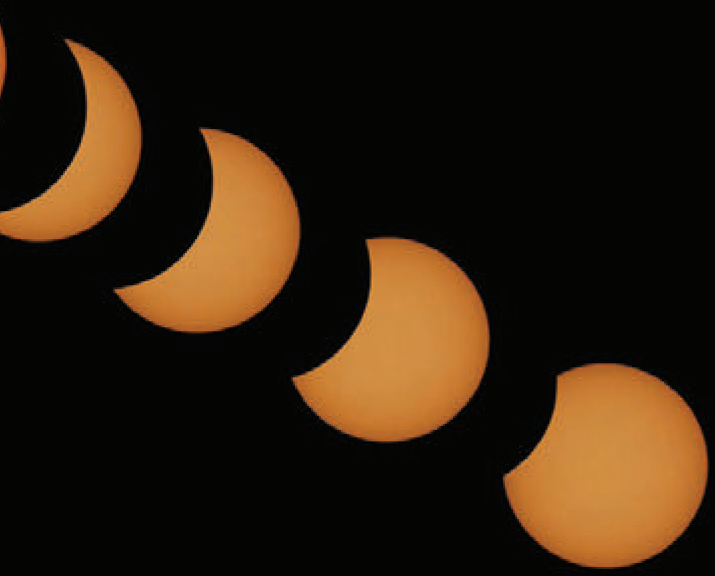
Top: *Flight path of Concorde 001 in the Moon's shadow on June 30, 1973.*

Above: *Supersonic Concorde aircraft, one of which was specially modified to observe the total eclipse on June 30, 1973.*



CHAPTER TWO

Understanding Eclipses

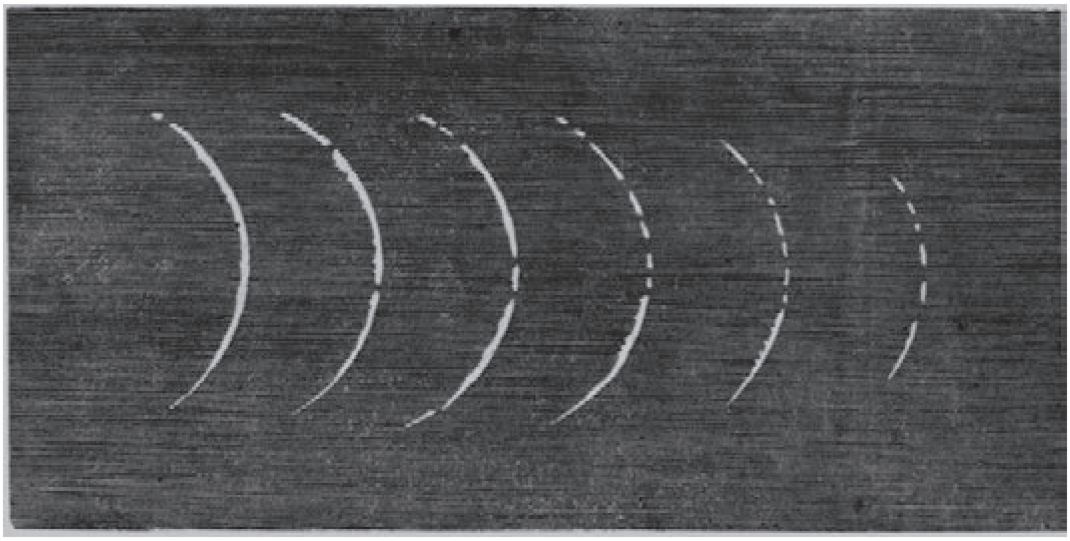


Above: *Crescent images of partially eclipsed Sun (1900 engraving).*

THE APPROACH OF DARKNESS

A total eclipse begins almost unnoticeably. First contact occurs when the Moon starts its passage across the face of the Sun. At first, only a small "bite" appears on the western edge of the Sun. Gradually, as more and more of the Sun disappears, an interesting effect can be seen: the tiny spots of light shining through the leaves of a tree, for example, show up on the ground as crescent images of the slowly vanishing Sun.

This partial phase of the eclipse leads to totality in about an hour. For most of that time, there is little hint of the approaching darkness. But as the bright area of the Sun is reduced more and more, the increasing darkness becomes noticeable. Daylight fades very quickly in the last few minutes before totality.



Opposite Bottom: *Shadow bands sometimes visible just prior to totality (1900 engraving).*

Left: *Baily's beads (engraving from the eclipse of July 18, 1860).*

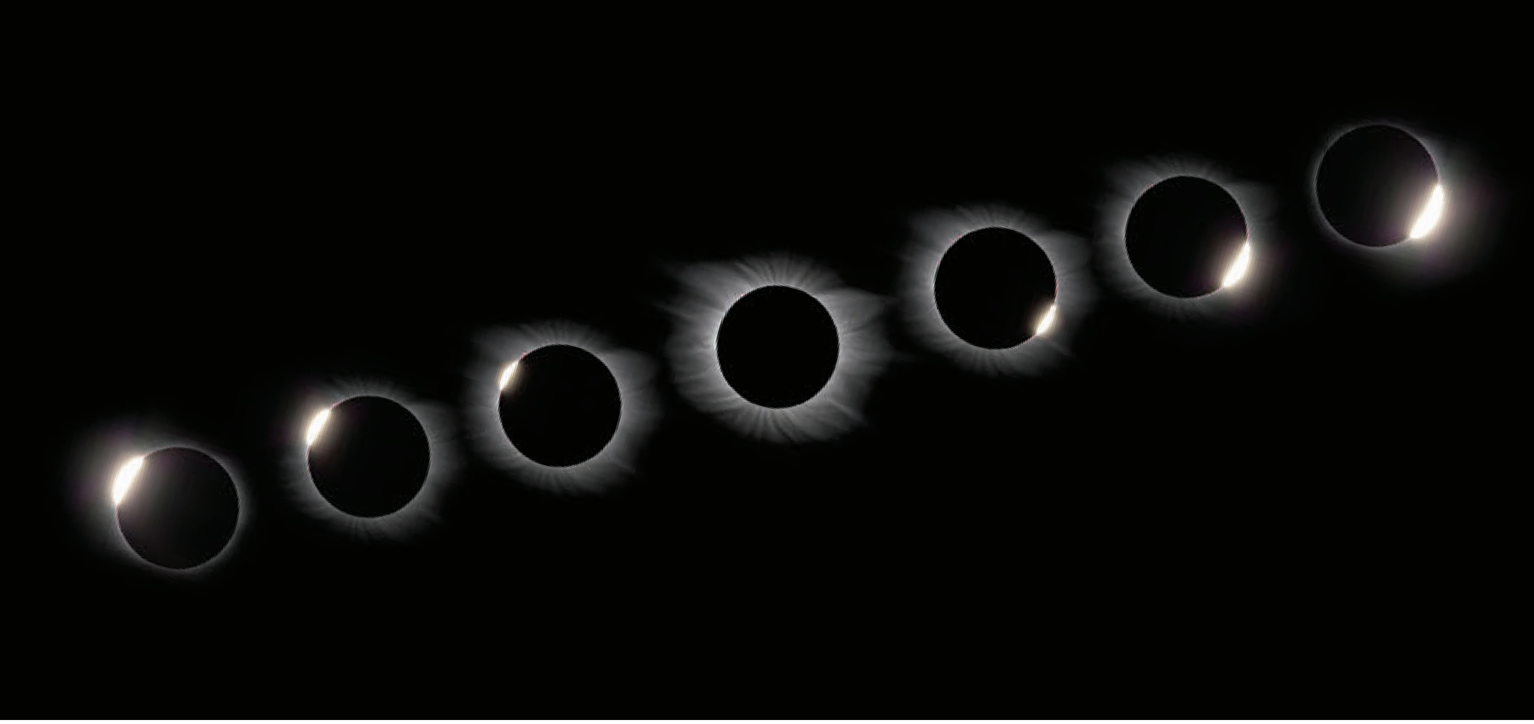
While a small crescent of the sun remains in the sky, a curious eclipse phenomenon is often observed. Thin wavy lines of alternating light and dark can be seen moving and undulating in parallel on plain light-colored surfaces. These so-called *shadow bands* are the result of sunlight being distorted by irregularities in the Earth's atmosphere. An open floor or wall is a good place to look for them. A similar effect is seen when the Sun shines through ripples on the surface of the water in a swimming pool; the wavy lines moving on the bottom of the pool resemble the shadow bands of an eclipse.

As the narrow crescent of the Sun finally begins to disappear, tiny specks of light remain visible for a few seconds more. These points of light are spaced irregularly around the disappearing edge of the Sun, forming the appearance of a string of beads around the dark disk of the Moon. These lights are known as *Baily's beads*, named after Francis Baily, the 18th century English amateur astronomer who was the first to draw attention to them.

Baily's beads would not be possible if the Moon's surface were perfectly smooth. The edge of the Sun is first hidden by the peaks of lunar mountains. The beads are the last few rays of sunlight shining through valleys on the edge of the Moon. Baily's beads make their brief appearance up to 15 seconds before totality. When a single point of sunlight remains, a beautiful "diamond ring" effect is created against the outline of the Moon. This final sparkling instant signals the arrival of the moon's shadow. The last ray of sunlight vanishes and totality begins.

> *O dark, dark, dark, amid the blaze of noon,*
> *Irrevocably dark, total eclipse*
> *Without all hope of day.*

– Milton, *Paradise Regained*



Above: *Composite sequence of photos showing the diamond ring effect both before and after totality. (March 29, 2006).*

THE SPECTACLE OF TOTALITY

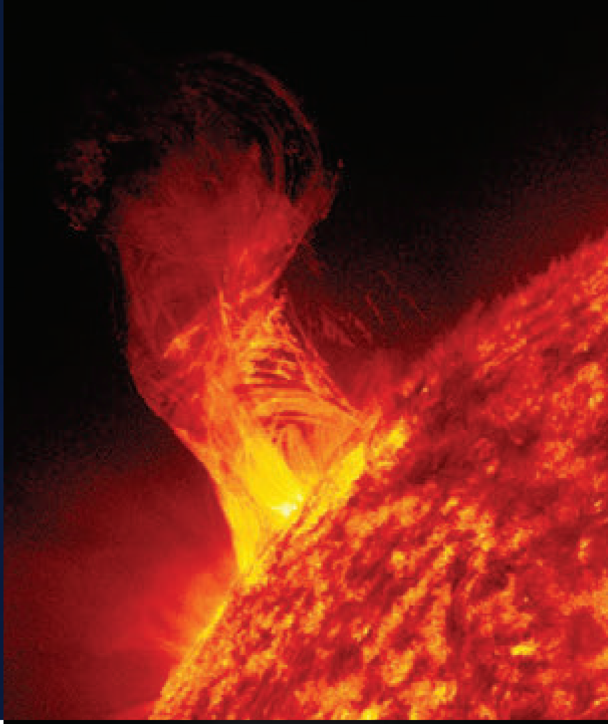
Suddenly the sky above is dark. The Moon's shadow, racing along the Earth at speeds up to several thousand miles per hour, brings a swift and dramatic nighttime effect. The sky near the horizon, where the eclipse is not total, still appears bright. The distant scattered light produces a slight reddish glow and unusual shadow effects. This daytime darkness is not quite as black as at night. But its startling onset and unearthly appearance combine to create a unique visual ambience.

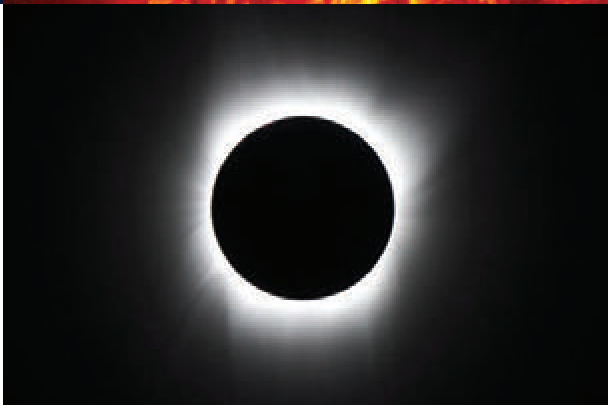
In the center of this darkened sky hangs the featured spectacle of the eclipse – the corona of the Sun. This pearly white crown of light shines in all directions around the darkened solar disk. A million times fainter than the Sun itself, the full glory of the corona is visible only during a total solar eclipse.

The corona consists of the ionized gases that form the outer atmosphere of the Sun. Although these gases extend many millions of miles into space, only the corona near the Sun is visible to the naked eye. Wispy plumes and streamers of coronal light reach out distances up to several diameters of the Sun before they fade into darkness.

The corona comes into full view when the leading edge of the Moon blots out the last ray of sunlight, and it remains visible throughout totality. For a few seconds both after the beginning and before the end of totality, a pinkish glow appears at the edge of the Moon. This is light from the Sun's lower atmosphere, the *chromosphere*. Its rosy color ("chromo" means color) comes from its main element, hydrogen.

Extending outward from the chromosphere are *solar prominences*. Usually several of these red cloud-like formations are visible during a total eclipse. Some prominences actually erupt, speeding away from the Sun at close to a million miles per hour. (This movement is not evident to the naked eye during the few minutes of totality.) They arch above the surface and then disappear, sometimes lasting only a matter of hours. A few of these erupting prominences have been seen to reach a height of nearly one-third the diameter of the Sun itself.





This marvelous view of the Sun clearly commands the center of attention during totality. But there are other sights to see as well. Because the direct light of the Sun is blocked, some of the brighter stars and planets become visible. Sometimes a total solar eclipse reveals a small comet on its path near the Sun.

The darkness of totality resembles nighttime, and plants and animals react accordingly. Birds stop singing and may go to roost. Daytime flower blossoms begin to close as if for the night. Bees become disoriented and stop flying. The temperature drops in the coolness of the Moon's shadow. All of Nature seems still and quiet for this brief moment of daytime darkness.

And then the shadow passes. A bright speck of sunlight flashes into view at the western edge of the Sun as the corona disappears. Totality has ended. The same events that preceded totality now occur in reverse order and on the opposite side of the Sun. Baily's beads appear, followed by a thin crescent of the Sun. Daylight returns as more and more of the Sun is gradually uncovered by the passing Moon.

Finally the complete disk of the Sun is restored. The eclipse is over. The Moon continues in its orbit around the Earth, casting its shadow off into the vastness of space. Nothing tangible remains of the eclipse except some photographs and scientific data. Yet the memory of the experience is permanent – the fleeting beauty of the corona etched into the mind's eye by the sheer grandeur of the event. There is simply nothing else like it. And now it is gone – but not forever. The necessary alignment of Sun, Moon, and Earth will occur again to create other solar eclipses.

Top Left: *Close up portrait of the inner corona showing ruby-red prominences and polar plumes (February 26, 1998).*

Top Right: *This detailed view of a solar prominence gives a sense of the large magnitude of these types of eruptions. This image was produced with special equipment using wavelengths of light outside the visible spectrum. (Note: this type of view is not seen during an eclipse.)*

Above: *Another view of the solar corona shows the variation in detail from one eclipse to another (July 11, 2010).*

TOTAL AND PARTIAL ECLIPSES

Twelve total solar eclipse tracks have crossed North America in the last one hundred years. The longest path of totality across the country came with the eclipse of June 8, 1918. This so-called "American eclipse" was observed from one corner of the nation to the other, all the way from Washington State to Florida. Astronomers were joined by crowds of interested people along the eclipse track to witness the wonder of this daytime darkness.

Now again in 2017, another eclipse track crosses the United States, this time from Oregon to South Carolina. And this time, tens of millions of viewers will be looking skyward to get a glimpse of totality on August 21, 2107. (The next opportunity for U.S. viewers will come April 8, 2024, when the Moon's shadow races from Texas to Maine.)

The sequence of eclipses from year to year is determined by two different cycles of the Moon. The familiar monthly change of the phases of the Moon is one of these. The other cycle involves the gradual shift in orientation of the Moon's orbit. Only when these two cycles are favorably combined (about every six months) can a solar eclipse occur.

A solar eclipse may occur only at a new Moon. During this lunar phase the Moon passes between the Earth and the Sun. The Sun shines on the side of the Moon facing away from us, casting a shadow toward the Earth. A new Moon appears every 29½ days, but usually the Moon's shadow passes completely above or completely below the Earth. This is because the Moon's orbit is tilted at a slight angle to the Earth's orbit; the Moon usually passes above or below the direct line of sight between the Earth and the Sun.

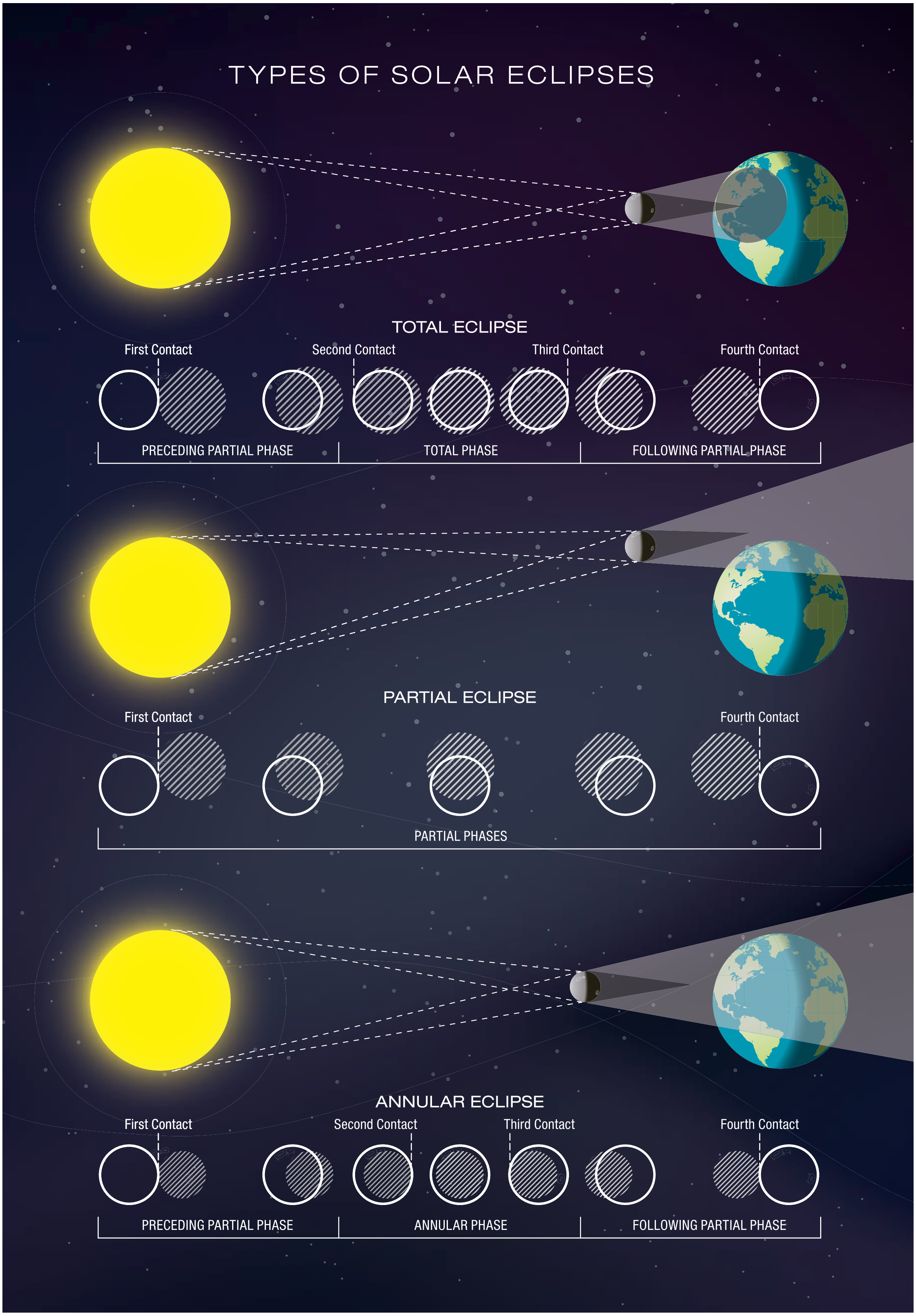
A *total solar eclipse* occurs when the umbra (complete shadow of the Moon) sweeps across the Earth. During a *partial solar eclipse*, only the penumbra (partial shadow of the Moon) touches our planet. The umbra passes either just above the North Pole or just below the South Pole, completely missing the Earth. No total eclipse is visible – only partial phases can be seen. It has the same appearance as the partial phases of a total eclipse, but is visible only in either northern or southern latitudes.

It is much more common to see a partial solar eclipse (or the partial phases of a total solar eclipse), since the partially eclipsed Sun is usually visible over wide areas of the Earth. Whether or not a solar eclipse will be experienced as a total eclipse or a partial eclipse is just a matter of a slight difference in alignment of the Moon during an eclipse. People who have witnessed these partial phases – which is an interesting phenomenon, but not particularly dramatic – may wonder why others get so excited about seeing a total eclipse. It seems like it is just a slight matter of degree. But don't be fooled by this analogy. There is a world of difference between a 99% partial solar eclipse and a 100% total solar eclipse. The spectacular view of the solar corona is visible only from within the path of totality of a total solar eclipse, and it is well worth the effort to position yourself so that you can experience it.

Eclipse contacts mark the transitions between different phases of an eclipse as viewed from a point on the Earth. For a total eclipse, *first contact* occurs at the instant the Sun's disk begins to be covered by the Moon. About an hour later, *second contact* marks the beginning of the total phase of the eclipse, and *third contact* signals the end of totality. The transition phenomena (Baily's beads, diamond ring effect, shadow bands, etc.) are visible just before second contact and just after third contact. *Fourth contact* occurs when the Moon passes completely away from the disk of the Sun.

For a partial eclipse (or the partial phases of a total or annular eclipse), first contact also occurs at the instant when the Sun's disk begins to be covered by the Moon. But since there are only partial phases for this type of eclipse, there is no second or third contact. Fourth contact signals the end of the eclipse.

