Jim Chung

# Astro-Imaging Projects for Amateur Astronomers

## A Maker's Guide

The Patrick Moore Practical Astronomy Series

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*For Denise, who gave me my first telescope one Christmas and has regretted it ever since!*

# Foreword

Amateur astronomers are make-do folks. Not in the sense that they settle for something inferior or expedient in the pursuit of their passion… rather, they tend to become makers in the process of doing what they do. Making was once an activity borne of necessity. In the mid-twentieth century, astronomical instruments were not readily found on store shelves. If you found yourself bitten by the bug to learn the night sky, you were more likely to search out plans for a 6″ Newtonian than to find a ready-made scope in a box. Today we can buy advanced instruments and accessories for all types of astronomical observation in a staggering array of choices from manufacturers around the world. Even with this convenience, there is more interest in ***making*** than ever before. Amateur astronomers are still fashioning and adapting instruments to observe the night sky and to record the wonders of the universe. We might assume that the reason one hacks apart a camera to modify its sensor is about being cheap. Surely thriftiness is a factor, but there is more to it than that.

Making is to discovery what cooking is to eating. Why would one struggle to take photos of distant galaxies when we have the Hubble Space Telescope to do it for us, in a depth and resolution far beyond our reach from earth. Why take photos of Saturn when the Cassini probe is darting through the ring system, snapping amazing images and sharing them with us from its Facebook page? Perhaps because doing it yourself, with the inevitable pain and frustration of failed efforts, opens the mind and spirit in a way that consumption of prepared information cannot.

I've never met Jim Chung, though I have known him for years. We live on opposite sides of a Great Lake, where the conditions for astronomy adventures are about as bad as they get. We have a few dozen nights a year when the skies open up to show Saturn's rings and less than a third of these offer air stable enough to see them clearly. We both have families, which assures that on most of these clear steady nights, our presence will be required elsewhere than in front of our telescopes. We both use a Macintosh, beautiful and intuitive computers with a sorry paucity of astronomy software. And we both enjoy the struggle to see how much we can accomplish within a few feet of our back door.

Like the pathway of discovery itself, the structure of this book is not a straight line. The projects, which can be enjoyed as stories in themselves, are intermingled with short essays on a variety of people and places, connected only by Jim's thinking process and the rambling that takes place naturally when we work to solve problems. Some hit surprising close to home. Alan Gee, who appears in an essay afternote, was a Buffalonian—a friend to my local astronomy club and a generous contributor of designs and instruments to the solar observatory at the Buffalo Museum of Science, where I volunteer as a research associate. Others—reflections on Ernst Abbé and his ideas on social reform and a discussion on how light pollution might interact negatively with human health—are fascinating walks that insert an enjoyable divergence from the detailed descriptions of Jim's maker projects.

The connection between making and doing has never been hotter than it is today. With the Internet always in our pocket, our neighborhood is the world. Tools and information are more accessible and affordable today than ever before. I've used my phone to photograph the moon through a 32 in. telescope on a mountaintop observatory and then used the same phone to record myself doing it, sharing both views a moment later with friends an ocean away. In his **Maker's Guide**, Jim shows us that full immersion in our projects can take trial and error, make a big mess, and can also lead to deeper appreciation and satisfaction than watching from the sidelines. Perhaps it's like taking a *selfie* where you wind up seeing deeper through inserting yourself in the picture taking. As every kid knows when demanding, "*I want to do it myself!*" in the doing is the joy. Roll up the sleeves, lay down some newspaper, and grab a screwdriver.

Buffalo, NY Alan Friedman
February 2015

# Introduction

I was born more than a decade too late to experience and be inspired by the launching of Sputnik and the Moon Race and hence came to astronomy rather late in my life. I'm more of a child from the dawn of the Digital Age, a time when Apple was a real computer company and not a maker of consumer electronic gadgets. I learned all about writing software, the gamer world, and the world of dial up BBS (bulletin board service) from my Apple][+. My other foot is firmly planted in a past era of hand manufactured goods engineered to last a lifetime, a time when people built their own telescopes if they couldn't afford to buy them. A lot of these same people were inspired by the projects that routinely appeared in the long running Scientific American column, *The Amateur Scientist*. Fortunately, the early columns which were devoted to amateur telescope making have been preserved in a thoroughly reedited three volume edition and in its entirety on CD. I'd like to think this book pays homage to *The Amateur Scientist* with my series of innovative projects, out of the box thinking but always on a budget and with materials and equipment easily at hand.

Consequently, this is a book for everyone at any level of amateur astronomy. I'm a busy dad, husband, and health care professional limited in both time and budget for what is to me a hobby. I'm not a retired tradesman with a fully stocked and equipped machine tooling workshop, just a regular guy with some hand tools and a cheap mini table saw, drill press, and sander working out of a garage stuffed to the rafters with hanging bicycles, strollers, and gardening tools. For three quarters of the year, I get the luxury of working on the driveway. Nothing gives me more satisfaction than the repurposing of found household items but at the same time the esthetic is not ignored. Even if you are not a builder, I think you will experience a lot of vicarious satisfaction from just the reading of each project as it develops to completion.

Many of these projects have an astrophotography flavor to them and that's because my primary interest in astronomy is imaging the cosmos, be it solar, planetary, or deep space. There are chapters devoted to technique and insider secrets. To provide relief from too much project building detail I've interspersed a few astronomy themed essays, which I hope leave you enlightened and informed.

Jim Chung
Toronto, 2014

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# Chapter 1

# DSLR Astro Imaging

Digital single lens reflex cameras (DSLR) were first used for astro *imaging* (as differentiated from photography which is terrestrial, stationary and short exposure) in 2003 with the introduction of the first sub $1000 DSLR, the Canon Rebel 300D. Second hand units only a few years old can be very inexpensive and lightly used as determined by reading the shutter actuation count in any exchangeable image file format (EXIF) header. DSLRs are such a staple commodity of any modern household that it's a natural entryway for beginners. They also represent a self contained total imaging system convenient for field use and capable of stunning professional results when wielded by advanced users. This chapter discusses DSLR topics that are rarely, if ever, broached in other astro imaging resources.

## Widefield Astro Imaging with Micro 4/3rds Cameras

As a parent I find solace in the belief that exposing your young children to a wide variety of life experiences will somehow pay dividends down the road. At least it was true for me because although I had but a passing interest in astronomy, the images of Voyager 1's Jupiter flyby and those of the repaired Hubble Space Telescope left such a lasting impression that it fueled a personal addiction for astronomical imaging that started a decade ago. One of my first successes with deep space imaging occurred during a family vacation at a resort in Ontario's cottage country (one of Shania Twain's earliest professional gigs). Being located some 2 h north of Toronto, the skies were unbelievably dark … and at the same time startlingly bright from the now visible dense star fields of the summer Milky Way. I was set up on the beach with my IR modified Canon 20D and AP Traveler



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refractor and Vixen GPDX mount and 12 V lead acid car battery and scattered empty carrying cases … and sweating from multiple trips to the parking lot. There had to be a better way.

Back in 2010, I was amongst the early adopters of a new class of digital cameras introduced by Olympus and Panasonic (Lumix) known as micro four thirds (μ43). Naming derives from the archaic notion of expressing the size of a solid state sensor in equivalent sized vacuum camera tubes expressed in inches. The sensor has a diagonal dimension of 22 mm, which is approximately the same as the active area of a 4/3″ vacuum tube. The nomenclature also refers to the aspect ratio of the sensor being 4:3, which is closer to what is seen by human vision (not 16:9 contrary to popular belief) than the standard 3:2 ratio of a full format 35 mm film sized sensor. What made these cameras exciting was that they represented a fresh digital centric redesign rather than merely modified film camera construction.

In the μ43 design, the pentaprism and mirror box is eliminated and live view on the rear TFT screen replaces the viewfinder. This screen is often hinged to allow easy viewing despite the angle of exposure, particularly beneficial for focus confirmation via live view during astro imaging. The loss of the mirror means thinner camera bodies with minimal flange back distances (the distance between lens flange and sensor) allowing the use of almost any camera lens with a proper adaptor, e.g., old film camera, 16 mm movie, and television camera lenses. Short flange back distance will also facilitate camera use in telescopes with limited back focus travel (Newtonians) and the room to include off axis guiders with camera lens. The μ43 sensor tends to be slightly smaller than Advanced Photo System (APS) sized sensors with a resultant crop factor of 2. A smaller sensor means lenses in general can be made smaller and lighter and a larger crop factor means smaller lenses will reach higher apparent focal length field of views. In fact Olympus mandates their lenses be fully digital with the ability to update lens firmware and that they also are telecentric to fully illuminate the pixel wells from corner to corner with on axis light waves (Fig. 1.1).

The ability to use such a wide range of legacy lenses is one of the strengths of this system for astro imaging where old lenses designed for manual focus operation are preferred. Autofocus (AF) is of no value in astro imaging and modern AF lenses usually have rudimentary manual focus rings with poor tactile feedback. Forgotten lenses like those from Canon's FD/FL era, which are not compatible with their current EOS system often languish on eBay as unwanted items but still contain superlative optics. These are lenses from the 1970s to 1980s so they benefit from modern optical coatings and improved light transmission. One of my favorite acquisitions is a Canon 55 mm f/1.2 lens at bargain basement prices. Bear in mind that these lenses were designed to deliver sharp performance in the large image circle of a 35 mm film negative so will deliver equivalent corner to corner performance on the much smaller μ43 sensor. Olympus in particularly has always been an advocate of compact light systems as evidenced by their legendary OM 35 mm film camera series. An adaptor is available to exploit the rich diversity of OM film lenses which are significantly smaller and lighter than their Canon and Nikon counterparts and are readily available at good used prices.

For the more courageous and those obsessed with pushing further the limits of compactness is the use of Olympus Pen F lenses on the μ43 body. Olympus made


**Fig. 1.1** Significant size differences between Canon T2i and Olympus EPL5, both sporting effectively similar focal length zoom lenses. In the interest of full disclosure the Olympus lens is particularly trick, when powered on it extends a further 3 cm

an incredibly compact 35 mm rangefinder film camera in the 1960s that could take two exposures on a single standard negative frame along with a family of high quality small lenses. In a design more then four decades prescient to the µ43, the Pen F was small enough with some pancake style lenses to slip inside a trouser pocket. Appropriately, Olympus calls their µ43 cameras digital PENs (Fig. 1.2).

I've owned both the Byers CamTrak and Kenko Skymemo as a solution to a portable tracking imaging mount but both are still too large to carry conveniently inside a knapsack along with camera, lenses and tripod. One needs to look back to the 1990s for a solution in the form of the Apogee MPFM (multipurpose fork mount) and the Pocono Series II GEM. Both can be found on used astronomy equipment sites for a fraction of their new cost (and far cheaper than current offerings like the Vixen Polarie or Ioptron Startracker) and are powered by similar microprocessor controlled stepper motor driving a 3 in. (76 mm) diameter, 96 tooth bronze worm gear. The Apogee is the more expensive mount but features fine DEC control, slow and fast RA speed correction which could be wired for modern autoguiding and no need for counterweights. The Pocono is slightly more compact and a polar scope can be adapted to it for increased tracking accuracy. Both mounts ride on a Manfrotto 410 geared tripod head, which makes polar alignment much easier. You can expect about 15 arcminutes of periodic error, which should allow accurate 5 min subexposures at a focal length of under 200 mm (Figs. 1.3 and 1.4).

Using DSLRs for astro imaging is a compromise because we are dealing with an uncooled sensor with a 12 bit analog to digital convertor (ADC) and electronics and


**Fig. 1.2** Canon 55 mm f/1.2 lens on Olympus EPL5, massive and ultrafast intimidation


**Fig. 1.3** Pocono II GEM on miniature tripod with OM series 135 mm f/3.5 lens and intervalometer


**Fig. 1.4** Apogee MPFM on Manfrotto 410 geared tripod head and with OM series 200 mm f/4 lens. Both Olympus lens have retractable sun shades which double for dew shields at night

firmware designed for taking good short exposure daylight images. But it's a great way to get started with astro imaging for minimal expense, it's convenient and simple to use in the field and careful selection of system and components can optimize your results.

Astro imaging is all about maximizing the signal to noise ratio and that can be accomplished by either increasing the signal or decreasing the noise. Increasing the signal involves maximizing the size of the pixels on the imaging sensor. Like a wider bucket, a larger pixel has more opportunities to capture photons and create a bigger signal. The μ43 cameras and Canon APS sized DSLRs have 4 μm square pixels while compact point and shoot cameras and smart phones have much smaller 1 μm square pixels. This is why the latter are never able to take good low light images. Signal can also be increased by choosing fast lenses, that is lenses with large apertures and low f numbers. Such lenses with good optical coatings will also ensure maximum light transmission per unit time and maximum signal. Removing the stock infrared (IR) blocking filter (and anti aliasing/AA filter) will improve signal by allowing more photons to reach the sensor.

Noise is pervasive and from many sources. Read noise refers to noise added by the sensor electronics during readout and the ancillary electronic components like the ISO gain amplifier and ADC. This can be subtracted from the image by taking bias frames, a black exposure with the lens cap on and at highest shutter speed. However sometimes the pattern of read noise is not spatially fixed and varies with frequency and is different from frame to frame. This is difficult to remove and manifests in horizontal or vertical banding.

Thermal or dark noise is the second most damaging noise in astro imaging and is the release of thermally agitated electrons in the sensor to mimic those released by incoming signal photons. Dark noise rises linearly with exposure duration and temperature and can be removed by subtracting dark frames. If your camera sensor is not operating at a stable temperature then it is difficult to make an accurate dark frame. In this case one needs to average many dark frames but you still are in danger of injecting dark noise during dark subtraction if the dark current of each pixel deviates from the master dark frame.

Quantization noise is the error that occurs in typical 12 bit DSLRs where there are only 4096 levels of intensities but the dynamic range or depth of each pixel well may be a much larger numerical value. To use the entire range of the sensor the ADC would convert a number of electrons to correspond to one ADU, this also is known as the system gain. The error or noise occurs because you now lose the ability to represent the difference of one photon impact since each ADU actually represents several photon impacts.

Finally shot noise is the natural fluctuation of the number of photons arriving from a target so that you don't get a single clean repeatable signal but a statistical distribution of photons deviating from the mean value. As the signal gets stronger the shot noise becomes less apparent. Shot noise from skyglow is probably the urban astro imagers greatest source of this type of noise.

You can choose to buy a DSLR with a sensor that produces low dark current because subtraction and correction will be easier and more effective. Imagers using dedicated astro imaging cameras have known for years that Sony makes sensors which produce low dark current but they tended to be small chips, they now make full format sized chips for their DSLRs. Quantization error can be eliminated by setting the system gain to one $e^-$/ADU and on a DSLR this is done by selecting the best ISO setting which preserves the full dynamic ranger of the sensor. Skyglow shot noise can be eliminated by shooting only at rural dark sites.

The µ43 system has matured considerably over the past 4 years and corrected many shortcomings reported by users such as slow focus, read noise and dark current. In 2012 Sony made a $600 million investment in Olympus and the current µ43 camera uses a Sony constructed CMOS sensor (IMX109, the baby brother of the Exmor sensor found in the Nikon D5100 and D7000). Sony sensors have found their way into Nikon DSLRs as well as their own *Alpha* cameras and all demonstrate very low dark noise production. There is no greater proof of concept than imitation by other camera companies. Today, every major camera company markets their own mirrorless compact camera which appear under the monikers CSC (compact system camera) EVIL (electronic viewfinder interchangeable lens) or MILC (mirrorless interchangeable lens camera). Since Olympus and Panasonic were first to market, their system remains the most desired because they offer the widest range of lenses (over 30) with many third party manufacturers like Schneider-Kreuznach, Leica, Kowa, Mitakon, SLR Magic, Tamron, Rokinon, Sigma, Samyang and Voigländer-Cosina adopting the platform. Some of these lenses feature very high grade optics and every enthusiast knows that camera bodies come and go but lenses last a lifetime and are what the serious user invests in. Rather like eyepieces!

I was less than enthralled with the astro imaging performance of the first generation of Olympus µ43 cameras (EP1) due to its high dark current which manifested as clearly visible pattern banding. My Canon Rebel T2i continued to be my astro imaging DSLR of choice until last year when I purchased the latest µ43 offering (EPL5). My personal study of its dark noise and published findings by DxO Labs confirm that this new µ43 sensor performs better than even the venerable Canon family of APS CMOS chips. I took a series of dark frames and had them debayered and compressed as 8 bit jpegs with on camera processing. Using the software *ImageJ*, I subtracted a bias frame from each dark frame and analyzed the dark noise in each. The standard error of the mean of each data point was so small that it was insignificant. What the graph does not show is that while the dark frames of the EPL5 displayed a uniform distribution of noise, the Canon T2i suffered from severe amp glow along the lower border of the frame at exposures longer than 5 min. It is unlikely that a dark frame subtraction can deal adequately with so much noise and cropping out of that section is required (Figs. 1.5 and 1.6).

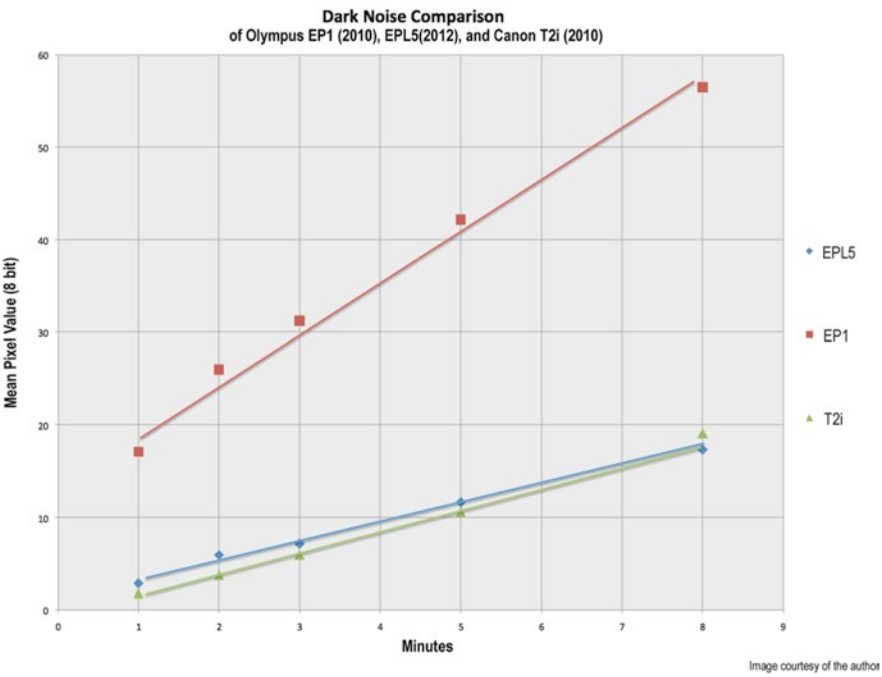


**Fig. 1.5** Dark noise comparison between Olympus EP1, EPL5 and Canon T2i

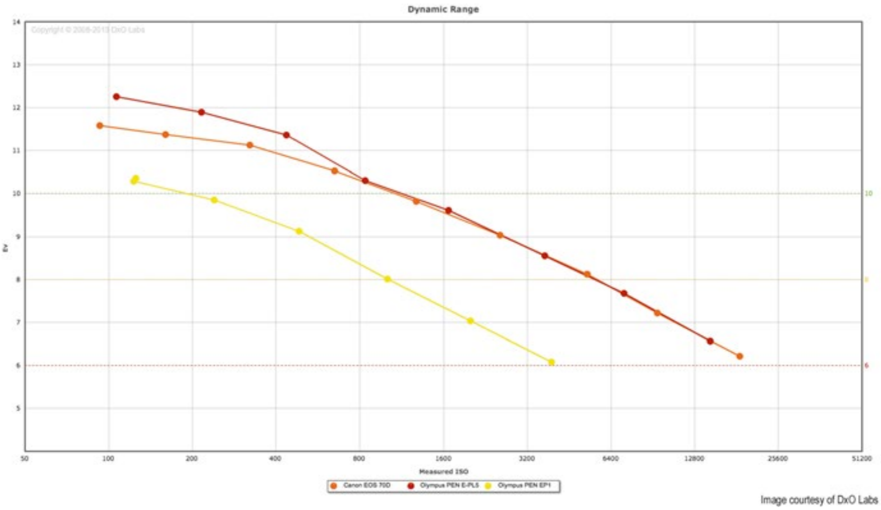


**Fig. 1.6** Dynamic range performance of Olympus EP1, EPL5 and Canon 70D

Like any other camera, the IR blocking filter and AA filter can be removed and replaced with clear glass to preserve autofocus and improve hydrogen alpha (Hα) response and resolution. It is a little more challenging to work within the tight confines of the μ43 body as compared to a full sized DSLR but it can be personally accomplished. Perhaps the greatest but not readily evident advantage is the compact size of the total imaging package of a μ43 system. Like telescopes, the most convenient and readily deployable camera is the one used most often and when paired with some compact motorized German equatorial mounts can be easily transported as an entire system in a small knapsack. The just released EPL6 features a new low ISO 100 setting and a built in intervalometer for time lapse photography although the longest shutter speed is still 60 s. Definitely airline friendly but more importantly travel friendly (Fig. 1.7).

## The Untold Secrets of Making Your Own Monochrome DSLR

A couple of Christmas' ago I asked Santa if he would bring me the new $8000 Leica *Monochrom* digital camera in consideration of the fact that he never brought me anything that I asked for as a child. But Santa really does know all his children well because the unbroken tradition of denial only made me even more determined to make my own! The *Monochrom* comes with the 18 megapixel (MP) full frame Kodak KAF-18500 monochrome sensor and a $1500 price premium over the conventional color Leica M9 camera on which it is based. Now all imaging sensors

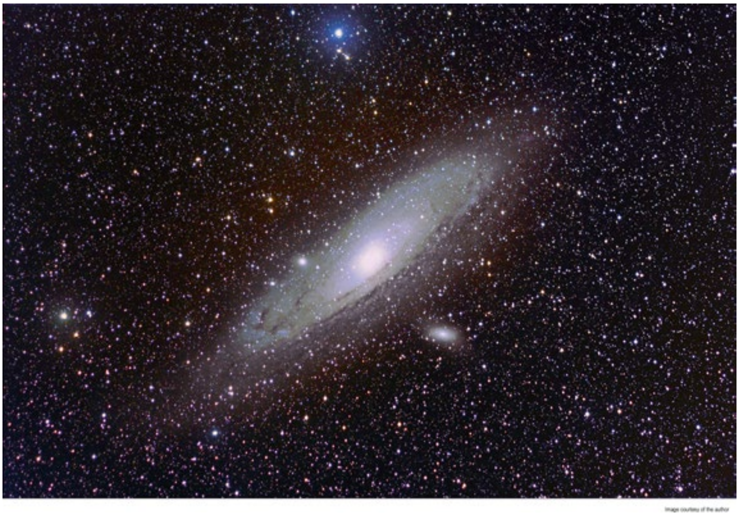

**Fig. 1.7** M31 Andromeda Galaxy, ISO 800 f/3.5 Zuiko 135 mm lens, 30 unguided 1 min exposures with EPL5, no flat or dark subtraction

start life as monochrome or black and white sensing sensors and it is only the application of a color filter array (CFA) or *Bayer* layer that allows the sensor to see in color. Common sense would indicate that monochrome sensors are cheaper to produce than color sensors but the reason why the *Monochrom* is more expensive than the M9 is because Kodak incurred losses in productivity by halting its production line of color sensors to produce a small number of monochrome sensors just for Leica, making them extraordinarily expensive on a per unit basis. I can't think of another modern example of this type of inverted economics, save one. As a child I lived through the period when leaded gas was phased out because lead is a well known neurotoxin. Tetraethyl lead was added to unleaded gas to prevent knocking and to reduce wear on valve seats. However, *unleaded* gas always cost more than leaded gas which was then referred to as *regular* gas. Studies have shown a strong correlation between a reduction in crime rates and the elimination of leaded gas and one that is causally linked because the transition date to unleaded gas varied from state to state in the American study.

Amateur photographers greeted the news of the *Monochrom* with general derision. Everyone knows that you can easily make a color image black and white with Photoshop or choosing the required camera mode so this was yet another overpriced Leica destined for the private glass cabinets of a collector. As astro imagers, we know better. We applauded Canon for the courage to produce the Canon 20Da and now the 60Da with improved red spectrum response geared specifically for imaging astronomers. So we can appreciate the Leica *Monochrom* for offering a camera with improved resolution and sensitivity, especially when used in narrowband imaging applications from within urban centers.

DSLRs are typically one-shot color cameras, and they accomplish this feat by having the CCD/CMOS sensor overlaid by a CFA known as the *Bayer* layer. The technique was proposed by Bryce Bayer (BYE-er) in 1976 while working for Eastman Kodak and is ubiquitous, found in every cell phone and tablet. Red, green, and blue filters are laid in a checkerboard style pattern so that color information can be sampled by the sensor. There are twice as many green filters as red or blue, because the green channel doubles as the luminance or detail bearing channel. The green color is the spread of wavelengths at which the monochromatic rod cells and the color perceiving M and L cone cells in the human retina respond best. Since each pixel records data from only one of three color channels, it cannot render true color on its own, so the image is reconstructed with a demosaicing algorithm that interpolates the RGB value of each pixel based on the information gleaned from its neighbors. The green luminance channel provides the fine detail information that is overlaid onto the RGB image. Since the Bayer layer is rotated 45°, each green or luminance channel is sampled every $\sqrt{2}$ pixel spaces in either horizontal or vertical direction. In other words, your brand-new 20-MP DSLR is capable of a resolution some 2–3× less than advertised.

But it gets worse. Aliasing is the effect of different sampled signals become recorded as identical or aliases of each other and you get a type of distortion known as a Moiré pattern when the total image is recreated. This occurs most often with objects showing repeating fine detail. Aliasing occurs because the Bayer layer is causing undersampling of the image. According to the Nyquist-Shannon sampling theory, this problem can be avoided by sampling at twice the frequency or resolution of the maximum resolution of the entire image. Since we are already undersampling, the maximum signal must be reduced and this is accomplished by utilizing a blur filter known as an antialiasing (AA) filter. This is usually found bonded to the IR blocking filter and typically reduces resolution by 15–20 %. The Leica *Monochrom* has no *Bayer* layer and hence no need for an AA filter, so its 18 MP sensor now has a resolution similar to a conventional DSLR with a 36–54 MP sensor. In practice, this is most apparent in narrowband astrophotography. The loss of the CFA automatically increases sensor sensitivity by more than one full aperture stop, but the ability of each pixel to record data during narrowband applications raises the final image's resolution enormously. In a typical DSLR, only the red pixels see Hα so 75 % of the pixels record no data and you are essentially forced to resize your final image to one-fourth of its native resolution.

As a quick aside, there are now Nikon and Pentax models which no longer come with AA filters as the megapixel race has stabilized and reached a practical limit but resolution gains are still desired. The Pentax K-3 has found a clever way to mimic an AA filter in circumstances where moiré patterns can manifest and that is by vibrating the sensor using the very same motors in its shake reduction camera stabilization system.

If you're like me, you can't afford to buy a Leica *Monochrom*. You could try to pick up 1 of 100 Kodak DCS760M DSLRs, made in 2001, on eBay, but they still go for $5000. Or, try the 39 MP Phase One Achromatic medium-format digital back for $43,000, but you still need a compatible Hasselblad or Mamiya body.

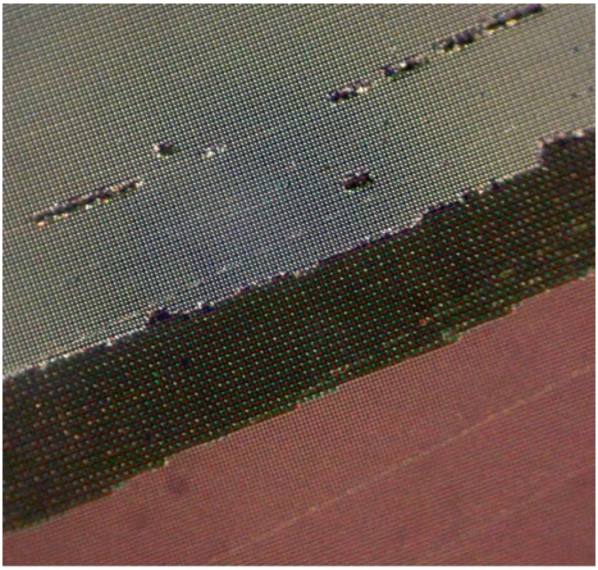


**Fig. 1.8** View of sensor surface at 100× magnification. From *top* to *bottom*: naked pixels, Bayer layer, microlens layer

A company based in New Jersey (www.maxmax.com) has been offering monochrome conversions of Canon DSLRs for the past 4 years. The procedure is not for the faint of heart and requires a clean room. Success is still variable enough that the company will not convert your camera for fear of destroying your sensor but rather sells preconverted units. The final thin sensor cover glass is removed and a 5-μm surface layer of the sensor removed with a proprietary process (likely physical) to strip both the microlens and CFA. A monochrome converted Canon T3i goes for $2000 and a Canon 5D Mk 3 for $6500.

The microlens layer serves to increase sensor sensitivity by focusing and concentrating light that would otherwise fall on nonphotosensitive areas of the sensor (in a CMOS as opposed to a CCD each pixel has its own amplifier circuit) onto the actual pixel. Stripping this layer away does reduce some sensitivity but it is more than made up for by the removal of the translucent *Bayer* layer. The naked sensor is now nearly a full aperture stop more sensitive than before (Fig. 1.8).

Of course there is a third way and that is to make your own. I anticipated a lot of experimentation by trial and error and hence a lot of ruined camera bodies and sensors so to mitigate the cost I turned to the very first practical DSLRs introduced a decade ago, namely the Canon 10D and the Nikon D40/D50. Both lines use 6.3 MP sensors, Canon makes their own CMOS while Nikon uses Sony manufactured CCDs. In our throwaway society, cameras this old are unwanted and unused so can be had for well under $100. Individual sensors can be sourced from eBay suppliers that strip and part out these cameras for even less.

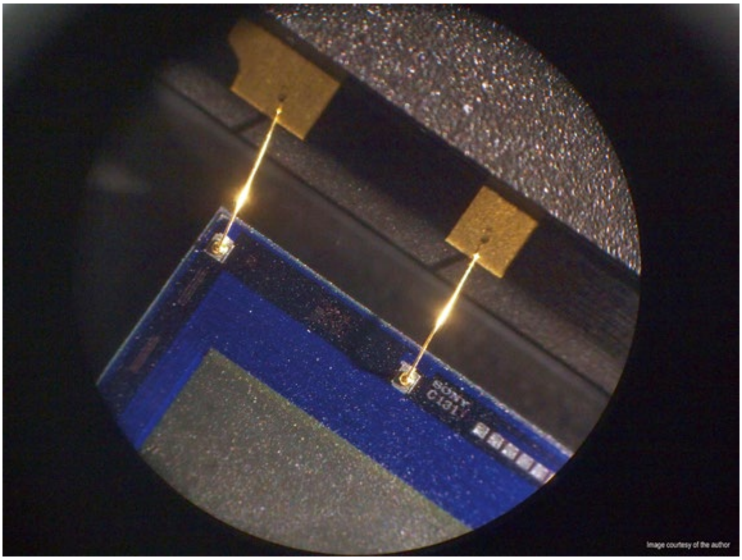


**Fig. 1.9** Fine gold connecting wires on sensor periphery at 100× magnification

The first step is to dismantle the camera and free the imaging sensor. This is not particularly difficult but it is very useful to review the correct sequence of steps performed successfully by others as flat flexible cable (FFC) connectors are very fragile and some desoldering is required. Excellent tutorials are available on www.lifepixel.com for a wide variety of cameras. Since I'm a Canon guy, I began with the 10Ds. Each sensor is protected by a thin coverglass that is very strongly glued to the chip body. My solution is to cut the glass along its periphery close to the edge of the adhesive bond strip, perforate the glass completely at the corners where there are typically no fine gold connecting wires and lift off the glass, sometimes in fragments. My day job allows me access to a 200,000 rpm electrically driven precision cutting diamond tipped drill and a pair of 4× *Carl Zeiss* loupes but this can be accomplished with a *Dremel* and a cut off wheel (Fig. 1.9).

The microlens layer is presumed to be made from polycarbonate plastic which can be dissolved away with chlorinated organic solvents. I have access to chloroform ($CHCl_3$) and dichloromethane ($CH_2Cl_2$) and I tried immersing the 10D sensor in each for several days with no effect. I have to stress that both chemicals are very volatile, highly flammable and extremely carcinogenic and should be used in a vented fume hood and handled with nitrile gloves. That said, I sealed the immersed sensors in some airtight glass *Tupperware* and then double bagged them in large *Ziploc* bags before banishing them to the main floor bathroom with door closed and ventilation fan running continuously. There was no effect on the 10D sensor. I then proceeded to remove the microlens layer with a mild commercial abrasive paste sold to remove scratches from motorcycle helmet visors (polycarbonate) carried by

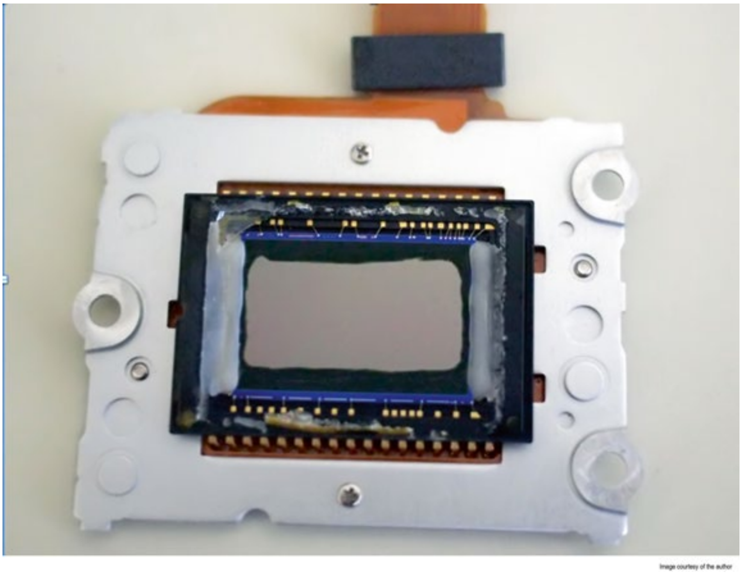

**Fig. 1.10** First successful monochrome conversion of D40 sensor

a slow spinning rubber cup. I was able to see layers being slowly ground away but there was no method to control ablation depth and no sensors returned any data when reinstalled. The same outcome was encountered when using less abrasive automotive clearcoat polishers, a razor blade and diamond impregnated silicone polishing points.

Having exhausted my supply of 10D sensors (some half dozen) I turned to the Nikon D40 and immersed them in the solvent bath overnight. The Sony made SuperHAD CCDs showed promise when the microlens layer was transformed to a viscous sludge that could be teased off with micro brushes and the underlying *Bayer* layer also gently rubbed off with cotton tipped applicators like *Q-Tips*. Nikon attaches their CCD chips to their ceramic chip bodies with a single center spot of adhesive, which becomes severely weakened after a solvent bath. This requires the chip be stabilized with the injection of flowable light cured bis-GMA dental resin along the edge of the chip and in available areas between the gold connecting wires. Complete microlens and *Bayer* layer removal was confirmed with a microscope and I was delighted to see the modified sensor produce an image (Figs. 1.10, 1.11, and 1.12).

The data from the raw Nikon files must be converted to a .tiff image file without undergoing demosaicing. This is conveniently done by using an open source program called *dcraw*, which is able to convert almost any camera raw file format in existence, including legacy models long unsupported by even their manufacturers, by reverse engineering the myriad of encryption methods. The author has spent thousands of hours over the past decade to keep his list of supported camera models current and even Adobe Photoshop's raw plugin uses his code—all for free!


**Fig. 1.11** Unmodified D40 color image


**Fig. 1.12** First monochrome modified D40 image

The program operates from the command line and is written in C so it can be compiled on many platforms. I used *Terminal* in Mac OSX to access its *Unix* command line:

./dcrawU –D –T *.NEF

to output the pure RAW data of any Nikon raw file found in the same subdirectory as the *dcrawU* executable file without any demosaicing or levels scaling into a .tiff file.

There is a significant improvement in sharpness, reduced noise and increased sensitivity in the monochrome D40. The conventional D40 exhibits "color noise" that manifests as abnormally colored blemishes, which become even more apparent when converted to grayscale. Presumably this noise has its origins in errors of color interpolation. The significant lack of this noise in the monochrome D40 means that it can be operated at higher ISO levels without sacrificing dynamic range; this is seen in performance tests of the Leica *Monochrom* as well. Such a benefit is especially good news for astro imagers as they are currently limited to shooting between ISO 400–800 to preserve what is also referred to as unity gain (Fig. 1.13).

The next generation of Nikons switched to Sony manufactured Exmor CMOS sensors and the D90 was the first DSLR to offer live view as well as record video.

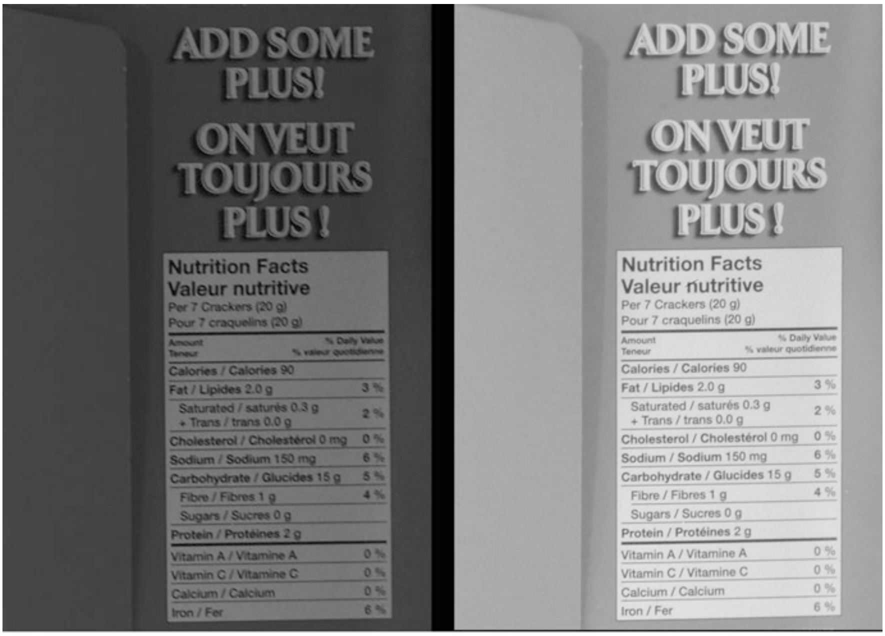


Image courtesy of the author

**Fig. 1.13** Comparison of normal D40 converted to grayscale (*left*) and monochrome converted D40 (*right*) showing significant gains in sharpness, sensitivity and lack of noise

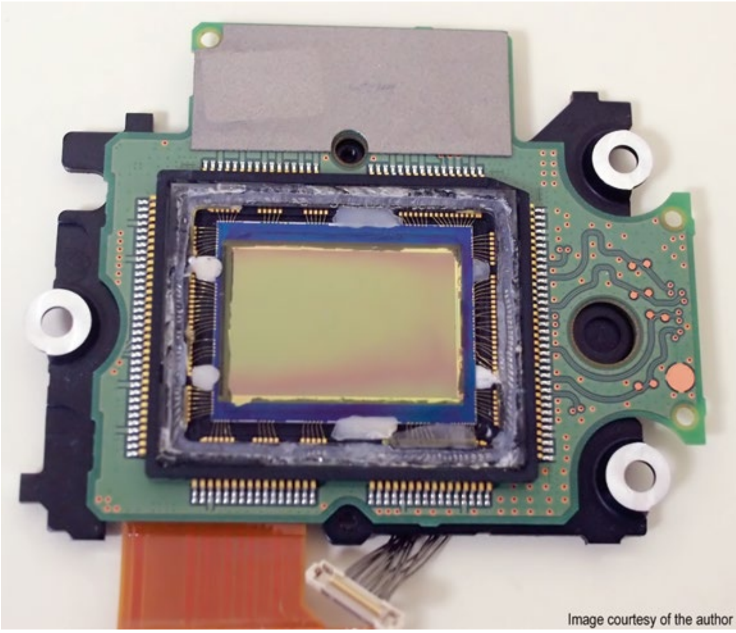


**Fig. 1.14** Converted D90 sensor

The D90 uses the Sony IMX038 CMOS and the physical size of the chip is much larger than earlier CCDs allowing the gold connecting wires to be separated from the active region by a wide empty border. This allows complete removal of the microlens and *Bayer* layer where before it was dangerous to strip those rows of pixels adjacent to the perimeter. With increased pixel density means increasing number of gold connecting wires and more opportunities to sever one of them (Figs. 1.14 and 1.15).

At the time Nikon had just introduced the D7000 and the D5100 which both use the same Sony IMX071 CMOS. Many astro imagers reported stunning low noise characteristics for this sensor and with brand new D5100s now priced at under $400, it was a bargain. This model became the camera that I converted most often although I did do a D7000 for a client in Rome. The Nikon D2X, D5000, D800 and D600 also use Sony CMOS' and I would be confidant in their conversion however more current models have sourced sensors from Renesas and Toshiba and hence are an unknown entity (Fig. 1.16).

For years astro imagers has shied away from Nikon DSLRs because of the infamous median pass filter that Nikon's on camera processing performed even on raw files which would delete faint stars. It's well known that even Canon is guilty of processing its raw files by rescaling the data to give the impression of extremely low dark noise when it's simply hidden and becomes more difficult to accurately subtract. Nikon is likely performing a simultaneous read noise and dark current subtraction on


**Fig. 1.15** M42 with monochrome converted D90 unguided 30×2 min subexposures with Astrotech AT72ED refractor and Baader 7 nm Hα filter

the D5100/D7000 to account for its amazing dark frame performance as hackers have shown with digital micrographs the perimeter of the active region is occupied by metal shielded black pixels which will output a value that is equivalent to the dark current that can be subtracted from all active pixels to bring the black level to 0. There are other regions where the pixels have no photodiode and these dummy pixels output read noise values. The Sony Exmor CMOS' definitely have lower readout noise and fixed pattern noise than Canon CMOS'. Dark current is also in the range of 0.15 electron per second at room temperature which under typical winter conditions means a dark current comparable to cooled CCDs. Nikon hackers have found the register on the Expeed Image Processor controlling the black level and a patch will be available soon to allow users to extract authentic raw files.

**Fig. 1.16** Rosette Nebula, 40 × 5 min subexposures AP Traveler refractor D7000 Baader 7 nm Hα filter

In the fall of 2014 *Nikonhacker* did release a firmware patch which disabled the "star eater" algorithm completely, allowed selecting a true NEF raw lossless file, and disabled the battery check so that a dummy battery running off external power for long exposure work can be used. The patch can also disable R and B channel scaling (so that RGBG will always be 1:1:1:1) and the factory aggressive black point setting. The age of Canon dominance in DSLR astro imaging may be coming to an end and Nikon knows this with the February 2015 release of the model D810A, a full frame DSLR with no AA filter and enhanced Hα transmission through the IR blocking filter, much like the Canon 60Da.

## Planetary Imaging with DSLRs

I had heard about using DSLRs that were capable of taking video footage to image planets a few years ago, but was initially skeptical about its efficacy, since large sensors and rapid frame rates didn't seem reconcilable. One of the tenets of planetary imaging is that rapid frame rates maximize the chance of freezing moments of good atmospheric seeing and obtaining high quality, high resolution images. The idea that a novice astro imager did not have to purchase yet another piece of specialized gear or burst his or her budget was appealing. I attempted my first

DSLR images of Jupiter and Saturn recently and was pleasantly impressed at their quality. The process also holds a unique advantage over conventional planetary imaging techniques.

It may be counterintuitive, but one does not use the DSLR's 1080p HD video mode to shoot planetary movies. This is because the camera has to downscale the image from its native 5xxx by 3xxx pixel array to 1920×1080, which results in significant loss in image detail. It's also unlikely the camera could maintain a rapid frame rate with that much 1080p data flowing in without highly compressing the steam and again losing data. It would also prove cumbersome to post process these massive files on your computer. Fortunate owners of the Canon T2i, 60D, and 60Da are able to take advantage of a video mode known as *640×480 crop mode*, whereby the camera shoots video at 60 frames per second (fps) using only the small patch of 640×480 pixels in the center of the sensor. This is also known in the vernacular as the region of interest (ROI). Even though other Canon models may offer a 640×480 video mode, it is not a crop mode and downscaling/binning of pixels is occurring to realize these dimensions and need to be avoided. For these Canon models or non-Canon DSLRs, the next best video mode to use is *5× Live View*. This requires the use of software like *BackyardEOS* (written by Ottawa native Guylain Rochon, who also produces *BackyardNikon*) and a USB connection between your computer and DSLR to capture the *live view* video preview at 5× magnification, which is typically 1024×680 in size and runs at 5–30 fps. There is still some rescaling of the video data, but the loss in resolution appears negligible. Movies are recorded in H.264 *QuickTime* format, which is personally convenient, since I use Macintosh *OSX*, but PC users will need to convert from QT to AVI to process the data or import the QT movies as individual frame images (JPEGs or FITs) into *Registax* or *Autoskakkert*!

I chose the fastest shutter speed possible, which is 1/60 s, and adjust the ISO until I achieve the desired image brightness, which also facilitates accurate manual focusing. Others may suggest using a star to focus or a Bahatinov mask but if the seeing is so poor that you cannot make out the edge of the planet disc to confirm your focus then you shouldn't be imaging. The DSLR screen is deceptive, because the recorded images are much darker, which is a good thing since people tend to overexpose bright features like polar ice caps. In *Live View* mode, the shutter speed is simulated, so choosing a slower speed will make the image appear brighter, but the slowest true shutter speed is limited to about 1/30 s. Owners of IR modified DSLRs (cameras that have improved red or Hα response) also rejoice, since the modification typically also removes the anti-aliasing filter, thereby improving resolution, which is more critical with planetary than deep space imaging (Fig. 1.17).

In comparison with images shot at the same time by conventional means, the DSLR appears to be more sensitive to seeing conditions and lacking in color separation and resolution. This may be attributed to undersampling, since the images should have been shot at closer to f/30, which would also compensate for the *Bayer* layer's intrinsic color deficiency but at the time I was limited to f/15 for technical reasons. The Jupiter results are not as good as the Saturn images, because they were taken shortly after dusk with my mobile 8″ SCT, which was not well collimated or temperature equilibrated, as my usual 12″ Newtonian setup at home has a tree-obstructed westerly view of setting Jupiter in late April (Fig. 1.18).


**Fig. 1.17** Raw frame from Canon T2i Crop Video Mode

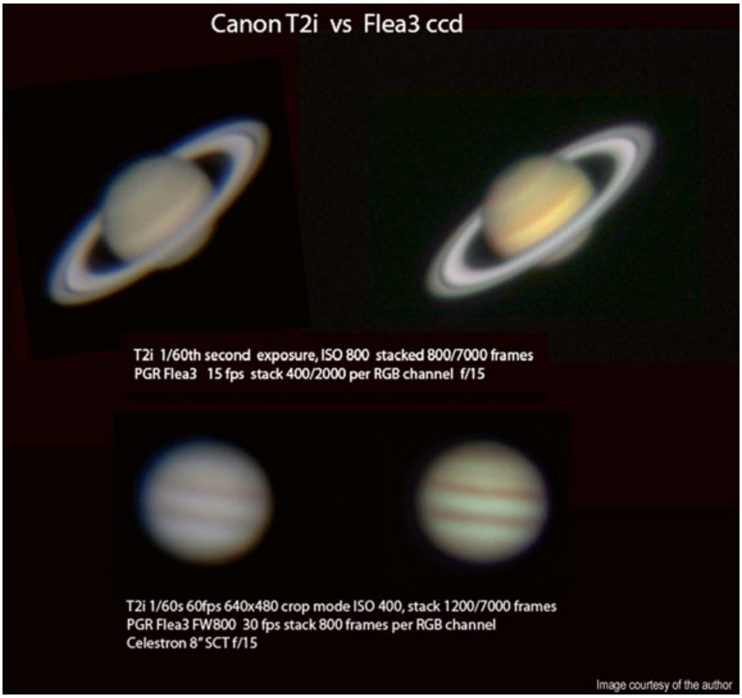


**Fig. 1.18** Comparison of Canon T2i and Point Grey Research Flea3 ccd

The low noise nature of the Canon DSLR CMOS sensor does allow one to increase ISO or gain without the noise increase one would expect from doing the same with conventional planetary CCDs. This allows the user to image at extreme focal lengths of well over f/40 and thereby obtain a prodigious image scale with a small-aperture scope, though it is unlikely that the image will resolve any additional detail at f/40 that cannot already be seen at f/25. You won't be seeing Encke's Gap with a 4 in. refractor!

The *Magic Lantern* development team has introduced a firmware enhancement for the Canon 5D Mark III that allows onboard SD-card recording of raw 14-bit 1080p video data. The dimensions of the ROI can be adjusted to allow an area as small as 640×480 to be recorded, which also aids in boosting frame rates. It's compatible with older cheaper models like the T1i and 50D and is a completely legal reverse engineered code that resides and runs concurrently with the original Canon code and offers other astro imaging features like built in intervalometer and 8 h bulb limit.

In conclusion, planetary imaging is definitely viable with a DSLR and provides results that better those obtained by Webcams and their rebranded brethen (Celestron Nextimage and Meade LPI). High frame rates (60 fps) the ability to increase gain (ISO) without equivalent noise increases, and the freedom from being tethered to a laptop for data acquisition are unique virtues that can make this the method of choice in certain imaging circumstances.

## Making a Fine Camera Lens Focuser and Finding New Life with Old Film Lenses

I was introduced to the harsh reality of the world at the age of 11 when I became a newspaper delivery boy. I would load up with as many papers that I could carry and ride out from the drop off location on my bike to the edge of my territory and deliver my load on foot before returning for more papers and riding out to another sector. It was fun. The worst part of the job was collecting the newspaper subscription charges from each client. YES that's right. People paid by cash every 2 weeks after the fact and I had to go door to door every 2 weeks to collect the cash and remit it to the company. Even though the clients were technically in arrears some hated to pay, hated the intrusion, and hated me because I was the corporate face. Today adults deliver newspapers by car and everyone has paid up months in advance directly to the newspaper publisher.

As things change, some clearly change for the better and some we just don't know. I did learn the value of money, hard work and a disarming smile but I would have ultimately learned all this and it's debatable if the lessons really took since I still have way too much astro gear.

Change was in the wind during 1985 when Minolta shocked the world with the introduction of the first true autofocus 35 mm SLR camera, the *a-7000*. Nikon and Canon scrambled to respond with Nikon introducing the *F-501* a year later. Canon delayed their camera for another year preferring to completely overhaul their design to truly embrace the electronic and digital age in time for their 50th anniversary. The new Canon *Electro Optical System* (EOS) was unveiled in 1987 but controversially featured a brand new and modern screw in EF lens mount with a longer back flange distance which made it completely incompatible with the legacy Canon FD breech lock mount lenses. The EF mount had a larger aperture, provided a surface for electrical contacts between body and lens, eliminated the aperture control ring and allowed the use of ultrasonic focusing motors and image stabilization systems to reside wholly in the lens. By contrast, Nikon preserved the F mount which required their early AF lenses to have the focusing motors reside inside the camera body and actuate the lens through a series of slow responding mechanical levers. As a result some Nikon AF lenses will not work in current Nikon bodies but all Canon *electro focus* (EF) lenses work in all Canon EOS bodies. As expected, Canon loyalists had to unhappily dump their FD lenses in order to remain current and these optically excellent lenses could be had on eBay a few years ago for very little until the advent of mirrorless cameras (μ43) and a guy named Ed Mika!

Ed is a mechanical engineer with a background in the automotive industry and lives 2 h north of Toronto. About 3 years ago he began fabricating 0.75 mm thin brass adaptors in his fully equipped CNC milling garage to allow the use of Canon FD telephoto prime lenses on modern Canon EOS bodies. He discovered that there was additional focus travel built into the FD telephoto primes to allow for temperature induced expansion and enough space to install a thin adaptor. Brass was chosen as the appropriate material, because it was soft enough not to damage the camera or lens flange but far stronger than aluminum and did not require anticorrosion coatings, whose thickness would have exceeded the demanding tolerances. In addition, a Dandelion AF-confirming chip bonded better to bare metal anyway!

The economics of this model are easily proven. My EF 200 mm L f/2.8 lens cost me $600 used, the very similar FD version can be had for as little as $150 on eBay, and the only functionality you give up is autofocus, which is of no use in astro imaging. The weapon sized EF 800 mm lens is $14,000, while the FD 800 mm is about $3000, and although not particularly useful for astro imaging, allows me to indulge in the fantasy of becoming a sports photographer and getting those free prime seats at the games. FD lenses high on Ed's list to acquire for astro imaging are the 14 mm f/2.8 L, 15 mm fisheye, 24 mm f/1.4 L, 35 mm f/2, 50 mm f/1.4, 100 mm f/2, 135 mm f/2 and 200 mm f/2.8. Keep in mind a preference for prime lenses since zooms typically incorporate design compromises that degrade optical performance. Quality camera lenses will also deliver a nice flat field from frame corner to corner and are often faster than comparable telescopes. The FD lenses feature the aperture control ring missing on all EF lenses and closing the aperture down a couple of *f* stops will often deliver optimal sharpness.

Ed has now shifted production from brass to ballistics grade extruded polymer which can be machined at even higher tolerances. The material is naturally nonreflective, and inherently more flexible than brass and safer during accidental collisions. The material can be so accurately machined as to occupy the chamfer margin on the body side of the lens mount to produce an effectively zero thickness adaptor needed for some FD lenses.

FD lenses can also now be used on dedicated astro imaging cameras because there are a variety of EOS to T thread adaptors available to connect EOS lenses but I have never seen a FD to T thread adaptor.

We're all familiar with the T-thread (M42 × 0.75 mm) attachment found on all manner of telescopes and accessories. The T does not refer to telescope but to the Japanese camera lens manufacturer Tamron, who introduced it in 1957 as a means to simplify their manufacturing process and inventory control. Dealers need theoretically stock only a handful of lenses, which could fit a multitude of camera models using an inexpensive camera specific T-ring adaptor. Like many good ideas, it did not catch on and disappeared in the 1970s. This means that there are plenty of good quality orphaned lenses available at low cost for widefield DSLR imaging. All dedicated astro imaging cameras come with a T-thread attachment as well. Pentax camera lenses also use a 42-mm diameter flange but have a coarser 1-mm thread pitch, which will prevent secure seating. The T-thread mount also has an unusually long flange-to-sensor distance specification (to ensure working with all known 35 mm camera bodies) of 55 mm giving it greater flexibility in custom applications.

One of the more prolific T-mount lens manufacturers of that time period was Vivitar. Like Kodak, the Vivitar company of today is a pale shadow of its former self. It was then known for pioneering computer aided lens design with optical performance rivaling OEM but at more affordable prices. Series I lenses from the 1970s to 1980s such as the fascinating 800-mm solid catadioptric lens originally built for the US Military by Perkin-Elmer still commands respectable eBay prices. Actual manufacturing was farmed out to a variety of companies, and the first two digits of the serial number denote this identity.

I was pleased to find this lens on eBay because this 300 mm f/5.6 was allegedly made by Olympus as denoted by serial numbers starting with 6. Olympus probably had some excess capacity prior to launching their OM series of cameras in 1972. Or did they? This bit of fiction has been perpetuated on the web for years ever since the first list of Vivitar manufacturers was posted a decade ago. Vivitar's own Product Manager who worked during the late 1960s confirms that Olympus, who was very protective of its brand, never made Vivitar branded lenses. But it certainly doesn't negate the excellence of this lens and its discussion regarding astro imaging usage. This lens was likely made by a top supplier, Kino Precision or Komine, and features a bespoke 18 blade diaphragm. The more blades the diaphragm has, the closer its opening describes a circle and the few diffraction artifacts that are produced when imaging bright stars (Figs. 1.19, 1.20, 1.21, and 1.22).

When you disassemble the lens, there is often an infinity focus stop in the form of a screw head protruding from the barrel that prevents you from further twisting the lens. Removing this screw or simply grinding it flat will give you several more millimeters of lens movement. In this case approximately 2.5 cm, more than enough space to install a thin off axis guider before the DSLR body and allow guided imaging.

All this talk of using camera lenses has lead to one of the most difficult aspects of DSLR astro imaging, obtaining and confirming optimal focusing. If you have *live view* then it's merely of matter of focusing on a bright star until its size is as


**Fig. 1.19** Vivitar 300 mm f/5.6 T mount lens from late 1960s


**Fig. 1.20** High quality construction showing 18 blade diaphragm

small and tight as possible. If you don't have live view then you have to take multiple images and enlarge them each time and compare. But it is often difficult to manipulate the manual focusing ring with fine control, especially on modern lenses

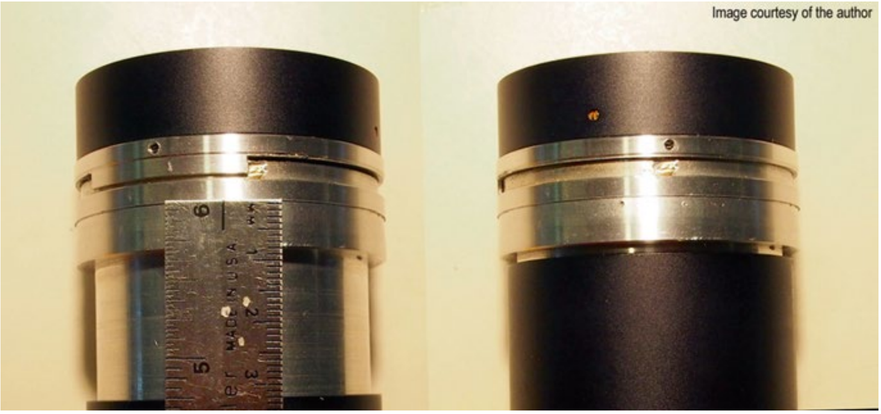


**Fig. 1.21** Removing infinity focus stop gains 2.5 cm of extra flange back distance


**Fig. 1.22** Capella taken with EP1 and Zuiko 135 mm f/5.6 showing diffraction spikes resulting from 8 blade diaphragm

where the focus ring might be operating by wire. That is, there is no direct physical connection between twisting the ring and lens barrel as you are merely triggering the autofocus motors. Here's a solution that will cost you under $20 (Fig. 1.23).

I purchased two pairs of polycarbonate hub centric rings that were large enough to fit around my largest telephoto prime lens (110 mm diameter) off eBay.


**Fig. 1.23** Fine lens focuser mounted on Canon EOS 300 mm f/4 L lens

These are automotive products designed to fill the gap between an aftermarket rim and the center bore of the wheel ensuring that the rim is mounted hub centric to minimize vibrations when the car is operated at high speed. Six, 2 in. nylon thumbscrews and some custom cut polycarbonate pieces sanded with a circular piece of sandpaper to match the arc of the hub centric rings and were later super glued to the rings. In this instance, the images speak volumes by themselves on how the fine camera lens focuser operates and is made (Figs. 1.24, 1.25, 1.26, and 1.27).

Afternote:

It is often difficult for beginner astro imagers to obtain accurate focusing. At the other end of the spectrum the serious imager utilizes expensive temperature compensating focusers to automatically adjust the focus point throughout the night as the optical tube microscopically contracts as it cools. But what if focusing stopped being an issue? What if there was a camera that could correct and refocus images after they were taken? That camera is the Lytro and the future of digital imaging has arrived.

Looking at this minimalistic, rectangular *über-gadget*, you might find my words too bold. In fact, techno pundits have deplored it as a toy, because it takes low-resolution images, has no wireless interface, and cannot do video. Sadly and not surprisingly, they completely miss the point. Lytro has upended and reconceptualized image taking, because *images are no longer taken but computed*. The ultimate goal is to turn the lens, aperture and shutter into software. The Ford Model T automobile was a terrible vehicle to operate (you had to hand crank the engine to start and manually advance or retard the ignition timing on the fly), but it profoundly


**Fig. 1.24** Homemade circular sanding disc

changed and continues to change all of our lives. The image-processing algorithms and CCD sensor modifications developed by Lytro hold the promise to do the same for imagers everywhere. Lytro company founder and CEO, Dr. Ren Ng has made his 2006 Stanford University doctoral thesis available on the Lytro website and I read it, several times. Unfortunately I still do not understand the mathematics behind his digital light-field camera but I think I can summarize how it works and what it means for astro imaging (Fig. 1.28).

A digital light-field camera records all the light rays within the camera as pixel data and by reverse ray tracing this data with proprietary algorithms, can correct the light-ray paths so that they converge at the correct focal plane. Images that are out of focus are the result of light rays not converging at a common focal plane, namely the CCD sensor. Since light-ray paths can be corrected *ex post facto*, out-of-focus problems can be remedied. Since each pixel of the resultant image can now be focused independently of each other, depth-of-field problems can be eliminated in portrait photography. For example, a wedding portrait often situates the groom behind his loving bride and in order to emphasize the couple, a large aperture (or small $f$-stop) is chosen that will result in a shallow depth of focus and allow the distracting background to vanish in a blur of unfocus or bokeh. However, if the depth of focus is too shallow, it becomes difficult to keep both partners in focus,


**Fig. 1.25** Sanding disc with sandpaper strip

since they are not standing within the same plane. Digital light-field imaging allows you to ensure that both figures remain in focus, deepening the depth of field while keeping the large aperture, which improves image quality through a high signal-to-noise ratio. Since the path of light rays can be corrected, this naturally leads to the correction of lens aberrations that also manifest as focus problems, in this case light rays not converging to a common point (Fig. 1.29).

For amateur astro imagers, fast imaging platforms like the Hyperstar ($f/2$) or camera lenses can be difficult to accurately focus because the range of optimum focus positions is very narrow. In the case of camera lenses, the act of focusing itself is very difficult to attenuate. Off-axis optical aberrations such as coma in reflectors and astigmatism in refractors become difficult to ignore with the availability of larger and larger imaging sensors. Spherical aberrations are also becoming more commonplace with the trend to larger diameter refractors, in which light rays passing through the periphery of the lens refract too strongly. The fundamental issue of good focus can be addressed with light-field imaging, and the addition of extra optical elements such as coma correctors or field flatteners may be avoided.

