

Introduction to Amateur Astronomy

TCAA Guide #1

Carl J. Wenning



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ABOUT THIS GUIDE

This *Introduction to Amateur Astronomy* guide – one of several such TCAA guides – was created after several years of thinking about the question of why more people don't become amateur astronomers. This remains a mystery for most amateur astronomers and astronomy clubs, but especially for the TCAA where we have a friendly and stable organization, outstanding resources, two good observing sites, a solid web presence, a nationally recognized award-winning newsletter, membership brochures, a good Facebook presence, regular publicity, and plenty of member education and public outreach. Despite these facts, membership in the TCAA has been roughly stable at around 40-50 members since the start of the club in 1960.

Why should this be when we have a metropolitan area of over 100,000 people? There appears to be two contributing causes: (1) people no longer understand the concept of a hobby, and (2) given the recent technological advances in telescopes and imaging equipment many people are flummoxed by what they need to know to pursue amateur astronomy as a hobby. This guide has been created in response to the latter impediment. A second publication, TCAA Guide # 3 – *Astronomy as a Hobby* – addresses the former impediment. ([http://tcaa.us/Download/Astronomy as a Hobby.pdf](http://tcaa.us/Download/Astronomy_as_a_Hobby.pdf))

This guide, TCAA Guide #1, introduces the basic knowledge with which a would-be amateur astronomer should be familiar. While it is not a substitute for learning more extensively about the science of astronomy, it provides the basic information one needs to bridge the gap from neophyte to an observer vested with the knowledge of what it takes to properly view the heavens using basic equipment – eyes, binoculars, and simple telescopes. As such, this is not a reference work. It is not intended to be the answer to all questions that an amateur astronomer might have; it merely provides sufficient information to get one started in the field of amateur astronomy. Amateur astronomy is a lifetime pursuit for many of us.

The author gratefully acknowledges the assistance of the following TCAA members who either provided guidance or conducted an editorial review: Tony Cellini, Dr. Allan Saaf, Ken Kashian, Jim Gibbs, and especially Geoff Hughes.

ABOUT THE AUTHOR:

Dr. Carl J. Wenning is a well-known Central Illinois astronomy educator. He started off viewing the heavens with the aid of his grandfather in the summer of 1957. Since that time, he continued viewing the night sky for nearly six decades. He holds a B.S. degree in Astronomy from The Ohio State University, an M.A.T. degree in Planetarium Education from Michigan State University, and an Ed.D. degree in Curriculum & Instruction with a specialization in physics teaching from Illinois State University.

Dr. Wenning was planetarium director at Illinois State University from 1978 to 2001. From 1994-2008 he worked as a physics teacher educator. Retiring in 2008, he continues to teach physics and physics education courses. He also taught astronomy and physics lab science almost continuously at Illinois Wesleyan University from 1982 to 1999. He has over 40 years of university-level teaching experience.

Carl became associated with the TCAA in September 1978 – shortly after he was hired to work at Illinois State University. Today he is an Astronomical League Master Observer (having completed 14 observing programs to date) and received the 2007 NCRAL Region Award for his contributions to amateur astronomy. He is a lifelong honorary member of the TCAA and is a member of its G. Weldon Schuette Society of Outstanding Amateur Astronomers. He is currently chairperson of the North Central Region of the Astronomical League (2017-2021) which includes Illinois, Iowa, Wisconsin, Minnesota, North and South Dakota, and the Upper Peninsula of Michigan.

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PREFACE: WHAT IT TAKES TO BECOME AN AMATEUR ASTRONOMER

Since the founding of the TCAA in 1960, amateur astronomy has changed dramatically. At that time, the norm in amateur astronomy was a 2.4" refractor or a 4.25" reflector. When telescopes were turned to the heavens, objects viewed consisted of bright solar system bodies, double stars, and few of the brighter nebulae, clusters, and galaxies. Since that time, there has been a tremendous growth in the size of available equipment and the number of accessories has expanded dramatically. Amateur astronomy today is much akin to professional astronomy of just a decade or so ago. As a result, it's much harder to bridge the gap from non-astronomer to amateur astronomer today. Thinking about this topic for a while, I have concluded that the following are things that people need to know and be able to do in order to wear the label "amateur astronomer" proudly:

- * **Possess a general knowledge of basic astronomy.** Consider the etymology of the word 'amateur'. This is a French word with a late 18th century origin. It is derived from the Latin word *amare* 'to love.' No one can be said to be a good amateur astronomer who does not 'love' the things of the firmament. Love is most frequently demonstrated by spending time with the object of one's love. Therefore, to qualify as an amateur astronomer, one must certainly will spend lots of time getting to know the subject matter. We must be careful to understand that "throwing money" at amateur astronomy such as buying an expensive telescope with little knowledge of astronomy or understanding what telescopes can be used for is an *illegitimate* way to become an amateur astronomer. People often spend lots of money buying a telescope, but do not have the 'love' necessary to employ it properly. Having lots of fancy equipment does not guarantee that one knows how to use it, what to look for, and the meaning of what is seen when observing with it. It's not unlike purchasing a musical instrument that one never learns to play. Owning a musical instrument does not make a musician! Reading systematically in the area of astronomy can help a person obtain a general knowledge of basic astronomy. This means picking up a recent book about astronomy and reading it from cover to cover. Library books and used college textbooks in astronomy are not hard to come by. This guide is not a substitute.
- * **Know how to use a sky map to find constellations.** Observers will have a hard time loving the sky if they don't know it intimately. Each and every amateur should be familiar with the major constellations (e.g., Orion, Leo, Cassiopeia, and Ursa Major) and, as time goes on, get to know the fainter constellations (e.g., Lynx, Sagitta, Camelopardalis, Leo Minor, and Delphinus) and asterisms of the sky (e.g., Summer Triangle, Keystone, Teapot, Job's Coffin, and Northern Cross). Many first-time night observers are overwhelmed with the confusing mass of stars seen in a dark cloudless sky on a good night. Many are the people who are flummoxed when they look at a sky map and see one set of directions reversed, not understanding that the map is "correct" only when held up to the sky. There are numerous free applications that can be used with cell phones and tablets that not only show the constellations, but that properly associate and orient the screen images with the portion of the sky to which the observer is directing attention. These can help the would-be amateur astronomer get to know the stars and where to find solar system and deep space objects among them.
- * **Understand the effect of light pollution on making celestial observations.** Light pollution – the illumination of the sky by either natural or artificial sources of light – produces a bright sky and reduces the contrast between the sky and objects located in it. With increasing light pollution most celestial objects become less visible. The limiting condition in this case is during the daytime when the sun "pollutes" the sky with light making it appear bright and blue and reducing the contrast so much that celestial objects cannot be seen without a telescope. While light pollution is caused by artificial light sources such as streetlamps, advertising displays, stadium illumination, and so forth, amateur astronomers must also realize that the moon's presence also can have a deleterious effect upon celestial observations. Objects readily observed on a dark night often cannot be seen at all on nights when the moon is located nearby and shining brightly. Neither can many sky objects be seen under urban lighting. The effect of light pollution on limiting magnitude should be understood as well.
- * **Understand the need for dark adaption.** People living in town stepping out for a few minutes at night hardly see any stars despite the fact that the sky seems tolerably dark. This is due to the facts that they are not dark-adapted, and the city sky is light polluted. Unless the eye has a minimum of about 20 minutes to adapt to faint-light conditions, it's hard to see well at night. Dark adaption is accomplished in two ways: (1) the pupil dilates, and (2) the retina produces rhodopsin ('visual purple') that sensitizes the eye's rods and cones to light. Without these adaptations, it's hard to see at night. Would-be amateur astronomers need to know that to get a good view of the sky one must go out to and remain for a while under dark-sky conditions. Rural nature centers are often good locations for doing so and budding amateur astronomers should know good places to view the night sky locally.
- * **Understand the effects of seeing and transparency on celestial observations.** Not all night skies are equal. Poor seeing – caused by turbulence in Earth's atmosphere – can make it difficult if not impossible to see minute details in objects being viewed telescopically. This shimmering of the air is responsible for the twinkling phenomenon that is so well known by amateur astronomers. On some nights,