For an annular eclipse, second contact marks the point at which the disk of the Sun completely surrounds the Moon, revealing the ring of bright light around the Moon. Third contact occurs when the Moon moves on to break the ring of light of an annular eclipse.

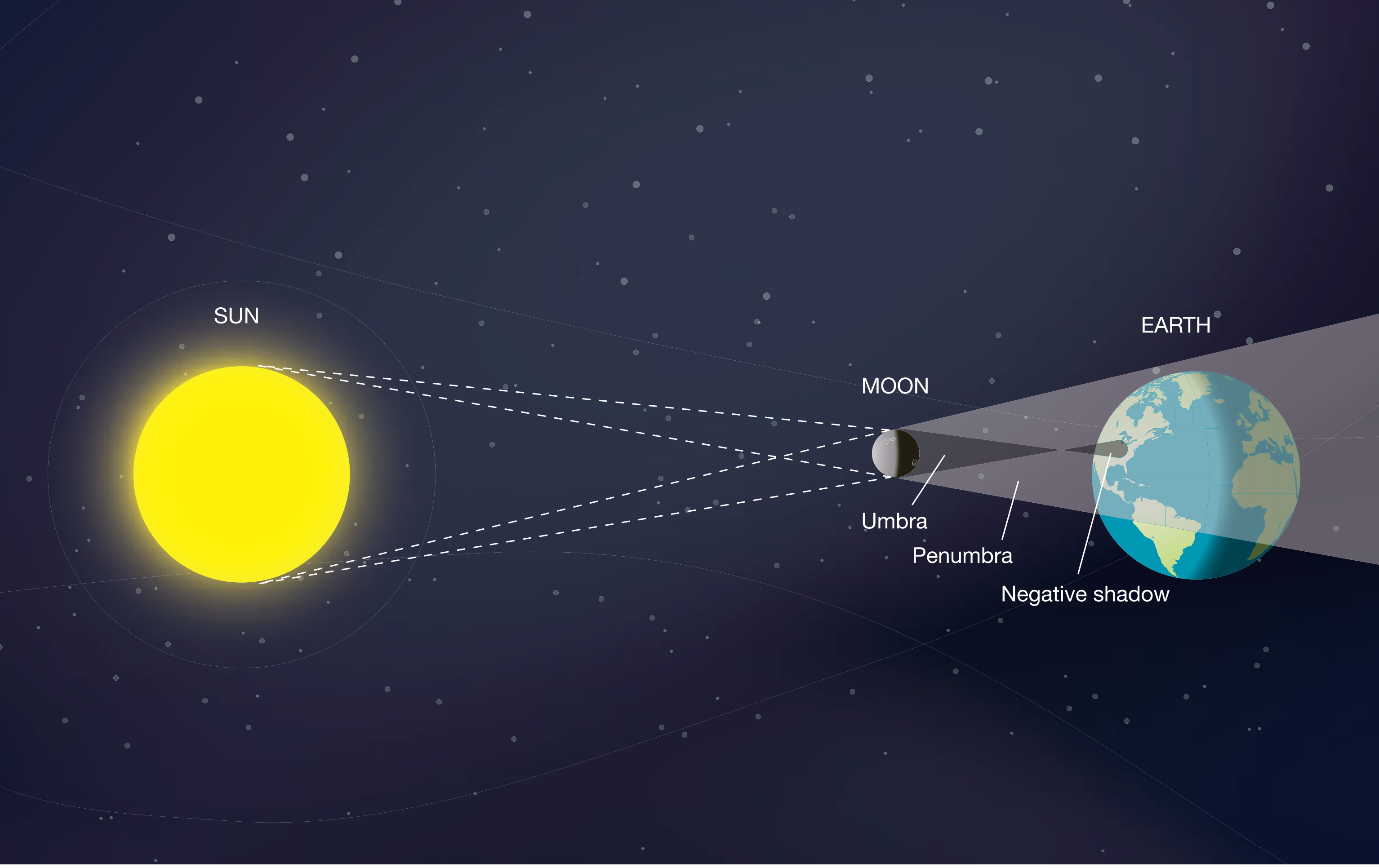

TYPES OF SOLAR ECLIPSES
TOTAL ECLIPSE
First Contact
Second Contact
Third Contact
Fourth Contact
PRECEDING PARTIAL PHASE
TOTAL PHASE
FOLLOWING PARTIAL PHASE
PARTIAL ECLIPSE
First Contact
Fourth Contact
PARTIAL PHASES
ANNULAR ECLIPSE
First Contact
Second Contact
Third Contact
Fourth Contact
PRECEDING PARTIAL PHASE
ANNULAR PHASE
FOLLOWING PARTIAL PHASE

Above: *Composite photo sequence of the phases of an annular eclipse. The Moon, when centered on the Sun, is not large enough to completely cover the Sun during an annular eclipse. The solar corona and other totality effects are not visible during this type of eclipse.*

ANNULAR ECLIPSES

A third type of solar eclipse occurs when the Moon's umbra passes across the Earth, but is not quite long enough to reach the surface; the shadow cone diminishes to a point above the surface of the Earth. This effect happens when the Moon is farther out in its orbit around the Earth. The Moon appears slightly smaller and is not large enough to completely cover the Sun. When the Moon is centered over the Sun, a ring of sunlight remains visible around the edge. This type of eclipse is called an *annular eclipse*. (Annular comes from the Latin word meaning "ring.") Because the Sun is not completely covered by the Moon, the dramatic effects of a total eclipse (corona, darkness, etc.) are not present at either annular or partial eclipses of the Sun.

The Moon passes from apogee to perigee and back again every 27½ days; the Earth-Sun distance varies on a yearly cycle. If an eclipse occurs when the Moon is near apogee (Moon farther from Earth) and the Earth is nearer to perihelion (Sun closer to Earth), the Sun will appear larger than the Moon. The Moon will not be able to completely block the Sun; the result is an annular eclipse. The Moon's umbra falls short of reaching the



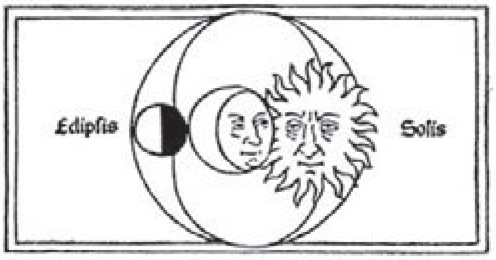
Earth, producing what is called a negative shadow. This is an extension of the umbra projected onto the Earth. Anywhere within the path of this negative shadow the eclipse can be seen as annular, with the Sun completely surrounding the Moon from behind. Outside the negative shadow, within the penumbra, the eclipse appears as partial. When an annular eclipse takes place with the Earth at perihelion and the Moon at apogee, the negative shadow attains its greatest width, as much as 230 miles.

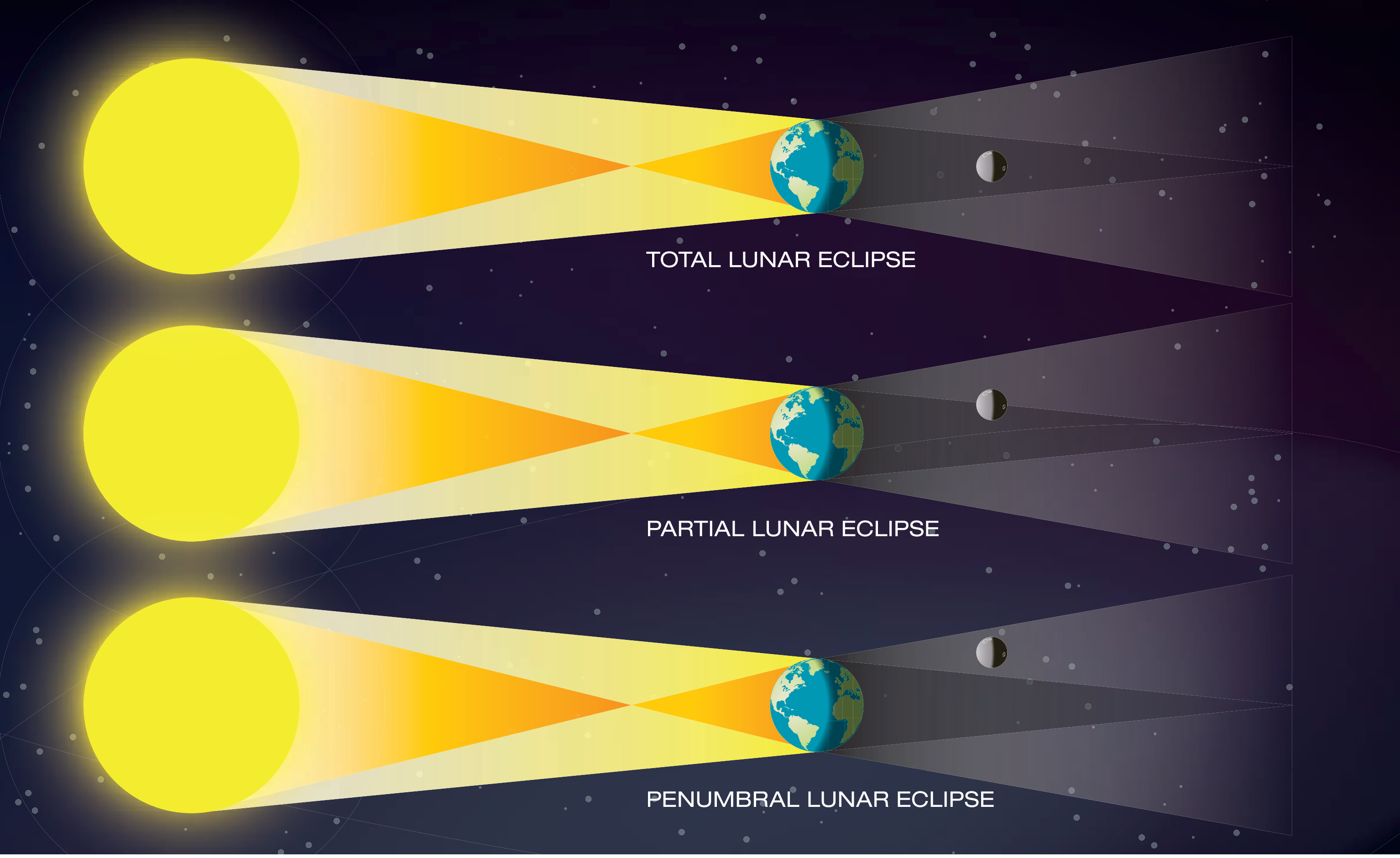
Most eclipses occur when the Sun and Moon are somewhere in between their closest and farthest points. If an eclipse is not a partial one, the relative effect of the distance is calculated to determine whether the type is annular or total.

A fourth type of eclipse has both annular and total phases. Called an *annular-total eclipse* (or sometimes a *central eclipse* or a *hybrid eclipse*), it starts out as annular, then becomes total, and finally reverts to annular, all in the same sweep of the shadow across the Earth. This rare type of eclipse occurs when the shadow cone of the umbra comes to a point right near the surface of the Earth. In the middle part of the eclipse, near noontime, the umbra just barely touches the Earth. The path of totality is very narrow. During the earlier and later phases of the eclipse, the umbra is not quite long enough to reach the points in the path around either side of the globe. Annular-total eclipses account for only about one in every 25 solar eclipses.

Above: *This diagram shows that during an annular eclipse, the complete shadow of the Moon (the umbra) does not reach the surface of the Earth.*

Below: *Solar eclipse woodcut from Johannes des Sacrobusco's* Opus Sphæricum *(1482).*





Top: *The diagram illustrates the different positions of the Moon in the Earth's shadow for the three types of lunar eclipses.*

Above: *A time-lapse composite photo sequence shows the Moon at successive positions during a total lunar eclipse.*

LUNAR ECLIPSES

An eclipse of the Moon, or *lunar eclipse*, takes place whenever the full Moon passes into the Earth's shadow, which is composed of two parts: the dark inner shadow, or umbra, and the lighter outer shadow, or penumbra. As in a solar eclipse, the Sun, Moon, and Earth are aligned in a straight line. But in this case, the Earth is between the Sun and the Moon. Also, there is not a lunar eclipse every month, because the full Moon usually passes slightly above or below the Earth's shadow.

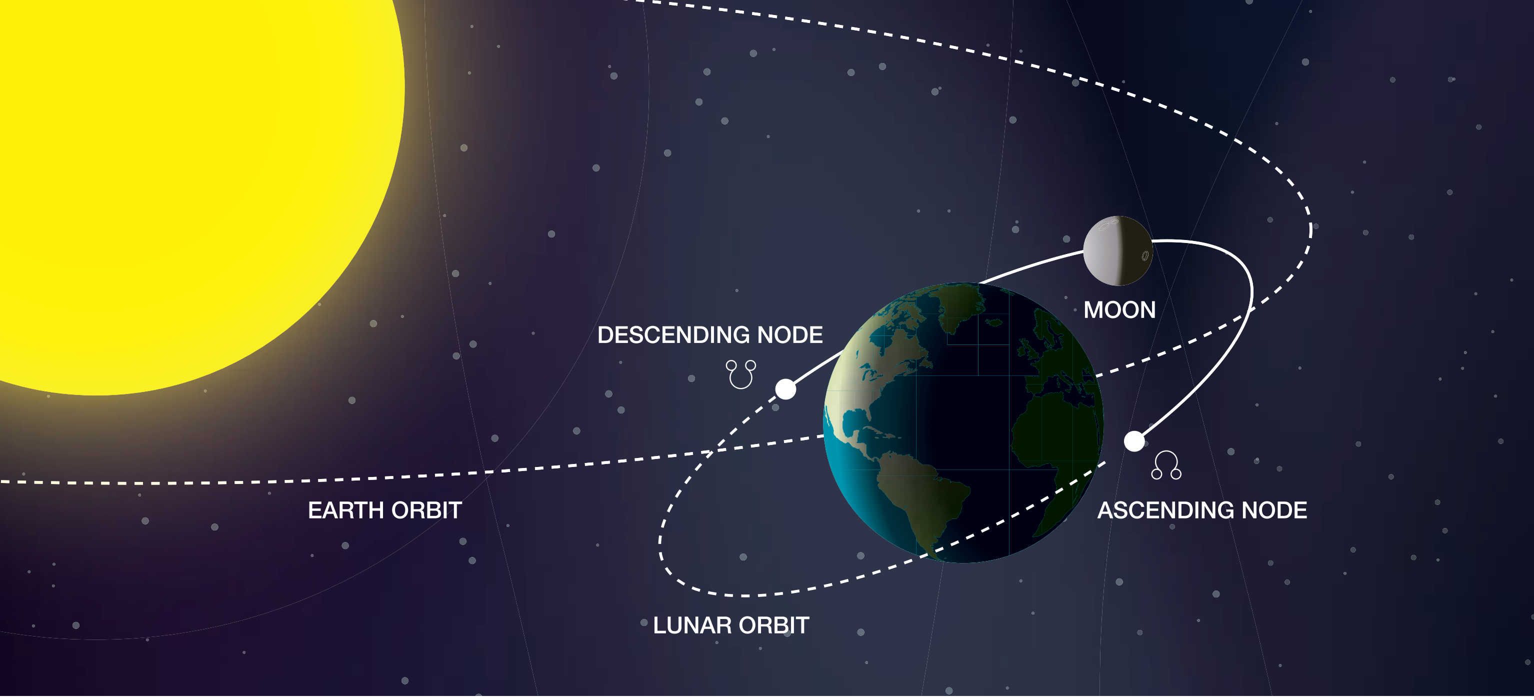
There are three types of lunar eclipses. A *total lunar eclipse* takes place when the Moon is completely engulfed by the Earth's shadow. This type of lunar eclipse offers the most unusual spectacle: the bright full Moon gradually darkens, and for up to an hour and a half appears a dull reddish or copper color. Although the Moon is in the complete shadow cone of the Earth, some sunlight is refracted by the Earth's atmosphere, with mostly the reddish wavelengths being reflected by the Moon. The exact color varies according to weather conditions at points near dawn and dusk at the time of the eclipse.

In a *partial lunar eclipse*, the umbra passes over only part of the Moon, causing only moderate darkening of the full Moon but with little of the reddish color effect. In a *penumbral lunar eclipse*, the Moon passes through only the penumbral portion of the Earth's shadow, and the darkening is scarcely noticeable.

Lunar eclipses occur at the rate of about 2.3 eclipses per year. Over time, total lunar eclipses account for about 36% of all lunar eclipses, partial about 27%, and penumbral about 37%. When a lunar eclipse does occur, it always happens 14¾ days before or after a solar eclipse. (Lunar eclipses occur during the eclipse seasons discussed on pages 48-49.) For example, there is a partial lunar eclipse on August 7, 2017, occurring at the full Moon before the total solar eclipse of August 21, 2017.

Many more people witness total lunar eclipses than total solar eclipses, even though they occur with roughly the same frequency. (Each century averages between 75 and 85 total eclipses of each type.) A lunar eclipse is visible from anywhere on the half of the Earth where it is nighttime during the hour or more that the Moon moves through the Earth's umbra (provided, of course, that the local night sky is clear enough to see the Moon). A total solar eclipse is visible only from within a narrow path of totality on a specific part of the Earth for just a few minutes at any location within that path.

Above: *The totally eclipsed Moon often appears with a reddish hue, the result of sunlight in the red wavelengths refracted by the Earth's atmosphere.*



Above: *The plane of the orbit of the Moon is tilted by about 5 degrees from the plane of the orbit of the Earth (called the ecliptic). This tilt accounts for the fact that eclipses – both solar and lunar – do not occur every month.*

Opposite: *Petrus Apianus'* Astronomicum Cæsareum *(1540) includes a rotating volvelle used to track the position of the lunar nodes (depicted as the head and tail of a dragon).*

THE ORBIT OF THE MOON

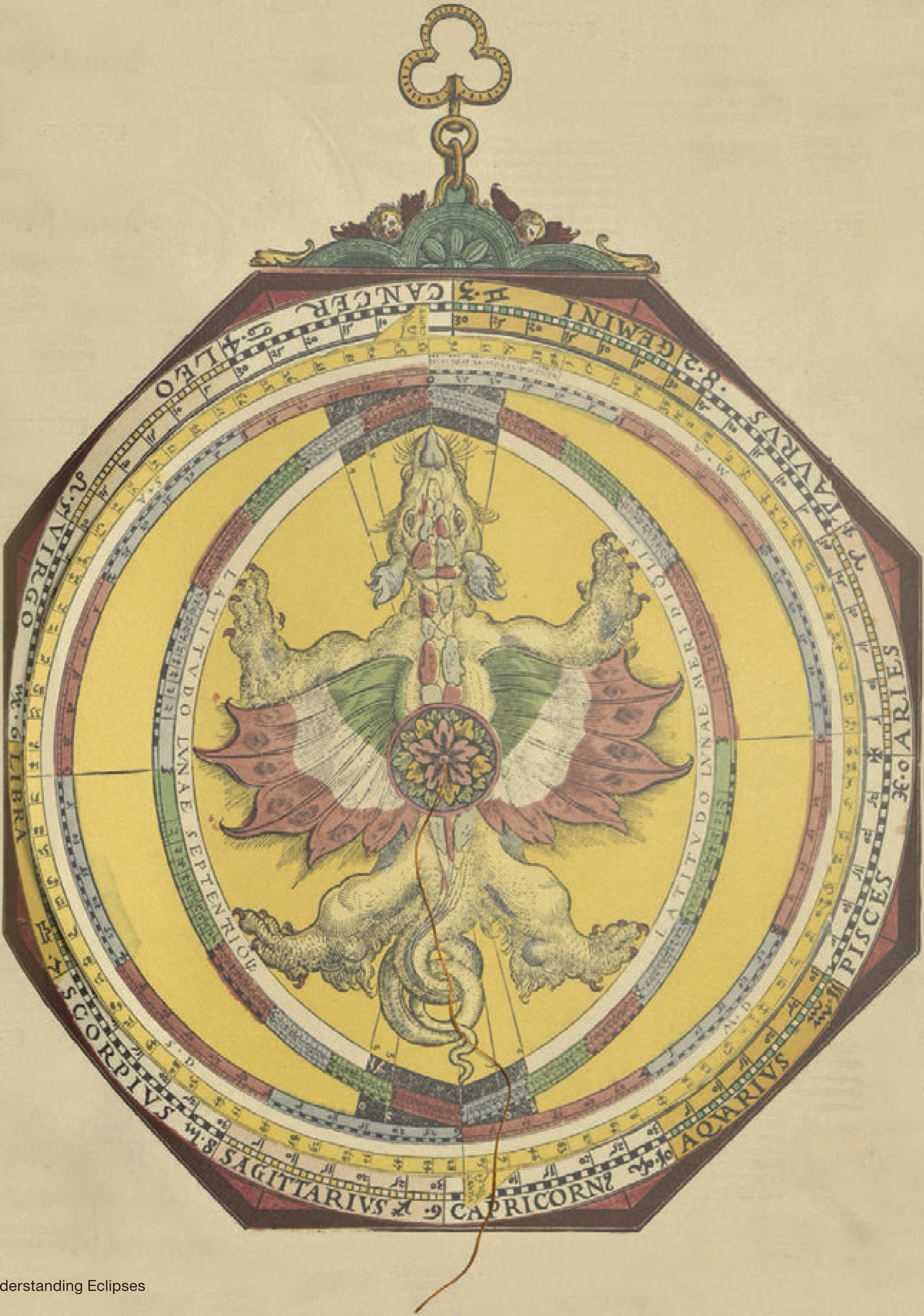
As the Earth moves around the Sun in its yearly orbit, the direct line of sight between them sweeps through a plane called the *ecliptic*. The orbit of the Earth defines this plane. As seen from the Earth, the ecliptic is the path the Sun appears to take across the sky during the year. The twelve signs of the zodiac are distributed around this path.

