Kalamazoo Astronomical Society

Looking Up Since 1936

Introduction to Amateur Astronomy

Part 4: *Telescope Tutorial*

www.kasonline.org

Table of Contents...

Starting Out Right

Anyone can become an amateur astronomer. There are no requirements other than a passion for the night sky. You can pursue this passion with as much or little effort as you desire. Many amateurs just enjoy looking up to the heavens on a clear night and pointing out the bright stars and imaginary shapes of the constellations. Others enjoy scanning the sky with binoculars and nothing else. The goal for many in this wonderous hobby is to purchase a telescope and take a closer look at the Moon, planets, and deep-sky objects.

The goal of the *Introduction to Amateur Astronomy* lecture series is to get you started off on the right foot. No one will punish you if you skip over the prescribed steps to a telescope, but this often leads to disappointment, frustration, and wasted money. If you educate yourself in the basic principles of astronomy, become acquainted with the bright stars and major constellations of each season, and learn to locate objects with binoculars, then you'll get much more joy out of your telescope - and, along the way, you'll know which one is best for you!

Telescope Terminology

Aperture

If any one thing affects the overall performance of a telescope the most, it is aperture: the diameter of the objective lens or primary mirror, specified in either inches, centimeters (cm), or millimeters (mm). You know how professional observatories are always after bigger telescopes? That's because the larger a telescope's aperture, the more light it will collect, and provide brighter images, and resolve finer detail. In general, you should buy the largest aperture telescope that fits your portability and budget requirements.

For example, a globular star cluster such as M13 is nearly unresolved through a 4-inch aperture telescope at a magnification of 150×, but with an 8-inch aperture telescope at the same power, the star cluster is 16 times more brilliant, stars are separated into distinct points, and the cluster itself is resolved to the core.

Aperture directly relates to ***light-gathering power***, the ability of a telescope to collect light. This can be expressed mathematically by using the area of a circle (using its diameter instead of its radius):

$$A = \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = \frac{\pi d^2}{4}$$

To compare the relative light-gathering powers (LGP) of two telescopes, the ratio of their diameters can be calculated by:

$$\left(\frac{LGP_A}{LGP_B}\right) = \left(\frac{d_A}{d_B}\right)^2$$

For example, how much more light will a 10-meter telescope (one of the world's largest) collect than a common amateur 10-inch (0.25m) telescope?

$$\left(\frac{LGP_A}{LGP_B}\right) = \left(\frac{10m}{0.25m}\right)^2 = 1600\times \underset{\textit{more light!}}{}$$

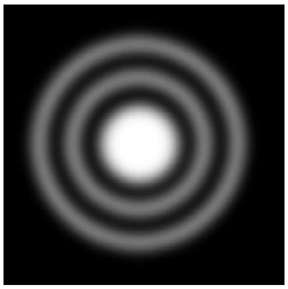
Angular resolution (or resolving power) is the ability of a telescope to reveal fine detail. The angular resolution α, in arcseconds, equals 11.6 divided by the telescope diameter expressed in centimeters.

$$\propto = \frac{11.6}{d}$$

For example, *w*hat is the angular resolution of a 10-inch (25cm) telescope?

$$\propto = \frac{11.6}{25} = 0.46''$$

A ***diffraction fringe*** (or airy disk) is a blurred fringe surrounding any image and caused by the wave properties of light. This is what limits the theoretical resolution of a telescope. Because of this, no image detail smaller than the fringe can be seen unless you use a larger-aperture telescope.



Of course, no telescope will ever be able to reach its theoretical resolution thanks to ***seeing***, a term used by astronomers to rate the steadiness or turbulence of the atmosphere. When the atmosphere is unsteady, producing blurred images, the seeing is said to be poor. A related term is ***transparency***, which refers to the clarity of the sky. The more transparent the sky, the more stars you can see.

Transparency is generally best after a surface cold front or low pressure system moves through the region and surface high pressure builds in. Typically, the air mass accompanying surface high pressure is cooler, drier, and more stable.

However, many times, especially during the fall, winter, and spring, the upper air pattern in this situation may have the jet stream in close proximity (within 300 miles), thereby causing poor seeing conditions due to turbulence in the upper atmosphere.

In addition, the local effects of strong radiational cooling, especially an hour or two after sunset, can contribute to poor seeing within the lower atmosphere despite very clear conditions.

Depending on how much moisture is in the air, the formation of dew, frost, and/or fog can also become a problem for observing. If early evening dew points are above the forecast lows for a given night and clear skies and light winds favor decent radiational cooling, then dew, frost, or fog will likely form.

Focal Length

A telescope's focal length is the distance (usually expressed in millimeters) from the lens (or primary mirror) to the point where the telescope is in focus (the focal point). Longer focal length telescopes generally have more power, larger images, and smaller fields of view.

For example, *a* telescope with a focal length of 2,000mm has twice the power and half the field of view of a 1,000mm telescope.

Magnification

No other characteristic of telescopes is so widely known and yet so misunderstood by most people. When beginners ask, "What's the power of this telescope?" we explain that the question is like asking a car salesman, "What's the speed of this automobile?". The car might, if pushed, do 90 or 120 mph, but does this really matter?

The magnification of a telescope is variable and is determined by the focal length of the telescope and the focal length of the eyepiece:

$$\text{Mag.} = \frac{\text{Telescope Focal Length}}{\text{Eyepiece Focal Length}}$$

For example, a 10mm eyepiece is being used with a telescope 2,500mm in focal length. What is the magnification?

$$250\times = \frac{\text{2500mm Telescope}}{\text{10mm Eyepiece}}$$

As power increases, image brightness and sharpness decrease rapidly. Half the power, four times the brightness. Twice the power, one-fourth the brightness. This is a basic law of optics.

With lower powers, you see brighter, sharper images and cover a larger area. It is easier to find your target, vibration is less troublesome, and things usually look more detailed. Experienced observers know this and usually use the lowest power available most of the time. Higher powers are quite useful for viewing small and distant objects like planets and double stars. Most observers have a selection of eyepieces to match the objects they are viewing.

The general magnification limit is 50× per inch of aperture, or 2 times the aperture in millimeters. For example, the maximum magnification of a 10-inch telescope is 500×. Please note that this is merely a guideline and assumes pristine conditions. The maximum magnification is highly dependent on the sky conditions and quality of your telescope.

There's also a limit to the *minimum* magnification a telescope can work at. The rule here is to multiply your telescope's focal ratio by 7. For example, an f/5 refractor will not be able to reach focus with an eyepiece of 35mm in focal length or longer.

Focal Ratio

The mysterious "f" number is really quite simple. It is the same number used by photographers and refers to the focal length divided by the aperture of the telescope. Photographically, the lower the focal ratio, the "faster" it will be.