viewing celestial objects is much like watching birds from under the rippling water of a swimming pool! Low transparency – poor sky clarity – also can make it more difficult to view objects. The sky is sometimes clear, often translucent (such as when one can see the moon or planets but not the stars), and frequently opaque (as when the sky is overcast with clouds).

* **Know what constitutes a good telescope.** This one can be tricky because there are so many telescope types and configurations, as well as other complicating factors – reflector, refractor, catadioptric, magnification, eyepieces, finders, Dobsonian, equatorial, push to, goto... Also consider the fact that many of the less expensive telescopes out there are toys (junk would be a better term). When people buy toy telescopes they become quickly disillusioned and soon drop out of amateur astronomy altogether. This is part of the problem with ‘throwing money at amateur astronomy’. To be a good amateur astronomer, it takes more than just a good telescope. It takes knowledge of basic astronomy, what constitutes a good telescope, the effects of observing conditions on viewing, what can be observed, where it is located, and so forth. *Purchasing a telescope without first going through the anticipatory steps circumvents the process of becoming a legitimate amateur astronomer.* It’s no wonder that that so many people fail in their aspirations to become amateur astronomers and why we find so few of them in today’s world. (This coupled with the fact that people have alternative ways of dealing with boredom, a failure to understand what a hobby entails (see TCAA Guide #3, *Astronomy as a Hobby*, <http://tcaa.us/TCAAGuides.aspx>), and a lack of ready access to a dark sky site are also complicit in this problem.)

* **Know how to use a telescope properly.** Consider the myriad of telescope-related terms in addition to the ones listed above: primary, secondary, collimation, eyepiece, finder, Telrad, laser pointer, polar alignment, slow motion control, slew, Barlow, apparent field of view, true field of view, resolving power, light-gathering power, eye relief, right ascension, declination, polar axis, polar alignment... The list goes on and on. No wonder people are confused even when they purchase a good telescope! Again, it takes time and effort – persistence – getting to know what to look for in a good telescope and how to use the telescope well. Observer knowledge also should include how to safely

observe the sun telescopically (or visually) as it is the only object in the sky that can be harmful to the human eye if viewed improperly.

* **Know what to observe.** A telescope user, no matter how well qualified in the use of the telescope, will use it to no avail unless he or she knows what to observe. The repertory of any observer should, at the minimum, include listings of solar system bodies and deep sky objects. The latter includes nebulae, clusters, galaxies, binary stars, carbon stars, quasars, black hole candidates, asteroids, planets, comets, the moon, the sun, and so forth. Every visual observer should know about and participate in the Astronomical Leagues’ myriad of observing programs. By completing these, the observer can avoid looking at just a few showcase objects that experienced observers have come to know all too well. Using these observing lists will open up the universe to a would-be observer. It is through completion of observing programs that visually oriented amateur astronomers can really excel. Every visual observer should have as a personal goal viewing every meaningful object within the visual range of his or her telescope. Such a goal can lead to views of considerably more than 1,000 different objects even for a modest size (8” – 11”) telescope.

* **Know how to find faint objects in the sky.** While constellations, asterisms, and the moon and planets are interesting to observe, they are not the end-all, be-all as far as celestial observations are concerned. Many people want to see the faint star clusters (globular and open), nebulae (emission, reflection, dark, and planetary), galaxies, and everything else that populates the regions between the stars of the various constellations. These are typically not visible without the use of a good telescope (though there are numerous exceptions such as the Orion Nebula, the Andromeda Galaxy, and the Pleiades star cluster for instance). Once one gets to know the star patterns, one can use a good sky map or app to find these celestial interlopers. By using a sky map with the locations of, say, the brighter Messier objects, one can use the eye or a set of binoculars to seek them out. In so doing, they learn the process of ‘star hopping’, moving from one recognizable star grouping to another in an effort to track down the desired object for viewing. This skill can then be applied to the use of a good telescope.

Even if an amateur astronomer were to know all this, there seems always more to be learned in this rapidly advancing hobby. As with any hobby, it takes time and effort to learn and understand how to do things right and perhaps more importantly, appreciate them and their meaning within the bigger picture. Astronomy is an all-encompassing subject where the individual is not required to own expensive equipment. Rather, it is sufficient to just have an interest in learning about the sky, the objects in it, and use their mind to comprehend it. TCAA Guide #1 will help you to learn what it takes to be an amateur astronomer in today’s world and move beyond mere infatuation to become a full-fledged lover of all things astronomical.

1. MOTIONS OF THE STARS

The sun, moon, stars, and planets all appear to move in the sky with the passage of time. Each of the movements is predictable, though some motions are more complex than others. Let's examine these motions so you have a better understand of how the sky "works".

The stars appear to rise and set daily. They do this as a result of Earth's rotation. As Earth spins from west to east, the stars move from east to west across the sky. We can characterize this motion by drawing paths on a celestial sphere – a large imaginary globe of indeterminate size that is centered on Earth. The only part of the celestial sphere we can "see" is that half which is above the horizon, the circle centered on the observer where the sky and land appear to meet. The remaining celestial hemisphere is below our horizon.

The celestial sphere, like the sphere of Earth, has poles and an equator. These are known as the north celestial and south celestial poles and the celestial equator. If one were to project Earth's pole and equator into the sky, they would "touch" the celestial sphere as shown in the figure below. The celestial poles appear directly overhead at Earth's poles and the celestial equator appears directly overhead for observers viewing from anywhere along Earth's equator.

Stars rise on the eastern half of the sky, reach their highest point in the heavens when they cross over the meridian (an imaginary circle passing from north to overhead to south) going from east to west, and setting in the western half of the sky. As they move across the sky, stars trace out circles on the celestial sphere as shown below.