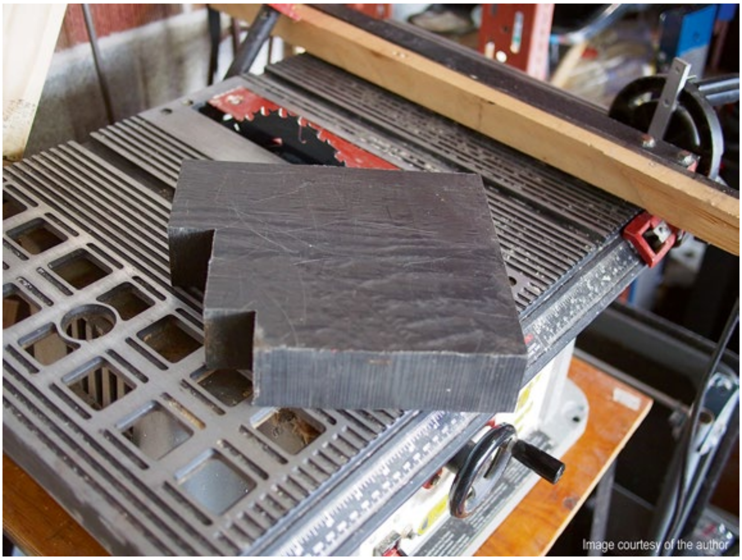


**Fig. 1.26** Large supply of polycarbonate plastic

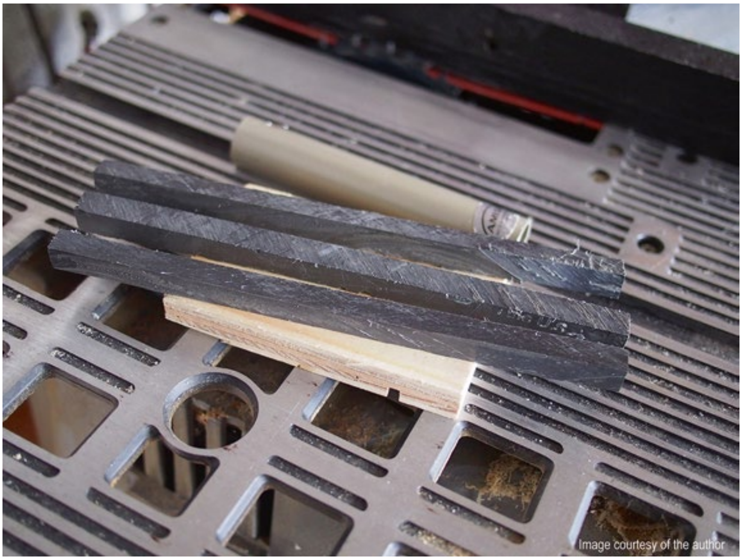


**Fig. 1.27** Polycarbonate cut into usable sized strips


**Fig. 1.28** The first Lytro camera

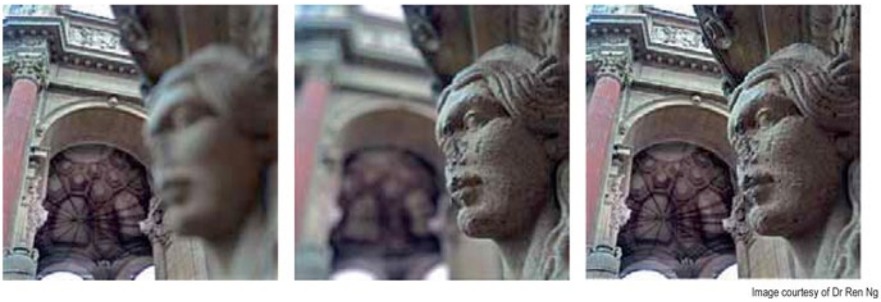


**Fig. 1.29** Refocusing on different areas of the image and enhanced depth of focus

Depth of field is not an issue with astro imaging, since all subjects are focused at infinity. Although this technique was demonstrated in Dr. Ng's prototype, consumer cameras and software are currently unable to perform this correction.

This type of lens aberration correction already occurs in modern cameras like the µ43 where the attached lens and its optical characteristics are identified in its firmware. The amount of barrel distortion and chromatic aberration it produces is corrected by in camera processing with the relevant correction parameters stored in the raw file.

Mathematically mapping all the light rays inside the camera seems improbable despite several assumptions designed to simplify the system. Instead of a five-dimensional representation of each light wave (a 3-D Cartesian coordinate for position and a 2-D one for direction), the lack of internal camera obstructions or scatter allowed Ng to express each ray as a pair of two coordinate values, one signifying the two dimensional position of the ray as it enters the optical plane and the second as it intersects the imaging plane. The radiance of any spot would be an integral expression of all light rays converging at that spot. The limited resolution of light-ray direction data collection also reduced the number of light rays processed to a finite quantity.

A microlens array (with an $f$-value matching the main camera lens) is placed a focal length over the CCD sensor, such that each lens covers a square array of pixels that will record the directional data of all light rays emerging from the optical plane and converging onto one pixel of the final image. The total resolution of the sensor is reduced by a factor equivalent to the size of each microlens pixel array. A full frame sensor (24 × 36 mm) with 2-μm pixels (a common size found in compact point-and-shoot cameras) yields an image of over 200 MP. If each microlens covered a 10 × 10 pixel array, then the final image would have a 2 MP size. There is an assumption that in the very near future even more pixel-dense sensors will be available, so that the final image will be of a respectable size.

Each microlens pixel array creates a subaperture image—a facsimile of the final image but reduced in scale and field of view. The directional data of each light ray are recorded as small parallax shifts; each subaperture image is similar to the ones beside it but with minute shifts. Those parts of the final image that are not in focus exhibit these small positional shifts, so that when the subaperture images are summed together, those areas become blurred. Areas that are in focus do not shift and when summed, exhibit sharpness and clarity. So instead of representing each light ray as a vector quantity and performing complex and repetitive calculations to reposition errant vectors, Ng developed a refocus algorithm that merely shifts these subaperture images the appropriate amount and direction before summing them all to create a final in-focus image. Even this algorithm proved very processor intensive, and so he developed another using a Fourier slice transformation that proved to be an order of magnitude quicker (Fig. 1.30).

The new Lytro camera is clearly intended as a proof-of-concept exercise, as the many engineering compromises required to lower the price point to the consumer level make it unattractive to the serious amateur. The real revenue for the company lies in licencing the technology to established camera manufacturers, which I predict will radically change the way we perform astro imaging in the next generation.

Still Lytro has pressed on with product development, raising $90 million in venture capital and announcing the release of a much more expensive camera, the $1600 Lytro Illum, in the summer of 2014. It features more of everything, processing power, sensor size, focal length and represents their first dedicated design whereas their first model was cobbled from off the shelf components. True to its design philosophy of upending imaging, the Illum doesn't feature an exotic multi element glass lens because its not concerned about capturing a conventional well corrected image. At Lytro "anything with a lens and a sensor" will do.

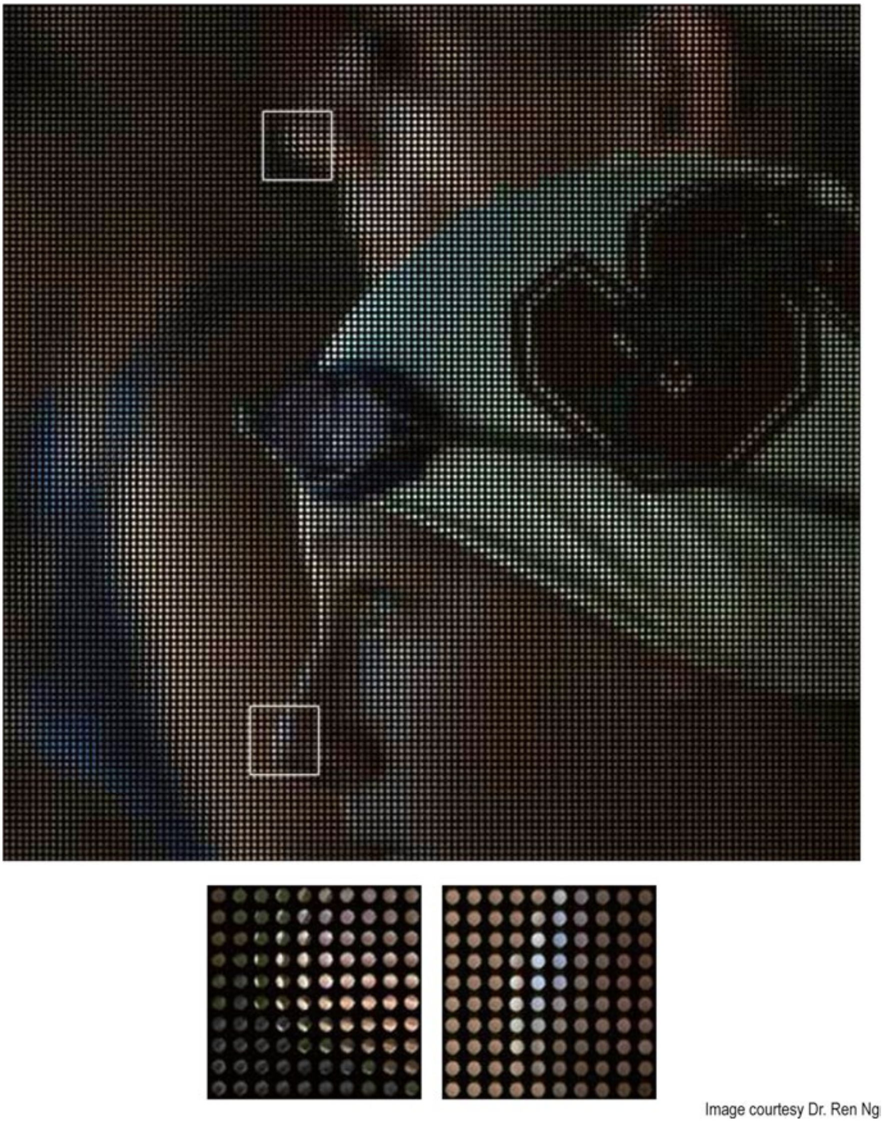


**Fig. 1.30** Closeup of subaperture image showing the image formed under each microlens which are combined to create the final whole image

## Making a Thermal Electrically Cooled *True* Monochrome DSLR for Less Than $300!

A year ago I was converting about a dozen current model Nikon DSLRs to monochrome sensing for people from all over the world. I stopped doing it because I felt obligated to financially absorb the occasional failures and I was also concerned about the reduced lifespan of the now opened and exposed cmos sensor. Japan experienced a rash of sensor failures in 2005 in a wide variety of consumer products and it was traced to the use of weaker, less expensive epoxy based chip casing (rather than traditional ceramic) allowing moisture and air to seep into the chip cavity and destroy it. Others have now carried the ball further downfield and have successfully converted Canon DSLRs by physically stripping away the microlens and *Bayer* layer by gently rubbing with just a simple bamboo chopstick! Aside from the fact that it take somewhere between 3 and 4 h to strip each sensor, the sensor no longer has an intact microlens layer and still needs to be resealed in a vacuum or nitrogen purged chamber in conjunction with glueing a new coverglass. The efficacy of the microlens structure cannot be overemphasized, at green color wavelengths one can see nearly twice the sensitivity over a plain, unadorned sensor.

There had to be a better way because I still lusted after the Leica *Monochrom* DSLR and wanted a fully functional camera to take true high contrast black and white terrestrial images and the occasional astro image.

Olympus introduced their new Evolt 500 DSLR in 2005 and was sold in Canada with a kit lens for the substantial price of $1500. Unfortunately the camera was eclipsed by the Canon 20D which had been introduced just a year earlier and had become the amateur astronomer's choice of instrument owing to the low noise performance of its cmos sensor. What is of interest is that the Olympus uses the 8 MP Kodak KAF-8300CE ccd sensor that is also manufactured in monochrome form, without the *Bayer* layer. The monochrome KAF-8300AXC chip is widely found in many different dedicated astro imaging cameras from SBIG, QSI, FLI, Celestron and Orion to name just a few. This is also an older style chip with dual inline pin (DIP) packaging meaning that the chip is soldered to a conventional circuit board by penetrating it rather than as a surface mounted component. The latter are much harder to desolder and resolder owing to the smaller contacts and proximity of them. Theoretically, anybody with a steady soldering iron can perform a little electronic surgery and transplant a monochrome 8300 chip for the original color one and make a *true* monochrome DSLR.

E-500 bodies can be found on eBay for around $100 and disassembly is not particularly difficult but some of the free flexible cables (FFC) are short and care must be taken to prevent damaging their zero insertion force (ZIF) sockets. The KAF-8300 sensors are sold by *Trusense Imaging Inc*. of Rochester, NY and can be had for as little as $100 for engineering grade chips with antireflection (AR) coatings and microlens layer. Engineering grade chips may come with dead pixels and cosmetic blemishes to the chip casing. Standard grade chips are $425 apiece. My experience showed that there were no discernable differences between the image quality of the engineering and standard grade chips (Figs. 1.31 and 1.32).

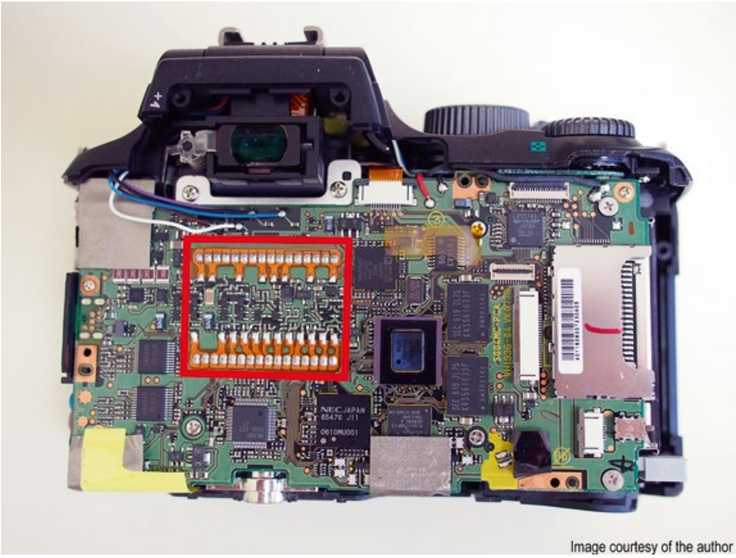


**Fig. 1.31** Sensor board is desoldered from camera motherboard

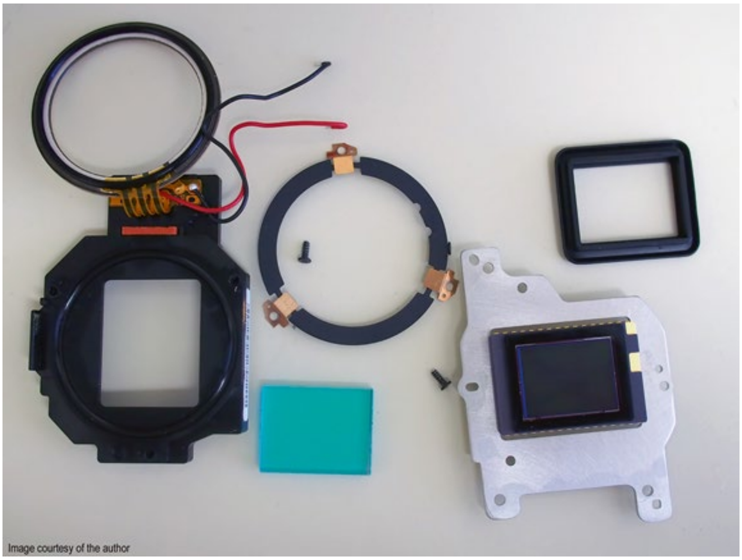


**Fig. 1.32** Disassembled sensor board showing ultrasonic dust removal system, IR blocking and AA filter and KAF8300 sensor


**Fig. 1.33** Gear puller used to remove bonded KAF8300 sensor from aluminum board

A small gear puller is useful to separate the chip, which is glued to the aluminum board. Make sure the aluminum board remains flat and is not warped after this procedure and all trace of adhesive is removed down to bare metal as this will affect alignment of the focal plane of the new chip (Fig. 1.33).

The aquamarine coloured IR blocking filter and anti aliasing blur filter is a multilayered glass element that must be removed and replaced with glass of known thickness and refractive index to maintain accurate autofocus capability of the camera. Some higher end DLSRs have a built in adjustment mechanism to allow technicians to fine calibrate the autofocus but in the Evolt this is not possible. The refractive index of various glass samples was determined by using an Abbé refractometer (a design invented by famed German physicist Ernest Abbé) and a high refractive index carrier liquid, 1-bromonapthalene (n = 1.6570). The refractometer was another eBay purchase at a ridiculously low price, a wonderful prewar instrument made by the *Spencer Lens Company* of Buffalo, NY. Charles Spencer made the very first achromatic doublet refractor in America at age 12 and a compound microscope by age 16. He formed his company in 1838 at the tender age of 25, selling and manufacturing 3–10″ reflectors and 1–3″ refractors and by 1850 was renowned for producing some of the world's best microscope objectives. The factory still exists today, after the company was bought and sold many times in the mid twentieth century. They now make Leica stereo microscopes (Fig. 1.34).

The key part of the refractometer is the rotating silver cube which houses the two halves of a high index glass prism. Liquids can be injected into a narrow passage between the two prisms and the rotation allows the angle of incident light to be altered. Light passes from the relatively high refractive index of the glass prism to a


**Fig. 1.34** Spencer Abbé Refractometer

sample and undergoes refraction but at a critical angle the light no longer refracts into the sample as the angle of refraction becomes 90°. In the refractometer eyepiece you see a light and a dark zone which corresponds to the region where no light passes into the sample since the angle of refraction is greater than the critical angle. The prisms cause colour dispersion and there are two secondary Amici prisms in the barrel of the refractometer that you can rotate to refocus the colour wavelengths, eliminating the dispersion so that you can see a sharp boundary (Figs. 1.35 and 1.36).

There's a finely etched metal scale where you can read off the refractive index to a precision of four decimal places after the device has been finely calibrated to a standardized reference sample which could be something as accessible as a white

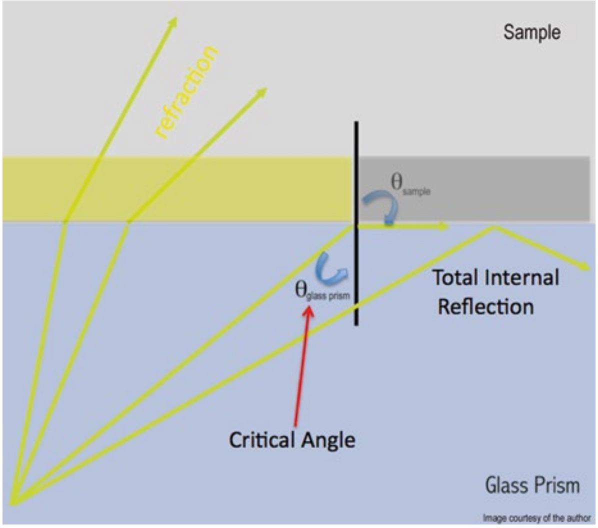


**Fig. 1.35** Describing the light and dark zones viewed through a refractometer

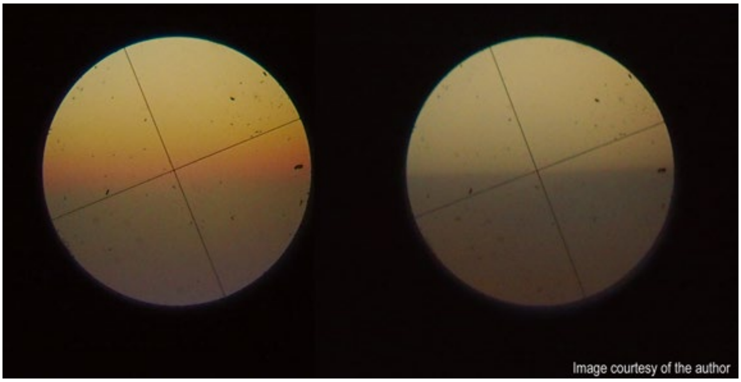


**Fig. 1.36** Color dispersion correction by refractometer

sugar solution. There are tables for the accurate index of refraction for differing concentrations of sucrose solutions at room temperature that you can make at home with some distilled water and a fine electronic balance of the type used to measure diet portions of food. In this case I used the laboratory grade bromonapthalene to calibrate. Bromonapthalene is also used to adhere the glass sample to the upper sample prism since the glass can't be injected into the cavity between the two prism halves (Fig. 1.37).

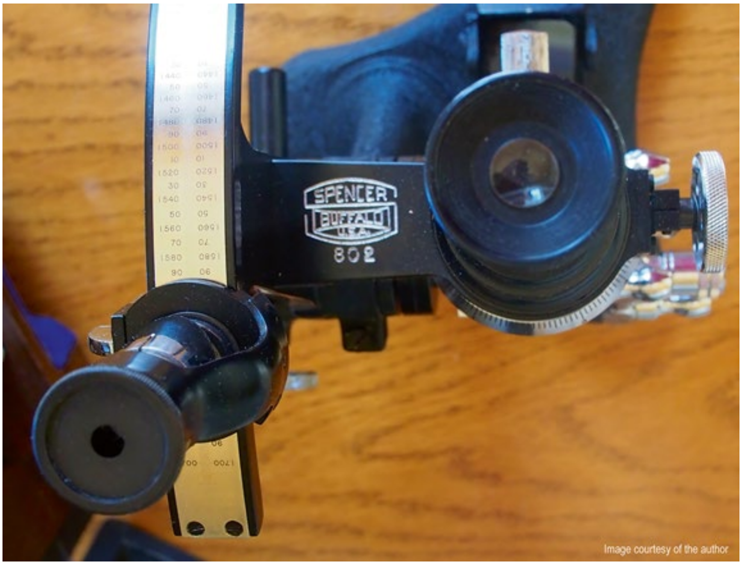


**Fig. 1.37** Reading the index of refraction scale on refractometer

Refractometers aren't just some sort of quaint lab instrument to be used in esoteric astronomy themed projects but are in widespread use to determine sugar concentration in grapes (and the best time for vintners to harvest them) and fat content of milk. They are also valuable in determining the identity of unknown substances.

The reason to go to all this trouble is because the IR/AA filter shifts the image plane backwards and we have to duplicate that same amount of shift in order for the autofocus to work correctly. The amount of shift depends on the thickness and the index of refraction of the new glass that is being used.

I sourced optical window glass of similar OEM thickness and size from Edmund Optics, Surplus Shed and Omega Optics (eBay). We see that the glass from Olympus, Omega Optics and Surplus Shed is identical and known as Schott BK7 glass which is the type of glass commonly found as the crown or leading element of a refractor. The glass from Edmunds is Borosilicate also known as pyrex which has very low thermal coefficient of expansion making it ideal substrate for making reflector mirrors (Table 1.1).

Using the equation to determine focal shift as a result of the optical window (ow):

$$\text{focal shift} = \left(n_{ow} \quad 1\right) / \left(n_{ow}\right) * \text{ow thickness}$$

**Table 1.1** Comparison of different glass refractive indices and resultant focal shift

| Glass source | Refractive index @ 22 °C | Thickness (mm) | Focal shift (mm) | Shim thickness to subtract (mm) |
|---|---|---|---|---|
| Olympus | 1.510 | 3.30 | 1.115 | 0.00 |
| Omega Optics | 1.517 | 3.00 | 1.022 | 0.09 |
| Edmunds | 1.465 | 3.10 | 0.984 | 0.13 |
| Surplus Shed | 1.517 | 3.70 | 1.261 | –0.15 |

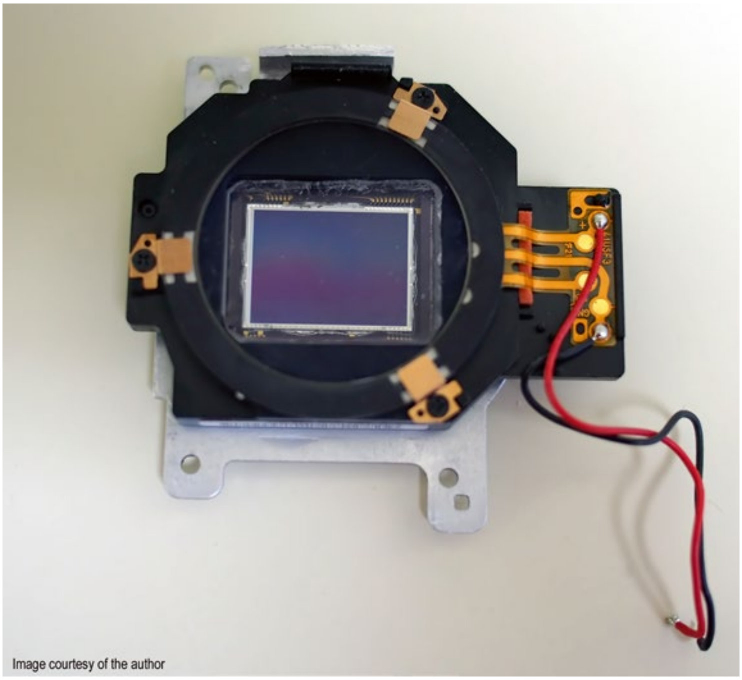


**Fig. 1.38** Final assembled sensor board with clear Edmunds glass

We can see that the Edmunds glass causes the image to form 0.13 mm more forward that the stock position of the sensor. Olympus uses a pair of shims to attain the factory focal shift distance, one that is 0.12 mm thick and one that is 0.25 mm thick. By deleting the thinner shim, we should be able to have good autofocus. Lastly the Edmunds glass was cut on one side to fit the enclosure which also houses the ultrasonic dust shaker (Fig. 1.38).


**Fig. 1.39** Significant resolution and sensitivity gain in monochrome conversion

The modified camera produces sharper images with light sensitivity increased by at least 2.5 full f stops. Previous monochrome modified cameras only produced about one full stop in improved light sensitivity (Fig. 1.39).

The second modification addresses the fact that 8300 chip is rather noisy. With long exposures thermal "dark" noise builds quite readily. I was inclined to thermoelectrically cool the chip via a Peltier semiconductor, but wanted to keep the camera looking completely stock. Luckily the chip already straddled a piece of aluminum so if I could somehow cool that piece of metal, I could cool the chip. There was just enough room to add a small piece of custom cut angle aluminum to connect the sensor assembly to the tripod screw hole at the bottom of the camera. A thermal electric cooler (TEC) unit was liberated from a 12VDC portable cooler of the type used to keep canned drinks cool during a long family car voyage. It was attached to a computer cooling fan to assist heat rejection on the "hot" side cooling fins and had a 1/4 × 20 tripod bolt tapped into the "cold" side heatsink and screwed into the camera to complete the cooling circuit (Figs. 1.40, 1.41, and 1.42).

I did not expect good cooling efficiency because of the roundabout fashion of directing the cooling to the 8300 chip but dark frame tests did show significant differences! (Figs. 1.43 and 1.44).

Finally, an example of astroimaging with the modified E-500. The strange artifact in the upper left hand corner is likely noise known as "amp glow", thermal noise from closely packaged ancillary electronics. This was a common problem in the Canon 20D as well and frankly these cameras were never designed to take long exposure astronomical images! The horizontal banding noise is something I have experienced in newer Olympus micro 4/3rds cameras although to a lesser degree and the current models have their sensors made by Sony and are as clean as any Canon DSLR (Fig. 1.45).

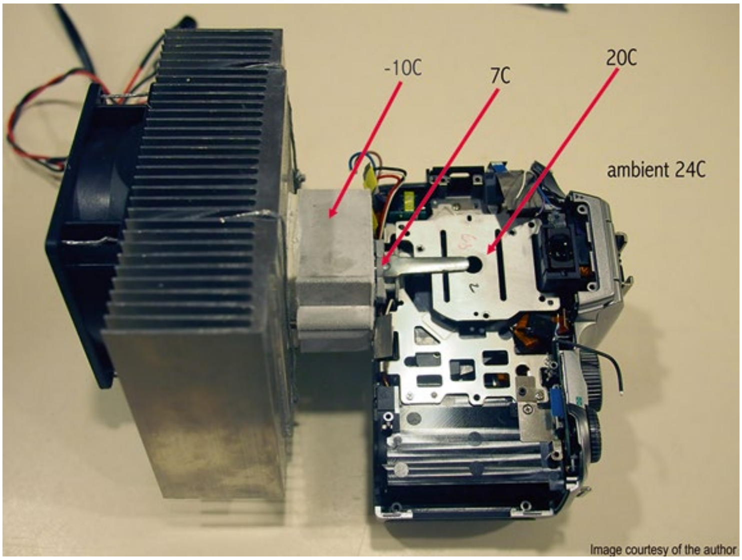


**Fig. 1.40** Temperature gradient in cooling system

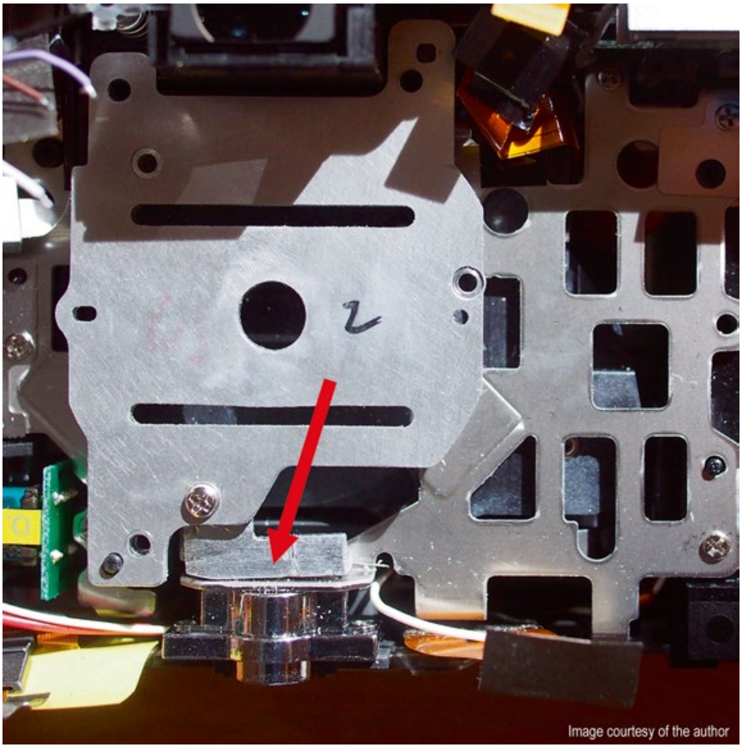


**Fig. 1.41** Connection between sensor aluminum board and camera tripod hole

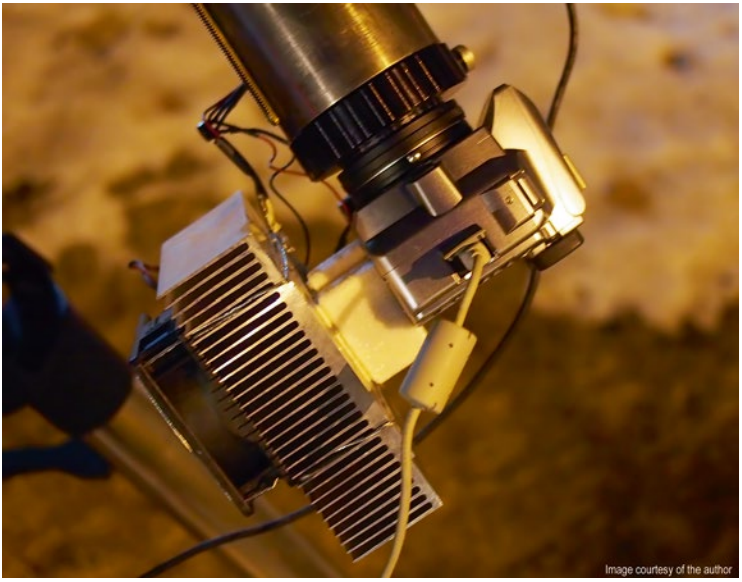


**Fig. 1.42** TEC in action, frost buildup visible on cold heatsink

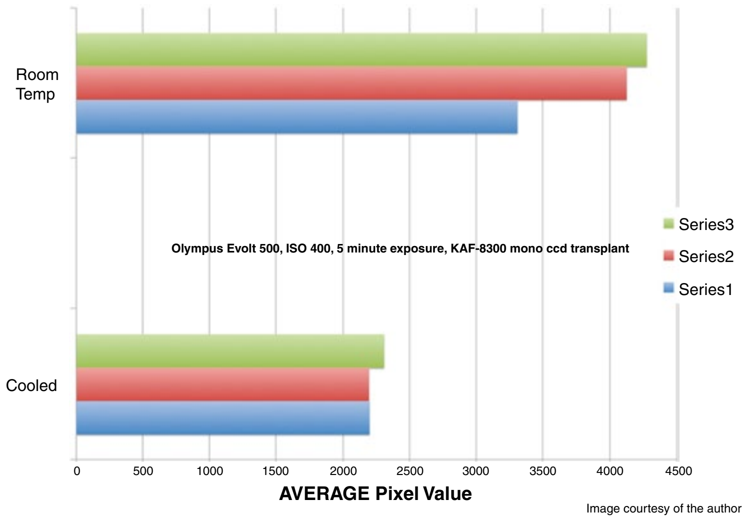


**Fig. 1.43** Comparison of TEC and uncooled camera dark noise

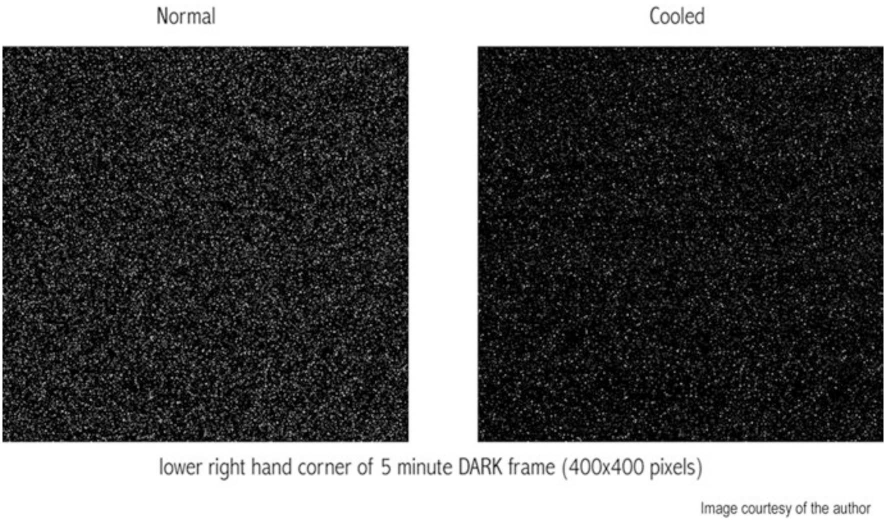


**Fig. 1.44** Actual dark noise samples

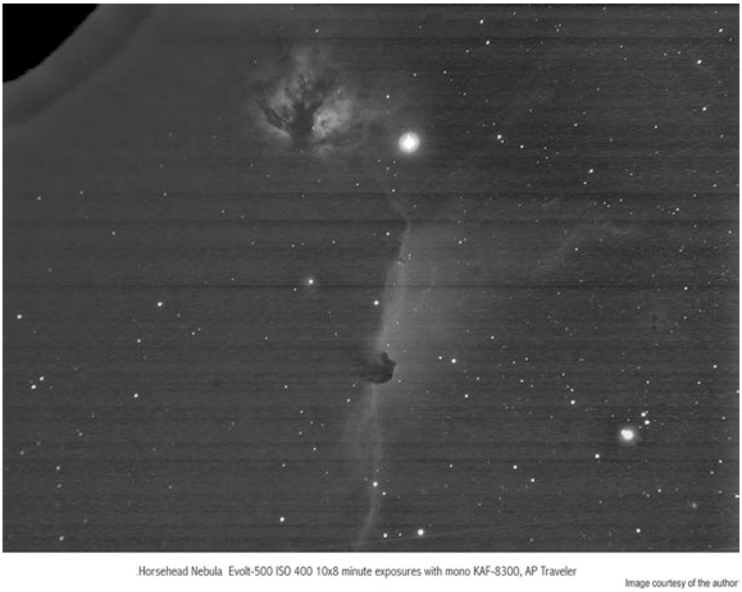


**Fig. 1.45** The Horsehead Nebula imaged in Hα narrowband with true monochrome DSLR

The majority of amateur astronomical imagers live in large urban centers and often have to drive long distances to find relief from light pollution. I've driven as far as 2 h one way and have been tempted to drive even further, across the US border to this mythical mountain top imaging nirvana called the Black Forest Star Party in central Pennsylvania. The cardinal rule to follow when astro imaging away from home is to keep it simple, because it's so easy to forget to bring that one tiny piece of equipment without which you cannot function. One time it was the 2″ adaptor that connects the camera to telescope. Another time it was the 12 V cable that powers the mount from the car battery. That's why I only take DSLRs when I go dark site imaging and only perform unguided imaging. DSLR astro imaging might be the best way to enter this hobby but improvements in technology mean the average imager could remain satisfied with this format and need not progress to "*serious*" equipment and still produce beautiful images able to elicit the envy of even the most hardcore amateur astronomer.

# Chapter 2

# Advanced Astro Imaging

Advanced astro imaging is the next step for the burgeoning amateur astronomer and typically involves the use of commercially made, thermo electrically cooled cameras for deep space imaging and industrial machine vision cameras for planetary and solar imaging. But even in this rarefied space, there is room for the builder to make equipment that augments and even forms the basis of his imaging train. All it takes is a little imagination, keeping current with internet discussion threads, and the power of a well written email.

## Current Concepts in Planetary Imaging

There are three tenets to follow with planetary imaging:

1. The bigger the scope, the better.
2. The faster the camera, the better.
3. The quality of the seeing (or atmospheric stability) trumps everything.

A large diameter scope allows you to gather more light, which provides a brighter image to the camera. This in turn allows one to reduce the noise in the image by reducing the need to amplify the signal (selecting a high gain) with the camera. This also allows one to use a shorter exposure. A larger scope also resolves more detail, rendering sharper, large scale images. Chromatic aberration and cost typically rule out refractors, so Newtonian reflectors and Cassegrains are the favored scope designs. In fact, Dobsonians represent the best value because an expensive high capacity equatorial mount is not required. Hand tracking can be further enhanced with a relatively inexpensive, tracking Poncet platform.



J. Chung, *Astro-Imaging Projects for Amateur Astronomers*, The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18546-0_2

The speed of the camera refers to both its shooting rate in terms of frames per second (fps) and its shutter or exposure speed. A shutter speed of 1/30th second allows a maximum shooting rate of 30 fps. When visually observing a planet, one often finds fleeting moments of wonderful clarity and sharpness, reflecting the variation in atmospheric seeing. Even during periods of good seeing, there will be moments when the atmosphere seemingly disappears and one glimpses what a planet might look like when viewed from outer space. A short exposure speed will allow you to capture and freeze those moments of good seeing, and software will allow you to select only those frames for processing that ultimately will reveal a trove of hidden detail. A fast shooting rate will also necessitate an interface system capable of high speed uncompressed data transfer. USB2 and Firewire400 can stream data at over 40 MB/s, which can support frame rates of 60 fps for a 640×480 pixel CCD. Firewire800 cameras now support 120 fps, and the ethernet GigE (gigabit ethernet) enabled cameras promise even higher rates. This fast rate is critical for quickly rotating planets such as Jupiter, and allows the photographer to collect as much data as possible before the movement of the planet induces blurring. The more data available the greater the likelihood of capturing a large number of individual high quality frames during moments of excellent seeing.

Webcams are a great way to enter the realm of planetary imaging, although there are a few caveats. You must choose a Webcam that allows removal of its lens. Fortunately, threaded adaptors (*Mogg*) are available to connect the Webcam securely within the 1.25 in. barrel of a scope. Firmware updates are available for some models, which will allow uncompressed data transfer. This limits the shooting rate to less than 10 fps, but will improve the quality of the images. Finally, all Webcams are color cameras and that will reduce the resolution of the image due to the Bayer layer covering the pixels.

Machine vision cameras, used in assembly line manufacture, with the fastest data interface are the choice of serious planetary imagers. *The Imaging Source* (Germany) and *Point Grey Research* (Vancouver) are the big names in this field. Because of their price point, such cameras offer fewer circuit design compromises and better noise control by incorporating the most sensitive CCD chips, such as the Sony ExHAD. Choice cameras are monochromatic, which necessitates using a filter wheel populated with filters of the primary colors (R, G, and B) and obtaining data through each such filter. A flip mirror is also a useful device to allow stress free alignment of the planet onto the tiny CCD chip. Centering a planetary image onto a CCD is a very difficult task, because most planetary imaging is done at high focal length, on the order of several meters. A zero image shifting motorized focuser is also most beneficial as it is *de rigueur* to refocus with every filter. Along with a motorized filter wheel, these devices also prevent the image jarring tremors induced by touching any part of the imaging train (Fig. 2.1 and Table 2.1).

ZWO is the newcomer and the ASI120MM has been a surprising product. Its small pixel size belies surprising sensitivity and quantum efficiency and confers a much larger image scale without needing to resort to additional focal length. The Scorpion is an older generation design but is ideal for making solar and lunar mosaics where sensitivity is not as important as sheer physical sensor size (Figs. 2.2, 2.3, and 2.4).


**Fig. 2.1** Some popular industrial planetary imaging cameras (from *left* to *right*) PGR Flea3 (adorned with self adhesive heat sinks), Celestron Skyiris 618M, ZWO AS120MM and PGR Scorpion 20SO

**Table 2.1** Specifications of the some popular industrial planetary imaging cameras

| | PGR Flea3 | Celestron Skyiris 618M | ZWO ASI120MM | PGR Scorpion 20SO |
|---|---|---|---|---|
| Sensor | Sony ICX618 | Sony ICX618 | Aptina MT9M034 | Sony ICX274 |
| Pixel size (µm) | 5.6 | 5.6 | 3.75 | 4.4 |
| Sensor size | 640×480 | 640×480 | 1280×960 | 1600×1200 |
| Interface | FW800 | USB3 | USB2 | FW400 |
| ROI mode | Yes | No | Yes | Yes |

You must let your large diameter telescope come to full thermal equilibrium either by forced ventilation or allowing enough time for it to happen, passively. During the summer in some climes this may be a very difficult to attain since temperatures drop precipitously once the sun sets. There is also a practical limit on how high a focal length one can image at and I generally stick to the f/20 rule. Image your scope at a maximum of about f/20, any higher will not result in any resolution gains given seeing conditions and aperture. Higher than f/20 will result in such a dim image that high gains will be needed to record data and introduce more noise than can be eliminated with extended stacking.

*Atmospheric seeing* is the high-frequency image fluctuations caused by the mixing of parcels of air of differing temperatures. At its worst, bad seeing makes a planet pulsate and undulate like it is being cooked in a deep fryer. Most of the time it is seeing and operator skill that limits the quality of planetary imaging. Properly choosing your imaging site can mitigate several local seeing factors. Re-radiation of accumulated daytime heat from the ground and nearby buildings results in local convection currents—look for a moderately elevated site or a flat grassy field. Try not to image downwind of a city or a mountain range, since the airflow will be turbulent.


**Fig. 2.2** Jim's Imaging Train: Optec powered 2″ RGB filter slide, JMI NGF-S motorized crayford focuser, Meade 644 flip mirror. On Newtonians, typically there is insufficient focus travel to incorporate the flip mirror so a good illuminated finder with a multiple etched reticle can be used to accurately position the planet. Surplus Shed and eBay are good sources for these reticles


**Fig. 2.3** Build your own motorized filter wheel, a project in progress. A manual 5 position 1.25″ filter wheel with 28BYJ-48 stepper motor and ULN2003 driver and Arduino, no motor shield needed

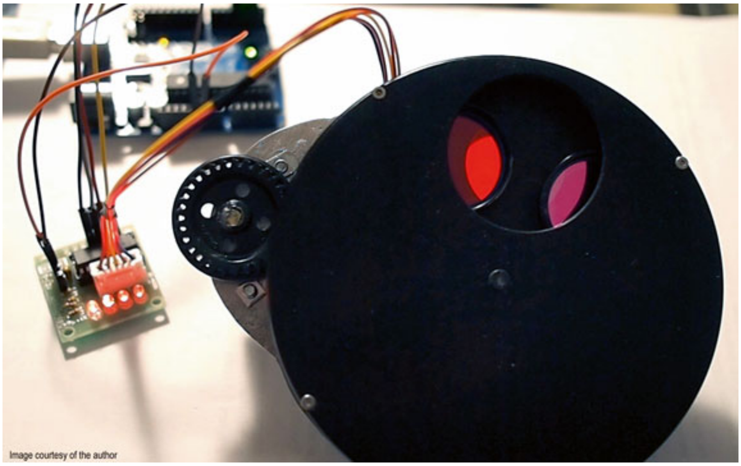


**Fig. 2.4** Filter wheel in action, coding and hard switches need to control filter wheel movement

Imaging downwind of a large body of water or a plain will produce smooth laminar airflow at your site. There are many useful Web sites to check the overhead wind conditions, such as the Unisys 300 mb (millibar) map plot. The altitude of the 300 mb surface is near 30,000 ft which also corresponds to the upper tropospheric jet stream. I like to confirm the predictions with Clear Sky Clock before expending the effort to drag out my equipment from the garage and spend time setting up but when I was younger I was out every clear and even not so clear night!

Challenging the convention that an overhead jetstream corresponds to bad seeing are the seeing predictions present on Skippysky (www.skippysky.com.au/NorthAmerica/). Here local conditions such as the Global Forecast Systems' 10 m wind and 2 m surface temperatures data are more heavily weighted then the 300 mb data to produce seeing predictions.

Do not attempt to image if it's windy, if a cold front has just passed, or if the stars are twinkling. High-altitude cirrus clouds at sunset can be a harbinger for good seeing, as is the presence of fog or mist, since poor transparency often coexists with excellent seeing. Finally, try to image the planet at its highest altitude or apogee since it will be furthest from the ground-level air turbulence and pollution, and you will also be imaging through a thinner section of the atmosphere. True imaging purists will relocate temporarily to island mountain tops, like Hawaii's Mauna Kea, the eastern coast of Florida, the Caribbean islands, or Arizona/New Mexico—all locations where the seeing is consistently excellent. Imagers like me, who are stuck in the Great Lakes basin (amongst the worst seeing areas on the planet), have to wait patiently for the occasional night of excellent stability.

Clearly, a lot of effort is spent acquiring imaging data, and an equal amount of effort is required to process it! Typically, you will be operating in the field with a laptop, using capture software to record a movie of planetary images onto a hard drive.

One should be prepared to have a lot of empty hard drive space. I personally have made the switch to solid states drives after experiencing a number of hard drive failures with the added benefit that solid states drives will support the higher write speeds demanded by USB3 and gigE interfaced cameras. Most people will be familiar with the public domain software *Registax*, which has been continually refined throughout the years by its author. I have recently taken to using *Autostakkert*! (primarily because I could not get *Registax* to run under my PC emulation environment on my Mac) and I found it refreshingly easy to learn and powerful. *OSX* users can choose from *Keith's Image Stacker* or *AstroIIDC*, although the latter is no longer available to new users. I continue to be a user of *AstroIIDC* and its demise leaves amateur astro imagers without the ability to use the Firewire equipped cameras from *Point Grey Research* (*PGR*).[1] Granted that this was always a small subset of amateur astronomers who insisted on using *OSX* vs *Windows* but the *DCAM* protocol allowed manufacturers like PGR to offer useful multiple video and reduced noise imaging modes on their Firewire cameras. The disabling of the CCD pixel gain amplifier and slowing of vertical pixel clock shift register results in significant reductions in read and dark noise.

These software packages perform a sorting routine to choose the sharpest frames among the thousands in a movie, and then stack those chosen frames. Stacking frames reduces the noise in the image in inverse proportion to the square root of the number of frames being added. Stacking 100 frames will result in an image with 1/10th the noise of a single frame. Noise occurs as a random value, whereas a true image detail remains a constant pixel value, so the averaging function tends to increase the signal more rapidly than the noise. The noise is a result of the camera circuitry, as images are typically shot at moderate to high gain. Reducing the noise allows further processing to be performed on real planetary details and not noise artifacts. One of the joys of planetary imaging is being able to develop an image with better color and resolution than is visually apparent at the eyepiece.

Freezing the seeing typically is achieved at shutter speeds of 1/30th second and faster. Faster shutter speeds do allow faster fps shooting rates so the ability to collect more data in a given time period is offset by increased noise in the data as higher gain levels are required to maintain an adequate histogram or image brightness. A minimum image brightness is need so that the stacking software is able to detect the planetary disc edges in its alignment routines. Adjusting the gamma or contrast during image capture can also facilitate this edge detection. Don't forget, noise reduction is an inverse square root function so a little extra noise requires a whole lot more stacked frames to eradicate. And remember that seeing trumps all, you simply cannot compensate for poor seeing with an ever shorter shutter speed whereas excellent seeing might allow you to use longer shutter speeds (greater than 1/30th second) to maximize the SNR and achieve that smooth unprocessed appearance that master planetary imagers consistently produce. It is this minimization of noise in the final stack that allows the use of Photoshop sharpening tools to further reveal hidden detail.

[1] OSX users can continue to use native capture software through the Open Astro Project. The Linux based OACapture is compatible with the IIDC compliant Firewire interfaced cameras as well as all the new cameras from ZWO.

It is true that imaging approaches are tailored to the target planet. Solar imaging requires zero gain and careful attention to the histogram to prevent oversaturation. In fact solar features can fluctuate so quickly that often one is unable to stack more than a dozen images in order to preserve the authenticity and sharpness of the image. Even at its greatest elongation, Mercury in either the predawn or dusk will always be low in the sky and hence a poor target. Daytime imaging is the solution but it can be difficult to visualize and find Mercury during the day and you must take care to avoid the always proximal Sun. Venus and Mars are very bright and if seeing allows can be pushed to beyond f/20 through the use of a slower shutter speed as planetary rotation is not an issue. Of course Venus can only be effectively imaged with a UV pass filter. A solar Ca-K line filter will also work. Jupiter's rapid rotation limits data collection time to between 2 and 3 min depending on the focal length used. The Sun, Mercury and Venus remain monochromatic targets and Mars and Jupiter are RGB targets. Saturn is quite dim and to achieve a decent image scale requires a LRGB approach where nonfiltered luminance data is collected at the desired image scale/focal length and overlaid over an enlarged RGB image. This RGB image is of reduced resolution shot at a shorter focal length in order to achieve an acceptable compromise between brightness and shutter speed. Uranus needs good seeing since the red channel data is nearly absent and the blue channel is typically of poorer quality due to atmospheric scattering.

I would like to touch on some advanced processing techniques being used by planetary imagers. One is referred to as "multiple alignment point stacking," where you perform the stack several times but each time relative to a different alignment point. This can give you improved sharpness and clarity in the local region around each alignment point, as seeing does not remain constant over the entire image frame, especially when shooting a target such as the Moon with a large CCD (1600 × 1200). Then it's a matter of cutting and pasting the different alignment-point regions together to form a mosaic image with improved sharpness throughout the frame.

Another technique applies to the special situation of a rapidly rotating planet such as Jupiter. Depending on the focal length utilized, you have approximately 2–3 min to acquire data before rotation makes it impossible to correctly align the frames in a stack. This effectively means that the photographer has only about a minute to obtain data through each RGB filter and at 30 fps that amounts to only 1800 frames. Add in time to refocus and rotate the filter wheel, and you may have to be satisfied with taking about 1000 frames per color channel. This ultimately reduces the number of optimal frames available for stacking and noise reduction—hence the attractiveness of cameras that can shoot at 120 fps. *WinJUPOS* is public-domain software that allows you to derotate images. This means that you can spend the full 3 min shooting each color channel. When you assemble your colour image, the individual RGB stacks will be widely out of alignment with each other because of Jupiter's rotation, but *WinJUPOS* will derotate them so that they can be correctly aligned! There are many online guides to assist with understanding how to operate WinJUPOS and it will correct both planetary rotation and field rotation effects for those imaging on alt/az platforms within a 15 min window before limb effects become too noticeable.

In my exploration of the latest planetary imaging cameras like the Celestron SkyIris and ZWO ASI120MM I made the shift to using a Windows 7 based Panasonic Toughbook and was pleasantly surprised to find that the bundled *Firecapture* software included very useful utilities like *Derotate* and *Debayer*. Although I am not a webcam or one shot color (OSC) camera imager, there continues to be processing advances that close the quality gap between monochrome/RGB imagers and OSC imagers. The demosaicing of the Bayer layer can lead to reduced resolution and artifacts like color anomalies and zipper textured edges. These are particularly egregious in the most simplest interpolation algorithm known as *nearest neighbor* where the missing color data at any one pixel site is simply borrowed from the nearest pixel that is overlaid by that corresponding missing color filter. *Debayer* offers you the choice of using several more advanced algorithms, namely *bilinear*, *HQbilinear*, *edge*, *smooth hue*, *adaptive smooth hue* and *vng* to debayer your Y800 encoded AVI. Nonadaptive algorithms like bilinear and HQbilinear average out the color data of surrounding like colored pixels. In smooth hue, the idea is that luminosity might change quickly but hue transitions tend to be mild so to preserve that, the green color data are interpolated first via bilinear then the red and blue data determined bilinearly with the neighboring red and blue values normalized by being divided by their green value.

Adaptive algorithms like edge, adaptive smooth hue and vng (variable number of gradients) attempt to detect edges by testing to see if the change in color values across a plane exceeds a certain threshold. If it does, then that is likely the edge of an image and you don't want to interpolate that pixel with data from pixels crossing that edge. The edge algorithm test for horizontal and vertical edge whereas vng additionally tests in the two other bisecting diagonal directions.

Astro images tend not to be like typical terrestrial images on which these algorithms are constructed to deal with. Astro image have very harsh edge transitions from color to black and back so *Autostakkert*! may have the very best solution, no interpolation at all! Drizzle was first conceived to restore lost resolution of undersampled widefield Hubble Space Telescope images by combining dithered images (identical images intentionally offset by a few pixels). *Drizzle debayer* is an algorithm that seeks to fill in missing color data at each pixel site by determining actual values from individual frames of the stack that are naturally dithered due to the inability of even a polar aligned tracking scope to maintain perfect centering at high focal lengths. As the image of the planet shifts several pixels during data collection before being manually returned to the center, different pixels are exposed to each planetary feature and it is possible to reconstruct the true RGB values of each feature with *drizzle debayer* on *Autostakkert*! with no loss in resolution and no loss in data, theoretically! In early 2015 Olympus introduced the new second generation OMD-EM5 camera which utilizes a Drizzle like algorithm to boost resolution and/or color fidelity by moving the imaging sensor one pixel in eight different directions with its 5 axis image stabilization system to create true, uninterpolated color data as well as expand the 16 MP sensor to produce a 40 MP image of improved resolution.

Current developments in demosaicing algorithms show increasing accuracy by exploiting not just the spatial domain (the rows and columns of an image) but the frequency domain where the individual pixel values are represented by a grid of sine waves which can be summed and expressed as a Fourier transform. Similarly, the venerable Bayer layer design which has survived four decades with no change may finally be replaced. The Bayer layer is responsible for 50–70 % light loss due to absorption by the color filters but Panasonic has suggested replacing the filter array with clear color splitters that separate either red or blue colored light rays and deflect them into adjacent unfiltered pixels with no transmission losses.

The future of amateur planetary imaging will likely be the commonplace use of telescopes with mirrors greater than 20 in. in diameter in order to take advantage of ever faster data transfer rates of new camera interfaces. These large telescopes will not be imaging at f/20 as it's unlikely terrestrial seeing will ever support such monster focal lengths but rather be used to increase the image brightness or signal allowing cleaner raw images and shorter exposure times. The ever faster interface data transfer speeds also mean no longer being restricted by a 640 × 480 sensor size. A 1280 × 960 sensor size makes it easier to locate the planetary image and easier to build solar and lunar mosaics.

This is currently being reflected by a new camera introduced by ZWO, the massive 1936 × 1216 pixel ASI172MM with the new Sony ICX174 CMOS sensor that can output full scale 2.3 megapixel data at a blazing 128 fps with the USB3 interface. This sensor is also available as the considerably more expensive PGR Grasshopper3 ($995). As impressive as the specifications are, a 128 fps shooting speed equates to a single frame exposure duration of less than 7 mS. There are few planets bright enough and telescopes with sufficient aperture to be able to take advantage of this speed but the more important take home message is the new CMOS dominance over CCD in sensor architecture. In fact, Sony has announced that they will be wrapping up CCD production over the next couple of years to focus solely on CMOS production.

Both CCDs and CMOS' (complementary metal oxide semiconductor) were conceptualized in the late 1960s but CCDs were easier to fabricate and gained early favor. It's with the improvements in lithography techniques that came with mass logic and memory chip production of the 1990s that lead to cheaper and better CMOS designs. There is one fundamental difference between the two designs. CCDs pass photon generated charges from pixel to pixel and convert them to voltage values at one or few output nodes sequentially, buffered and sent as analog signals which are amplified and converted digitally outside of the sensor. CMOS' convert the charge to voltage at each pixel, independent and in parallel to every other pixel and the amplifier and A/D components are also located on sensor. Traditionally the tight packaging of logic circuits at each pixel occludes a portion of the photosensitive region making CMOS' less light sensitive and prone to fixed pattern noise like banding artefacts. The current use of back illuminated CMOS' sensors and noise reduction algorithms have negated these early disadvantages. CMOS strengths as compared to CCD remain rapid digital data flow through

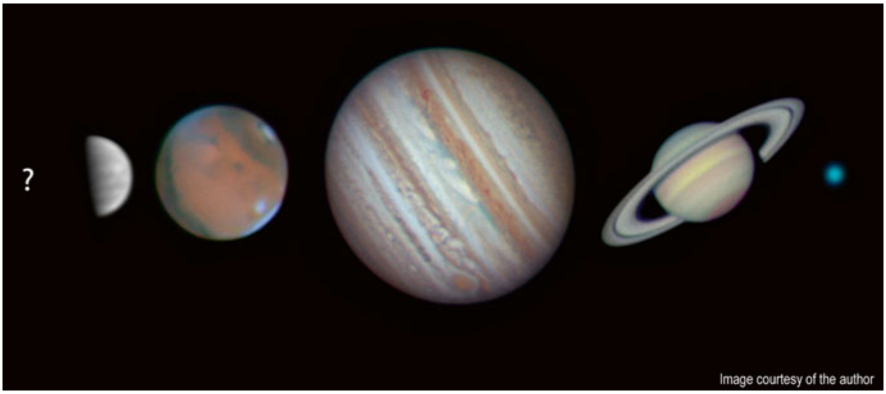


**Fig. 2.5** Some of my best planetary images from Toronto

multiple output nodes with no bottlenecks, very low power consumption and low heat generation. Interestingly, developments in CMOS were driven by consumer demands for 1080p HD video recording (to be superceded by the even more resource intensive 4k video) on small, battery prohibitive smart phone devices. The fast transfer of image data of megapixel sized CMOS sensors have made them a natural fit for planetary imagers. It is far less technically demanding to keep a planetary image centered on a larger sized chip that is also able to shoot at the rapid frame rates needed to freeze the seeing (Fig. 2.5).

## How to Image Like the Pro's for Under $1000

From time to time, amateur astronomers experience an affliction known as aperture fever or the desire for a larger telescope. This is not a uniquely North American phenomenon, where bigger is better by default. As telescopes go, bigger is generally better, although it may not be practically better. Astro imagers suffer a further malady known as sensor fever, where they wish they had a bigger and more sensitive CCD sensor so as to make the most of their limited imaging time.

The largest imaging sensor is currently operating with Pan-STARRS 1 (Panoramic Survey Telescope & Rapid Response System) on Mount Haleakala in Hawaii. It has approximately 1.4 billion (giga) pixels and an active area of 40 $cm^2$. However it is not monolithic but an array of 64 × 64 ccd chips, each 600 × 600 pixels in size. *Semiconductor Technology Associates* has made imaging cameras for the Hubble Space Telescope and the Cassini orbiter and currently make one of the largest single wafer imaging chips, the 111 megapixel STA1600B boasting 9 μm, 10,560 × 10,560 pixels. They will also likely manufacture the 3 gigapixel ccd array (made of 189 individual 4000 × 4000 ccds) for the planned LSST (Large Synoptic Survey Telescope) in Chile.

These sensors of course have about as much in common with budget minded amateur astronomer as the famous Alpine/Countach poster[2] of the 1980s did with the teenage boys who occupied the bedrooms that it adorned. I do a lot of narrowband deep space imaging from my light infested Toronto home because I don't have many opportunities to get away to distant dark sites. Narrowband imaging utilizes filters that pass at specific wavelengths corresponding to the spectral line emissions of certain elements but the bandwidth is very narrow, on the order of 3–12 nm. The most popular filters detect Hydrogen Alpha emissions (Hα) at 656 nm and doubly ionized Oxygen emissions (OIII) at 501 nm which are very common in planetary and diffuse nebulae. The imaging data can be mapped to the red and green/blue channels respectively to create a high resolution image of natural appearance. The extremely narrow bandpass of these filters completely negate the effects of urban light pollution and even the full Moon but do require subexposures in the tens of minutes. Many narrowband imagers advocate 30 plus minute subexposures in order to obtain good SNR in their images but I'm hesitant about the odd tracking/guiding error or errant aircraft ruining one or more of these long exposures so my approach is to use 10 min exposures with the most sensitive camera to achieve the same level of SNR. About 5 years ago I decided to purchase a QSI532 (Quantum Scientific Instruments) dedicated astro imaging camera because it contained the Kodak KAF3200 ccd. This chip with microlens delivers an 85 % quantum efficiency (QE) at the important Hα wavelength.

Newer chips may be larger, cheaper and with lower dark current but none has eclipsed the sensitivity of the KAF3200 which is the reason why decade old SBIG (Santa Barbara Instrument Group) ST10XME cameras still command a healthy price on the second hand market and new cameras with this chip continue to be made.

SBIG also manufactures the more expensive STXL6303E camera with KAF6303E ccd that is a favored amongst the higher ranks of amateur narrowband astro imagers. This chip has twice as many pixels and is the same size as an APS sensored DSLRs while retaining large 9 μm pixels and a 65 % QE at Hα. Finger Lakes Instruments (FLI) and Apogee also make similar cameras.

If a camera manufacturer has a reputation for making scientific grade instruments this means that the supporting electronics are designed to allow the camera to deliver performance within the specified parameters published by the *sensor/ccd* manufacturer. Things like poor RF (radio frequency) shielding, faulty grounding or substandard components can introduce the type of fixed pattern noise that we have seen earlier in DSLRs. This is understandable in consumer products made to a stringent price point and dedicated astro imaging cameras are more expensive for this reason. DSLRs are also designed to operate in an environment of nearly infinite SNR overwhelming and covering any pattern noise. With astro imaging, even if the pattern noise is present at a level below that of read noise, it will become clearly visible with histogram stretching and subexposure stacking like any faint cosmic feature. It will even be visible in raw frames because the human visual cortex has been designed to be particularly adept at detecting spatial patterns, able to average

[2] *Body by Lamborghini, High fidelity by Alpine*

**Table 2.2** Performance specifications for various Kodak ccds (from Kodak datasheet)

| | KAF6303E | KAF3200 | KAF8300 |
|---|---|---|---|
| Pixel dimensions | 3072 × 2048 | 2184 × 1472 | 3448 × 2574 |
| Diagonal dimension | 33.3 mm | 18.1 mm | 22.5 mm |
| Pixel size | 9 μm | 6.8 μm | 5.4 μm |
| Full well capacity | 100,000 $e^-$ | 55,000 $e^-$ | 25,500 $e^-$ |
| QE @ 650 nm | 65 % | 90 % | 48 % |
| Read noise | 15 $e^-$ | 7 $e^-$ | 10 $e^-$ |
| Dark current at 25 °C | <10 $e^-$/pixel/s | <7 $e^-$/pixel/s | <200 $e^-$/pixel/s |
| Dynamic range | 76 dB | 78 dB | 64 dB |
| Blooming gate | NABG | NABG | ABG |
| Nominal SBIG price | $8000 | $7000 | $2000 |

out the fixed pattern across thousands of pixels even though it's impossible to tell if any one individual pixel contains pure random noise or pure random noise plus a fixed pattern signal. Typically this quality of design and construction applies to all the big name camera manufacturers so that even bargain priced models based on the ubiquitous and relatively inexpensive KAF8300 sensor deliver excellent performance. Looking at just the sensor performance criteria can be very instructive in selecting the most appropriate camera for the imaging circumstance (Table 2.2).