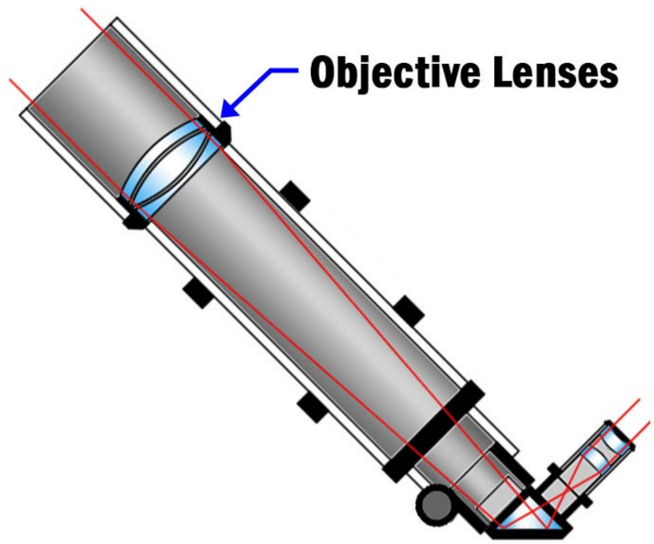
For example, *a* telescope with a 2,500mm focal length and an aperture of 10-inches (250mm) has a focal ratio of 10 (2500/250 = 10). This is written as f/10.

Smaller f/numbers result in wider fields of view and lower magnification, making them best suited for nebulae, galaxies, and many other deep-sky objects. Medium focal ratios (f/8 to f/11) can be used for low - or high-power applications by switching eyepieces.

Telescope Types

Refractors

The familiar long tube, with lenses in front and the eyepiece in back, has in modern times evolved into two distinctly different kinds of telescopes, achromatic and apochromatic.



When white light passes through a lens, its constituent colors are refracted at different angles. This results in blue or orange halos around bright objects like the Moon, planets, and stars. These halos are referred to as a ***secondary spectrum***, with the overall effect known as ***chromatic aberration***. It plagued the first refractors. One early solution was to make refractors with tremendously long focal lengths, which helped mask this effect.

Achromatic refractors use two lens elements to help reduce chromatic aberration. One element is a concave lens composed of Flint glass, with the other being a convex lens made from crown glass. Newer ***apochromatic refractors*** use more exotic lenses like extra-low-dispersion (ED) glass or fluorite to completely eliminate chromatic aberration. This comes at a high price, literally! Apochromats (apos) have the highest cost per inch of aperture out of all telescope designs. The good news is that, thanks to competition, costs have come down in recent years.

The astronomical refractor is the same basic type commonly seen in department stores, so many beginners may give it a bad rap. This is undeserved, as even the lower-cost achromats from reputable makers will perform quite well.

If equipped with a sturdy mount, a small refractor is very nice for observing the Moon, planets, many of the larger star clusters, nebulae, and so forth. With a 45° diagonal, a small astronomical refractor can make a very nice terrestrial telescope. When used with a standard 90° star diagonal, refractors show a left-to-right reversed image.

Refractor Pros:

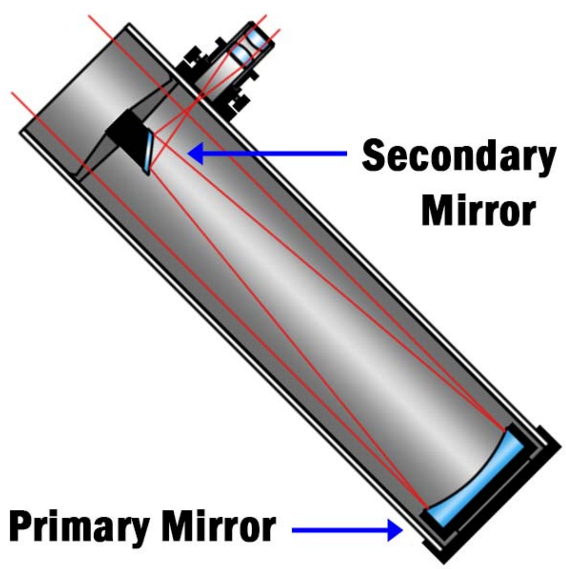
- Easy to use and reliable due to the simplicity of the design.
- Little or no maintenance:
  - The objective lens is permanently mounted and aligned.
  - Sealed optical tubes reduce image-degrading air currents and protect optics.
- High-contrast images with no secondary mirror or diagonal obstruction:
  - Excellent for lunar, planetary, and binary star observing, especially in larger apertures and longer focal lengths.
- Color correction is good in achromatic designs and excellent in apochromatic, fluorite, and ED (extra-low-dispersion) designs.
- Good for distant terrestrial viewing (when used with 45° diagonals).

Refractor Cons:

- More expensive per inch of aperture than Newtonians or catadioptrics:
  - The cost and bulk factors limit the practical, useful maximum size of the objective to small apertures.
  - Less suited for viewing small and faint deep-sky objects such as distant galaxies and nebulae because of practical aperture limitations.
- Heavier, longer, and bulkier than equivalent aperture Newtonians and catadioptrics.
- They are difficult to collimate if the optics are knocked out of alignment.
- Some color aberration in achromatic designs (doublet).
- Poor reputation due to low-quality imported toy telescopes; a reputation unjustified when dealing with a reputable manufacturer.

Reflectors

A very popular and economical telescope, the Newtonian reflector (invented by none other than Sir Isaac Newton in 1668) is primarily an astronomical instrument. It uses a concave parabolic primary mirror to collect and focus incoming light onto a flat secondary (diagonal) mirror that, in turn, reflects the image out of an opening at the side of the main tube and into the eyepiece.



Simple to manufacture (many amateurs still choose to grind their own mirrors), resulting in the lowest cost per inch of aperture of any type of telescope. Thus, Newtonians are available in the widest range of apertures.

Although heavier and somewhat more difficult to transport than similar-sized catadioptric telescopes, the Newtonian is preferred by many astronomers who want a large aperture at a moderate cost. Six- and eight-inch Newtonians are easily carried in an automobile, and the tube detaches from the mounting in seconds. Newtonians are generally not suited to earthly observation, as the image is upside -down.

Newtonians need occasional cleaning and collimation (optical alignment of the primary and secondary mirrors), but you can easily do this yourself. Optical performance is excellent. The large aperture makes them ideal for deep-space views of galaxies, star clusters, and nebulae. The simple optical design results in sharp, high-contrast planetary and lunar views for longer focal lengths, too.

Reflector Pros:

- Lowest cost per inch of aperture compared to refractors and catadioptrics since mirrors can be produced at less cost than lenses in medium to large apertures.
- Available in a wide range of apertures (from 76 mm to 32 inches!):
  - Excellent for faint deep-sky objects such as remote galaxies, nebulae, and star clusters.
- Low optical aberrations and deliver very bright images due to the generally fast focal ratios (f/4 to f/8).
- Mid- to long-focal-length versions are very good for lunar and planetary work.
- Reasonably compact and portable up to focal lengths of 1,000mm.
- Higher-end models are excellent for deep-sky astrophotography.

Reflector Cons:

- Generally not suited for terrestrial applications.
- Open optical tube design allows image-degrading air currents and air contaminants, which, over a period of time, will degrade the mirror coatings and cause telescope performance to suffer.
- Slight light loss is due to secondary mirror obstruction when compared with refractors.
- More fragile than refractors or catadioptrics and thus require more maintenance (such as collimation). Reflectors 6 inches in aperture and larger will require collimation each time they are used.
- Suffer from off-axis coma, which is an aberration that makes stars look like comets at the edge of the field-of-view. This can be overcome through the use of "coma correctors." (like the ones available from Tele Vue and Baader Planetarium).
- Large apertures (over 8 inches) are bulky and heavy when mounted on German equatorial mounts and tend to be expensive.