When watching stars rise in the eastern sky in mid northern latitudes, they appear to move to the upper right. Stars appear to move down to the lower right as they set in mid northern latitudes. In the south the stars appear to

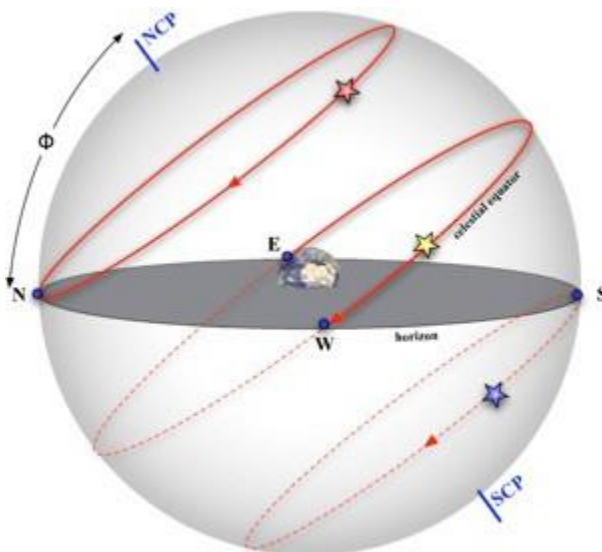
move from left to right executing an arch. Stars in the northern sky move in a counterclockwise direction around the North Star.

Note that if a star rises due east, it sets due west. Paths of all stars are parallel to one another. Stars rising in the northeast set in the northwest. Stars rising in the southeast set in the southwest. Stars close enough to the north celestial pole (NCP) will in fact never rise or set but are continuously in the northern sky. These are the north circumpolar stars. Stars close to the south celestial pole (SCP) never rise or set and are continuously below the southern horizon from the perspective of a northern hemisphere observer. These are the south circumpolar stars. Stars that rise and set are called equatorial stars.

One's latitude, the angular distance from Earth's equator as seen from the center of Earth, ϕ , determines whether stars are circumpolar or equatorial for a given observer. The elevation of the NCP is always equal to the observer's latitude in the northern hemisphere. The elevation of the SCP is always equal to the negative of the observer's latitude (ϕ is considered < 0 in the southern hemisphere).

For a northern hemisphere observer, the farther north a star is from the celestial equator, the longer it is in our sky. Similarly, the farther south a star is from the celestial equator, the shorter it is in our sky.

Note that because of our mid-northern latitude in central Illinois (ϕ is approximately equal to 40° North), stars do not rise straight up in the east and set straight down in the west. That only occurs at the equator where $\phi = 0^\circ$. What would happen if the observer's latitude were $+90^\circ$ (at the North Pole)? At this location stars neither rise nor set but merely move parallel to the horizon.

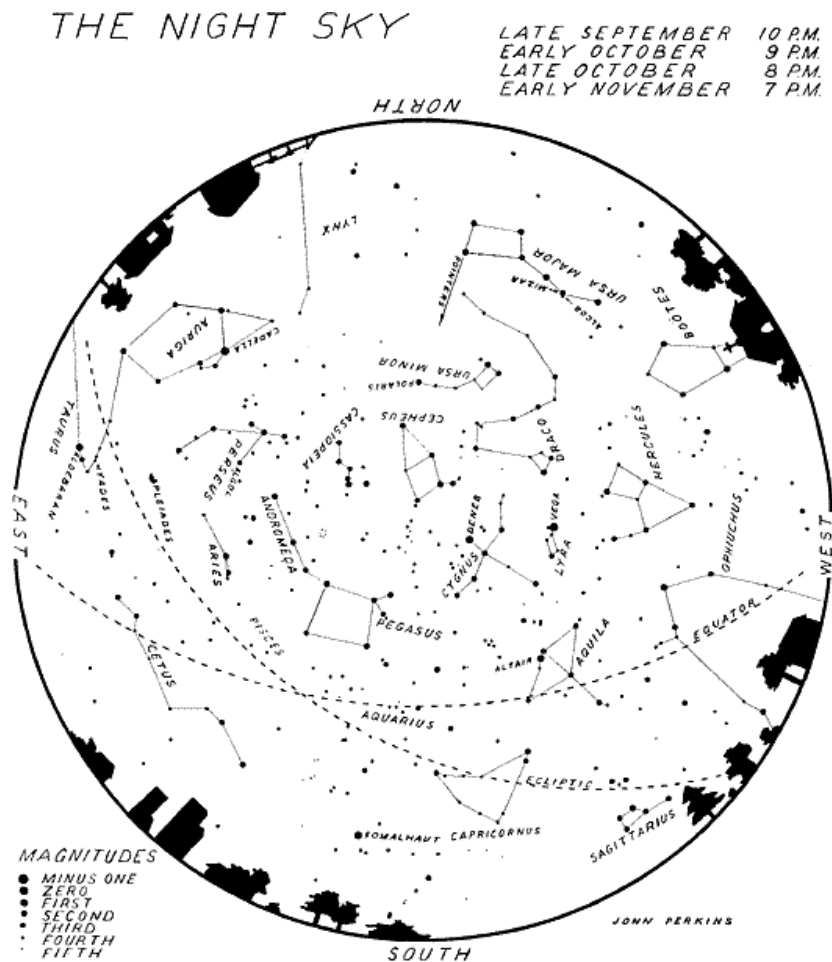


2. SEASONAL SKY MAPS AND CONSTELLATIONS

A seasonal sky map shows the stars and constellations as they would appear over a particular location at a given date and time. Sky maps typically can be used within one hour of the prescribed times to find constellations and bright stars in the nighttime sky. Go outside and, with the sky map below and a red filtered flashlight, if necessary, identify objects in the sky near the times indicated as a function of date. It is best to view the sky from a dark location.

Look carefully at the sky map example before getting started. The center of the map represents the zenith – the

overhead point in the sky. The outer circle represents the horizon. Along the horizon you will find the directions NORTH, SOUTH, EAST, and WEST. At first their positions in relation to one another might seem incorrect; note especially how east and west appear reversed from that of a traditional land map. You must remember that sky maps are drawn to represent the sky and not the earth. When holding the sky map *overhead* it can be oriented so as to match the actual directions. N.B. Your *Introduction to Amateur Astronomy* course instructor will provide you with a better sky map and observing exercise. Use those.



Note the patterns – constellations and fragments of constellations called asterisms – that fill this representation of the nighttime sky. You will observe that some dots representing stars are larger than others. This indicates that stars appear with different brightness. Large dots represent bright stars; small dots represent dim stars. “Pointed disks” – the diameter of which is related to brightness – represent planets when present. The sky map above shows the heavens for a mid-northern latitude during autumn at the times indicated.

Because dark adaption is necessary for viewing the fainter stars and Milky Way, be certain to use a dim, red-filtered flashlight to view the sky map at night. This will allow you to move quickly between map and sky without having to readapt. If you use a bright white flashlight, your dark adaption will be destroyed, and you’ll have a tough timeseeing the constellations depicted on the sky map. Go to www.skymaps.com to download free sky maps for each month of the year.

3. THE PLANISPHERE – AN ANALOG COMPUTER

A planisphere is a circular star map formed by projecting from the perspective of the NCP a part of the celestial sphere onto a plane that shows the appearance of the heavens at a specific time and place. The portion of the sky visible at any point in time is determined by the position of a horizon ring that rests atop the rotating star map as shown in the accompanying image. The relative motion of the two is pre-determined by a pin in the star map passing through the NCP, essentially through the North Star. The image to the right shows a typical planisphere.