The orbit of the Moon is tilted by about 5.15 degrees to the ecliptic. For half of its orbit, the Moon is above the ecliptic plane; the other half, below. The two points where the Moon's orbit intersects the ecliptic are called nodes. The *ascending node* marks the point of the Moon's passage to the upper part of its orbit; the *descending node* is the point where the Moon moves into its orbit below the ecliptic plane.

For a solar eclipse to occur, the Moon must be at or near one of its nodes when it passes between the Earth and the Sun. In other words, the new Moon must occur when the Moon is close enough to the ecliptic plane so that the lunar shadow will cross some part of the Earth. This connection with eclipses is the reason the plane is named the ecliptic. A deeper, symbolic meaning is found in the astronomical symbols used for the Moon's ascending node (☊) and the descending node (☋). These symbols are generally supposed to represent the head and tail of the dragon swallowing the Sun according to the ancient belief about eclipses. In earlier times, the nodes were actually known by the fanciful titles "Dragon's Head" and "Dragon's Tail."

> *Methinks it should be now a huge eclipse*
> *Of Sun and Moon.*

–Shakespeare, *Othello*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CAPRICORNI
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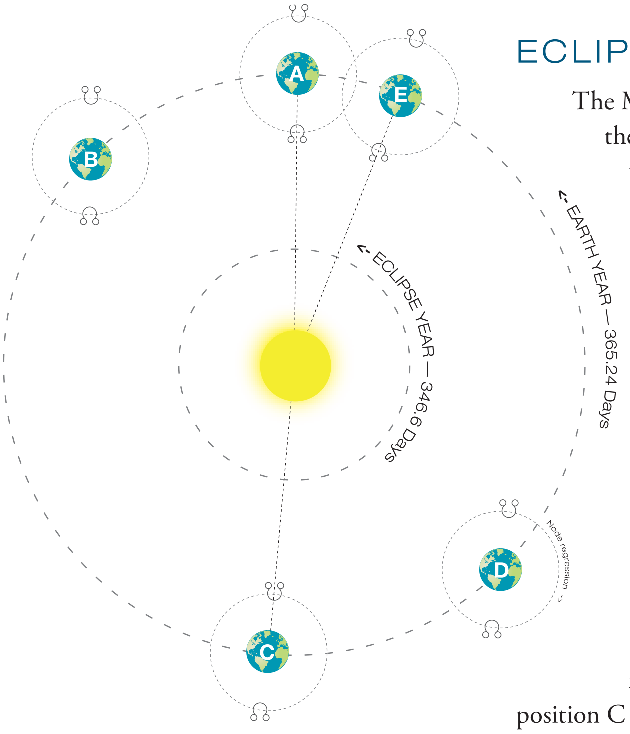


Above: *The eclipse year is marked by the return of a lunar node to the same position relative to the Sun and the Earth. Because the Moon's orbit is slowly regressing, it takes less than a full calendar year – 346.6 days – to complete an eclipse year.*

ECLIPSE SEASONS

The Moon and its orbit naturally move with the Earth as it travels around the Sun every year. If the lunar nodes were stationary (with respect to the stars), the ascending node would be lined up between the Earth and the Sun at the same time each year. (Likewise for the descending node half a year later on the opposite side of the Earth's orbit). But the nodes of the lunar orbit are not quite stationary; they are gradually shifting their orientation in space. By the time a node is in line with the Sun again, it has regressed slightly. This alignment happens sooner than if the nodes were not moving. Thus it takes less than a full year for a node to be realigned between the Earth and the Sun. This period, called the *eclipse year*, is about 346.6 days long.

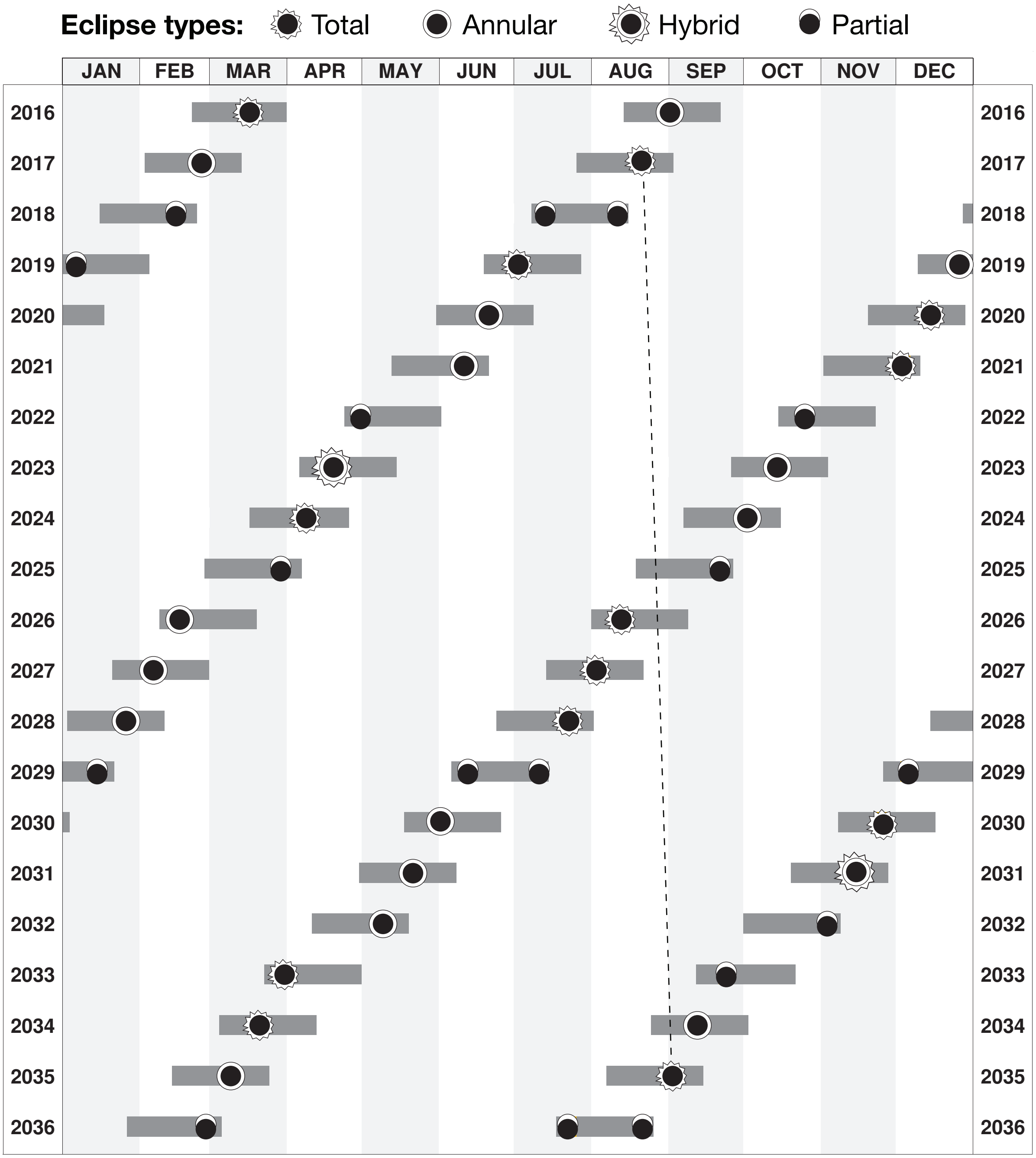
The diagram to the left illustrates the regression of the Moon's nodes through an eclipse year. At position A the ascending node is lined up between the Earth and the Sun. This is the beginning of an eclipse year. As the Earth moves on (as in position B), the node passes out of the Earth-Sun alignment. About six months later position C is reached where the descending node lines up between the Earth and the Sun. But because the nodes themselves are slowly regressing, this alignment occurs about nine days before the Earth reaches the point exactly opposite A. As the year continues, the descending node passes out of alignment (as in position D). Finally, at position E, the ascending node returns to a position between the Sun and the Earth. But because of the gradual regression of the nodes, the return takes only 346.6 days, an eclipse year. This is 18.6 days short of the full year it takes for the Earth to return to A.

Recall that a solar eclipse occurs when the Moon passes between the Sun and the Earth (this is the definition of new Moon) at or near one of the lunar nodes. The new Moon need not perfectly coincide with a node to have an eclipse. When the new Moon appears within 18¾ days before or after the alignment of a node, a solar eclipse will take place. This creates a 37½-day time window for eclipses. These periods when the conditions are favorable for an eclipse are called the *eclipse seasons*. These seasons occur whenever a node is near alignment. This happens twice each eclipse year, once every 173.3 days.

The diagram on the opposite page shows the timing of all solar eclipses within the eclipse seasons from 2016 to 2036. The eclipse seasons occur earlier and earlier each year. When a node returns to its alignment with the Sun, the calendar date will be about 18¾ days earlier than in the previous year. The repetition of these alignments gradually moves the eclipse seasons through all the months in a regular pattern over a period of years.

Because there is a new Moon every 29½ days, at least one new Moon appears during each 37½-day eclipse season. Therefore, at least one solar eclipse must occur during each eclipse season. Since there are at least two eclipse seasons every year, there must be at least two solar eclipses every calendar year. Some eclipse seasons have two solar eclipses. In this case, one new Moon appears near the beginning of the time window and the following one near the end of the time window. Two of these "double seasons" in the same year produce a total of four solar eclipses. The maximum number of solar eclipses in one calendar year is five, and this happens only rarely. In this case a year with two double seasons has the fifth eclipse squeezed in at the beginning of January or the end of December. This is possible because the eclipse year is shorter than a calendar year. This last occurred in 1935 when there were solar eclipses on January 5, February 3, June 30, July 30, and December 25. There won't be another calendar year containing five solar eclipses until the year 2206.

SOLAR ECLIPSES AND ECLIPSE SEASONS (2016-2036)



Above: *Solar eclipses can occur only during an eclipse season, a 37½-day window of time when a lunar node is in position between the Sun and the Earth. When the new Moon occurs near the midpoint of an eclipse season, the result is an annular or total eclipse. When the new Moon occurs near the beginning or end of the window, the result is a partial eclipse. The vertical dashed line connects the August 21, 2017 eclipse with the next eclipse (September 2, 2035) in the same saros series.*

Above: *This Cuneiform clay tablet, on display in the British Museum in London, records the appearance in 164 BCE of a comet – later confirmed as Halley's Comet. Ancient Babylonian astronomers kept detailed records of celestial events, which aided their discovery of the saros series for eclipses.*

THE SAROS CYCLE

The eclipse seasons repeat year after year, but the timing of each eclipse within successive seasons does not follow a simple pattern. The lunar month from new Moon to new Moon (29.53 days) is called the *synodic month* (from the Greek word for "meeting" or "conjunction"). An eclipse year (346.62 days) does not come close to being an exact multiple of these periods (324.83 days in eleven synodic months, 354.36 in twelve). A longer cycle, close to an exact multiple of these two periods, would be useful for making eclipse predictions. This is the saros cycle discovered by Babylonian astronomers in ancient times. The saros (meaning "repetition") lasts exactly 223 synodic months. That's a period of 18 years 11⅓ days (or 18 years 10⅓ days if five February 29ths fall within the period). The saros coincides very closely with 19 eclipse years:

223 synodic months (29.5306 days) = 6,585.32 days
19 eclipse years (346.6200 days) = 6,585.78 days

This resonance between the periods of these two cycles produces a repetition of eclipses in a remarkably short time. (In terms of astronomical cycles, 18 years is a short time!)

To illustrate how the saros works, see the diagram of eclipses seasons from 2016 to 2036 on the previous page. A total solar eclipse occurs on August 21, 2017, the path of totality crossing the United States from Oregon to South Carolina. Because a solar eclipse takes place on that date, we know that the Moon must be new and that a node must be near alignment with the Sun. Eighteen years and eleven days later the saros cycle repeats. Because 19 eclipse years have passed, the same node is near alignment. It is a new Moon again because exactly 223 synodic months have passed. This results in a total solar eclipse on September 2, 2035. The cycle is repeated, but this eclipse is visible from China, Korea, Japan, and the Pacific Ocean.

The saros has an extra 0.32 portion of a day included in its period (6,585.32 days). When the cycle repeats, the Earth will have rotated beyond its position at the former eclipse by this fraction of a day. The subsequent eclipse will be seen about a third of the way around the globe to the west. After three saros cycles, an eclipse takes place near the original longitude of the eclipse 54 years earlier. However, each eclipse in the series moves a little farther in the same direction toward one of the poles of the Earth. The September 2, 2035, eclipse track falls at slightly more southerly latitudes than the eclipse of August 21, 2017. This gradual shift in latitude occurs because the new Moon at each succeeding saros moves slightly with respect to the node (more southerly for a saros at the ascending node; more northerly for the descending node). The half-day difference between 19 eclipse years and 223 synodic months (6,585.78 - 6,585.32 = 0.46 days) causes this change.

Below: *The paths of totality for seven successive total eclipses in the same saros series change in a regular pattern every 18 years. The paths, which are similar in shape, gradually widen and shift to more northerly latitudes as the saros progresses. The longitude for each successive eclipse shifts to the west a little more than one third of the way around the globe.*

What's more, successive eclipses in a saros are likely to be of the same type. This is a result of the close coincidence between the saros (6,585.32 days) and 239 anomalistic months (239 x 27.5545 = 6,585.54 days). When the saros repeats, the Moon will be almost the same distance from the Earth as before. If the Moon is farther away, the eclipses will be annular; if the Moon is closer, the eclipses will be total. Also, because the eclipses take place at the same time of the year (only 11 days' difference), the Earth-Sun distance is almost the same. This almost exact resonance between the eclipse year, the synodic month, and the anomalistic month, coupled with the saros being close to an even number of years, results in remarkable cycles centuries long.

A series of eclipses, each separated by this 18-year 11⅓-day cycle, is called a *saros series*. Because the resonance between 19 eclipse years and the saros is not exact (0.46-day difference), a saros series cannot go on indefinitely. Eventually a series reaches a point when the eclipses are no longer visible; the umbra passes too far above or below the Earth to be seen. A single saros series spans more than 1,200 years and includes between 68 and 75 solar eclipses. The saros series that includes the August 21, 2017, eclipse is shown below.

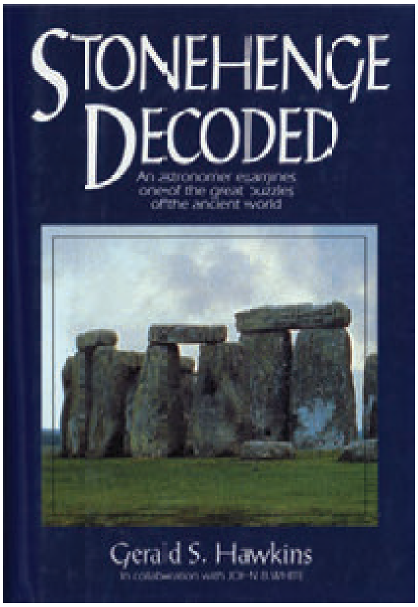
A Complete Saros Series of Solar Eclipses (Saros 145)

Date	Eclipse Type
1639 JAN 04	Partial
1657 JAN 14	Partial
1675 JAN 25	Partial
1693 FEB 05	Partial
1711 FEB 17	Partial
1729 FEB 27	Partial
1747 MAR 11	Partial
1765 MAR 21	Partial
1783 APR 01	Partial
1801 APR 13	Partial
1819 APR 24	Partial
1837 MAY 04	Partial
1855 MAY 16	Partial
1873 MAY 26	Partial
1891 JUN 06	Annular
1909 JUN 17	Hybrid
1927 JUN 29	Total
1945 JUL 09	Total
1963 JUL 20	Total
1981 JUL 31	Total
1999 AUG 11	Total
2017 AUG 21	**Total**
2035 SEP 02	Total
2053 SEP 12	Total
2071 SEP 23	Total
2089 OCT 04	Total
2107 OCT 16	Total
2125 OCT 26	Total
2143 NOV 07	Total
2161 NOV 17	Total
2179 NOV 28	Total
2197 DEC 09	Total
2215 DEC 21	Total
2233 DEC 31	Total
2252 JAN 12	Total
2270 JAN 22	Total
2288 FEB 02	Total
2306 FEB 14	Total
2324 FEB 25	Total
2342 MAR 08	Total
2360 MAR 18	Total
2378 MAR 29	Total
2396 APR 09	Total
2414 APR 20	Total
2432 APR 30	Total
2450 MAY 12	Total
2468 MAY 22	Total
2486 JUN 02	Total
2504 JUN 14	Total
2522 JUN 25	Total
2540 JUL 05	Total
2558 JUL 17	Total
2576 JUL 27	Total
2594 AUG 07	Total
2612 AUG 18	Total
2630 AUG 30	Total
2648 SEP 09	Total
2666 SEP 20	Partial
2684 OCT 01	Partial
2702 OCT 13	Partial
2720 OCT 23	Partial
2738 NOV 04	Partial
2756 NOV 14	Partial
2774 NOV 25	Partial
2792 DEC 06	Partial
2810 DEC 17	Partial
2828 DEC 28	Partial
2847 JAN 08	Partial
2865 JAN 18	Partial
2883 JAN 30	Partial
2901 FEB 10	Partial
2919 FEB 21	Partial
2937 MAR 04	Partial
2955 MAR 15	Partial
2973 MAR 25	Partial
2991 APR 06	Partial
3009 APR 17	Partial

Left: *This table lists the 77 eclipses in what astronomers call Saros Series No. 145, which includes the total solar eclipse of August 21, 2017. This series includes 41 total eclipses, 34 partial eclipses, one annular eclipse, and one hybrid (annular-total) eclipse.*

Above: *Light-colored Aubrey holes (more evident at top and right) form a circle around Stonehenge. Researchers believe that these 56, evenly-spaced chalk-filled depressions in the ground were used to track the progression of the lunar nodes, and thus predict eclipses.*

Below: *In his 1965 book* Stonehenge Decoded, *Gerald Hawkins first posited the theory that moving markers around the 56 Aubrey holes could track the position of the lunar nodes.*

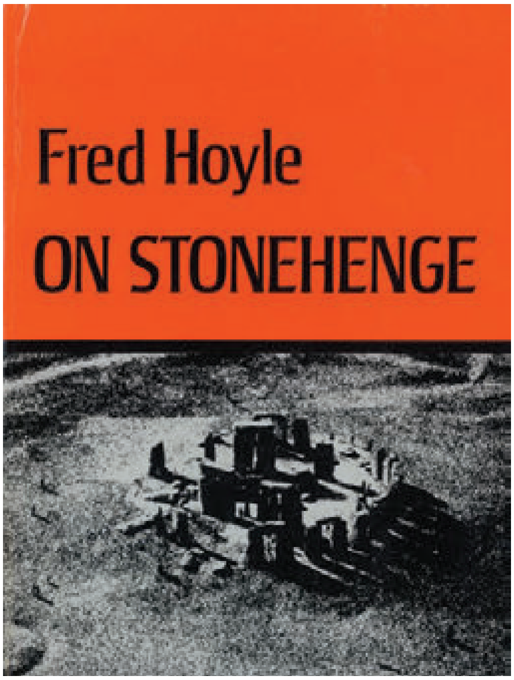


SECRETS OF STONEHENGE

There is no evidence that the builders of Stonehenge knew of the saros. But they didn't need to. The saros is merely a coincidence of celestial cycles; the marking of the monthly and yearly cycles at Stonehenge would work fine even if the saros did not exist. The likely purpose behind the pattern of these ancient stones and markers – to predict eclipses – has been revealed by the studies of two modern astronomers, Gerald Hawkins and Fred Hoyle.

The key to this fascinating discovery lies in the number 56. That is the number of so-called *Aubrey holes* (named after 17th century antiquarian John Aubrey) that form a ring about 300 feet in diameter around the large stone monuments in the center. Dug to a depth of several feet and then filled with chalk, these holes are evenly spaced around the circle. They were established about 2400 BCE as part of the early phase of Stonehenge, some 300 years before the giant stone pillars were erected. The purpose of the Aubrey holes was for many years a mystery to those who studied Stonehenge.

In his 1965 book *Stonehenge Decoded*, astronomer Gerald Hawkins explained his interpretation of the Aubrey holes. How does the number 56 relate to eclipses? Recall that the nodes of the Moon's orbit are regressing; they are moving slowly around the Earth from east to west. A complete revolution of these invisible orbital points takes 18.6 years (not to be confused with the 18-year saros cycle). To accurately predict eclipses from year to year, this regression cycle must be carefully recorded. Yet the builders of Stonehenge did not (as far as we know) use any form of writing. How could they mark this cycle? Three times 18.6 is very nearly 56.