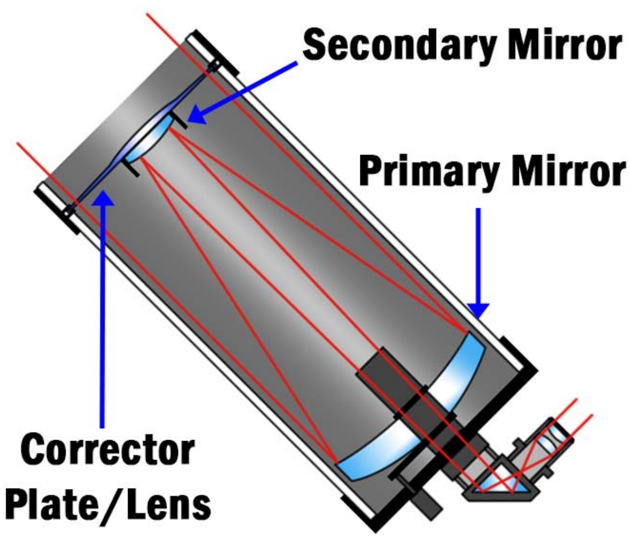
Schmidt-Cassegrain (Catadioptrics)

Catadioptric telescopes have combined the best features of other types into very compact, lightweight instruments. They use both mirrors and lenses, resulting in telescopes that are only about twice as long as they are wide. Unlike the basic refractor and reflector, these telescopes have distinctly modern 20th-century designs.

The features are many: the closed-tube, lightweight, rugged designs are easily portable, and their optical performance is nearly equal to other telescope types. Little if any maintenance or alignment is required. Like refractors, catadioptric telescopes can be used either astronomically or terrestrially. The lightweight optical assembly for apertures under 10 inches allows very strong mounts to be made very light in weight. Camera adapters and many varied accessories are widely available.

The only significant disadvantage is just what might be expected: with the exception of apochromatic refractors, compound telescopes cost more than other telescopes of equal aperture.

In Schmidt-Cassegrains, the most common type of catadioptric telescope, light enters through a thin aspheric Schmidt correcting lens (called a corrector plate), then strikes the spherical primary mirror and is reflected back up the tube and intercepted by a small secondary mirror, which reflects the light out an opening in the rear of the instrument where the image is formed at the eyepiece. The SCT design was made commercially economical due to the optical production innovations of Tom Johnson at Celestron International in the early 1960s. His techniques for producing the complex-curved Schmidt corrector plate were the foundation for every major manufacturer in the business today.



The Maksutov-Cassegrain telescope is perhaps best known due to the introduction of the Questar telescope in the 1950s. The "Mak," introduced by Dmitry Dmitrievich Maksutov in 1944, uses a deeply curved, thick front corrector lens, with a reflective spot on the corrector acting as the secondary mirror. The most popular Maksutov telescopes today are 90mm in diameter. Spotting scope models are used for both astronomical and terrestrial observing. Large-diameter models are very difficult to manufacture and take a long time to reach thermal stability at night, but they can rival apochromatic refractors with high-contrast views of the planets.

Schmidt-Cassegrain Pros:

- It is considered by some to be the best all-around, all-purpose telescope design. Combines the optical advantages of both lenses and mirrors while canceling their disadvantages:
  - Excellent optics with razor-sharp images over a reasonably wide field.
  - Good for lunar, planetary, and binary star observing.
  - Good for deep-sky observing or astrophotography.
- A closed-tube design reduces image-degrading air currents.
- Most are extremely compact and portable.
- Durable and virtually maintenance-free.
- Large apertures are less expensive than equivalent-aperture apochromatic refractors.

Schmidt-Cassegrain Cons:

- More expensive than Newtonians of equal aperture.
- Slight light loss is due to secondary mirror obstruction compared to refractors and most reflecting telescopes.
- Takes longer for optics to reach thermal equilibrium as compared to equivalent-size reflectors.
- Image can shift when focusing, especially in apertures over 10 inches.

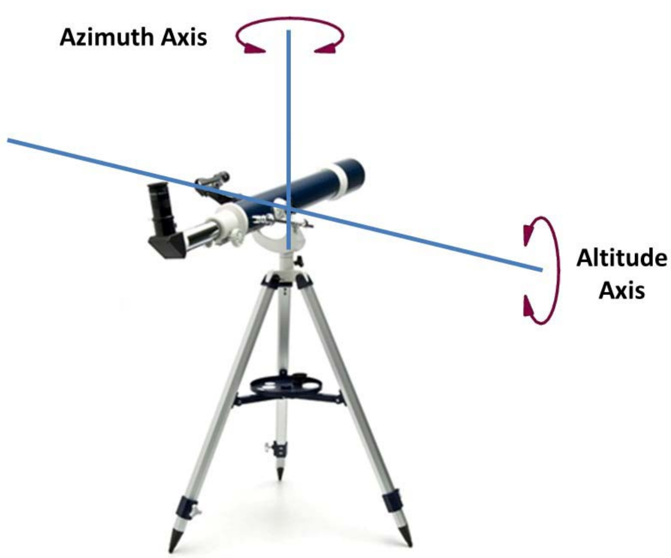
- Narrow field-of-view compared to fast Newtonians (f/4 – f/8).
- Larger apertures (10 inches and up) are pretty heavy.

Telescope Mounts

A mount can account for at least half the cost of a telescope system. The best optics in the world are useless without a good, sturdy mount (especially when used for astrophotography). An astronomical telescope requires a much different mount than a small terrestrial scope. The two basic types of mounts are altazimuth and equatorial.

Slow-motion controls are a real convenience on any non-computerized telescope. You'll be adjusting the aiming of your telescope quite often to follow objects and find new ones. On a simple telescope, you just push the tube to adjust the aim. Slow-motion controls let you simply turn a knob to make precise adjustments, greatly smoothing the movement.

Electric motor drives (clock drives) work along with an equatorial mount to drive the telescope across the sky at just the right speed to cancel the apparent motion of the heavens. It's a real surprise to most people to see how quickly even a large object like the Moon will drift right out of view unless a motor drive is in use.



Altitude-Azimuth Mounts

The altazimuth (alt-az) mount has two motions: altitude (up and down) and azimuth (left and right). It is the simplest type of mount, as it is much more intuitive for beginners to use when compared to German equatorial mounts. No setup alignment is required, and they are low in cost. Alt-az mounts also have the advantage of keeping the eyepiece in a convenient position at all times. Many astronomical refracting telescopes are used with altazimuth mounts today. It is ideal for terrestrial use, although a good altazimuth mount with slow motion controls will work very well for astronomy. Many are now motorized or even computerized!

Dobsonian telescopes are very popular since they use a rocker-box-style altazimuth mount. In fact, it is the rocker box that *makes* it a Dobsonian. The telescope itself is a Newtonian reflector. This design was made popular by noted amateur astronomer and Vedantan monk John Dobson. It revolutionized observational astronomy by making much larger-aperture telescopes available to amateurs.

Mr. Dobson was never interested in patenting or profiting off the design. His goal was to get as many telescopes out there as possible so people could share their views of the universe with others. (Read more about John Dobson in the **February 2014 issue** of *Prime Focus*, page 4). Observing through Dobsonian telescopes 18 inches and greater can be *very* addictive and lead to an affliction known as ***aperture fever***, an obsession for a bigger, better telescope. You've been warned!