Note that the horizon is not represented by a circle; rather, it's an ellipse. This is due to the fact that when one reproduces more a whole hemispherical sky on a flat piece of paper distortions naturally occur. This much as would happen if one were to flatten half of an orange peel onto the surface of a table. The peel would stretch and even tear at its edge in order to conform itself to the flat surface. Distortion also occurs because not all of the sky can be seen at any one point in time as many of the stars are below the horizon. This distortion results in a non-circular star map and constellations in the southern part of the sky are distorted horizontally (and perhaps vertically depending on the type of projection method used). Other types of sky maps showing much more limited regions of the sky are available that use various types of projections that minimize certain types of distortions as we shall see.

The planisphere's star map is rotated such that the current time is set adjacent to the current standard (not daylight saving) time. During standard time (late autumn through early spring), the date and time are set according to the time read on one's watch or clock. During daylight saving time (early spring through late autumn) the date must be set against the time read on one's watch or clock *minus one hour*. This is so because daylight saving time adds one additional hour to standard time so that sunrise doesn't occur too early and sunset effectively occurs later in the day while people are still out and about.

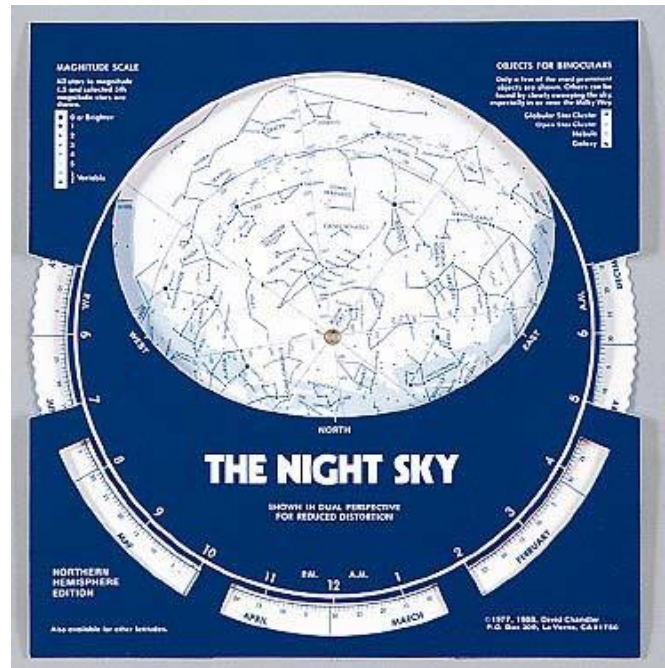
Planispheres can be prepared for any northerly or southerly latitude. (Planispheres for the equator are considerably different from the one shown here.) If you ever acquire a planisphere, get one designed for your home latitude or the latitude where you will be using it.

The virtue of a planisphere is that it can fairly accurately mimic the appearance and motions of the sky. Note how, as you rotate the star map, the North Star (under the brass

tack) stands pretty much still – just as it does in the real sky. Stars rise everywhere along the eastern half of the sky and set everywhere along the western half of the sky. Stars reach their highest point in the sky as they pass over the meridian, an artificial line that crosses the sky running from southern horizon, through the overhead point (the center of the horizon ring), and through the north celestial pole.

Note that east and west are not opposite one another with respect to the zenith point. Similarly, cardinal points (NSEW) are not located at equidistant points along the horizon. This is a consequence of the distortions produced by this type of planisphere.

Better quality northern latitude planispheres will use the back side of the device to show the southern sky rather than to use the front of the planisphere. By using a different mapping procedure, one can get less distortion and a better expectation of what you will see when you look into that portion of the sky.



Planispheres are a form of analog computer. They mechanically predict what the sky will look like at some date or time for a given latitude. Better still are modern digital computers in their various forms.

4. OBSERVING APPLICATIONS FOR COMPUTERS, CELL PHONES, AND TABLETS

While working with planispheres and printed star maps can be both fun and instructive, they are to a great extent part of a bygone era. Today they have been almost entirely

replaced with applications available for cell phone and tablets in both the iOS and Android platforms.

Some of these devices with appropriate applications can be held up against the sky and show the background

stars and planets. Constellations are shown with lines connecting stars. As the device is moved across the sky, the display screen similarly changes. Each constellation and star can be labeled, and detailed information is available by merely taping on the object in question. Because these devices show only small regions of the sky at once, the displayed images have very little distortion.

A quick visit to Apple Apps Store or to the Google Play Store, one can readily find a number of free and low-cost observing applications suitable for the amateur astronomer. The situation is much the same for laptop and desktop computers though they cannot be so conveniently used outdoors.

Without a doubt, observing applications for use on cell phones and tablets have revolutionized observing. Back in 2010, the author completed his Deep Sky Binocular observing program through the Astronomical League. The first 42 of 60 observations were completed using his iPad's *SkyVoyager* program as a guide. The last 18 observations were completed using an updated version of *SkyVoyager* called *SkySafari*. He couldn't have been more impressed or pleased with the fruitful nature of the assistance.

Shortly thereafter, the author was able to configure his iPad's *SkySafari* program to work in conjunction with a *SkyFi* wireless device tied into his CPC 1100 computer driven "GoTo" telescope. To give some sense of the utility of this combination, consider their impact on the author's Herschel II observing program. This Astronomical League observing program focuses on 400 NGC deep space objects (mostly galaxies) not previously addressed in the Herschel 400 observing program. During a single 3.5-hour time span in November 2010, he found, observed, and recorded observing notes for 42 NGC objects – galaxies, planetary nebulas, and open clusters – during his first observing session. Many of these objects are "faint fuzzies," hard to find without a detailed finder chart.

The *SkySafari* not only drives the CPC1100 directly to the celestial object with the click of a few buttons, but

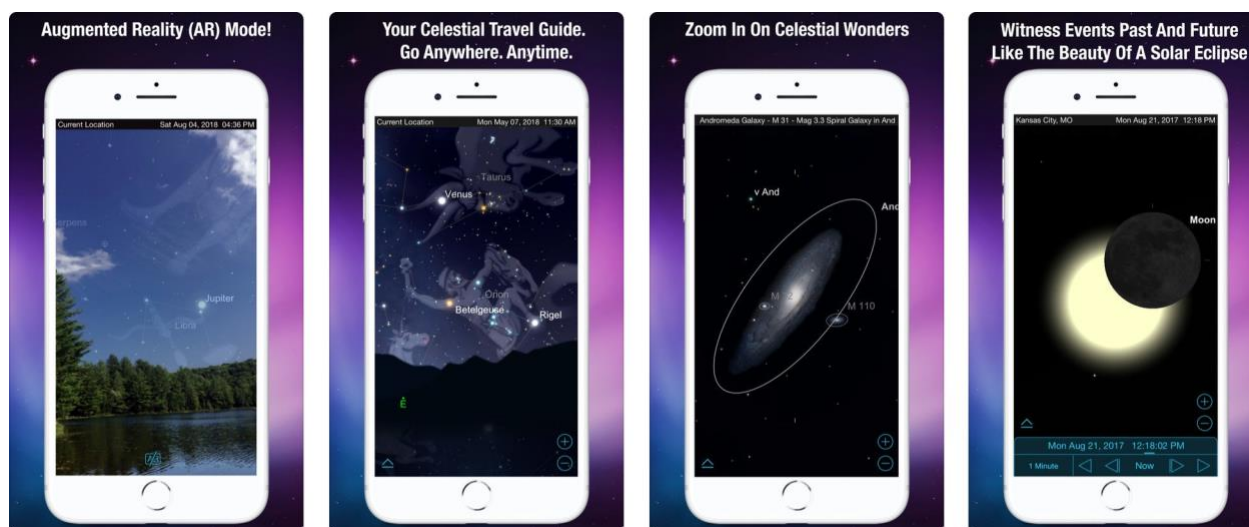
provides a detailed star map of the vicinity that precisely fits a circular field of view of his chosen eyepiece and is properly oriented to match the semi-inverted image, the type of field that occurs with a Schmidt-Cassegrain telescope that employs a right-angle prism immediately before the eyepiece.