Read noise is satisfyingly low and not an issue in any of the above cameras. Assuming a well regulated thermoelectric cooler that can keep a stable set temperature, the larger dark current in the 8300 model shouldn't be a problem and can be accurately subtracted out upon processing although lower dark current is always a preferred starting point. Where the 8300 falls behind is in its lower well capacity which leads to reduced dynamic range. One might argue that this is offset by the 1000× saturation antiblooming protection but this impacts on the nonlinear response of the 8300 sensor making it unable to be used in applications like photometry and participation in the AAVSO's (American Association of Variable Star Observers) Citizen Sky program. The small pixels of the 8300 also lead to reduced QE as the physical bulk of the gate structures over each pixel assumes a greater proportional of the photosensitive area. There are unfortunately no budget priced back illuminated ccd cameras at this date. This makes it a virtual tie between the 6303E and 3200 chip for the narrowband imager. The 3200 is more sensitive but the 6303E can cover more than twice the sky area with each image. But they both represent an onerous financial outlay for the budget minded astro imager.

So when a number of KAF6303E sensored cameras made by a microscopy imaging company called Photometrics became available on eBay for $499 apiece a couple of past summers ago, I jumped at the opportunity. The Quantix 6303E is an air and liquid cooled laboratory grade camera with a proprietary PCI interface card and 68 pin RS422 serial cable. A biotechnology company had purchased approximately 250 units at $25,000 each in 2005 and decided to liquidate the hardware as they deemed it too slow for their purposes. They were likely conducting rapid large scale bioassays using porous micrometer sized encoded silicon particles that, when bonded to DNA or a protein, would alter the spectral reflectivity of the particles. Thousands of these particles would line the surface of a microscope slide, each one with distinct position; the slides would be mechanized and scanned at high speed with the camera system. These cameras are still available currently for $1000 on eBay.

A number of modifications would have to be performed before the cameras could be adapted for recording the sky.

I don't have a permanent observatory, so I was averse to using a desktop computer to host the camera, given its rather restrictive PCI interface. Fortunately, Dell and IBM make docking stations for some of their laptops that come with a PCI interface slot. The decade old Latitude family Dell laptops are compatible with the D/Dock Expansion Station that comes with a half height PCI slot. I picked up a decade old IBM ThinkPad T30 and docking station locally for only $60.

The KAF6303E sensor is a full frame sensor as opposed to the interline transfer sensor found in many Sony designs and other Kodak chips. The interline sensors dedicate a masked off portion of each pixel to which the accumulated charge in each pixel are all simultaneously transferred at the end of each exposure. The sensor is immediately ready to image and a shutter is not required to allowed the accumulated charge to be downloaded. This reduces the well depth and QE of each pixel. The full frame sensors requires a shutter to stop the light signal otherwise as the rows of charge are shifted downwards towards the horizontal shift register they continue to collect charge resulting in ghosting or blurring artifacts. The Quantix camera had an electronic shutter option, so there were jumper terminals on the motherboard that provided a 24 VDC signal that could be used to drive it. A Prontor 40 mm electronic shutter was found for $60 at *Surplus Shed*. For about $250 I had a local shop fabricate an aluminum housing to hold the shutter and provide a T thread mount for a 2″ nosepiece. Free software was provided with the camera but *Maxim DL and CCDSoft* also speaks the PVCAM protocol used by this camera. There is also an ASCOM driver written by an amateur astronomer which opens up even more popular and economical possibilities like *Nebulosity* (Figs. 2.6, 2.7, 2.8, 2.9, 2.10, and 2.11).

The camera's TEC provided an impressive Δ55 °C reduction in temperature maintaining a stable −30 °C even amidst the heat of a midsummer's night. According to the Photometrics operating manual, the camera actually only functions in 12 bit mode with a maximum full well of 85,000 $e^-$ under high dynamic range mode. The read noise is 21 $e^-$ and the system gain is 20 $e^-$/ADU. Perhaps the camera is optimized for microscopy imaging so there is some loss in astronomical performance but the narrowband images obtained were nonetheless most acceptable (Figs. 2.12 and 2.13).

The possession of two astro imaging cameras naturally evolved into a dual scope/dual ccd configuration allowing the simultaneous gathering of Hα and OIII data and halving the time required to construct a narrowband "rgb" image. The Quantix6303E was connected to the AP Traveler via an Astrotech AT2FF flattener and the QSI532 was connected to an Astrotech 72ED refactor with a Televue TRF-2008 0.8× reducer/flattener. The combination shorter focal length scope and reducer made the QSI FOV closer to that of the Quantix. The AT72ED was aligned precisely

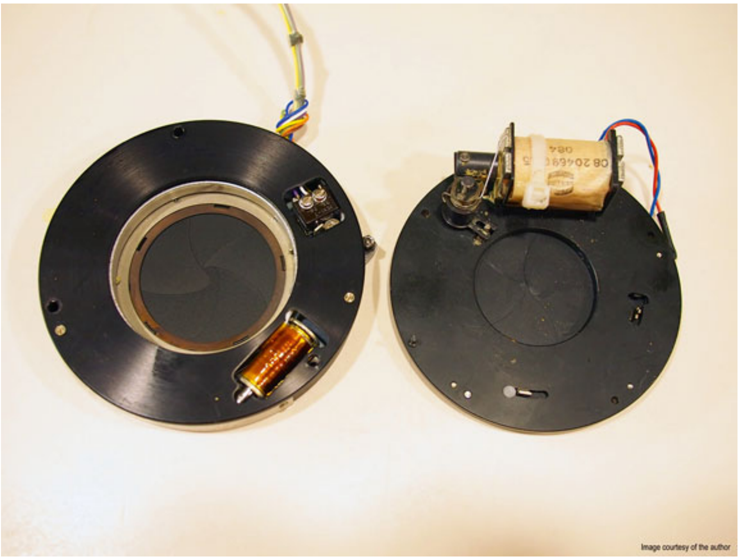


Fig. 2.6 Ilex electronic shutter (*left*) and Prontor electronic shutter (*right*)

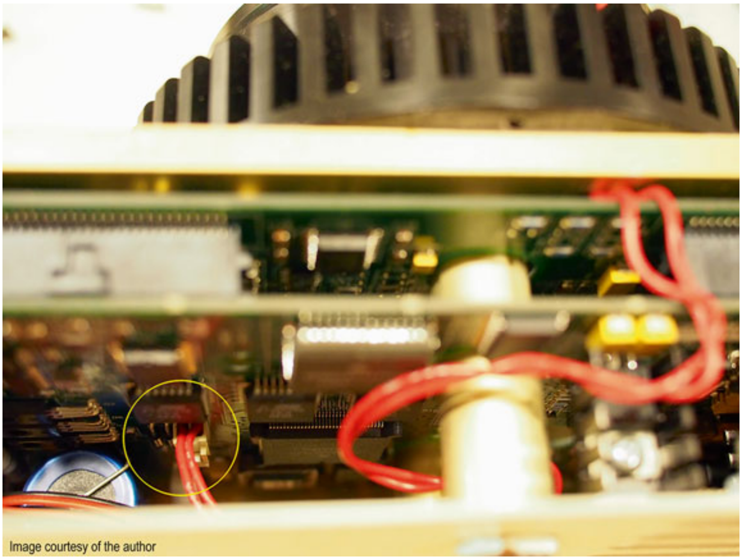


Fig. 2.7 Motherboard jumper connections to power shutter


**Fig. 2.8** The Photometrics Quantix6303E microscopy imaging camera

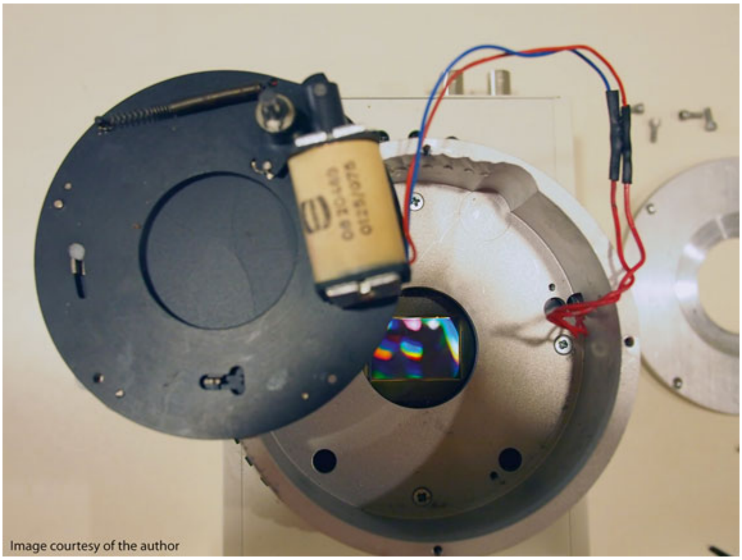


**Fig. 2.9** Custom aluminum enclosure for shutter


**Fig. 2.10** Shutter installed


**Fig. 2.11** Finished astro modified Quantix6303E

Image courtesy of the author

**Fig. 2.12** Center crop of NGC281 Pac Man Nebula, 4 h of 10 min subexposures with each of 2″ Baader Hα and OIII filters, Quantix6303E and AP Traveler refractor


**Fig. 2.13** Full image of NGC6888 Crescent Nebula, 2 h of 10 min subexposures with 2″ Baader Hα and 7 h with OIII filters, Quantix6303E and AP Traveler refractor

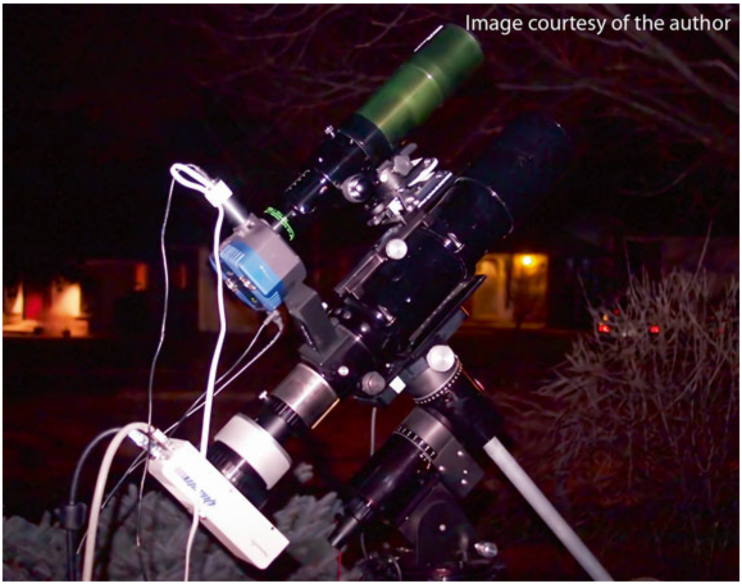


**Fig. 2.14** Dual scope/dual ccd setup

to match the center of the FOV of the AP Traveler with a Skywatcher Deluxe Guidescope mount. Both scopes were guided with the built in off axis guider on the QSI. The QSI collected Hα data through a 1.25″ Astrodon 3 nm bandpass Hα filter and the Quantix used a 2″ Baader OIII filter (Figs. 2.14 and 2.15).

The astronomy community was an early adopter of ccd technology as early as the 1970s because they recognized the high QE, low readout noise and high dynamic range would doom the photographic plate. They only had to wait for devices of sufficiently large surface area. I was pleasantly surprised to learn that Dr. Willard S. Boyle who shared in the 2009 Nobel Prize for Physics for his invention of the charged coupled device was a Canadian. He was born in Nova Scotia and was home schooled by his mother until high school as a consequence of his physician father's practice in a remote northern Quebec logging town. He joined the Royal Canadian Navy during the Second World War and flew carrier based Spitfire fighters. After getting his doctorate from McGill, he worked at Bell Labs and rose steadily to executive positions. It was here in 1969, over a brainstorming coffee break, that he and Dr. George E. Smith devised the concept of the CCD. He retired in 1979 and returned to Nova Scotia to open an art gallery with his wife. He was 86 when he passed in 2011.

Afternote:
One of the best narrowband deep space targets visible from the Northern Hemisphere is Messier #1, the Crab Nebula. I've imaged it several times over several years and yet I never failed to be amazed by its intricate color and structure


**Fig. 2.15** NGC2359 Thor's Head with dual scope/dual ccd setup, 9 × 10 min subexposures

unlike most post supernova nebulae. It also had a special place in my heart as likely the first nebula I had ever heard of.

My interest in astronomy was first piqued in the summer of 1995, when my wife (then GF) and I were travelling two-up on motorcycle through the Okanagan Valley *en route* to Banff. I have never experienced such dry heat in Canada: we had shed our leathers to ride in regular clothes as we visited wineries and orchards, while temperatures peaked into the mid 40s. We also made a stop at the Dominion Radio Observatory at White Lake near Penticton, because I thought the pair of large white parabolic antennae made a good photo op. We went inside for a tour of the main building, and I was particularly drawn to a deep-space image accompanied by ancient Chinese text reporting the appearance of a *Tianguan* (ζ Tauri) "*guest star*" in AD 1054 that was so bright it was visible in daylight for 23 days. This guest star is the supernova SN 1054, which is now the pulsar at the heart of Messier 1, the Crab Nebula. The display went on to explain the historic significance of the Chinese text, being the first human-recorded observation of a supernova! It was a defining moment in my life, and it set in motion one of those inextricable micro-events that culminated in a rediscovered passion for astronomy about a decade ago.

Strictly speaking, SN 1054 was not the earliest recorded observation of a supernova. That credit belongs to writings found on fourteenth-century BC (Shang Dynasty) oracle bones comprising the ninth chapter of *Yin-Xu-Shu-Qi-Hou-Bian*: "On the 7th day of the month, a great new star appeared side by side with the Antares αSco." Now recording this natural phenomenon is not particularly onerous or cerebral, it just takes a pair of keen eyes and dark skies (not in shortage back then!). What is astounding is the unbroken record of astronomical data-keeping from 206 BC to AD 1912 by the Chinese Emperor's Astronomical Bureau—the world's longest-lived civil service! So how was it possible for a single society to sustain this effort, when no others could?

As the leader of an agrarian economy, it was crucial for the Emperor to produce a calendar so that the impact on irrigation of the season, from snow melt in spring to the onset of the monsoon in mid-summer, could be predicted. He relied on a court-appointed Astronomer-Royal to use astronomical observation to maintain the accuracy of this calendar. By 484 BC, the year was determined to be 365.25 days long through the employment of bamboo-stalk sundials in the day and water-driven clocks at night. By AD 25, accurate observations of the lunar synodic period collected over many decades allowed the rough prediction of solar eclipses using a cycle that returned the spectacle to approximately the same longitude every 54 years (the *exeligmos*). A star chart of the complete sky containing approximately 1350 stars was completed in the seventh century AD (Tang Dynasty). Observations of novae, sunspots, and comets were studiously recorded from two official imperial observatories in the capital, and then compared with each other to avoid false reports. Records from outlying areas of the country were also forwarded to the bureau to confirm observations. Further evidence of the assiduous scientific conduct of the Astronomical Bureau can first be seen in Indian astronomers taking up residence in the capital, followed in later years by Islamic astronomers during the Yuan and Ming dynasties. These ancient applications of cultural tolerance and intellectual collaboration brought many advances in Chinese thought and science.

Astronomy may have been an empirical pursuit rather than a theoretical one in China, and the lack of deductive geometry resulted in a weakness for describing planetary movements, but the cosmological model of *Hsuan Yeh*, where space is infinite and celestial bodies float at rare intervals, is more enlightened than any model from the West. Western thought was hampered for a 1000 years by the Greek fondness for circular planetary orbits and an Earth-centric model with the heavens populated by perfect and changeless bodies arranged in concentric crystalline spheres. The paucity of European astronomical observation prior to the Renaissance is attributed to this belief of a perfect cosmos, for surely there is nothing to see if nothing ever changes.

Europe, however, would be instrumental in bringing the wealth of ancient knowledge to light during a period of Chinese political instability. The Sino-Japanese war of the 1930s and the Second World War in the Pacific threatened to destroy valuable and ancient Chinese texts, a fate that would likely have been repeated in later years during the purges of Mao's Communist regime. An unlikely Cambridge biochemist by the name of Joseph Needham was seconded by Churchill into the Diplomatic Corps and sent to war-torn China to rescue as much of the old knowledge as possible and to deliver scientific equipment and supplies to deprived Chinese researchers. He was uniquely qualified for this role—a stranger-than-fiction Indiana Jones-like personality. A natural polyglot, he taught himself Chinese with the help of a Chinese postdoctoral fellow who later openly became his life-long mistress. He was a brilliant and charismatic man who was able to improvise under trying conditions, including even Japanese attacks while travelling back and forth across China for a period of more than 5 years. Upon his return to Cambridge, he occupied a pair of small suites on the ground floor of Caius College (one of which would be later occupied by Stephen Hawking) and began reading his staggering collection of Chinese books.

One in particular was the 1888 edition of the largest book in the world, the *Kuchin Tu-shu Chicheng* or *The Complete Collections of Illustrations and Writings of Ancient and Modern Times* that was commissioned in 1700, took 26 years to write, and amounted to the sum of all Chinese knowledge at the time—in nearly 2000 volumes! Needham set out to write a seven-volume distillation of this knowledge entitled *Science & Civilization in China*. Though he died in 1995, the Needham Research Institute carries on his work to this day and the 27th volume was published recently.

Along with meticulous record keeping, the ancient Chinese used an equatorial coordinate system very similar to our modern one, making possible identification of unique Chinese constellations and star names. The Chinese calendar, based on a 60-day lunar cycle, is easily transposed to the Gregorian calendar so that exact dates and locations of astronomical phenomenon can be deduced. SN 1054 was readily identified as the Crab Nebula, especially as the remnants are clearly visible; it lies in close proximity to ζ Tauri, and its expansion rate agrees with a creation date some 950 years in the past. Since we now know the date of SN 1054 was 1054 July 4, we know the exact age of this pulsar and can refine existing theories about aging neutron stars, such as the rate at which their rotation slows as they age. With the launch of the *Chandra X-Ray Observatory* in 1999, mining Chinese astronomical data has never been easier. In AD 386, a guest star was recorded in the southern sky, and the transposed sky coordinates allowed *Chandra* to discover and confirm the remnants now known as G11.2-0.3.

In AD 240, the Chinese recorded the first observation of a major “broom star,” later identified as the world’s first recorded sighting of Halley’s Comet. In AD 530, they recorded Halley with more precision, stating that, on September 1, it appeared 1° NW of star *Xiatai* (in Ursa Major). This precise date and location allowed mission controllers of the European Space Agency to refine the ephemerides of its 1986 apparition to allow a successful rendezvous of the *Giotto* spacecraft with its nucleus.

The precise timing of first and second contact of the lunar eclipse of AD 434 on September 4, using a water clock, was used recently to support the discovery of a reduction in the rotation of the Earth that cannot be explained merely by tidal forces exerted by the Moon and the Sun. It may be a result of slowing induced by tectonic rebound in the Northern Hemisphere as glaciers retreated from the last Ice Age, or by the expansion of the atmosphere due to the impact of recent global warming! (Fig. 2.16)

## Make Your Own On-Axis Guider

A few years ago, I was introduced to yet another revolutionary new concept in guided imaging. A company by the name of Innovations Foresight (www.innovationsforesight.com) has introduced an *on-axis guider* that promises to address a number of shortcomings associated with other forms of autoguided astro imaging.

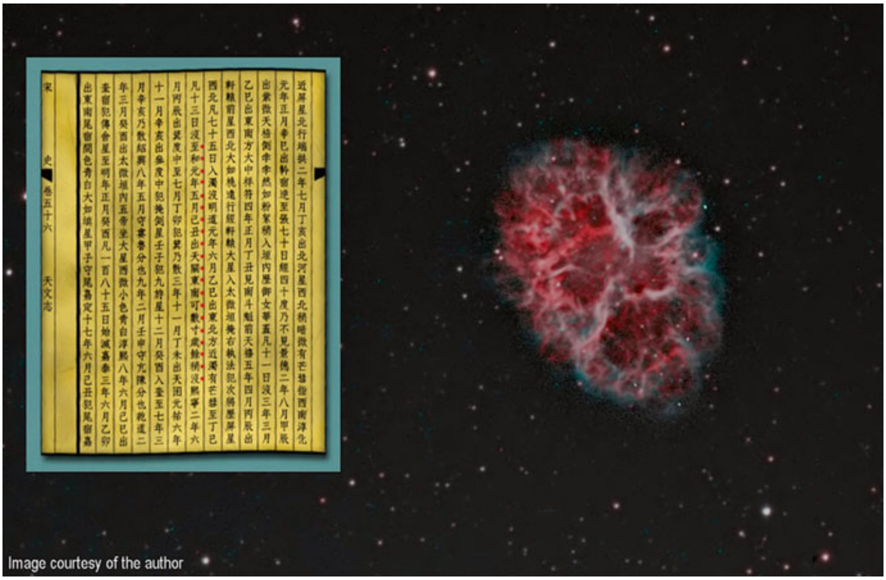


**Fig. 2.16** Author's Narrowband Image of Crab Nebula with Chinese astronomical record of supernova in 1054 AD, Celestron 150 mm achromatic refractor f8, QSI532 ccd, 5 h of 10 min subexposures (Ha:O3:O3) mapped to RGB

Image exposures that are minutes long require corrections to the tracking of the telescope mount in order to keep the image sharp and the stars round. Tracking errors in the mount can be due to poor polar alignment, deficiencies in the worm and gears of the motor drive system, and sky seeing fluctuations over time. With increasing focal length, these can accumulate to the point where they become visually obvious. In the not so distant past, guiding corrections were made manually by the operator as he or she stared through an illuminated reticule eyepiece and adjusted the mount with the hand controller to keep a guide star cemented between the crosshairs. Today, a guide camera issues the corrections to the mount automatically.

Most guide cameras look through a smaller secondary guidescope and this system works well with short focal length imaging. It is difficult to rigidly mount the guidescope to the main telescope, and the two scopes may exhibit independent movement referred to as differential flexure. This movement may be near microscopic, but still be enough to introduce error in the guiding corrections. These errors become especially apparent under the high focal length imaging of small planetary nebulae like the Eskimo, Turtle or Ring.

Even the most secure guidescope mount cannot eliminate one area of common differential flexure—the tendency of the primary mirror in Schmidt Cassegrain telescopes (SCTs) to move slightly (mirror *flop)* due to weight shifts as the scope changes angulation while tracking throughout the night. More precisely, the centrally perforated primary mirror wobbles about the central baffle tube because of the slack necessary to allow it to slide up and down it to achieve focus. The traditional solution has been to use a small pick up prism in the optical train of the imaging camera to capture the guide star. Known as an off axis guider (OAG), this is a compact and lightweight addition that eliminates all forms of differential flexure, since the guide camera shares the same view as the imaging camera. However the OAG's prisms must be placed only in the periphery of the optical train to avoid casting a shadow on the image, and it can be challenging to find a bright-enough guide star in the severely limited field of view.

Innovation Foresight's ONAG provides a full central axis field of view from which to select a guide star by using a mirror to split the beam and send an extended visible spectrum of light (370–750 nm) perpendicularly to the imaging camera while passing near infrared (IR) light while straight through to the guide camera. More than 75 % of main sequence stars are Class M and radiate infrared energy which ccds are well suited to seeing since QE peaks in this region. IR light is also less sensitive to seeing conditions allowing more accurate guiding then would otherwise be possible with plain visible light. Innovations Foresight also claims that not only are guide stars easier to find, but they are no longer subject to the peripheral aberrations of coma that is common in reflectors and SCTs, making guiding more accurate. I believe the centroid computing algorithms used in autoguiding software cope as easily with coma flared stars as with normal round stars, so this is likely a specious selling feature.

Being a budget minded astronomer, I wondered if it was possible to make my own version of this ONAG for considerably less than the market price of $1000. The critical component is clearly the dichroic beamsplitter mirror and I began searching eBay for something suitable. I had acquired a very well made all metal, second hand True Technology flip mirror to use as the ONAG for $40. It had the all important 45° stop for the flip mirror. Most of the eBay sourced mirrors were unable to fit dimensionally into the True Technology flip mirror and also transmit well within the red region. I wanted a mirror that would reflect both the critical Hα and OIII wavelengths and transmit in the IR since I am primarily an urban narrowband astro imager. I was most fortunate to find a Carl Zeiss FT660 DRLP (DichRoic Long Pass) mirror for only $30 from Omega Optics. It is used in fluorescence microscopy where a high pressure mercury lamp provides incident energy to excite the fluorophores in a cell culture and the longer wavelength specimen emission is allowed to pass through the beamsplitter into the camera. The fluorophores can be linked to molecules that can bind to specified targets in the organic sample making them visible and allowing real time tracking in live cells. The mirror reflects 95 % at two peaks centered at 436 and 620 nm and transmitted 90 % at 670–800+ nm. My QSI532 ccd can be seen in the imaging position and a Starlight Express Lodestar in the guide camera position. My version lacks the XY mechanical stage so I am unable to take full advantage of all the available guide stars on axis but it appears to work well. The mild elongation of the star shapes in the raw image is probably due to astigmatism that I introduced in not strictly verifying the 45° placement of the beamsplitter mirror (Figs. 2.17, 2.18, 2.19, 2.20, 2.21, and 2.22).

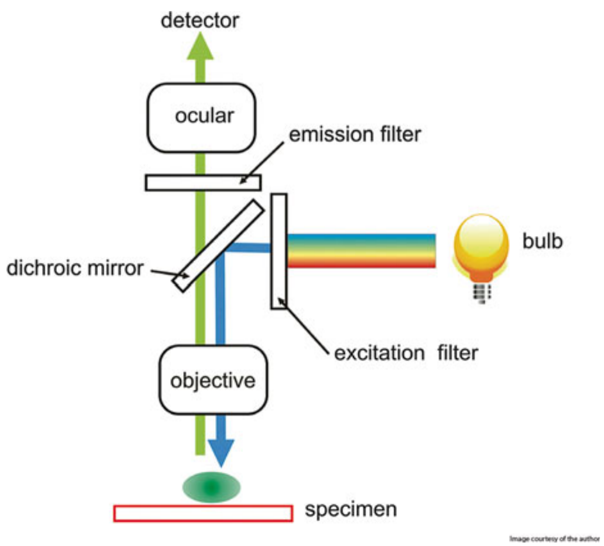


**Fig. 2.17** Schematic of fluorescence microscopy showing longer wavelengths of emission passing through dichroic mirror towards camera


**Fig. 2.18** True Technology flip mirror disassembled into component parts. The rotating flip mirror is discarded

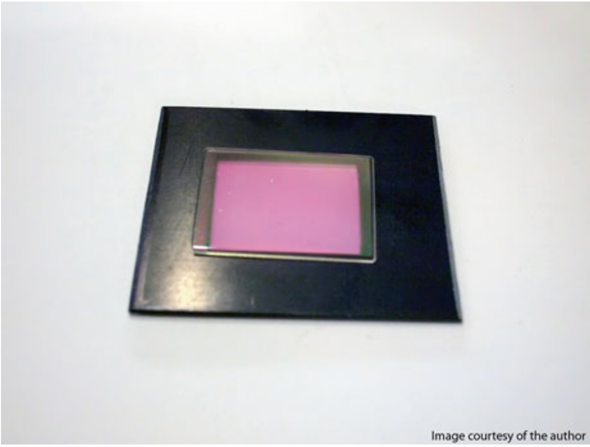


**Fig. 2.19** Carl Zeiss FT660 DRLP epoxied onto flip mirror stop


**Fig. 2.20** ONAG being assembled

It's a simple matter to attach a Tau Ceti XY finder on the guide camera port of my ONAG to finish our low cost build. I found a competing product from Orion online for $50 second hand price and like many things manufactured in China it was identical in appearance to the Tau Ceti, likely lifted and rebranded from the same manufacturing line (Fig. 2.23).


**Fig. 2.21** Imaging the Eskimo Nebula at f/10 on 8″ Celestron SCT. Bonus points to those who can explain why the Celestron SCT is white (this is the OEM factory paint) and not black, grey or orange. The SCT dates back to the 1990s

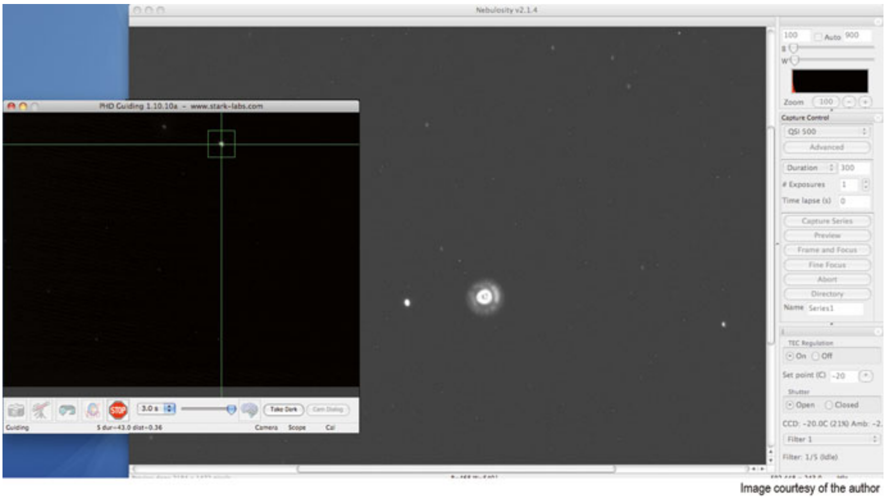


**Fig. 2.22** Nebulosity controlling the QSI532 camera, showing raw 5 min Hα image of the Eskimo Nebula. PHD is also running concurrently and is guiding on a star, likely the same star shown to the *left* of the nebula. The Eskimo Nebula is a particularly good example to showcase the virtues of the ONAG since there are very few stars in this region. Under the limited FOV imposed by imaging at this focal length I don't believe there are any guidestars available to a conventional off axis guider


**Fig. 2.23** Orion XY finder improves the FOV of small guide camera ccd sensor

## Guide Free, Diffraction Limited Imaging with EMccds

*Lucky imaging* is a term coined by David Fried in a 1978 paper in which he discussed the probability of obtaining a sharp short exposure image through poor sky seeing turbulence. In 2007, the University of Cambridge and Caltech demonstrated this technique with the 5 m Hale telescope at Palomar. Using an EMCCD (electron multiplying) camera with adaptive optics and short exposures of less than 100 ms, they obtained diffraction limited performance in the visible spectrum rivalling that of the Hubble Space Telescope. In preceding sections I've demonstrated how imaging developments in microscopy can be easily transferred to amateur astronomical applications. Microscopy imaging has driven the commercial development of EMCCD technology, such that it is currently within the reach of financially well off amateur astronomers, and will continue to disseminate more widely with time. Not personally belonging to the former group, I relied upon the generosity and quick willingness of Princeton Instruments in arranging the loan of one of their current EMCCDs, the PhotonMAX 1024B. All it took was one well written email! Strictly speaking we are not building an EMCCD and the PhotonMax has a price of approximately $50,000 so it flies against the spirit of amateur astronomy on a budget. But I think the experience of using an EMCCD is invaluable and proves the adage that you'll never know if you don't ask.

An EMCCD differs from a conventional CCD in that the electron signal is multiplied on board the imaging chip prior to readout, in a process similar to a photomultiplier. Secondary electrons are generated for each signal photon/electron when higher-than-typical (20–40 V) clock voltages needed for electron transfer are applied. This accelerates the charge carrier electrons to high enough velocity to generate additional electron carriers via impact ionization in a special portion of the CCD's serial register.

A CCD generates "read noise" from its circuitry, particularly when faint signals are preamplified prior to conversion from analogue to digital values; typically, a well-designed CCD has a read noise value of 13 $e^-$ rms (root mean square). This means that single photon signals cannot be detected, because the signal does not rise above this read noise floor. One solution is to increase the signal with a prolonged exposure, but this requires an expensive tracking mount with guiding corrections that will also be subject to variations in atmospheric turbulence or seeing. An EMCCD reduces the read noise to 1 $e^-$ rms while increasing the signal by 1000×, allowing a concomitant reduction in exposure time that obviates the need for a tracking mount. Similar in fashion to amateur planetary imaging, the short exposure allows the freezing of good seeing, so that stacking selected good frames with the requisite software allows an amateur to obtain diffraction limited results regardless of seeing conditions.

The PhotonMAX utilizes a back illuminated frame transfer 1024 × 1024 CCD with large 13 μm pixels and a QE of 90 %. Back illumination refers to the clever way of increasing QE by reverse mounting the sensor so that light enters the chemically thinned back of the ccd and is no longer partially absorbed or reflected by the gate circuitry occluding the conventional face of the pixels. A powerful thermo electrical cooler lowers operating temperatures to −55 °C, resulting in a dark current of only 0.08 $e^-$/pixel/s. The camera was designed to allow real time intracellular imaging of very faint light signals. This includes techniques such as fluoresce-in-situ hybridization (FISH), where fluorescently labelled antisense strands of DNA display the location of genes on individual chromosomes, helping to determine whether translocation events can account for genetic anomalies (sorry, I could not resist wielding my Biochemistry degree) (Fig. 2.24).

Fortunately, the PhotonMAX came equipped with a standard C-mount lens thread. Among my collection of astro odds and ends, I found a C-thread to T-thread adaptor that allowed me to mount a 2-in. to T-thread adaptor and connect the EMCCD to my 8-in. Celestron SCT. I could not rely on this union to support the very heavy PhotonMax and had to make a long custom cut dovetail bar. I purchased a piece of 3 × 24 × 1/2 in. thick aluminum plate from my local *Metal Supermarket* outlet for only $15 as it was just a piece of offcut waste material. I angled my table saw blade to 30° and cut on the right hand side of the blade to end up with 60° bevel. I fed the cut bar with the opposite end to cut the other side. To prevent kick-back I screwed a piece of wood on the fence to trap the piece of aluminum and fed it with a long dowel. A sharp, well oiled, carbide blade is essential to prevent binding and the blade shattering. I don't advocate this method although I have personally performed it twice safely and the cost saving are substantial. Be sure to file off the sharp edges at the very end (Figs. 2.25, 2.26, 2.27, and 2.28).


**Fig. 2.24** The PhotonMax 1024B EMCCD


**Fig. 2.25** Home made 24 in. long Losmandy D style dovetail bar


**Fig. 2.26** Cutting the dovetail bar on a table saw

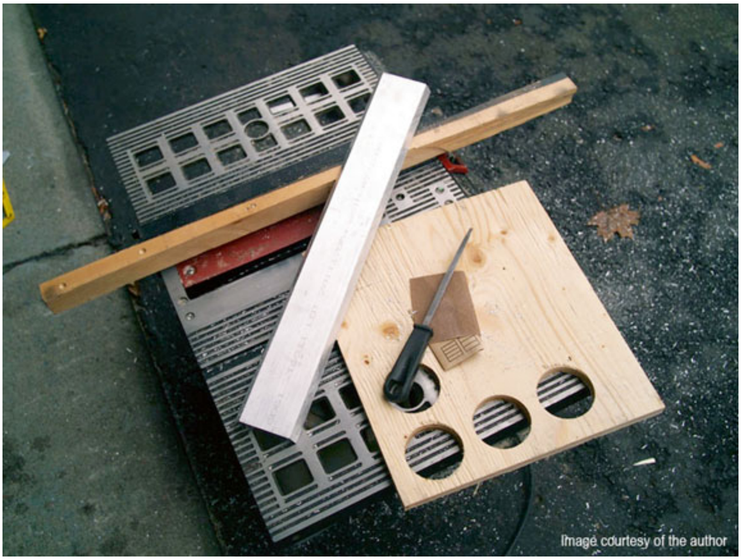


**Fig. 2.27** The finished product


**Fig. 2.28** PhotoMax EMCCD mounted in tandem with 8″ Celestron SCT. Why is this Celestron SCT white? Back in the 1990s Vixen and Celestron shared product line but often sold each other's items in their own colors. Black Vixen manufactured fluorite refractors bearing the Celestron name are common second hand finds. Apparently Vixen sold white 8″ SCTs in Japan. This SCT was a special order, painted white at the factory but sporting Celestron labels

Because I live in the city, I was unable to demonstrate sub second imaging in visible light, but the EMCCD was perfectly responsive with narrowband imaging. Using only 30 s subexposures (although shorter exposures would have been preferable, as there is evidence of some horizontal star blooming) I managed to image the Dumbbell Nebula in under 10 min, unguided, at a focal length of 2000 mm.

As CCDs have become more affordable, and so, hopefully, will EMCCDs. There are some inherent disadvantages to the EMCCD that may be a barrier to mass market production. There can be a variable number of electrons produced during the EM process that can lead to an increase in overall shot noise and reduction in the effective QE. High dynamic range can only be maintained at low frame rates. The sensors are only made by two manufacturers and are expensive and currently limited to a maximum of 1024 × 1024 pixels. High power consumption requires very substantial thermo electric cooling.

New developments in the field of sCMOS (scientific CMOS) low light imaging may be the technology that reaches amateur astronomers first, since these chips offer some of the virtues of EMCCD and have the advantage of being lower in cost, having much faster frame rates (planetary imaging applications?), higher resolution (6.5 μm pixels), and larger arrays (5.5 megapixels). These types of sensors will be a boon to the young urban amateur astronomer who doesn't have much spare time to devote to imaging nor lives in an area with a large percentage of clear nights. I returned the PhotonMAX after only a week and I still miss it! (Fig. 2.29)


**Fig. 2.29** M27 Dumbbell Nebula imaged in narrowband with only 15×30 s subexposures in Hα and OIII with a PhotonMax1024B EMCCD at f/10!!!!!!!

Imaging with dedicated astro imaging cameras is akin to driving an exotic Italian or German supercar. The thrill of seeing such a strong and clean image never fades but like I intimated in the previous chapter, there is a time and place for such cameras. After all you really need to be driving your Honda Accord when volunteering at the food bank or going to your class reunion. A fixed telescope setup is ideal for such a system and in the summer months I've occasionally been able to keep an imaging system erected for several nights in a row either on my front doorsteps (much to the consternation of my wife!) or in the backyard patio. Although this is but a brief taste of what a permanent observatory feels like, it is wonderful to be able to simply park your mount at the end of the night and have the GOTOs and focus be perfect for the next night and to be able to start imaging immediately without the long delay of setup and the mad scramble to find necessary components. I have on one occasional taken my QSI532 camera to a distant dark site and was very successful at imaging M33 (Triangulum Galaxy) but it was logistically a grueling affair having to rush home the next morning. These caveats are not meant to dissuade the burgeoning astro imaging from taking the plunge into the professional world and it doesn't need to cost a lot of money but the journey will take a lot of dedication and time.


**Fig. 2.30** M33, the Triangulum Galaxy taken with QSI532 ccd with Starlight Express Lodestar autoguider/OAG, AP Traveller refractor and AP400GTO mount in Algonquin Provincial Park. Macbook using Nebulosity and PHD software for data acquisition and autoguiding control

The dichotomy that exists between deep space imaging and planetary imaging is fascinating. The latter are fundamentally hostage to atmospheric seeing conditions. While deep space imagers do benefit when the seeing is good through improved guiding accuracy and tighter star dimensions, planetary imagers can do everything perfectly and still obtain mediocre results. A successful planetary imager requires perseverance and being out there every clear night to seize those brief and elusive moments of perfect seeing! (Fig. 2.30)

# Chapter 3

# Public Outreach Applications

Amateur astronomers are amongst the friendliest, most inviting people that I know. They're always eager to share their passion about the cosmos and what better way than throwing a star party. In the summer time, our local Royal Astronomical Society of Canada chapter (Toronto Center) holds close to a dozen events each month from solar viewing, city planet viewing, countryside deep space viewing and every weekend at the venerable David Dunlap Observatory where people marvel at the fully functional 74″ telescope. The professionals in our club gave us tips but the one I remember best is to always put on a smile, even in the dark. Kids are probably our toughest audience because frankly there has never been a more informed generation in history so they have seen it all. It's a little hard for them to get excited about fuzzy grey blobs in an eyepiece when they can instantly bring up a glorious full color Hubble image on their smart phones. I once had to talk for over an hour to a large group of young campers but not one of them was bored or restless, and I was smiling a mile wide the whole time. The following are some projects that have direct public outreach applications.

## Supersize Your PST and Easy, Inexpensive Ca-K Line Imaging

The decade old Coronado (now Meade) Personal Solar Telescope (PST) must rank as the most popular solar telescope ever made. I initially took up solar viewing so that I could feed my astro imaging addiction during the daytime as well but I soon came to appreciate the dynamic nature of the Sun, the daily changes in active regions, the appearance of monster prominences and real time observation of flare formation. I also came to especially enjoy solar public outreach events since most



J. Chung, *Astro-Imaging Projects for Amateur Astronomers*, The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18546-0_3

people have no idea that the Sun has such a writhing tempestuous nature. The problem with the PST is that it delivers *tantalizingly* good views from its small 40 mm aperture. The Coronado SolarMax II 90 mm front mounted etalon would go extremely well with my 105 mm Astro-Physics Traveler refractor. I'm told the detail and resolution gained by increased aperture are jaw droppingly incredible, for a cool $3000. What is a budget minded amateur astronomer to do on those cloudy winter nights? Supersize your PST!

Even though the PST has a 40 mm aperture, its economical price was made possible by using a much smaller 20 mm air spaced etalon. An etalon is a resonant structure that works by bouncing light back and forth between two partially reflective mirrors. It will only transmit light of a certain wavelength that happens to be an integer multiple of twice the cavity width. In order to see solar surface detail the bandwidth must be less than 10 nm requiring the etalon surfaces to be polished to a flatness of 1/100 wave quality. This is placed 200 mm ahead of the focal point of a 40 mm doublet f/10 refractor (the long gold anodized barrel). The rectangular metal housing contains a pentaprism and a 5 mm diameter Hα blocking filter (BF5) with a bandwidth of 1–5 nm to filter out all the hundreds of unwanted bands from IR to UV. The blocking filter is the one item that periodically needs replacing since it's subject to such concentrated energy. The pentaprism travels up and down the focusing shaft and is prone to misalignment and image distortion. The BF5 is too small, causing image vignetting at higher focal lengths. In fact, the only piece of the PST to be used in this modification is the etalon itself.

The gold barrel and etalon are heavily secured with thread adhesive and are best dismantled with a boa strap wrench, instead of damaging teeth this type of wrench has a braided rubber strap that provides a gentle yet powerful grip. The etalon has a 50 mm diameter, 1 mm pitch thread; a 2 in. barrel adaptor to fit this can be purchased from a telescope shop in Linz, Austria (www.teleskop-austria.com). Along with some plastic PVC plumbing pipe and a BF10 blocking filter, the critical 200 mm separation between etalon and focal point is preserved (Figs. 3.1, 3.2, and 3.3).

This PST module must be installed into a 2 in. focuser of a f/10 or slower refractor. Alternatively, one of the many common short f/5 refractors could be used in conjunction with a telecentric Barlow such as a 2× TeleVue Powermate or 2× Siebert Telecentric barlow. A regular Barlow will not work, because the etalon must be exposed to quasi parallel light rays like that encountered in a f/10 instrument and in fact there is a negative lens built into the front of the PST etalon to expand the light rays of a f/10 cone into parallel ones. In North America, it's go big or go home and I had just acquired a used 6 in. Celestron achromatic refractor which I could mask down to 5 in. to bring it from its native f/8 to f/10. This was the very well regarded Celestron C6-R which I continued to use post modification as a deep space narrowband imaging scope. The optics are very well corrected and it delivers sharpness and resolution as good as telescopes costing tenfold.

An energy-rejection filter is required at the very front of the optical train (the refractor objective) and is typically made of optically polished Wratten #25 red glass. This eliminates dangerous IR radiation and also reduces light intensity. Daystar makes these in a variety of sizes for their rear-mounted solid etalon systems.


**Fig. 3.1** The components of a PST


**Fig. 3.2** The 20 mm aperture PST air space etalon with 2″ adaptor attached

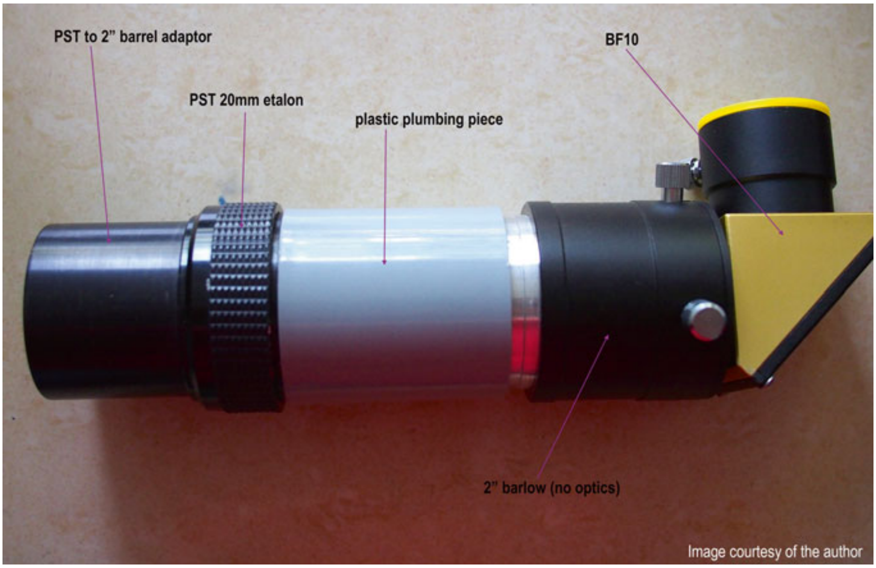


**Fig. 3.3** The Supersized PST module complete

Baader also manufacturers the D-ERF, optical-quality glass polished to 1/10th wave peak-to-valley with dielectric coatings. Both these choices tend to get rather expensive in large diameter sizes, and an affordable alternative is sold by Rosco International (www.rosco.com), a company that specializes in lighting equipment for theatrical, TV, and movie productions. They sell custom sized UV/IR blocking glass designed to protect their coloured filters from the heat of stage lamps for unbelievably reasonable prices. I added a pair of #25 red camera filters to the PST etalon's 2 in. adaptor nosepiece for additional safety and light attenuation.

To reach focus, the optical tube assembly was shortened on a custom rotating jig made from four rollerblade wheels and a Dremel cutting tool. The wheels support the C6-R's OTA allowing it to rotate while I held the Dremel's cutting disc square to the tube allowing a perfect cut to be made. At this point I also installed a much better quality single speed 2″ GSO crayford focuser to replace the stock rack and pinion which had too much slack (Fig. 3.4).

Like the original PST, the supersized PST has a center sweet spot of optimal resolution/contrast but at the higher focal length it occupies a comparatively smaller percentage of the total field of view. This is because the Coronado etalons are tuned to come on band by slightly tilting it so that light crosses perfectly perpendicularly. As the Sun viewed from the Earth is far from a point source of light, the light coming from it is going to come from different angles depending on where on the Sun it is originating. So tuning the etalon to one part of the Sun will cause it to fall out of tune on other parts hence the sweet spot effect. The sweet spot is much less apparent in front mounted etalons (e.g., SM90 II) because the light from the edge

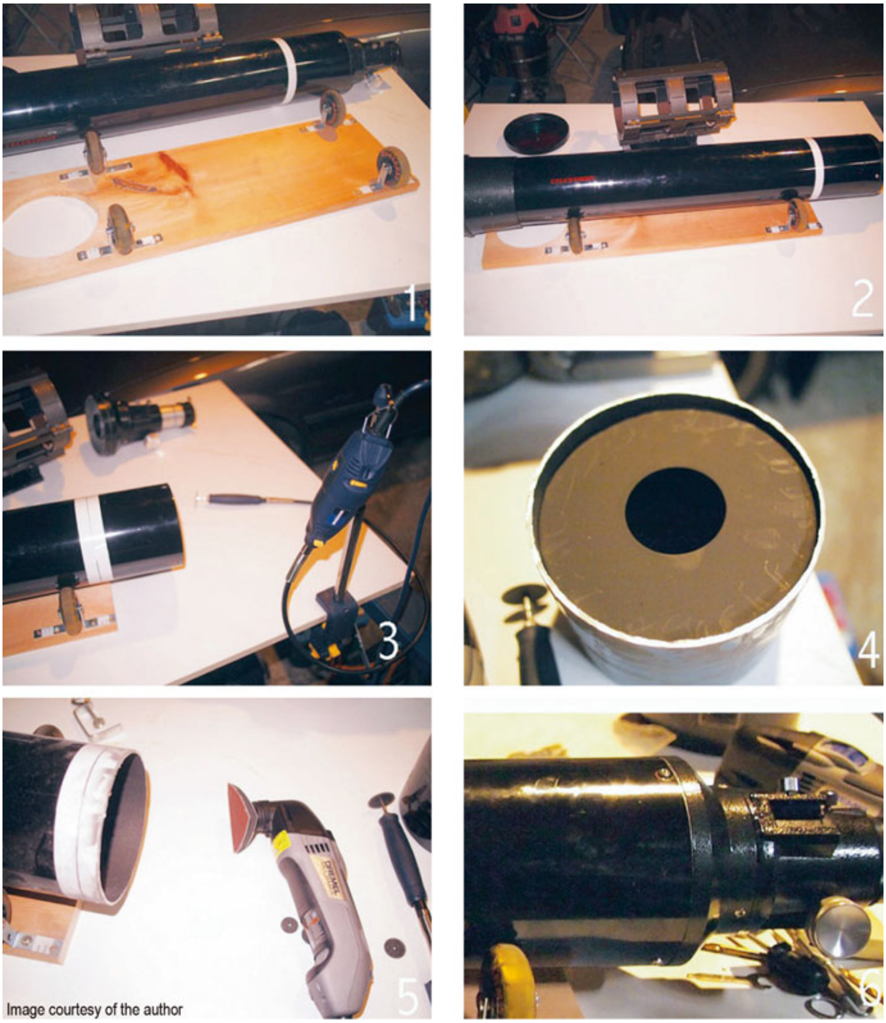


**Fig. 3.4** Reducing the length of the C6-R on homemade jig. I just missed cutting into the final baffle, keen eyes will see that my cut is indeed perfectly square but the factory welded baffle is slight askew!

of the Sun across the etalon is about 0.25° or equivalent to f/110 cone angle. Internal etalons like the PST and the exaggerated supersized PST show an even more pronounced sweet spot effect because of the magnified range of incidence angles. The stock 20 mm Kellner eyepiece was likely chosen because it delivers a FOV just large enough to see the entire solar disc and the sweet spot is not that apparent, only the prominences are not visible around the entire circumference simultaneously. This means that a complete solar disc image will require a mosaic

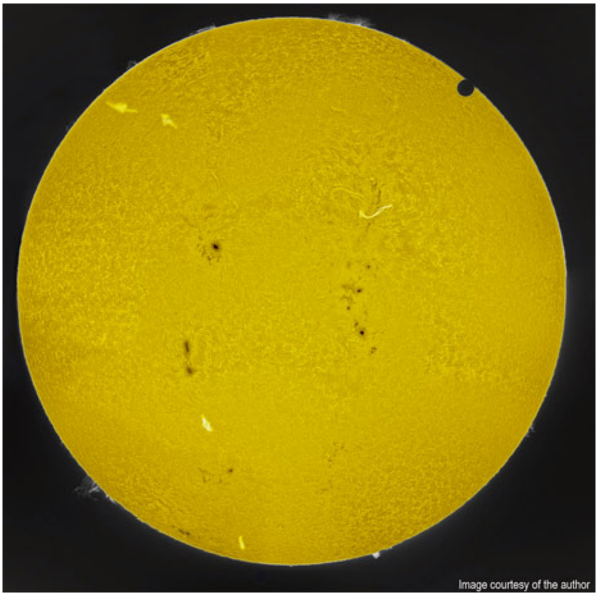


**Fig. 3.5** 2012 High resolution image of Transit of Venus, although widely imaged I have yet to see another amateur capture the detail in as large an image scale. One of highlights of my amateur imaging career! June 5, 2012 Collingwood Ontario PST f/25 solar mosaic with PGR Scorpion ccd, Second Contact 1818 h

approach and a whole lot more post processing effort, but it can be done. The extra aperture does deliver greater resolution and it's unlikely the seeing can ever support an aperture larger than 5 in. or a focal length of approximately 1200 mm. During the 2012 Transit of Venus, I took the day off work because I reasoned that this was truly a once in a lifetime event that could not be missed. I certainly won't be able to make the next transit in 2117, nor will my teenage son, which is a sobering thought. So unpredictable was the weather forecast in the city that I drove north a couple of hours to the club's dark sky observatory facility where clear skies welcomed us all day. The supersized PST delivered epic resolution documenting a memorable Venus transit for many years to come (Figs. 3.5 and 3.6).

My used PST cost about $350, the used BF10 another $300 and the etalon adaptor about $60. The Celestron C6-R was a steal for $200, the upgraded focuser cost nearly that much.

*Omega Optics*, my goto eBay source for all manner of optical filters, is selling Ca-K line filters for a very reasonable $200. They come as a stackable pair passing at 394 ± 0.5 nm with a 10–20 % transmission rate and a bandwidth of <4 nm. No ERF is required for usage and this is not really a visual filter since most eyes my age are rather insensitive in the near UV spectrum. For imaging use I found the light attenuation insufficient, a neutral density filter, variable polarizing filter, or even a

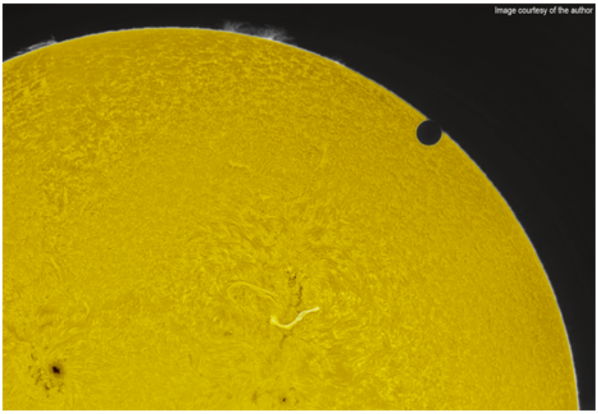


**Fig. 3.6** Cropped version of the preceding image highlighting the fine detail obtained from the supersized PST

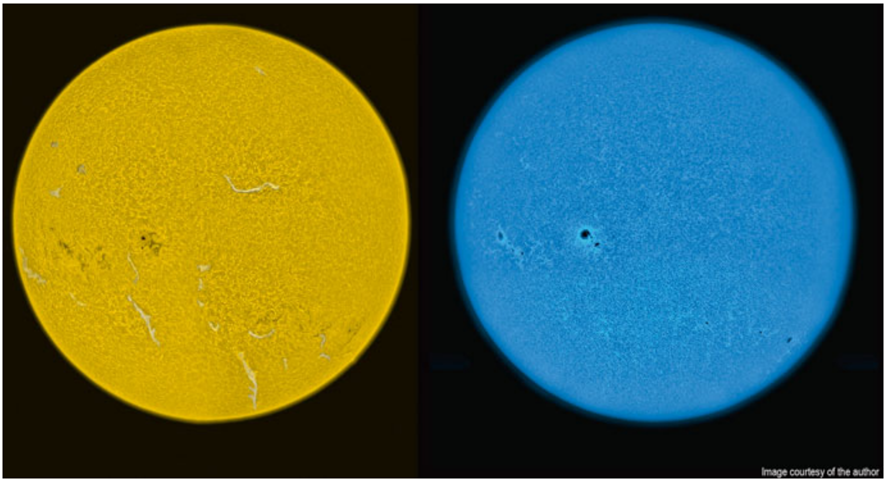


**Fig. 3.7** A comparison between Hα and Ca-K line images taken with the C6-R

light pollution filter was needed to prevent saturating the ccd. The Ca-K line shows regions above the photosphere hotter than Hα and both lower and higher than Hα. This line is very sensitive to magnetic fields, darker areas are areas with weaker magnetic fields. The Ca-K line images typically show supergranulation and much more distinct umbra and penumbra regions of sunspots with brighter surrounding plage areas (Fig. 3.7).

## The Digital Schmidt Camera

At the turn of the last century, most of the large observatory telescopes were Newtonian reflectors. Their combination of small field of view (FOV), slow optics and off axis coma were serious obstacles to film photography. Several nights and numerous exposures would be necessary to document an extended nebula and this limitation hindered deep sky photography for two decades. It would seem that a short focal length primary mirror would be the obvious solution, however it is technically very difficult to precisely grind a fast, large diameter parabola. Coma also increases proportionally with diameter and inversely to the square of the focal ratio of the mirror.

In 1931, an obscure Estonian optician named Bernhard Voldemar Schmidt proposed a design which offered a flat, distortion free large FOV and extremely fast optics. Using a spherical primary mirror coupled with a thin zero power aspheric lens (Schmidt corrector plate) that is weakly convex at the center and weakly concave around the periphery to eliminate all spherical aberration, he could provide photographers a wide flat field sharp from corner to corner. Even the way the corrector plate was manufactured was unprecedented—he warped a piece of parallel plate glass with a gentle vacuum to introduce a slight curve and then polished the upper surface flat. On release of the vacuum, the glass plate would spring back into aspheric shape. He completed a revolutionary 14.5 in. aperture f/1.7 camera but unfortunately died in 1936 and like van Gogh never experienced his due recognition because his ideas were simply too bold. It took another decade and in 1949 the famous 48 in. f/2.5 Samuel Oschin Schmidt camera was constructed at Palomar and began its revolutionary 7 year sky survey of the northern hemisphere, arguably the most important achievement responsible for understanding the cosmos. In contrast, it would have taken the 200″ Hale reflector 10,000 years to finish the exact same survey!

Digital imaging technology was preordained to be integrated with the Schmidt camera. The Catalina Sky Survey is an array of Schmidt cameras with ccd sensors in place of film designed to track and catalog near Earth objects. Even comet hunter David Levy had his Meade 12″ Schmidt camera converted to digital with an SBIG STL11000 ccd and he can now take hundreds of $3° \times 2°$ images each night capturing stars down to 18th magnitude. Contrast this to the old days when he used hydrogen hypersensitized Kodak B&W film and could only take at most ten exposures per night and still had to develop them in the morning as well as staying up the entire night.

My Schmidt camera was made sometime in the 1970s and Celestron apparently only made about 800 examples. Celestron stopped making then in 1980 but continued providing optics to a small one man company, Epoch Instruments. For the next 20 years they continued to support and manufacture new instruments until 2001. I was motivated to convert my Schmidt camera for astro outreach applications. The incredibly fast f/1.5 optics would allow almost real time narrowband imaging allowing the public to see deep space objects in high contrast near real time video from within the city. To try and purchase a 300 mm focal length camera lens at f/1.5 would be either impossible or cost in the tens of thousands of dollars.

The Celestron Schmidt camera consists of an 8″ spherical primary mirror and a zero power aspheric corrector plate to correct spherical aberration. A three vane spider suspends a 35 mm film carrier on special rods made of zero expansion Invar with the focus preset at the factory. Given the speed of the optics it's safe to conclude that the zone of focus is extremely narrow so you don't want to ever disturb the factory adjustments as it's unlikely one could ever restablish optimal focusing without some sort of bench testing apparatus. The focal plane of the camera is unusual in that it is curved and the carrier deforms the film negative precisely to follow this curve. In fact each glass plate of the Palomar Sky Survey had to be deformed with a special jig before being placed in the camera. I didn't want to alter the focus position of the spider in case I want to experiment with film one day and placing a ccd/camera inside the tube increases the size of the central obstruction and introduces the complexity of liquid cooling—you don't want a fan blowing hot exhaust air in there! So I rigged up a secondary mirror that snaps on the spider's magnetic coupler allowing an eyepiece or ccd placement external to the loading port. The external hole is lined with PVC pipe fittings that functions like a helical focuser. The only ccd I had small enough to fit inside the 2″ barrel was my Starlight Express Lodestar guide camera (Fig. 3.8).

Using a 7 nm bandwidth Hα filter, I was able to image M42 and the Running Man nebula quite thoroughly in 30 s. The Horsehead nebula was clearly visible after a 1 min exposure. Both images also show stars in the periphery starting to defocus due to the nonconformity of the ccd's flat imaging plane. A field flattening lens must be placed right on the focal plane of the ccd sensor and in general the focal length of this plano convex lens is given as:

$$\text{Focal Length of flattening lens} = \text{focal length}\left(\text{Schmidt camera}\right) / \text{n}\left(\text{flattening lens}\right)$$

I was able to easily order a 26 mm diameter, 200 mm focal length lens made from BK7 glass online from *Newport Corporation* in California, they have an amazing stock of varied size and strength lenses. For best effect the lens needs to lie right on the imaging sensor chip which is difficult because of the intervening ceramic chip body and optical glass window. You would have to cut the lens into a rectangular shape and remove the optical window, doable but technically challenging (Fig. 3.9).

Wanting a dramatically larger field of view I looked at other camera offerings from Starlight Express. Being budget minded a used and long discontinued HX916 ccd was purchased. It preceded the very popular SXV-H9 and has a similarly sized Sony 1300×1030 ccd. The Starlight Express cameras all have a cylindrical form factor and are easily dissembled so getting access to the ccd chip would not be a problem. The diameter of the camera is nearly 3 in. so a much large focuser based on the Crayford design was built (Figs. 3.10 and 3.11).

Like all well intentioned ideas, the concept is solid and proven but just has not been completely implemented for lack of time. It is one viable way to show urban dwellers deep space objects through narrowband filters in a quasi real time format (Fig. 3.12).