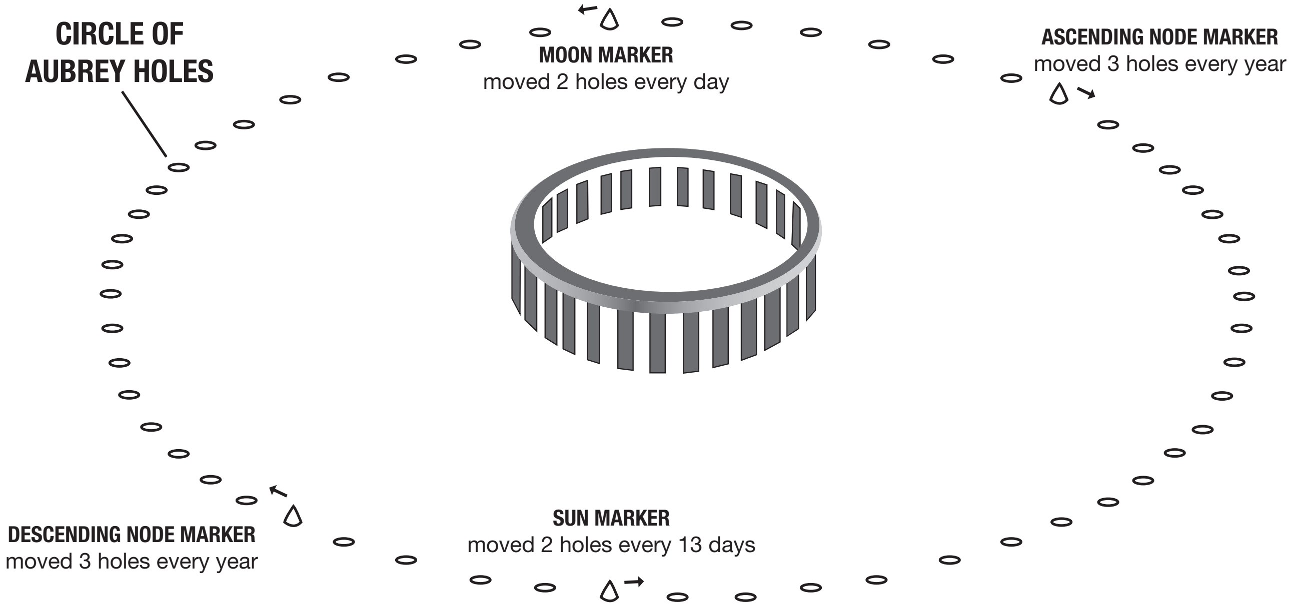
Above: *In his 1977 book* On Stonehenge*, Fred Hoyle expanded on Hawkins' theory by showing how the Aubrey holes could also be used to mark the movement of the Sun and the Moon.*

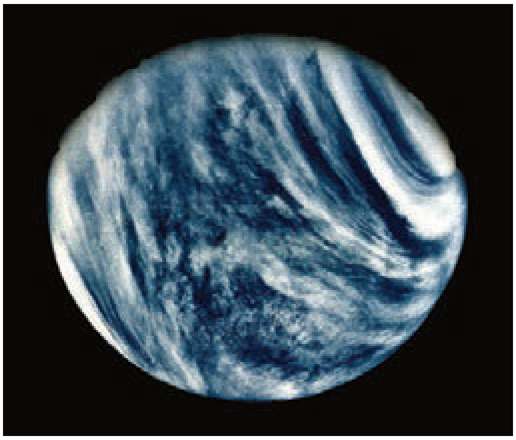
Below: *This diagram shows how the 56 Aubrey holes can be used to track to progression of the Sun, the Moon, and the lunar nodes, thus serving as a predictor of eclipses.*

According to Hawkins, moving a marker (such as a stone) three Aubrey holes each year makes a complete revolution of the system in 18⅔ years, close enough to the actual value for use in eclipse predictions. Two of these markers, on opposite sides of the Aubrey ring, would show the position of the nodes at all times. The astronomical alignments at Stonehenge, too precise to be mere chance, imply knowledge of the 18.6-year cycle of the lunar nodes. It seems plausible that the Aubrey holes were used to mark this cycle.

Fred Hoyle's 1977 book *On Stonehenge* shows how the number 56 may also be used to mark the movement of the Sun and the Moon. According to Hoyle, if a Sun marker is moved two holes every thirteen days, a complete circuit takes 364 days (56/2 x 13); this is only 1¼ days short of a full year. If a Moon marker is moved two holes every day, a complete circuit (28 days) is very close to the lunar month. These small discrepancies can be easily corrected using observations of the actual positions of the Sun and Moon.

Viewed in this way, Stonehenge represents a working model of the Sun-Moon-Earth system. The Sun, the Moon, and the lunar nodes, each represented by markers, revolve around the Earth located in the center. When the markers coincided, an eclipse would take place. All the necessary information (periodically corrected by actual observations) would have been available to the Stonehenge "astronomers" to use the 56 Aubrey holes as a primitive computer to predict eclipses.





Top: *A Mayan pyramid at Chichen Itza, Yucatan, Mexico.*

Above: *The planet Venus, shown here as seen through a telescope, played an important role in Mayan cosmology.*

MYSTERIES OF MEXICO

Halfway around the world from Stonehenge, another mysterious culture of sky watchers built stone monuments to mark the motion of celestial objects across the sky. The landscape of Mesoamerica is dotted with clusters of pyramids, temples, and observatories built by the Mayans and the Aztecs, chiefly during the first Millennium CE. These structures display a wealth of astronomical alignments, confirmed by research in the new discipline of archaeoastronomy, that are especially focused on the Sun, the Moon, the planet Venus, and the Pleiades star cluster. And unlike Stonehenge, surviving historical documents from the Mesoamerican period clearly indicate that these early cultures recorded eclipses and knew of eclipse cycles.

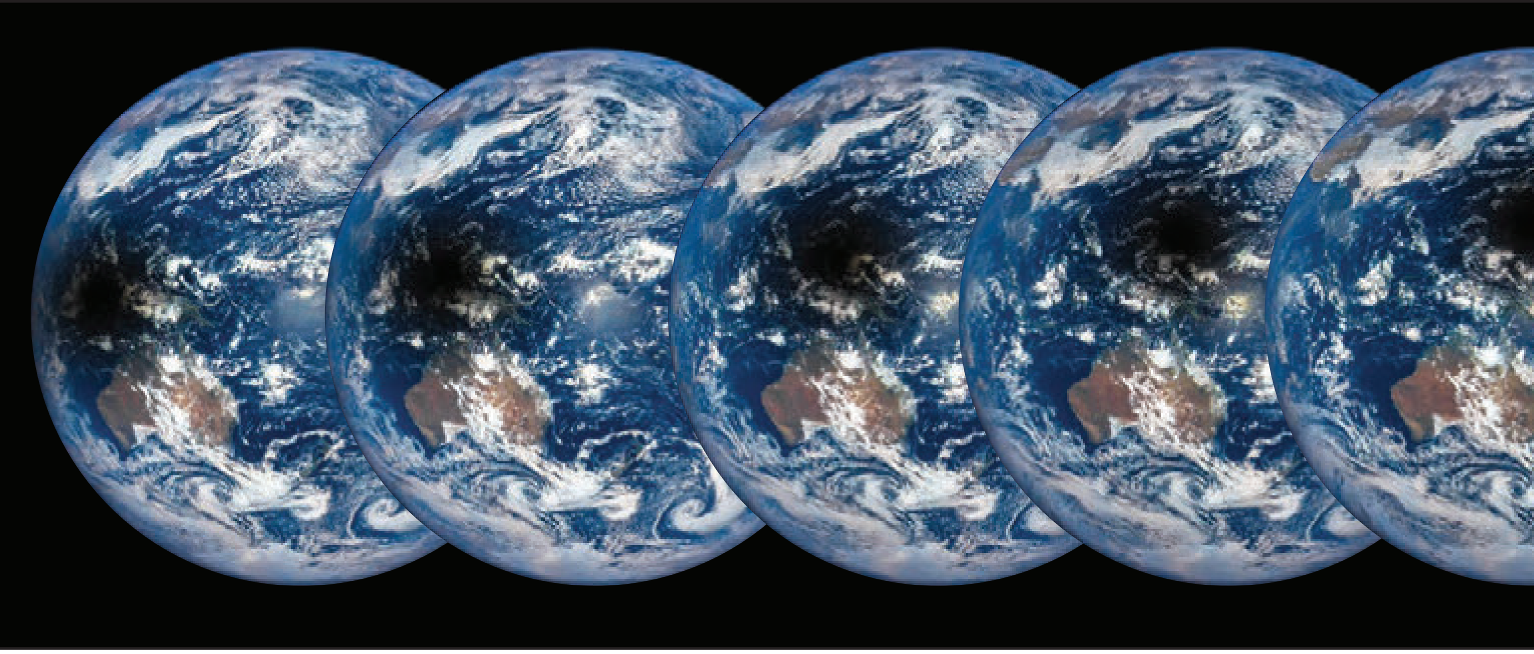
A key document showing knowledge of eclipse cycles is the Dresden Codex, one of four surviving Mayan picture books that include astronomical tables and almanacs. The Dresden Codex (named for the German city with the library that houses the document) contains vividly colored black and red glyphs and blue and yellow figures painted on the flattened bark of the wild ficus tree. In addition to a series of 260-day almanacs and precise data on the motion of Venus, the Dresden Codex contains several pages of eclipse tables. These tables show groupings of specific numbers: a series of the numeral 177 followed by the numeral 148 followed by the picture glyph for an eclipse. The numbers represent days, and the cumulative total of days recorded on a several pages spans a period of more than 32 years.

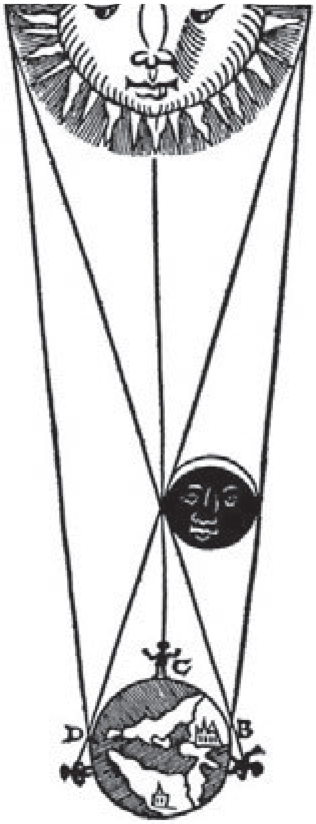
In his 1980 book *Skywatchers of Ancient Mexico*, Anthony F. Aveni shows how these tables are related to eclipses. The numbers 177 and 148 are near exact multiples of 6 synodic months (6 x 29.53 = 177.18 days) and 5 synodic months (5 x 29.53 = 147.65 days). Once an eclipse is observed, these numbers can be used to count the days until the next "danger period" (what today we call an eclipse season) during which an eclipse may occur. Three intervals – 177 days, 325 days (177 + 148), and 354 days (177 + 177) – apply to either solar or lunar eclipses. For example, the table on page 84 of this book shows that the next total solar eclipse after the one on Dec.14, 2020, occurs 355 days later on December 4, 2021. Similarly, the two total lunar eclipses in 2018 – on January 31 and July 27 – are separated by 177 days.

The eclipse table in the Dresden Codex even makes allowances for small corrections necessary over time. In a few instances, the number 178 appears in place of 177, indicating the need to add an extra day to the cycle. This would apply to the 2020-2021 interval discussed above (177 + 178 = 355 days). The expression of these complex cosmic cycles through a pair of numbers (177 and 148), along with the means to periodically correct the intervals based on observations, represents an amazing feat of understanding. One can only speculate what other Mesoamerican achievements would be worthy of our marvel today had more of their historical documents survived the onslaught of Western civilization.

Top: *The Pleiades star cluster (visible in the constellation Taurus) held particular significance for Mayan astronomers.*

Above: *Pages 52 and 53 of the Dresden Codex show three large pictures, each representing an eclipse. Many of the surrounding glyphs stand for misery, malevolence, and death – all of which the Mayans supposedly associated with eclipses.*





Above: *Solar eclipse diagram from Peurbach's* Theoricæ Novæ Planetarum *(1553).*

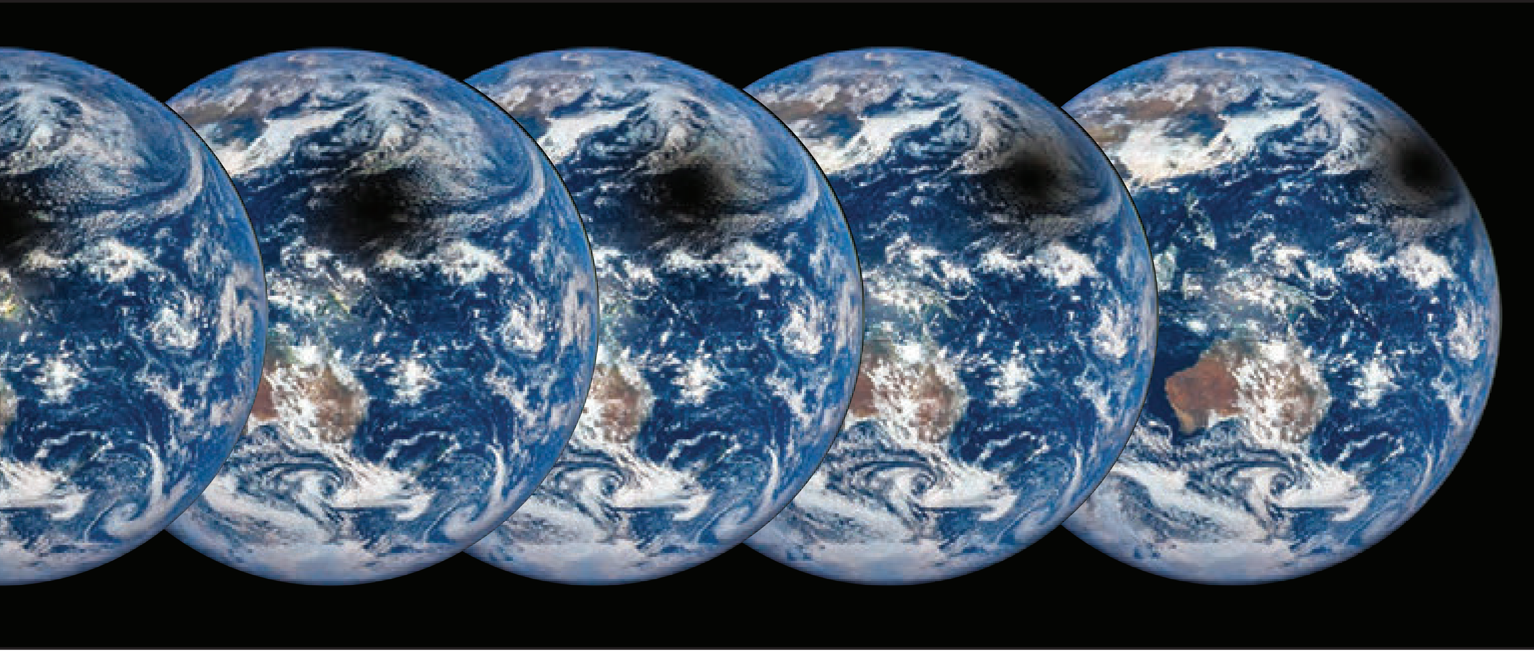
MOTION OF THE MOON'S SHADOW

Ancient stone monuments in various parts of the world show that the builders had all the information needed to predict eclipses, including a way of keeping track of the nodes of the lunar orbit. The position of these invisible points in space – sometimes symbolized as dragons or serpents – helps determine the path of the Moon's shadow as it moves across the Earth toward the east during an eclipse.

Why does the shadow move eastward? Both the Moon and the Sun "rise" in the east and "set" in the west. This apparent motion across the sky (from east to west) is the result of the daily rotation of the Earth. Our planet is steadily spinning eastward; thus objects in the heavens (including the Sun and the Moon during an eclipse) seem to move toward the west. For a place in the path of totality, the entire duration of an eclipse (from first contact until fourth contact) is about two hours. During that time the Sun and Moon move through a part of their path across the sky from east to west.

The Moon's shadow, however, moves in the opposite direction: eastward. This happens because the Moon is revolving in its orbit from west to east. The umbra moves eastward with the Moon as it passes between the Sun and the Earth. This creates the effect of the Sun seeming to overtake the Moon during an eclipse. Because the Sun is farther away, it passes westward behind the Moon and casts a shadow that moves eastward on the Earth.

As the umbra sweeps eastward, an observer located in the path is also moving eastward due to the rotation of the Earth. But the Moon's shadow moves faster than any point on our rotating planet; the umbra always overtakes a stationary observer in its path. The faster the shadow is moving, the shorter is the duration of totality. How fast the umbra moves over a point on the Earth's surface depends mainly on two factors: (1) the latitude (distance from the equator) of the point in the path, and (2) the time of day totality occurs at that point.

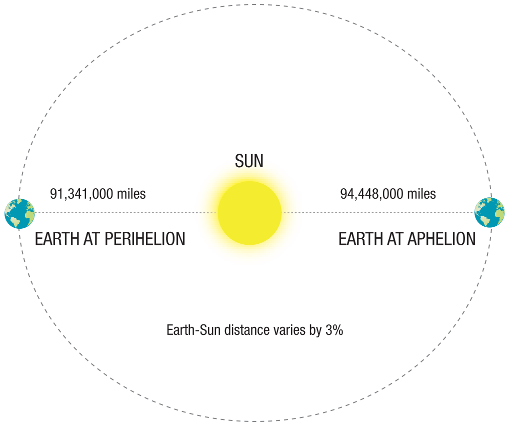


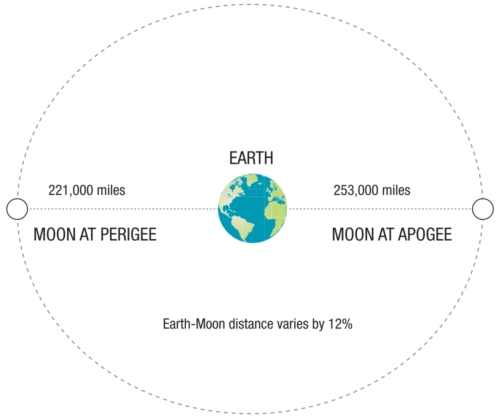
Above: *Sequence of satellite photos (left to right) of the Moon's shadow moving eastward across the Earth during the total solar eclipse on March 9, 2016. Notice how the Earth rotates about 45 degrees from the start to the finish of the eclipse (about 3 hours).*

The first factor is the latitude. A point on the equator travels the complete circumference of the Earth (nearly 25,000 miles) in twenty-four hours, a rate of about 1,040 miles per hour. Points at higher latitudes (either farther north or farther south) don't have as far to go around the Earth in a day's rotation. The rotational speed of a point on the Earth becomes progressively slower at greater and greater distances from the equator. But the umbra's speed through space in the vicinity of the Earth is the same (about 2,100 miles per hour) regardless of latitude. The difference between this value and the speed of the point on the Earth is the speed of the umbra across that point. The result is that the shadow moves more slowly in the tropics (within 23½ degrees latitude of the equator) and moves faster at points of greater latitude.

The other major factor affecting the speed of the shadow is the time of day the eclipse takes place. The umbra moves slowest across places where totality happens at noontime. When totality occurs earlier or later in the day, the umbra strikes the Earth at an oblique angle. The shadow at sunrise or sunset moves faster across the land or water than if it were closer to being perpendicular to the Earth's surface.

The combination of these two factors – latitude and time of day – determines the speed of the umbra. The umbra moves slowest when totality occurs at noon in the tropics. The speed is important because it affects the duration of the eclipse: the slower the shadow, the longer the time of totality. But another factor is just as important in determining the duration of totality: the width of the path made by the Moon's shadow.





Top: *Diagram showing the variation in the Earth-Sun distance over one year.*

Above: *Diagram showing the variation in the Earth-Moon distance over one month.*

Opposite: *James Ferguson's "Eclipsareon" from* Chamber's Encyclopædia *(London, 1779). This astronomical contrivance could exhibit the "time, quantity, duration, and progress of solar eclipses." The date and time of an eclipse would first be set on the dials at the base of the globe. Then the frame containing the screen of concentric circles would be adjusted for the Moon's latitude. A light source (such as a candle) would be used to project the shadow. By turning the crank, the circular screen would move across the frame, casting its simulated umbra on the rotating globe.*

THE WIDTH OF THE PATH

The width of the shadow reaching the Earth depends on how far away the Sun and the Moon are at the time of the eclipse. These distances vary because the orbits of the Earth and the Moon are not perfect circles, but ellipses. In an elliptical orbit, there are two extreme points: one where the orbiting body is closest to the body it revolves around and another point where the orbiting body is farthest away. The umbra reaches its maximum width if an eclipse occurs when the Earth is farthest from the Sun, called *aphelion*, and when the Moon is closest to the Earth, called *perigee*. (These terms are formed with the prefixes *ap-* or *apo-* meaning "from," and *peri-* meaning "near"; *helion* refers to the Sun and *gee* to the Earth.)

Under these conditions the Sun appears slightly smaller and the Moon slightly larger than average. Thus the Sun can be covered by the Moon for a longer time. A wide umbra moving slowly across the Earth produces a long total eclipse. The longest possible duration of totality, 7 minutes and 31 seconds, occurs when the following conditions are met:

(1) The observer is at the equator

(2) Totality occurs there at noon

(3) The Earth is farthest from the Sun (aphelion)

(4) The Moon is closest to the Earth (perigee)

The total eclipse of June 20, 1955, the longest of the twentieth century, came close to meeting these conditions: it reached a maximum duration of 7 minutes and 7.7 seconds in the South China Sea. On July 16, 2186, the sun will be eclipsed by the moon for 7 minutes and 29 seconds, very close to the theoretical maximum.

The Earth-Sun distance and the Earth-Moon distance vary in regular cycles. The Earth orbits the Sun once a year, reaching its closest point (perihelion) in early January and its farthest point (aphelion) in early July. However, these orbital points are not stationary; each year they occur a fraction of a day later in time. Their slow revolution around the Sun takes about 20,000 years for a complete cycle. Ten thousand years ago the positions were reversed: perihelion was reached in July and aphelion in January. Ten thousand years from now this will again be the situation.

The Moon's orbit follows a similar motion around the Earth, but the time scale is greatly reduced. The Moon returns to its perigee (or apogee) in about two days less than it takes for a full Moon cycle (synodic month). This shorter 27½-day cycle is called the *anomalistic month*. This is the time it takes for the Moon to return to its original position the same distance from the Earth. These orbital points (lunar perigee and apogee) are slowly revolving around the Earth, making a complete revolution every 8.85 years.