Not only was the author able to more easily find objects, but hints from the star maps provide him with additional information such as object size, orientation, and appearance. Once objects are observed, they are checked off the observing list along with an automatically recorded statement of the time and date of observation. The convenient note pad portion of the software allows for (almost encourages) detailed note taking. What previously was a hand scrawled, nearly illegible, half dozen words, becomes a clear, typewritten note of typically 2-3 lines. The cold does not affect one's ability to take notes when using a hunt-and-peck approach with the iPad's virtual keyboard.

In addition to all these features, *SkySafari* allows users to develop an individualized observing list for use at the telescope. Prior to going out to observe, one can enter celestial objects into an observing list. Once one observation was completed, one is able to immediately proceed to the next without any sort of hesitation.

Suffice it to say, iPad (or a cell phone which has a bit smaller and less convenient screen) working with *SkySafari* and *SkyFi* has revolutionized the way observers conduct observing sessions. In addition to the "GoTo" telescope, observing app such as *SkySafari* are one of the most impressive and powerful observational aids amateur astronomers have seen in more than a half century of sky watching.

The version of *SkySafari* shown below is available for only \$2.99 and is one of the best purchases you'll make in relation to amateur astronomy. There are several good alternatives to *SkySafari*, so be certain to check them out before making your purchase.

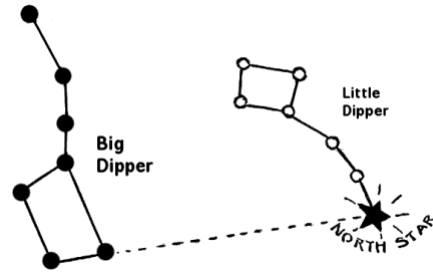


5. HOW TO FIND NORTH IN THE SKY

When one watches the northern stars over the course of a night they trace out entire circles in the northern sky. The stars appear to move in a counterclockwise fashion. The North Star, whose name is Polaris, is located very close to the north celestial pole (within about $2/3$ of 1°) and is therefore the one star about which all others appear to move. To find north, draw a line straight down to the horizon from Polaris.

Contrary to widespread belief, the North Star is not the brightest star in the sky. In fact, it is the 49th brightest star in the sky with 48 other stars being brighter. It is confused with being brightest because it is important and therefore famous. The brightest star in the sky is the star Sirius located among the stars of Canis Major, the Big Dog.

As noted above, finding the direction north is easy to do once one finds the North Star. The problem is, which of the many stars visible at night is the North Star and how



does one confirm its identity? The way to find it is to use the pointer stars of the Big Dipper. Extend a line out of the bowl about a dipper's length and you'll run into a star. If this star is the star at the end of the handle of the Little Dipper, you can rest assured that you have found the North Star.

Again, as misleading as the image above might be, remember, the North Star is only a moderately bright star and by no means the brightest star in the sky.

6. MAGNITUDES

Apparent magnitude: Astronomers use the system of magnitudes to describe the apparent brightness of stars as seen from Earth. The first to use magnitudes was the Greek astronomer Hipparchus. In his very rudimentary classification system, the brightest stars were classified as first magnitude ($m = 1$). The second brightest stars were classified as second magnitude ($m = 2$) and so forth. The dimmest stars visible to the unaided eye under a very dark sky were classified as sixth magnitude ($m = 6$).

In 1856, Hipparchus' rudimentary system was formalized by the astronomer Norman Pogson who defined a first magnitude star to be 100 times brighter than a sixth-magnitude star, thereby establishing the logarithmic scale we still in use today. (N.B. If you are not comfortable with the mathematics of logarithms, feel free to skip over that content which is not useful to you. You need not understand logarithms to benefit from their use. Skip ahead to the next section if you wish.) This scale implies that a star of magnitude m is roughly 2.512 times as bright as a star of magnitude $m+1$. This figure, 2.512, is the fifth root of 100. With the introduction of photometry, a method that could actually count photon by photon the light received from a star, a way became available to more accurately define the magnitudes of stars. Under this new system Sirius, the Dog Star, the brightest star appearing in our night sky, has an apparent magnitude of -1.4 .

At this time, Pogson used the star Vega as a standard benchmark for 0 magnitude, and the brightness of stars were thereby measured in relation to this star. (Today we use the "north polar sequence" of some 30 stars to define the benchmark.)

Because astronomer can nowadays measure the amount of light reaching Earth from a star, we define the apparent magnitude in terms of flux (F), a number proportional to the photon count, as follows: $m_{\#} = -5 \log_{10} \left(\frac{F_{\#}}{F_{0}} \right)$ or more commonly in base

Apparent stellar magnitude	Brightness relative to Vega
-1	250%
0	100%
1	40%
2	16%
3	6.3%
4	2.5%
5	1.0%
6	0.4%

10, $m_{\#} = -2.5 \log_{10} \left(\frac{F_{\#}}{F_{0}} \right)$ where $F_{\#}$ is the observed flux of a given star and F_{0} is the flux of the reference star of magnitude 0 such as Vega. Inverting the above formula for a magnitude difference of $m_{\#} - m_{\#} = \Delta m$ implies a brightness factor of $F_{\#}/F_{0} = 10^{\Delta m/2.5} = 10^{0.4 \Delta m} \approx 2.512^{\Delta m}$. With this latter formula, we can compare the apparent brightness of different objects. In the current evening sky (June 10, 2016), Mars (Ares) shines at apparent magnitude -1.80 . The star Antares (rival of Mars) shines at $+1.07$. How many times brighter is Mars in comparison with Antares? $F_{\#}/F_{0} = 2.512^{(A-B)}$ implies $F_{\text{Mars}}/F_{\text{Antares}} = 2.512^{(-1.80 - 1.07)} = 2.512^{-2.87} = 14.1$. That is, Mars is some 14 times brighter than Antares on the date in question. A magnitude difference of 2.87 would not suggest this

comparison directly; therefore, amateur astronomers should know how to make use of these formulas.

Magnitude addition is a bit complex. Still, if one wants to determine the apparent brightness of a pair of double stars, one can add their magnitudes in the following manner: $m_0 = -2.5 \log_{10}(10^{B-A} + 10^{B-C})$ where m_0 is the resulting magnitude after adding the brightness of stars whose magnitudes are m_1 and m_2 .