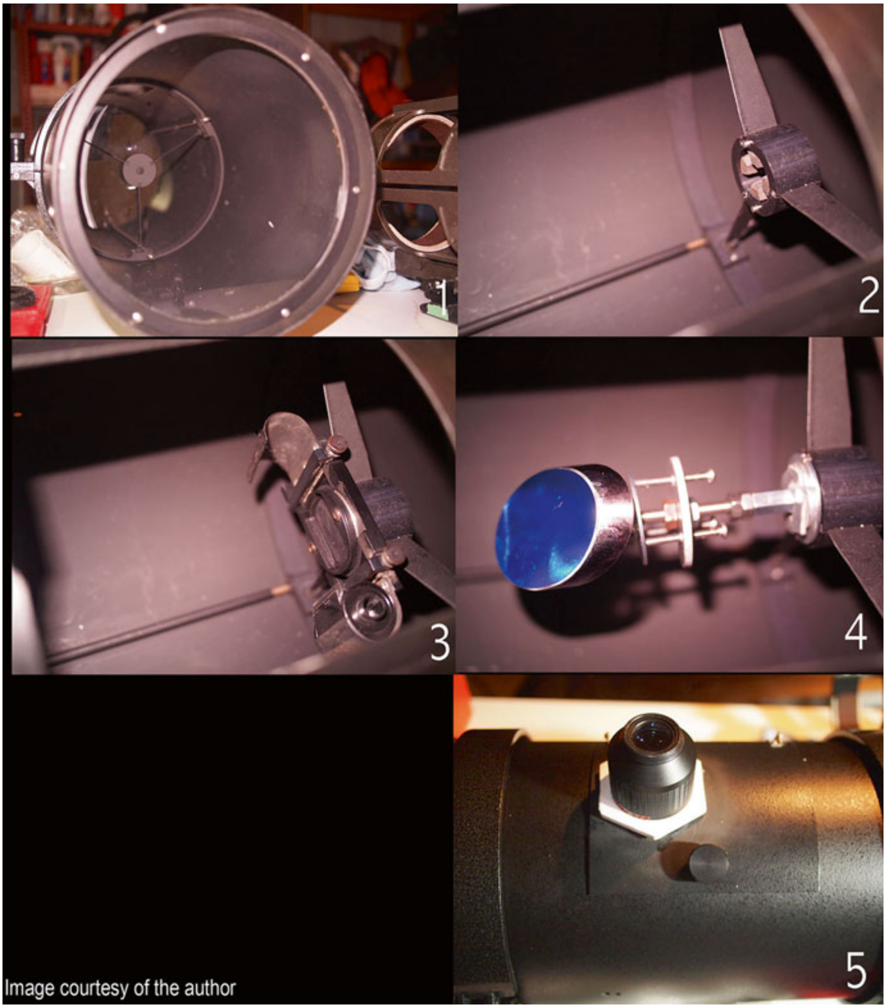


**Fig. 3.8** The fabrication of a internal diagonal mirror to reflect the image out of the tube and onto a ccd

## How to Throw a Proper Planetary Eyepiece Shootout Party (and Make an Eyepiece Turret)

I recently caught the visual observing eyepiece bug. I've always been primarily an imager with maybe half a dozen generic eyepieces so I wanted to see how the other side lives. I went on a small shopping spree for planetary eyepieces on all the usual used astro websites. As a budget minded amateur astronomer I spent strictly no

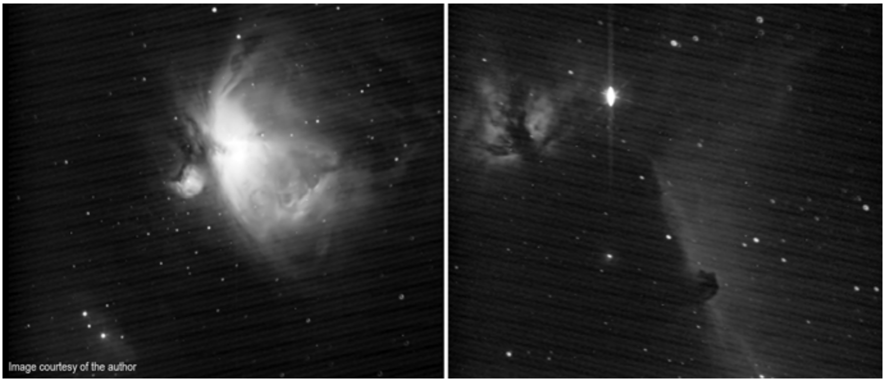


**Fig. 3.9** M42 and The Horse Nebula in narrowband imaged with Starlight Express Lodestar guide camera


**Fig. 3.10** Dissected Starlight Express HX916 camera wearing Newport Optics flattening lens

more than $200 per eyepiece knowing that I could later resell these eyepieces at little or no loss (Fig. 3.13).

In comparing classical versus modern eyepiece designs it seems intuitive that the Nagler eyepiece should cost more because of its complex build and all the glass elements involved. But the current prices of TMB Supermonocentrics made by APM and the Zeiss Abbé Orthos (ZAO) are about $600 apiece, eclipsing the prices of most Televue eyepieces.


**Fig. 3.11** Three inch monster crayford focuser construction

After reading many online reviews and forum threads I've come to the rather dubious conclusion that evaluating an eyepiece is like evaluating fine wine. The eyepiece connoisseur who collects $1500 Carl Zeiss Jena Monocentrics can see much more than I'll ever be able. As a man of science, I was particularly dismayed at how eyepiece comparison studies were conducted. The winner always appeared to be a foregone conclusion (Fig. 3.14 and Table 3.1).

One of the problems with eyepiece comparisons is that there is no control for operator bias. Tests need to be conducted as a single blind study so that the viewer has no knowledge of the eyepiece identity. Unfortunately a true blind test cannot be engineered because even the most causal amateur astronomer knows the difference between a classical Plössl design and a modern multilens design like a Televue Nagler just by the size of the eyepiece, good eye relief and its apparent field of view (AFOV). In other words you can't disguise eyepieces, old school eyepieces are tiny in size, field and eye relief.

The only way to ensure a true single blind study is to recruit complete astronomy novices. Every year my family throws a large Thanksgiving party and after being plied with drink and fowl, our guests could be guilted into volunteering for this study!

The target was the Moon approaching its apogee in the south on Thanksgiving night under good seeing conditions and viewed with a 4 in. Astro Physics Traveler


**Fig. 3.12** Comet Hale Bopp taken with a single 8 min exposure on Fuji 100 film showing fantastic round stars from corner to corner of a 35 mm negative. Image courtesy of Dr. Dan Schechter. For the 1985/1986 return of Halley's Comet, NASA contracted a number of 200 mm Celestron Schmidt cameras to be prepared for field use throughout the world so that photographic documentation of the comet could be recorded

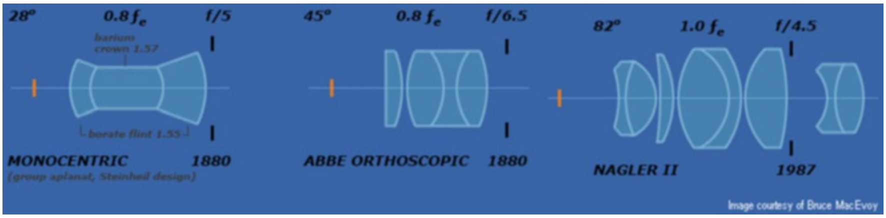


**Fig. 3.13** Popular planetary eyepiece lens designs

refractor that was polar aligned and pier mounted at a comfortable standing height. A five eyepiece turret was used such that all eyepieces were carefully prefocused and the viewer could rapidly shuffle through them. This is a very important consideration as it increases the likelihood that the viewer is observing all eyepieces under the same seeing conditions which can change from moment to moment by eliminating the time consuming task of removing, reloading and refocusing each eyepiece. I believe it also reduces visual fatigue since it's easier to recall what the other four eyepieces looked like when you can quickly shift from one to the next one.

This is a critical parameter often missed by eyepiece studies. They make no attempt to control the seeing conditions as studies are sometimes conducted over


**Fig. 3.14** A planetary eyepiece lineup of between 4 and 6 mm

**Table 3.1** Names and specifications of eyepieces from Fig. 3.13 from left to right starting with back row

| Eyepiece name | AFOV (°) | Eye relief (mm) | Elements/ groups | Design | Used price |
|---|---|---|---|---|---|
| Burgess Optical/TMB 4 mm | 58 | 16 | 6/4 | Proprietary | $60 |
| Pentax SMC 5.2 mm XL | 65 | 20 | 7/5 | Proprietary | $170 |
| Speers Waler 5–8 mm | 84 | 12 | 9/1 | Proprietary | $180 |
| Meade UWA 5000 4.7 mm | 82 | 14 | 7/4 | Proprietary | $80 |
| University Optics 6 mm HD | 43 | 4 | 4/2 | Ortho | $70 |
| Smart Astronomy 6 mm | 52 | 5 | 4/2 | Plössl | $13 |
| Pentax SMC 3.8 mm XP | 42 | 2.7 | 5/3 | Ortho | $175 |

several nights because not all the eyepieces were available at the same time! While only an indoor test can truly reveal subtle differences between eyepieces, a rapid method of changing eyepieces ensures that at least they are all being subjected to the same seeing conditions. This makes an eyepiece turret a necessity and not just a luxury accessory. They are perceived to be the latter since they can be difficult to manufacture and expensive to purchase. The $1500 Van Slyke billet aluminum six eyepiece turret comes to mind and can be found at http://www.observatory.org/turret.htm. As a budget minded amateur astronomer I was determined to find another way.

The images below detail how one can easily fabricate a five eyepiece turret using 2″ black ABS plastic plumbing fittings, electrical conduit couplers and nylon thumbscrews. The electrical conduit couplers are eyepiece holders (Figs. 3.15a–d, 3.16a, b, 3.17a, b, 3.18a, b, 3.19a–c, and 3.20a–c).

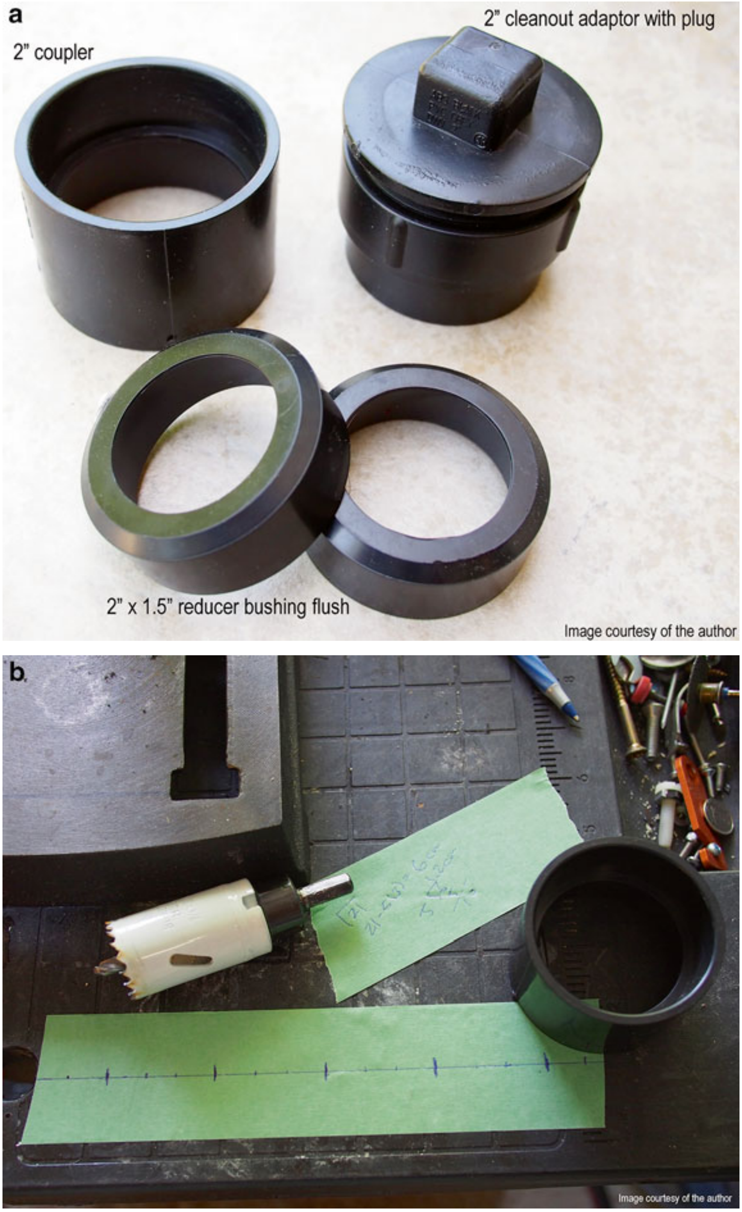


**Fig. 3.15** The outer rotating eyepiece sleeve was drilled for five 1.25″ eyepieces with a small drill press and hole saw. The inside of the sleeve was cleaned of cutting debris with a spindle sander


**Fig. 3.15** (continued)

In application, the eyepiece with the shortest focuser intravel is determined, that eyepiece is brought to focus and the other eyepieces are focused by slightly lifting them out of their respective eyepiece holders.

The less glass an image needs to pass through, the less degradation in brightness and contrast it experiences as there are internal reflections that occur at every

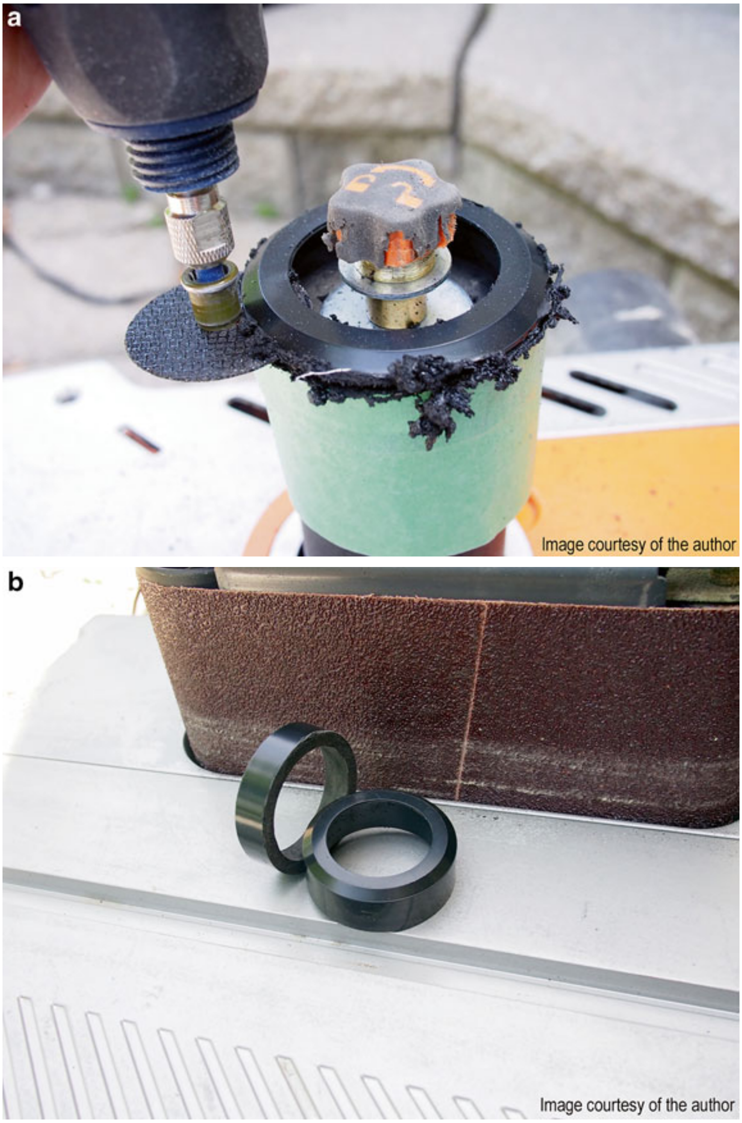


**Fig. 3.16** An internal spacer is shortened to make a square end for good end adhesion to a second internal spacer

glass/glass interface and especially at every glass/air interface. Modern antireflection coatings are very good at minimizing transmission losses of this nature and all eyepieces were fully multicoated. That said, the preferred eyepiece designs by planetary observers tend to be the classical, simpler designs since fewer groupings of elements means fewer glass/air interfaces. The orthoscopic design features a triplet stack of three elements followed by a simple planoconvex eye lens. The modern day Plössl


**Fig. 3.17** A final end ring is from the same material used to make the rotating sleeve and when the pieces are glued together will prevent the sleeve from coming off

is a mild variation of the original design and features two identical aplanatic doublets with their crown biconvex elements facing inwards.

An orthoscopic eyepiece has four glass/air interfaces and if uncoated can expect 4 % light loss at each interface yielding $0.96 \times 0.96 \times 0.96 \times 0.96 = 0.85$ or 15 % light loss. An uncoated modern multielement Televue Nagler eyepiece would be subject to nearly 40 % light loss. Not only is light lost but the internal reflections cause scatter that reduce contrast. Modern multicoatings can reduce losses to as little as one tenth of a percent. In the late nineteenth century, British scientist observed that

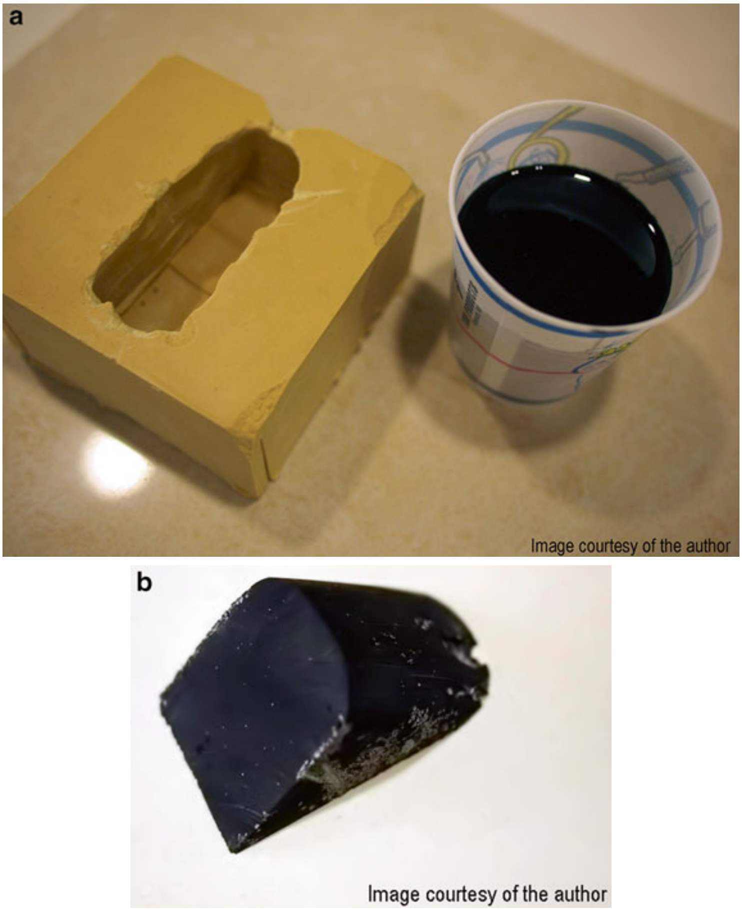


**Fig. 3.18** A negative impression of the curved hollow inside chamber of the turret was taken and a positive stone model made to allow the casting of a polyurethane resin 45° wedge to support a small mirror flat (from a 1.25″ mirror diagonal)

older, tarnished lens transmitted more light than brand new lenses and this turned out to be layer of zinc oxide. Then in 1935, Zeiss developed the first optical coating based on $MgFl_2$ that reduced internal reflections by destructive interference and this remained a military secret throughout WW2 and one of the reasons why captured Zeiss binoculars attained mythical status amongst Allied officers.

The eight subjects (n = 8) were randomized as were the eyepiece turret position which were labeled with a number from one through five. Since we were using the five eyepiece turret, I arbitrarily removed the Speers Waler and Burgess Optical/TMB eyepiece from this study so we would have two modern eyepieces and three classical eyepieces. The subject's final eyepiece selection was communicated privately to me so as not to influence the waiting subjects. All eyepieces were thoroughly cleaned.

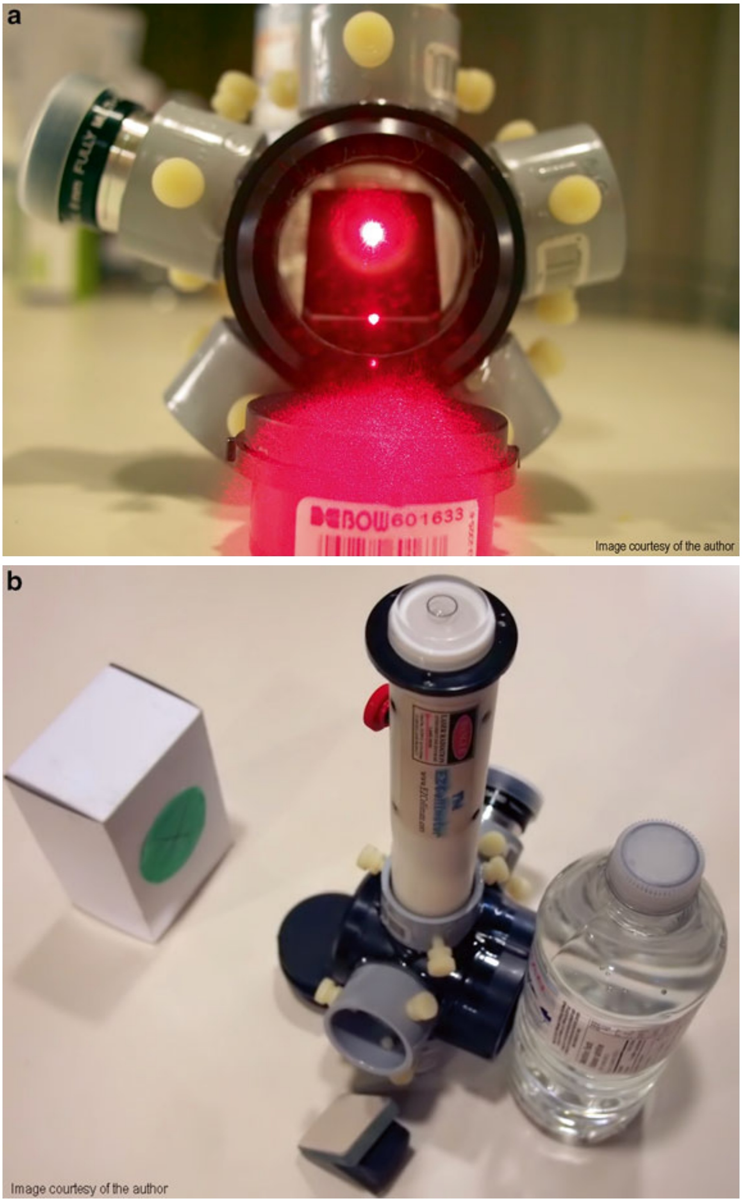


**Fig. 3.19** The angle of the wedge was fine tuned with a collimating laser to ensure the image reflected through the midline of the nosepiece and eyepiece holder. A metal 2″ nosepiece with T threads was glued to the turret body, a component commonly found with dedicated astro imaging cameras. Three equidistant nylon thumbscrews kept each eyepiece secure


**Fig. 3.19** (continued)

Medium magnification of 100–150× was used which is far below the 60×/aperture inch rule. The eyepieces had been tested the night prior for the amount of in travel focus required, the UO HD eyepiece required the most in travel and that was brought to focus with the refractor focuser. The other eyepieces' focus was then achieved by slightly unseating them from their holders. The purpose of the test was not to rank the eyepieces but to simply choose one overall best eyepiece. The astro community consensus is that the Pentax 3.8 mm XP is one of the finest eyepieces ever produced featuring a nearly unheard of 98 % overall transmission rate, extra low dispersion glass, and lanthanum glass elements. It is only marginally surpassed by the Zeiss Abbé Orthos (ZAO) and TMB Monocentrics. If this eyepiece could be blindly chosen as the best performing eyepiece by the group it would legitimize the price differential of high end eyepieces.

I instructed the viewers to disregard the differences in AFOV and brightness since the focal lengths are not identical but to simply choose the one that they felt gave the best view in terms of on axis sharpness. None of the eyepieces exhibited "kidney beaning" exit pupil behavior or glaring internal reflections. Similarly I chose to concentrate on on-axis performance and ignore any aberrations likely to be present off axis. I did not want to evaluate contrast because the brain may be fooled by a darker background giving the appearance of better contrast and because the AFOV of the eyepieces are not equal. Some widefield eyepieces are able to show the entire half

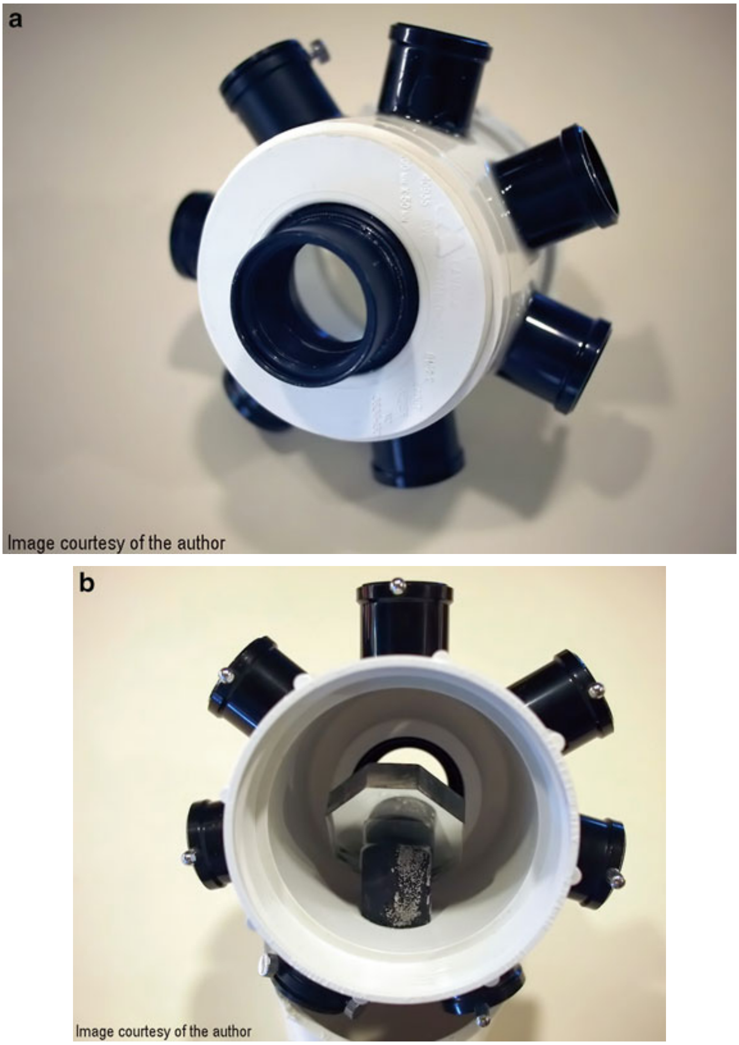


**Fig. 3.20** A larger seven eyepiece turret can be made with large white PVC plumbing supplies, a 2″ diagonal flat and cheap plastic eBay 1.25″ mirror diagonals bought in bulk to salvage their eyepiece holders

Moon against a dark black background. Overwhelmingly the Meade was the choice (n=6) and then the Pentax XL (n=2). Interestingly the subjects who chose the Pentax XL were torn between it and the UO HD and were also significantly older than the median age of 22. It's very likely that age confers a more discerning nature.

After the guests left, I spent some time observing crater Plato located on the Moon's mid northern limb. I could detect no significant differences in sharpness or detail from the cheapest to most expensive eyepiece.


**Fig. 3.20** (continued)

I began to have misgivings about the design of the study. Was it possible that the group of novices were distracted by the wide field views and comfortable eye relief of the Meade UWA and made them feel it was the sharper, better eyepiece? There is a biological effect at work since larger fields of views tend to excite the nervous system possibly influencing pupillary dilation and I can attest that astronomy novices are easily excitable! I could install field stops in the modern eyepieces and reduce their AFOVs but the differences in focal lengths would still exist and images of a smaller scale always tend to look sharper. I realized that the only method to normalize these differences as well as eye relief would be use a small sensored ccd to record the eyepiece image via eyepiece projection.

Again using plumbing fittings, I quickly made two different sized eyepiece projection to C thread camera adaptors because of the large size of some of the modern eyecups and to be compatible with my 640×480 Point Grey Research Flea2 ccd. This small camera puts no strain on the eyepiece and can be placed very close to the eyelens to minimize the magnification effect that imaging via eyepiece projection tends to produce. Thus, the eyecups were screwed to their lowest position or rolled down. Single 1/30th second exposure frame captures of each eyepiece image were made and these were either reduced in size scale or cropped to equalize focal length and AFOV. No other image processing was performed and each image was clearly subject to the seeing of the moment. I debated capturing conventional streams of images, selectively stacking and then sharpening this stack as this would normalize seeing conditions and make comparisons easier but I think all this processing might introduce other differential factors (Fig. 3.21a, b).


**Fig. 3.21** Making eye projection adaptors to fit the modern an classical eyepieces, images recorded by Point Grey Research Flea2 ccd (640×480)

A new total of the complete seven eyepieces were tested and RASC members were invited to participate through the Yahoo group forum and view the images online. (https://dl.dropboxusercontent.com/u/4852049/EyepieceShootout.jpg) These experienced observers were still blind to the eyepiece identity and chose the best and worst images. The waning gibbous Moon was very high in the Southern sky at

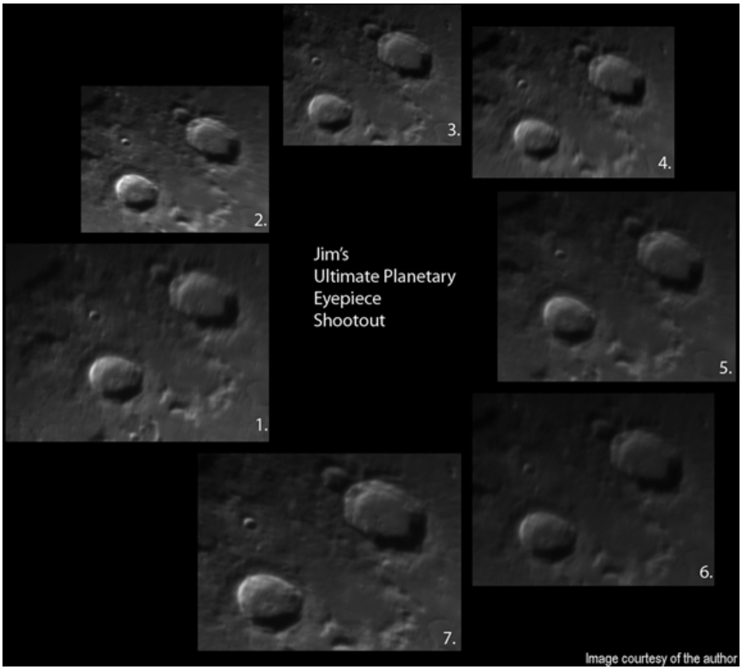


**Fig. 3.22** Seven eyepiece images, choose the best and the worst!

5 AM with seeing as good if not better than Thanksgiving night and data was collected over a 20 min interval. The craters in the image are identified as Aristotles (right) and Eudoxus (Fig. 3.22).

With 17 respondents, the results were unanimous. The best eyepiece was the Speers Waler 5 mm and the worst was the Smart Astronomy 6 mm Plössl (two chose the BO/TMB). Again, the Pentax Ortho was not chosen but four respondents did mention it as a close second. Interestingly, the cheapest eyepiece turned out to be the worst and the eyepiece with the most elements (9!) performed the best on planets. I would like to add that the Speers Waler (Wide Angle Long Eye Relief) is designed and made by Vancouver optician Glenn Speers and has been often called the poor man's Nagler. It's strange form factor is a little off putting to some users but I say Shop Canadian!!!

The conclusion I reach is that when eyepieces are compared on a level playing field, most modern eyepieces with good coatings perform very well indeed. Expensive eyepieces may be either more comfortable to use such as the TeleVue Delos/ Pentax XWs or are classical designs produced in small numbers but made to the very best quality that reveal very subtle and nuanced extra detail. However to appreciate the ZAOs and TMB Monocentrics one must have excellent seeing conditions and if good seeing happens only 5 % of the time and you are only out observing a few time a month … it'll be a long time before you get to use those ZAOs!

The reason why the ZAO eyepieces deliver both in this performance and in price is that Zeiss spends more then twice the standard time in polishing their lens elements to eliminate the subsurface damage under the fine ground surface which will turn hazy after the coatings are baked on. Zeiss also multicoats each lens surface with specific regard to its unique refractive index rather than subject all elements to the same treatment as high index glass require upwards of five coats. Zeiss eyepieces can never benefit from economies of scale because only cheaply manufactured eyepieces can ever be offered at popular prices and because this is a highly specialized niche market. Aside from collectors who covet their eyepieces merely as acquisitions, you get what you pay for in this hobby with diminishing returns at the top end. Luckily for the majority of us, very good performance can be had for very reasonable costs.

Afternote:
We've encountered Ernest Abbé's genius previously in Chap. 1 but scientists often toil in isolation with little regard to the real world around them. Take the example of Wernher von Braun who pursued his rocketry research with apparent ignorance of the consequences of his work (specifically the people of London who endured his barrage of V2 missiles and the slave labor force who made his weapons). This is what makes Ernest Abbé, the man, so compelling because he was also known as a great social reformer, pioneering human and worker's rights decades in advance of any governmental policies and persevering through the two wars, the division, and reunification of Germany.

Abbé was asked by Carl Zeiss to join his company in 1866 and use math and science to improve the manufacturing process of his optical instruments. They became partners in 1875 and brought on board a young chemist named Otto Schott to provide a source of quality glass. When Zeiss died in 1888, Abbé became the sole owner but rather than enjoy his vast fortune he divested himself of ownership by creating the Carl Zeiss Foundation to become sole owner of both Carl Zeiss and Schott enterprises with strict corporate statutes of how profits were to be distributed independent of shareholder's interests. Profits would be channeled to support science with university endowments, charities, and champion worker's rights in the company. Abbé termed this "responsible entrepreneurship" and some of his early worker's reforms are so incredibly prescient that the world still hasn't completely caught up to him:

- executive salary is never to exceed tenfold the income of an average worker of more than 24 years of age who has been employed for at least 3 years
- executives never get a share of profit bonus' at the end of the year.
- wages can never be reduced, only raised and reserve funds are to be drawn on in times of financial crises
- wages are fully paid on the 12 days of holiday per year that the company is closed
- all workers share in the profits at year's end which on average has been 8 %
- reduce the work day from the normal 12 h to 8 with no reduction in pay

- every worker who entered employ before age 40 and has worked at least 5 years is entitled to a pension in case of disability and if death ensues is passed on to his family
- after 15 years the pension rate is 50 % increase yearly by 1 % up to 75 %
- provisions for illness insurance, healthy and clean work conditions and fresh food available at cost in company concessions

In the United States and increasingly in Canada we are witnessing decades of worker's rights eroded by the spread of globalization. Wages and benefits have been cut, job security lost and health and well being of worker's families undermined while corporate profits and executive compensation continues to obscenely grow, often untaxed in offshore locations. Where are the Abbé's of the twenty-first century?

## Real Time Narrowband Visual Viewing with Image Intensifiers

New attendees at city star parties are typically very excited at the prospect of looking through a real telescope for the first time in their lives. Looking at the Moon, Jupiter or Saturn never fails to disappoint and can be a moving, spiritual experience. And truth be known it's really because I've been kissed and hugged so often that I keep hosting star parties! However when it comes to observing deep space objects its *caveat venditor* all the way. From the city only globular clusters are easily seen and they all look like variations of each other and can get stale fairly quickly. Galaxies and nebulae are what people are looking for but they have unfortunately been spoiled by the glorious long exposure images from the Hubble Space Telescope and are expecting to see the same through your eyepiece. Techniques like dark adaptation, averted vision, and the use of specialized contrast enhancing visual filters will be of no benefit in the city because the sky is simply too bright to see any of these structures.

It's getting increasingly common at star parties to see emission nebulae imaged with short exposures by sensitive ccds through Hα filters and displayed on a laptop screen with some rudimentary histogram adjustments to improve contrast. I've resigned myself to the fact that it is impossible to see galaxies from within the city so at least this is a wonderful way to demonstrate a subset of nebulae with details hinting at the images found within the pages of *Sky & Telescope* but the public is left at best half satisfied. There is no real involvement between observer and the telescope because the images do not occur in real time but take minutes to develop. Then there are the skeptical observers who insinuate that you're running a sleight of hand slide show. And frankly they're right. The public needs to be able to look through an eyepiece and see these sights for themselves.

While Hα filters are excellent at negating light pollution and revealing emission nebulae, they are not visual filters as the eye's sensitivity in low light is particularly poor at these wavelengths. The attenuation of light intensity is so extreme one would require a telescope with a massive aperture and extremely fast optics in order to transmit enough light through such filters for the human eye to be able to even register an image. Enter the image intensifier.

Image intensifiers are vacuum tubes that amplify the photons which impact on the cathode end by converting them into electrons via the photoelectric effect. These are then accelerated by high voltage to strike a phosphor screen at the anode and form an image. Phosphor screens typically emit a green light and are made of rare earths oxides or halides (e.g. gadolinium, lanthanum, yttrium) with decay times of a few hundred nanoseconds to a few milliseconds. Like most current technology that we enjoy, it represents a refinement of discoveries which took place in World War 2. The first image intensifiers, Generation 0, were employed by German snipers and were large, fragile tubes utilizing a silver-oxygen-cesium (S1) photocathode coating. Electron acceleration was the primary means of image intensification and sensitivity was only good in the UV and IR regions with a luminance gain of only 150× so these units could not be used passively but only in concert with an IR floodlight.

Experiments with new photocathode coatings in 1956 yielded a multialkali sodium-potassium-antimony-cesium (S20) combination which enhanced sensitivity and spectral response. These Generation 1 image intensifiers have good image resolution (25–30 line pairs per mm), wide dynamic range, low noise and are inexpensive to manufacture. But luminance gain is still low (<1000×) due to a reliance on electron acceleration through a high voltage field (15–36 kV) which makes them inadequate for passive use. A simple solution to boost gain was to combine three single tubes in series so that each tube amplified the output of the preceding tube in a cascade fashion leading to luminance gains of greater than 30,000×. The drawbacks are that they are very bulky (40 cm in length) and suffer from low SNR since the noise present in each tube is subsequently amplified by the next stage.

The leap from Generation 1 to Generation 2 in the early 1970s is by far the most expansive, primarily due to the invention of the microchannel plate (MCP) that amplifies electrons emitted from the photocathode by generating many more additional secondary electrons. The MCP is made from a large solid core of glass enveloped by a sleeve of dissimilar glass (lead). The glasses are heated together and stretched into very small diameter fibers which are compressed together to form bundles. These bundles are sliced at an angle (≈8°) to obtain thin discs (2 cm diameter and 0.5 mm thick) and then chemically treated to remove the core glass to form up to six million parallel traversing channels. In turn these channels are coated with a secondary electron emitter like cesium iodide or copper iodide and photoelectrons are driven through the channels by a constant field voltage of 600–900 V. As they collide and bounce off the walls of these channels (as they must due to the channel angulation) multiple electrons are released within the MCP such that each single photoelectron liberates up to hundred of thousands of electrons. The MCP input web surface is coated with nichrome to provide electrical contacts for all channels and also has a low secondary electron emission coefficient that allows it to scavenge electrons which miss the channel entrances (only 45 % of the MCP cross sectional area) by creating secondary electrons which are pulled into nearby channels by electrostatic forces. Early MCPs had channels 10–12 μm in diameter arranged in a hexagonal pattern with 12–15 μm, center to center spacing. More recent MCP have 6 μm channels resulting in enhanced resolution of greater than 64 line pairs/mm.

Generation 2 tubes also use a new S-25 photocathode coating which is actually just a thicker S-20 layer leading to extended red response and reduced blue response. High voltage power supplies are also much smaller than those found in Generation 1. The close spacing of the MCP to the cathode and anode phosphor screen and the tight spacing of channels results in images lacking the distortion found in Generation 1 tubes and also in overall reduced bulk.

Generation 3 was developed in the 1980s and represent the cutting edge of technology accessible to the civilian populace. It is characterized by a novel gallium arsenide or gallium arsenide phosphorus photocathode coating which increases the image intensifier's sensitivity particularly in the near IR. But the coating is chemically labile and attacked by ionized gases present in small amounts in image intensifiers and driven by the electrical field in the MCP back to the photocathode. Significant degradation is observed after only 100 h of operation. To prevent this, a thin film (1–3 mm) of sintered aluminum oxide is attached to the entrance of the MCP but this in turn traps about 30 % of electrons emitted by the photocathode. Such thin film Generation 3 image intensifiers are still two to three orders of magnitude more sensitive than Generation 2 in the visible spectrum and surpass them in durability with over 15,000 h of operating life. Filmless Generation 3 image intensifiers were developed in 1998 and delivered excellent performance as expected but were too sensitive to mechanical shock and too expensive to manufacture for practical usage (Fig. 3.23).

The concept of using image intensifiers for assisted astronomical viewing is not new and was commercially pioneered in the late 1990s with the Collins $I^3$ eyepiece made by Colorado based Collins Electro Optics. This consisted of a thin film Generation 3, ITT manufactured image intensifier coupled to a Televue eyepiece but has been out of production for many years. Second hand examples occasionally surface but they cannot be exported outside of the United States or sold to non US citizens in compliance with the International Traffic in Arms Regulations act. Interestingly, this act applies to all NATO alliance countries despite the fact that the armed forces of said members possess the same military night vision technology as the US and there are local dealers here in Toronto that can sell me Generation 3 image intensifiers. However, the market is so vast in the US for used and surplus military hardware that prices approach affordability for the amateur astronomer. Used Generation 3 image intensifiers can be had for under $1000 in the US whereas prices in Canada for new pieces are at least 3–5× more expensive.

As a result many people have been experimenting with the popular E2V (formerly English Electric Valve Company Ltd) P8079HP Generation 1 image intensifier that is commonly available for under $100. These were manufactured in the mid 1980s for use as a night sight in British Challenger tanks and is a cascade design with three individual image intensifier units coupled together with fiber optic elements. Surprisingly the datasheet reports luminance gains of 100,000× which is better than most Generation 3 thin film designs but there are no SNR values given.

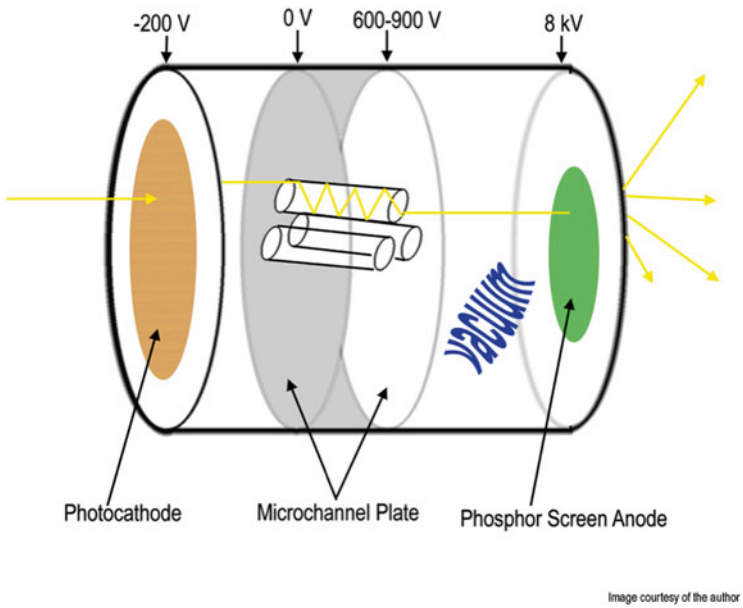


**Fig. 3.23** Components of Generation 3 image intensifier

The unit operates on 3–7 VDC and is very large, a 70 × 200 mm cylinder massing at over 1 kg. I ran my example on a single lithium CR123 battery and encased it in ABS plastic plumbing fittings with an old 2 in. Celestron 50 mm plossl eyepiece to magnify the output on the phosphor screen. The ergonomics are really poorly suited for astronomical use and despite high gains the SNR response was insufficient to reveal any additional details when viewed through a Baader 2″ Hα filter with a 7 nm bandpass width. I think the unit might perform better in dark sites with visual nebula contrast boosting filters but my goal is to find something that can be used in an urban center. As a safety aside, there is some concern that the high internal voltage of a Generation 1 tube might be able to generate x rays, especially dangerous given the close operating proximity of the viewer. Intrigued, I exposed one of my dental digital xray sensors for several minutes at the image output window of the P8079HP. I'm happy to put to rest another internet rumor as absolutely no trace of x ray radiation was detected (Fig. 3.24).

My second attempt involved scoring a great eBay deal on a Russian built Generation 2 from the mid 1990s, the impressively named ROMZ Rostov Cyclop 11B2. It came as a complete night vision apparatus with a 85 mm f/1.2 lens and an IR illuminator powered by a 9 V battery. I liberated the image intensifier unit, which has the perfect dimensions to fit into a standard 2″ diagonal. It apparently has luminance gains of about 60,000× and exhibits the characteristic Generation 2 feature of its phosphor screen turning black instantly upon powering down as

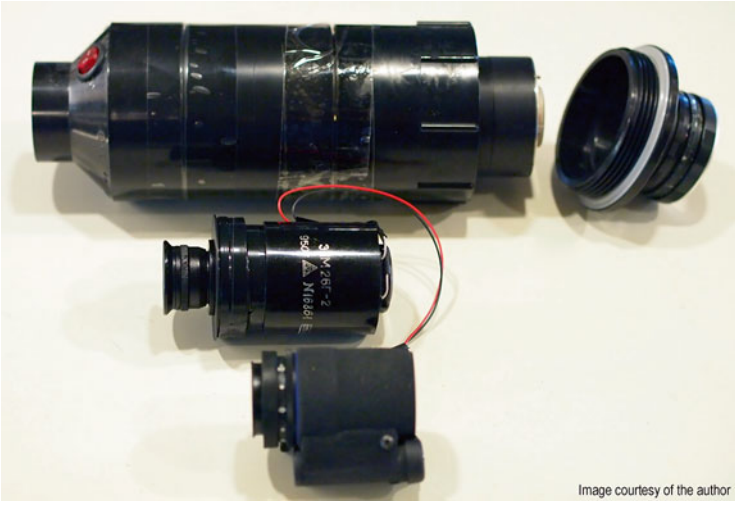


**Fig. 3.24** Three generations of image intensifiers from *top* to *bottom*: E2V P8079HP, ROMZ Rostov Cyclop 11B2, Generation 3 thin film monocular

compared to other generations where the phosphor screen fades away like a TV from the 1960s. The Rostov however exhibited too much noise to clearly see any emission nebula structures when operating under the extremely low signal conditions of an Hα filter (Fig. 3.25).

So my journey approaches its inevitable ending, that of procuring a used and relatively inexpensive Generation 3 thin film image intensifier. In the interests of non-self incrimination I will not enter into the details of the transaction. The unit is powered by two AA batteries and is housed in a monocular unit with a standard C thread mount. My original intention was to use the modified Schmidt camera since a strong signal will maximize chances of success but the odd form factor was not compatible with even the monster Crayford focuser I had constructed. Ultimately I managed to put together a 8″ f/1.7 instrument using my venerable Celestron 8″ SCT with a Alan Gee reducer in the baffle tube, a Meade f/3.3 reducer screwed onto the visual end and a 0.5× reducer onto the nose of the Generation 3 monocle. With the use of a 1.25″ diagonal some crucial spacers had to be deleted to allow focus attainment and the speed of the system drops to about f/2.2.

In the late summer sky of northern latitudes there are not that many bright planetary or emission nebulae that can be seen at civilized hours. The best target is M27, the Dumbell Nebula, and through the Generation 3 image intensifier the shape of it is clearly visible through a 1.25″ Hα filter with a larger than average bandpass of approximately 15 nm to improve the signal strength. I popped out again early in the morning and managed to also visualize M42 and the Horsehead nebula quite clearly and with adequate detail. Certainly these images are coarse but they are unmistakably recognizable. The strength of the Generation 3 is the ability to display a background

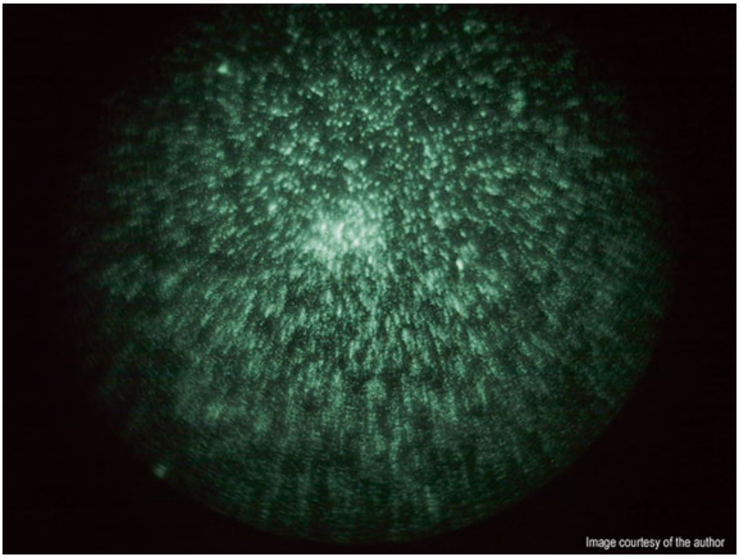


**Fig. 3.25** M27 viewed through Hα filter with Rostov image intensifier

of low signal strength with a minimum of noise. Even at a dark site about an hour outside of Toronto and using a visual nebular contrast filter the image was certainly cleaner and smoother but not necessarily more detailed. My preferred filter at a dark site is the DGM Optics NPB (narrow pass band) filter which is similar to old favorites such as the Lumicon UHC or Orion's Ultrablock by having FWHM (full width half maximum) of 24 nm at the OIII doublet and Hβ spectral lines but also includes an additional 80 % transmission peak at the Hα line. This is a decidedly odd feature for a visual filter since human eyes really can't see at this wavelength at such low light levels but it is tailor made for image intensifier viewing. The only benefit at a dark site is the visualization of galaxies with the image intensifier. It has been estimated than a Generation 3 image intensifier can give you the throughput of a scope some 3× larger in aperture (Figs. 3.26, 3.27, 3.28, 3.29, and 3.30).

My final experiment was an attempt to combine the Rostov Generation 2 with the Generation 3 image intensifier to obtain even more nebulosity detail. I was able to couple the Gen 3 as the lower stage to the Gen 2 with a relay lens made by Edmunds Optics (MVO f/4), which was available on eBay at a much reduced price. I achieved focus but once again the Rostov background was very noisy and although M27 is significantly brighter, it is not any more distinct. The images in the Gen 3 alone are preferable, if faint. Two Gen 3 image intensifiers connected by the same relay lens would work wonders (Figs. 3.31a–c, 3.32, and 3.33).

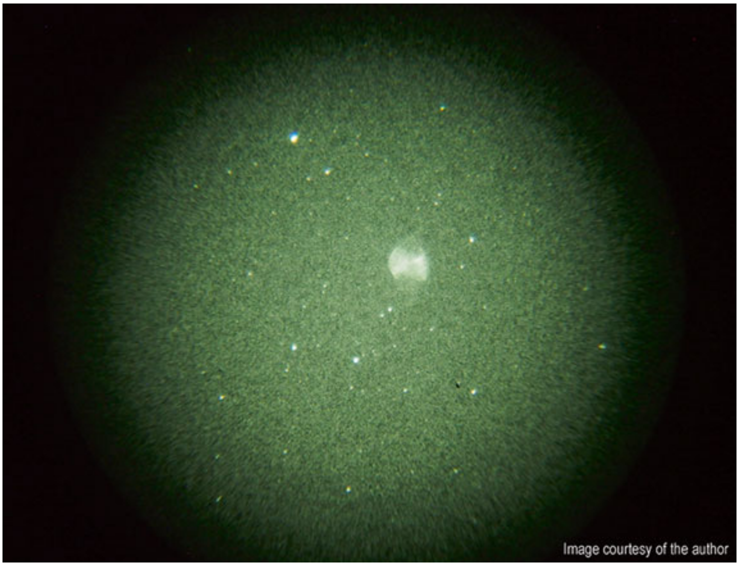


**Fig. 3.26** M27 viewed through Generation 3 image intensifier and Hα filter in Toronto through Celestron 8″ SCT @ f/1.7


**Fig. 3.27** M42 viewed through Generation 3 image intensifier and Hα filter in Toronto through Celestron 8″ SCT @ f/1.7


**Fig. 3.28** North American Nebula through Generation 3 image intensifier and Hα in Toronto and 105 mm AP Traveler @ f/2.8


**Fig. 3.29** M42 viewed through Generation 3 image intensifier and DPM visual nebular filter at dark site through Celestron 8″ SCT @ f/2.2


**Fig. 3.30** M31 viewed through Generation 3 image intensifier at dark site through Celestron 8″ SCT @ f/2.2

Afternote:
I've enjoyed my *Baader* manufactured Alan Gee (*ghee*) f/6 flattener reducer for nearly a decade. It's an air spaced doublet designed by Roland Christen of *AstroPhysics* fame based on the ideas expressed in Gee's 1984 *Sky & Telescope* article. Gee's stroke of genius was to insert the reducer deep into the middle of the SCT's baffle tube when all others were external only. His reducer contributes less to the system's aberrations and produces corner round stars and no vignetting (the fall off in the uniform illumination of the field of view) with sensors up to APS size. His ideas undoubtedly influenced the later redesign of Meade's ACF and Celestron's Edge SCT. Unfortunately Gee passed away a scant 7 years later, well before the Internet was established and before his many accomplishments in amateur telescope making could be digitized and preserved. If you're not as famous as Ernest Abbé and nobody writes your biography, your legacy is manifest as printed primary sources abandoned and forlorn in dusty library archives. I had access to some printed material with some aspects of Gee's life and a day searching on the Internet yielded some clues which filled out his later years. Ever since I bought the Alan Gee reducer I always wondered … who was Alan Gee?

Alan Edward Gee was born in Jacksonville, Florida in 1916 and became an amateur telescope maker at the age of 13 by making several 6″ reflectors and even a 12.6″ behemoth which garnered an early entry in *Scientific American*. In 1936 he entered the US Military Academy at West Point, New York and in his sophomore year he acquired permission to restore the neglected and delapidated West Point

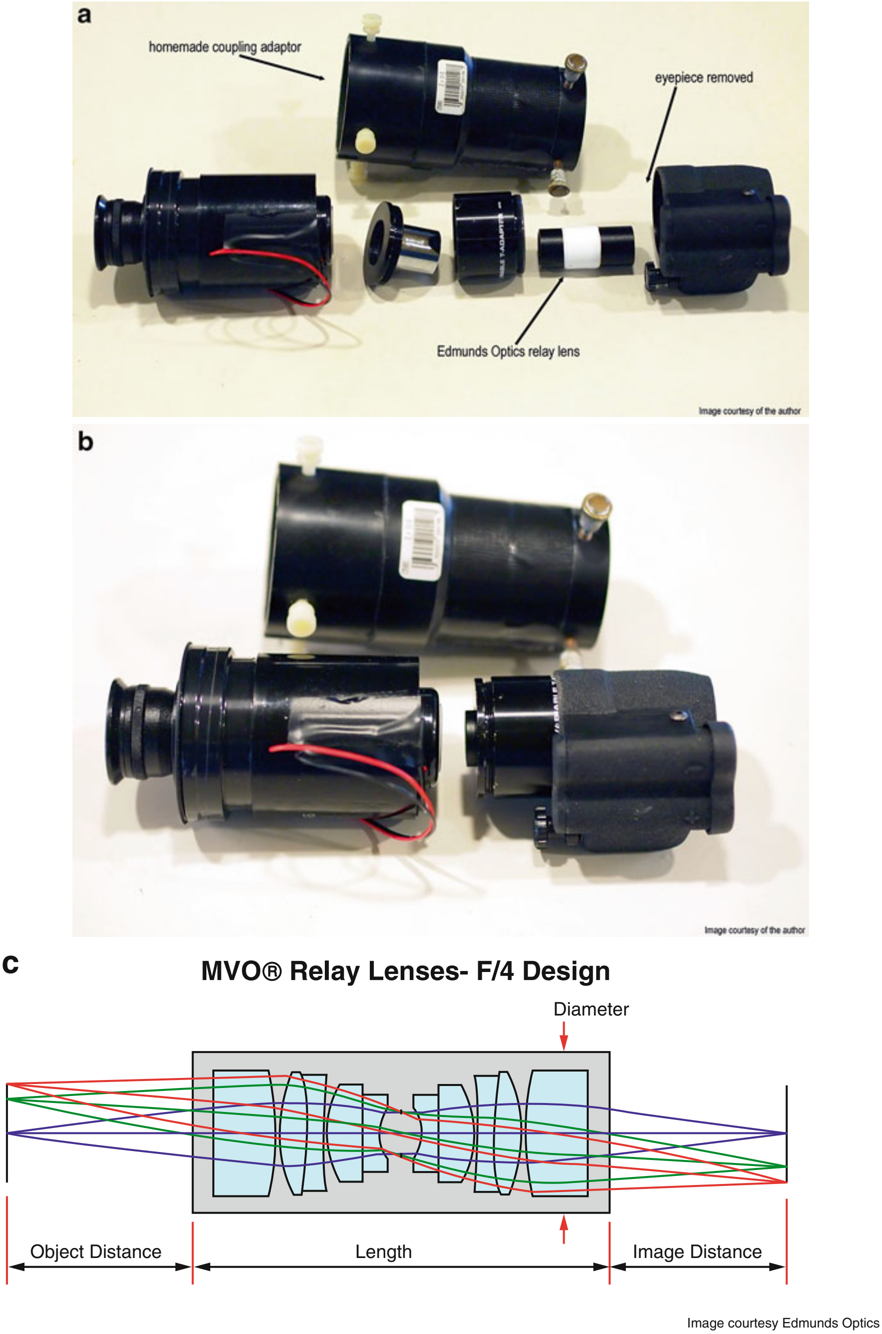


**Fig. 3.31** Breakdown of components using Edmunds Optics MVO f/4 relay lens to couple Generation 3 image intensifier to Rostov Generation 2 image intensifier

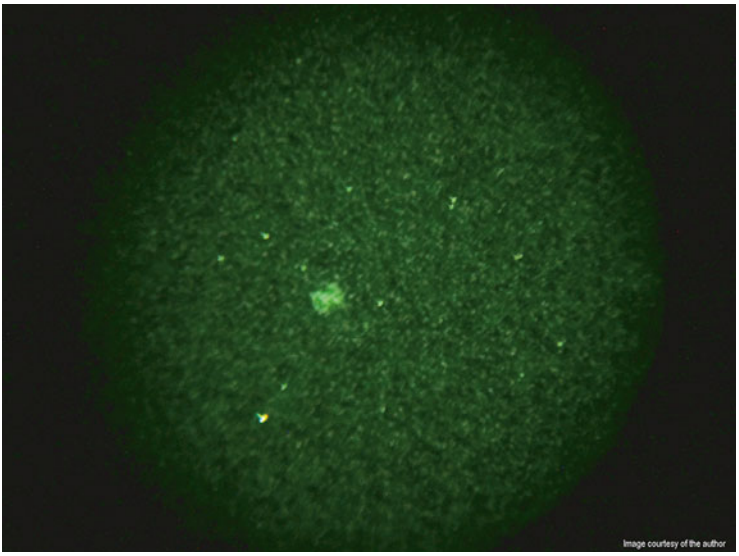


**Fig. 3.32** M27 with coupled Gen3/Gen2 image intensifier


**Fig. 3.33** Celestron 8″ SCT operating at f/1.7 with coupled Gen3/Gen2 image intensifier

observatory at Lusk Reservoir. It housed an optically excellent 12″ Clark refractor in a novel light weight paper covered dome but the weight driven clock drive was beyond salvaging. So he built a synchronous motor drive combined with a sidereal clock for it and another for a 12.5″ fork mounted reflector. West Point granted him considerable latitude to use the restored facilities and he spent much time observing and built a camera for photographing planets. He graduated in 1940 and the observatory fell once again into disuse with the valuable Clark objective ultimately disappearing.

He was commissioned as a second lieutenant and assigned to Vancouver Barracks in Washington State, where he was able to collaborate on the construction of a 20″ telescope. After the war, Lt. Colonel Gee of the Ordnance Department was sent to the University of Rochester for 2 years postgraduate studies in optics and design. He was then assigned as Chief of Fire Control Division at the Frankford Arsenal in Pennsylvania, which includes the best of the US Army's optical laboratories. During this period he continued to build many refractors and contributed a chapter on the mathematical design of achromatic doublet objectives that included full spherical aberration and coma correction for *Ingnall's Amateur Telescope Making*.

After resigning from the military in the 1950s, he joined the Instrument Division of the *American Optical Corporation* rising to Product Manager in the 1960s. Ironically, the Instrument Division was previously the Spencer Lens Company and all ophthalmic instrument manufacturing was done at this Buffalo, N.Y. location. In 1967, the pharmaceutical company *Warner Lambert* bought American Optical. In the mid 1970s Gee took out several patents pertaining to scanning electron microscope applications which were ultimately sold to *Nanometrics* in 1983; a company based in Sunnyvale, California that manufactures, markets and services microscope based measurement and inspection stations for the semiconductor industry. Gee was living in Sunnyvale by the late 1970s so he was likely consulting for *Nanometrics* as he transitioned to full retirement. Before leaving Buffalo, he bequeathed the *Buffalo Museum of Science* a 7.5″ solar telescope and Hα monochromator capable of resolving prominences. The monochromator is a stack of quartz plates of diminishing thickness' separated by polarizing filters allowing a bandpass width as narrow as 3 Å at the Hα line.

Gee was presumably active in the West Coast amateur telescope making scene and has written about his variant of the Poncet equatorial platform for dobsonian telescopes. He died in 1991 and leaves behind a son and two granddaughters.

Public outreach is a natural extension for a hobby that is so universally attractive to the lay public. Not only is it a marvelous way for one human to connect to another at a decidedly deeper level, it's an opportunity to educate and correct urban myths that we all find rather offensive. Like the belief that astronomy and astrology are the same. Or that astrology is even a science. And that this is the year that Mars approaches so close to the Earth that it will appear as big as the Moon. Speaking of which, if you type, "Is the Moon" in the Google search window, you will be shocked at what appears as the most popular matching queries from global internet users. Shocked and saddened.

# Chapter 4

# Amateur Telescope Making

I particularly enjoy making telescopes because it's a romantic notion to make the instrument that you conceivably can use to make a new scientific discovery with all the opportunities to be involved in citizen science available today. Astronomy is a uniquely nascent science that embraces amateur and professional alike. None of these projects involve the making of any optics, that is a subject only suitably written by an expert. The telescope projects that follow will hopefully alter your definition of what a telescope can be, what you can do to improve your store bought telescope, and what forgotten treasures can be found at garage sales and resurrected.

## An Ultraportable, Open and Folded 8.5″ Refractor

I would wager good money that you, the one reading at this moment, have more than one telescope and that you have more than one type of telescope, be it some sort of Cassegrain reflector, Newtonian reflector or refractor. And as a guy I get this, you need a scope for every occasion be it deep space, planetary or solar observing.

Before I was married, I had at one point five motorcycles. One for every occasion. There's the 1968 BSA Victor Special and 1974 Triumph Bonneville for the vintage events, the Honda RC30 for the Sunday morning high speed canyon carving rides with the boys, the Honda Pacific Coast for touring and the Yamaha VMax for intimidating the Harley Davidson riders posing at Starbucks.

But if we were only allowed one telescope I think there is no better optical instrument to observe or image with than a refractor. The design can be permanently collimated, quickly cooled, immune to tube currents, and produces the highest



J. Chung, *Astro-Imaging Projects for Amateur Astronomers*, The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18546-0_4

contrast images since there is no energy robbing central obstruction. Often a small refractor will seemingly outperform a much larger aperture SCT or reflector because larger scopes tend to be more sensitive to the seeing conditions and the high contrast view of refractors make them appear to out resolve their theoretical limits.