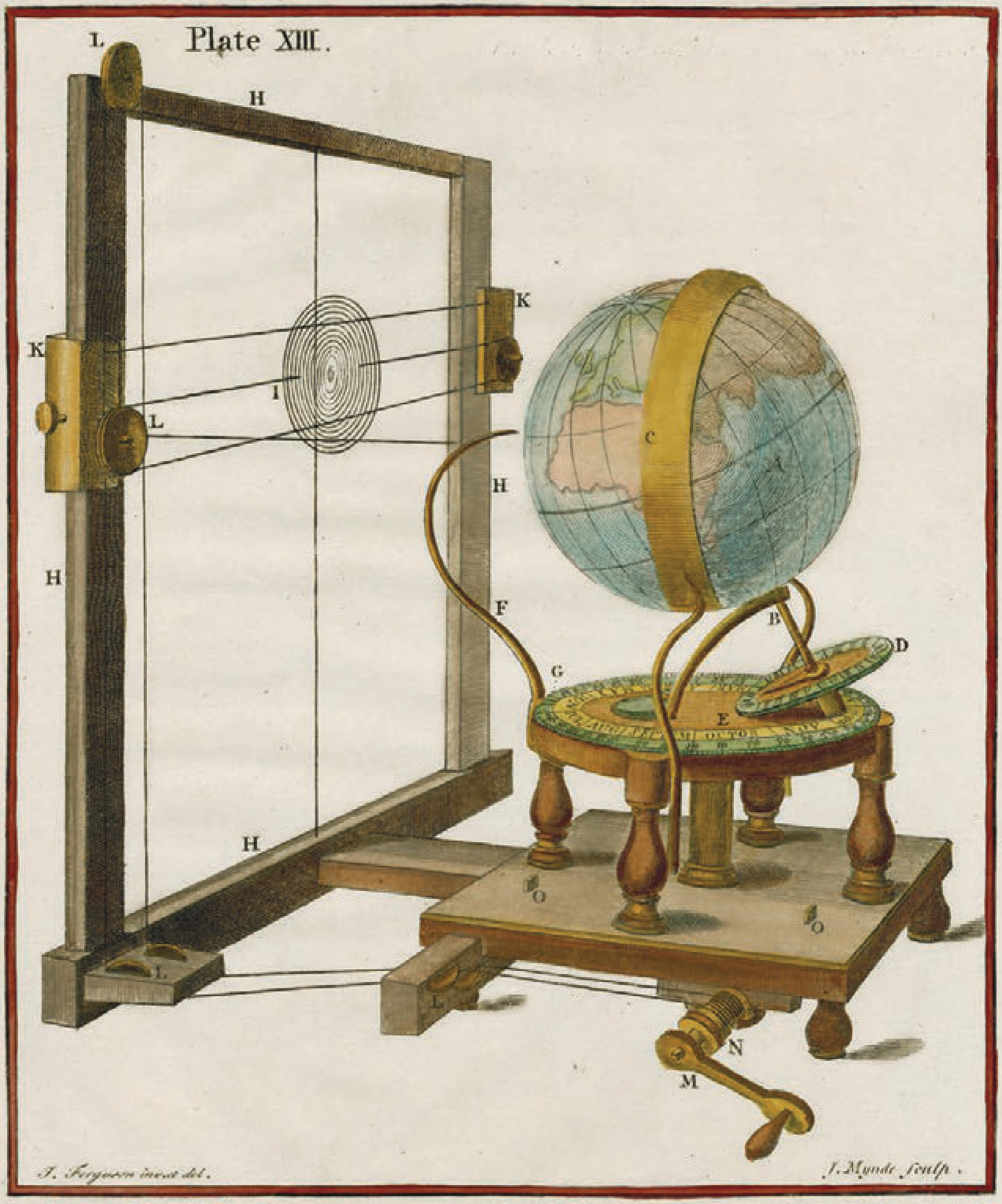


Plate XIII.
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TOTAL SOLAR ECLIPSES (1923-2017)

The table on these two pages lists all the total and annular-total solar eclipses from 1923 to 2017. Each eclipse is described by its date, the maximum duration of totality, the maximum width of the path of totality, and the major geographical areas along the path from which totality is visible. The six eclipses shown in **bold** are all in the same saros series that includes the August 21, 2017 eclipse. (For a list of total solar eclipses from 2017 to 2061, see page 84.)

* Annular-total (hybrid) eclipse
** Last total eclipse in saros series
*** First total eclipse in saros series

Date	Max Duration (min:sec)	Max Width (miles)	Path of Totality
1923 SEP 10	3:36	106	Pacific Ocean, S. California, Mexico
1925 JAN 24	2:32	130	Great Lakes, NE United States, Atlantic Ocean
1926 JAN 14	4:10	92	Africa, Indian Ocean, Borneo
1927 JUN 29	**0:50**	**48**	**England, Scandinavia, Arctic Ocean, Siberia**
1928 MAY 19**			(Umbra barely touched Antarctica)
1929 MAY 9	5:06	122	Indian Ocean, Malaya, Philippines
1930 APR 28*	0:01	1	Pacific Ocean, United States, Canada
1930 OCT 21	1:55	54	S. Pacific Ocean
1932 AUG 31	1:44	104	Arctic Ocean, Canada, New England
1934 FEB 14	2:52	79	Borneo, Pacific Ocean
1936 JUN 19	2:31	83	Greece, Turkey, Soviet Union, Japan
1937 JUN 8	7:04	156	Pacific Ocean, Peru
1938 MAY 29 ***	4:04	420	S. Atlantic Ocean
1939 OCT 12	1:32	276	Antarctica
1940 OCT 1	5:35	137	Colombia, Brazil, Atlantic Ocean, S. Africa
1941 SEP 21	3:21	91	Soviet Union, China, Pacific Ocean
1943 FEB 4	2:39	146	Japan, Pacific Ocean, Alaska
1944 JAN 25	4:08	90	Peru, Brazil, W. Africa
1945 JUL 9	**1:15**	**57**	**U.S., Canada, Greenland, Scandinavia, Soviet Union**
1947 MAY 20	5:13	124	S. America, Atlantic Ocean, Africa
1948 NOV 1	1:55	53	Africa, Indian Ocean
1950 SEP 12	1:13	90	Arctic Ocean, Siberia, Pacific Ocean
1952 FEB 25	3:09	89	Africa, Middle East, Soviet Union
1954 JUN 30	2:35	96	U.S., Canada, Iceland, Europe, Middle East
1955 JUN 20	7:07	159	Indian Ocean, Southeast Asia, Philippines, Pacific Ocean

1956 JUN 8	4:44	269	S. Pacific Ocean
1957 OCT 23**			(Umbra barely touched Antarctica)
1958 OCT 12	5:10	131	Pacific Ocean, Chile, Argentina
1959 OCT 2	3:01	76	New England, Atlantic Ocean, Africa
1961 FEB 15	2:45	164	Europe, Soviet Union
1962 FEB 5	4:08	92	Borneo, New Guinea, Pacific Ocean
1963 JUL 20	**1:39**	**63**	**Pacific Ocean, Alaska, Canada, Maine**
1965 MAY 30	5:15	124	New Zealand, Pacific Ocean
1966 NOV 12	1:57	53	Pacific Ocean, S. America, Atlantic Ocean
1967 NOV 2***			(Umbra barely touched Antarctica)
1968 SEP 22	0:39	68	Soviet Union, China
1970 MAR 7	3:27	99	Pacific Ocean, Mexico, Eastern U.S., Canada
1972 JUL 10	2:35	111	Siberia, Alaska, Canada
1973 JUN 30	7:03	160	Atlantic Ocean, Central Africa, Indian Ocean
1974 JUN 20	5:08	216	Indian Ocean, Australia
1976 OCT 23	4:46	125	Africa, Indian Ocean, Australia
1977 OCT 12	2:37	63	Pacific Ocean, Colombia, Venezuela
1979 FEB 26	2:49	195	NW United States, Canada, Greenland
1980 FEB 16	4:08	93	Africa, Indian Ocean, India, Burma, China
1981 JUL 31	**2:02**	**68**	**Soviet Union, Pacific Ocean**
1983 JUN 11	5:10	125	Indian Ocean, Indonesia, New Guinea
1984 NOV 22	1:59	53	New Guinea, Pacific Ocean
1985 NOV 12	1:58	430	Antarctica
1986 OCT 3*	0:01	1	N. Atlantic Ocean
1987 MAR 29*	0:07	3	S. Atlantic Ocean, Africa
1988 MAR 18	3:46	109	Sumatra, Borneo, Philippines, Pacific Ocean
1990 JUL 22	2:32	130	Finland, Soviet Union, Aleutian Islands
1991 JUL 11	6:53	160	Hawaii, Mexico, Central America, Colombia, Brazil
1992 JUN 30	5:20	182	S. Atlantic Ocean
1994 NOV 3	4:23	117	South America (Peru, Bolivia, Paraguay, Brazil)
1995 OCT 24	2:09	48	Iran, India, Southeast Asia
1997 MAR 9	2:50	220	Mongolia, Siberia
1998 FEB 26	4:08	94	Galapagos Islands, Panama, Colombia, Venezuela, Guadeloupe, Montserrat, Antigua
1999 AUG 11	**2:22**	**69**	**Europe, Middle East, India**
2001 JUN 21	4:56	124	Atlantic Ocean, Southern Africa
2002 DEC 4	2:03	54	Southern Africa, Indian Ocean, Australia
2003 NOV 23	1:57	308	Antarctica
2005 APR 8*	0:42	100	S. Pacific Ocean
2006 MAR 29	4:06	114	Africa, Turkey, Russia
2008 AUG 1	2:27	147	Greenland, Russia, China
2009 JUL 22	6:38	160	India, China, Pacific Ocean
2010 JUL 11	5:20	160	S. Pacific Ocean, southern tip of South America
2012 NOV 13	4:02	111	Australia, Pacific Ocean
2013 NOV 3*	1:39	35	Atlantic Ocean, central Africa
2015 MAR 20	2:46	287	N. Atlantic Ocean, Norwegian Sea, Svalbard
2016 MAR 9	4:09	96	Indonesia, N. Pacific Ocean
2017 AUG 17	**2:40**	**71**	**United States (from Oregon to South Carolina)**

REPETITION OF ECLIPSES

Where a total eclipse is visible depends mainly on three factors. First, the longitude of the eclipse path is determined by which part of the Earth happens to be facing toward the Sun and the Moon when the eclipse occurs. Second, the latitude of the eclipse path is a function of how close the Moon is to a node when the eclipse occurs. The closer to a node, the nearer to the tropics will the umbra pass across the Earth. And third, the area covered by totality depends on the width (and length) of the path. The wider the path, the more locations experience totality.

Astronomers use these and other factors to compute the precise path and timing for a given eclipse. The repetition of eclipses follows very regular patterns in time. Eclipse seasons and saros cycles come and go like clockwork. Of the four types of solar eclipses, partial eclipses are the most common. The following table gives values for the relative distribution of each type of eclipse:

Type of Solar Eclipse	Proportion of All Solar Eclipses
Partial	35%
Annular	33%
Total	28%
Annular-total	4%

But the main attraction of eclipses is totality. The repetition of total solar eclipses at a given place on the Earth, however, does not seem to follow any discernible pattern. The map on the next page shows all total eclipse paths across North America between 1918 and 2024. For example, Carbondale, Illinois is in the path of totality for the eclipses in 2017 and 2024. Yet many parts of North America have not experienced a total eclipse for centuries.

Partial phases of solar eclipses can be seen about every 2½ years from any particular spot on the Earth. The best estimate for total eclipses is to say they recur at the same location about every 360 years on the average. This figure is based on the average area of the paths of totality, the total surface area of the Earth, and the overall frequency of total eclipses. But the actual circumstances for particular locales vary, sometimes widely, from this estimate. The table below helps illustrate the apparent random nature of the recurrence of eclipses at the same place. The examples were chosen, not to prove any lack of pattern, but to present the flavor of the variation involved.

Location	Dates of Consecutive Total Eclipses	Years in Interval
London	29 OCT 878 – 22 APR 1715	837
Jerusalem	30 SEP 1131 BCE – 4 JUL 336 BCE	795
Great Pyramid of Egypt	1 APR 2471 BCE – 29 JUN 2159 BCE	312
Stonehenge	8 MAY 1169 BCE – 7 MAY 1066 BCE	103
Goldendale, Washington	9 JUN 1918 – 26 FEB 1979	61
Yellowstone National Park	29 JUL 1878 –1 JAN 1889	11
Tomb of Tutankhamun	31 MAY 957 BCE – 22 MAY 948 BCE	9
Carbondale, Illinois	21 AUG 2017 – 8 APR 2024	7
Lake Okeechobee, Florida	19 AUG 2259 – 22 DEC 2261	2½
Southern New Guinea	11 JUN 1983 – 22 NOV 1984	1½

Total Solar Eclipse Paths Across North America (1918-2024)

CHAPTER THREE

How to Observe an Eclipse

HOW TO OBSERVE AN ECLIPSE

The spectacular sight of a total solar eclipse is for most of us a once-in-a-lifetime event. Unless you're an astronomer or an avid eclipse follower, you'll probably get only one chance to see it. It's estimated that only one in a thousand people ever experiences totality. This wondrous spectacle of the complete halo around the Sun can't be seen under any other earthly circumstances. Astronomers are able to observe part of the corona without an eclipse using a *coronagraph*, a kind of telescope invented in 1931. But the naked-eye view of the corona – the spectacular visual centerpiece of an eclipse experience – is visible only from within the path of totality.

In addition to the sight of the corona, there are other marvelous phenomena to observe during a total eclipse. The daytime darkness and the swift onset of the Moon's shadow add to the drama of the few short minutes the corona is visible. Shadow bands, Baily's beads, the reaction of plants and animals – all add to the excitement and impact of the inexorable alignment of Sun, Moon, and Earth. It's simply a matter of being in the right place at the right time … and knowing what to look for.

The time and location of each eclipse, of course, is different. But the observation site considerations and the viewing techniques are essentially the same for all total solar eclipses. The eclipse of August 21, 2017, is used as the example in this chapter to illustrate how to observe an eclipse.

Opposite: *Path of the Moon's shadow on the Earth during the "New Year's Day Eclipse" of January 1, 1889. The illustration shows a direct telegraph line from San Francisco to New York that was made available to the astronomers in California for the purpose of sending word of the results of their eclipse observations to observers stationed in the path farther east.*

THE PATH OF TOTALITY

Early in the morning of August 21, 2017, as seen from a point in the Pacific Ocean about 1,500 miles northwest of Hawaii, the Sun rises. But instead of the familiar orange ball coming up over the horizon, the blackened disk of the eclipsed Sun appears. The umbra, the complete shadow of the Moon, makes its first grazing contact with the edge of the Earth at sunrise and the total eclipse begins. The shadow races eastward at thousands of miles per hour toward the west coast of United States, where the Sun is already up this Monday morning.

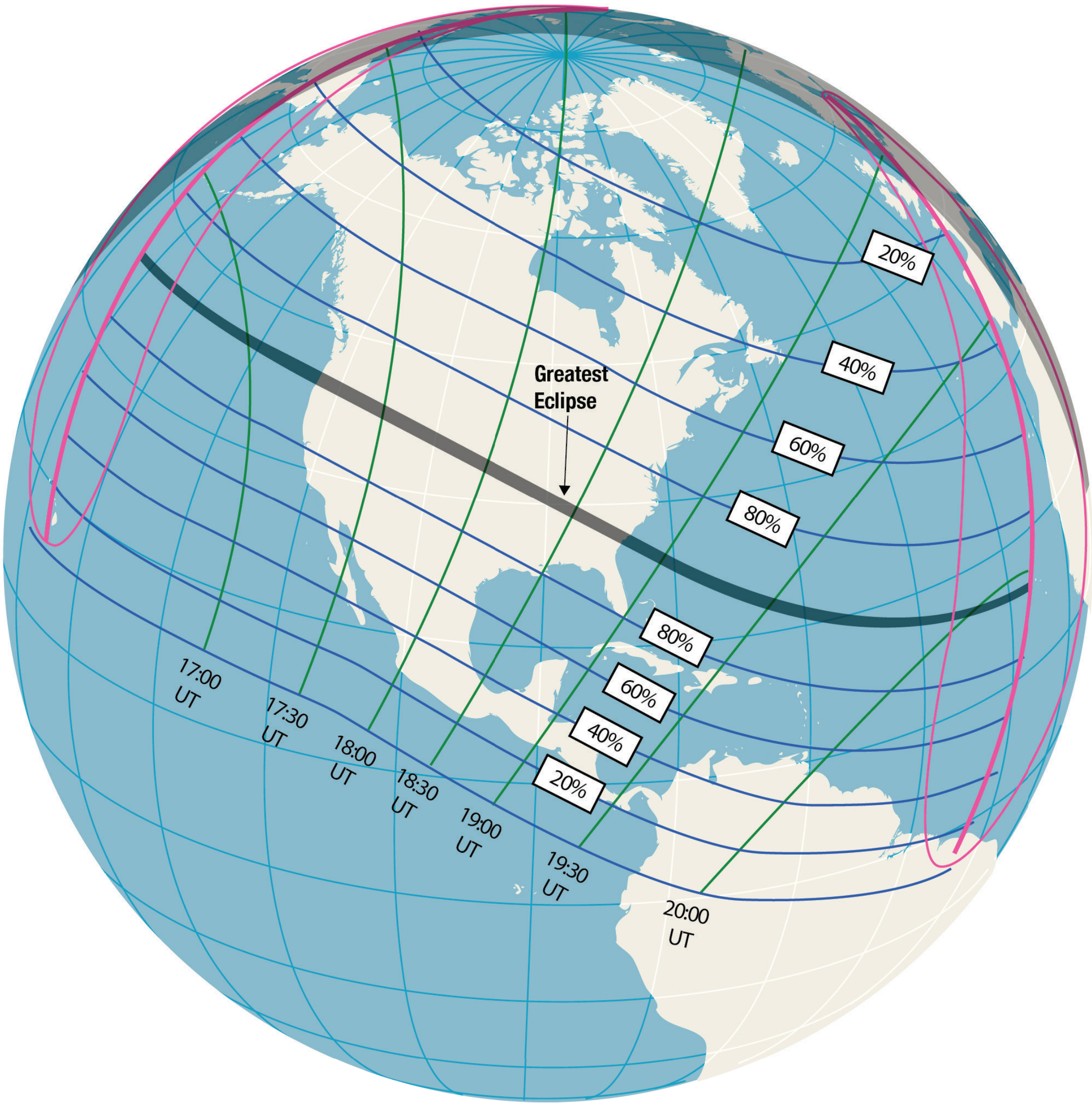
The umbra first touches land near the Pacific coast town of Lincoln Beach, Oregon, at 10:16 a.m. local time (PDT). The shadow, moving at more than 2,400 miles per hour, sweeps along a 62-mile-wide path blotting out the Sun for up to 2 minutes across the state. As the eclipse continues inland, the shadow slows its movement and the path gets slightly wider, covering parts of Idaho, Wyoming, Nebraska, Missouri, and southern Illinois. Here the event reaches greatest eclipse at a point near Carbondale, Illinois. The shadow reaches its maximum width (71 miles) and totality reaches its maximum duration (2 minutes and 40 seconds).

Opposite: *The path of the Moon's shadow on August 21, 2017, is shown on the map at 30-minute intervals as the shadow sweeps from west to east. The blue lines running east-west show curves of equal magnitude of the partial phases at 20% increments, indicating the greatest percentage of the Sun covered by the Moon as seen from points along these lines. The farther away from the path of totality, the less of the Sun's disk is blocked out. (For more details on the path of totality, see the map on pages 72-73.)*

By now the eclipse is about half over. At its slowest point, the shadow is moving about 1,450 miles per hour. It begins picking up speed as it moves southeast over parts of Kentucky, Tennessee, North Carolina, Georgia, and South Carolina, where it heads out into the Atlantic Ocean at 2:47 pm local time (EDT). It takes only about an hour and a half for the Moon's shadow to sweep across America. Finally, the total eclipse ends at sunset about 400 miles southwest of the small island nation of Cape Verde off the Atlantic coast of Africa. The Moon's shadow leaves the Earth and continues its course through space.

The passage of the Moon's umbra over the Earth, from sunrise in the Pacific to sunset in the Atlantic, takes a little more than three hours for this eclipse. During that time it travels about 8,600 miles across the surface of the Earth. That's an average speed of about 2,700 miles per hour. The area covered by the path of totality amounts to approximately 500,000 square miles, or about 0.26 percent of the total surface area of the planet. The path of totality touches land only in United States, including a number of major cities. The partial phases of the eclipse are visible from all of North America, where every state in the continental U.S. and much of Canada will experience at least a 60% partial eclipse

August 21, 2107 Total Solar Eclipse



At the point of Greatest Eclipse:
Duration of totality = 2 min 40 sec
Width of path = 71 miles

Times are given as Universal Time (UT)
Subtract 7 hours for Pacific Daylight Time
Subtract 6 hours for Mountain Daylight Time
Subtract 5 hours for Central Daylight Time
Subtract 4 hours for Eastern Daylight Time
(For areas not observing Daylight Saving Time subtract one additional hour)

Eclipse Predictions by Fred Espenak, NASA's GSFC

SELECTING AN OBSERVATION SITE

The partial phases of a total solar eclipse are usually visible over a wide area (all of North America and parts of South America on August 21, 2017). But only within the path of totality can you see the spectacular and striking effects. The difference between experiencing a total eclipse and a partial eclipse is, literally, "the difference between night and day." Those who live within the path or take the opportunity to travel there have the chance to be rewarded with one of the most fleeting and beautiful visions of Nature's grandeur.