Absolute magnitude: Flux decreases with distance according to the inverse-square law. That is, if you double the distance of a given star, it will appear $(1/2)^2$ or $1/4$ as bright as before. Hence, a particular apparent magnitude could equally well refer to a star at one distance, or a star 4 times brighter at twice that distance, etc. When one is interested in the *intrinsic* brightness of an astronomical object, then one refers not to the apparent magnitude but its absolute magnitude. The absolute magnitude, M , of a star or astronomical object is defined as the apparent magnitude it would have as seen from a distance of 10 parsecs or about 32.6 light years.

Distance modulus formula: Absolute magnitude, M , is related to apparent magnitude, m , by the following

expression: $m - M = +5 \log_{10} d - 5$ where distance, d , is expressed in parsecs. This expression assumes no interstellar dimming. The value of $m - M$ is known as the distance modulus, and the entire expression is known as the distance modulus formula. If two of the three terms in the formula are known, then the third can be solved for uniquely. If, for instance, the parallax of a star can be found through observation (which is readily done for nearby stars), then from knowledge of its apparent magnitude its absolute magnitude can be found. If, for instance, a star's absolute magnitude can be found using spectral analysis and the Hertzsprung-Russell diagram, then knowledge of its apparent magnitude can be used to determine a star's distance.

N.B. Magnitudes are a bit more complicated than presented here. Apparent magnitude is a function of color and is affected by the presence of interstellar darkening and reddening. Cosmological red shift also can affect apparent magnitude. Bolometric magnitude is a magnitude that takes into account the full range of a star's emission, not just in a particular wavelength region such as visible light. Keep in mind that this is merely a short introduction to magnitude systems and in no way is to be considered a full treatise on the matter.

7. MOTIONS OF THE SUN

The sun rises in the eastern sky each morning and sets in the western sky each evening. The spinning of Earth causes this motion. As Earth turns from west to east, the sun appears to move from east to west across the sky. The path that the sun takes across the sky changes each day due to the 23.5 degree "tilt" of Earth's axis of rotation. On the first day of our summer, the sun rises roughly in the northeast and sets roughly in the northwest. At midday the sun is high in the southern sky but never passes directly overhead. (That can occur only for people living between the tropics of Cancer and Capricorn.) On the first days of autumn and spring the sun does tend to rise due east and set due west and is located about half way up in the southern sky at midday. On the first day of winter the sun rises roughly in the southeast and sets roughly in the southwest. At midday it is low in the southern sky. The changing elevation of the midday sun and changing directions of the rising and setting sun is due not only to Earth's axis being inclined to its orbit, but because Earth is in orbit around the sun as well.

As Earth moves around the sun, the sun appears to shift about 1 degree eastward among the background of stars each day. (This is why we have 360 degrees in a circle.) This eastward motion of the sun cannot be directly observed due to the bright sky, telltale evidence can be found in the drift of the constellations. Each evening the constellations appear to rise and set about 4 minutes earlier. This occurs because of the sun's daily motion among the background stars. It takes Earth about 4 minutes to turn through one additional degree each day to bring the sun back to the same location in the sky.

The exact path of the sun traced out among the stars is known as the ecliptic. The constellations through which the sun appears to move over the course of the year are known as the zodiac. The sun, moon, and planets are always located among the stars of the zodiac because all planets orbit the sun in approximately the same plane.

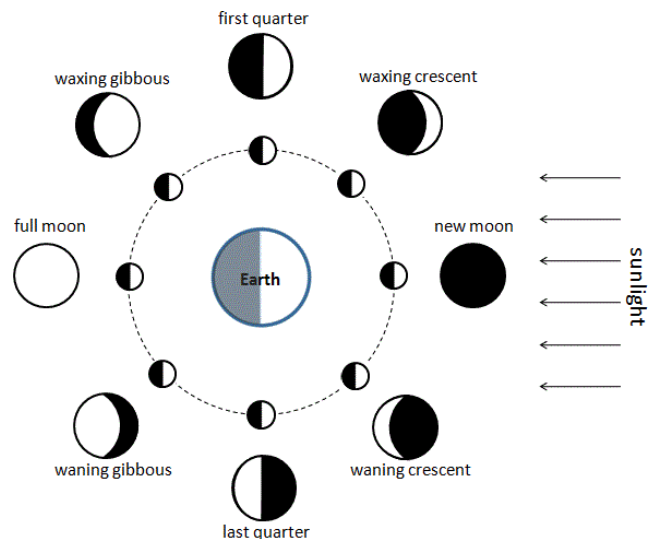
8. MOTIONS AND PHASES OF THE MOON

The moon's motion is very similar to that of the sun. However, its eastward motion among the stars is much more rapid and easily discerned from night to night. Because Earth spins on its axis, the moon rises and sets as does the sun. However, because the moon orbits Earth in a

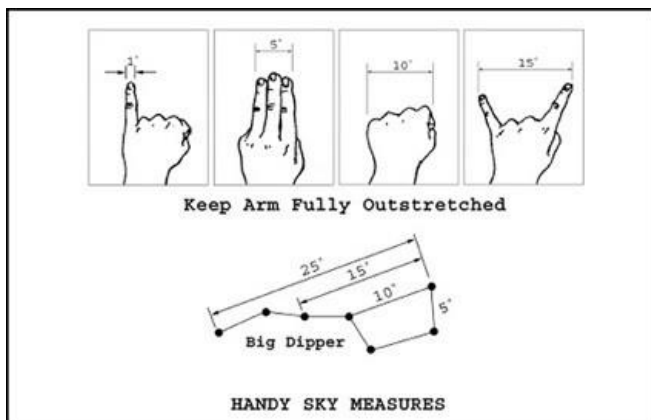
period of about a month, its eastward motion among the background stars occurs at a rate of about 13 degrees per day. Hence, from one night to the next, the moon's eastward progression among the stars of the zodiac is easily seen. The moon's rapid eastward motion accounts for the

fact that it rises and sets about 50 minutes earlier each day on average.

As the moon orbits Earth, we see more and then less of its sunlit surface over the course of a month. This accounts for the phases of the moon as shown here. When the moon is in the same direction in the sky as the sun, its far surface is lit whereas its near surface is dark; this gives us the new moon. As the moon continues to orbit we see more and more of its sunlit surface. When the moon is $\frac{1}{4}$ in its orbit around Earth, it is at the first quarter phase. Half of the moon's visible surface is lit – that nearest the sun. Eventually the moon is roughly opposite the sun in the sky, and its surface appears fully illuminated. The reason we don't have eclipses of the sun at new moon phase and eclipses of the moon at full moon phase is because the moon's orbital plane is inclined by just over 5 degrees to Earth's orbital plane. The moon passes above or below the sun a new phase and above or below Earth's shadow at full phase.



9. ANGULAR MEASURES IN THE SKY



The distances between objects or the sizes of objects in the sky are measured in angles. For instance, the sun and moon both appear to have an angular size of about $\frac{1}{2}$ of 1° . The Big Dipper is about 25° long from the tip of the handle to the tip of the bowl.

Because humans are scaled roughly the same, it is possible and literally very “handy” to measure angular distances with the outstretched arm. Fingers in various combinations are good approximations of angular measures as shown in the image below.