However, well color corrected or chromatic aberration (CA) free refractors using extra dispersion (ED) glass become prohibitively expensive as apertures increase above the 4″ diameter size (interestingly because of economies of scale as there is no demand by consumer camera companies for ED glass larger than 4″ in the manufacture of camera lenses). This obsession with *airline compact* refractors is another example of the current consumer gadget frenzy where thinner, lighter, smaller is in. In the 1960s, people enjoyed CA free and reasonably priced refractors (using normal glass) like the classic Unitron long tube, high focal length scopes. As a simple rule of thumb devised by Sidgewick, CA becomes negligible when the focal ratio (*f*) divided by the diameter in inches is greater than 3. Today, companies like *D&G Optical* specialize in making large aperture, high *f* value achromatic doublet refractors but these are monster optical tube assemblies (OTA) greater than 10 ft in length requiring equally monster mounts to support them.

The execution of a folded refractor design to address unwieldy OTA lengths has never really seized the minds of amateur telescope makers despite both *RE Brandt* and *Unitron* selling folded refractors right through to the end of the 1980s. A folded refractor uses one or more optically flat mirrors to redirect the light path back onto itself and thereby reducing apparent OTA length. The redirections can also be outside the main light path plane allowing the eyepiece to be uniquely placed along the RA axis. This allows the visual observer to stay in one constant position the whole night long even while the scope and mount are tracking an object across the sky.

I was fortunate to acquire a used 8.5″ f/12.5 *D&G* lens and cell recently and decided to build a refractor that was small enough to transport in a normal car and light enough to be mounted on a normally affordable GEM mount. Although I typically use my 12″ f/5 Newtonian to image planets, it is very difficult to transport to star parties and one needs aperture to show planets at their very best. The Newtonian has a central obstruction from its secondary mirror of about 3″, which in practice means is delivers contrast similar to a 9″ aperture refractor. Although the Sidgewick ratio of the lens is only 1.5, stopping down the lens to 6″ will produce a ratio of 3 if the CA proves too intrusive. By folding the light path twice, I can reduce the original 9 ft OTA to under 3 ft. By constructing a pole frame it is open (lighter in weight and quicker to cool down) and by making the poles retractable, the OTA length can be reduced to only 2 ft for storage and transport! In fact I managed the near impossible, it fits in the back of my tiny vintage Japanese sports car (Fig. 4.1).

The focal length of the lens was confirmed to be 106 in. by focusing the image of the sun onto a piece of plywood and measuring the distance between the two. The four bulkheads are made from high quality ¾″ Baltic Birch plywood. The aluminum tubing was sourced from nearby *Maple Leaf Communications*, which market it for building shortwave radio antennae and the self locking telescoping tube buttons from *McMaster Carr*. Optical flats were bought used from eBay, often as remains of discarded optical testing equipment and were recoated by Normand Fullum (Quebec).

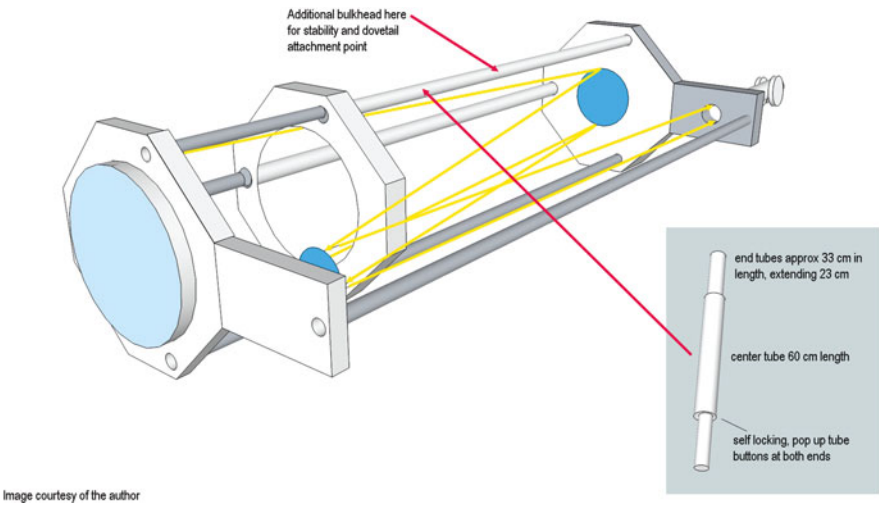


**Fig. 4.1** Sketch-Up initial design of the open folded 8.5″ f/12.5 refractor

The four bulkheads were cut by hand with a jigsaw and a cardboard template. Since each ended up a unique shape (!), I could not rely on the edges to make accurate measurements for cutting the baffles and the holes for the four aluminum tubes. I bolted the four sheets of plywood together and drilled the centers of the four tubes and two baffles to ensure that when all the holes are completed, the bulkheads will be correctly aligned (Fig. 4.2).

The flat sizes (a 6″ and a 3″, both rated at *1/10th* wave surface accuracy) and baffle opening sizes were calculated by considering the light cone as an isosceles triangle and the bulkheads the bases of a series of similar triangles. A scale rendered drawing greatly helps to determine the size and position of the secondary and tertiary baffle openings (Fig. 4.3).

At this point I'd like to dispel the notion that complex ATM can only be performed by skilled tradesmen within their own well equipped workshops. My workshop is literally my driveway working with rudimentary portable tools and knowledge acquired from watching too many home renovation shows. This project took 1 week to complete, working a few hours each day. Planning and acquiring parts took about 4 months (which also includes time waiting for Spring to arrive).

To mount the scope, I recycled the 3 ft long Losmandy style dovetail plate I made for the EMCCD project and attached it to a solid oak base straddling the aluminum tubing between the two central bulkheads. This was further reinforced with a pair of ¼″ 90° angle aluminum. The aluminum tubes were connected to the bulkheads with the use of 1″ and 7/8″ internal diameter shaft couplers (*Fastenal*) and the tubing connected to the end bulkheads with Fab-Lok expanding sleeve anchor bolts inserted into the open end of each tube. The optical flat cells were

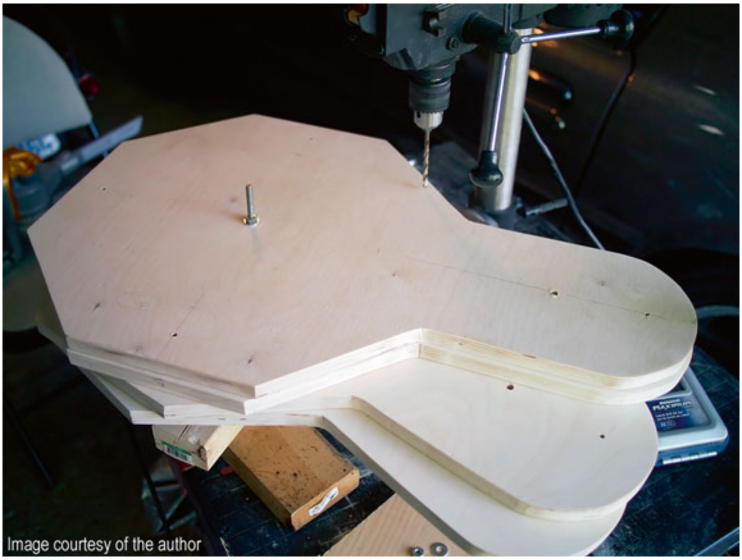


**Fig. 4.2** Bulkheads bolted together to ensure that holes cut for the two baffles and four tubes will be in correct alignment

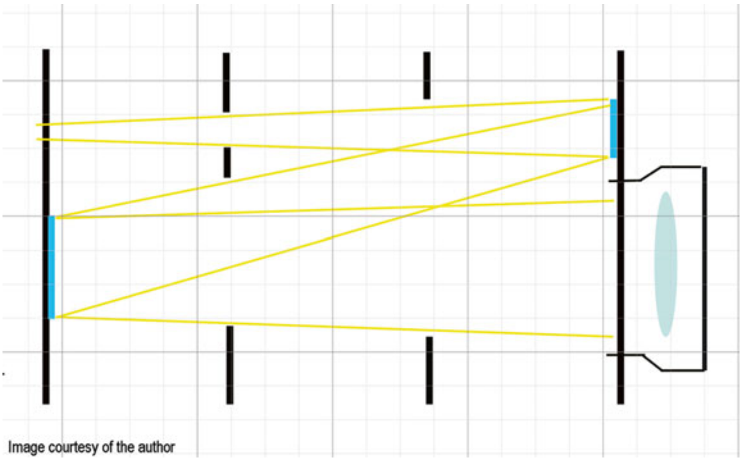


**Fig. 4.3** Scale diagram showing light path and size of baffles needed

made from PVC drain pipe caps with reduced thickness and mounted on three equidistantly spaced spring loaded screws. The length of these screws can be altered with attached wingnuts allowing three dimensional positioning of the cell. The optical flats were passively glued to the cells with judicious application of silicone sealant.


**Fig. 4.4** Collimation of folded refractor using paper circles with marked centers

Collimation of all these optical elements can appear complex but is quite simple with the use of a laser collimator, the type used with Newtonian reflectors. I used the 2″ *Hotech* laser collimator with the self centering adapter. I cut paper circles with marked centers to attach on all three optical surfaces and centered the focuser to the 3″ optical flat. I'm using a *JMI* EV-2nM motorized crayford focuser which has built in orthogonal adjustment on the mounting place, alternatively one can adjust any focuser with custom shims. I then adjust the 3″ flat until it was centered on the 6″ flat, and then the 6″ flat until it was centered on the lens objective. The lens cell has push/pull adjustment and was collimated when the return beam reflecting off the back of the posterior lens element was centered on the *Hotech*'s targeting faceplate. The lens itself had been recently returned from *D&G Optical* with its elements cleaned and with the correct air gap spacing (Fig. 4.4).

While not the featherweight I envisioned, the completed scope weighs in at 50 lb, which is significant savings over the original 9 ft long, 85 lb conventional refractor (Figs. 4.5, 4.6, 4.7, 4.8, and 4.9).

At 100× visual magnification, one can easily observe significant CA around Vega but initial experiments with an Aries Chromacor-Null are very promising since they reduced the violet haze to levels nearly undetectable. The Chromacor I and II was


**Fig. 4.5** The completed open and folded refractor

introduced a decade ago to specifically correct the chromatic aberration of several popular 6 in., f/8 Chinese achromatic refractors and in effect make them affordable large aperture semi apochromatic refractors. Sensitive to collimation, centering and position placement in the light cone, the small device is made of ED glass and needs to be placed 161 ± 2 mm ahead of the eyepiece fieldstop. This necessitates the use of several 2 in. diameter barrel extenders in front of a diagonal. A typical 2″ diagonal will use up approximately 100 mm of focus distance. For the f/12 folded refractor, Aries suggests extending that distance some extra 75–100 mm (Figs. 4.10, 4.11, and 4.12).

Perhaps the best test of optical performance came during the Toronto RASC center's July city observing session. Despite the low sky positioning of Saturn, the seeing was near excellent that hot and humid night and we were able to observe a stable image of Saturn at 600× magnification, well beyond the theoretical limits of an 8.5″ scope. It was truly my best visual experience of Saturn, crisp with horizontal disc bandings just perceptible and a Cassini division big enough to fall into! (Figs. 4.13 and 4.14).

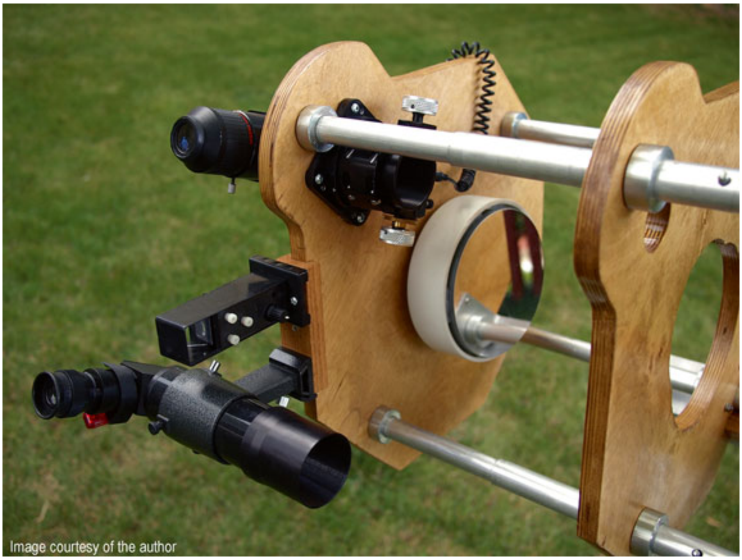


**Fig. 4.6** Detail of focuser, 6″ flat and two finders


**Fig. 4.7** Detail of oak saddle


**Fig. 4.8** Detail of reinforcing angle aluminum, motor shaft couplers, dovetail bar


**Fig. 4.9** Detail of Fab-Lok expanding sleeve anchor bolts holding end bulkheads to aluminum tube ends

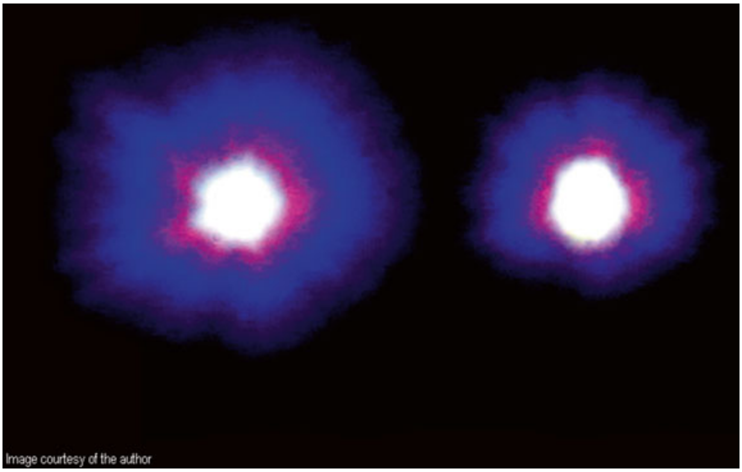


**Fig. 4.10** Chromatic aberration of Vega of refractor (*left*), and with refractor and Aries Chomacor-N (*right*)

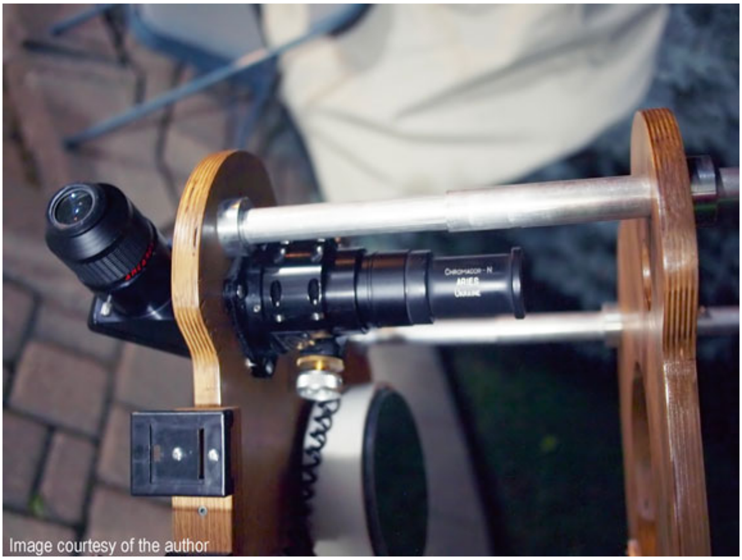


**Fig. 4.11** Aries Chromacor-N mounted on 2″ diameter barrel extenders the correct distance away from eyepiece field stop

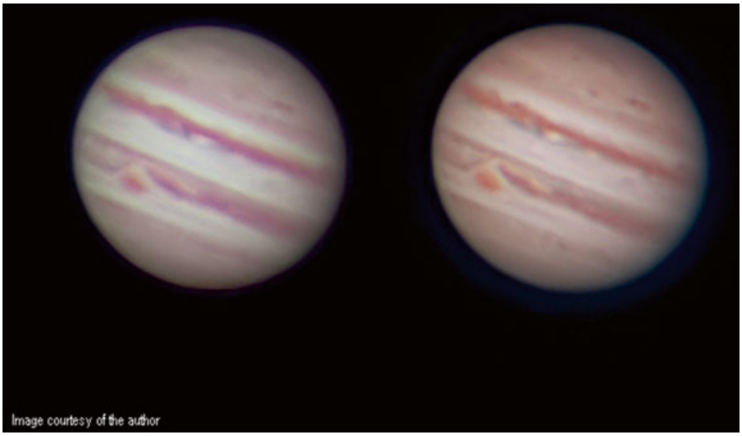


**Fig. 4.12** Jupiter imaged with PGR Flea3 at f/30 (*left*) and with Chromacor-N (*right*). Significant correction to color fidelity and increased detail shown on *right image*. Even though CA is not readily apparent visually these images show how much detail and resolution is lost with an achromatic refractor, you just don't realize it


**Fig. 4.13** M57 Ring Nebula, 2 h of 10 min subexposures with 3 nm Astrodon Hα and OIII filters and QSI532 ccd, 8.5″ f/12.5 refractor, EQ6 mount

Afternote:
I thought it would be interesting to read through the issues of *Sky & Telescope* for the last three decades of the twentieth century for basic knowledge useful to observers, imagers and amateur telescope makers that we may have forgotten—or things we were told to believe in without really knowing the scientific basis behind them. For example, I finally understand what Carly Simon was singing about in her


**Fig. 4.14** Not everyone can say they can carry an 8.5″ f/12.5 refractor in the back of a tiny two seater sports car

song *You're so Vain*. The March 7th total solar eclipse passed right over Sydney, Nova Scotia (April, 1970). While the magazine remains tight lipped about the identity of her scorn, here are some of the highlights in my 30 year overview:

Technical aspects of Bernard Schmidt's mysterious vacuum method (he never wrote it down) of producing the aspheric Schmidt corrector plate were discussed in great detail: namely a glass plate was deformed in the centre by a vacuum and then ground spherical. When the vacuum was released, the plate sprang back into the desired corrector profile. Celestron refined this process for mass production, allowing the proliferation of commercial SCTs (June, 1972).

Details of a revolutionary new focuser invented by English amateur John Wall in 1971—the now ubiquitous Crayford focuser—were described in September 1974! John continues to be a frequently internet contributor and his latest creation are large aperture apochromatic dialyte refractors.

Cooling film cameras improved their sensitivity, leading to amateur-built custom boxes to immerse the camera body in dry ice during imaging, foreshadowing cooling of DSLRs with modified TEC iceboxes (August, 1975).

Perkin-Elmer (the folks who goofed on the *Hubble Space Telescope*) advertised their microdensitometer, which could scan a 35-mm negative at 1-μm intervals. Unfortunately, that would result in 864 million pixels recorded onto 124 reels of magnetic storage tape, but their data acquisition system could handle it! Today's amateurs can buy an off the shelf FLI Proline PL50100 CCD with 52 million pixels that any laptop can handle. Proscope was selling their 12-in. Ritchey-Chretien scopes for $8750, which is about $34k in today's dollars. Today, AstroTech will happily sell you their mass produced 12 in. RC for only $4k. There was commentary on the wonderful increase in light transmission from the application of state-of-the-art $MgFl_2$ lens coatings and 97 % reflectance mirror aluminization (May, 1976).

The very best amateur planetary film photography was showcased and they were (with no disrespect) worse than my first fumbling attempts with Webcam imaging. The article concluded that good seeing is the single most important determinant for success (September, 1976). That still remains unchanged today!

At that year's Stellafane, a homemade digital setting circle that stored the coordinates of 256 celestial objects was showcased. It was comprised of over 110 integrated circuits and cost $250 to make (October, 1976)!

Adrien Poncet of France described his revolutionary idea: a flat platform that pivoted along a sector resulting in an equatorial movement that could be located well below the plane of the optical train. Poncet or equatorial platforms are now widely used by owners of large Dobsonians to enable RA tracking without the expense of servo-controlled GOTO systems (January, 1977).

Mike Simmons explored the age old question of what is the best 8-in. scope design for film photography based on the performance criteria of optical speed, off-axis performance, and size of the flat field. He ran his designs through self-written ray-trace software on his home computer and came up with some interesting conclusions and three winning designs at f/5.6. One design was a concentric Schmidt-Cassegrain that modified commercial SCTs by placing the corrector plate at the centre of the curvature of the primary mirror, and having both primary and secondary mirrors share the same centre of curvature. The downside is that the OTA becomes three times the length of conventional SCTs. The Simak Maksutov-Cassegrain was modified by making all four surfaces spherical, freeing the secondary from the corrector, and moving it inward toward the primary. A simple plano-convex flattening lens can be used to further improve star sizes, and a short tube length is preserved. Finally, a design familiar to us all: a refractor with four elements in two groups including a fluorite or extra-low-dispersion (ED) element similar to the Petzval design found in some Tele Vue scopes. Now, as in the 1980s, an 8-in. scope of this design remains prohibitively expensive (July, 1980). The Simak design reappeared briefly in the early 2000s as an AstroPhysics Maksutov-Cassegrain with Russian manufactured optics (Aries Instruments, Ukraine). Slightly more than two dozen were made; they have an incredible planetary imaging performance, and command steep, used prices of over $40,000.

A perfectly made scope operating in perfect conditions will still have its performance limited by the diffraction effects arising from the wave nature of light. A star test under high magnification will reveal a central circular Airy disc surrounded by fainter concentric rings, a phenomenon that is a consequence of that diffraction. English astronomer G.B. Airy showed mathematically in 1835 that the diameter of a star's disk is inversely proportional to the aperture of the scope. Larger scopes resolve stars as finer points of light. In a refractor, the Airy disc contains 84 % of the light energy and the first ring contains 7 %. In a 30 % obstructed scope like an SCT, the Airy disc contains only 68 % of the energy and the first ring 22 %, causing a reduction in contrast of an object (February, 1983). This is the reason why a 4-in. refractor in less than ideal seeing will often visually outperform a much larger reflector or SCT, especially for planetary viewing.

I was eagerly anticipating the start date of the CCD imaging revolution and found it with French amateur Christian Buil's image of Jupiter taken with his home-made CCD (January, 1985). Christian (who is still very much active in the field) used his Apple //e computer to generate the clock pulses necessary to read out the pixels, but, to simplify matters, he constructed a single-line sensor of 1700 pixels, each 13 μm square. He constructed two-dimensional planetary images by stopping his mount's clock drive and letting the image drift across the sensor to produce a natural scanning effect. Incidentally, Christian's scope was none other than the 40-in. at Pic du Midi as the line between amateur and professional astronomer continually blurs.

John Richter introduced the idea of curved spider vanes to eliminate diffraction spikes when imaging through a Newtonian scope. The optimal configuration was a set of three equally spaced vanes, each describing a 120° arc (May, 1985).

Stephen Larson shows how a simple high-pass filter image process can bring out the detail in a single 0.1-s CCD image of Mars taken with a 61-in. scope. Amateurs would soon produce images rivalling those taken by space probes, when it was understood that post-processing techniques were as important as careful preparation during data acquisition (May, 1989).

Peter Ceravolo commented on the frequently inflated claims of optical performance by scope manufacturers. Scopes advertised with diffraction-limited optics imply that any defects will be masked by its diffraction pattern, which was generally regarded as 1/4 wave. This tolerance may be too loose, especially for planetary observing/imaging, where the loss of contrast at 1/4 wave is considerable. He noted that there has been a reduction in planet watching coincident with the rise in popularity of SCTs and large-mirror Newtonians. He believed it was due to a combination of large central obstructions and the spotty optical quality of popular commercial instruments that reduced contrast and rendered planetary observing a less satisfying pursuit (December, 1989). In the end, you get what you pay for, but also undeniable is the unprecedented and excellent value we enjoy even with less than perfect instruments today. The smoothness of the optics is also important because a well corrected but rough mirror will generate so much light scatter that it reduces image contrast. In the same issue, Dennis di Cicco attempted to settle the ongoing battle between Meade and Celestron as to who made the best 8-in. SCT, but, in doing so, shattered some myths—the SCT is a compromise instrument. It's a scope optimized for aperture size and portability that can do many things but does them merely adequately. Largely unknown was the fact that even a perfect set of SCT mirrors must be placed within a single millimetre of their designed separation distance to maintain diffraction-limited performance. The problem arises when focus is achieved by moving the primary mirror back and forth.

Shigemi Numazawa of Japan pioneered the use of a CCD video camera to record planetary images. The CCD had a greater sensitivity than film, and he could use exposures as short as 1/30th second. He discovered that if he played back the frames at a slow rate, he could detect large changes in seeing that were not obvious when played at the normal 30 fps rate, deducing that poor planet imaging resulted from the collective blurring of bad seeing during long exposures. To improve the roughness or poor S/N ratio of a single video image, he chose 20–30 of the best frames (using a high quality VCR) and shot multiple exposures onto a single frame of Kodak TMax B&W film right off the TV monitor, allowing for careful alignment of each frame. Despite a process fraught with many technical challenges, his results were superior to film, and, although taken with a C11, rivalled those from a large observatory reflector. He theorized that frames could be digitally grabbed and processed by computer that could effortlessly make a composite from hundreds of frames (February, 1992). Today's amateurs capture three channels (RGB) of data in 1/120th to 1/30th second exposures, often comprising several thousand frames, of which hundreds are stacked with increasingly sophisticated software and with minimal hardware.

Peter Ceravolo returned to an S&T-sponsored telescope shootout to determine if 1/4 wave optics really were diffraction limited as scope manufacturers would have had us believe. He constructed four identical 6-in., f/8 reflectors with mirrors figured to 1-, 1/2-, 1/4- and 1/10-wave, and with diagonals flat to 1/10-wave or better for the best three. Testers easily dismissed the 1- and 1/2-wave scopes but found it difficult to choose between 1/4- and 1/10-wave optics unless the seeing was stable and good. Since scope manufacturers often tout consumer satisfaction as the golden measure of quality, the typical amateur probably will be happy with 1/4-wave optics under average seeing conditions. From a statistical point of view, there will often be units that fall below this level if 1/4-wave is the manufacturing goal. Under excellent seeing conditions, observers and imagers alike will appreciate diffraction limits that exceed 1/4-wave (March, 1992).

Bill Kelley introduced one of those fascinating ideas that somehow failed to bear fruit even 20 years later. He epoxied a screw bolt to the centre of a spherical 6-in. f/5 mirror and then mounted the mirror on a plywood disk with a ring of carpeting supporting its periphery. When he tightening the single central mounting bolt with a wingnut, the mirror deformed enough to become a paraboloid. More tightening resulted in a hyperboloid figure. Although Ronchi tests confirmed the change in figure, the degree of mirror warping required could be easily determined in the eyepiece by simply sharpening the stars down to a pinpoint. Other advantages of this system included the ease of manufacturing a smooth accurate spherical mirror, no requirement for a mirror cell, and, when temperature dropped and a mirror naturally tended to become overcorrected, the ability to quickly readjust the figure (June, 1992).

Bill Zmek answered another age old question: is an unobstructed scope design superior for planetary observation? He devised an equation to show that the contrast in an obstructed scope had the same characteristics as a smaller scope with a diameter equal to the difference between aperture and secondary-obstruction diameter, despite the transfer of energy from the Airy disc to the first diffraction ring of an obstructed scope. Reflectors were perceived to be inferior because they are more susceptible to wavefront errors emanating from poor collimation, mirror-cell strain, and thermal gradients from the open tube. If these factors are well controlled, then performance could be expected to be equivalent to a slightly smaller refractor but at a substantially lower price point (July, September 1993).

My journey from the 1970s through to the 1990s saw issues grow from about 70 pages to over 150 pages, much of that in increased advertising space. A strong astro marketplace is good for *S&T* and for the amateur community. It appears that over our past decade, globalization, the recession, and the rise of Internet commerce have shrunk ad revenue and the size of recent issues. I suspect that articles and columns also get shrunk, merged, or eliminated. Certainly, articles about film photography have vanished completely, never to return. Articles about amateur telescope making and astronomical calculations used to involve making your own electronic circuits and programming your home computer. I think these talents still exist in our community, but both electronics and software are getting so complex as to require engineering degrees. We are also enjoying an unprecedented era of affordable astronomical gear, which removes a lot of the motivation to make it ourselves.

Articles are becoming increasingly complex, which is good for the *cognescenti* but difficult for beginners starting out in the hobby. This portends that astronomy may mature into a science to which amateurs will no longer be able to contribute. Magazines such as *S&T* often have a backlog of articles to publish and cannot compete in a timely fashion with the dissemination of cutting edge techniques or equipment reviews such as those on Cloudy Nights and similar Internet sites. But, like newspapers, there will always be a role for professionally trained journalists, fact checkers, and proofreaders that cannot be eclipsed by the lone blogger.

## A Tale of Two Dobsonians

My man cave doesn't have a beer fridge, a foosball table or a large plasma screen with an Xbox One, PS4 and Wii U. It is a crowded, unheated garage within which I toil and writhe like a contortionist to avoid all the usual suspects in addition to a 1968 BMW motorcycle, an 1985 Mazda Rx7 and several swinging overhead bicycles suspended from the rafters.

Five years ago I was trying to find a large aperture scope to further my planetary imaging. The 14″ Celestron Schmidt Cassegrain (or C14) is a very popular choice but it's price was above my budget, I didn't have a GEM mount large enough to carry it, it's very difficult to mount single handedly and SCTs typically require star collimation (although the new Hotech SCT laser collimation system obviates this condition). I realized that a large reflector mounted in the simple Alt/Az fashion popularized by John Dobson fit my needs the best. Meade, Orion and SkyWatcher were all marketing truss type dobs but the collapsible nature of the 3 pole system of the SkyWatcher design meant effortless storage and setup. I would require motorized tracking in order to perform high focal length planetary imaging but I would have to implement that myself (SkyWatcher has a fully motorized GOTO version now) (Fig. 4.15).


**Fig. 4.15** SkyWatcher 12″ f/5 collapsible dobsonian reflector

I was fortunate to find a 12 in. example secondhand locally from another amateur who wanted to move up to an Obsession Ultracompact dob. I've taken it upon myself to introduce the official rules of telescope *modding*, namely:

1. *The mod must not look like a mod* (the thing being modded must retain a stock appearance).
2. *The mod must be as simple as possible* (anybody can perform them with simple tools).
3. *The mod must be as inexpensive as possible* (so as to encourage recycling and the use of found household items).

I decided the simplest way to confer motor driven capability was to use the Meade Autostar system. This system is very popular because the Autostar firmware on the 495/497 handset (but not the 494) allows the user to change the gear ratio values for both the azimuth (Az) and altitude (Alt) axes. This means that Meade drive motors can be used with any size of worm and ring gear and still maintain tracking and GOTO accuracy. There were two main engineering obstacles. The dob rotating surfaces are designed with friction in mind so that the tube stays where you aim it. I needed to redesign the Az and Alt bearing surfaces to reduce friction in order to reduce strain on the drive motors and improve the smoothness of movements. A fellow amateur kindly and generously donated an unwanted Meade DS114 telescope which allowed me to cannibalize a pair of DS drive motors, the Alt/Az axis shafts and clutches making this mod even easier to accomplish.

The DS motors are generally found on entry level GOTO Meade telescope products and feature very small motors of the type found in 1:32 scale slot cars. Consequently they are very heavily geared to generate sufficient torque and their maximum slew rates become quite slow when larger than stock ring gears are used. Each motor has a 36 vane shaft encoder but the combination of plastic gears and low grade carbon brushes (causing arcing and soot buildup between the commutators of the armature) can lead to poor drive performance and GOTO accuracy. However neither of these concerns affect this specific application because we do not need to rely on GOTO to find planets for they are visually apparent. We just want fine telescope movement control that is not possible manually. Autostar has nine levels of motor speed control which is performed via pulse width modulation.

The previous owner had removed the original circular array of roller bearings on the Az surface presumably because there was not enough *stiction*. This is a term amalgamating the concepts of stickiness and static friction whereby the threshold of friction is low enough to allow movement with the gentlest of nudges. There remains enough stickiness to immediately stop the scope once the force of said nudge is removed. This was simply upgraded with the installation of a Lazy Susan ball bearing from Lee Valley Tools.

The original Alt bearing was similarly rudimentary with the metal hub of the OTA sliding over some plastic dowels. The four dowels were replaced with plastic covered ball bearings allowing the OTA to pitch up and down with zero effort. The new bearings were also the same diameter as the dowels allowing the use of all the original drilled holes in the mount (Figs. 4.16, 4.17, 4.18, and 4.19).

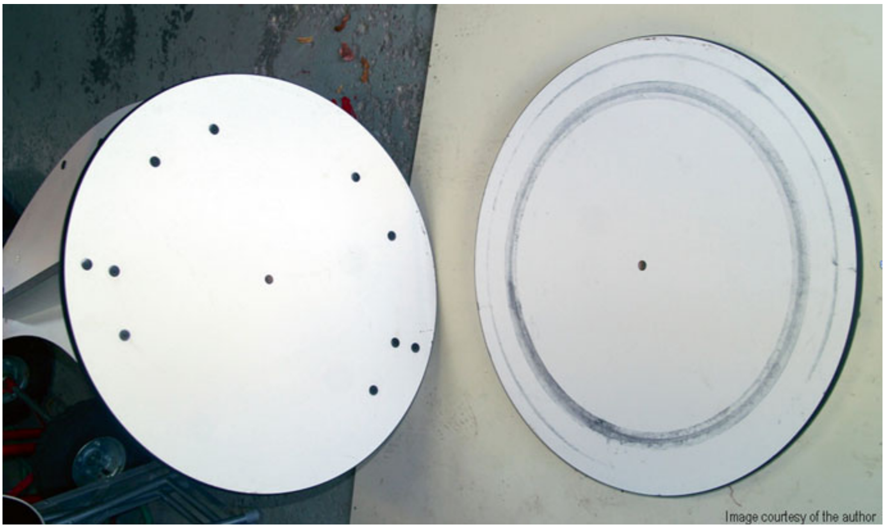


**Fig. 4.16** Original condition of Az bearing surface, raw melamine

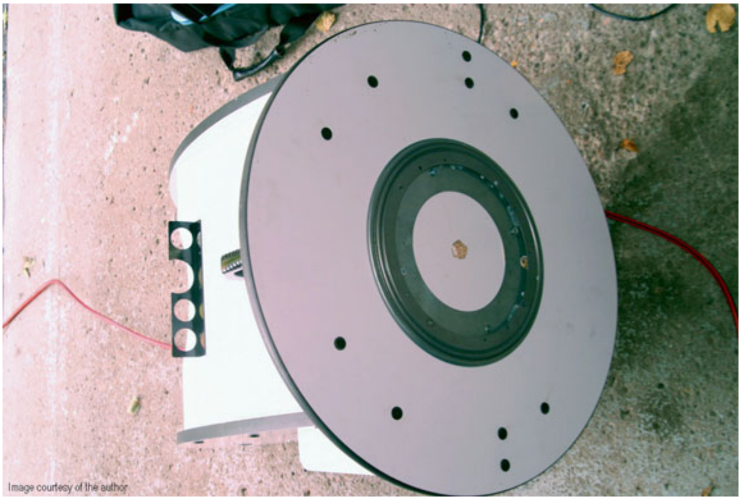


Fig. 4.17 Lazy Susan bearing installed on Az surface

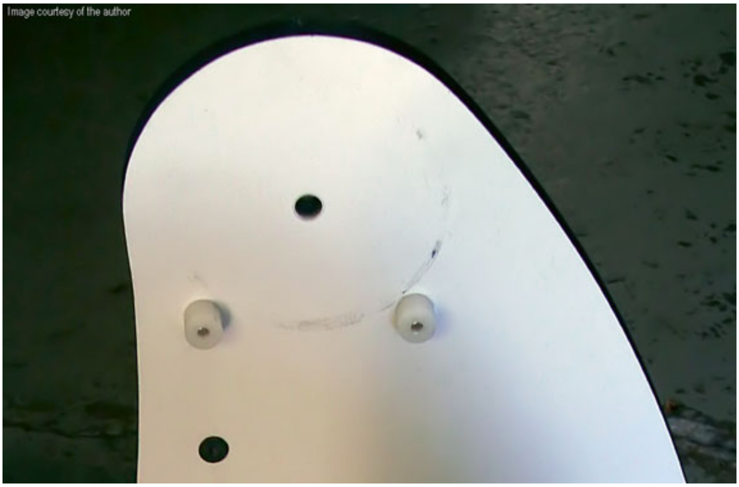


Fig. 4.18 Original Alt bearing system

Recycling the shorter of the two shafts from the Meade DS114 mount, I attached it to the cover plate of an electrical junction box and epoxied it to prevent it from working loose. This was screwed onto the base of the dob mount and would be rigid while the upper section would rotate around it. The Az drive system is shown where a ring gear sits on top of the protruding Az shaft. The Alt shaft happens to have the


**Fig. 4.19** New Alt bearing system with ball bearing

exact same thread size and pitch as found on the hub of the OTA and also allowed the use of the stock Alt handle hole. The clutch system is a series of nonrotating washers indexed to a longitudinal keyway cut into the ring gear shaft. A nut squeezes the washers against the ring gear so that the shaft turns with the ring gear. The worm shafts were retrofitted with a large plastic Meade spur gear that is designed to mesh with the output gear of the DS motors. The other altitude bearing is captured with the screw-in stock lifting handle. The Meade DS and ETX line of scopes use a 60 tooth ring gear and have an Alt/Az ratio of 1.36889. The new Alt ring gear has 112 teeth so the new ratio is $112/60 \cdot 1.36889 = 2.5552613$ (Figs. 4.20, 4.21, 4.22, and 4.23).

The cooling fan is just a computer fan mounted on rubber plumbing washers to help isolate the mirror cell from potential vibrations. It's connected via telephone extension cable to the AUX port of the Autostar panel which happens to also carry 12 VDC. The fan is drawing air out of the tube through the bottom of the mirror cell. Magnetic weights can slide up and down the steel tubular mirror box to adjust

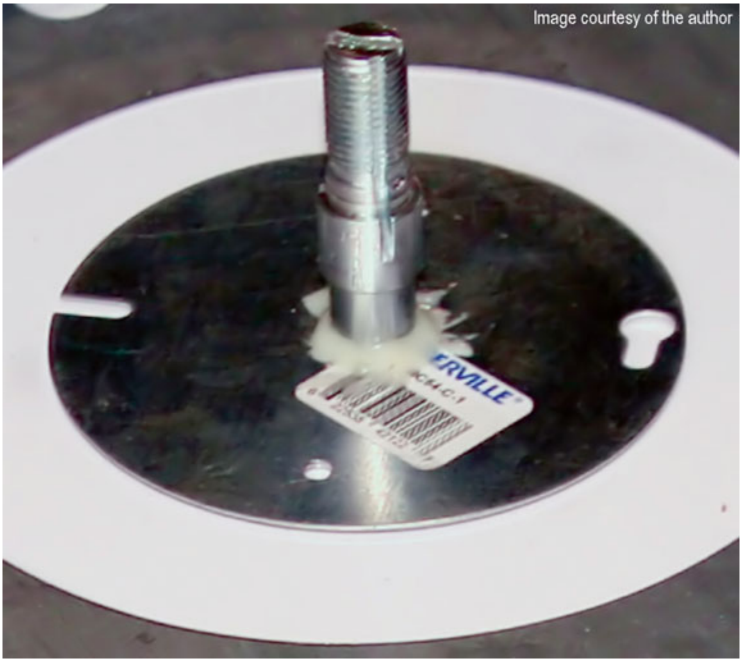


**Fig. 4.20** New Azimuth shaft

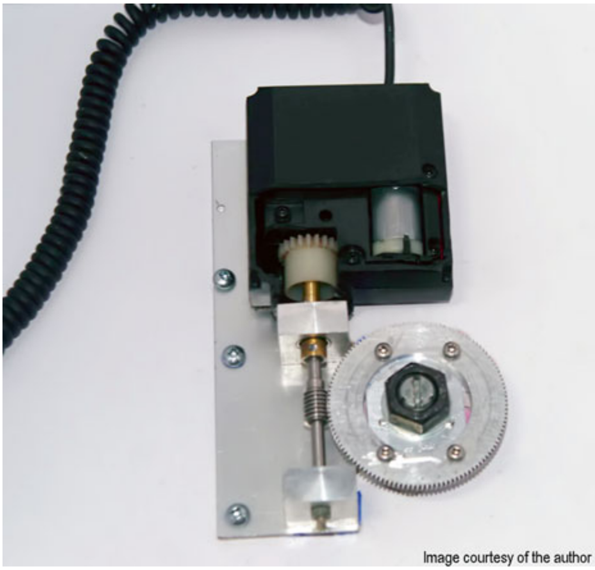


**Fig. 4.21** Azimuth motor system

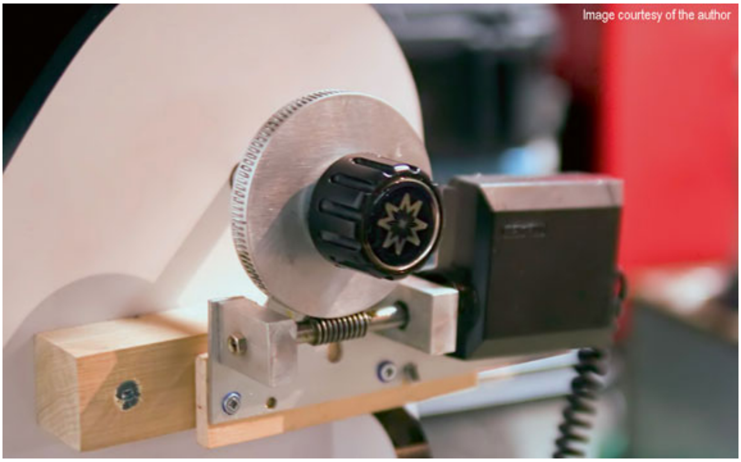


**Fig. 4.22** Altitude shaft with ring gear and worm motor system

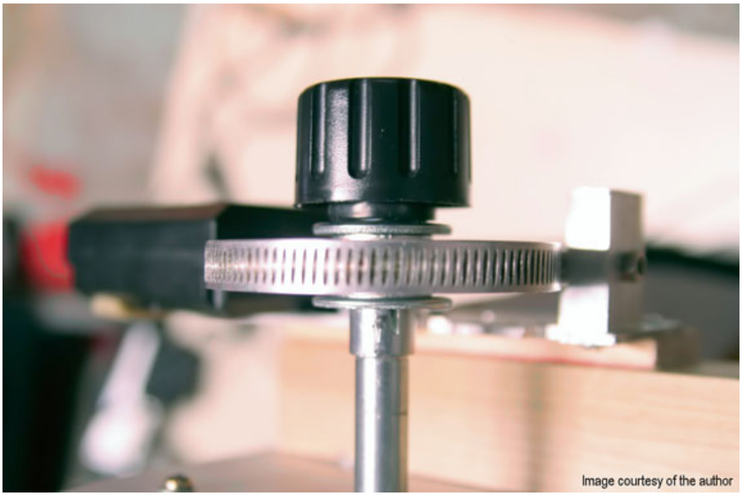


**Fig. 4.23** Closeup view of altitude ring gear

the balance for eyepieces or imaging equipment. The modified dob allowed me to image and track planets at approximately 6000 mm focal length and with minor inputs using the handset allowed minute positional corrections necessary to keep a planetary image centered on the small imaging camera's ccd (Figs. 4.24, 4.25, 4.26, and 4.27).

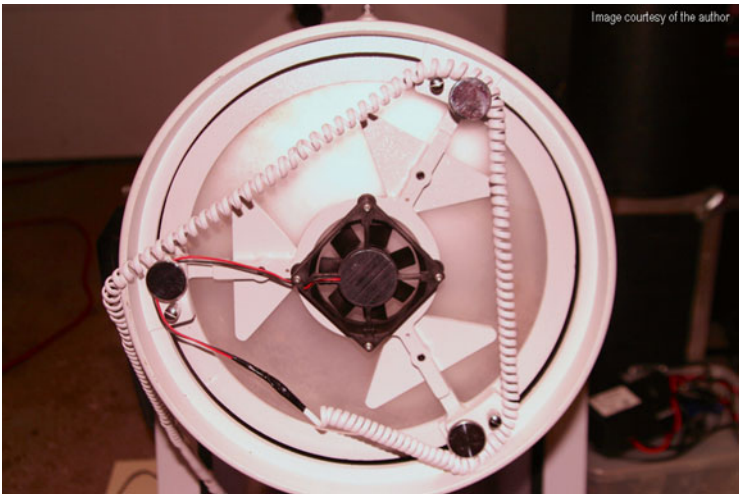


**Fig. 4.24** Cooling fan

Recently I picked up the optical components from an Orion 12″ conventional tube dob which prompted me to build what I term a *rat dob*. This is a concept carried over from my automotive endeavours where a rat rod is a modified car with such design purity that it favours function completely over form. Hence it is often minimalistic and unfinished in appearance. In fact it is sometimes intentionally ugly to further delineate its execution from those who are all show but no go. I couldn't bring myself to make an ugly telescope but my goal was to make one as simple as possible (Fig. 4.28a, b).

The inspiration to build this particular dob was in part to salute the achievements of a neighbor of mine, Major Jim Benton of the RCAF (Royal Canadian Air Force). During the Second World War, he flew Sunderland aircraft as part of Great Britain's Coastal Command, rescuing downed aviators in the English Channel and attacking German U-Boats. When I met Major Jim he had great difficulty walking and got around on a motorized scooter. As he had never seen any of the planets through a telescope before, I was determined to build a lightweight dob that I could roll over to his house and have him view through in a sitting position. The season happened to be just right to view a setting Jupiter in the early evening and a man who had done more things than most could ever dream of got his first opportunity to look through a telescope.

Instead of a tube or truss system to support the secondary and focuser, a single pole is used. Instead of three or four vanes, only one curved spider vane is used. Instead of two altitude bearings, one is deleted and replaced with a simple pivot joint. The mirror box is made very low profile and despite the appearance of a manual push-to dob, there is a hidden motor drive system with some go under the


**Fig. 4.25** Changing ratios in Autostar menu

hood. Lastly, old and recycled materials are used. The plywood was liberated from the dumpster bin of one of my neighbours who was undergoing a major home renovation.

The computer fan was fastened to the back of the mirror cell and the cell itself rides on springs centered by machine bolts. These three bolts run through brass bushings attached to the wooden structure and secured by wingnuts. This permits the mirror cell to be precision tilted during collimation (Fig. 4.29a, b).

The Alt bearing is a partial circular arc cut from plywood that runs on three bearings recycled from a recent overhaul of an EQ6 mount. My original design involved attaching a flexible nylon rack on the circumference of the Alt bearing (seen in blue

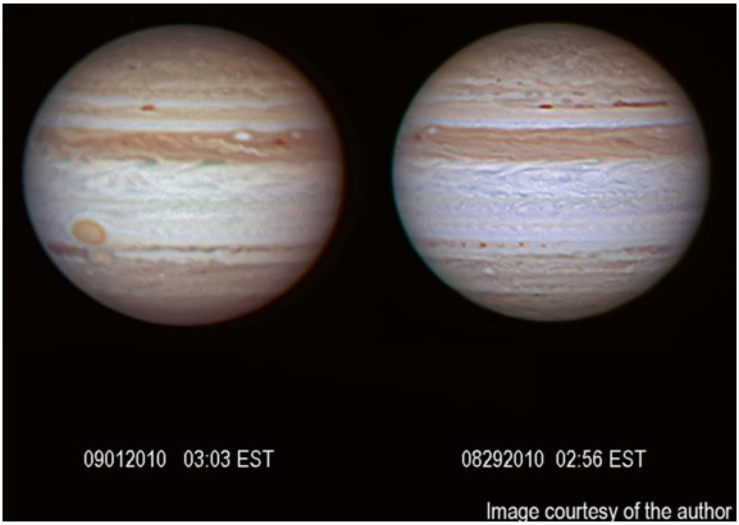


**Fig. 4.26** High resolution Jupiter images obtained from motorized dob

in Fig. 4.31) and driving it directly with a worm or gear. That didn't work out because I also wanted to hide all the motors in the bottom of the dob. Instead I have the Alt motor drive a threaded rod which when spun drives a piece of aluminum up and down its length. In turn, this piece of aluminum is eccentrically attached to the sole dob altitude bearing via a pivot and can push or pull the bearing along its arc.

The Az drive system is more standard. The mirror is protected with a cut down plastic cake cover and the single pole is from a retired patio umbrella. A 12VDC lead acid gel battery powers the unit and a light shroud was cut from a piece of aluminum dryer exhaust ducting (Figs. 4.30a–d, 4.31, and 4.32).

I give you the Mod Dob Job meets the Rat Dob.

## No Requiem for a Classical Cassegrain

My planetary imaging telescope of choice has been a 12″ Skywatcher f/5 collapsible Newtonian mounted on a Skywatcher EQ6 but I've always disliked its weight and the need to stand precariously on a chair to view through the finderscope. Being budget minded, I planned to convert the Newtonian into a Classical Cassegrain reflector. This scope design was invented in 1672 by Laurent Cassegrain, a French Catholic priest who also taught high school science. It uses a primary parabolic mirror and a hyperbolic convex secondary mirror with the image forming behind the primary mirror. The funny thing is that I don't think he ever made one because it's quite difficult to grind the correct shape of the secondary and the technology


**Fig. 4.27** Final modified dob configuration

was not available until the twentieth century to bench test its figure. This would allow me to reuse the parabolic primary mirror and tube structure while having a compatible hyperbolic convex secondary fabricated. Instead of drilling a central perforation through the primary mirror, I would redirect the image to an eyepiece with a diagonal flat secured to the primary center with adhesive (Fig. 4.33).

Not many opticians are willing to make classical cassegrain secondaries because it is a relatively difficult process. Robert Royce provides this service not for amateur astronomers but for the military and scientific community and he would not attempt to match an existing primary but only produce complete sets. Mike Lockwood was willing to work with my primary mirror but expected that it would need some refiguring, a 7–8 month gestation and a $5000 bill.

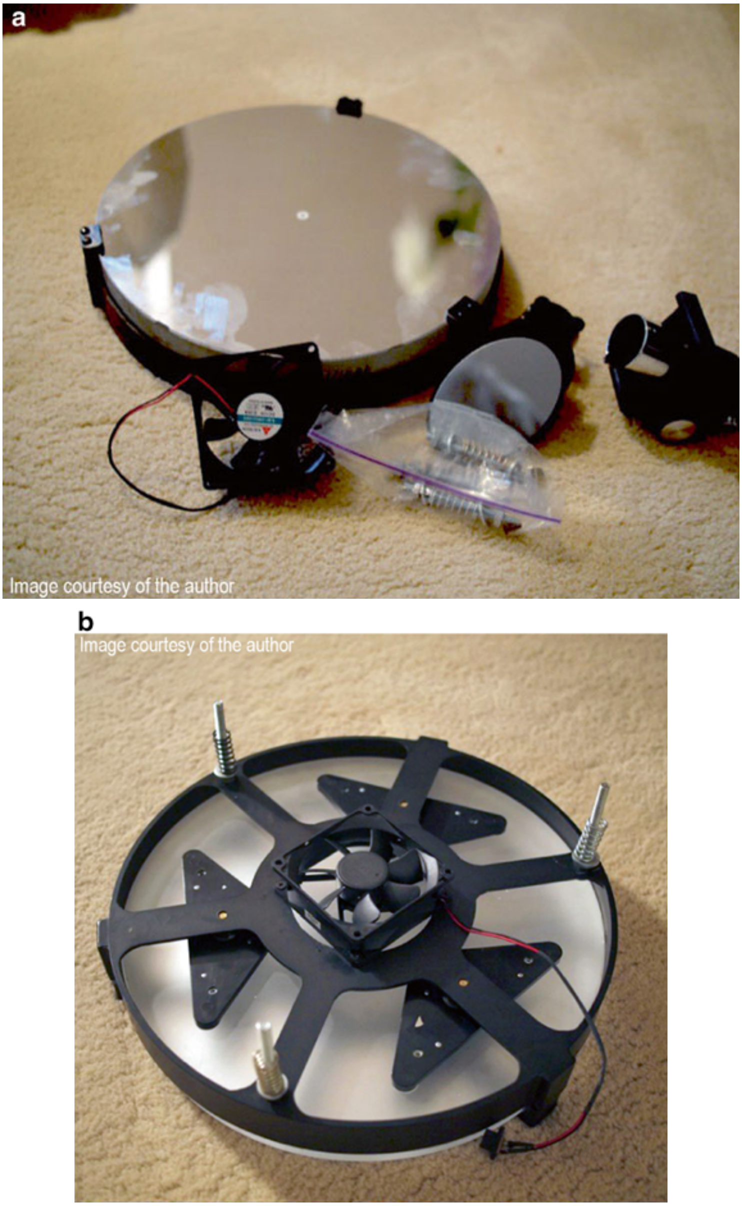


**Fig. 4.28** Optics from a 12″ Orion f/5 full tube dob

Just when all seemed lost, I had a chance meeting with a scope nearly as old as myself. A 12″ f/13 classical cassegrain and its 24″ big brother were installed in 1968 at York University, located in the northern end of Toronto. The scopes were made by *Competition Associates* of Cambridge, Massachusetts—a company that started life as a tuner garage for fast, high end sports cars owned by well heeled

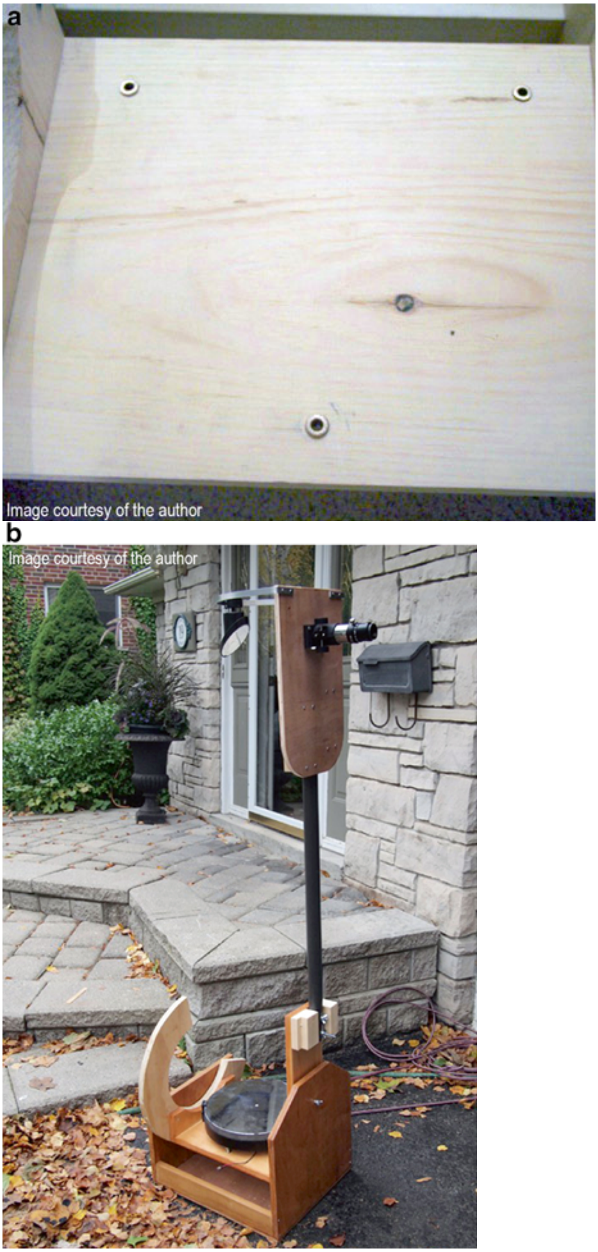


**Fig. 4.29** Mirror box with brass bushings, finished dob


**Fig. 4.30** Motor drive system hidden under mirror box

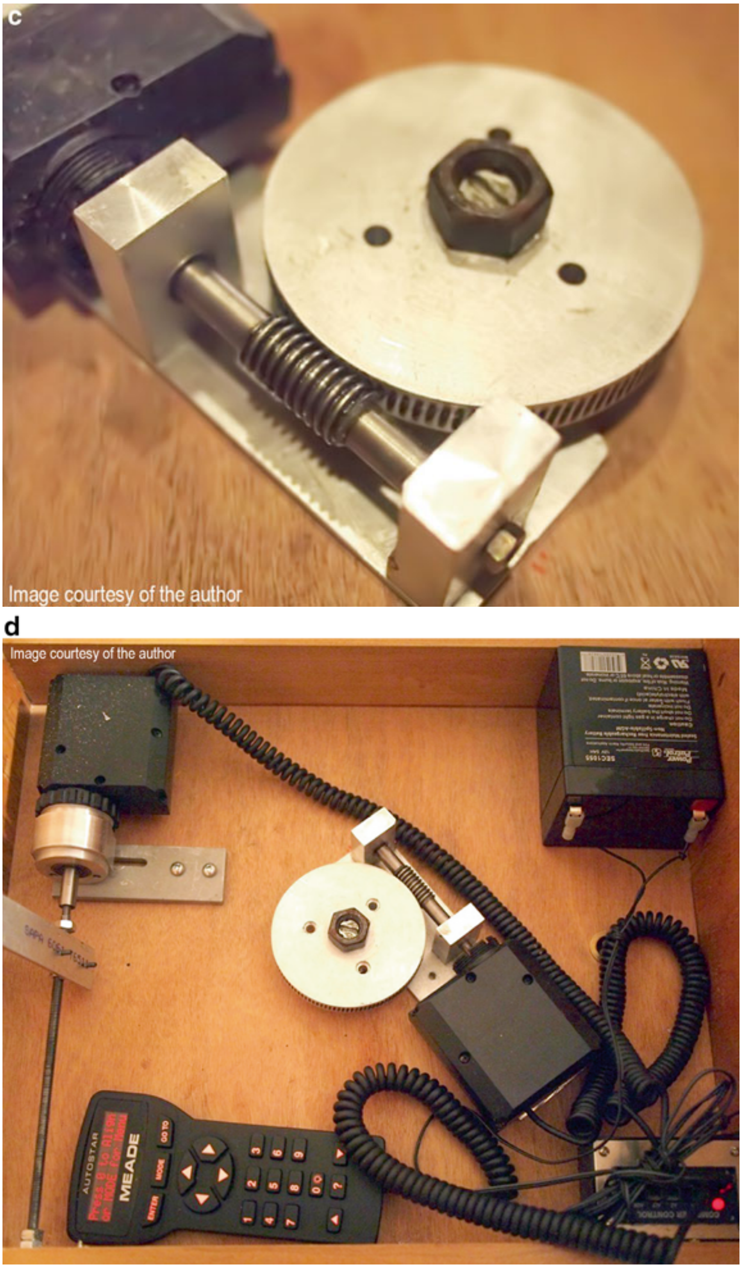


**Fig. 4.30** (continued)


**Fig. 4.31** Cake lid covering mirror. Secondary mirror diagonal suspended on a single curved spider made from hand bent aluminum bar

Harvard university students. The owner of the company had contacts with the Smithsonian Institute in Washington, D.C. and built them a fork mounted camera platform. A telescope subsidiary was subsequently born. Ealing Corporation, a large UK firm with a long history of microscope making bought out Competition Associates in the same year and this line of reflectors became widely known as the Ealing Educator/Research series with aperture sizes ranging from 8″ to 24″. Ealing promoted the 8″ scope as a breakthrough in pricing at just under $3000, or the average price of a new car in 1970. The scopes featured optics made by *The Optical Craftsmen*, a custom fiberglass tube and a massive cast iron mount with *Byers* gears and *Timkin* tapered roller bearings driven by synchronous AC motors. Dick Nelson, founder of *The Optical Craftsmen*, revealed in a 1997 interview shortly before his death that his optics were consistently figured to a value of 1/20th wave and that he ground optics for institutional telescopes up to a maximum aperture of 24 in. The scope saw faithful service despite being abused by undergraduate students dropping wrenches into the scope and was replaced in the summer of 1999 by the current 16″ Meade SCT. The complete system was donated to a small club and for the next decade remnants of only the OTA circulated amongst amateur astronomers and was even acquired as seized property in lieu of payment, until they found me.


**Fig. 4.32** Light shroud, necessary for urban use

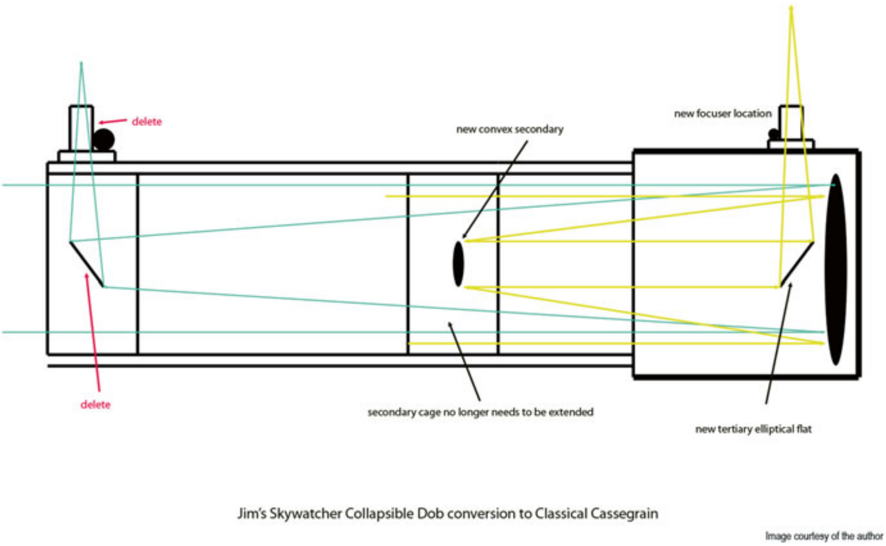


**Fig. 4.33** Converting my 12″ SkyWatcher Newtonian to a 12″ Classical Cassegrain


**Fig. 4.34** Horace Dall's folding cassegrain reflector, the ultimate expression of elegant minimalism

Open design reflectors offer advantages in cool down time and weight reduction and the minimalism is personally appealing. I was pleasantly surprised to discover that such designs are hardly new. Horace Dall was a British optician who in 1932 formulated a modified cassegrain design using a primary aspherized paraboloid and a spherical secondary (which is much easier to make). Alan Kirkham of Oregon also independently arrived at the same design a few years later, hence the Dall-Kirkham cassegrain variant which are commercially found in the Takahashi Mewlon line of reflectors. In 1947, Dall built a clever folding 3.5″ D-K reflector that could be placed in a vest pocket and we've only been emulating the master ever since (Fig. 4.34).

The optics and their respective mirror cells were in fine condition and the only salvageable items. The specifications of the optical set were hand engraved on the back of the secondary including the important separating distance between the faces of the primary and the secondary. The primary mirror cell was mounted between a two sheets of ¼″ thick and 18″ diameter aluminum which had been custom cut with ventilation holes at *AC Waterjet*, a Toronto company that specializes in precision computerized high pressure water stream (with abrasive particles) cutting of all manner of materials and thicknesses. I suspect my project was one of their easier jobs. The baffle tube is very important in cassegrain designs because unlike in a Newtonian, the eyepiece is directly in the path of incoming light rays, which can wash out the image unless they can be blocked. Traditionally the baffle tube is attached to the mirror and cell and they move as one but this can put stress on the mirror, which can distort its figure or worse cause physical damage! (Figs. 4.35, 4.36, and 4.37).