Your choice of a site within the path should be guided by four main factors:

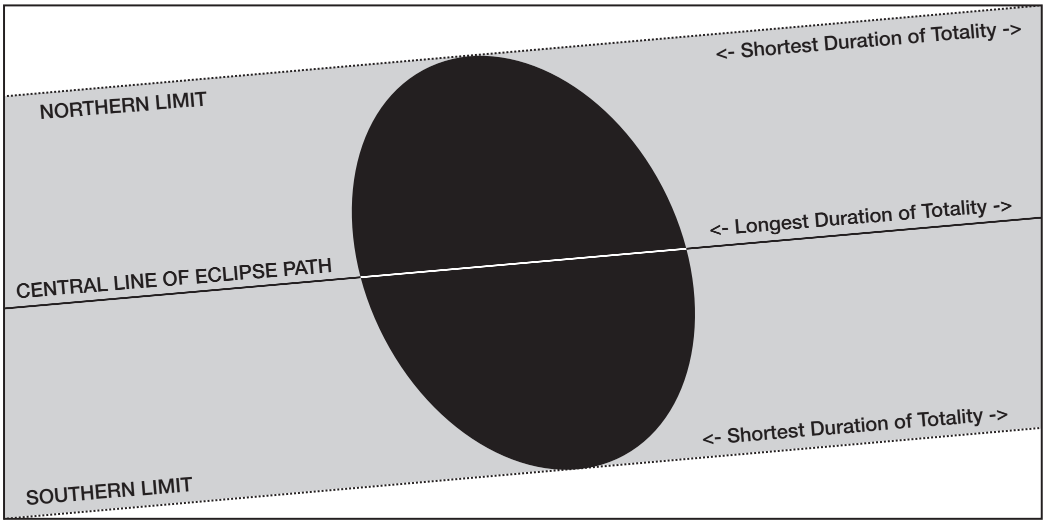
1. Duration of totality at the site
2. Unobstructed view of the Sun
3. Chances for clear skies
4. Opportunity for last-minute mobility

The map on pages 72-73 shows the path of totality over the United States on August 21, 2017, from Oregon to South Carolina. For any given locale, a point nearer the central line of the eclipse has more time in totality; this is because the Moon's shadow, which forms an ellipse on the surface of the Earth, is wider nearer the center of the path. The diagram below shows this variation across the path. If you are located just within the path, totality will not last very long – less than a minute. However, the "edge phenomena" of a total eclipse (Baily's beads, diamond-ring effect, and view of the chromosphere) will last longer there.

To ensure an unobstructed view of the eclipse, you need to know approximately where the Sun will be in the sky. You don't want any trees, buildings, or mountains, for example, blocking your view. An easy way to determine this is to look for the Sun from your vantage point a day or two before the eclipse at the same time of day that totality occurs at your location. This will tell you if anything is in your way.

The location of the Sun in the sky at the time of totality varies according to geographic location. In Oregon, where the eclipse occurs at mid-morning, the Sun's angle above the true horizon (altitude) is about 40 degrees, almost halfway above the horizon. As the shadow moves eastward, the Sun's altitude increases to almost 65 degrees near maximum eclipse in Illinois, and then gradually sinks slightly as it moves across the eastern states in the path. It's important to realize that the angle of

Right: *The width of the shadow and the duration of totality decrease farther away from the central line of the eclipse.*



altitude is measured from the true or level horizon. This doesn't account for any hills or mountains visible from your location. Also, if you're on a hill or tall building with a good view of the west, you may get a chance to see the approach of the Moon's shadow as it races toward you across the surface of the Earth.

The compass direction to look for the Sun at the time of totality depends on the time of day at your location. In the morning in Oregon, the totally eclipsed Sun will appear in the east-southeast. As the shadow moves on, the Sun's location shifts toward the south: at about one p.m. local time in Missouri, the Sun is located due south. By the time the shadow reaches South Carolina, the Sun is visible in the southwest.

Roses have thorns, and silver fountains mud;
Clouds and eclipses stain both Moon and Sun.

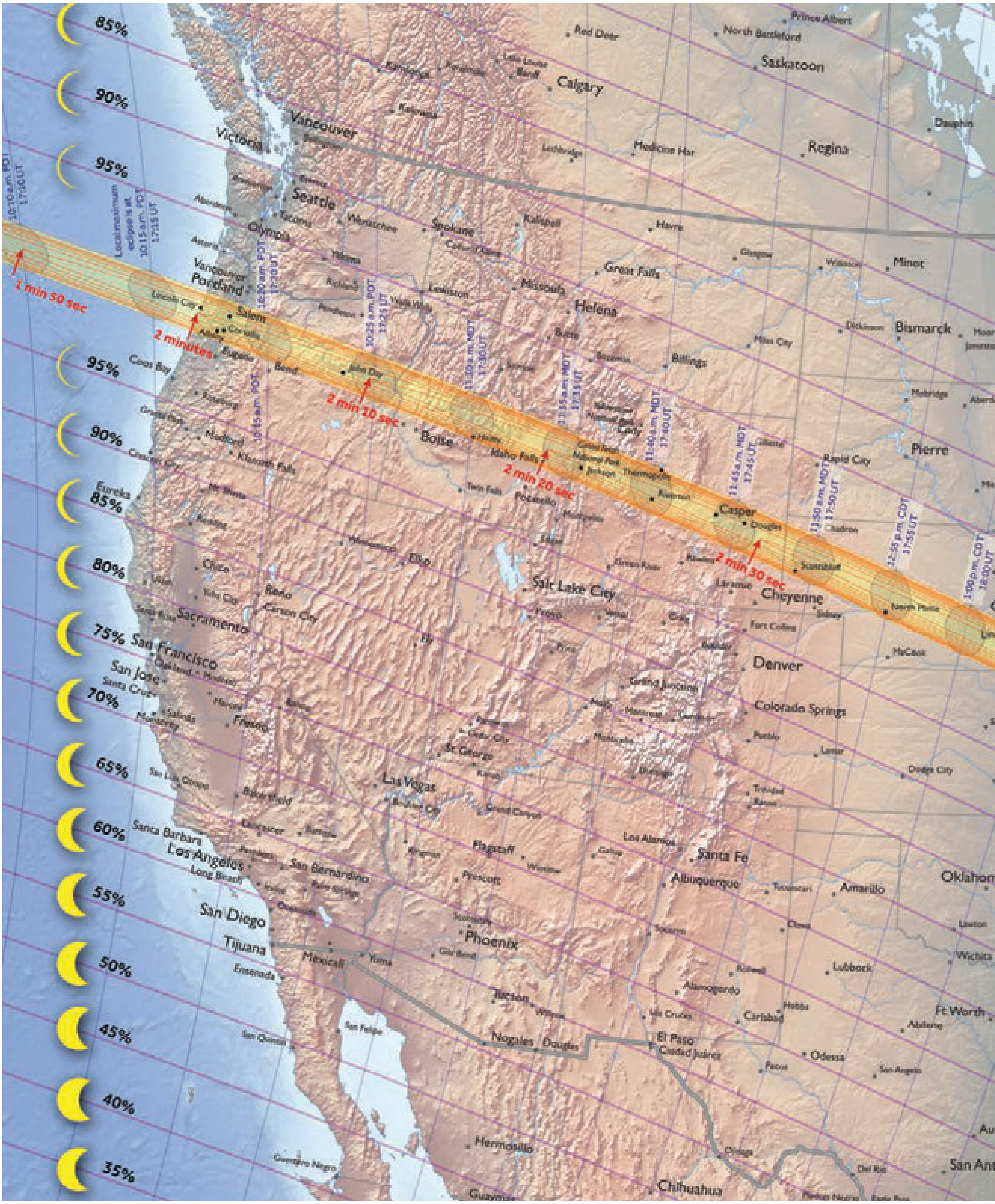
– Shakespeare, *Sonnet XXXV*

The third factor in choosing a site is the weather. Unless you fly above the clouds to observe an eclipse, you'll always have to take some risk on the weather. But there is a lot you can do to optimize your chances to see the eclipse. The meteorological term for cloudy skies is "sky cover." It is measured in numbers from 0 to 10, with each number representing a tenth. (For example, a sky cover of 4 indicates 40% overcast, or 60% clear.) Weather Bureau records will show the average sky cover for different places along the path at the time of year of the eclipse.

The weather prospects for the August 21, 2017 eclipse are generally very good. August is a sunny month over much of the United States, but the chances for cloudy weather vary greatly from one location to another. For example, locations on the Columbia Plateau east of the Cascade Range in Oregon average up to 70% clear skies. Locations farther east experience diminishing prospects due to summer thunderstorms, where east of the Mississippi River the chances for clear skies are as low as 30%.

These sky cover predictions are only general estimates covering large areas. Local weather conditions can be very different for places a short distance apart. Check the local weather forecasts a few days before the event to get a better idea of cloud movements. You'll want to avoid places likely to have fog; also, stay away from mountain ridges where clouds tend to gather.

Perhaps the greatest asset in finding clear skies for an eclipse is the fourth factor: last minute mobility. Driving a few miles to a clearer location could save the day for you. In this regard, you may want to select an area that provides easy east-west mobility, most likely on an Interstate highway, such as I-70 between Kansas City and St. Louis. Of course, a heavy concentration of eclipse chasers may produce traffic gridlock. Please drive safely!

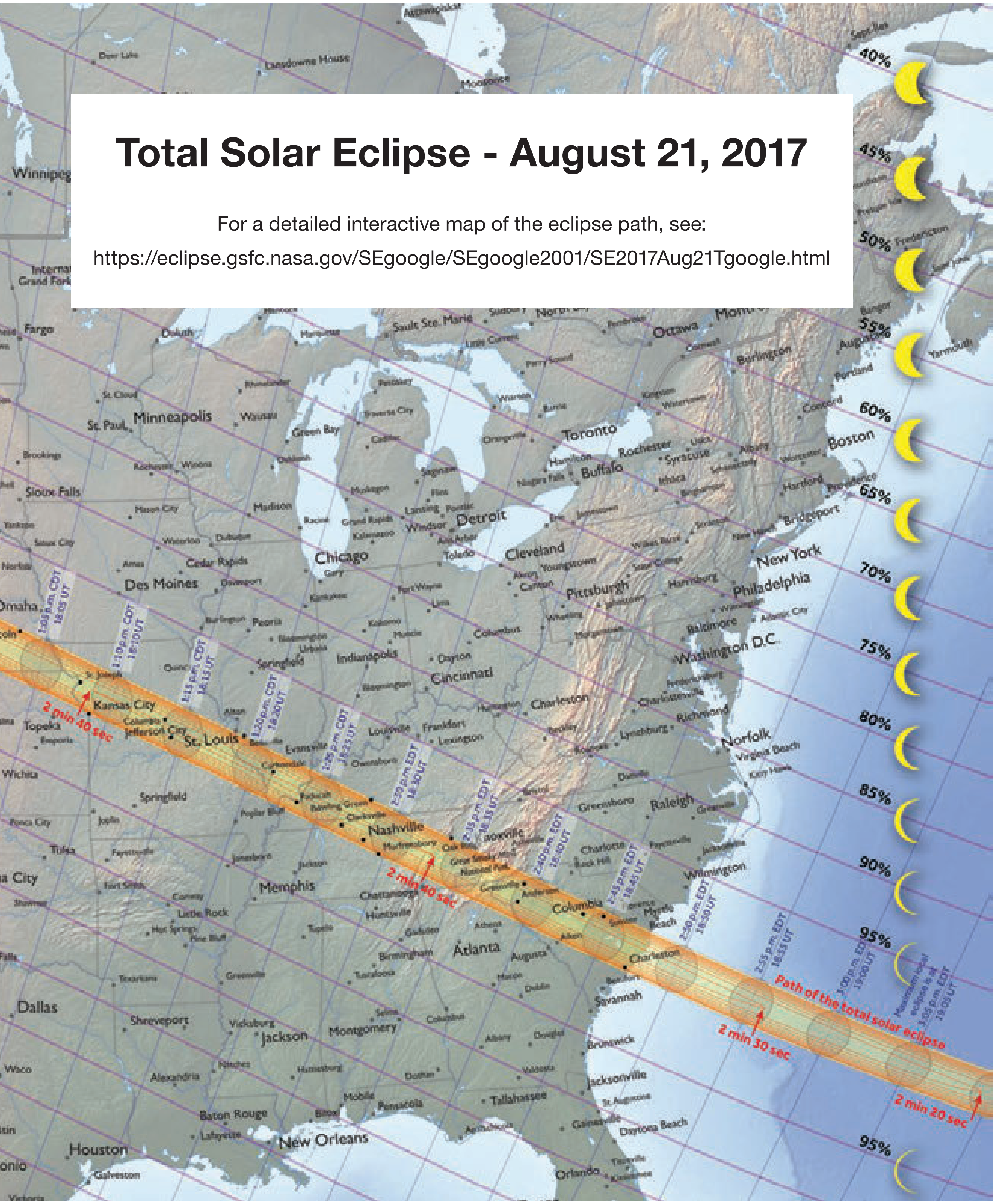


Map provided by Michael Zeiler, GreatAmericanEclipse.com

Total Solar Eclipse - August 21, 2017

For a detailed interactive map of the eclipse path, see:

https://eclipse.gsfc.nasa.gov/SEgoogle/SEgoogle2001/SE2017Aug21Tgoogle.html



OBSERVATION SAFETY PRECAUTIONS

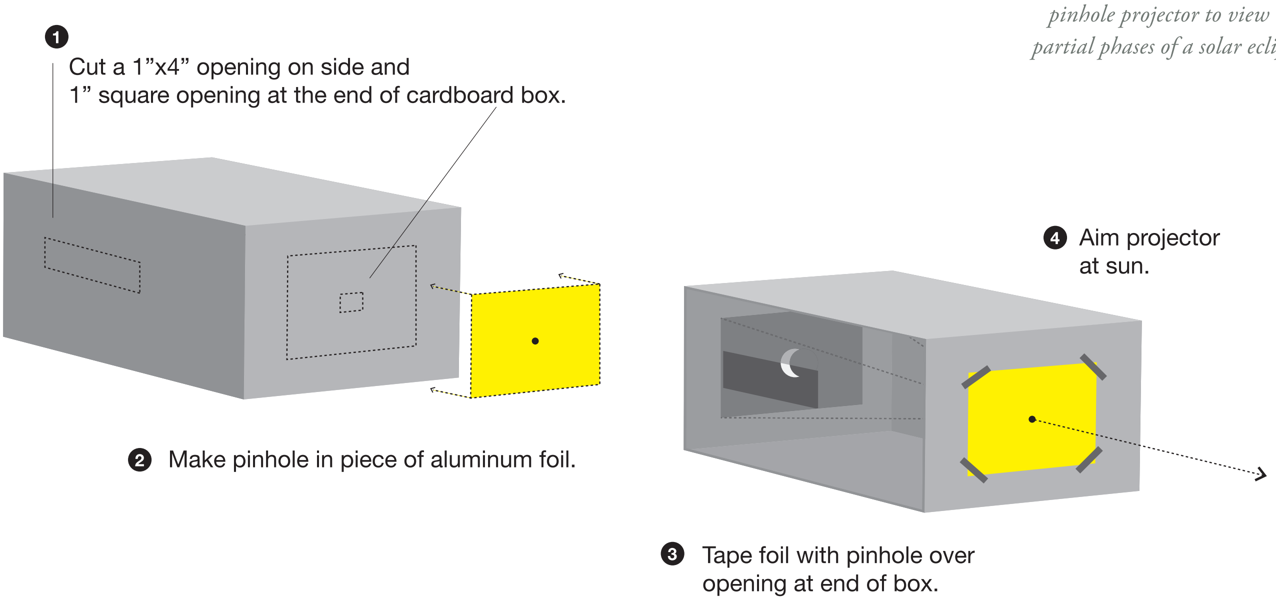
The total phase of a solar eclipse, when the sky is dark and the corona is visible around the Sun, is a beautiful sight. The best way to observe the event during these few brief minutes is simply to look directly at this glimmering halo in the sky. The corona is a million times fainter than the bright disk of the Sun; there is no danger of eye damage when looking directly at the corona or the prominences during totality. Binoculars may reveal even finer detail, but most observers agree that the naked eye is the best "instrument" for viewing the full glory of the event.

For about an hour before and after the total phase the Sun is only partially obscured. This is when it is dangerous to look directly at the Sun. Normally the Sun is too bright to look at anyway. Humans have an instinctual reaction to look away from the bright Sun. But during the partial phases, the Sun does not appear as bright, and you may be tempted to look directly at the Sun. DON'T DO IT! The danger of damaging your eyes does not depend on brightness. As long as any portion of the Sun's disk remains visible it can still cause eye damage.

The lenses of your eyes act as tiny magnifiers; if you look at the partially eclipsed Sun, its rays are focused on the retina of your eyes and can burn them. This is the same sort of thing that happens when you use a magnifying glass to focus the Sun to a pinpoint on paper or leaves to burn a hole in them. The only difference is that it is your eyes that would be burned. Part of the danger lies in the fact that the retina is not sensitive to pain; you wouldn't even feel it happening. But a retinal burn is permanent and irreversible, producing a blank spot in the most vital part of your field of vision.

Astronomers observe the sun directly through professionally manufactured optical filters that screen out the hazardous rays of the Sun. But unless you are trained in their use, it is not recommended that you try this method. And you're taking a big chance if you try to improvise your own filter. During the March 7, 1970, eclipse in the United States there were 145 reported cases of people who damaged their eyes by looking at the partially eclipsed Sun either directly or through sunglasses, exposed film, smoked glass, and the like. None of these homemade devices can be guaranteed safe. Instead, use professionally manufactured "eclipse glasses" made with optical grade film that filters out most of the Sun's rays to protect your eyes from damage during the partial phases of the eclipse. Play it smart and don't take any chances with your precious gift of vision. And… don't forget to remove your eclipse glasses during the minute or two of totality. Otherwise you'll miss the beauty of the solar corona, which is not visible through the filter material.

Below: *Building and using a pinhole projector to view the partial phases of a solar eclipse*



SAFE VIEWING TECHNIQUES

In addition, there are some perfectly safe ways to observe the partial phases of the eclipse without looking directly at the Sun. These methods involve viewing the image of the Sun projected onto some surface; the image can be focused by having the sunlight pass through a pinhole. This is the same effect seen when the light from the partially eclipsed Sun shines through the leaves of a tree, creating tiny crescent images in the shadow on the ground. The diagram above illustrates how to build and use a simple pinhole projector. This is a safe and recommended way to observe the passage of the Moon across the face of the Sun during the partial phases of a solar eclipse. (If the eclipse is televised, it would also be safe to view it on the TV screen.) And don't forget: during the few minutes of totality it's OK to look directly at the Sun's corona.

You might find it interesting to see how you would judge the degree of darkness during totality. Scientists in the past, before sensitive light-measuring instruments were available, carried out elaborate experiments to obtain some measure of the darkness. Comparisons were made to candlelight, moonlit nights, twilight, etc. Reports were given on the readability of instrument dials and various sizes of print. One experimenter even proposed that the opening and closing of plant leaves and blossoms be used as a gauge of the relative darkness in the Moon's shadow. In general, it is darker nearer the center of the path of totality and in clearer weather. (Clouds scatter light.) You may also want to observe shadow bands. Put up a flat white sheet or screen at least three feet wide facing the Sun and look closely for the faint ripples of light a few minutes just before and just after totality.

Because the light of the Sun is blocked out during totality, the sky turns dark and stars and planets become visible. Although this daytime darkness lasts only a few minutes, many of the other objects in the heavens may be seen and identified. For the eclipse on August 21, 2017, the Sun is in the constellation Leo. The brightest object in the sky is Venus, positioned to the right of the eclipsed Sun, with Jupiter looming to the left. Mars, Mercury, and several bright stars may also be visible. On rare occasions (as in 1882 in Egypt) a small comet may be visible.

CAPTURING SOLAR ECLIPSE IMAGES

Taking pictures of a total eclipse can be as simple as aiming your cell phone camera and pushing the button, or as complex as using sophisticated cameras mounted on telescopes driven by motors. You're not likely to get good results with the first method, but you needn't go all the way to the other extreme to produce some satisfying pictures of the corona during totality. The whole field of photography is filled with technical details. The discussion here is intended only as an overview – enough basic information to let you decide if you want to get more details from some of the sources listed as References at the end of the book.

The main problem in using a cell phone or pocket camera to photograph the corona is the short focal length of the lens. Pictures taken with these types of cameras produce a very small image of the black disk of the eclipse. (You can test this in advance by taking a photo of the full Moon; the small image is not very satisfying.) A camera with a lens of greater focal length will produce better results. For example, a 600mm lens will produce a circular image about 1/4 inch in diameter. This is a good fit for 35mm film or for a digital SLR camera, and gives you some leeway for errors in centering the image. There are also telephoto lenses that attach to a cell phone camera. It's a good idea to mount your camera on a tripod and to bracket exposure times from 1/500 second to 2 seconds; for exposures longer than 2 seconds for this size lens you should use an equatorial drive mount. (This device is explained in astrophotography references.). And there is no need for any camera filters during totality.

To shoot the partial phases of the eclipse you'll need to use a filter or two to produce the equivalent of a 5.00 neutral density filter. Be sure you don't try to look at the Sun through these filters; they are designed for photographic use only and are not safe for your eyes. And don't look through the viewfinder at the partially eclipsed Sun. A good subject for a camera lens of shorter focal length is a multiple exposure of the complete sequence of the eclipse from first to fourth contact. Use the filters for exposures of the partial phases every 5 or 6 minutes, and take one exposure of totality with the filters removed. Be sure that your camera is securely mounted and that you don't knock it out of position during the two hours or so you have it set up.

There are some good photo subjects during an eclipse other than the Sun itself. You may want to try to capture shadow bands on high-speed film using short exposures. But don't feel too disappointed if they elude your camera; they have proven very difficult to photograph, and they aren't visible at every eclipse. The crescent images of the partially eclipsed Sun seen in the shadow of a tree can make a good picture. Or you may want to try sequence of shots showing the darkness of the landscape before, during, and after totality.

Shooting video of the eclipsed Sun will not add much drama, since there is no perceptible movement of the corona or other objects in the sky during totality. You might want to have a video camera handy in case you happen to experience shadow bands, which do show movement. Also, if you have an elevated vantage point with a view to the west, you may be able to capture a few frames of the onrushing shadow as it sweeps across the landscape toward you in the last few seconds before totality. Perhaps the best suggestion for taking video is to capture the excitement of others before and after the eclipse. Use the time during totality to simply take in and enjoy the spectacle.

If you're interested in solar eclipse photography, check the References section for more detailed sources of information. Or you may want to get in touch with a local amateur astronomy group; there you can swap ideas with people who have learned from experience. But whatever your attempts to photograph an eclipse, don't get so lost in your camera that you forget to look up at the corona – a sight whose beauty no camera can reveal nearly as well as the human eye itself.