For measuring angular distances more than 15° , say 30° , two spans of fingers covering the distance in two equal 15° lengths is an adequate approximation.

10. THE CELESTIAL SPHERE

The celestial sphere is an imaginary sphere of large but indeterminate size with Earth located at its center. The poles of the celestial sphere are aligned with and are located directly over the poles of Earth. The celestial equator lies along the celestial sphere in the same plane as Earth's equator. There are many other reference points and circles on the celestial sphere with which all amateur astronomers should be familiar:

Zenith – The point on the celestial sphere directly over an observer's head.

Nadir – The point on the celestial sphere directly under an observer's feet.

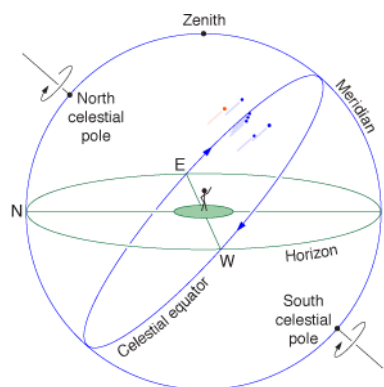
Meridian – A circle splitting the sky into eastern and western halves. The circle is fixed relative to the observer and passes from the north point on the horizon (N), through

the zenith, to the south point on the horizon (S). It is the meridian to which AM and PM refer. Ante meridiem (Latin) is “before the meridian” and refers to the morning hours. Post meridiem (Latin) is “after the meridian” and refers to the afternoon hours. When the sun is on the meridian it is local solar noon. Objects are at their greatest altitude in the sky when they cross the meridian (transit) going from east to west due to Earth's rotation.

Celestial Equator – A projection of Earth's equator into space. When an object is on the celestial equator, it is located directly over Earth's equator.

Ecliptic – The circle on the celestial sphere that represents the path of the sun’s motion over the course of a year. The motion is only apparent being caused by Earth’s orbital motion around the sun. The ecliptic is inclined some $23^{\circ}44'$ of arc to the celestial equator.

Horizon – Just like Earth’s equator, Earth’s horizon can be projected onto the sky for use with an alternative coordinate system. The problem with this coordinate system is that it moves with the observer. Celestial coordinates are roughly fixed on the sky but for slow precession of the First Point of Aries, γ , among the background of stars.



11. ALTITUDE AND AZIMUTH

Stating the locations of objects in the sky can be done in a variety of ways. For instance, a planet is 3 degrees to the west of the head of Leo the Lion. But what happens when there are no nearby convenient markers or if someone doesn’t know the constellations as is often the case? Then the best thing to use to identify the location of an object in the sky is its altitude and azimuth.

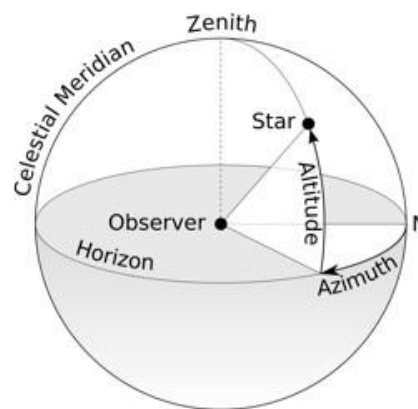
Altitude refers to the angular distance of an object above the horizon. An object with 0° altitude will appear on the horizon. An object at the zenith (the overhead point) will have an altitude equal to 90° . An object half the way up in the sky will have an altitude of 45° , $1/3$ way 30° , $2/3$ way 60° and so forth.

Azimuth refers to the angular distance of an object from the direction north measured eastward around the horizon. The azimuth of an object that is due north is 0° , east 90° , south 180° , west 270° , and so forth. The numbering

continues northward reaching 360° at the north point which is the same as 0° .

The location of an object $1/3$ way up in the northwest would be as follows:
altitude 30° ,
azimuth 315° .

While this is a convenient system for finding objects in the sky, it is time dependent. As Earth rotates and objects rise in the eastern sky, move left to right across the southern sky, and then set in the western sky, their altitudes and azimuths change.



12. RIGHT ASCENSION AND DECLINATION

The earliest method used to find objects in the sky was with the use of constellations. Star patterns were identified as various types of objects such as gods, humans, and animals. A celestial object might be located “below the belt of Orion” or “near the head of Cygnus.” These location descriptions were too imprecise for tracking moving objects such as planets (wanderers). Over the course of time, a celestial coordinate system known as right ascension and declination was developed.

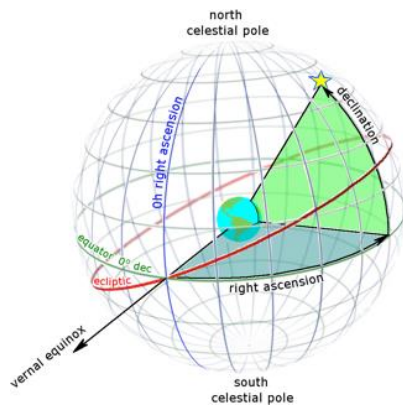
Right ascension (R.A.) and declination (Dec.) are to the celestial sphere as longitude and latitude are to Earth’s globe. Just like Earth, the sky has two poles and an equator – celestial poles and equator as compared to terrestrial poles and equator. The sky’s coordinates are projections of earth’s coordinate system onto the celestial sphere.

R.A. is analogous to Earth longitude. It is expressed in hours ($1^h = 15^{\circ}$ at the celestial equator, C.E.), and is measured *eastward* along the C.E. from the First Point of

Aries (γ – sometimes called the Vernal Equinox), the position of the sun on the date of the March equinox. On the March equinox the sun is directly on the celestial equator and has a R.A. of $0^h0^m0^s$ by definition. An object 90° east of γ will have an R.A. of $6^h0^m0^s$. Hours of R.A. are used instead of degrees because meridians of R.A. converge at points away from the C.E. and meet at the celestial poles. The span of 1^h of R.A. is therefore not always 15° . The span of arc for 1^h of R.A. equals $15^{\circ}\cos\delta$ where δ represents the declination.

Dec. is analogous to Earth latitude. Dec. is measured in degrees north (+) or south (–) of the C.E. The Dec. of the north celestial pole (NCP) is $+90^{\circ}$; the Dec. of the south celestial pole (SCP) is -90° . Points with equal Dec. values lie equidistant from the celestial equator along parallels of Dec.

Consider how R.A. and Dec. can be used to uniquely determine the position of an object in the sky. Say that an object has the following R.A. (α) and Dec. (δ): $\alpha = 5^h 0^m 0^s$, $\delta = +55^\circ$. Can you find the location of that object on the celestial sphere?



There is only one such location, and it is shown in the image to the left.

Telescopes, especially computer “goto” telescopes, will use the R.A.-Dec. coordinate system to find objects in the sky. Fortunately, amateur astronomers don’t often have to work with this system any longer. Not so long ago telescopes had setting circles that used R.A. and Dec. but no longer as many found their use rather confusing in practice.

Some older telescopes even used hour angles (H.A.) to find celestial objects where $H.A. = \text{local sidereal time (l.s.t.)} - \alpha$. Do you find R.A. and Dec. somewhat confusing? Just wait until you delve into sidereal time and you’ll really get to understand the meaning of the word.