Altazimuth Advantages:

- Lower cost compared to an equatorial design.
- Most compact type of mount.
- The eyepiece is always in a convenient position.
- Easy to use for terrestrial viewing.

Altazimuth Disadvantages:

- Will only track if motorized or computerized.
- Must be mounted equatorially (using a wedge) in order to be used for astrophotography.

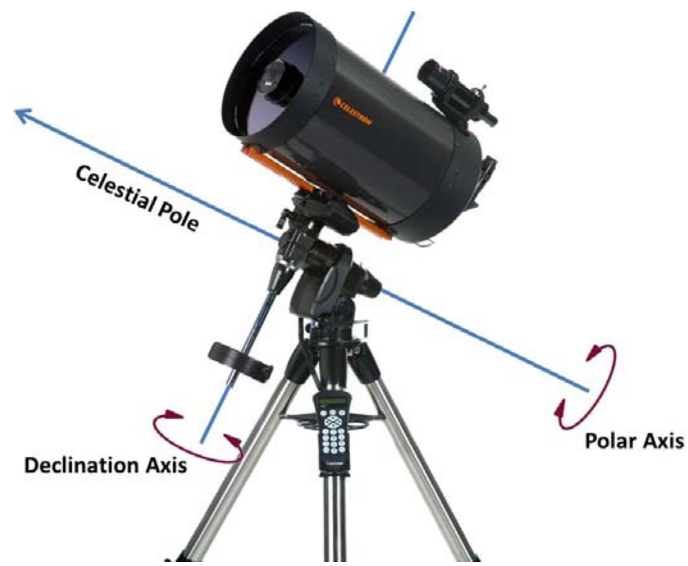
Equatorial Mounts

Equatorial mounts are designed specifically for astronomical use. As Earth rotates once each day, the stars and planets appear to move across the sky. To follow a celestial object, the telescope must track a curved path at exactly the correct rate. An equatorial mount has one axis tilted so that it is parallel to Earth's axis of rotation. By then simply rotating the telescope in one axis only, objects will appear to sit still when viewed through the scope.

Fork mounts are a very popular equatorial mount design, being well suited to the short tubes found on catadioptric telescopes. The companion equatorial wedge tilts the 'polar axis' of the telescope to line up with the celestial sphere for astronomical use. Usually, the base of the fork mount can be attached to the tripod without the wedge for terrestrial altazimuth operation or general viewing at night.

German equatorial mounts are easily recognized by their counterweights extending opposite the optical tube. Refractors and Newtonian reflectors are often found on this kind of mount, and recently, some Schmidt-Cassegrain designs have again become popular.

German mounts have a right ascension (R.A.) axis that is aimed toward Polaris, the North Star, to polar align the mount. Once aligned, the telescope can track the sky using slow-motion controls or a clock drive to rotate the right ascension axis. This axis allows motion from east to west. The telescope rotates around the mount's declination (Dec.) axis in order to allow movement north and south.



These mounts function very well, with the inconvenient and sometimes awkward counterweight being the major drawback to this design. They are much easier to polar align and balance compared to fork-mounted telescopes.

German Mount Advantages:

- Allows automatic tracking with a clock drive.
- Can be use with a variety of optical tubes.
- It is easy to point to most areas of the sky.
- Good for astrophotography.

German Mount Disadvantages:

- Heaviest type of mount.
- Longer setup time for large telescopes.

Electronically Assisted Astronomy

Electronically Assisted Astronomy (EAA) is the use of technological aids for the enhancement of astronomical viewing. Unlike astrophotography, EAA typically uses exposures ranging from 10 to 30 seconds. EAA is a form of astrophotography. However, the purpose of EAA is to observe in near real time, while the goal of astrophotography is to produce a quality image. EAA can be done with light intensifiers, video cameras, CCD or CMOS cameras, or smart telescopes specifically engineered for the task. More on the latter shortly.

There are several reasons amateur astronomers may utilize EAA over traditional observing. EAA can increase observable detail and bring dim objects within reach. An observer may have poor eyesight, be disabled, or live in light-polluted conditions. The viewer can observe from a more comfortable location, position, or posture. Large-aperture telescopes that are heavy, difficult to transport, and time-consuming to setup aren't necessarily required. There are fewer equipment requirements than with astrophotography (i.e., no polar alignment or autoguiding). Observations in other parts of the spectrum (i.e., near infrared and ultraviolet) become possible, and deep-sky objects can be viewed in color. Finally, you can easily document your observations by saving the images.

EAA is typically done by stacking short exposures over a short period of time, whereas astrophotography normally stacks long exposures over a long period of time (even over multiple nights). Both are done to increase the signal and reduce noise. EAA is often used to see more than you might if you were just using an eyepiece, while the purpose of astrophotography is generally to create the best image possible.

Unlike astrophotography, most types of mounts can be used. Any motorized mount, equatorial, alt-azimuth, or sky tracker is preferable. A mount with GoTo capability is not required but is recommended. Any style of telescope will do, but it is recommended to start with a low-f/ratio (short focal length) refractor. Focal reducers can also reduce exposure times. Any imaging device listed earlier will work. Cooled cameras are not required, but they help reduce noise and increase sensitivity. A focus mask (i.e., Bahtinov) is often used, as well as LED panels for taking flat fields.

Those with laptops running Windows could use Sharpcap or ZWO's ASI Studio for camera control and image acquisition. Cloudmakers offers a suite of astrophotography software for Apple users, including AstroImager, AstroGuider, AstroTelescope, and AstroDSLR. Raspberry Pi and Linux systems could use Stellarmate/Astroberry or Kstars/Ekos.

Similarly, you can invest in a ZWO ASIair. These are small, portable computers specifically designed for EAA, or astrophotography, and can be controlled wirelessly from your smartphone or tablet computer. The ASIair eliminates the need for additional software, USB hubs, power supplies, and a Wi-Fi router. It's many features include polar alignment, focus, autoguiding calibration, target selection, platesolving, live stacking, autorun, creating an imaging plan, mosaics, and video/planetary imaging.

EAA is also an excellent outreach tool. EAA makes viewing and speaking about deep-sky objects with a small audience simpler, as opposed to each person taking a turn looking through an eyepiece. You do not need to teach people how to use the telescope, i.e., where to touch (or not touch) and how to focus. EAA puts the emphasis on the excitement and wonder of what you're looking at instead of the equipment.

Smart Telescopes

A smart telescope is an all-in-one unit that combines a telescope, tracking mount, camera, and computer into one compact and highly portable imaging system. Controlled with an app on a smartphone or tablet, smart telescopes automate many of the complex processes of EAA and astrophotography, such as star alignment, focusing, and tracking. Simply choose the target you would like to view, and the telescope will automatically slew to and center it. Even more complex processes like image stacking and processing are all done for you. Groups of up to 20 people can view the images taken by the telescope on their own smartphones, while the owner of the telescope maintains control.

The first smart telescope released was the Enhanced Vision Telescope (eVscope) from the French manufacturer Unistellar. It was a 4.5-inch (114mm) reflector with a focal length of 450 mm. It was conceived in January 2015 and exhibited at the Consumer Electronics Show in Las Vegas in January 2017. Unistellar partnered with the SETI Institute in July 2017 and started a crowdfunding campaign later that same year. Over 2,100 backers pledged $2.2 million to make the eVscope a reality. After several delays, the first production units began shipping out in early 2020.