**Fig. 4.35** Independent baffle tube mounting


**Fig. 4.36** Baffle tube components from plastic plumbing pipes

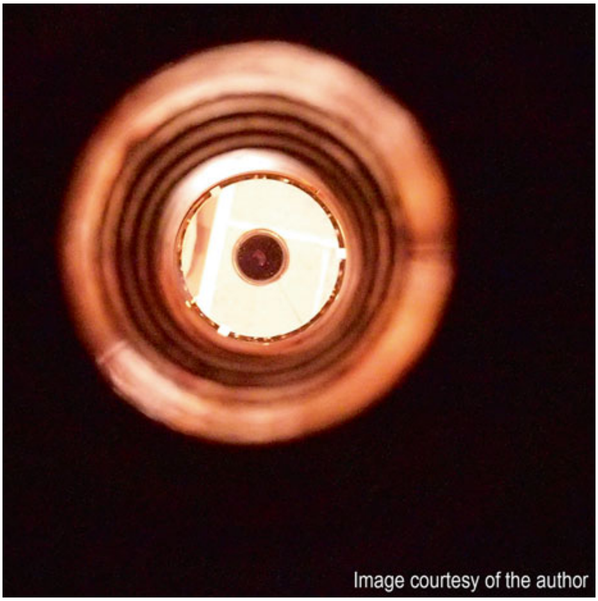


**Fig. 4.37** Looking through the baffle tube at the reflection of the 1° mirror in the 2°

The length of the baffle tube and the diameter openings of the individual baffles can be determined by drawing a scale diagram. Or using these formulas and a spreadsheet.

$$\text{Baffle Tube Length} = (WB + Wb - cd \quad iB) / (c - i)$$

$$\text{Baffle diameter} = (Bi + Zi + cb - cZ) / (B = b)$$

Where W = baffle tube internal diameter, B = 1° and 2° mirror separation, b = back focus distance behind the 1°, i is the final image size (13 mm), c is the 2° diameter and Z is the distance behind the 1°.

The central baffle tube was constructed of 2″ diameter ABS plastic plumbing components and thin aluminum sheet baffles cut with hole saws. The baffle tube itself was mounted independent of the primary mirror so that it would not impose any strain on the glass and could be collimated on its own (Fig. 4.38).

An 18″ diameter plywood ring suspended the secondary cell via a used vintage Novak 14″ four vane spider and a long ¼ × 20 bolt so that the position of the secondary relative to the primary could be varied. While it's certainly possibly to scale up the single arm suspended secondary in Dall's original design, I was concerned about rigidity, bulk and weight. My secondary cage was attached to the primary cage by three 1.3″ diameter hollow carbon fiber poles (eBay surplus remnants) with

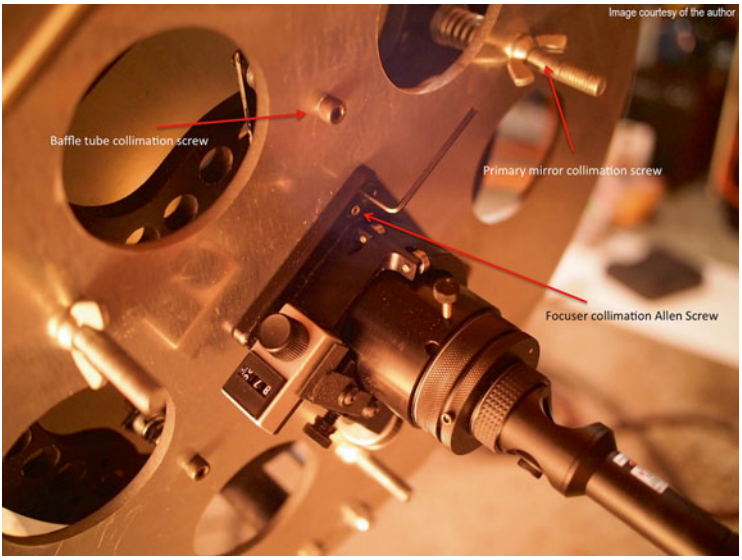


**Fig. 4.38** Rear detail showing multiple sets of adjustment screws for collimation purposes

an internal bore of $1^{1/8}$ in. riding on six 4″ by $1^{1/8}$ in. solid aluminum tubes. About 100 µm of metal had to be removed from the aluminum tubes before the carbon fiber poles would slide over them in a fit that was airtight. The poles were secured to the aluminum tubes with quick release mountain bike seat post clamps. The focuser is a vintage *JMI* NGF crayford with an analog DRO, flat surfaced mounting flange and important collimating Allen bolts. A Telrad and 9×50 right angle finderscope with an illuminated *Surplus Shed* etched glass reticle complete the package (Figs. 4.39a–c and 4.40).

The collimation process appears initially daunting given all the adjustable regions of the scope but it's simply a matter of making all the optical surfaces square with each other. The spider vanes were adjusted until the secondary was centered with the focuser. A 2″ Hotech laser collimator was inserted in the focuser and it was adjusted until the beam hit the center of the secondary. The secondary was adjusted until the return beam hit the Hotech's scribed crosshair markings. The focuser and secondary are collimated. A 2″ Howie Glatter holographic laser collimator was inserted into the focuser and its red grid pattern thrown up onto a projector screen. The fainter grid pattern reflected off the secondary and onto primary is shown superimposed on the brighter grid pattern emanating directly from the focuser. The primary is adjusted and collimated to the secondary when the two grid patterns are properly centered (Figs. 4.41, 4.42, and 4.43a, b).

Of course, absolute collimation confirmation is best performed on a star. I find it much easier to use one of my planetary imaging cameras and a 2× Barlow and slightly defocus the star. The overlaid reticle pattern makes it very easy to determine when all the concentric rings are correctly centered (Fig. 4.44).

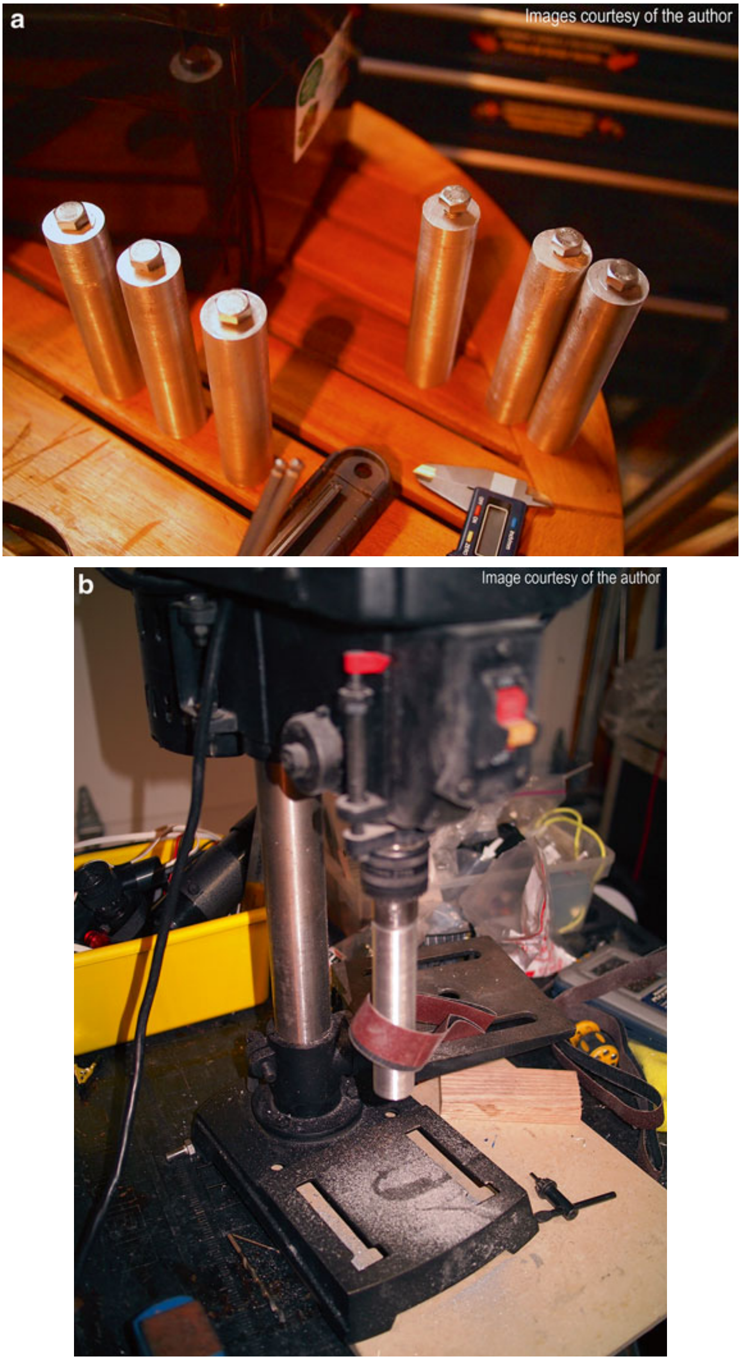


**Fig. 4.39** Preparation of aluminum tubes to retain carbon fiber poles

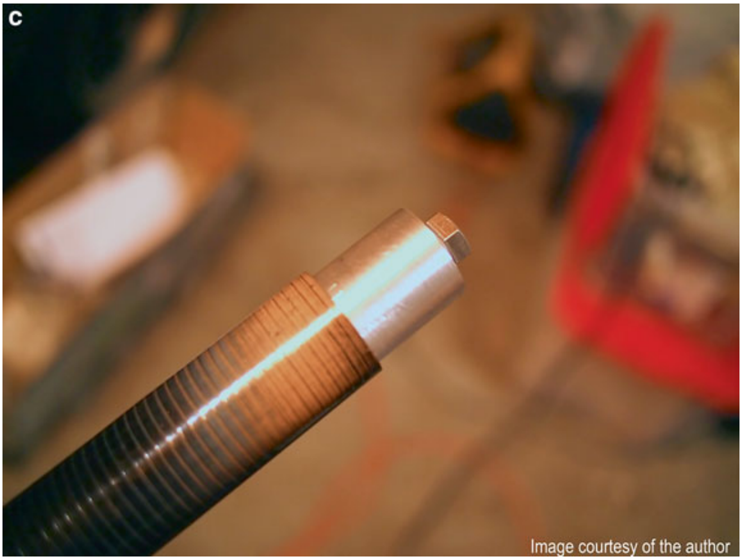


**Fig. 4.39** (continued)

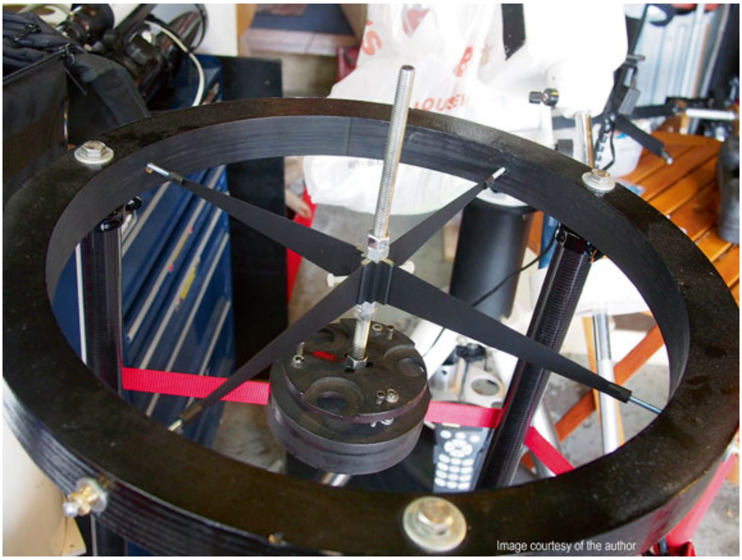


**Fig. 4.40** Secondary plywood cage with a vintage four vane 14″ Novak spider

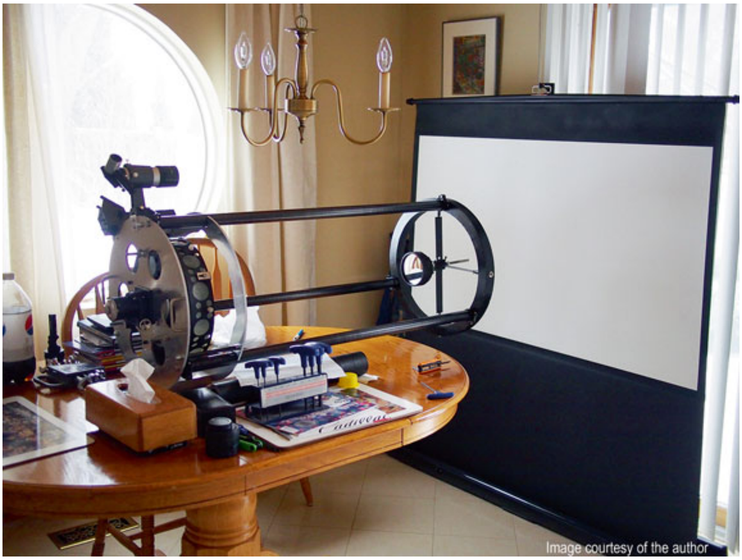


**Fig. 4.41** Indoor collimation of cassegrain reflector

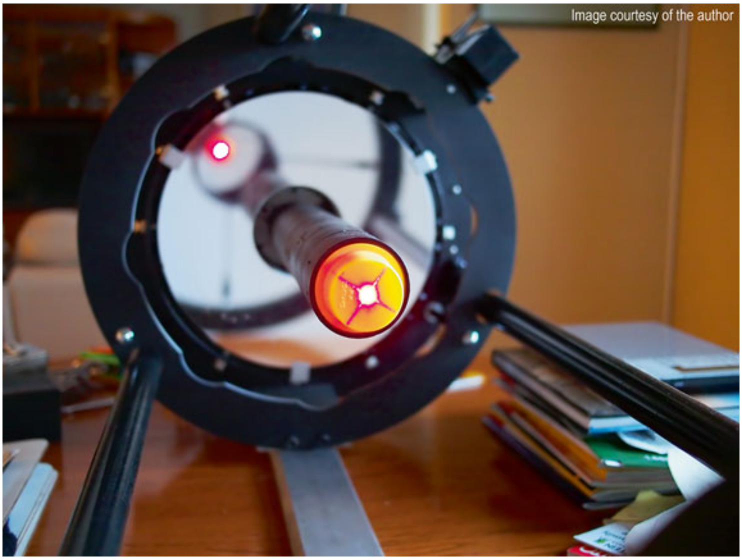


**Fig. 4.42** Collimation of baffle tube

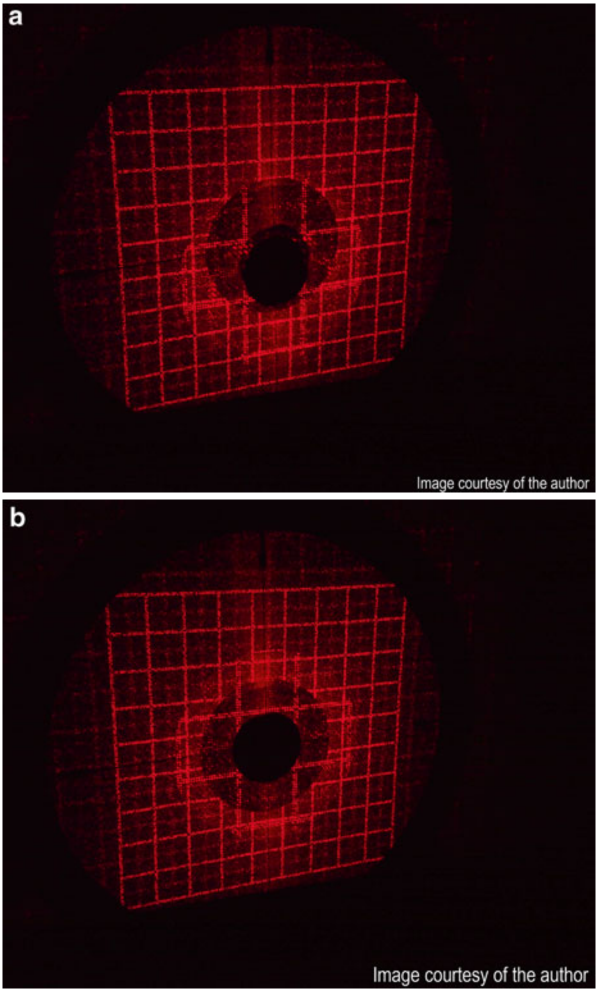


**Fig. 4.43** Use of Howie Glatter holographic laser collimator to align 1° mirror to 2° mirror

Weather has not been the most cooperative and by the time I could test the planetary performance of the scope, only Mars and Saturn were in the evening sky, both low and small! The scope is significantly lighter than the Newtonian it is replacing and I no longer need to double stack barlows to achieve f/20 to f/30 focal lengths which is sure to improve image quality. More importantly, the legacy of an important optical instrument has been preserved and valuable resources have been recycled (Figs. 4.45 and 4.46).

My concluding anecdote is surely an example of the unpredictability of life. I had both the 8.5″ folded refractor and 12″ cassegrain in the back of my station wagon/estate car facing forwards with the rear seat folded flat for extra cargo space.

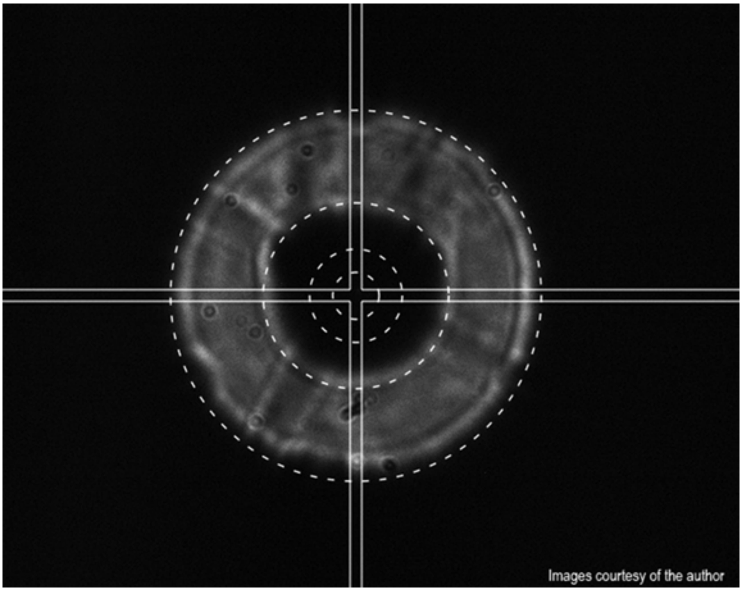


**Fig. 4.44** Startest with ccd camera


**Fig. 4.45** Final cassegrain in action

Heading home from a local ATM meeting, I was stopped at a traffic light pointing due west. It was an early spring evening and the setting Sun was blinding me. Looking away across the front passenger seat I noticed a plume of smoke rising from behind it. Fearing an electrical fire, I quickly looked behind the passenger seat

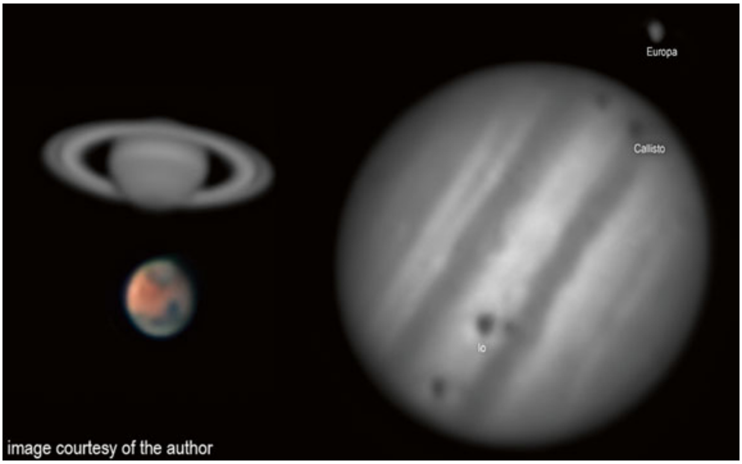


**Fig. 4.46** Saturn, Mars and Jupiter imaged at f/26 with PGR Flea3


**Fig. 4.47** The most improbable telescope accident in history!

and observed a small circle of intensely bright smoldering leather. I must have slept well the night before because I instantly deduced that the 1° cassegrain mirror had caught the low sunlight and happened to be optimally positioned to focus it on the back of the car seat. Even if I tried to duplicate this random chain of events, I would never be able to replicate this outcome, such is life! (Fig. 4.47).

## Garage Sale Finds

It has always been a cosmic mystery to me as to why garage sales attract so much interest. Rarely is there anything of quality worth purchasing as it's mainly accumulated cheap junk being jettisoned to make room for the new incoming cheap junk. I do make an exception for telescopes because I was looking for one kind in particular and the typical family telescope heirloom is one that was bought decades ago, used a few times until interest flagged and then forgotten in a dusty spider infested corner until garage sale time came around. I'm not talking about the really poor quality department store telescopes that exist today, I'm talking about the golden age of telescopes from the late 1950s through to the early 1970s when Unitron's long focal length achromatic refractors and mounts were as revered as much as Astro-Physics compact apochromatic refractors and mounts are regarded today. Back then, even department store brands like Sears and Bushnell were high quality Japanese made optical instruments that could deliver views as good as modern telescopes. But this was a sentiment that I had to confirm for myself as I began stalking the weekend garage sale scene. They were also not cheap, costing about $400, which in today's money is about $2500.

The Japanese optical industry in the late 1950s was very diverse and made of hundreds of small family run companies making binoculars, eyepieces and telescopes for export. Every product was scrupulously inspected to ensure export quality by the government body, the Japanese Telescope Inspection Institute (JTII). As time progressed, many of these companies would be bought out and merged or vanish from attrition until the few companies that we are familiar with today emerged. American companies would tender specifications for a refractor and one of these small Japanese companies would win the bid and fill the contract. Subsequently telescopes marketed in the US under names such as Sears, Bushnell, Mayflower, Royal Astro, ATCO, LaFayette, Jason, Tasco, Monolux, Swift, Shine Manon but to name a few could be made by different Japanese companies depending on the model in question. The most common telescope manufacturing companies were Hitomi Optical Machine Co (HOC), Hino Optical (H.O.C.), APL, SYM, Towa (Circle T), Kenko, A^V^A, Carton (C.O.C), Mizar (Circle M) and Southern Precision Instruments (SPI).

The dirt encrusted wooden box measuring about 1 ft by 4 ft was deceptively promising. Scopes of this period were traditionally packaged with a mount and accessories in a dovetailed box made of 3/8″ thick Philippine mahogany and often manufactured by a Chinese company called Yashio Purai Wood. The interior could have compartments with green felt lined plywood dividers or molded Styrofoam inserts. The seller was about a decade younger than I and said it was an ATCO telescope from the 1960s which had belonged to his Dad. The telescope was dirty but appeared complete. A deal was made (Fig. 4.48).

The scope was an 80 mm f/15 achromat with a noncollimatable lens cell which appeared in fine condition. It was painted with a silver grey hammertone finish with dark grey accents and of all metal construction. The dew cap was badly dented, the

**Fig. 4.48** ATCO 80 mm f/15 refractor see first light in a very, very long time

finder scope bracket was missing both a screw and a thumbscrew and the mount spreader and tripod brackets were rusty. ATCO (American Thermo Ware Company) was registered in 1960 and disappeared in 2001 and they imported and distributed laboratory related optical instruments and glassware. On the ATCO label, the small symbol APL appears in the lower left corner. APL is the Japanese optical company which made this telescope and stands for either Apollo Labs or Apollo Business and Industry. They were subsequently bought out by another company called Koyu and then ultimately became a part of Vixen Optics. Similarly Mizar became part of Meade and A$^{v}$A which made Swift branded telescopes became Takahashi. The gold JTII label with green lettering means this scope belongs to the period between 1966 and 1972 (Fig. 4.49a, b).

I have seen other ATCO refractor models with the traditional white tube motif so I felt justified in changing the color scheme. The dew cap dent was addressed by forcing a can of ground coffee through it to recover its original circular shape. The mount was disassembled and each piece individually repainted as well as the removal of old and hardened cosmoline lubricating grease. Cosmoline is a US military packing grease dating from the Second World War used to prevent rust from forming on stored weapons. When the volatile components evaporate off with time, it leaves a hard waxy residue that is both sticky and nonlubricating. This was replaced with Super Lube which is a modern synthetic lubricant containing a suspension of Teflon particles. Rust was removed from the tripod legs and the wood was refinished with a stained polyurethane and the nails holding the metal brackets replaced with brass wood screws (Figs. 4.50, 4.51, 4.52, and 4.53).

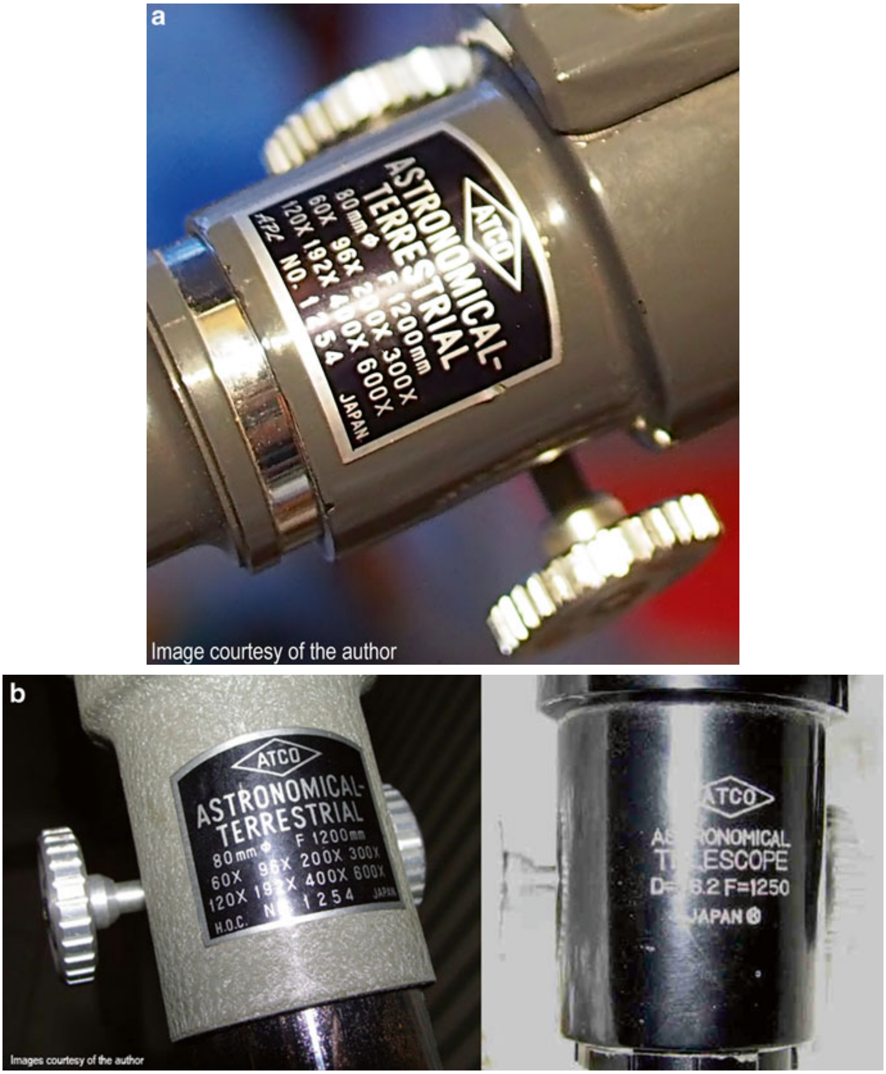


**Fig. 4.49** ATCO telescope label. Earlier examples of the same Atco Model 1254 showing variations due to sourcing from different Japanese manufacturers. Likely 1961 model made by H.O.C. (*left*) and perhaps mid 1960s model made by Circle K (*right*). There is considerable confusion as to what company holds this maker's mark as records from this period are sparse. Circle K likely represents Koyu or Kenko but could also be Pentax and King Optical. Minor changes in appearance and both tubes were white

The original 0.965″ visual end is unusual because it causing vignetting of the much larger diameter focuser barrel. Vixen (SKU #3720) makes a 1.25″ adaptor that threads into the 36.4 mm focuser barrel and allows use of modern eyepieces. I cleaned the wood box and replaced the missing handle with a generic guitar case


**Fig. 4.50** Dented dew cap being restored with perfect fit can of ground coffee

handle which fit perfectly, right down to the spacing of the screw holes! Here is a product that has been in continuous production for likely more than 70 years and not changed at all! (Figs. 4.54, 4.55, and 4.56).

Since the mount lacks the facility for a polar scope, I removed the screw on front inspection cap and fabricated an adaptor to hold a green laser securely. This allowed accurate alignment with Polaris which made planetary tracking under high magnification observing possible with the manual controls. I decided to go one step further and adapt a contemporary Celestron stepper motor drive unit with a swinging attachment to engage a gear on the RA shaft. Several members of our local club gathered to observe Saturn at about 200× magnification and we all concluded that this 60 year old 80 mm refractor outperformed a modern Celestron 8″ SCT, the views were decidedly sharper with more contrast (Figs. 4.57 and 4.58).

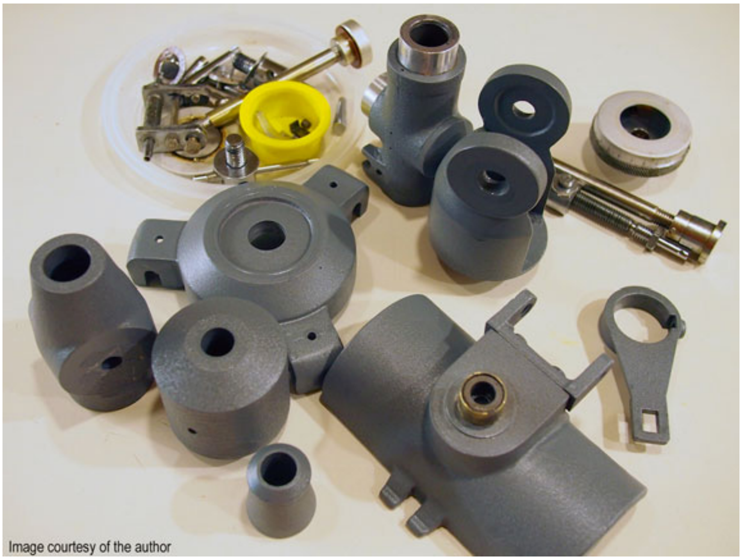


**Fig. 4.51** Mount in pieces and painted, best reassembled as soon as the paint dries before the memory fades


**Fig. 4.52** The completed mount is a high quality equatorial mount, much better than current EQ3 examples


**Fig. 4.53** Finished scope, mount and tripod

## Electroplating in Your Kitchen

Electroplating doesn't seem to have anything to do with making telescopes but as we have seen in the preceding sections, telescope restoration is a pervasive activity for the amateur telescope maker, especially here in the Great White North. Telescopes that have been left outside under the protection of the excellent *Telegizmos 365* series covers still manifest corrosion, especially with fasteners that are unique and often not replaceable.

My Celestron CGE mount developed some corrosion around the large bolts that hold the mini pier to the mount and to the pier adaptor plate. The bolts look to have


**Fig. 4.54** Modern Vixen 1.25″ visual back

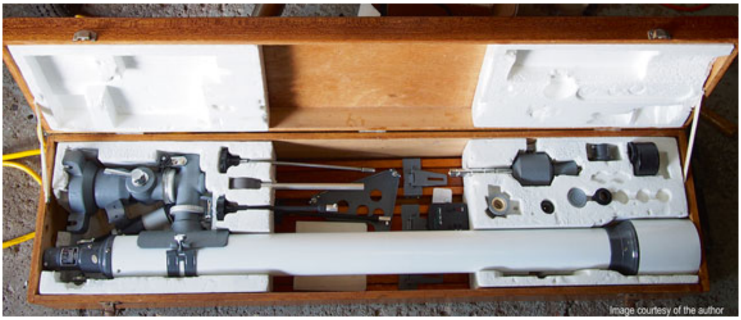


**Fig. 4.55** Restored box

been originally anodized black. Rather than try to abrade off the rust with steel wool, I decided to try electrolytically removing the rust. Rust comes in two forms, the red flaky outer layer of ferric oxide ($Fe_2O_3$) and an inner layer of hard dark black iron oxide also known as magnetite. It's actually a mixture or FeO and $Fe_2O_3$ but the lattices are so intertwined that they cannot be separated. Applying a DC current with the rusty bolt at the cathode will reduce the iron oxides back to iron;

$$2FeO \bullet Fe_2O_3 + 4e^- \rightarrow 2Fe + O_2\uparrow + 2Fe_2O_3$$


**Fig. 4.56** New guitar case handle


**Fig. 4.57** Hotech green laser aligning ATCO mount with Polaris

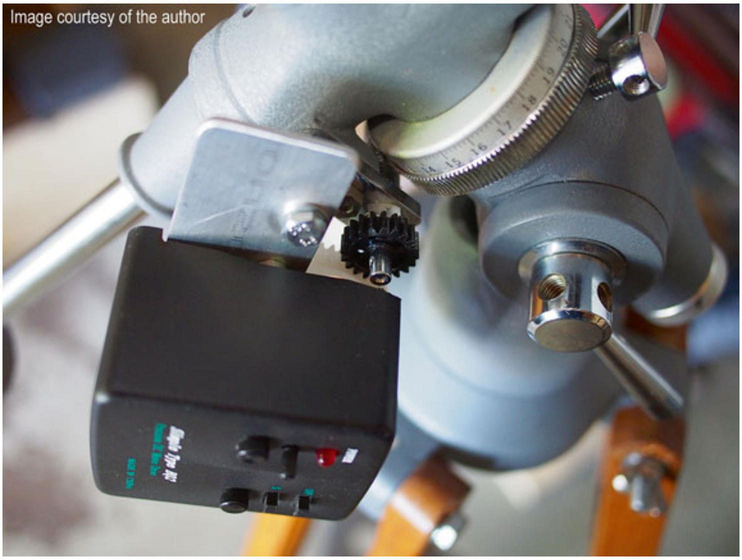


**Fig. 4.58** Modern stepper motor drive adapted to work on ATCO mount

The production of gaseous oxygen helps separate the loose ferric oxides produced and already present and they rise to the surface of the solution to form an ugly brown froth. At the anode an iron source is needed to liberate the electrons and iron oxides formed on the electrode surface, I used a large nail. The supporting aqueous solution is typically a 10 % solution of sodium carbonate or washing soda. If this is not available, baking soda (sodium bicarbonate) can be decomposed by 200 °C heat in an oven for an hour to produce sodium carbonate.

$$2NaHCO_3 + \text{heat} \rightarrow Na_2CO_3 + H_2O\uparrow + CO_2\uparrow$$

A 12 V car battery can be the source of power, I used a Pyramid 20 amp 13.8 V power supply. It only takes a few minutes and a quick wipe to restore the original finish to the CGE bolt (Fig. 4.59).

At this point the bolt is still very prone to corrosion and the second step is to electroplate it with a layer of nickel. A solution of nickel acetate is prepared by immersing pure nickel into a solution of acetic acid. White vinegar is very nearly pure but dilute acetic acid (5 % solution) and pure nickel can be purchased as bars on eBay. In this instance being Canadian is fortuitous because the Canadian Mint maintains a very high level of metal purity in its coinage. Dimes and quarters from 1969 to 1999 are 99.9 % nickel while most pre-1981 five cent pieces are also 99.9 % nickel.

$$Ni + 2CH_3COOH \rightarrow C_4H_6NiO_4 + H_2\uparrow$$

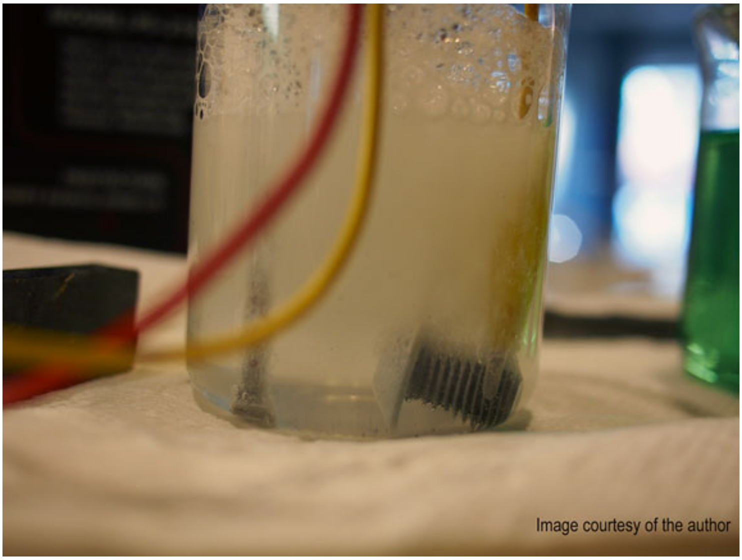


**Fig. 4.59** Electrolytic rust removal of CGE bolt

This reaction is normally very slow at room temperature so to accelerate it I add a pinch of salt to improve conductivity of the vinegar and apply a high current voltage to two immersed nickel electrodes with the Pyramid power supply. This will cause the anode electrode to dissolve more Ni into solution than will form at the cathode since the anode is usually more efficient and a pale green solution will form indicative of nickel acetate. Be aware that this solution is classified as carcinogenic. The solution will get quite hot so you may have to run it in bursts to allow it to cool down in between and be aware of the explosive potential of the hydrogen gas being produced (Figs. 4.60, 4.61, and 4.62).

Once the solution is formed, simply swap out the cathode nickel electrode for the CGE bolt but change the power source to a smaller voltage, I use two AA batteries. It takes a few minutes but the smaller voltage results in a smoother deposition of nickel onto the CGE bolt (Figs. 4.63 and 4.64).

Afternote:
In Chap. 1 we dealt with chloroform and dichloromethane, agents as strongly carcinogenic as nickel acetate. As a chemistry major who worked in a variety of labs for summer employment, I was well acquainted with the proper safe handling of carcinogenic, radioactive and just outright lethally poisonous reagents. Which is why I was little dumbfounded to discover that light pollution is also a likely carcinogen.

Light pollution is the universal scourge to all modern astronomers, amateur and professional alike. In 1935, the University of Toronto opened the David Dunlap Observatory featuring its 76″ mirror poured from the same batch of *Pyrex* used by

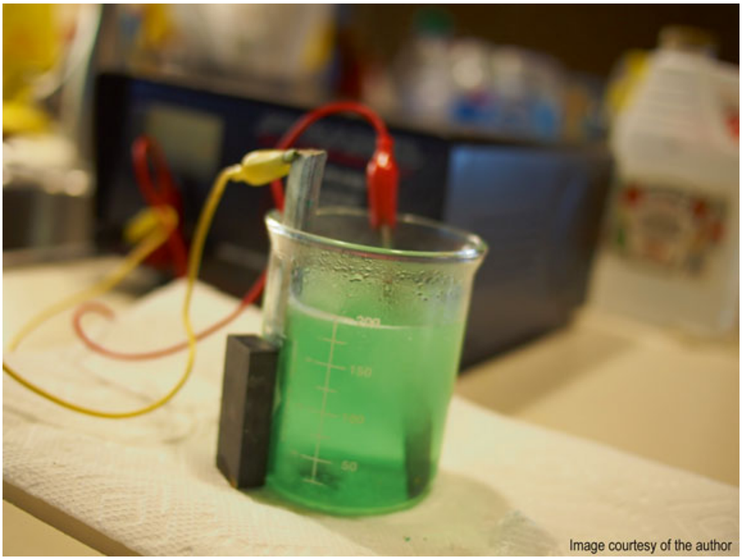


**Fig. 4.60** Making a nickel acetate solution. A magnet is used to keep one of the nickel electrodes captive to prevent it touching the other electrode

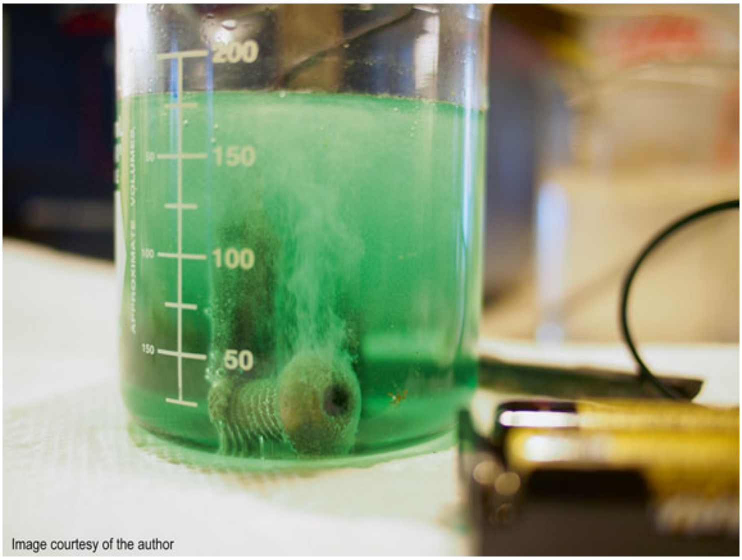


**Fig. 4.61** Nickel plating the CGE bolt


**Fig. 4.62** Nickel plating a Canadian one dollar coin. The original appearance of the *Loonie* is shown in the *lower image*


**Fig. 4.63** Rusty CGE bolt, Rust removal of CGE bolt, Nickel plated CGE bolt

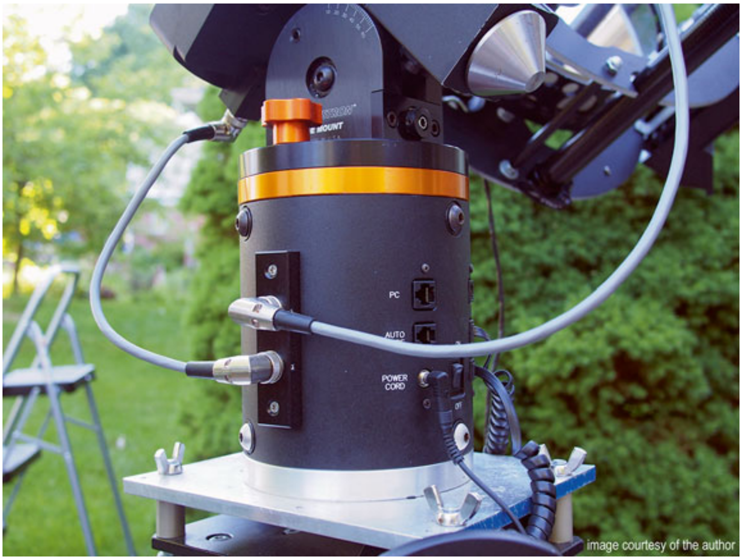


**Fig. 4.64** Restored CGE mount

Corning Glass Works to make the 200″ Hale mirror. It was located about 25 km north of the university, which is in the heart of downtown Toronto. After only 70 years, the University decided to sell the land, buildings and observatory to developers because the encroaching glow from the city had made it impossible to perform worthwhile science with the fully functioning telescope. Fortunately, the Toronto chapter of the RASC now operates, maintains and is continually restoring all the historic facilities and ancillary telescopes while hosting sold out open houses and talks on weekends.

The 2007 La Palma Declaration defined light pollution from the perspective of astronomers as:

A) Environmental pollution consisting of the excess of harmful or annoying light
B) Wasted light from city and outdoor lights that makes it hard to see the stars at night, and
C) Misdirected, unshielded, excessive and/or unnecessary night lighting aimed upwards or sideways, scattering light across the atmosphere, brightening the night sky, while diminishing the view of it.

Interestingly, in the same year the World Health Organization (WHO) during a meeting in Leon, France stated the shift work is a 2A risk factor for cancer in humans. If astronomers are verbose, then the doctors of the WHO are too succinct. What is left unsaid and implied is that the brightly lit environments of the shift worker, light pollution by any other name, are implicated as a cancer risk factor.

This was quite a revelation to me because we're not speaking about a correlative effect but a causative one. I was to learn further that the tentative biological definition of light pollution would read as "light emission from artificial sources given in the dark phase of the 24 h cycle which wavelength and/or intensity can suppress pineal gland melatonin production, disrupt rhythms and initiate a stress response".

Let's compare the levels of illumination in question. The Sun produces 100,000 lx while a full moon only 0.2 lx and an overcast moonless night 0.00005 lx. By comparison street light can range from 5 to 50 lx and interior home lighting 30 to 300 lx. But it's not just a matter of light intensity but the wavelength in question. The shift to energy saving fluorescent and led based lighting has emission peaks closer to blue rather than the red peak of incandescent lighting resulting in markedly deleterious effects on humans.

Most people are familiar with the existence of a biological clock or circadian rhythms in the body and when you travel quickly to a vastly different time zone this clock clashes with the environment resulting in the phenomenon of jet lag. The body exhibits regular daily variations in alertness, body temperature, heart rate, blood pressure, etc. controlled by the biological clock, which is genetic on the cellular level and hormonal on the organism level. The timing of these hormonal signals are crucial for the success of an organism, carnivores can't be active and hunting when their prey are sleeping and flowers can't be closed while pollinating bees are about. This clock calibrates itself daily at sunrise and at sunset and initiates seasonal adaptations brought on by longer dark phases.

The biological clock is located in the suprachiasmatic nuclei (SCN) of the hypothalamus (at the top of the brainstem) and comprises some 10,000 neurons. It receives its main input from the Retino-Hypothalamic Tract (RHT) but instead of relaying stimuli from the rods and cone cells of the retinal which utilize the protein/pigment rhodopsin, the RHT receives stimuli from nonimage forming photoreceptors (NIFP) on the retina containing the pigment melanopsin. NIFP have a peak response sensitivity to blue light in the 460–480 nm wavelength and the resultant stimulation of the SCN causes suppression of melatonin synthesis in the pineal gland (also in the brain). As will be shown later, melatonin has far reaching effects on the immune system, and antioxidant and antioncogenic properties. The blue sensitivity of NIFP means that led based lights cause 5× and 20× more melatonin production suppression than illumination from equivalent intensity high pressure sodium bulbs and orange low pressure sodium bulbs, respectively.

In addition, the exposure to light pollution or light at night (LAN) can cause a phase shift in the established cycle of a circadian rhythm like the variations of body temperature throughout the day. Exposing individuals to even a single bright pulse of light at the beginning of the dark phase (night) will cause a delayed phase shift of up to 4 h and exposure to light near the end of the dark phase will cause an advanced phase shift of similar magnitude. Again there is no clear understanding of the effects of delayed or accelerated timing of circadian activities like hormonal secretions but clearly timing and order must be of critical importance. While experiments of this nature are not possible in humans they have been extensively demonstrated with short day (SD) acclimated field voles, a pest rodent. Short days correspond to winter temperature conditions and long nights for breeding. LAN exposed voles resulted in reduced reproduction and ultimately death since they couldn't resist the low winter temperatures. The control group population tripled in size and maintained their cold acclimatization in the form of boosted metabolic rates. An important source of heat production in small mammals is nonshivering thermogenesis (NST) where heat produced by catabolism does not involve muscle contraction (shivering). Adrenalin is responsible for activating NST and its theorized that melatonin either increases the number or affinity of adrenalin receptors in brown adipose tissue (heat generating brown fat).

Melatonin (N-acetyl-methoxytryptamine) is a neurohormone produced and secreted by the pineal gland after dusk in humans and increases between 2:00 and 4:00 AM before subsiding and terminating about 3 h after sunrise. The amino acid tryptophan is the ultimate precursor in the synthesis pathway which leads first to serotonin and then a two step reaction to melatonin with catalyzing enzymes under the control of the SCN.

There are melatonin receptors on the surface of lymphocytes and increased melatonin results in increased total spleen lymphocyte counts and phagocytic (foreign body eating) action and a generalized stimulation of the immune system. Melatonin is also an antioxidant and in plants has the main role of scavenging free radicals produced during photosynthesis. Melatonin is also a direct antioncogenic agent for breast cancer and prostate cancer. For breast cancer it is believed that melatonin modifies cell surface estrogen receptors and increase methylation of DNA, that is the addition of methyl ($CH_3$) groups in exchange for hydrogens on select cytosine and guanine base sites which are important in the regulation of DNA transcription (that Biochemistry degree comes in handy!).

Mice inoculated with prostate cancer cells were divided under two different photoperiods, short and long days (SD and LD). Half of the SD mice experienced LAN for 30 min 7 h after lights out while half of LD mice were injected with melatonin and then drank water laced with melatonin during the dark phase. Predictably LD mice had significantly bigger tumors than SD mice since SD mice should have increased melatonin production. Melatonin introduced LD mice had tumor sizes similar to the SD group while LAN disturbed SD mice had tumors as large as those in the LD group also supporting the melatonin antioncogenic theory.

We can't perform experiments of this nature in humans so most of our studies here involve retrospective epidemiological surveys. Populations that would be most susceptible to higher cancer rates would be nighttime shift workers like hospital employees, bus drivers, cashiers, flight attendants, etc. Populations at low risk would be the blind, residents of extreme latitudes with long polar nights, long sleepers, people working in mines, residents of extreme rural areas or countries with limited access to electricity. A study involving 78,000 nurses with 2500 incidences of breast cancer found a moderate increase in breast cancer risk among those who worked night shifts and higher risks for those worked 30 or more years on night shift.

The highest cancer rates are found in developed countries and the lowest rates in Africa. GDP has a strong association with rates of breast and prostate cancer but high GDP is also associated with better quality medical care and better and earlier detection of cancer. Developing countries are also unlikely to maintain a good cancer registry since other needs are more urgent. But GDP is a good predictor of how extensive a nation's electrical network is, accessibility and the degree of a whole variety of light pollution. Indeed per capita electrical consumption as a measure of light pollution also correlates strongly with breast and prostate cancer rates.

So what does that mean to the amateur astronomer? Well being an amateur astronomer is likely not good for one's long term health because it disrupts the normal sleep cycle, and deprives us of the healthy levels of sleep for those with normal daytime employment. But all individuals need to heed the danger of light pollution, not the light pollution that is the bane of astronomers but the more insidious light pollution found in all modern homes of the twenty-first century: the computer monitor, the flatscreen tv, the led nightlights, the tablets and smart phones. All sources of short wavelength light pollution that are inadvertently left on all night long while we sleep, often in close proximity. Since this is a relatively new phenomenon it is unknown the extent of its effect on our health vis-à-vis LAN sleep. You might be sleeping and sleeping long hours but how is LAN disrupting your natural cycles through the melatonin pathway?

## Making a Sub 0.7 Å Hydrogen Alpha Solarscope

We've already encountered the supersized PST project and for the budget minded purists it fails in two regards. The final expenditure was probably in the neighborhood of $700 and it was more of a telescope modification rather than a fully fledged ATM project. So to completely address both points I offer the construction of a sub 0.7 Å Hα solarscope for under $300. This scope will resolve solar surface details with the contrast of a double stacked PST and again takes advantages of the incredible price savings available through our favorite surplus optics eBay seller, *Omega Optics*.

*Omega Optics* has a pair of filters for under $200 that are both Fabry-Pérot (FP) solid etalons with a nominal bandpass width of 1.5 Å or 0.15 nm and an original cost in excess of $1000 due to the need to deposit multiple interference coatings to obtain the incredibly narrow bandpass. One only needs to price the 3 nm wide narrowband imaging filters available from Astrodon to realize this is no idle boast. The thicker of the two filters is a laminated assembly 5 mm thick consisting of six independent filters. A glass substrate provides $10^3$–$10^6$ magnitude of attenuation from the deep UV to the far IR and functions as an energy rejection filter (ERF). A second pair of filters of the FP interference type produce $10^4$–$10^6$ magnitude attenuation from 500 to 1100 nm with a transmission window in the mid red spectrum. The final two filters are a pair of ultra narrow Hα filters centered at 656.3 nm and are actually fabrication rejects since their center wavelength (CWL) is just slightly longer than the Hα wavelength of 656.28 nm. The second thinner filter is cyan in transmission color and is a single narrowband etalon with a similar 0.15 nm bandpass width centered at 656.3 nm. Each filter alone would be capable of resolving prominences but not the granulation and filaments of the photosphere. But by carefully controlled tipping of the filters you can shift the CWL to exactly 656.28 nm and the overlapping interference pattern of two 0.15 nm bandpass filters in serial positioning will result in an even more narrow bandpass of 0.08 nm. This is in fact how Coronado and Lunt utilize their double stack systems to enhance the resolution from 0.07 to 0.05 nm. The front, double stacking 0.07 nm bandpass etalon, is tilted with respect to the standard 0.07 nm etalon to interact in tandem and allow the two etalons to overlap and deliver a final bandpass of 0.05 nm.

The most primitive filters rely on the absorbing properties of its substrate to control its transmission characteristics—think colored glass. The transition from low to high absorption is too gradual to allow sharply defined narrowband transmission profiles needed in solar applications. For this we need to rely on modern thin film interference filters where multiple layers of optical coatings with varying refractive indices are vacuum deposited and the reflections that occurs at the interface between layers produce waves of constructive or destructive interference—the end result determining the nature of the filter's bandpass. The optical layers consist of condensed metal films separated by a nonabsorbing dielectric spacer such as zinc oxide or cryolite with an effective thickness equal to one half of the desired transmission wavelength. Each layer in essence acts like an FP solid etalon. In applications like solar viewing the unwanted, reflected radiation is some $10^6$ more intense than the Hα transmission and requires severe attenuation of the unwanted wavelengths. Achieving this means the building of more than 20+ etalon cavities in series with as many as 100 layers achieving an optical density of $\gg$10 in the non bandpass regions and with a transmission profile that is more rectangular, steeper and more narrower than the typically triangular shaped FP pass band.

These square bandpass filters are sensitive to the angle of incidence like all dielectric interference filters. The angle of incidence is measured as the deviation from the normal or perpendicularity to the filter surface and the greater the angle, the greater a corresponding shift to a shorter CWL. The *Omega Optics* pair of filters uses this phenomenon because careful tilting on the order of 3°–5° will induce a CWL shift to exactly the Hα emission line.

The filters need to function in a slow environment greater than f/30 so that the light rays are approximately parallel to each other and the optical axis. This can be achieved with the use of 4× telecentric barlows but those marketed by TeleVue and Siebert don't specify what objective focal length is required to develop telecentricity. Only those manufactured by Baader specify that they must be used with an 800 mm focal length telescope. The safer route is to stop down an old style achromatic refractor and I used a Celestron 90 mm f/11 Astromaster stopped down to 40 mm aperture or about f/25. These are available new for under $200 and used for a quarter of that price. I had previously shortened the tube and installed a 2″ focuser for binoviewing applications so I was able to build a stand alone module to house the *Omega Optics* etalons and their custom made controlled tilting mechanism.


**Fig. 4.65** Omega Optics solid Fabry-Pérot etalons and custom polycarbonate housings

The filter housings were made from polycarbonate with the base rounded to conform to a piece of 2″ diameter black PVC plastic plumbing pipe. A rectangular opening was cut into the top half of the pipe to allow access to the filters. The filters had to be able to be tilted in two axes perpendicular to each other. The rotational or yaw axis was established by connecting the base of filter housings to the plastic pipe with nylon threaded bolt and wingnuts. The friction of the wingnut allowed small rotations to be implemented and held. The filter housing is a two piece flip design held together by an upper hinge and spring loaded so small changes to the pitch angle could be changed and held by a nylon locknut (Figs. 4.65 and 4.66).

The thicker filter with the built in ERF was placed in the forward position and the rotated until a bright image was visible. The second filter was placed and rotated until once again the solar disc was visible. Then the pitch angle of each filter was increased until surface detail became visible (Figs. 4.67, 4.68, and 4.69).

Unfortunately, I didn't have enough space to install a third thin filter in tandem with the other two. Likely I would need to shorten the optical tube length some more, redesign thinner filter housing and perhaps eliminate the diagonal to allow an even longer module. This third filter would allow the scope to function below 0.07 nm in a style reminiscent of a now defunct Italian product called CromixSun. This system consists of five modular etalons that could be daisy chained together to view the sun from anywhere between 0.15 nm to less than 0.05 nm depending on how many etalons were connected. Each etalon had to be brought on tune by controlling the tilt with a thumbscrew (Fig. 4.70).


**Fig. 4.66** Housing showing flip movement in pitch axis with spring loaded nylon threaded machine screw


**Fig. 4.67** Completed module with 1.25″ diagonal and 2″ nose. Open access allows rotation and tilt adjustment of filters


**Fig. 4.68** Module in action

**Fig. 4.69** Celestron 90 mm, f/11 achromat stopped down

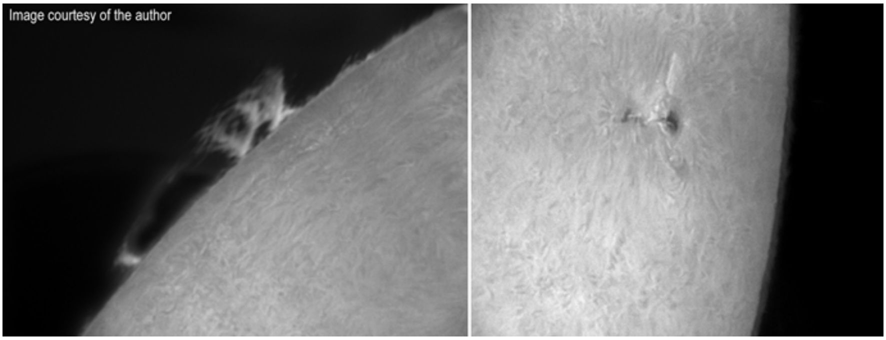


**Fig. 4.70** Solarscope operating at approximately 0.8 Å or 0.08 nm

I was delighted to learn from our local ATM group that there are now two **Tool Library** locations in Toronto, a place where members can borrow tools from an inventory of over 3000 tools. There is also available a supervised complete wood workshop, a 3D printer and laser cutter which drastically elevates what can be made by the ambitious telescope maker. This nonprofit organization began in 1979 in Berkley, California and there are now over 40 **Tool Library** locations throughout North America. There's an old running joke that only the less intellectually endowed took shop class in high school but I am so grateful that I experienced 2 years of mandatory shop classes when I was in elementary school. Technology will only make the machines in our lives more complex with time and the ability to tinker ever more crucial if we don't want to completely surrender our autonomy.

# Chapter 5

# Astronomical Projects for Supporting Applications

So you knew that the last chapter would be filled with the unglamorous unwanted stepchildren of astronomy. Those devices that only an astro geek would understand and desire. Nonetheless they have real value to the amateur astronomer by keeping one's equipment working optimally and painlessly.

## Making an Affordable Atmospheric Dispersion Corrector

As an aspiring planetary imager I'm always looking for methods to improve and refine my results. The future of amateur planetary imaging lies with the increasing use of large aperture telescopes greater than 14″ in diameter including professional grade observatory instruments. Larger aperture telescopes are more sensitive to atmospheric seeing because they have more resolving power hence able to record finer aberrations. Larger telescopes are also more sensitive to the phenomenon of atmospheric dispersion.

The refractive index of the atmosphere is not constant, it is less at the zenith of the sky and greatest at sea level owing to the change in atmospheric density. This means that light will refract more strongly at sea level than at the sky's zenith and light of shorter wavelength (in the blue region) will refract more strongly than longer wavelength light. As a consequence a celestial object near the horizon will have its color emissions separated such that the RGB colours will not intersect at a common focal point and the resultant image in both eyepiece and camera sensor will be smeared.

For my 12″ classical cassegrain, its resolving power and local seeing conditions means that I can disregard the effects of atmospheric dispersion when imaging



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planets that reach an elevation of at least 60° and I was fortunate that in the past few years the northern latitudes have enjoyed Jupiter and Mars approaching opposition at very high apogee. This is another reason why serious planetary imagers journey to the Caribbean to ply their trade, not only is seeing more consistently excellent but all planets transition at the zenith so atmospheric dispersion is completely absent. But the prediction for the near future does not bode well. While Jupiter attains 63° in 2015 for my Toronto location, Mars and Saturn will only manage 25° and 28°, respectively. I was also hoping to image Mercury for the first time during the 2014 maximum elongation in the predawn and it will manage to be only 12° above the horizon on November 1, 2014. Clearly, I will have to take steps to compensate for atmospheric dispersion.

British astronomer George Airy experienced difficulty measuring the solar transits of Mercury and Venus when the sun was low in the sky and at its most stable seeing because of the visual effects of atmospheric dispersion. He found that he could cancel atmospheric dispersion by placing a wedge shaped prism in front of the eyepiece and acquired a set of six different sized wedges ranging from 2° to 16° to suit different solar elevations. Later in 1870, Airy and Simms discovered that they could also achieve this effect by tilting the eye lens of a Ramsden eyepiece relative to its field lens. Fellow compatriot Horace Dall developed the elegant solution of shifting one element of a two element achromatic lens whose internal radii are equal but opposite. If the two elements are held together by the capillary forces of a layer of oil and one element is permitted to slide out of position relative to the other, atmospheric dispersion can be cancelled. Incorporating this feature in a Barlow lens would allow it to serve the dual purpose of increasing focal length and correcting dispersion.

The most popular solution is to use a pair of counter rotating wedge prisms in a design penned by Risley. The rotation allows a continuous control of dispersion correction over a wide range such that the correction can be fine tuned for the changes of elevation of a planetary body throughout the night. Each atmospheric dispersion corrector (ADC) must be calibrated because although dispersion is mainly dependent on sky altitude (and very slightly on temperature, humidity and barometric pressure) it can change with the focal length of the telescope and the distance separating the ADC and the focal plane. A night spent tracking a bright star will allow you to predetermine how many degrees of rotation (0°–180°) of one wedge prism relative to a fixed wedge prism is required to correct dispersion at every elevation and it can they be performed on the fly during a serious imaging session (Fig. 5.1).

It's obvious that an imager using a one shot color camera could benefit from an ADC but what about the purist who images with RGB filters. Doesn't the reconstruction of the color image from three monochrome images correct the out of phase problem? No, because even high end dichroic color filters have a wide bandpass of 100 nm, wider still for the blue filter. The atmospheric dispersion will affect the wavelengths passing through each color filter such that each monochrome image will suffer some degree of blurring. The use of an ADC will restore this lost detail.

There are of course commercial ADC units available. It is unfortunate that the sole North American manufacturer, Adirondack Video Astronomy, no longer

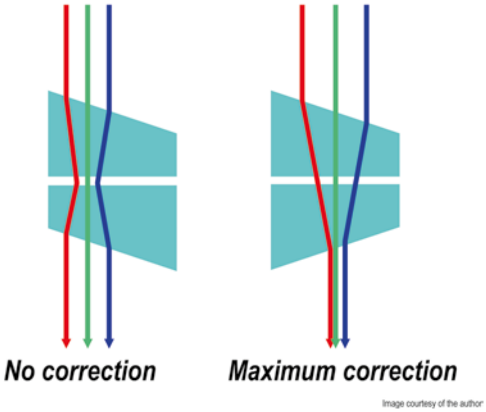


**Fig. 5.1** Risley prisms showing how 180° rotation can effect dispersion correction

produces its example but there are several from European sources. Astro Systems Holland and Pierre Astro have units available for under 400 Euros while Optiksysteme Gutekunst (formerly Argus Optics) offer models ranging from 3400 to 6700 Euros! They claim that wedge shaped prisms induce asymmetry and degrade optical performance while their design uses plano parallel plate prisms of equal refractive index but different dispersion. One distinct advantage of the Optiksysteme Gutekunst corrector is that it induces no image shift while the correction is being dialed in. The Risley prism system can cause significant image shift which requires that corrections be slowly made and incrementally to allow retargeting of the image subject onto the ccd sensor. All ADC units perform best at high focal length to minimize astigmatism and should therefore be placed after a Barlow. Since most people image in excess of f/20 this is typically not an issue.