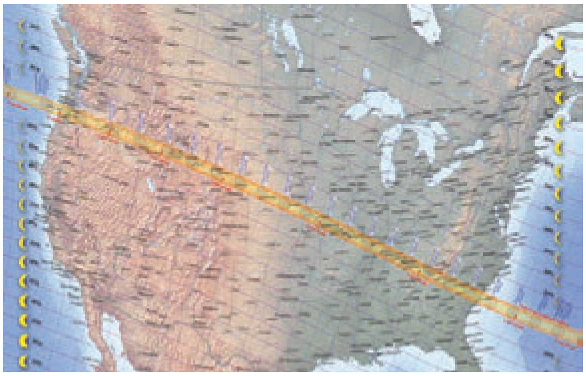
Observing totality is a way of experiencing not just these brief events but a larger sense of our solar system as well. Being in the path is a unique way of becoming part of this perfect alignment of the Sun, the Moon, and the Earth. Few ever forget the experience of totality.

Right: *This dramatic image is a composite of several different photos take at 5-minute intervals during the total solar eclipse on June 21, 2001 in Zambia.*

SITE SELECTION

Plan ahead to find the best place to watch the eclipse.

1. **Select a viewing location that is well within the path of totality.** The closer you are to the centerline, the longer you will experience totality. If you are anywhere outside the path, you won't get to see the beautiful solar corona, the wispy halo of light surrounding the Sun. This is the main attraction of the event.
2. **Find an unobstructed view.** Make sure that no buildings, trees, mountains, or anything else blocks your view of the Sun.
3. **Seek the best chances for clear skies.** If you have the choice to travel, the lowest rate of cloud cover happens in some western parts of the path, especially in Oregon east of the Cascade Mountains. But it's always a matter of luck whether eclipse day will dawn cloudy or clear at any particular site.



4. **Be ready for last-minute mobility.** You might be able to drive out from under a cloud cover and find a break in the clouds where you can see totality. However, if you're in or near a populated area, you may encounter traffic jams. This strategy works best in rural areas, especially in the state of Wyoming for August 21, 2017.

EQUIPMENT

No special equipment is required to view the solar corona during totality. Simply look up and take in the magnificent view during the few minutes of darkness. Equipment that may enhance other parts of your experience includes:

- **Eclipse glasses, pinhole projector.** For viewing partial phases.
- **Binoculars.** Use only for viewing totality, NOT for partial phases, even through eclipse glasses.
- **Smart phone.** Handy for checking last-minute weather, traffic, and social media updates.
- **Camera.** Unless you are an avid photographer with special lenses, filters, and equipment, don't bother trying to photograph or make a video of the eclipse. Just sit back and take in the few minutes of this awesome spectacle in the sky. Use your camera instead to capture images and video of how people react to this experience, especially right after totality.

PREPARATION

Here are some reminders to help you maximize your enjoyment of the eclipse event:

- **Arrange to take the day off.** August 21 is a Monday, so plan ahead, especially if many of your co-workers might have the same idea.
- **Line up your lodging well in advance.** If you need to stay overnight, make plans as soon as possible. Many hotels, motels, and campgrounds are already booked solid.
- **Get an early start on eclipse day.** The highways are likely to be crowded.
- **Bring folding chairs.** Especially ones that recline. Also, blankets, pillows.
- **Carry essentials with you.** Don't forget food, water, sunscreen, sunglasses (NOT for viewing the eclipse), sun hat, insect repellent, etc. Since local services may be overwhelmed, have a backup "restroom plan."

EYE SAFETY

During Partial Phases

Best Safe Viewing Methods:

- Approved eclipse viewing glasses made with aluminized polyester film
- Pinhole projector

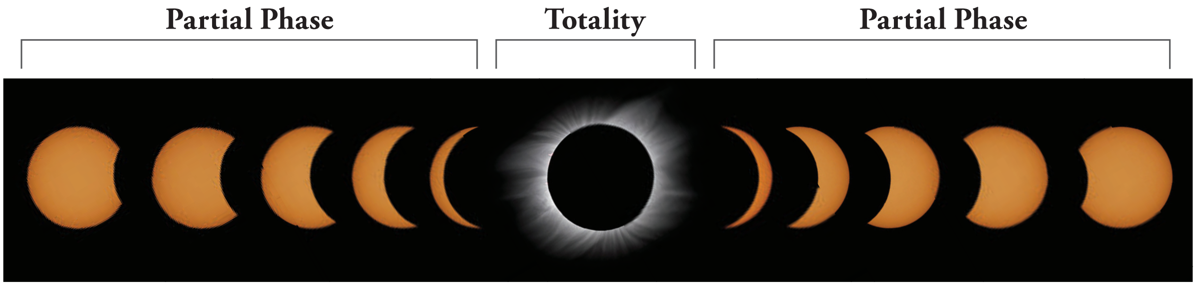
DO NOT USE sunglasses

DO NOT USE binoculars, even if viewed with eclipse glasses

DO NOT USE unapproved filters or home-made devices

During Totality

- View the solar corona directly with the naked eye
- Use binoculars to get a more detailed view of the corona
- Relax and enjoy the view



WHAT TO LOOK FOR

Partial Phase Before Totality

- Moon begins to cover the Sun
- Crescent images of the Sun projected on surfaces
- Noticeable darkening (begins about 15 minutes before totality)
- Shadow Bands (2 or 3 minutes before totality)
- Baily's Beads (½ minute before totality)
- Diamond Ring effect (just seconds before totality)
- Approach of the shadow from the west

During Totality

- Corona
- Prominences
- Chromosphere
- Stars and planets
- Darkness of the landscape, "sunset" at the horizon
- Plant and animal reactions
- Temperature drop

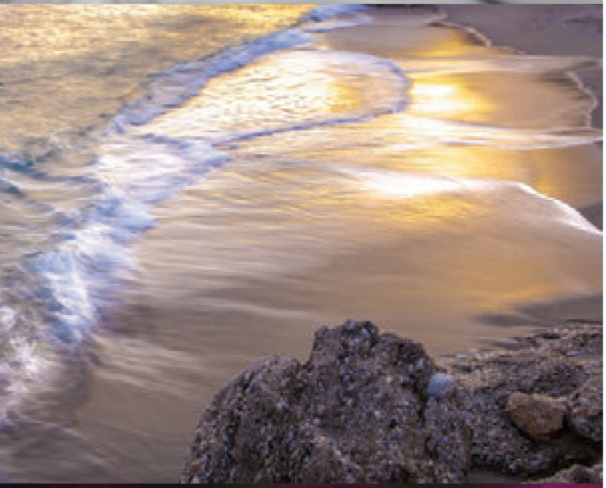
Partial Phase After Totality

- Darkness passes
- Shadow moves eastward
- Diamond Ring effect
- Baily's Beads
- Shadow Bands
- Gradual lightening of sky
- Crescent images of the Sun
- Gradual uncovering of the Sun

ECLIPSE VIEWING ETIQUETTE

If you are viewing the eclipse in the vicinity of other people, please use some common courtesy so that you don't infringe on their enjoyment of the event.

- Turn off the flash on your camera. The bright light can temporarily blind other viewers.
- Avoid making too much noise (loud music, conversation, etc.). Some people may want to experience the quietude of the event. However, a crowd may begin spontaneous cheering at the moment totality begins.
- Don't permit children or pets to cause a disturbance.
- Be careful not to block the line of sight for cameras or telescopes that others may set up.



THE EXPERIENCE OF AWE

In the past few decades, scientists have begun in earnest to study the emotion of "awe" – that "Oh, wow!" feeling you get when you see a beautiful sunset, hold a newborn baby, or hear Beethoven's Fifth Symphony performed live. Awe takes you out of your ordinary day-to-day consciousness and generates a new open-mindedness and sense of reverence. Awe is exhilarating. Awe is inspiring. Awe is, well … awesome.

Eclipse chasers know all about awe. It's what drives them to travel the globe seeking the chance to see totality again … and again … and again. Some dedicated (addicted?) umbraphiles have seen twenty or more total solar eclipses.

What is it about this phenomenon that induces awe? At the center of the experience is the magnificent view of the solar corona. Observers over the past several centuries – both scientists and ordinary folks – have described the sublime beauty of this sight using phrases such as "euphoric," "transcendent," "otherworldly," and other superlatives. Many say that it is difficult to find the words to adequately describe the feelings. Photographs, as striking as they may be, do not do justice to actually seeing the corona in person.

The sudden onset of almost total darkness during the middle of the day is another awe-inducing part of a total solar eclipse. This unnatural "midnight at midday" has a disquieting effect on humans and nature alike. The dramatic darkening accelerates in the few minutes before totality until at last the Moon's shadow, moving at more than a thousand miles per hour, sweeps across your location on the Earth.

Seeing this motion of the umbra, along with knowing that you are positioned in perfect alignment with the Moon and the Sun, often gives way to a visceral understanding of the vast physical scale of the event. The Sun (about 93 million miles away) is casting a shadow of the Moon (about 240,000 miles away) across a path on the Earth (no more than a few hundred miles wide) where you, a single individual, are standing.

Finally, the rarity of the experience can impart an expanded sense of time as you recognize the fleeting nature of the moment. A total solar eclipse can serve as a reminder of the arc of one's lifetime in the context of these regular cycles that have been repeating for millions of years.

As a result, a total solar eclipse can provoke very intense feelings of awe. Many experience a renewed child-like sense of wonder, not only about the eclipse but about the world in general. Indeed, witnessing an event on this scale can make you feel very small, and at the same time very connected.

Scientists are able to study the effects of awe by exposing people to some of the other, more usual sources of awe such as music, the arts, panoramic nature views, and the generosity of strangers. They are finding that awe affects us in specific ways. On a physiological level, awe seems to suppress both the sympathetic nervous system (the "fight/flight" response) as well as the parasympathetic nervous system (the "rest/digest" response). Interestingly, humans experience this same pleasant combination of nervous system responses – described as a calm yet energized state – in the moments after intense exercise, for example. We also know that awe stimulates the release of dopamine, a neurotransmitter chemical associated with the rewards of novelty and pleasure.

From a cognitive point of view, awe promotes more open-mindedness, allowing us to view things in new and unexpected ways. And the feeling of smallness generated by awe can lead to more "prosocial" behaviors such as cooperation and empathy.

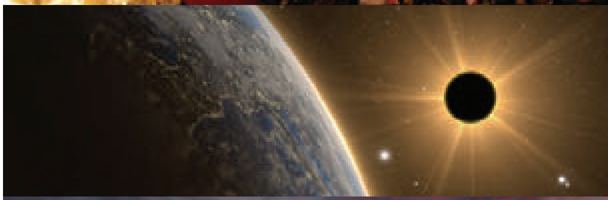
With all these benefits – pleasant feelings, openness, a sense of connectedness – it's no wonder that people seek to repeat the experience, especially on the grand scale of a total solar eclipse.

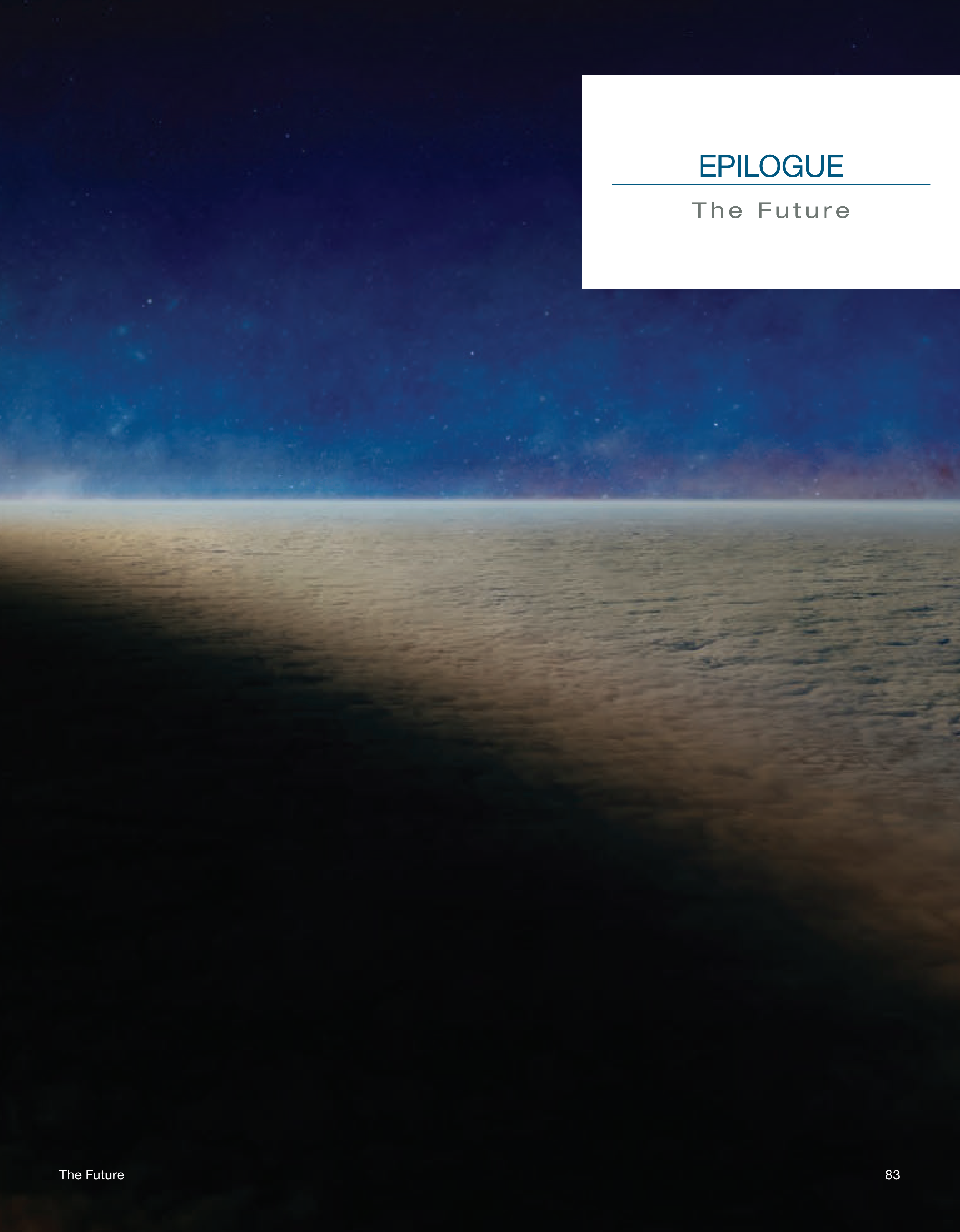
But there's another feeling that many experience as totality approaches: a primal sense of fear. This is not a feeling that induces fight or flight, since today we know that an eclipse is a natural, predictable event. Rather, observers describe this feeling – especially near the onset of darkness – as an almost subconscious, deep knowing that something is amiss. It's not hard to imagine how members of a primitive society might have been terrified by such an extraordinary experience. This primal fear, which is nothing to be actually afraid of, can be somewhat unsettling, and can actually add to the drama of your personal experience.

If you've never seen a total solar eclipse, perhaps you will be among the millions of people who will get the chance on Monday, August 21, 2017. Most Americans will see only the partial phases and afterwards wonder, "What's the big deal?" But if you position yourself in the path of totality and are fortunate enough to have clear skies, you will be rewarded with an unforgettable experience of awe.

> *"The perfect golden ring of light with a blazing jewel set in it was a sight that will never be forgotten … [T]he great lesson of the eclipse to the masses of those who saw it is that one little unusual phenomenon in the skies makes us realize how closely akin we all are in this common planetary boat out on an ethereal sea that has no visible shores."*

– The New York Times, January 25, 1925





EPILOGUE

The Future

Total Solar Eclipses (2017-2061)

Date	Maximum Duration (min:sec)	Maximum Width (miles)	Path of Totality
2017 AUG 17	**2:40**	**71**	**United States (from Oregon to South Carolina)**
2019 JUL 2	4:32	124	S. Pacific Ocean, Chile, Argentina
2020 DEC 14	2:10	56	Chile, Argentina
2021 DEC 4	1:54	260	Antarctica
2023 APR 20*	1:16	30	Indonesia
2024 APR 8	4:28	122	Mexico, United States, Canada
2026 AUG 12	2:18	182	Greenland, Iceland, Spain
2027 AUG 2	6:22	160	Gibraltar, N. Africa, Saudi Arabia
2028 JUL 22	5:09	143	Indian Ocean, Australia, New Zealand
2030 NOV 25	3:43	105	S. Africa, Indian Ocean, Australia
2031 NOV 14*	1:08	24	Pacific Ocean
2033 MAR 30	2:37	485	Alaska, Arctic Ocean
2034 MAR 20	4:09	99	Central Africa, Middle East
2035 SEP 2	**2:54**	**72**	**China, N. Korea, Japan, Pacific Ocean**
2037 JUL 13	3:58	124	Australia, New Zealand
2038 DEC 26	2:18	59	Australia, New Zealand
2039 DEC 15	1:51	236	Antarctica
2041 APR 30	1:51	44	Angola, Congo, Uganda, Kenya, Somalia
2042 APR 20	4:51	130	Sumatra, Borneo, Philippines
2043 APR 9			(Umbra barely grazes Siberia)
2044 AUG 23	2:04	281	Greenland, Western Canada, Montana, North Dakota
2045 AUG 12	6:06	159	U.S. (CA to FL), Hispaniola, NE coast of S. America
2046 AUG 2	4:51	130	Eastern tip of Brazil, Angola, Botswana, S. Africa
2048 DEC 5	3:28	100	Chile, Argentina, Namibia
2049 NOV 25*	0:38	13	Saudi Arabia, Yemen, Indian Ocean, Indonesia
2050 MAY 20*	0:21	16	South Pacific Ocean
2052 MAR 30	4:08	102	Mexico, Louisiana, Florida, Georgia, South Carolina
2053 SEP 12	**3:04**	**72**	**North Africa, Saudi Arabia, Yemen, Sumatra**
2055 JUL 24	3:17	125	South Africa
2057 JAN 5	2:29	63	South Atlantic Ocean, Indian Ocean
2057 DEC 26	1:50	220	Antarctica
2059 MAY 11	2:23	59	Pacific Ocean, Ecuador, Peru, Brazil
2060 APR 30	5:15	138	Africa, Middle East, China
2061 APR 20	2:37	347	Svalbard, Barents Sea, Russia, Kazakhstan

* Hybrid (annular-total) eclipse

Eclipses show in bold are in the same saros series that includes August 21, 2017.

THE FUTURE

The eclipse on August 21, 2017 is the first one visible from the continental United States in more than 38 years. The previous event was the total solar eclipse of February 26, 1979 that crossed Washington, Oregon, Idaho, Montana, North Dakota, and parts of Canada. The next total solar eclipse visible from the United States occurs on April 8, 2024.

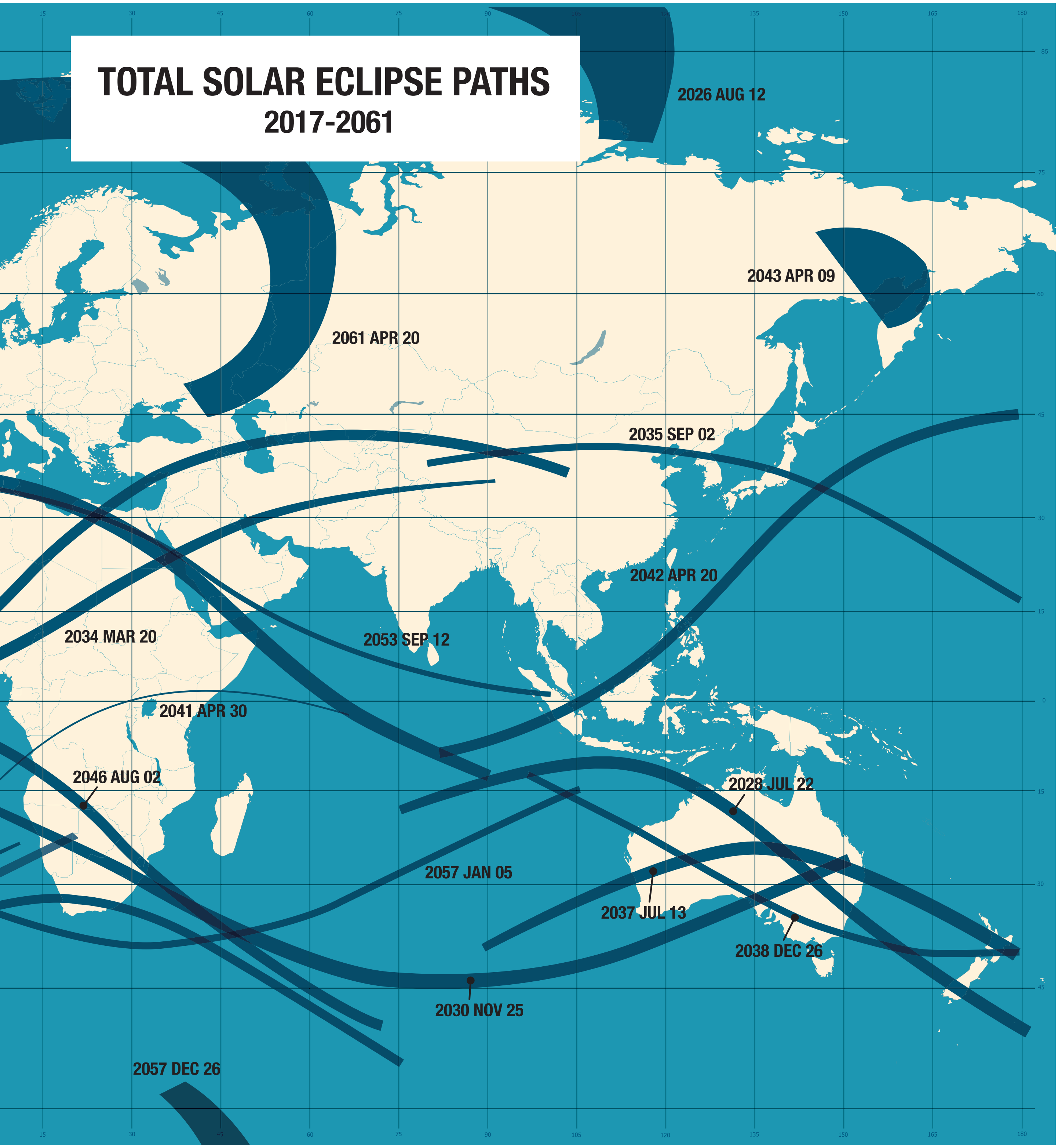
Thirty-eight years without a total eclipse over the continental U.S. is unusual. But there are also times of plenty. In the 38 years between 1594 and 1632 there were eight total eclipses visible from the U.S. or Canada. And in the 23rd century, six total eclipses will be visible from the United States in the years 2245, 2252, 2254, 2259, 2261, and 2263 – a busy 18 years.