Today, Unistellar offers several smart telescope models, including the Equinox 2 and Odyssey (both $2,499), Odyssey Pro ($3,999), and eVscope 2 ($4,899). Both of the Odyssey telescopes are 3.1-inches (85mm) in aperture with focal lengths of 320mm, while the Equinox 2 and eVscope 2 each have 4.5-inch (114mm) mirrors with 450mm focal lengths.

Vaonis, another French company, first released the Stellina in April 2019. Stellina's unique design has earned the company many industry and design awards, including the Red Dot Design Award in 2018 and the CES Innovation Award for Digital Imaging in 2021. It features an 80mm refractor with a 400mm focal length and an integrated dew heater. At the base of the telescope is a 6.4 MP Sony IMX178 CMOS sensor with a CLS (city light suppression) light-pollution filter in front of it. The current price is $3,999.

Other models from Vaonis include Hestia, Vespera II, Vespera Pro, and Hyperia. Hestia is the first ever smartphone-based telescope and costs only $299. It looks more like a book or a digital projector. The front of the telescope has an offset 30mm lens. Line up your smartphone camera with the Hestia ocular on top. This increases the magnification of your smartphone's camera 25 times. So, yes, it does not come with its own imaging sensor, but you need to use a smartphone (or tablet) with all the other smart telescopes anyway!

The Vespera II features a 50mm lens with a 250mm focal length and a Sony IMX 585 color sensor with a resolution of 3840 x 2160 (8.3 megapixels). Among its many features are live mosaic capture. It will automatically create panoramas of large targets, like the Andromeda Galaxy. The Vespera Pro has the same aperture and focal length as its sibling but has a Sony IMX 676 color sensor with a resolution of 3536 x 3536 (12.5 megapixels). It costs $2,999.

Finally, the Hyperia telescope is in a league of its own. With a 5.9-inch (150mm) triplet apochromatic lens and 1,050 mm focal length, it is the largest refracting smart telescope on the market. It uses Sony's IMX455 full-frame monochrome sensor that has a 61-million-pixel image definition. When in use, it is nearly 7 feet tall and weighs 165 lbs., so it's not nearly as portable as other smart telescopes. It can be yours for the staggering price of $45,000!

Hong Kong-based DWARFLAB launched the DWARF II smart telescope in August 2022. Its design seems to be patterned after the "heads" of the Mars rovers Curiosity and Perseverance. It has a periscope design with two lenses, each with an aperture of 0.9 inches (24mm). One is a wide-angle lens with a focal length of 48mm, a resolution of 2 Megapixels, and a field of view of 50°. The other is a telephoto lens with a 100mm focal length, a resolution of 8 Megapixels, and a field of view of 3°. It includes a UHC light pollution filter and two solar filters (one for each lens). The classic version costs $459, and a deluxe version sells for $595.

Chinese-based ZWO, well known for their planetary, autoguiding, and deep-sky cameras, started shipping the SeeStar S50 smart telescope in August 2022. It features a 50mm aperture refracting telescope with a focal length of 250mm, a Sony IMX462 color sensor with a resolution of 1920x1080 pixels, weighs just 6.6 lbs. (3 kg), and costs only $499. The SeeStar also includes a light pollution filter, a solar filter, and a dark frame filter.

Celestron announced its own smart telescope in January 2024. The Origin Intelligent Home Observatory

uses a 6-inch (152mm) version of its Rowe-Ackermann Schmidt Astrograph (RASA). In the RASA design, the Sony IMX178 6.44 MP color CMOS sensor lies at the front of the telescope tube, not the back, creating an ultra-fast f/2.2 system with an extraordinarily wide field of view while providing sharp images to the edge. Its single fork-arm mount houses an internal lithium battery capable of over 6 hours of continuous use. One fan helps eject air from the back of the telescope, while another in the base helps keep the Raspberry Pi 4 Model B computer cool. The Celestron Origin sells for $3,999.

Many new smart telescope models will certainly be released in the future as Electronically Assisted Astronomy grows in popularity.

Eyepieces

Standard eyepieces have a barrel diameter of 1.25 inches and are interchangeable with all telescope models. Eyepieces with 0.965-inch barrel diameters are often of lower quality and have been historically included with cheap department store telescopes. They should be avoided.

Some very low-power, wide-field eyepieces are supplied in extra-large 2-inch barrels, which have breathtaking "porthole in space" performance if your telescope has a suitably-sized diagonal or eyepiece holder that fits them. Some cost more than quality telescopes and can be quite heavy, making balance an issue with some telescopes.

Huygens

The first compound eyepiece was invented by Dutch astronomer Christiaan Huygens in the late 1660s. Huygens eyepieces contain a pair of plano-convex elements. These oculars, commonly supplied with department store telescopes, have a narrow field-of-view, and the image quality suffers from spherical and chromatic aberrations, image curvature, and an overall lack of sharpness. What do you expect from an eyepiece invented over 360 years ago? If you're not sure if you own a Huygens eyepiece, check and see if an H is etched on the barrel. For instance, an H25mm indicates a Huygens eyepiece with a 25mm focal length. It's best to replace it.

Ramsden

This design was created by Jesse Ramsden in 1782. As with the Huygens, a Ramsden eyepiece consists of two plano-convex lenses. However, the Ramsden elements are flipped so that both convex surfaces face each other. The eye relief is better, but the aberrations are as bad as the Huygens style or worse. Therefore, like the Huygens, it is probably best to pass it by in favor of other designs.

Kellner

Carl Kellner introduced the first achromatic eyepiece in 1849. Based on the Ramsden, the Kellner eyepieces replace the single-element eye lens with a cemented achromat. This greatly reduces most of the aberrations common to Ramsden and Huygens eyepieces. Sometimes called modified achromats (MA) or super-modified achromats (SMA), Kellners feature fairly good color correction and edge sharpness, little curvature, and apparent fields of view ranging between 40° and 50°.

Perhaps the greatest drawback of the Kellner design is its tendency for internal reflections (otherwise known as ghost images). Thanks to antireflection optical coatings, this effect is almost eliminated when Kellners are used with telescopes 8 inches and smaller.

Kellners represent a good buy for budget-conscious owners of department store telescopes looking to replace Huygens eyepieces. However, Plössl eyepieces can be found at very affordable prices today, especially on the used market.

RKE

An RKE eyepiece is an adaptation of a Kellner eyepiece designed by Dr. David Rank for Edmund Scien-

tific. Instead of using an achromatic eye lens and a single-element field lens, the RKE (short for Rank-Modified Kellner Eyepiece) does just the opposite. The computer-optimized achromatic field lens and single-element eye lens combine to outshine the Kellner in just about every respect. Actually, the performance of the three-element RKE is most comparable to that of the four-element orthoscopic, with a moderate apparent field-of-view (45° for the RKE) as well as good color correction and image clarity. Both work well at all focal lengths on all telescopes.