What is at issue is cost. There are already many components in the optical train of a serious planetary imager and here is yet another one. So let me show you how to make your own ADC.

The critical components are the wedge shaped prisms. They are available from Edmunds Optics with a 1 in. diameter made to ¼ wave surface accuracy and from BK7 crown glass. They can be purchased with transmission coatings and I bought a pair that produce a 4° refraction angle. Physically the wedge describes a 7.5° angle (Figs. 5.2, 5.3, and 5.4).

I cut custom prism holders out of my handy slab of polycarbonate with 1.25″ hole saws to fit into the barrel of an old Meade Barlow with the optics removed. The 1.25″ polycarbonate discs were bored out with 15/16″ drill bit. The prisms were held in their circular frames by friction alone. The two prisms were stacked on top of each other with their two flat sides touching and a thumbscrew was attached to the upper prism to allow it to rotate a full 180°. A hollow plastic plug was machined out of electrical conduit parts to keep prisms in full contact with each other (Fig. 5.5a–d).


**Fig. 5.2** Cutting prism retaining rings from polycarbonate


**Fig. 5.3** Shaping prism retaining rings to fit Meade Barlow


**Fig. 5.4** A pair of prism in custom retaining rings


**Fig. 5.5** Final assembly of ADC

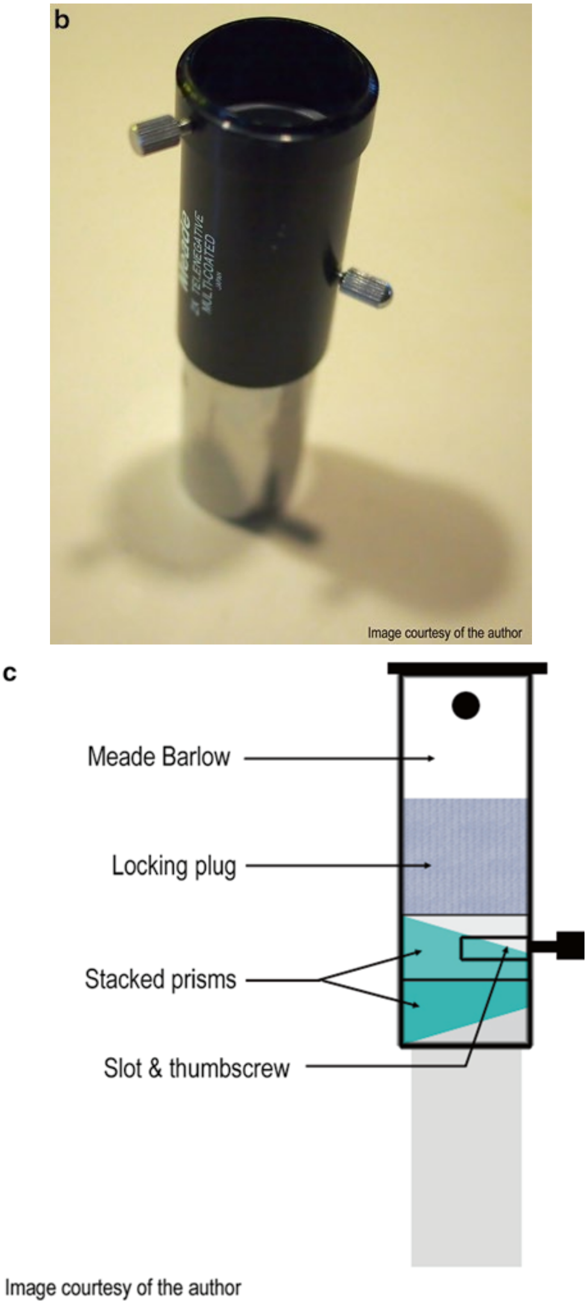


**Fig. 5.5** (continued)


**Fig. 5.5** (continued)


**Fig. 5.6** Image shift as correction is enabled on ADC

A thumbscrew was attached to the rotating upper prism and a horizontal slit cut into the body of the Barlow to allow the thumbscrew to operate. Total expenditures were well under $150 (Figs. 5.6 and 5.7).

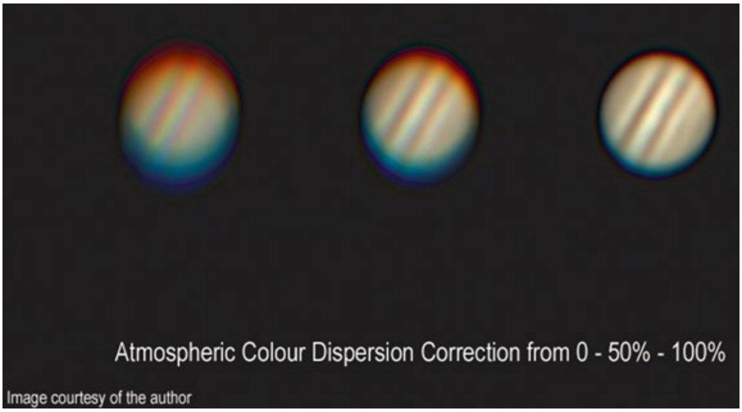


**Fig. 5.7** Maximum correction to low altitude, setting Jupiter

## Making an Electrically Powered, Variable Height Pier for Less

Mounting a long heavy telescope like a big refractor on a pier is a common practice. It eliminates collisions of the optical tube with any tripod legs and elevates the position of the eyepiece to a comfortable viewing level. For people with permanent observatories, a pier is the preferred mounting solution. I don't have one, and I like to bring my big scope to public star parties, but even lifting it onto my EQ6 on a pier of modest height is a challenge for two people.

The perfect product for making a portable pier is the Tri Pier 2 made by Pier Tech, an American company that got its start manufacturing roll-off-roof observatories that occupy a very small footprint. The Tri Pier 2 adds short, stabilizing legs to a height-adjustable pier made from a pair of nested aluminum rectangular tube extrusions. An electrical actuator (a motor driven screw that pushes a sliding extension out at low rpm and very high torque) inside the pier slides the outer extrusion up and down relative to the inner extrusion. Not only are you able to easily mount your scope when the pier is at its lowest position, but people of different height can observe in a relaxed standing position by tailor made height adjustments. A rising pier can also allow your scope to clear the walls of your slide off roof shed and access more of the horizon. Pier Tech retails this for $3200.

Linak is a family owned Danish company that specializes in making electrical actuator devices for many applications, including health care (adjustable hospital beds) and furniture (height adjustable work stations) industries. Their Desklift DL2 lifting column is capable of hoisting 250 kg and looks remarkably like the Pier Tech pier (www.linak.com/products/Lifting-Columns.aspx?product=DL2). It's common knowledge that Pier Tech merely repurposes the DL2 for their application. I discovered a trove of brand new DL2s for only $250 each, including the important control box, from a custom furniture manufacturer. Steve Raymonds of Stone Dimensions has graciously agreed to share his contact information, so get them while you can (steve.raymonds@stonedimensions.com).

The DL2 can be used right out of the box as a permanent pier, as it comes with predrilled top and bottom plates for bolting onto the floor and into your mount. Because I wanted it to function as a portable pier, I had to add four stabilizing legs. Since the walls of the extrusions are not flat, there was room for flat-head machine screws to attach the legs from within the pier. I also made locking struts for each leg with screw-in levelling feet affixed to the bottom of each leg. The legs were not designed to bear the load of the pier, just to provide light ground contact and prevent tipping (Figs. 5.8a, b, 5.9a–d, 5.10, 5.11, 5.12, 5.13, 5.14a, b, 5.15, 5.16a, b, and 5.17).


**Fig. 5.8** Linak Desklift DL2 with control box on top in retracted and fully extended positions


**Fig. 5.8** (continued)

## A Simple, Portable Geodesic Dome Observatory

I suspect that the spherical design of observatory domes became prevalent due to the combination of the engineering virtues of light weight (it has to rotate), strength, and minimal surface area. For the amateur astronomer, building a dome structure is difficult and not for the weekend novice. The urban astronomer is often prevented from erecting a permanent structure at his residence and needs a solution that can be assembled and dismantled with ease. This solution should also be portable, so that it can be brought into the field for dark-site star parties and offer owners security for their equipment and protection from the elements. I will reveal how a simple and portable geodesic-dome observatory can be built over a weekend with PVC plumbing supplies, tarpaulin, cyanoacrylate (crazy glue), duct tape, and a drill press.

Buckminster Fuller is widely credited with inventing the geodesic dome, for which he received a U.S. patent in June 1954, but he was probably unaware that, 20 years earlier, Walther Bauersfeld erected the first geodesic dome and received a German patent for it. He was the chief engineer at Carl Zeiss, and the structure became the company's planetarium at Jena in 1926.

The geodesic dome is composed of approximately equal triangles whose vertices lie on the surface of a sphere. Other more complex polygons can be used as the basic repeating shape, but, unless the joint at which the struts meet can be made absolutely rigid, the structure will flex, with disastrous consequences! Only the triangular shape can maintain the dome structure rigidly, even if the individual strut joints are not. The simplest geodesic dome is based on an icosahedron, which is a regular 20-sided solid, each side being an equilateral triangle. This design is known


**Fig. 5.9** Linear actuator controls DL2 movement with its actuator extension bolted to the bottom plate. When it extends, its body pushes against the top plate and the inner aluminum extrusion rises. The inner and outer extrusions are engineered to tight tolerances, the inner extrusions has fixed runners traveling up and down the corrugated channels of the outer extrusion to guide its movement and maintain stability

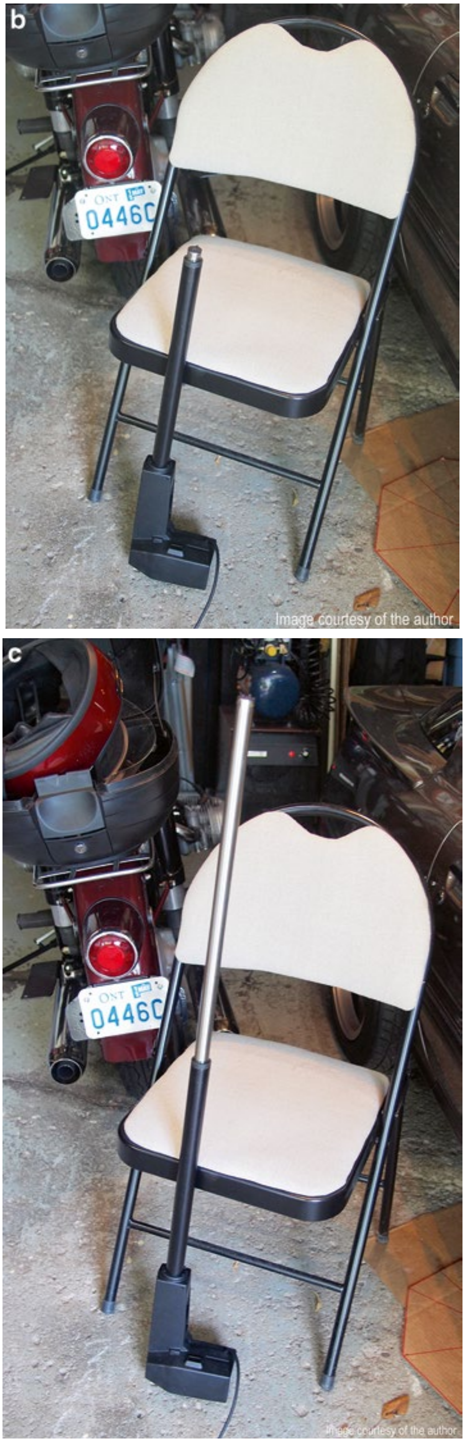


**Fig. 5.9** (continued)

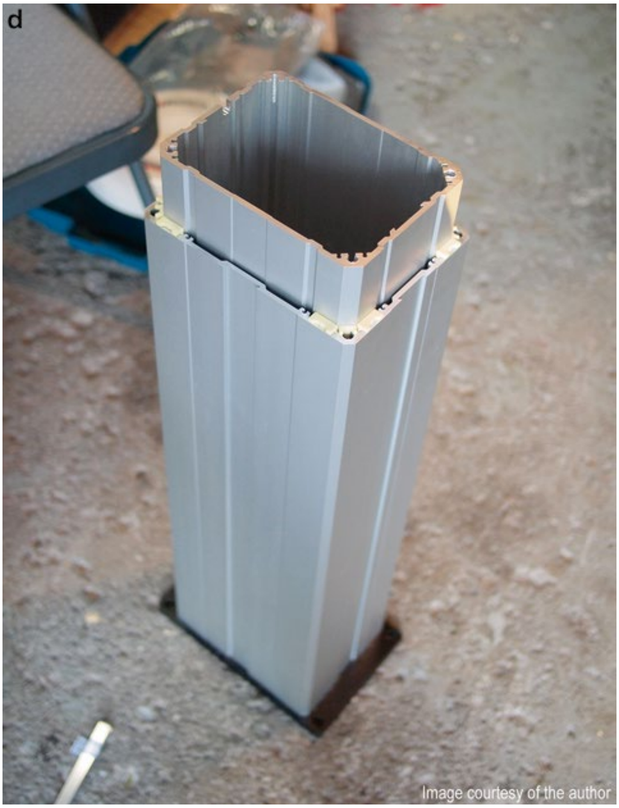


**Fig. 5.9** (continued)

as a single-frequency dome. Further subdividing each equilateral triangle into smaller, similar triangles increases the frequency of the dome as well as better approximating the spherical shape. However this also greatly increases the build complexity, as the triangles are no longer congruent, so both the strut lengths and angle of strut intersection vary.

The struts in this project are 3 ft long and comprised of Schedule 40, 1⁄2-in. PVC pipe. These can be bought in 10-ft lengths and cut down, or found in precut 3-ft lengths used in building underground sprinkler systems. The hubs where the struts meet are made from 3-in. diameter PVC sewer pipe cap and 1⁄2-in. couplers. Eleven hubs are required and the couplers must meet the hubs at the critical angle of 32°. The five hubs that form the base of the dome have only four struts, while the remaining six hubs have five. The angle of the strut couplers can be maintained by making a custom drilling jig for a small drill press.

The couplers are glued to the hubs initially with cyanoacrylate to quickly bond in their position and then strengthened with polyurethane adhesive such as LePage's


**Fig. 5.10** Aluminum from metalsupermarket.com, 1″×1″×2″ blocks for the leg hinges, 1″×2″×20″ hollow pieces for the legs


**Fig. 5.11** Solid aluminum bar was driven by force into the ends of the legs and threaded leveling feet attached

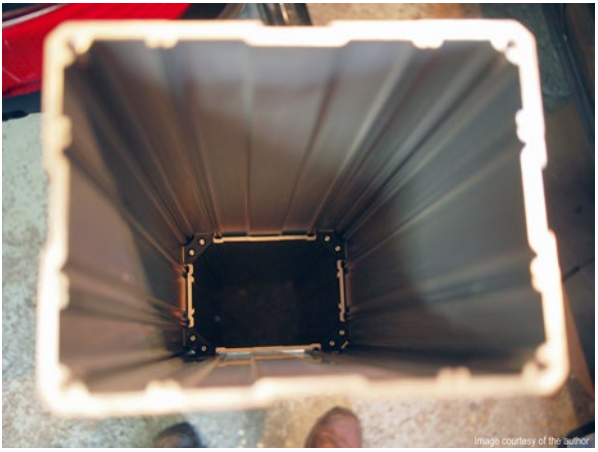


**Fig. 5.12** Looking at the internal surface with DL2 upside down. Inner extrusion runners visible


**Fig. 5.13** Leg hinge mounts fixed to outer extrusion via flat head machine screws placed in recessed surfaces of the extrusion. Inner extrusion is able to pass without interference

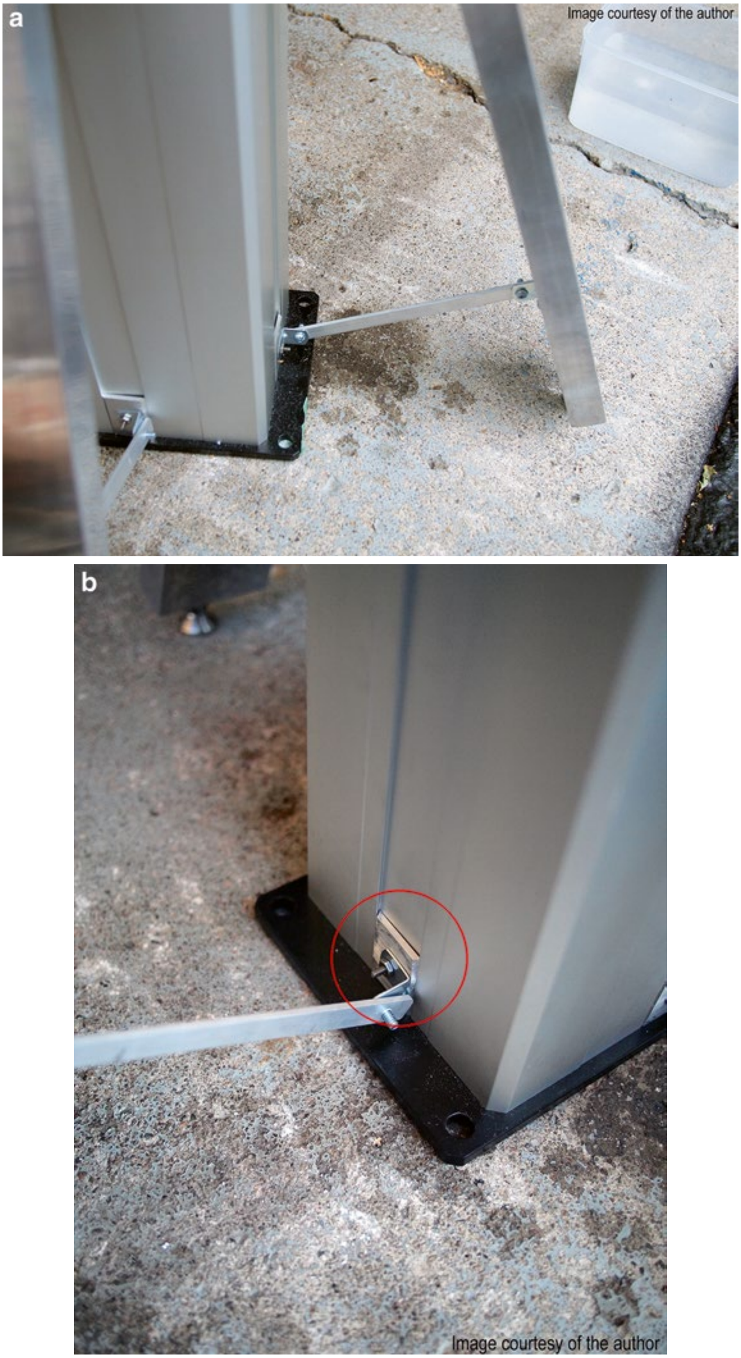


**Fig. 5.14** Legs are stabilized by locking struts that are in turn secured to the outer extrusion by a piece of undercut aluminum traveling freely in one of the recessed channels of the outer extrusion


**Fig. 5.15** Retracted leg with collapsed strut

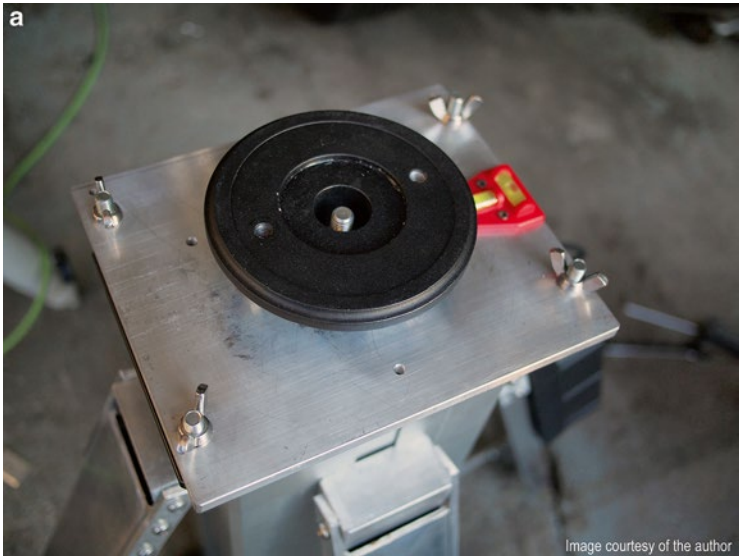


**Fig. 5.16** Homemade top plate for mounting of EQ6

b

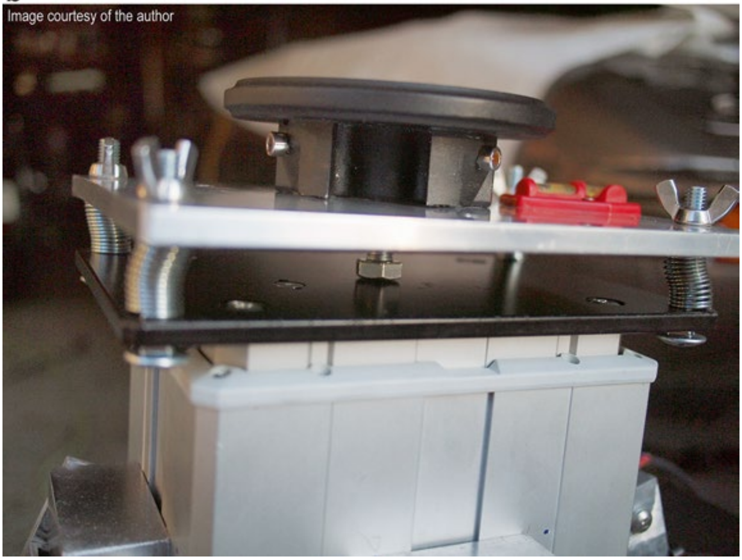


**Fig. 5.16** (continued)


**Fig. 5.17** Electrically powered variable height pier in action

PL Premium Ultra. The struts are simply friction fit into the hubs so there are no screws to fumble around with in the dark, and the dome can be assembled single handedly by first erecting the base perimeter, then the individual triangular walls, followed by the top.

The skin of the dome is made from heavy duty UV-resistant tarpaulin material, cut into equilateral triangles using a wooden template, and taped together from the interior with Gorilla Tape™. A flap was cut and a strut removed to allow the dome to open for telescope operations. This flap was secured with a long self-adhesive zipper used by contractors to provide a zippered doorway in polysheeted construction sites.

A Velcro secured flap in the rear allows entry and provides enough space for one individual to sleep alongside or monitor his or her imaging equipment. The dome has a 6-ft diameter floor and is slightly less than 5 ft high at its apex. A ground sheet can be placed first and then the dome secured to the ground with tent stakes in the event of windy conditions, although this will prevent rotation of the dome necessary to align it with the imaging target. The skin currently drapes over the structure passively but could be internally fastened to the struts. Non astro applications are only limited by one's imagination, such as fabricating the skin from camouflage material to convert it into a hunting blind (Figs. 5.18, 5.19, 5.20, 5.21, 5.22, 5.23, and 5.24).

Afternote:
The famous Greek philosopher Plato believed that symmetry was a fundamental property of the universe and that each of the four elements (air, water, fire and earth) could be represented by one of the five perfect solids. A perfect solid is a 3D shape whose surfaces are comprised only of perfectly symmetrically geometric shapes. The icosahedron of the geodesic dome is one example of such a perfect solid.

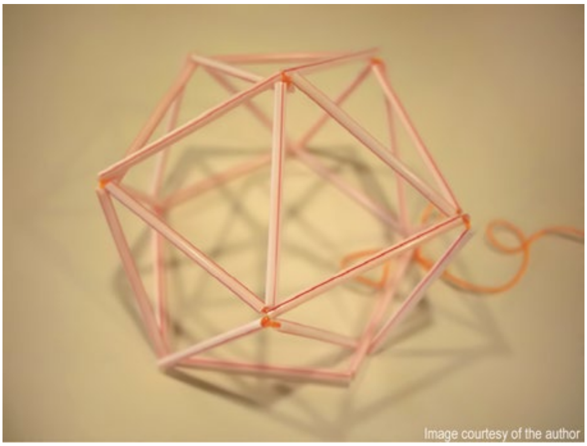


**Fig. 5.18** Scale model and proof of concept with 3″ drinking straw struts

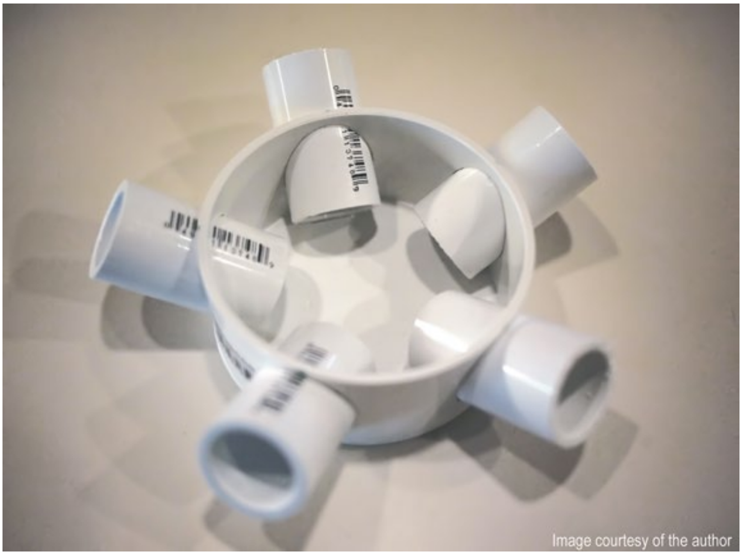


**Fig. 5.19** Hubs with 1/2'″ couplers precisely angled


**Fig. 5.20** Jig used to drill holes in hubs at the precise angle

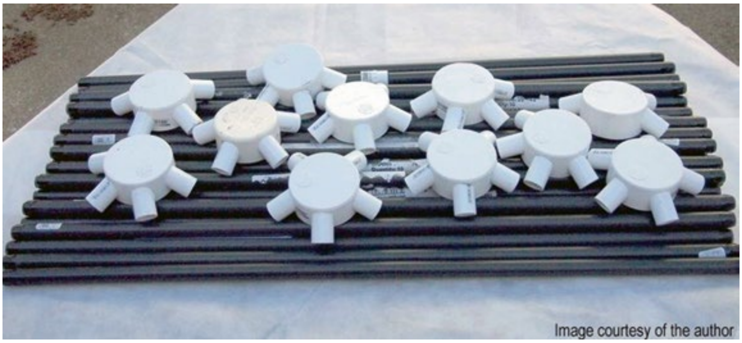


**Fig. 5.21** The complete set of struts and hubs to assemble one dome


**Fig. 5.22** The domes are reproducing!

It was this preoccupation with symmetry that allowed the Ancient Greeks to develop geometry to such a great extent and in doing so they were beholden to finding symmetry in places where it really didn't exist. Like music and astronomy.

On the face of it, there doesn't appear to be any commonality between music and astronomy and that's the way I also perceived it while listening to the local classical music radio station in my car during an emergency food run. The program host's


**Fig. 5.23** Cutting the individual equilateral triangle panels from a sheet of tarpaulin material, which are ultimately taped together to form the skin of the dome


**Fig. 5.24** Finished dome with zippered opening revealed and one strut removed to allow telescope viewing or imaging

(highbrow stations like public radio and jazz don't employ DJs) velvet baritone seque went something like this:

> and that was the first movement of Symphony Number Eight, the Allegro Assai by William Herschel. Herschel is better known as the Father of Modern Astronomy because it was on this day in 1781 that he discovered the planet Uranus. Can you imagine the conversation around the watercooler at his next rehearsal?

I was astounded as I had never known that Herschel was a musician, let alone such an accomplished one.

Herschel was born (1738) in Hanover, Germany as the second son to a family of ten children of which only six survived to adulthood. His father was an oboist in the Hanover Military Band attached to the Hanoverian Footguards regiment and both William and his brother Jacob joined him in like fashion as they came of age. King George II of England was a member of the royal German dynasty that controlled Hanover. During the 7 Years War between England and France, the Herschel men saw combat and defeat (1757) and the father convinced his two sons to desert and seek their fortunes in England. William also played the cello, violin, piano, harpsichord and organ and was a skilled craftsman able to fabricate his own instruments, this versatility characteristic of professional journeyman musicians of his period. He found early employment as a sheet music copyist in London. Later he was appointed the director of the Durham Militia Band and undismayed by a complement that consisted of merely two oboes and two French horns, he composed martial music that played to their strengths. He became first violinist for the Newcastle Orchestra and then organist at St John the Baptist Church in Leeds and Halifax before achieving premier recognition as the organist of Octagon Chapel in Bath with the princely annual salary of £400 in 1767. This decade also proved to be his most productive as he composed 24 symphonia and several concertos for oboe, violin and keyboard. His music may not be the enduring calibre of his contemporaries Handel, Haydn and Mozart but to the ear of this most mediocre (but once professional) musician they speak of the innovation and creativity of Herschel's well ordered and complex mind. His music is not derivative or forgettable and I found it pleasing to listen to and I enjoyed its carefully crafted structure. He was promoted to director of the Bath Orchestra in 1770. Herschel rescued his sister Caroline from a life of domestic servitude in Hanover (1772) to become a soprano soloist while his brothers Dietrich, Alexander and Jacob also became members of the orchestra.

Despite the burdens and demands of becoming the family patriarch, he found time for the selfish pleasure of reading scientific texts in bed including Robert Smith's *Harmonics* and *Optiks* and James Ferguson's *Astronomy*. In 1771 he began construction of a series of Newtonian reflectors often spending up to 16 h a day grinding the speculum mirror while his sister spoon fed him his meals. He became so taken with astronomical observation that he was forced to reduce the number of his musical pupils and his last professional music appearance was in 1782. By this time he had gained recognition for the discovery of Uranus with the Copley medal, membership into the Royal Society and appointment by King

George III as *king's astronomer* with a life time royal stipend of £200 annually. Giving up music was apparently not difficult as Herschel writes:

> All this while I continued my astronomical observations & nothing seemed now wanting to compleat my felicity than sufficient time to enjoy my telescopes to which I was so much attached that I used frequently to run from the Harpsichord at the Theatre to look at the stars during the time of an act & return to the next Music.

And when the King later commissioned Herschel to build the world's largest telescope, a 48″ reflector, novelist Frances Burney writes:

> The King has not a happier subject than this man … who is indulged in license from the King to make a telescope according to his new ideas and discoveries, that is to have no cost spared in its construction and is wholly to be paid for by His Majesty. This seems to have made him happier even than the pension, as it enables him to put in execution all his wonderful projects, from which his expectations of future discoveries are so sanguine as to make his present existence a state of almost perfect enjoyment.

I've come to realize that Herschel is no anomaly as we have two contemporary musicians who have achieved critical and financial success before progressing to a second career in astronomy.

Brian May received his Bachelor of Science degree in Physics from Imperial College and began working as an astronomer studying the radial velocities in the zodiacal dust cloud using optical spectrometry. He was also lead guitarist in a local band fronted by childhood chum and neighbour Farrokh Bulsara, aka Freddy Mercury. When the band *Queen* hit the big time in the early 1970s, May had to give up astronomy and more than 30 years would pass before he was able to resume his research and receive his doctorate in 2007. And like Herschel, throughout his five decade musical career he played the same electric guitar (*Red Special*) that both his father and him spent 18 months making when he was 15 years old. The guitar was crafted from a century old mahogany fireplace mantle piece and featured solderless pickup connections decades before anyone else tried it.

Closer to home, our own Wayne Parker was bassist for a band called *Glass Tiger* that caught the public eye in 1984 and he maintained his passion for astronomy by touring for the next decade with a TeleVue Genesis refractor. When life resumed and he was getting too busy with his own software distribution company to easily enjoy astronomy, he decided he had to find a way back. In 2003, he launched SkyShed which offered optimized designs for roll off roof observing sheds to be followed with Skyshed POD in 2006.

The origins of a relationship between Music and Astronomy began with the Ancient Greeks. Pythagoras observed that the pitch of a musical note generated from a vibrating string depends upon its length and that if you halve the length of the string you produce the same note but pitched one octave higher and that this interval could be expressed as a 1:2 ratio. He was obsessed with the notion that universe could be defined within the constraints of small integers and was delighted to discover that consonant or harmonious sounding intervals such as a perfect fifth (five whole tones above the tonic, e.g. C-G) are exactly 2:3 and a perfect fourth can be made from a 3:4 ratio. By expressing harmony mathematically he was the first to reduce a quality (sound) into a quantity and thereby opening the doors to the concept that the universe itself could be described mathematically.

Since objects produce sound when in motion, he reasoned that the planets moving in orbit should also produce a sound and that this sound is harmonious since the separation ratios of the planets as a distance proportional to their speed relative to the Earth also seemed to correspond to the tonal musical intervals of the Pythagorean scale. This *music of the spheres* was what Kepler also looked for when proposing his laws of planetary motion and he found that the ratio of each planet's angular velocity at perihelion and aphelion was identical to one of the established musical interval ratios. Saturn had a ratio of 4:5 with corresponds to a major third while Jupiter at 5:6 is a minor third.

As it turns out, constructing scales based on pure ratios of small integers results in some intervals which are horribly dissonant and as music became more complex through the Middle Ages with more polyphony and key changes these bad intervals became more common. The modern 12 tone even tempered scale was invented to solve this problem whereby the octave is divided into 12 exactly equal intervals so that interval ratios are within 1 % of the perfect system envisioned by Pythagoras. Vincenzo Galilei (the father) was an early advocate of this system and this seeming rejection of a pure abstract mathematical model of the world was the path his son Galileo and the rest of us would later follow. It took an even later Italian by the name of Gabriele Veneziano in 1968 to revisit the Pythagorean construct and propose that matter, force, even space and time are composed of tiny vibrating strings instead of a point particle. String theory remains the best candidate to unify the incongruous theories of Quantum Mechanics and General Relativity.

So what it comes down to is music has very little to do with math and even less to do with astronomy. I also believe that playing Mozart to your unborn fetus will do nothing to raise its intelligence. Learning music and the ability to sight read musical score may raise math scores because both involve quick pattern recognition and decoding skills. That three prominent musicians found careers in astronomy has more to do with astronomy as an infant science even in the twenty-first century. I am grateful that amateur astronomers continue to make meaningful contributions to the real science of astronomy because it allows me the most tenuous of footholds in academia, a world that so many of us leave in order to chase the North American dream.

## Build Your Own Advanced CT (Cassegrain Telescope) Laser Collimator

I think everybody should own an 8″ Schmidt Cassegrain telescope because it is such a versatile instrument. It has significant aperture, yet is lightweight and compact. It has a high native focal length but can be operated in near wide field mode with optical reducers. It is however an instrument designed with many compromises and a thorough understanding of them is necessary to get the most of out of this scope.

One of the most critical aspects of SCT care is to maintain collimation. Unlike most refractors, SCTs must be collimated periodically during periods of good seeing with a bright star. SCTs are so sensitive to mirror misalignment that even a quarter turn of only one of the secondary mirror's collimation screw too much or too little will jeopardize optical performance considerably. This is probably why people often prefer the views through smaller refractors because many are designed never to fall out of the factory, bench tested collimation, even though the larger 8″ SCT should have more resolving power … if properly collimated.

The optics in a SCT are ground to deliver diffraction limited performance at only one fixed distance separating the primary from the secondary mirror. In order to make the instrument more user friendly for non astro applications, they designed the focusing mechanism to move the primary up and down the central baffle tube so that a great range of focus travel was possible. Not only do you immediately get less than theoretical maximum optical performance, you lose the ability to adjust the primary mirror's position (tilt) since the primary is not in a fixed mirror cell. Not being able to adjust the primary means that the user has to rely on the factory to have accurately centered the secondary with respect to the primary otherwise there will not be enough adjustment play from only one end to achieve perfect collimation. And don't forget the slop likely to be encountered in the visual back which relies on crude castings to be simultaneously centered to the secondary mirror and orthogonal. This is why all homemade telescopes are made with multiple points of adjustment since most amateur telescope makers are unable to manufacture at machine shop tolerances.

So while the case for collimation has been made, how to collimate is also a concern. SCT's are very sensitive to thermal equilibration and if coming from inside a house to outside will require a long period of cooldown before tube currents stabilize enough to enjoy good sky seeing. The movement of the primary mirror requires some degree of slop between its central perforation and the baffle tube. So if you collimate the scope at one angle of elevation and then change that angle considerably for viewing or imaging reasons, the primary mirror will undergo minor positional resettling that may spoil the collimation.

Then there is the precious time wasted undergoing star collimation that is time which otherwise could have been spent observing or imaging. The ability to precollimate the SCT during the daytime and only refine the collimation with a few tweaks with a star at night is very desirable, especially when this is a reality for all Newtonian owners.

Never has it been more true that imitation is the sincerest form of flattery but I'm also doing so in order to demonstrate how easy it is to replicate Hotech's CT Laser Collimator at very little cost and ultimately allow you to collimate your SCT in the daytime. The Hotech is simply three peripheral led lasers and a central led crosshair emitting laser set into a bullseye target. The lasers are aligned at the factory to be perfectly parallel to each other so when they enter the corrector plate of a SCT it mimics light traveling from a distant star. The central crosshair laser helps with establishing perfect perpendicular centering with the primary mirror and the three peripheral beams bounce off the primary, the secondary, through the baffle and then

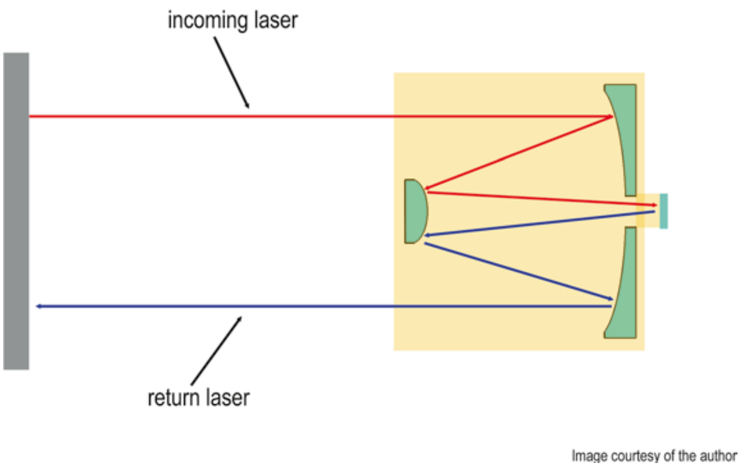


**Fig. 5.25** Schematic of Hotech Advanced CT Laser Collimator in action

off an installed mirror flat in the visual back before exiting the corrector in a reverse path (Fig. 5.25).

All this beam travel and the convexity of the secondary mirror makes this a very sensitive test since even any small misalignment will be readily apparent. If the exiting beams don't hit the Hotech target in a symmetrical but inverted pattern then the secondary needs to be adjusted until it does. At this point collimation is achieved.

I designed the target with Photoshop and printed it on adhesive A4 sized paper. This was transferred to the surface of a piece of ¼″ thick aluminum. The laser holes were drilled and the very inexpensive 5 mW led lasers (*red laser dot diode module* or some partial string search combination) modules were purchased from eBay, three conventional and one with crosshair emission pattern. The lasers were sequentially glued to their positions with epoxy but before it dried, each laser was aimed at their own position on an identical bullseye target some 30 ft away to ensure accurate laser collimation.

The aluminum plate was fastened to some aluminum angle with a 1/4 × 20 hole tapped to receive the tripod screw of a Manfrotto 410 Junior geared head on top a Manfrotto tripod. The Hotech comes with a fine adjustment stage but the Manfrotto is far superior is terms of rigidity and fine control, every astroimager and photographer should have one. The lasers are wired in parallel to 3VDC power supplied by twin AA batteries (Fig. 5.26a–c).

Operation is identical to instructions posted on Hotech's website, namely the distance between SCT and collimator panel and aligning the panel until it is centered and perpendicular to the primary mirror. Centering can be aided by lighting internal screw tips with the laser crosshair pattern protruding into the optical tube and spaced at 90° intervals. I would also place the SCT mount into Alt/Az mode so that adjustments can be made at both ends and focus should be at infinity with all items in your normal optical train present. If you're a purist you can also collimate the SCT at its preferred angle of operation since the laser collimation panel can also be equivalently angled (Fig. 5.27a, b).

The return mirror flat in the visual end was purchased from Surplus Shed and installed into an empty SCT threaded external filter ring. The return beam pattern is weaker, not as coherent as the Hotech unit but the Hotech uses much higher grade lasers. Still, the return pattern is visible enough to allow secondary mirror adjustment. Collimation is now good (Figs. 5.28 and 5.29a, b).

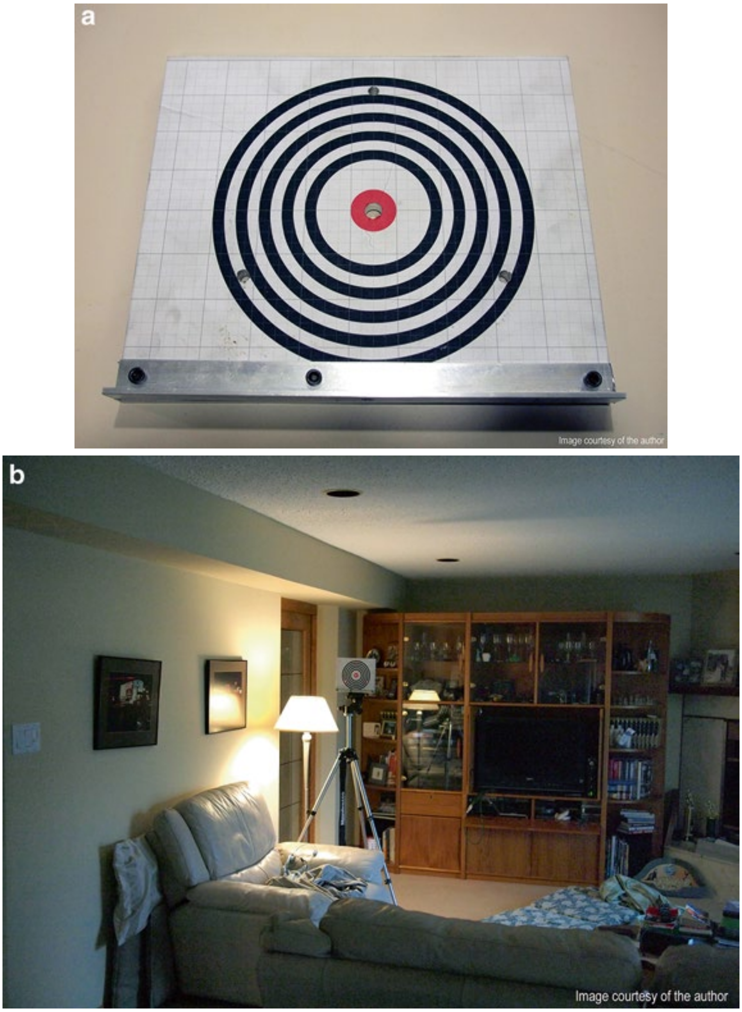


**Fig. 5.26** Jim's CT Laser Collimator and collimation of lasers

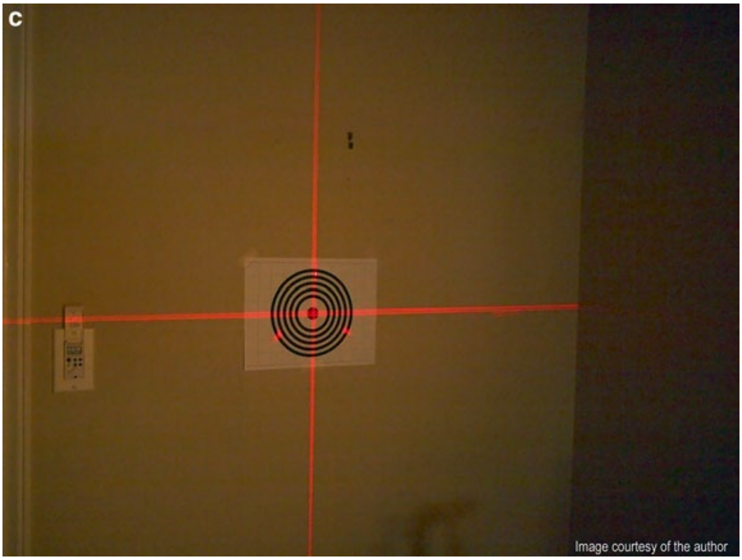


**Fig. 5.26** (continued)


**Fig. 5.27** Orthogonal centering of Jim's CT Laser Collimator with C8 primary mirror

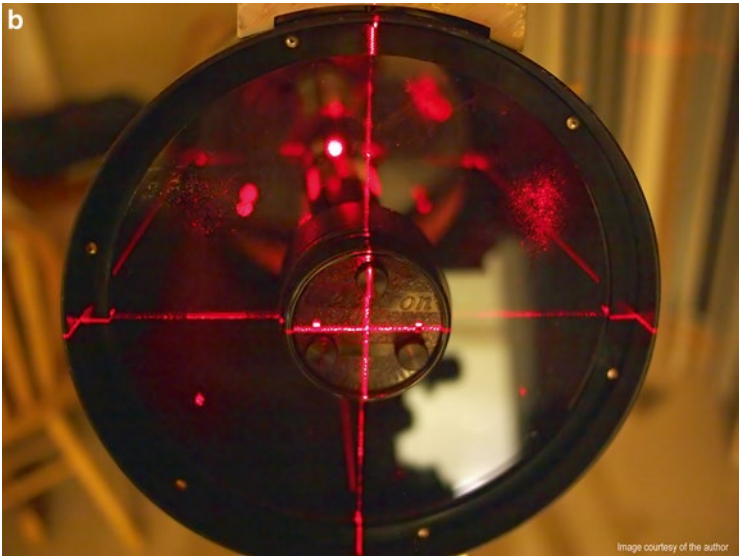


**Fig. 5.27** (continued)


**Fig. 5.28** Return beam optical flat installed in empty SCT filter ring

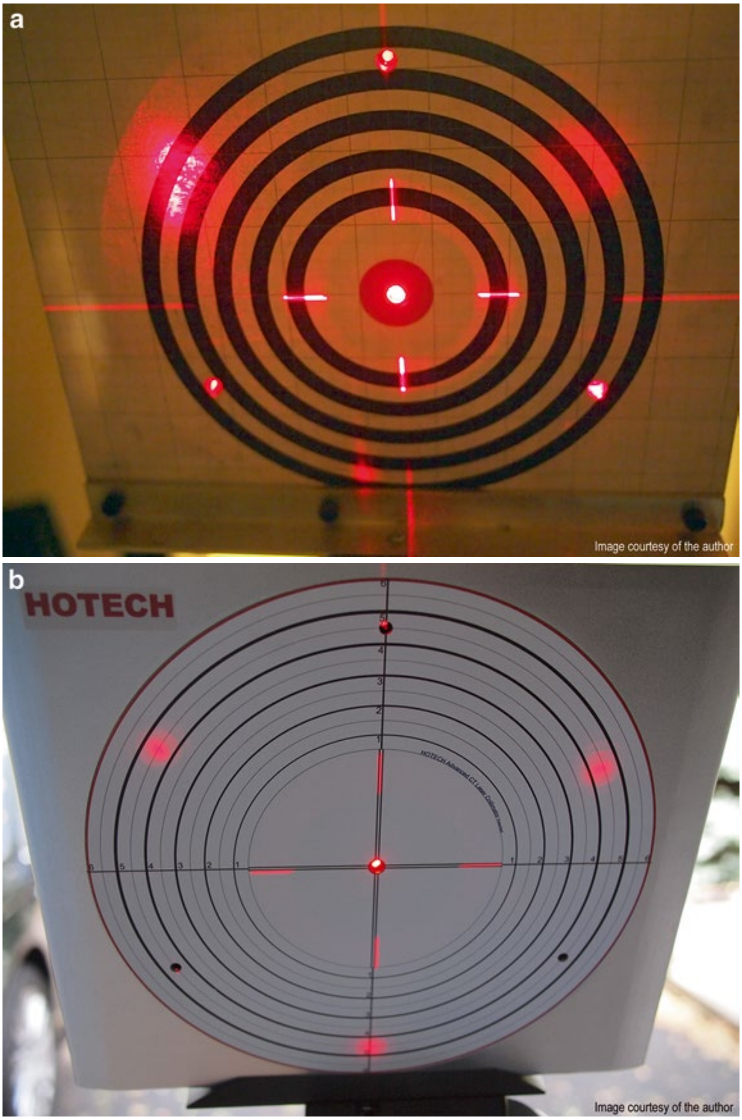


**Fig. 5.29** Comparing the original and the imitator's return laser beam pattern

## Affordable Spectroscopy for Amateur Astronomers

It would not be hyperbole to assert that nearly all our knowledge of modern astronomy comes from spectroscopic studies of the cosmos. It allows us to determine the chemical composition, physical properties and radial velocities of astronomical bodies. Using Doppler shift it can measure dark matter content, the masses of a binary star system, the rate of expansion of the Universe and the presence of an exoplanet. Stars with very similar spectral composition are likely to have similar temperatures and luminosities. This allows distance estimations based on their apparent brightness for distant stars that trigonometric parallax are unable to compute. Astronomical spectroscopy is really a highly specialized form of astro imaging that shares all the same technical difficulties. The only difference is that you can't do astrophysics imaging through colored glass filters!

Amateur astronomers are enjoying a resurgence in the nearly forgotten art of spectroscopy owing to the easy availability of ccd technology and reasonably priced off the shelf spectrometers. CCDs also enjoy a 90 % quantum efficiency as compared to photographic plates which demonstrate long exposure reciprocity and only a 1 % quantum efficiency. The process has simply gotten much easier along with supporting software to analyze and calibrate data. Spectroscopy is also the future by which amateur astronomers can continue to contribute scientific data that complements the works of professionals through agencies such as the AAVSO. I never discount the contributions of amateurs because they have the freedom to determine when and what they are studying which is surprisingly at odds to professionals who are locked into tight and distantly scheduled observing slots.

Most everyone is familiar with the historic experiment of Newton dispersing sunlight with a glass prism into its constituent colors. We stand on the shoulders of several more giants including master glass maker Joseph von Fraunhofer, whose self made prisms were able to separate the solar spectrum with such resolution that he was able to observe approximately 600 dark lines. He labeled the nine most prominent ones alphabetically and this notation survives in his honor to this day, as well as explaining some of the esoteric scientific nomenclature that we were taught to accept in school—more on that!

Chemists in the nineteenth century were doing more than physicists in determining the atomic nature of matter. Bunsen and Kirchoff observed that burning chemical salts in a flame produced a spectra consisting of a series of discrete bright lines at consistent wavelengths or color of light versus the continuous spectrum of sunlight. They realized each element produced a distinctive set of lines and a method by which to identify said element. In fact although helium is the second most prevalent element in the universe, it was not isolated on Earth until 1895 but it was discovered 20 years earlier when a French astronomer took a spectra of the sun's chromosphere during an eclipse. He observed a previously undenoted spectral line close to the Fraunhofer $D_1$ and $D_2$ lines of sodium.

But classical concepts of matter could not explain why elements released energy at such finely defined wavelengths. It was only after the Bohr was able to describe the structure of an atom combined with the quantum theory of Planck and Einstein that things started to make sense. Electrons can only exists at discrete energy levels and transit between these levels. Light is not just a wave with an oscillating electric charge able to absorb or emit a continuous stream of radiation but is a particle or photon with a defined quanta of energy.

$$(\mathrm{E})\mathrm{nergy} \propto \nu\,(\text{frequency of light}) \propto \mathrm{c}\,(\text{speed of light}) / \lambda\,(\text{wavelength})$$

such that each wavelength of light has a defined value of energy, shorter wavelength light (UV and beyond) having more energy than longer wavelength light (IR).

When I was an undergraduate student I was required to take the most feared courses in the science faculty: organic, physical and quantum chemistry. The concepts were foreign and difficult to comprehend and ultimately ruinous on one's grade point average. I now have a son in first year university and it saddens me that his generation is likely even more preoccupied with grade/mark performance at a time in their lives when they should be taking chances and discovering themselves. In quantum chemistry we were taught that the energy levels for an electron in an atom is described by a set of four *quantum numbers*.

The principal quantum number is ***n***. The angular momentum quantum number = ***l***. The magnetic quantum number = ***m***. The spin quantum number = ***s***.

***n*** is the main energy level or shell (***n*** = 1 is the ground state) with sublevels described by ***l*** where there are (***n***) ***l*** sublevels for each ***n*** shell (***l*** = 0,1,2,3 …). The ***l*** sublevel describes the 3D distribution of the electron cloud with the highest ***l*** value being spherical in shape and lower ***l*** values being increasingly asymmetrical with electrons spending more time closer to the nucleus, hence lower energy values. Each ***l*** sublevel has an ***m*** sub-sublevel and each ***m*** level can have either an ***s*** number of ½ or −½ (Fig. 5.30).

In school I was also taught to refer to the l sublevels as s, p, d, f and g orbitals, such that a 3l(0) and 3l(1) level would be more easily written as 3s and 3p, respectively. It's only now that I understand the letters are a tribute to Fraunhofer and they refer to the four spectral series of lines detected when combusting sodium which Fraunhofer had named sharp, principal, diffuse and fundamental.

For the special case of hydrogen, all m and l levels are deemed degenerate meaning each level has the same energy as the next so they are equal and no subdivision is needed. The energy of the electron just depends on its quantum number and spin number. So if the electron were to fall from n = 3,4,5 to n = 2 a specific quanta of energy would be emitted and a specified wavelength. This spectral series happens to occur in the visible spectrum and is referred to as the Balmer series where the transition from n = 3 to n = 2 results in the famous Hα line. The transition from n = 4 to n = 2 is the Hβ line.

Sodium resides in the same alkali metal column as hydrogen in the periodic table and also sports a sole electron in the outer valence shell (n = 3). The difference is that the angular momentum levels are not degenerate in sodium so you have four series of transitions that occur in the visible spectrum. The most famous being the transition from 3p to 3s which occurs as an emission line in the yellow region at 589 nm.

There are also ionization transitions known as free-bound where an ejected electron returns to form the neutral form of the element. The [CaII] line is a transition from $Ca^{+1} \rightarrow Ca$ in the sun and was labeled by Fraunhofer as a K line, hence Ca-K line emission viewing. The other common ionization transition familiar to narrowband imagers is the [OIII] line, a double pair centered around 500 nm and occurs frequently in emission and planetary nebulae as $O^{+2} \rightarrow O$. This however is known as a forbidden transition in that it is never observed to occur in the

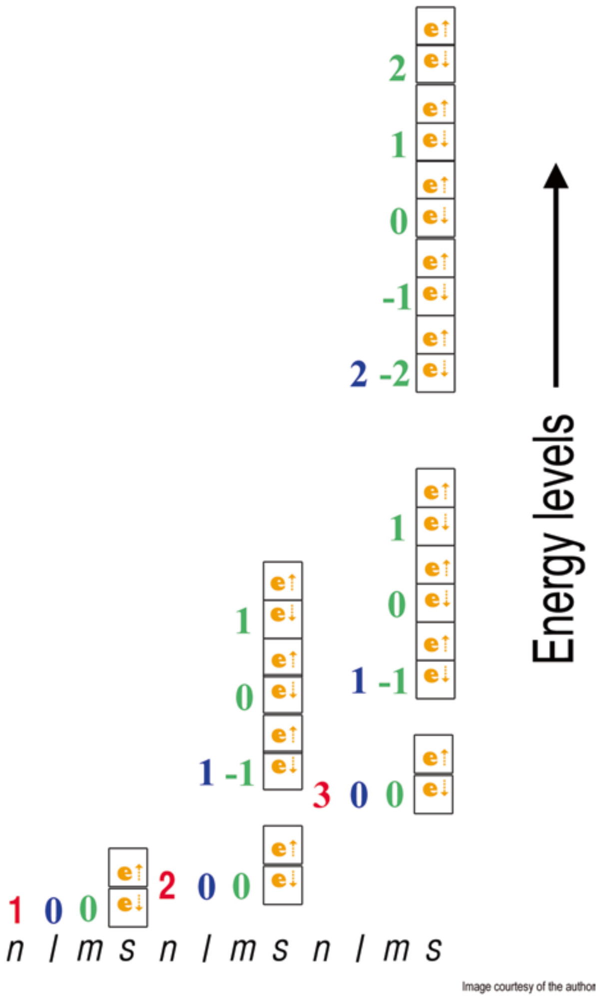


**Fig. 5.30** Quantum energy levels for electrons in the first three shells

laboratory and breaks the quantum theory transition rules. For years these lines were observed spectroscopically and attributed to a new unknown element until it was realized that the diffuse conditions in nebulae preclude the probability of atomic collisions so there is sufficient time for metastable states to decay via weak, forbidden line emissions.

The Doppler effect allows us to calculate the speed at which a star is approaching or receding from us. If the expected spectral lines are shifted to longer wavelengths then the star is moving away from us. The spectral lines can also exhibit broadening due to a Doppler rotational shift or from collisional distortion as a result of increased temperature and pressure.

Wien's Law tells us that the wavelength of peak intensity of a star's spectrum can let us determine the star temperature. This allows us to sort stars according to spectral types based on star temperature and spectral line profiles. Stars of the same type will have similar luminosity and interstellar distances can thus be determined by comparing apparent brightnesses. The presence of an orbiting large exoplanet can be shown by the planet inducing a wobble to its star, one leg of the orbit a Doppler red shift will be observed and on the other leg a Doppler blue shift.

Modern spectrometers do not use a prism but a dispersion grating, a plastic film embossed with thousands of fine grooves per millimeter coated with a highly reflective material. It functions by reflection so there are no absorption losses to attenuate faint stellar sources as would occur with a prism. High groove density will increase the resolution of the spectrometer but limit the range of its wavelength coverage. One of the easiest sources of a grating is an inner layer of a blank DVD which has about 1300 lines per mm (l/mm). Homemade spectrometers can be made using such a grating, a collimator, and a lens to focus the beam onto a webcam.

For once I will advocate the purchase of a premade unit in favor of making your own, because for the price it simply can't be beat. www.science-surplus.com sells refurbished compact crossed Czerny-Turner design spectrometers likely used in a medical lab setting. Originally a B&W Tek Model BTC-110S it features a SMA 200 μm diameter glass fiber optic delivering the light signal to a 50 μm slit, which ultimately determines the optical resolution and throughput of the unit. The crossed Czerny-Turner design consists of two concave mirrors and one plano diffraction grating. The first mirror collimates the light from the slit into parallel beams onto the diffraction grating and mirror 2 focuses the dispersed light onto the detector, a linear monochrome ccd (Sony ILX511) 1 × 2048 pixel array, 14 μm × 200 μm in size. The unit comes with an 1800 l/mm grating, a serial interface and software for under $200. The components of the optical bench do need to be aligned with care but the website instructions are clear (Figs. 5.31 and 5.32).

Most astro spectrometers place the entrance slit directly in the optical train of the telescope to avoid transmission losses associated with the fiber optic lead but this can stress the telescope connection with significant mass. I stripped the sheathing off one end of the fiberoptic and drilled an appropriately sized hole through the center of a section of 1.25″ hardwood dowel so that the fiberoptic cable was held by friction. The difficulty is ensuring that a focused image of a star falls exactly on the 200 μm diameter target and only direct line of sight can verify both correct focus and alignment. I sanded the dowel end smooth and painted it flat black and glued on a 1″ circular mirror flat with which I had drilled a small central hole with a water cooled diamond bur. This mirror allows visual confirmation of focus and placement of star over fiber optic tip. A piece of a diagonal mirror flat on an adjustable swivel below the primary light path from the telescope and a relay lens connected to an eyepiece above the light path allows direct viewing of the fiber optic tip. The eyepiece can be replaced with a guide camera to allow off axis guiding for longer exposures. A variable brightness red led eyepiece illuminator was placed to allow visualization of the fibre optic cable tip, otherwise it's too dark to see it by just starlight alone (Figs. 5.33, 5.34, 5.35, 5.36, and 5.37).