Total eclipses will continue to occur on the Earth at the predictable rate of about once every year and a half. The 44-year period from 2017 to 2061 provides 34 chances to view totality. (This includes total and annular-total eclipses.) If you were to position yourself on the Earth at the point of maximum eclipse for each of these events, and you were blessed with clear skies during totality, you could spend 102 minutes in the shadow of the Moon. That's an average of about 2½ minutes per year under optimal conditions. This extreme rarity of totality, coupled with its visual beauty and true cosmic grandeur, makes it one of the most exquisite natural experiences available on planet Earth.

Our Sun and Moon have planned a number of interesting opportunities for us to experience totality in the next four decades. Some paths cross highly populated areas. Others touch the Earth in exotic vacation spots. Still others only graze remote ocean regions. At each appointed rendezvous, the Moon's shadow is sure to be there. Perhaps you will be there, too.


2033 MAR 30
2044 AUG 23
2026 AUG 12
2042 APR 20
2024 APR 08
2052 MAR 30
2027 AUG 02
2017 AUG 21
2060 APR 30
2035 SEP 02
2045 AUG 12
2059 MAY 11
2019 JUL 02
2038 DEC 26
2020 DEC 14
2055 JUL 24
2048 DEC 05
2021 DEC 04
2057 DEC 26

TOTAL SOLAR ECLIPSE PATHS
2017-2061



NOTABLE FUTURE ECLIPSES

July 2, 2019: If the 2017 eclipse has turned you into an eclipse-chaser, your next chance is about two years later in South America, where it's winter in July. Most of this path is over the Pacific Ocean. But it ends at sunset just a few miles outside Buenos Aires, where you might see the dramatic view of the eclipsed Sun slipping below the horizon.

April 8, 2024: Another North American total eclipse only seven years later! This 120-mile wide shadow – with as many as four minutes of totality – comes ashore at Mazatlán, Mexico, and moves to the northeast where in Texas, the cities of Austin, Ft. Worth, and Dallas lie with the path. The shadow continues across Arkansas, Missouri, and southern Illinois. Here it intersects the previous path of the 2017 eclipse, with Carbondale, Illinois near the centerline again. The shadow moves on to cover some major cities, including Indianapolis, Cleveland, Buffalo, and Montreal, and then after crossing Newfoundland, heads out to end in the middle of the North Atlantic Ocean.

August 12, 2026: An unusual eclipse track that actually moves westward near the North Pole before swinging southeast over Greenland, Iceland, and Spain. Reykjavik, Madrid, and Barcelona are near the edge of the path, and Palma de Mallorca is near the centerline just before sunset.

August 2, 2027: This the longest total solar eclipse in the remainder of the 21st Century, with a maximum of 6 minutes and 23 seconds of totality. The shadow races east from the Atlantic Ocean directly over the Strait of Gibraltar, where the path is about 150 miles wide. It sweeps along the southern Mediterranean coast, and crosses the Nile Valley at Luxor, very close to the point of maximum eclipse. Here the Sun is at an altitude of more than 80 degrees, almost directly overhead. At this time of year in this part of Egypt, the chances for clear skies during the eclipse are extremely high, an almost near certainty. This fact, combined with the long duration and tourist attractions of Luxor, will make this a popular travel destination on this day. About 20 minutes after crossing Luxor the shadow engulfs Mecca in Saudi Arabia, and then passes over Yemen and the tip of the Horn of Africa before moving out to sea in the Indian Ocean.

July 22, 2028: This, another long eclipse, passes from one end of Australia to the other, including Sydney in mid-afternoon, which is right on the centerline. Near sunset, the path crosses Dunedin on South Island, New Zealand. Earlier that morning, in the Indian Ocean, the umbra passes over the tiny Cocos Islands and Christmas Island, both territories of Australia.

November 25, 2030: A late spring eclipse in the morning over southern Africa. The shadow crosses Windhoek, the capital of Namibia, and Durban on the South African coast. Then, after traversing the Indian Ocean, the eclipse ends later in the day in South Australia and Queensland.

March 20, 2034: This eclipse track first touches land near Lagos, Nigeria, and sweeps northeast across Chad, Sudan, and the southwest corner of Egypt, including the upper reaches of Lake Nasser. The path then crosses Saudi Arabia (just missing Medina) and continues across Iran, Afghanistan, and Pakistan (Islamabad is on the centerline), finishing at sunset in western China.

September 2, 2035: This eclipse – the next in the saros series containing the August 21, 2017 event – begins in western China, and the Moon's shadow reaches Beijing at mid-morning. The track then passes over North Korea, including the capital Pyongyang, but misses Tokyo by about 15 miles.

July 13, 2037: A great "down-under" eclipse that crosses the continent of Australia, passing directly over the massive sandstone monolith of Uluru (Ayers Rock) just before noon, where you can experience 3 minutes 11 seconds of totality. New Zealand's North Island is also in the path just before sunset.

December 26, 2038: Seventeen months later another "down-under" eclipse crosses both Australia and New Zealand again. The eclipse track passes between Sydney and Melbourne, and just misses Wellington, the capital of New Zealand.

April 30, 2041: This path crosses two African capitals – Luanda, Angola and Kampala, Uganda – as well as parts of the Democratic Republic of the Congo, Kenya, and Somalia. Unfortunately, it occurs at the height of East Africa's rainy season, dashing hopes for clear skies or a safari side trip.

August 23, 2044: For this event, the eclipse track moves westward over Greenland and Nunavut before swinging south over western Canada, ending at sunset in Montana and North Dakota. This eclipse is the next in the saros series that includes the August 12, 2026 eclipse that has a similarly shaped track 18 years earlier.

August 12, 2045: Another grand American eclipse that sweeps across the United States from Northern California to Florida, crossing the cities of Redding, Reno, Salt Lake City, Colorado Springs, Oklahoma City, Jackson (MS), Montgomery, Tampa, Orlando, and Miami. The greatest duration of the eclipse – 6 minutes and 6 seconds – happens at Port St. Lucie on Florida's Atlantic seaboard. The path continues across the Bahamas, Hispaniola, and the northeast coast of South America, including the mouth of the Amazon River.

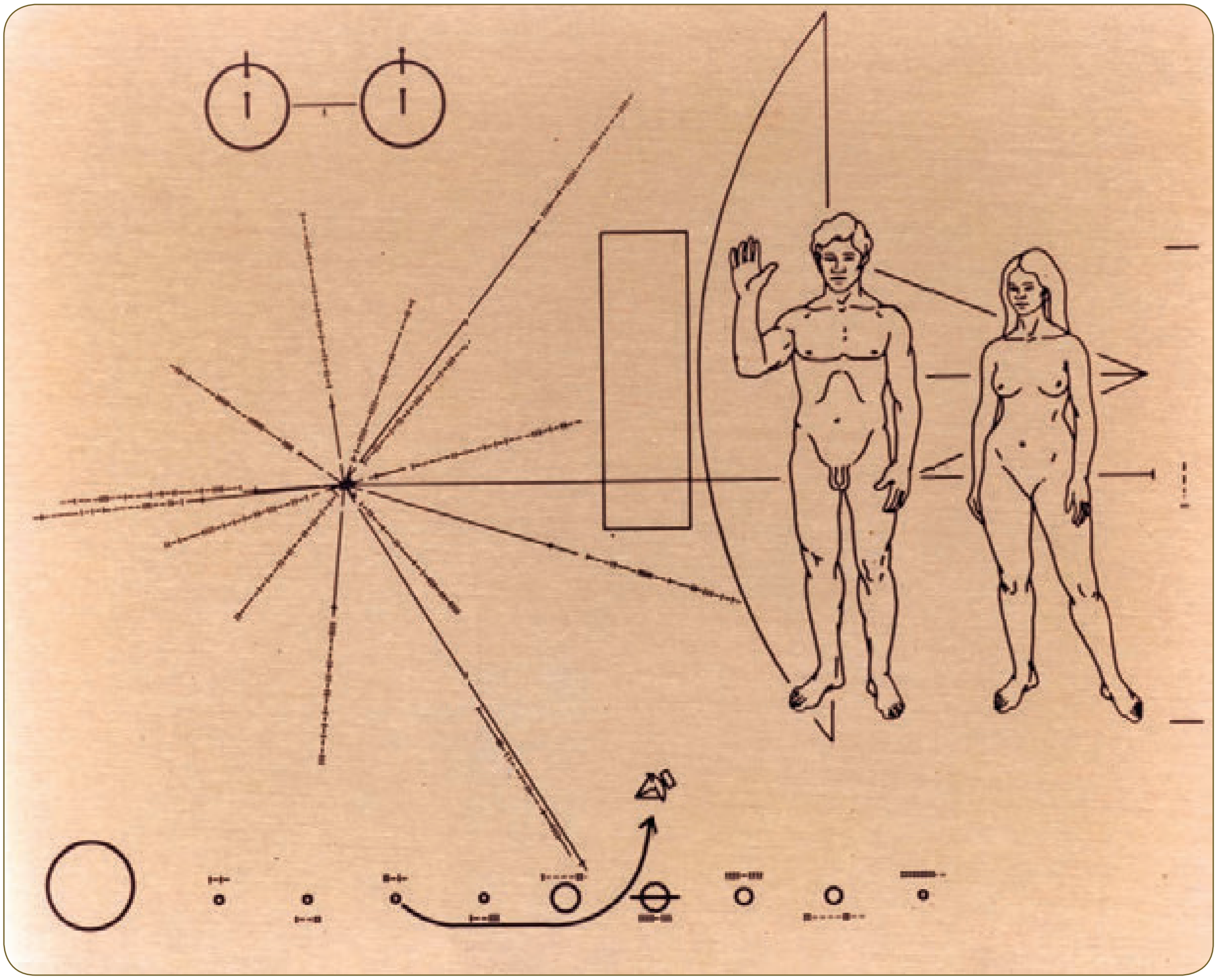
August 2, 2046: This eclipse begins at sunrise on the east coast of Brazil and takes all morning to cross the Atlantic, making landfall in Angola where maximum totality lasts 4 minutes and 51 seconds. The path continues to the southwest, crossing Botswana, South Africa, and Swaziland. The eclipse makes a dramatic exit at sunset in the southern Indian Ocean as seen from the small, extremely remote Kerguelen Islands, a French territory also known as the Desolation Islands.

March 30, 2052: The Mexican resort town of Puerto Vallarta welcomes the shadow of the Moon as it crosses inland from the Pacific Ocean. The path continues to the northeast, barely touching Brownsville, Texas and the tip of Louisiana's bayou country. It makes landfall again at Panama City, Florida, and passes across Savannah and Charleston before ending in the Atlantic.

September 12, 2053: This path is remarkably similar to the event on August 2, 2027, crossing from the Strait of Gibraltar to Yemen, although this time Luxor and Mecca each fall just outside the path of totality. This eclipse ends at sunset on the island of Sumatra.

July 24, 2055: On this day the eclipse path crosses land only at the tip of South Africa, just missing Cape Town by about 20 miles.

April 30, 2060: Another dramatic sunrise eclipse starting on the east coast of Brazil, and then crossing Africa through Ivory Coast, Ghana, Niger, Libya, and the northeast corner of Egypt. The entire island of Cyrus is in the path, which later crosses Turkey, the Caspian Sea, and four "stan" countries of the former Soviet Union (Turkmenistan, Uzbekistan, Kazakhstan, and Kyrgyzstan).



Above: *Plaque attached to Pioneer 10 spacecraft (launched in 1972).*

Below: *Artist conception of Pioneer 10 spacecraft passing Jupiter.*

FROM THE STONE AGE TO THE SPACE AGE

Eclipses are one of the few types of events that we can predict with certainty centuries into the future. The surety that the Moon's shadow will pass over a certain place on the Earth at a certain time in the future may somehow confer a reassuring sense of continuity to our fragile existence as a race of human beings. A space-age experiment also reflects our efforts to preserve a record of our existence on Earth.

In 1987, the Pioneer 10 space probe became the first human-made object to leave the solar system. It passed beyond Pluto's orbit and entered the realm of deep space, traveling at a speed of seven miles per second. Before Pioneer 10 was launched in 1972 to study Jupiter, astronomers Carl Sagan and Frank Drake persuaded NASA to include in the program a unique experiment: Attached to the spacecraft is a plaque designed to identify its origin to any intelligent extraterrestrial beings who might intercept it. The figures and diagrams etched on the gold plaque convey nonverbal information about the solar system, its location in the Galaxy, and the inhabitants of the third planet, Earth.

Above: *William Blake's "The Serpent Temple," from Jerusalem (1820).*

The two human figures represent typical earthlings. Their size is shown in comparison to an outline of the Pioneer 10 spacecraft in the background. The two circles at the top represent atoms of hydrogen, the most abundant element in the universe. The starburst pattern shows the direction and distances to specific stars. At the bottom of the plaque are the Sun and the planets. Pioneer 10 is shown on its path leaving Earth, swinging by Jupiter, and passing forever beyond our solar system.

We have come a long way from stone monuments to interplanetary space probes. Yet our fascination with the Sun, the Moon, the stars, and the planets remains. Early attempts to understand the heavens were based on astrology: the supposed prediction of earthly events based on the positions of the planets. It was against this background that modern astronomy has evolved. As we increase our knowledge of the universe and understand more how everything is related, new patterns of reality will emerge. That is the destiny of science. Our expansion into the solar system is already bringing us exciting new views of other planets and other moons. But none of these planets or moons can produce an eclipse like we see here on Earth; this perfect matching of our lunar and solar disks is unique in the solar system. It's this remarkable coincidence in time and space that gives us this experience we call a total eclipse of the Sun.

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GLOSSARY

altitude – the angle (in degrees) above the level horizon where an object in the sky appears. (The object's azimuth is also needed to pinpoint its position.)

annular eclipse – a solar eclipse that occurs when the apparent size of the Moon is not great enough to completely cover the Sun. A thin ring of sunlight can be seen around the black disk of the Moon.

annular-total eclipse – a solar eclipse that has both annular and total phases. (Also called a central eclipse or hybrid eclipse.)

anomalistic month – the time it takes for the Moon to travel from apogee to perigee and back again (about 27.6 days).

aphelion – the point in the Earth's orbit that is farthest from the Sun. Currently the Earth reaches aphelion in early July.

apogee – the point in the Moon's orbit that is farthest from the Earth.

ascending node – the point in the orbit of the Moon where it passes from below the ecliptic plane to above (see node).

Aubrey holes – the 56 chalk-filled holes (named for John Aubrey) that mark the outer ring of Stonehenge. These holes may have served as "counters" to help in marking the cycles needed to predict eclipses.

azimuth – the compass direction (in degrees) where an object in the sky appears. (The object's altitude is also needed to pinpoint its position.)

Baily's beads – the effect seen just before and just after totality when only a few points of sunlight are visible at the edge of the lunar disk.

BCE – Before the Common Era, a newer, more widely accepted abbreviation for dates previously denoted as B.C.

canon – in ancient times, an historical record of events. In modern astronomy, a canon is a listing of celestial events, such as eclipses, over a period of time.

central eclipse – in some references, a central eclipse refers to an eclipse that has both annular and total phases. (See annular-total eclipse.)

chromosphere – the lower atmosphere of the Sun that appears as a thin rosy ring around the edge of the solar disk during a total eclipse.

contact – one of the instances when the apparent position of the edges of the Sun and the Moon cross one another during an eclipse. They are designated as first contact, second contact, third contact, and fourth contact.

corona – the upper atmosphere of the Sun that appears as a halo around the Sun during a total eclipse.

descending node – the point in the orbit of the Moon where it passes from above the ecliptic plane to below (see node).

draconic month – the time it takes for the Moon to return to a node (about 27.2 days).

eclipse – the alignment of celestial bodies so that one is obscured, either partially or totally, by the other.

eclipse season – the period of time when the Sun is near alignment with a lunar node, during which eclipses may take place. For solar eclipses, this time window of 37-½ days occurs every 173 days.

eclipse year – the length of time it takes for a lunar node to return to its original alignment with respect to the Sun (about 346.6 days).

ecliptic – the plane of the Earth's orbit around the Sun. As seen from the Earth, the Sun appears to move across the ecliptic during one year.

equinox – either of the two days when the periods of daylight and darkness are of equal length. The vernal equinox is usually March 21; the autumnal equinox is usually September 23.

first contact – the beginning of a solar eclipse marked by the edge of the Moon first passing across the disk of the Sun.

fourth contact – the end of a solar eclipse marked by the disk of the Moon completely passing away from the disk of the Sun.

heel stone – the large upright boulder (or menhir) at Stonehenge that is aligned with the summer solstice sunrise.

hybrid eclipse – a solar eclipse that has both annular and total phases. (See annular-total eclipse.)

latitude – distance on the Earth (measured in degrees) north or south of the equator.

longitude – distance on the Earth (measured in degrees) east or west from a reference line, usually the line running between the poles passing through Greenwich, England.

lunar eclipse – the passage of the Moon into the shadow of the Earth, always occurring at a full Moon.

negative shadow – the extension of the umbra of an annular eclipse that delineates the path from which observers may see the ring of Sun of the annular eclipse.

node – the two points where a tilted orbit intersects a geometrical plane. The Moon's orbit intersects the ecliptic plane at the ascending node and the descending node.

partial eclipse – an eclipse during which only the partial shadow touches the Earth (for a solar eclipse) or the Moon (for a lunar eclipse).

penumbra – the part of a shadow (as of the Moon) within which the source of light (the Sun) is only partially blocked out. Compare: umbra.

perigee – the point in the orbit of the Moon that is closest to the Earth.

perihelion – the point in the orbit of the Earth that is closest to the Sun. Currently the Earth reaches perihelion in early January.

prominence – a large-scale gaseous formation above the surface of the Sun.

regression – the movement of points in an orbit in the direction opposite from the motion of the orbiting body. For example, the Moon travels from west to east, but its nodes are regressing from east to west.

saros – the eclipse cycle with a period of 223 synodic months, or 6,585.32 days (18 years and about 11 days).

second contact – the beginning of the total phase of a solar eclipse marked by the leading edge of the Moon first completely obscuring the Sun.

shadow bands – faint ripples of light sometimes seen on flat, light-colored surfaces just before and just after totality.

solar eclipse – the passage of the new Moon directly between the Sun and the Earth when the Moon's shadow is cast upon the Earth. The Sun appears in the sky either partially or totally covered by the Moon.

solstice – the day when the noontime Sun is either highest in the sky (summer solstice is June 22) or lowest in the sky (winter solstice on December 22).

spectroscope – a scientific instrument that breaks light into its component wavelengths for measurement.

sunspot – a magnetic disturbance on the Sun that appears as a dark blotch on its surface.

synodic month – the time from one full Moon to the next (about 29.5 days).

third contact – the end of the total phase of a solar eclipse marked by the trailing edge of the Moon first revealing the Sun.

total eclipse – an eclipse during which the Moon’s umbra touches the Earth (for a solar eclipse) or the Earth’s umbra completely engulfs the Moon (for a lunar eclipse).

totality – the period during a solar eclipse when the Sun is completely blocked by the Moon. (Totality for a lunar eclipse is the period when the Moon is in the complete shadow of the Earth.)

umbra – a complete shadow (as of the Moon) within which the source of light (the Sun) is totally hidden from view. Compare: penumbra.

Universal Time (UT) – a time standard based on the rotation of the Earth. UT is a modern version of Greenwich Mean Time (GMT), the mean solar time on the Prime Meridian at Greenwich, London, UK.

zodiac – the division of the ecliptic into twelve equal parts; each of these parts or "signs" is identified by a name and symbol.

ILLUSTRATION CREDITS

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90	Pioneer 10 plaque, NASA
90	Pioneer 10 spacecraft passing Jupiter, NASA
91	William Blake's The Serpent Temple, Special Collections Division, University of Washington Libraries

LIST OF MAPS

LIST OF TABLES

INDEX

ABOUT THE AUTHOR

Bryan Brewer wrote the first edition of *ECLIPSE* in anticipation of the total solar eclipse on February 26, 1979. He was fortunate enough to witness totality on that day, and has been hooked on eclipses ever since. But because it would be difficult to build a career as a writer around such infrequent events, he moved on to other endeavors in communications, technology, and business. During the 1980's he was involved in evangelizing the then nascent technology of CD-ROM, co-authoring *The Compact Disc Book*, contributing writings to numerous magazines and books, and presenting educational seminars. Bryan also produced the audio compact disc *Self-Guided Relaxation* by Joel Levey.

Bryan published the second edition of *ECLIPSE* for the July 11, 1991 total solar eclipse, where he traveled to Hawaii for the event. Although clouded out on that day, he continued with his passion for eclipses, leading eclipse tour groups to Brazil (1994), the Caribbean (1998), and Germany (1999).

Bryan then turned his attention to the startup world, and has served as a consultant, educator, and advisor to hundreds of early stage companies, helping them raise more than $100 million in funding from investors and other sources. In 2016 he launched the free Minimum Fundable Company Test (www.mfctest.com) to help entrepreneurs gauge the viability of their efforts.

Bryan continues to enjoy his passions for science, mathematics, geography, history, and psychology, which give him the background to write engagingly about all aspects of eclipses. The log house he built near Mt. Rainier (mentioned in previous editions of this book) continues to serve as a family vacation retreat.

The Sun and the Moon are dancing
circles in the sky.
The shadow is advancing,
the dragon passes by.
And in the darkest moment
in the soul's dark night,
Great Mystery reveals itself
and the darkness turns to light.