Orthoscopics

Introduced in 1880 by Ernst Abbe, the orthoscopic eyepiece has become a perennial favorite of amateur astronomers. It consists of a cemented triplet field lens matched to a single plano-convex eye lens. The result is an eyepiece with no chromatic or spherical aberration. There is also little evidence of ghosting or curvature of the field. Orthos offer flat views with apparent fields between 40° and 50° and moderate eye relief that is typically a millimeter or two shorter than the focal length. Color transmission and contrast are superb, especially when combined with today's optical coatings. Despite their stellar performance, only a handful of companies manufacture orthoscopic eyepieces, so they're a little hard to find.

Erfle

The Erfle, the granddaddy of all wide-field eyepieces, was originally developed in 1917 by Heinrich Erfle for military applications. With apparent fields of view ranging between 60° and 75°, it was quickly embraced by the astronomical community as well. Internally, Erfles consist of either five or six elements; one variety uses two achromats with a double convex lens in between, while a second has three achromats.

Erfles give observers an outstanding panoramic view of the deep sky. The spacious view takes its toll on image sharpness, which suffers from astigmatism toward the field's edge, especially in telescopes with fast focal ratios. Therefore, Erfles are not suited for lunar and planetary observing.

Plössl

One of the most highly regarded eyepieces around today, the Plössl features twin close-set pairs of doublets for the eye lens and the field lens. The final product is an excellent ocular that is comparable to the orthoscopic in terms of color correction and definition but with a somewhat larger apparent field-of-view. Ghost images and most aberrations are sufficiently suppressed to create remarkable image quality.

Though it was developed in 1860 by Georg Simon Plössl, an optician living in Vienna, Austria, the Plössl eyepiece took more than a century to catch on. That all changed in 1980, when Tele Vue introduced a line of Plössls. Today, many companies offer Plössls at a wide range of prices. In general, you get what you pay for.

Ultra Wide-Field (i.e., Nagler)

These hybrid eyepieces were initially intended to meet the demanding needs of amateurs using Schmidt-Cassegrain telescopes and huge Newtonian reflectors, but they also work equally well in refractors and longer focal length reflectors. Most of these company-proprietary designs use multicoated lenses made from expensive glasses to minimize aberrations. Other plusses include huge apparent fields of view, which let users not only see sky objects but also experience their grandeur firsthand. Most also offer longer eye relief than other, more generic designs, which is a big help for those forced to wear glasses.

The disadvantages of the ultra-wide-field eyepieces are their price and weight (some telescopes may need to be rebalanced). The legendary “Termi-Nagler” or “Holy Hand Grenade,” the Tele Vue 31mm Type 5 Nagler eyepiece, sells for $698 and weighs 2.2 pounds! The newer Tele Vue 21mm Ethos eyepiece sells for a whopping $894!!!

Apparent & Actual Field-of-View

The apparent field-of-view refers to the eyepiece’s edge-to-edge angular diameter as seen by the observer’s eye. Generally, it is best to select eyepieces with at least a 40° apparent field because of the exaggerated tunnel-vision effect of anything less. An apparent field in excess of 60° gives the illusion of staring out the porthole of a spaceship!

By knowing both the eyepiece’s apparent field (typically specified by the manufacturer) and magnification, we can calculate just how much sky can squeeze into the ocular at any one time. This is known as the actual or true field-of-view, and can be approximated using the following formula:

$$\text{Actual Field} = \frac{\text{Apparent Field-of-View}}{\text{Magnification}}$$

*For example, w*hat is the actual field-of-view of a Tele Vue 31mm Nagler eyepiece when used with a 2,350mm focal length telescope?

$$1.1° = \frac{82° \text{ Apparent Field}}{76\times}$$

For reference, the Full Moon is about ½° in angular diameter.

Telescope Accessories

Barlow Lenses

An extremely useful tool every amateur astronomer should have is a Barlow lens. The Barlow lens was invented by Peter Barlow (1776-1862), an English writer on pure and applied mathematics. A Barlow lens is a concave lens that, when placed between a telescope’s objective lens or mirror and the eyepiece, will increase the magnification of the telescope.

A Barlow lens will connect directly to your eyepiece. The most common Barlow is the 2× Barlow. A 2× Barlow will double the magnification of the eyepiece it is attached to. For example, if you are using a 20mm eyepiece on a telescope with a 1,000mm focal length, you would have 50× magnification. If you attach a 2× Barlow lens to that eyepiece, you will double the effective magnification of that eyepiece to 100×.

One of the greatest advantages of a Barlow lens is that it will not only double the magnification – it will effectively double your eyepiece collection! If you had a 32mm, 26mm, and 10mm, for example, adding a 2× Barlow would be like owning a 32mm, 26mm, 16mm, 13mm, 10mm, and 5mm. A Barlow is much more cost-effective, as it is usually less than the price of one eyepiece!

Powermates

Tele Vue Optics' Powermates look very much like Barlow lenses and perform the same end result, providing increased magnification. However, traditional Barlows are two-element devices containing a negative doublet. The negative doublet causes the light rays to diverge as they exit the Barlow. This in turn causes the exit pupil to move outward and can cause vignetting, a reduction in image brightness at the edges of the field-of-view, in long focal length eyepieces. Powermates use a *positive* field lens to redirect field rays. The result is an exit pupil that stays where the eyepiece designer intended and resolves the issue with vignetting, providing an evenly illuminated field.

Finderscopes

Finderscopes are small, low-power, wide-field refracting telescopes mounted piggyback on the main telescope. Their sole purpose is to help the observer aim the main telescope toward its target. Most experienced observers agree that the smallest useful size for a finderscope is 8×50. Most finderscopes display an upside-down image, but some are available that give a corrected image. Finders with a variable illuminator (as shown below) make it easier to see the crosshairs in the dark. If you plan on doing astrophotography at some point, then you might want to consider choosing a finderscope that can double as a guidescope (more on this in Part 5).

One-Power Finders

Many amateur astronomers have replaced their optical finderscopes with a reflex or one-power finder, while others use them together. They allow the observer to quickly and accurately place an object in the telescope's field-of-view using most of eyepieces without having to figure out exactly where in the sky the optical finder is pointing. Basic one-power finders project a red dot, while others use a series of concentric circles. Owners of all non-computerized telescopes (especially Dobsonians) should strongly consider using a one-power finder.

Red Dot Finders

A red dot finder is a simple but efficient point-where-you-want-to-go device for finding celestial objects. They superimpose a tiny, LED-powered red dot at infinity on the sky. When aligned with your telescope's field-of-view, the dot shows you exactly where your telescope is pointed. It's easier than a standard finderscope because what you see through the red dot finder is a non-magnified, naked-eye view of the sky that is correctly oriented, not upside down. The brightness of the dot can be adjusted to suit your preferences. Thumbwheels allow the positioning of the dot horizontally and vertically for precise alignment with the main telescope.

Tel-Rad

Perhaps the handiest device ever invented for the telescope, Tel-Rads are a one-power (no magnification) heads-up display, appearing to project a red bull's-eye onto the night sky. This target makes finding celestial objects extremely easy. The Tel-Rad fits on almost any scope and is a highly recommended accessory. **Laminated books** are available that show how to align the Tel-Rad circle against the naked-eye stars to find deep-sky objects.

Rigel QuikFinder

The QuikFinder is a vertical version of the Tel-Rad that projects an adjustable-brightness, 0.5° diameter red circle onto an angled window. Unlike the other one-power finders, the QuikFinder's red circle can be set to pulse off and on (this feature is available as an option for the Tel-Rad). Because of the QuikFinder's compact size, it is better suited for use with giant binoculars or small telescopes, such as short focal length refractors.