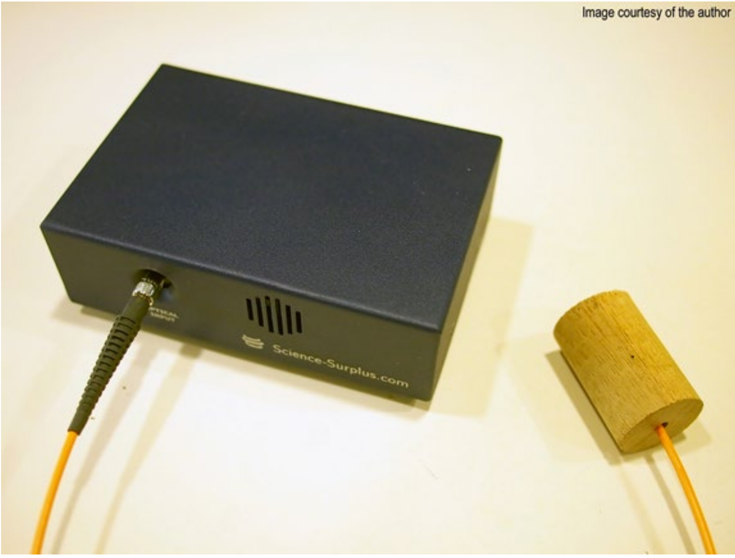


**Fig. 5.31** Surplus Science B&W Tek BTC-110S spectrometer

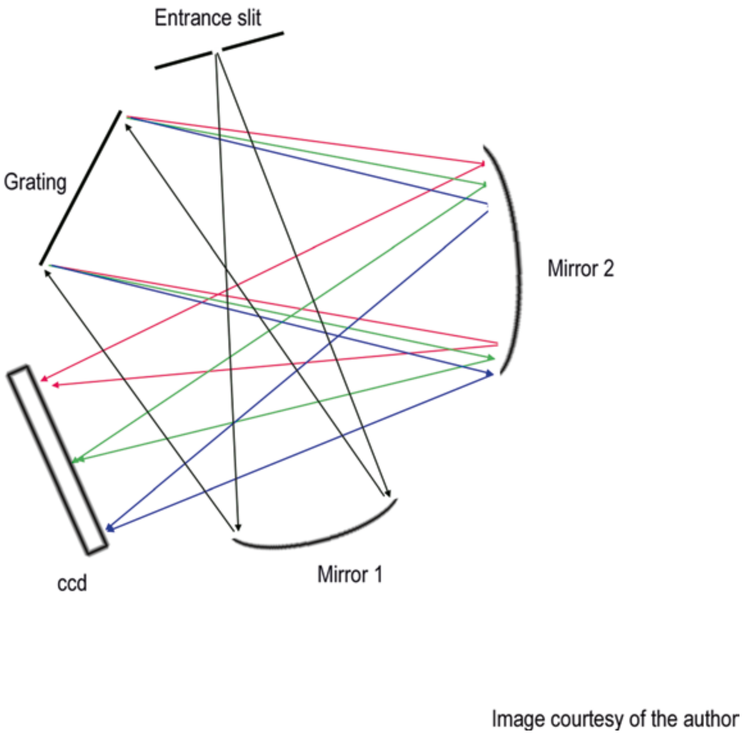


**Fig. 5.32** Crossed Czerny-Turner compact spectrometer design


**Fig. 5.33** Black PVC pipe fiber optic housing and off axis eyepiece/guide camera viewer


**Fig. 5.34** Completed unit

The spectrometer can be wavelength calibrated by performing a third degree polynomial regression on a source with a known spectral profile but I fudged it by moving the focusing mirror until my Howie Glatter red collimating laser was peaking around 550 nm on the computer display. The unit also has a cooling fan built into the motherboard but apparently the jumper connections have to be replugged

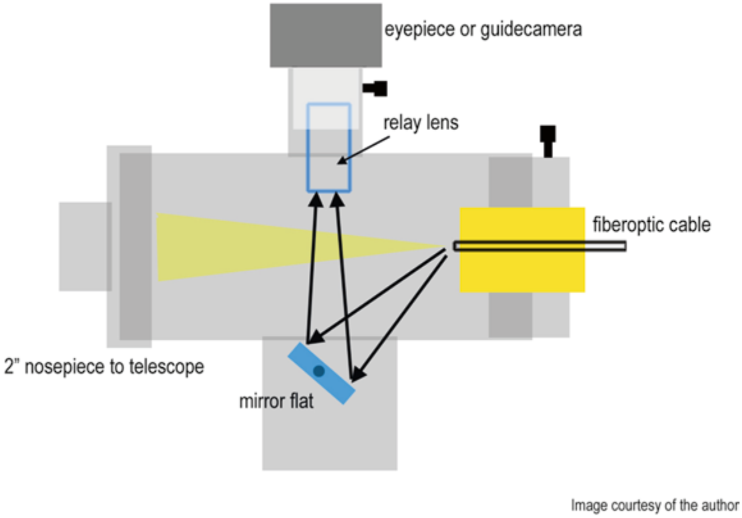


**Fig. 5.35** Schematic of unit

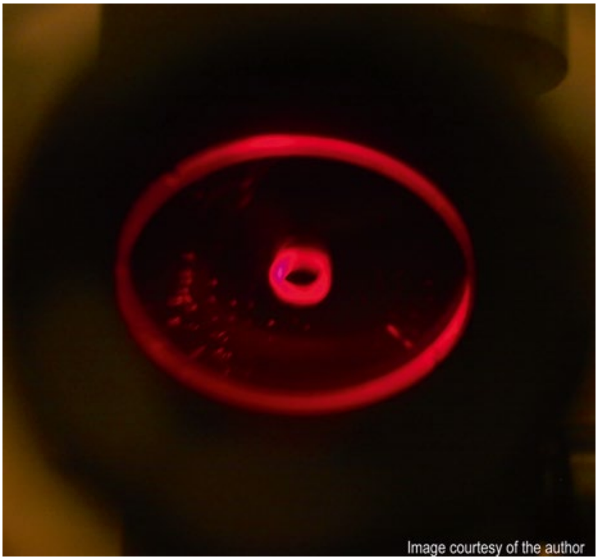


**Fig. 5.36** Closeup of fiber optic target illuminated by red led as seen through eyepiece and relay lens


**Fig. 5.37** Dental mirror flat

to restore power to the fan. Since the ccd is not thermoelectrically cooled, having the fan running would be very useful in reducing thermal noise. It remains a non-trivial matter to accurately place a stellar light source onto the small fiber optic opening and the approaching cloudy winter season in my area precluded opportunities to play with the system. Still I managed to obtain a spectra of our Sun and the dips in the profile correspond to the dark lines seen by Fraunhofer. This is also known as an absorption spectra since elements in the sun's atmosphere absorb energy at their specific energy/wavelength levels leaving holes or lines in the continuous spectra of the sun (Figs. 5.38 and 5.39).

## A Direct Drive Telescope Mount

It comes as a bit of a surprise to novices that the most expensive component of an effective astro imaging setup is the tracking telescope mount. While nearly every aspect of astronomy has benefited from infusions of modern technology, the telescope mount is still fundamentally a design more than a century old. While professional

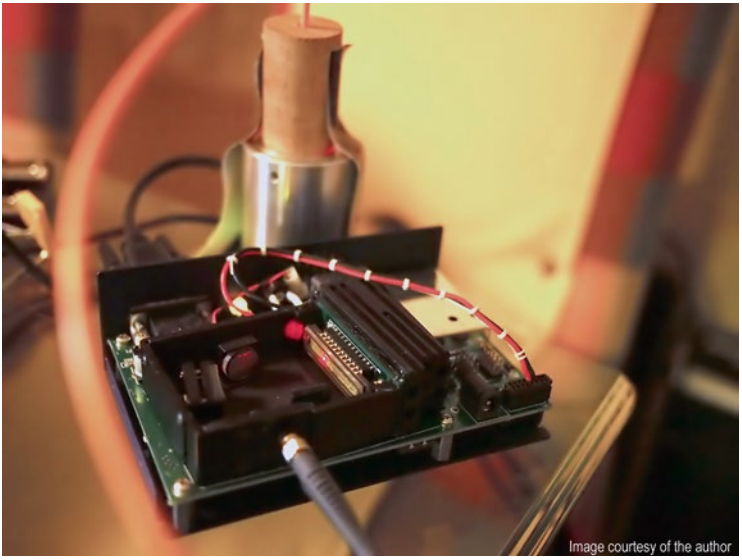


**Fig. 5.38** Aligning components of optical bench

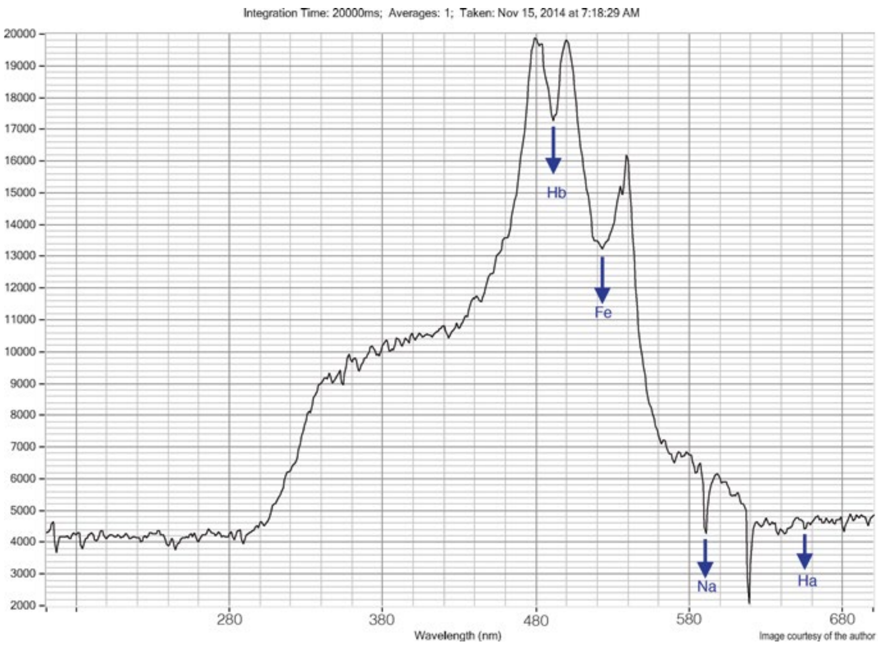


**Fig. 5.39** Solar spectra of the sun

astronomers have moved forward in this respect, amateur astronomers are beholden to only what they can purchase and those manufacturers overwhelmingly persist in the tried and true but tired worm and ring gear drive design. If the manufacturing tolerances are low, the worm introduces periodic error in the tracking motion as a result of surface roughness. There is reduced stiffness and backlash because the worm and ring gear cannot mesh too tightly without provoking seizure. Backlash being the phenomenon that occurs when a worm must reverse direction. There is a significant delay in reaction as the slack between worm and ring gear is picked up. The interface between worm and ring gear must also be lubricated and unless the correct grease is used (such as lithium based or synthetics containing suspended Teflon particles) the onset of cold weather can exacerbate both periodic error and backlash.

Astro Systeme Austria (ASA) sell a complete line of direct drive telescope mounts utilizing brushless electric motors that directly, without the intervention of any gear train, mobilize the RA and DEC axes. I've seen them in action and they are seductively quiet, rapid and fluid in an almost organic fashion. They are also expensive. The periodic error of these mounts is typically less than 1 arcsecond. Popular astro imaging mounts boast periodic error of less than 10 arcseconds while much more modestly priced mounts have errors in the mid double digits. I wondered if an amateur with nearly no knowledge of electronic engineering could attempt to build a rudimentary direct drive telescope mount using a brushless electric motor. What follows is more a proof of concept rather than a polished project that will perhaps inspire you to further develop it.

I found an appropriately sized brushless electric motor on eBay for a ridiculously low price, a Kollmorgen RBE-0181X series motor. Formerly Inland Kollmorgen, the company makes many different kinds of electric motors for industrial and defense applications. Brushless motors differ from conventional brush motors in that they lack the splint ring brush assembly that allows self commutation, that is the change in direction of current flow in the coil windings and hence the magnetic field direction which spins the rotor. The development of digital electronics have made this style of electric motor popular because although commutation is a more complex process, the lack of brushes makes the motor highly efficient (>96 %), highly reliable (400,000 rpm) and with low noise/EMI (no brush arcing). The RBE-0181X specs promised the high torque performance needed to hold the payload of a telescope and camera rigidly by the nature of its 12 powerful neodymium rare earth magnets on its rotor surface. Even at rest it required 120 N of force to separate the rotor from the stator housing. The motor was supplied in frameless form so the first step was to fabricate a structure that would allow the motor to run (Fig. 5.40).

Using some aluminum tubing I fashioned a rotor shaft that fit snuggly by friction through the rotor's central perforation as well as to a pair of common roller bearings. Since I would never be able to make the bearing supports accurate enough to suspend the rotor inside the stator with a constant air gap, I decided to make the position of the stator adjustable by suspending it within a piece of 4″ aluminum pipe with four machine bolts. By wrapping the rotor with a piece of 30 μm thick plastic strip, it fit snuggly and evenly into the stator, and the stators relative position

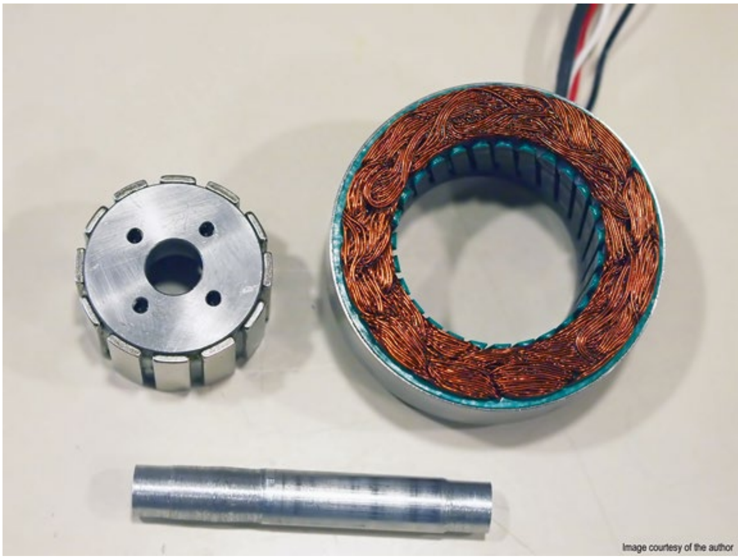


**Fig. 5.40** Kollmorgen RBE-0181X brushless electrical motor in frameless form, rotor, stator and homemade rotor shaft

was locked into place with the four machine bolts. After pulling the strip of plastic away, the rotor was confirmed to spin freely. The rotor face was designed with four holes which were tapped and a structure with a standard 1/4×20 tripod threaded screw was affixed to the rotor. This would be the telescope/camera attachment point (Fig. 5.41a, b).

Brushless motors typically have three sets of windings or coils to generate the fluctuating magnetic field vector. The coils all meet at a common ground connection in the middle of the stator so each coil flows into the other two and only three wires emanate from the stator. So at any time two coils are energized in a brushless motor.

Radio controlled hobbyist aircraft like quadracopter drones utilize brushless motors because they deliver high thrust and lightweight packaging. In these applications, motor speed is controlled by an electronic speed controller (ESC), a pre-made miniaturized semiconductor package that determines the coil firing order and frequency for commutation. Obviously, the ESC must know at all times the rotor position and it determines this information by sensing the back electromotive force (BEMF) of the unenergized third coil. Since the rotor is spinning, the magnets on it are going to induce an electrical current in the third inactive coil and this current will be either a trapezoidal or sinusoidal shaped waveform. The position of the signal at any time on this stable waveform will correlate with the position of the rotor and after a period of calibration the ESC is able to control the speed of the motor. It is in fact quite trivial to get our brushless motor spinning with a store

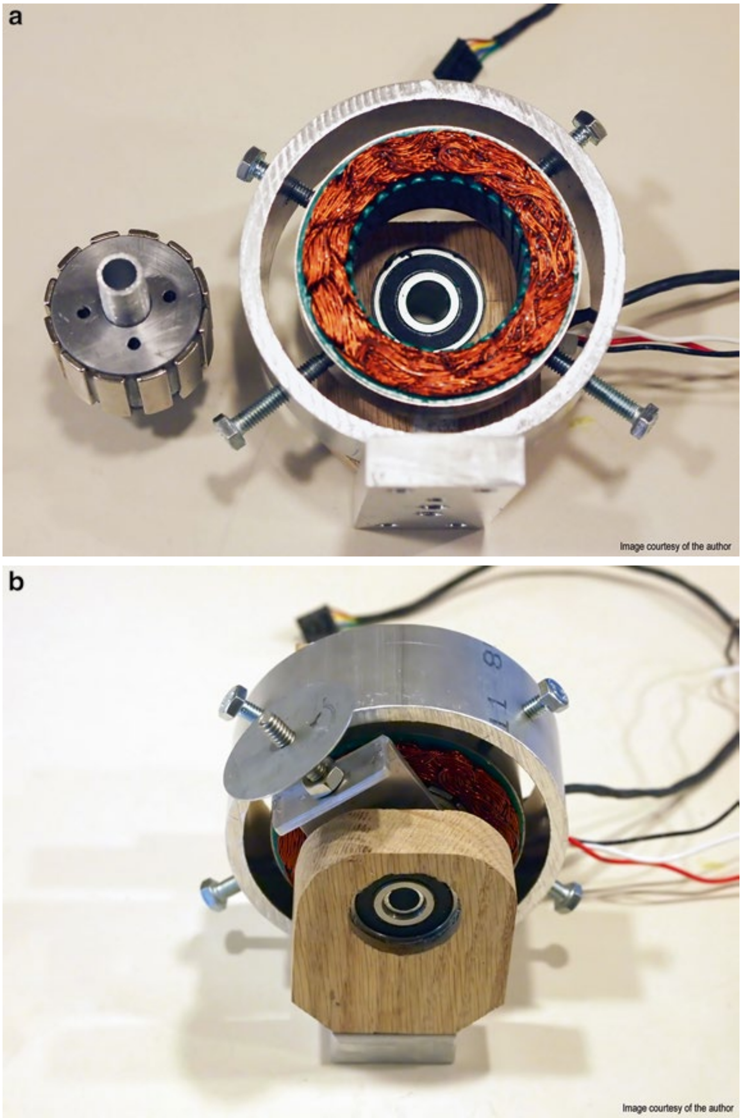


**Fig. 5.41** Making the supporting motor structure

bought ESC with the speed control provided by input from an Arduino Uno but the ESC is not designed for slow speed applications. By about 60 rpm, the motor begins to stumble because at low speed the BEMF becomes faint to nonexistent (Fig. 5.42).

The only other way to determine rotor position and effect commutation is by Hall Effect sensors. These are semiconductors which generate a clean on/off or

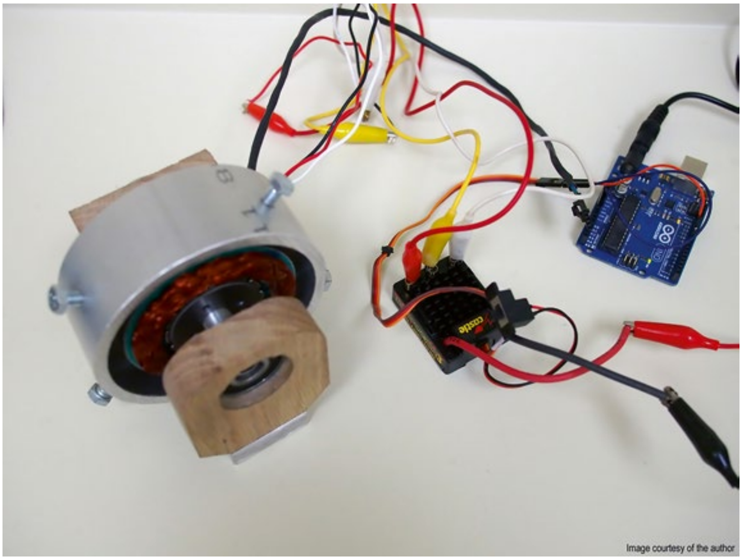


**Fig. 5.42** Motor running with Arduino and R/C electronic speed controller (ESC)

High/Low signal in the presence of a magnetic field. In our motor, there are three sensors placed 45° apart from each other on a circular circuit board distal to the stator coils but within reach of the rotor magnets. In addition to the three phase wires, a five wire cable carries the sensor outputs and the use of a multimeter determined which three wires carried the signal (Orange, Yellow and Brown) and which were the Ground and Positive (5vdc) wires (Fig. 5.43).

The use of an oscilloscope becomes vital at this point to determine the shape, distribution and order of the Hall Effect sensor signals relative to the BEMF of the three coils. These can be quite inexpensive even brand new because some are designed to interface with a computer via USB connection and use the computer's display to show the signal waveform. I ran mine in Windows 95 emulation mode on my Macbook Pro.

BEMF profiles were generated by passively spinning the motor with a powered screwdriver that seemed to deliver a constant rotational speed of about 120 rpm. What the figures show us is that the BEMF waveforms for BR, that is the Black coil relative to the Red coil, is sinusoidal and the curve of each phase is shifted 120° laterally to each others'. If we were to commutate by firing each phase sequentially, R(ed)W(hite) → B(lack)R → WB then there would be periods of decreasing torque as the sine wave fell before the next phase took over. If we invert the negative sine wave (run the current with reversed polarity) we could bridge the valley between RW and BR with the phase BW. This would greatly smooth out the torque delivery curve such that the peak to peak torque ripple is less than 13 % (Figs. 5.44, 5.45, and 5.46).

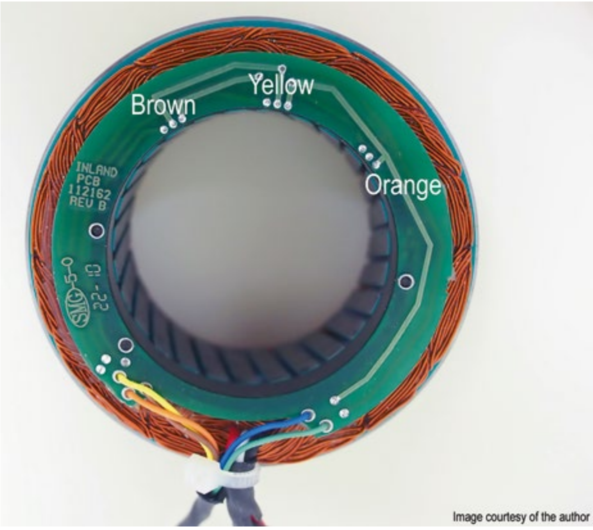


**Fig. 5.43** Closeup view of stator showing position of three Hall Effect Sensors

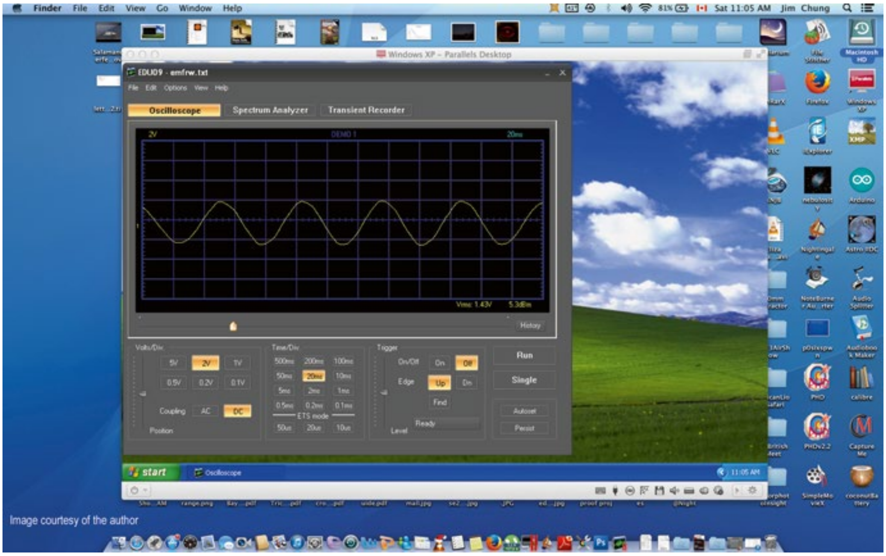


**Fig. 5.44** Vellemann Oscilloscope running on PC (Parallels Emulation in OSX)

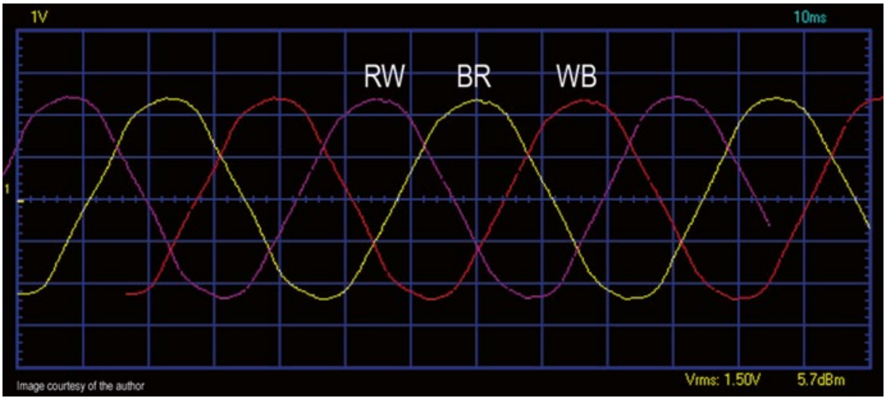


**Fig. 5.45** Sinusoidal back EMF waveforms of the three motor phases B(lack)R(ed), RW(hite), and WB

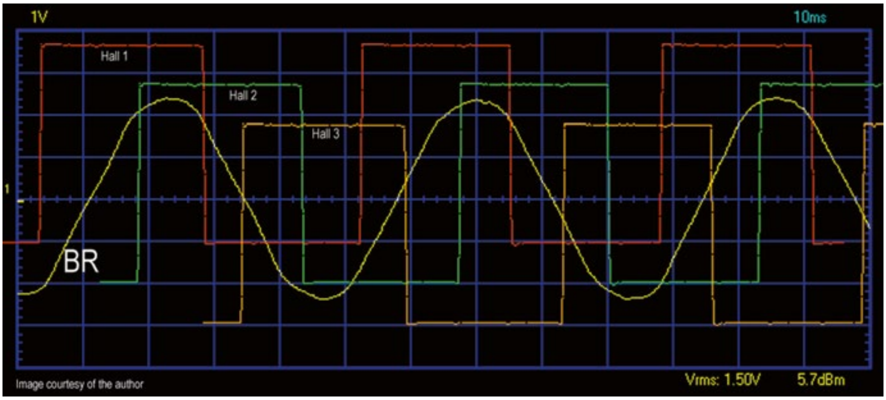


**Fig. 5.46** Hall Effect sensor signals in relation to the BR phase BEMF

The question remains, how and when do we fire this six phase commutation? If we superimpose the Hall Effect sensor signal to BR we see that they are also separated by a 120° phase shift. In fact the timing of any phase corresponds exactly to a unique Hall Effect sensor combination. Studying the figures below reveal the unique sensor combinations that when in effect will trigger the firing of that phase (Figs. 5.47 and 5.48, Table 5.1).

The electronics of the circuit were built on a solderless breadboard and center around a three phase motor driver integrated circuit. The L6234 is a triple half

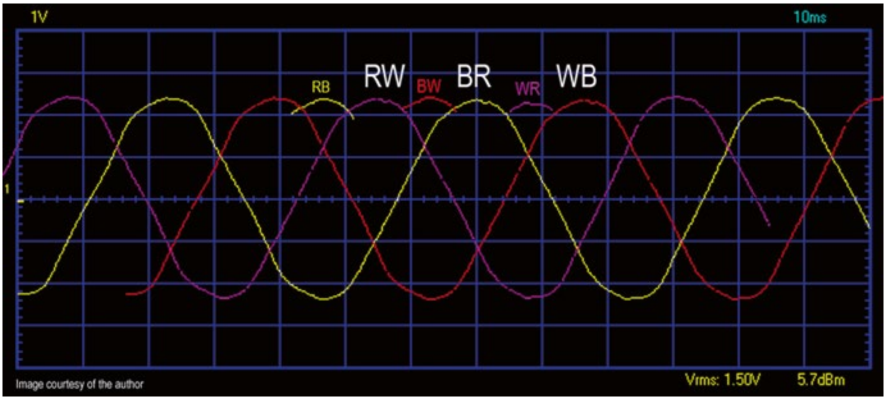


**Fig. 5.47** Six phase commutation scheme for one complete revolution RB → RW → BW → BR → WR → WB

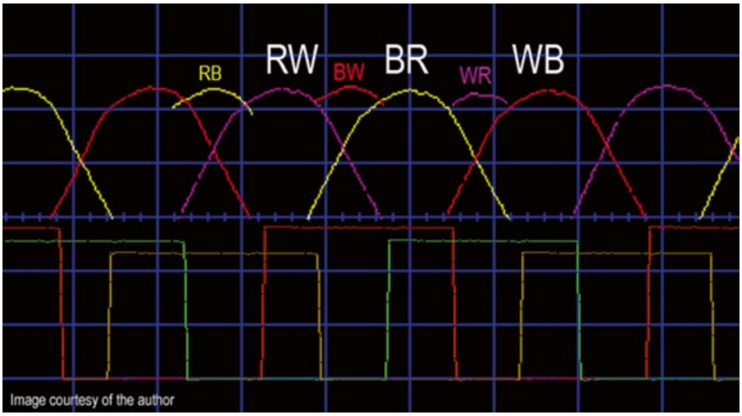


**Fig. 5.48** Hall Sensor logic can be expressed as a three digit binary number describing conditions when each of the six phases should be triggered

**Table 5.1** Breakdown of the six Hall Sensor combinations which correspond to the six phases of commutation

| | H1 (red) | H2 (green) | H3 (brown) | Binary → Decimal |
|---|---|---|---|---|
| R(ed)B(lack) | 0 | 0 | 1 | 4 |
| RW(hite) | 1 | 0 | 1 | 5 |
| BW | 1 | 0 | 0 | 1 |
| BR | 1 | 1 | 0 | 3 |
| WR | 0 | 1 | 0 | 2 |
| WB | 0 | 1 | 1 | 6 |

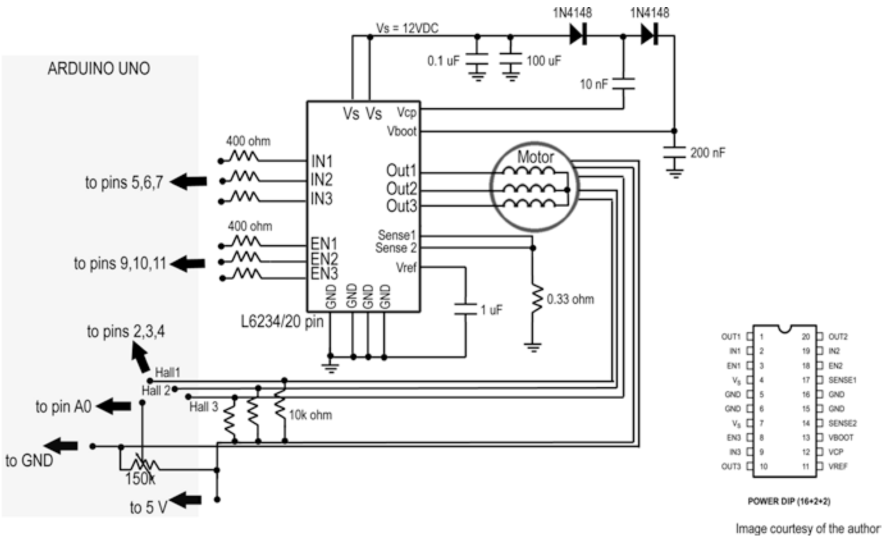


**Fig. 5.49** Circuit schematic of brushless motor drive system and pin assignment for the L6234 IC

bridge design, with each half bridge composed of two DMOS transistors to control the direction of current flow to one of the three phases. The chip functions under logic control, when EN1 is enabled HIGH and IN1 is also HIGH the upper transistor is selected and current flows to OUT1. When IN1 is LOW the lower transistor is selected and current flow to OUT1 is reversed (Fig. 5.49).

Speed control is performed via the 8 bit pulse width modulation (PWM) from three pins of the Arduino Uno. PWM is the application of voltage is a series of rapid on and off pulses ranging from 0 to 100 % of the duty cycle. PWM is far superior to using decreased voltage via variable resistance since there are no thermal losses and you can have maximum torque even at slow speed with a low PWM rate. The PWM frequency can be varied on the Arduino so lower frequencies would improve the resolution of slow speed control. Programming the Arduino is performed on the host computer, compiled and then uploaded to the processor on the Arduino. It runs off the USB 5vdc while the brushless motor and IC are fed by a separate 12vdc power supply, the IC is capable of operating up to 52vdc (Figs. 5.50a, b and 5.51).

In building the circuit make sure that the resistors are placed in parallel to the Hall sensor outputs otherwise the signal will not be read correctly by the Arduino. Both Vs legs of the L6234 need to be fed +12vdc in order to operate and watch for the polarity when using electrolytic capacitors.

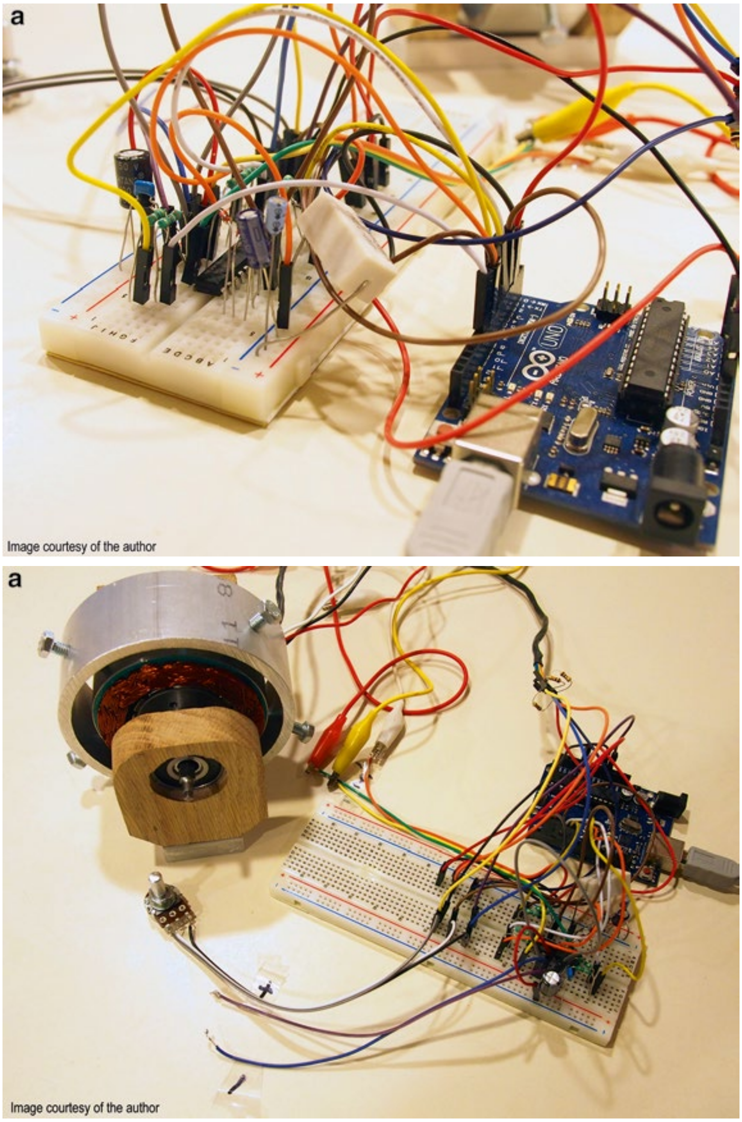


**Fig. 5.50** Close up of breadboard and final assembly

Although the motor can be coaxed to run at sidereal speeds the tracking speed is not regulated. The placement of an external ring of encoders will improve the resolution of the rotor position and allow a closed loop regulation of tracking speed. The idle third phase could also be bought online to smooth out the rotation and increase rigidity with the enhanced resolution afforded by additional encoders.

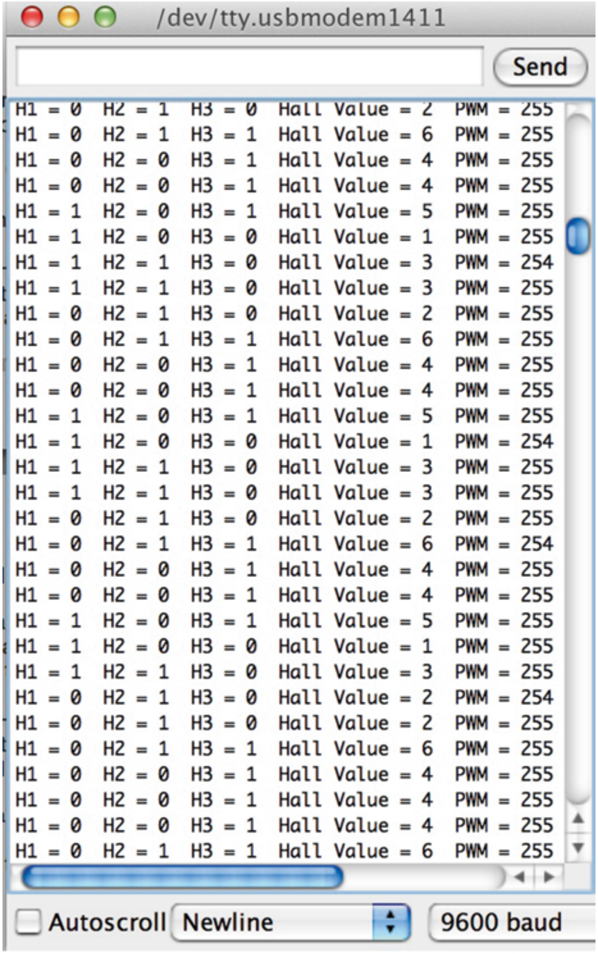

Image courtesy of the author

**Fig. 5.51** Arduino log of Hall Sensor outputs

```
// Jim's Direct Drive Brushless motor

int HallSensor1;
int HallSensor2;
int HallSensor3;
int HallValue = 1;
int motorSpeed = 0;
int potentiometer = 0;
```

```
void setup ()
{
 pinMode(2,INPUT);
 pinMode(3,INPUT);
 pinMode(4, INPUT);

 pinMode(5,OUTPUT);
 pinMode(6,OUTPUT);
 pinMode(7,OUTPUT);
 pinMode(9,OUTPUT);
 pinMode(10,OUTPUT);
 pinMode(11,OUTPUT);

 int prescalerVal = 0x07;
 TCCR1B &= ~prescalerVal;
 int prescalerVal2 = 1;
 TCCR1B |= prescalerVal2;// sets PWM to 32 kHz for
 pin 9 & 10
 TCCR2B &= ~prescalerVal;
 TCCR2B |= prescalerVal2;// sets PWM to 32 kHz for
 pin 3 & 11

 Serial.begin(9600);

}
void loop ()
{
 potentiometer = analogRead(0);
 motorSpeed = map(potentiometer, 5, 1023, 0, 255);
 HallSensor1 = digitalRead(2);
 HallSensor2 = digitalRead(3);
 HallSensor3 = digitalRead(4);
 HallValue = (HallSensor1)+(2*HallSensor2)+(4*HallS
 ensor3);

 Serial.print("H1 = ");
 Serial.print(HallSensor1);
 Serial.print(" H2 = ");
 Serial.print(HallSensor2);
 Serial.print(" H3 = ");
 Serial.print(HallSensor3);
 Serial.print(" Hall Value = ");
 Serial.print(HallValue);
 Serial.print(" PWM = ");
 Serial.println(motorSpeed);

if (potentiometer > 1)
{
```

```
if (HallValue == 1)
{
  digitalWrite(5,LOW);
  digitalWrite(6,HIGH);
  digitalWrite(7,LOW);
  analogWrite(9,0);
  analogWrite(10,motorSpeed);
  analogWrite(11,255);
}
if (HallValue == 2)
{
  digitalWrite(5,LOW);
  digitalWrite(6,LOW);
  digitalWrite(7,HIGH);
  analogWrite(9,255);
  analogWrite(10,0);
  analogWrite(11,motorSpeed);
}
if (HallValue == 3)
{
  digitalWrite(5,LOW);
  digitalWrite(6,HIGH);
  digitalWrite(7,LOW);
  analogWrite(9,255);
  analogWrite(10,motorSpeed);
  analogWrite(11,0);
}
if (HallValue == 4)
{
  digitalWrite(5,HIGH);
  digitalWrite(6,LOW);
  digitalWrite(7,LOW);
  analogWrite(9,motorSpeed);
  analogWrite(10,255);
  analogWrite(11,0);
}
  if (HallValue == 5)
  {
  digitalWrite(5,HIGH);
  digitalWrite(6,LOW);
  digitalWrite(7,LOW);
  analogWrite(9,motorSpeed);
  analogWrite(10,0);
  analogWrite(11,255);
  }
```

```
        if (HallValue == 6)
        {
          digitalWrite(5,LOW);
          digitalWrite(6,LOW);
          digitalWrite(7,HIGH);
          analogWrite(9,0);
          analogWrite(10,255);
          analogWrite(11,motorSpeed);
        }
}
```

## A Motorized Base for Giant Dobs

I recently was fortunate to purchase a used home built 18″ ultralite truss dob with a Steve Swayze reconfigured vintage Coulter mirror. This would be my first foray into the world of truly large telescopes which I define as anything greater than 14 in. given the great profusion of 14″ Celestron SCTs. Every diameter increase by a factor of $\sqrt{2}$–1 or approximately 41 % doubles the light collecting ability of that instrument, in my case the 18″ dob more than doubles the capacity of my 12″ classical cassegrain. I was thinking of using the dob to improve the quality of my planetary images by reducing noise and increasing frame rates with its enormous signal strength. This would necessitate the construction of a motorized base to allow high focal length tracking. With the fast approaching Opposition of Jupiter and the dob in shipping transit (in five individual boxes!), I decided to build the base after obtaining some accurate measurements and photographs from the previous owner/builder.

Designing and building a component to fit another one sight unseen is fraught with all sorts of dangers and unanticipated consequences so careful planning would be required.

I would once again turn to the system of Meade Autostar and DS motors to drive the system because it is so versatile and I have a nice stockpile of handsets and motors. Sketching the design in scale with Photoshop allowed me to visualize the layout of motors and bearings and actually drove the design process since some configurations clearly would not fit space wise (Fig. 5.52).

The design determined the minimum size of the base to be a 30″ diameter circle made from 18 mm thick Baltic Birch plywood. I've cut large plywood circles in the past with a jig saw but I found the results to be amateurish having failed the color within the lines test in Kindergarten. I wanted a mechanical way to cut perfect circles quickly and consistently.

The method I arrived at involves extending the length of my small table saw's cutting table by bolting a 20 in. long piece of wood onto it and drilling a hole 15 in. from the blade. I then drilled a similar sized hole in the center of a 4′ × 3′ piece of plywood and bolted that piece to the table extension. The piece of plywood was now

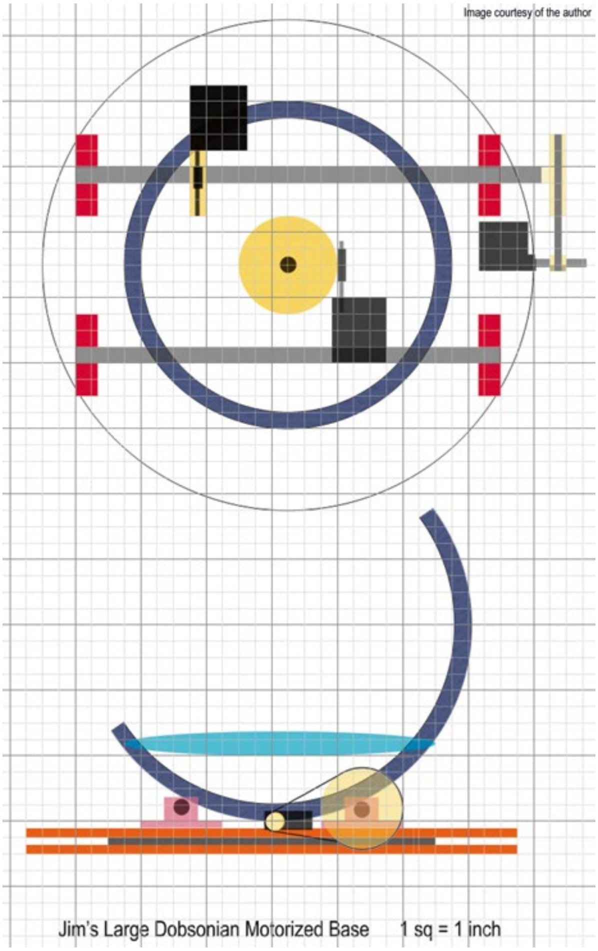


**Fig. 5.52** Preliminary design of the large dob motorized base

able to rotate and by incrementally raising the blade, I was able to cut perfect plywood circles. The circles were sanded and finished with outdoor grade polyurethane varnish. The two pieces were connected with a large 20 in. *lazy susan* circular bearing so that each plywood circle could rotate with respect to the other (Fig. 5.53).

The aluminum bearings of the dob, instead of resting and riding on Teflon coated rocker rails would sit on a pair of ¾″ diameter solid aluminum rods that rotate in a pillow block bearing system. The pillow blocks sit 23″ apart to accommodate the width of the ultralite dob and the fore and aft pair are separated by 12″ so the lower arc of the dob bearings just clear the plywood surface. The separation of the pillow blocks is critical because it impacts on stability and clearance issues. If the block were separated maximally by the 24″ diameter of the


**Fig. 5.53** How to cut large perfect plywood circles on a miniature table saw

bearings then they would have to be severely raised to allow the 12″ arc clearance of the bearings. Some simple high school geometry will determine a formula for this clearance.

$$b = 12 - a = 12 - \sqrt{\left(144 - c^2\right)}, \text{by simple Pythagorean theorem}$$

where b is the amount of space needed to clear the lower swinging arc of the dob bearing and c is the separation of the two rotating aluminum rods (Fig. 5.54).

The azimuth axis movement is controlled by a spare 7.5″ brass 359 teeth Byers gear I had lying around with the worm fitted to a Meade DS motor.

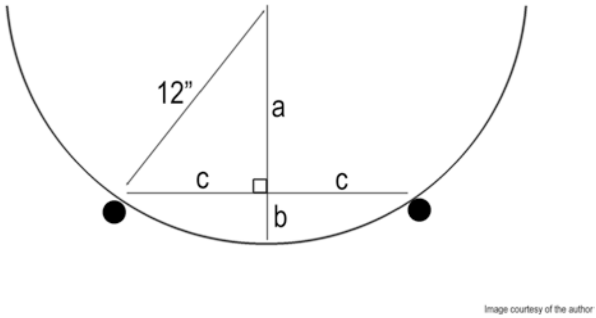


**Fig. 5.54** Mathematically solving clearance issues

The Altitude axis requires the placement of its ring gear outboard since there is not enough space under the aluminum bars without interference from the dob's mirror box structure. The outboard position also makes it difficult to engage a conventional worm with ring gear so I decided to go with a pair of 1/5″ pitch timing belt pulleys (eBay) connected by a cogged rubber timing belt. The larger pulley is connected directly to the protruding end of one of the aluminum bars and the dob can still be pitched manually by sliding the aluminum bearings over the one fixed aluminum bar so no clutch system is needed here.

By calculations alone, the maximum fore/aft separation of the two aluminum rollers is 12 in. (as limited by the diameter of the 30″ circular base) which has a b value of 1.6″. Without having to artificially raise the height of the bearing pillow block there is just enough clearance for the swinging dob bearings.

Be sure to inspect your pillow bearings (Fastenal), because they're inexpensive the ball bearings are press fitted into a cast iron block and often the bearings are not correctly aligned. A hammer and steel punch can correct the orientation which is confirmed with a steel carpentry right angle (Fig. 5.55).

A conventional drill press is unable to function with such a large piece of wood, fortunately they do manufacture these very inexpensive precision drill guides to allow you to drill straight holes (or even holes at a constant angle) (Fig. 5.56).

The Lazy Susan ball bearing was bought from eBay. Originally designed to be used on a dining table it came with short plastic feet protruding from opposite surfaces of the bearing to separate the dining table from the spinning central serving platter. The feet have to be removed and the bearing holes drilled through and countersunk. Much cheaper than buying a dedicated Lazy Susan from Lee Valley Tools which looks the same with the same 550 lb weight capacity but with all holes drilled properly (Fig. 5.57).

Recycling the shaft from a Meade DS mount used in the Skywatcher 12″ Collapsible dob project. I shortened the shaft, tapped some ½″-13NC threads onto the shaft and into the 3.5″ circular aluminum base and crazy glued the two to produce a rigid, fixed vertical shaft. Half inch drill bits are not that common and rarely


**Fig. 5.55** Accudrill Precision Drill Guide

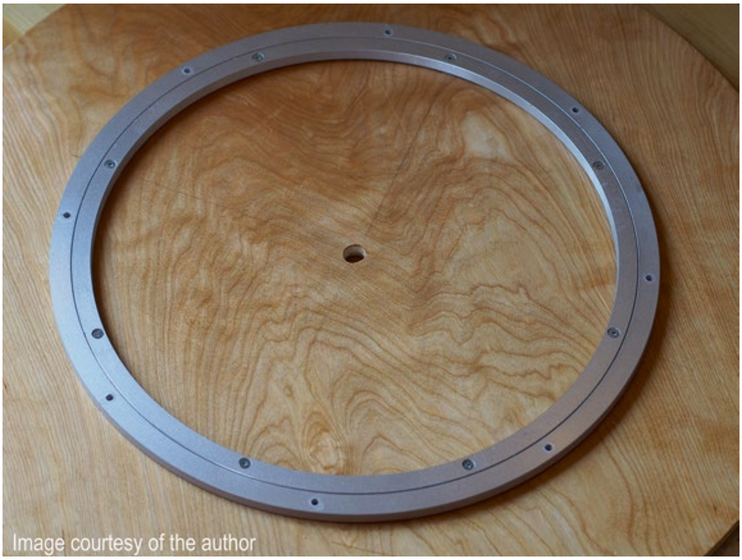


**Fig. 5.56** Lazy Susan azimuth bearing


**Fig. 5.57** The azimuth shaft

are included in an assorted package. To tap the ½″ hole I only had a 3/8″ drill bit as my largest bit so I gradually worked up to the final thread by tapping successively larger sizes and using a cylindrical hand file to wear down the earlier threads (Fig. 5.58).

A temporary jig fabricated out of loose lumber in order to hold the drive altitude shaft rigid and stable and allow accurate thread tapping of the aluminum bar to affix a 3/8″-16NC machine bolt. This will mate to the 3/8″ bore of the large timing belt pulley (Fig. 5.59).

Despite center punching the aluminum bar with a sharp instrument to promote accurate biting of the drill bit and using successively larger bits, there was some drill creep and the final hole was slightly off center. This will result in eccentric movement of the timing pulley and unnecessary tension on the belt. Such are the machining tolerances of the home telescope builder without dedicated tooling machinery. Luckily the solution is to flatten the off center surface so that the pulley can be mounted correctly centered and lock in the position with the two hex bolts in the pulley hub.

The ultralight dob finally arrived and was very well made by fellow amateur astronomer Doug Herren. It featured a nicely welded mirror box made of one inch


**Fig. 5.58** Tapping threads into one of the aluminum bars

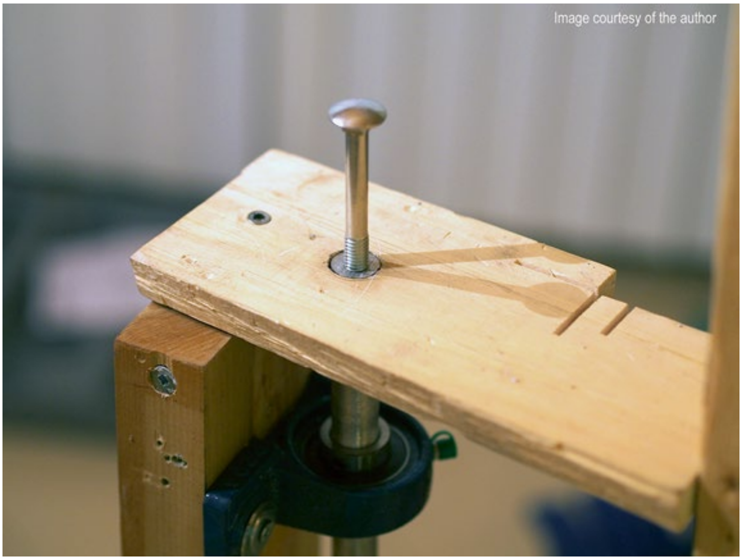


**Fig. 5.59** 3/8″ machine bolt threaded into end of ¾″ diameter aluminum bar

rectangular steel tubing, an 18 point floating mirror cell and 24″ diameter Obsession aluminum bearings following the design recipe presented in David Kriege and Richard Berry's seminal text (1997) "*The Dobsonian Telescope*". I was gratified that it fit the dob base very well with only a few unforeseen complications. Firstly, there was not enough clearance with the mirror box frame and the azimuth shaft so the pillow bearings had to be raised about one and a half inches on some cast metal plumbing pieces. I discovered that the Obsession bearings came coated with slippery ebony star laminate and there was simply not enough stiction between that material and the aluminum rollers. My first solution was to apply some heat shrink material onto the aluminum bars which worked but then I noticed that the mirror box frame was also not flush with the contact undersurface of the bearings causing an interference when the dob was rotated past 60° (Fig. 5.60a, b).

The solution was to install some pieces of high pressure hardware store rubber tubing which also provided even better grip than the heat shrink nylon material. Of course with the installation of the truss poles and the upper truss ring, this balancing counterweight will naturally help the dob maintains its current position (Fig. 5.61).

The azimuth worm was spring loaded to provide a quick release clutch mechanism to allow quick manual rotation of the dob since the motorized system is geared very low for high torque but slow rotational speed (Fig. 5.62).

A pair of stout tensions springs are needed to maintain grip as the dob rotates to its maximum horizontal limit. The mild eccentricity in the large timing pulley meant that belt tension was not always optimal and slippage could occur under heavy load, such as when the dob is most rotated (near horizontal). The solution

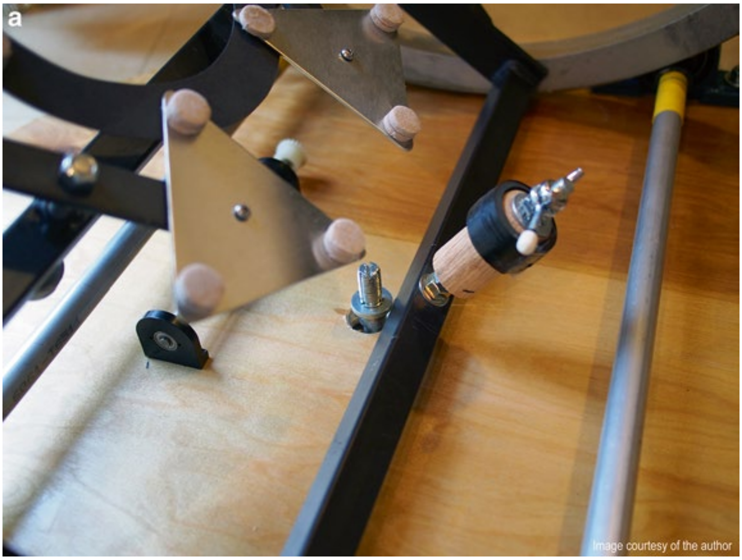


**Fig. 5.60** Unforeseen clearance issues arise


**Fig. 5.60** (continued)

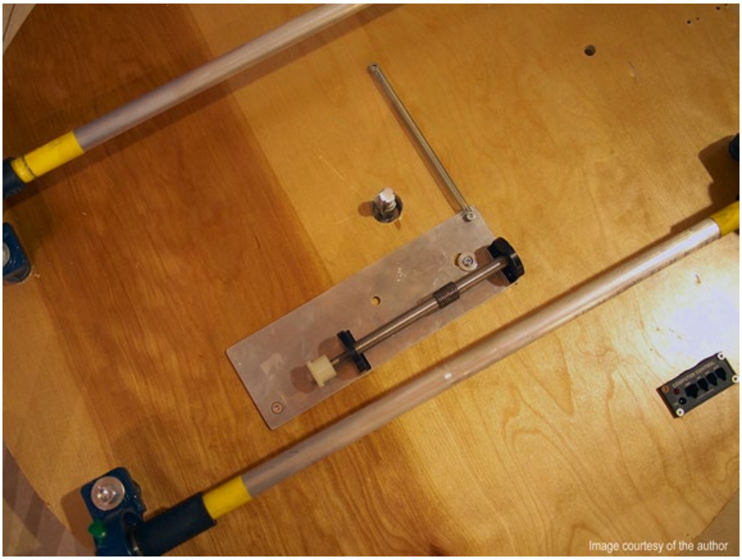


**Fig. 5.61** Azimuth axis clutch system

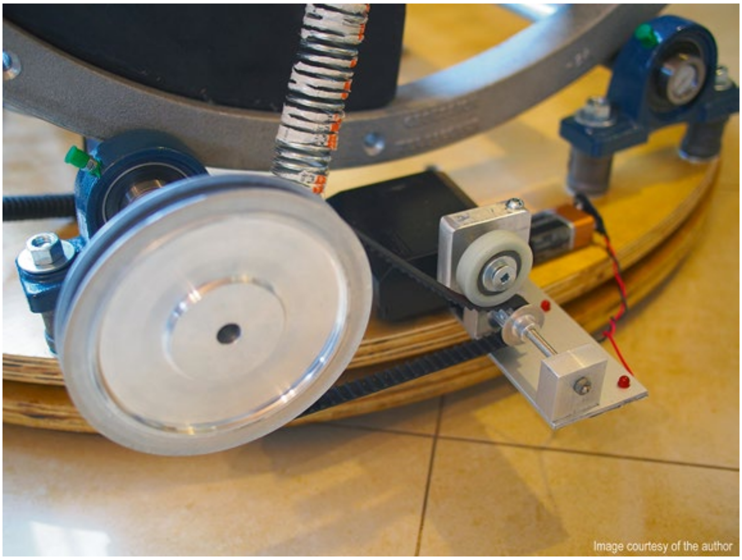


**Fig. 5.62** Altitude gear system with belt tensioner

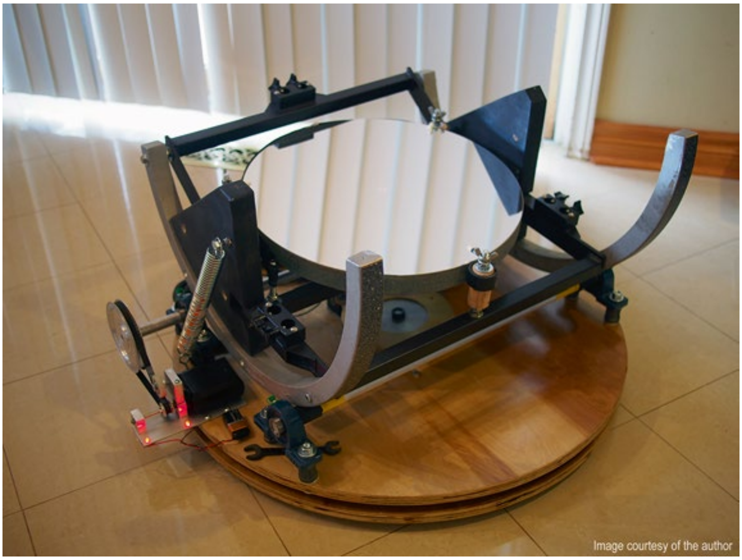


**Fig. 5.63** Completed tracking and motorized base for large dobs

was to install a second belt tensioning wheel. Flashing red leds are present to prevent accidental tripping in the dark over the protruding altitude gear system, a larger diameter base would have prevented this design drawback (Fig. 5.63).

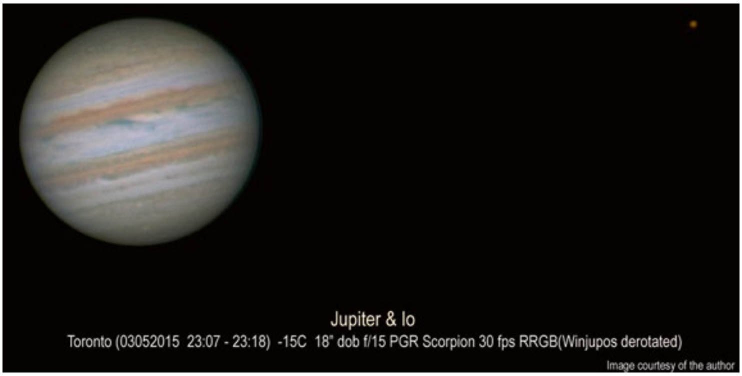


**Fig. 5.64** Image of Jupiter obtained with 18″ dob and motorized alt/az base

As detailed in an earlier section, the Autostar system allows you to change the gear ratios so that the DS motor GOTO calibration can be preserved with alternate gear systems. When you select a Meade mount with the DS motors (either a DS or ETX mount) the calibration ratio is 0.02281483333 for each worm gear tooth. For the azimuth axis the gear ratio becomes 359 × 0.0228148333 = 8.1905. For the altitude axis, the calculation is a slightly more complex. The DS motor turns a 10 tooth timing pulley which is connected by belt to a 68 tooth pulley. This gear ratio is 6.8:1. The 68 tooth pulley rotates the aluminum roller bar which has a diameter (with the rubber hose in place) of 27 mm. This rotates against the dob's aluminum bearings which have a diameter of 612 mm. Since circumference is directly proportional to diameter the effective gear ratio of dob to the 68 tooth timing pulley is 612/27 = 22.8:1. The combined gear ratio from dob to the 10 tooth timing pulley is the product of 6.8 × 22.8 = 154.4:1, it takes 154 rotations of the DS motor output shaft to complete on complete altitude rotation of the dob so the altitude ratio is 154 × 0.0228148333 = 3.5186. Since the clockwise rotation of the DS motor output shaft results in ultimately pitching the dob downwards and counterclockwise in azimuth just like the stock Meade mount, the gear ratios remain positive in sign (Fig. 5.64).

I had a chance to bring the dob to a recent RASC gathering at the DDO and the surprising consensus was that the views of Jupiter were better than those in the monster 74″ observatory reflector. The GRS was just appearing around the far limb and fine band details were occasionally glimpsed when the seeing cooperated. More impressive but perhaps less obvious to some of the participants is the ease at which I transported and deployed the dob in the parking lot. The heaviest piece was the mirror and mirror box which came in at about 60 lb and everything was assembled and collimated in about 15 min. A telescope this size not housed in a permanent observatory but easily portable was unheard of a generation ago.

This chapter has really become a potpourri of ideas embracing mechanical and electrical engineering, quantum physics and writing code. There's a tendency in the professions to specialize because the consolidation of all this new knowledge takes additional years of postgraduate study. And it's more lucrative. Which is why it's so hard to find a family physician that is accepting new patients because all them have become specialists. Now, more than ever, is the need for generalists. People who know a little something about everything yet know enough to stay out of trouble and know when to call in the specialists. Generalists also make good amateur astronomy makers.

# Chapter 6

# Conclusion

Upon reaching this page I hope that your journey was as rewarding and enjoyable as I have found mine to be. As I sit back and gather my thoughts, I come to the realization that amateur astronomy is a very special kind of hobby.

It's a hobby that while superficially juxtapositions with cutting edge technology actually has much more to do with the past. Every photon we observe is a window into the past, some the far distant past beyond the comprehension of mere human existence. Every exaltation of wonder and awe that greets the image of the Hubble Deep Field are but echoes of the wonder and awe Neolithic man expressed for every comet or meteorite. At every imaging session it's while I confront a bewildering tangle of power and data cables that I can easily imagine myself as a nineteenth century scientist like Faraday, Edison or Tesla surrounded by overly complex Victorian steampunk contraptions performing pioneering science that so many amateur astronomers continue to do today.

Astronomy is also a hobby with an unprecedented online presence with every conceivable discussion group populated by friendly and knowledgeable people from all walks of life. Even though I became active only a decade ago, my personal steep learning curve was scaled by lurking online and reading hundreds of detailed discussion threads. To this day, this is still the best way to attain breaking news on new technology, procedures or concepts. Amateur astronomers are collegial and quick to share their wisdom and experience which has fostered many online friendships with people I have never met in person, the very best of social networking.

Finally astronomy is the fascinating story of human nature. Our continuous thirst for understanding is the product of our astronomical existence, remote in the outskirts of own galaxy looking in at the overpopulated center. I cannot imagine the type of culture that must exist at the galactic center, where the night sky does not



J. Chung, *Astro-Imaging Projects for Amateur Astronomers*, The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-3-319-18546-0_6

exist because of the close proximity of stars and therefore no comprehension of the magnitude of the cosmos. Astronomy also reminds us of the very temporary nature of our own personal existence and the unexpected twists of life that we are sure to encounter. Galileo was already a revered polymath at the University of Padua and recognized father of modern science before he fell into the commercially lucrative trade of telescope manufacturing. Merchants used his telescopes to manipulate commodity prices by gleaning the knowledge of inbound maritime freight while it was still at sea. Never did Galileo expect that his innocent astronomical observations with said telescope would result in condemnation for heresy and house arrest for the remainder of his life by the Vatican!

I never expected to write this book because I never expected to take up astronomy as a hobby. Likewise, my wife Denise never expected that a simple Christmas gift in the form of a Televue Ranger refractor would have such far reaching and unintended consequences. Perhaps she'll grant me a pass when she reads this book!

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