Filters

Colored Planetary Filters

Colored planetary filters are essential for the observation of surface detail on the Moon and planets that is often virtually invisible without filtration. Most are inexpensive and can be purchased in sets to save even more. Please see page 23 for a listing of all colored filters available and a breakdown of the features they will enhance.

Deep Sky or Nebula Filters

Light pollution reduction filters (also called nebula filters) come in three varieties:

Broadband: widest bandwidth and brightest image, but least amount of blocking light pollution. Examples: Lumicon Deep Sky, Orion Sky Glow, and Thousand Oaks LP1.

Narrowband: narrow bandpass in the green visual spectrum. Darkens sky further, with more dramatic contrast between the sky and nebula. A good general-purpose filter for emission nebula. Examples: Lumicon UHC, Orion Ultrablock, Thousand Oaks LP2.

Line: Oxygen III (or OIII) is most popular; it has a very narrow band-pass centered on green doubly ionized oxygen emission lines. Highest contrast and maximum blocking of light pollution. Good for planetary nebulae and supernova remnants.

Solar Filters

A proper solar filter is made to fit snugly over the *front* of your telescope, where it reduces the intensity of sunlight before it enters the tube. Filters are made of glass or a silvery Mylar-like material that blocks 100% of ultraviolet and infrared light and 99.999% of the Sun's visible light, allowing safe views of our local star for extended periods of time. **Sun filters that came with department store telescopes and thread onto eyepieces should NOT be used and thrown away.** For observing sunspots, one of the best solar filters on the market is the Baader Planetarium Filter, available from Kendrick Astro Instruments. They show the Sun in a natural white color, which also allows the use of colored filters to bring out different details. Thousand Oaks Optical uses their own Solarite material, which they say will never develop pinholes or scratches. This material gives a yellow-orange solar image, which many prefer for photographic purposes as well as visual use.

Hydrogen-alpha solar filters and telescopes are fairly expensive, but they allow you to observe filaments and prominences that can change in a matter of minutes. Lunt Solar Systems and Coronado (now owned by Meade) manufacture some of the best H-alpha filters and solar telescopes around today. Coronado's Personal Solar Telescope (PST) is a dedicated H-alpha telescope and costs $900 (the KAS owns one to loan to members)! Lunt also sells a dedicated 40mm H-alpha telescope for $749.

Dew Prevention

Dew occurs when the actual air temperature falls to the dew point. At the dew point, water condenses out of the air to form droplets. If the dew point is below freezing, frost forms instead of dew. These droplets like to form on telescope optics and ruin a night of observing.

It's a problem that all amateur astronomers must face, regardless of their choice of telescope type. Refracting and catadioptric telescopes are at the greatest disadvantage to dew because of their exposed glass surfaces. Reflectors typically do not have as much of a problem with dew on the primary mirror (since it is deep inside the optical tube), but their secondary mirrors can experience dew problems. The following tips will help you win your fight against dew.

Anti-Dew Accessories

The first and most inexpensive method of preventing dew formation is to block heat's path to the sky. This is commonly done using a dew shield. Dew shields are a particularly useful tool for those with refractors or compound scopes that have corrector plates. Refractors have shields built in, but dew shields for catadioptric telescopes can be purchased or made at home. If you don't want to spend a bunch of money on one, you can make one using just some flexible foam (i.e., a sleeping bag pad) and a few other simple supplies. Basically, it is just a tube, about 1.5 times as long as its diameter. Dew shields can also help prevent stray light from entering your telescope, so they're good to use if you have dew issues or not.

Commercial dew controllers and heaters are also available from companies like Astrozap, Kendrick, and Thousand Oaks that will gently heat your optics to just above the dew point, so dew does not form. While dew heaters can be an expensive solution, they work very well. They will almost entirely banish dew from your observing sessions, leaving you more time to actually use your telescope.

If you don't want to spend any money, there are passive methods of preventing dew. One of these is to set up your telescope on higher ground, on top of a hill, for example. Colder air tends to settle in low spots and will more likely be below the dew point, so stay high and dry. Also, a slight breeze is helpful in preventing dew as it keeps the air mixed. For lack of a breeze, you can also use a small fan, much like the small fans mounted on some commercial Dobsonians and Newtonians. Even using a window fan can help keep the air mixed.

Tel-Rads are also known for dewing up rapidly, so if you cover them with a tube of foam or something similar, it will help to prevent dew. Covering objects so they can't see the dark sky is the most effective way of preventing dew, so put your finder's cap back on when you're not using it, for example.

Purchasing Advice

- Educate yourself. Read the books recommended in Part 2 of the lecture series.
- **Join your local astronomy club and attend their observing sessions.** Seeing a telescope online or even on the showroom floor will tell you very little about a telescope's capabilities. The best way to understand what the various types of telescopes can do is to *look through them*.
- Take advantage of your club's telescope loan program (if applicable).
- Attend star parties and astronomy conventions and trade shows (see a partial list in the Star Party section of our **Astroweb Yellow Pages**).
- NEVER, EVER buy a telescope at a department store. They are all, without exception, JUNK!
- Purchase a telescope from a reputable dealer and/or a knowledgeable salesperson.

In Conclusion

Above all, choose a telescope that seems to fit your lifestyle and personality. Do not worry too much about specifications and other technical details. If you choose a reputable brand and use common sense in picking a telescope that appeals to you, you won't go wrong. Just remember that...

Colored Planetary Filter Breakdown

#8 Light Yellow: Useful in observing red and orange-colored phenomena in the belts of Jupiter and in enhancing the level of observable detail of small orange-red zonal features within the belts of the planet. Increases contrast of maria on Mars.

#11 Yellow-Green: Contrasts well with the red and blue characteristics of surface features on Jupiter and Saturn. Darkens the maria visible on Mars, and clarifies the Cassini division in Saturn's rings.

#12 Yellow: Contrasts strongly with blue-colored features on Jupiter and Saturn, while enhancing red and orange features. Lightens red-orange features on Mars, while reducing or blocking the transmission, and thereby increasing the contrast, of blue-green areas.

#21 Orange: Use on Jupiter and Saturn to enhance detail in the belts and polar regions. Sharpens boundaries between yellow-orange areas and blue-green regions on Mars, resulting in a darkening of edge-detail in the maria.

#23A Light Red: On telescopes of 6" aperture and larger the #23A does approximately the same functions as the #21 filter, but with stronger contrast and enhancement of marginally defined blue-green surface detail. Useful primarily on Jupiter, Saturn, and Mars.

#25 Red: Strongly blocks the transmission of blue and blue-green wavelengths, resulting in very sharply defined contrast between, for example, blue-tinted cloud formations on Jupiter and the lighter-toned features of the disc. Also useful for the delineation of the Martian polar ice caps and maria.

#38A Dark Blue: Increases contrast between the reddish belt structures and enhance detail of Jupiter's Red Spot. Also useful for the study of dust storms on Mars, as well as Saturn's belt structure. Increases contrast of subtle cloud markings on Venus.

#47 Violet: Useful for the study of Martian polar cap regions and for the observation of occasional phenomena in the upper atmosphere of Venus. Enhances contrast between the rings of Saturn. Use only on telescopes of 8" aperture and larger.

#56 Light Green: Excellent for the observation of Martian polar ice caps as well as yellow-tinted dust storms on the Martian surface. Increases contrast of the red and blue regions in Jupiter's atmosphere as well as in the cloud belts.

#58A Green: Use on telescopes 8" and larger to reject blue and red-toned structures on the surface of Jupiter and thereby increase their contrast relative to lighter parts of the disc. Also use for the enhancement of Saturn's cloud belts and polar regions. Strongly increases contrast of Mars' polar ice caps.

#80A Blue: A popular filter for the study of Jupiter and Saturn. Enhances contrast of rilles and festoons in Jupiter's cloud belts, as well as details of the Red Spot. Brings out detail in Saturn's belts and polar phenomena.

#82A Light Blue: Useful on the Moon, Mars, Jupiter, and Saturn, this subtle pale blue filter enhances areas of low contrast while avoiding significant reduction of overall image brightness.

Some Recommended Observing Books

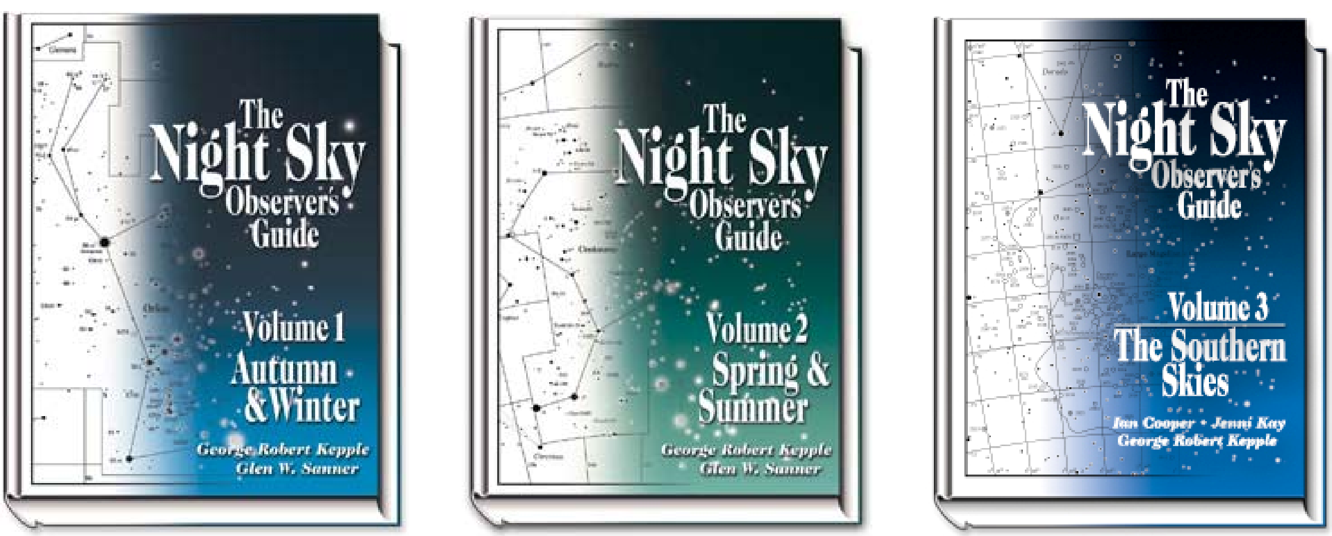
Deep-Sky Companion Series by Stephen James O'Meara

Published by Cambridge University Press

Annals of the Deep Sky Series

Published by AAS Sky Publishing/Willmann-Bell

The Night Sky Observer's Guide Series



Published by AAS Sky Publishing/Willmann-Bell

The Star-Splitter

"You know Orion always comes up sideways.
Throwing a leg up over our fence of mountains,
And rising on his hands, he looks in on me
Busy outdoors by lantern-light with something
I should have done by daylight, and indeed,
After the ground is frozen, I should have done
Before it froze, and a gust flings a handful
Of waste leaves at my smoky lantern chimney
To make fun of my way of doing things,
Or else fun of Orion's having caught me.
Has a man, I should like to ask, no rights
These forces are obliged to pay respect to?"
So Brad McLaughlin mingled reckless talk
Of heavenly stars with hugger-mugger farming,
Till having failed at hugger-mugger farming,
He burned his house down for the fire insurance
And spent the proceeds on a telescope
To satisfy a life-long curiosity
About our place among the infinities.

"What do you want with one of those blame things?"
I asked him well beforehand. "Don't you get one!"

"Don't call it blamed; there isn't anything
More blameless in the sense of being less
A weapon in our human fight," he said.
"I'll have one if I sell my farm to buy it."
There where he moved the rocks to plow the ground
And plowed between the rocks he couldn't move,
Few farms changed hands; so rather than spend years
Trying to sell his farm and then not selling,
He burned his house down for the fire insurance
And bought the telescope with what it came to.
He had been heard to say by several:
"The best thing that we're put here for's to see;
The strongest thing that's given us to see with's
A telescope. Someone in every town
Seems to me owes it to the town to keep one.
In Littleton it may as well be me."
After such loose talk it was no surprise
When he did what he did and burned his house down.

Mean laughter went about the town that day
To let him know we weren't the least imposed on,
And he could wait — we'd see to him tomorrow.
But the first thing next morning we reflected
If one by one we counted people out
For the least sin, it wouldn't take us long
To get so we had no one left to live with.
For to be social is to be forgiving.
Our thief, the one who does our stealing from us,
We don't cut off from coming to church suppers,
But what we miss we go to him and ask for.
He promptly gives it back, that is if still
Uneaten, unworn out, or undisposed of.
It wouldn't do to be too hard on Brad
About his telescope. Beyond the age
Of being given one's gift for Christmas,*
He had to take the best way he knew how
To find himself in one. Well, all we said was
He took a strange thing to be roguish over.
Some sympathy was wasted on the house,
A good old-timer dating back along;
But a house isn't sentient; the house
Didn't feel anything. And if it did,
Why not regard it as a sacrifice,
And an old-fashioned sacrifice by fire,
Instead of a new-fashioned one at auction?

Out of a house and so out of a farm
At one stroke (of a match), Brad had to turn
To earn a living on the Concord railroad,
As under-ticket-agent at a station
Where his job, when he wasn't selling tickets,
Was setting out up track and down, not plants
As on a farm, but planets, evening stars
That varied in their hue from red to green.

He got a good glass for six hundred dollars.
His new job gave him leisure for stargazing.
Often he bid me come and have a look
Up the brass barrel, velvet black inside,
At a star quaking in the other end.
I recollect a night of broken clouds
And underfoot snow melted down to ice,
And melting further in the wind to mud.
Bradford and I had out the telescope.
We spread our two legs as it spread its three,
Pointed our thoughts the way we pointed it,
And standing at our leisure till the day broke,
Said some of the best things we ever said.
That telescope was christened the Star-Splitter,
Because it didn't do a thing but split
A star in two or three the way you split
A globule of quicksilver in your hand
With one stroke of your finger in the middle.
It's a star-splitter if there ever was one
And ought to do some good if splitting stars
'Sa thing to be compared with splitting wood.

We've looked and looked, but after all where are we?
Do we know any better where we are,
And how it stands between the night tonight
And a man with a smoky lantern chimney?
How different from the way it ever stood?

★ ★ ★

by **Robert Frost**