13. TELESCOPES VERSUS BINOCULARS

Many would-be amateur astronomers are disappointed when I suggest that the first thing they should consider purchasing for sky watching is a good set of binoculars and an observing guide. They are clearly of the opinion that “high power” is all that one needs to see things in the sky. The fact of the matter is that many low-surface-brightness

objects and/or objects of large angular size are best viewed using low magnifications. There are several reasons for this. But first, let’s consider a number of well-known celestial objects that are best viewed by northern hemisphere amateurs using low-power binoculars or spotting scopes rather than telescopes.

- | | | |
|-----------------------------|-------------------------|-------------------------------|
| • Trifid Nebula | • Witch Head Nebula | • Pleiades |
| • Barnard’s loop | • California Nebula | • Triangulum Galaxy |
| • Rho Ophiuchi complex | • North American Nebula | • Orion Nebula |
| • Hyades (star cluster) | • Beehive Cluster | • Perseus Double Cluster |
| • Andromeda Galaxy | • Scutum star cloud | • Coma Star Cluster (Mel 110) |
| • Veil Nebula / Cygnus loop | • Rosette Nebula | • Alpha Persei Cluster |
| • Helix Nebula | | |

While most binoculars and spotting scopes don’t have the benefit of large aperture, they do have one thing that is critical to observing low-surface-brightness objects – low magnification. This might seem counterintuitive, but consider the following two facts:

Low magnification binoculars and spotting scopes can provide a much wider field of view than will a telescope. The field of view of say a Celestron 5” f/10 spotting scope is much larger than that provide by a Celestron 11” f/10 telescope given the same eyepiece. Let’s say we have an 18mm eyepiece with an apparent field of view of 52° – typical of an inexpensive Plössl eyepiece. First consider the resulting magnifications of the two instruments using this particular eyepiece which are calculated by dividing the focal length of the objective (F) by the focal length of the eyepiece (f):

$$M_{11''} = F/f = 2,794\text{mm}/18\text{mm} = 155.2X$$

$$M_{5''} = F/f = 1,270\text{mm}/18\text{mm} = 70.6X$$

Next consider the true field of view given by the

following formula: true field of view of an eyepiece (T) equals its apparent field (A) divided by resulting magnification.

$$T_{11''} = A/M = 52^\circ/155.2X = 0.34^\circ$$

$$T_{5''} = A/M = 52^\circ/70.6 = 0.74^\circ$$

Hence, the field of view is more than twice as wide (with an area 4.7X as much) in the lower-power telescope. So, larger objects can more easily be observed in lower-power instruments due to their larger fields of view given the same eyepiece. Now, it is quite true that using eyepieces that provide different magnifications and apparent fields of view will yield different true fields of view. For instance, longer focal length eyepieces will produce lower magnifying powers. Eyepieces with 82° and 100° fields of view show a considerably wider true field of view than our example Plössl eyepiece. Unfortunately, these multi-element wide-field eyepieces are quite expensive – some ranging in the hundreds of dollars. Lower magnification (longer focal length) eyepieces can have the same effect, but the size of

the exit pupil becomes so large that all the light gathered by the telescope cannot enter into the human eye. The lower the magnifying power, the wider the cone of light exiting the eyepiece. This results in vignetting which effectively reduces the aperture of a telescope.

Low magnification binoculars and spotting scopes typically provide a much brighter image than will a telescope. This statement might be surprising to a good many amateur astronomers. With larger aperture telescope lenses and mirrors, how can this be? The explanation has to do with the effect of magnification. Consider a typical human eye fully dilated to say 8mm. In comparison, an 11" (280mm) mirror can collect gather about 1,225 (35^2) times more light than can the fully dilated eye. However, when an image is magnified, the surface brightness of the thing observed is reduced. For instance, with my CPC 11" I most commonly observe at 87x. An object 87 times higher and 87 times wider will have a surface brightness of only $1/7,569$ that of the non-magnified image (87^2). The object is therefore $1,225/7,569$ times as bright as observed with the unaided eye! That is, the object is only 16.2% as bright as the real thing when observed with this telescope. Consider the effect of a 7x50 set of binoculars on apparent image surface brightness. With each lens gathering 39 times ($(50\text{mm}/8\text{mm})^2$) the amount of light as the eye, each objective makes a diffuse celestial object 39 times brighter

than seen with the unaided eye. At a magnification of 7, the object is reduced in brightness to $1/49$ the naked eye view. This combination results in a comparative surface brightness of $39/49$ or 79.6%. Hence, in comparison with the telescope combination cited, the *binoculars* will produce an object nearly five times brighter in terms of surface brightness. This is critical when observing low surface brightness objects such as those in the list above.

Of course, this presentation is rather simplistic because it does not take into account such things as secondary aperture blocking, reflection of light by eyepieces, utility of higher magnifications in seeing greater detail, and so forth. Nonetheless, it does shine light on why higher-power telescopes are not always the best instruments for viewing objects of the heavens. This goes to explain why so many amateurs have telescopes of different apertures and designs as well as a variety of binoculars. No one telescope is suitable for observing everything in the sky.

I hope that this helps our novice amateur astronomers gain a better understanding of the recommendation of binoculars and observing guides as the first place to start when purchasing astronomical viewing equipment. There has the added bonus, too, that binoculars can be used for much more than astronomical viewing should interest in sky watching wane.

14. USING BINOCULARS

Binoculars consist of two optical tube assemblies each called a monocular. Let's say for the sake of the discussion that you own a 6x42 pair of binoculars. First off, what do these numbers mean? The 6 refers to magnifying power. The 42 refers to a 42mm aperture. Binoculars come in a variety of types such as 7x35, 7x50, 10x50, and 15x70. Typically, the larger the aperture the better when it comes observing the dim objects of the night sky. Higher magnification can help, but "easy does it." Binoculars that magnify 10x are a lot harder to use than those that magnify 7x. This is because your hand shaking is also magnified. Binoculars of 15x and 20x almost always need to be mounted for effective use.

Lots of people have a hard time focusing binoculars because, quite frankly, they don't know what they are doing. There are two focusers on most quality binoculars. There is a center focus (sometimes called the *Instafocus*) between the two optical tube assemblies. This focuses both monoculars at the same time. One of the two eyepieces will

have an independent focus usually inscribed with the symbols and word +2, +1, 0, -1, and -2 diopters. The diopter focus is needed because most peoples' eyes are not the same. When used without the usual eyeglasses, viewers might have to adjust the two monoculars separately. If the user's eyes are identical, then the diopter focus will read 0 diopters when properly focused. Again, for the sake of the discussion, let's say that the diopter focus is on right monocular.

Closing your right eye and looking at a very distant object, focus your left monocular using the center focus. Then, opening your right eye and NOT touching the center focus, use the diopter focus to bring the image in the right monocular into clear view. Both monoculars should now be well focused. Once this latter adjustment is made, the observer can use the center focus to adjust both monoculars when observing objects near and far, both of which will have their own focus setting. A clear image should be present for each eye.

15. HOW TELESCOPES WORK

Telescopes are a mystery to those who have never studied them. This lack of understanding arises from the

fact that most people don't know how lenses and mirrors work. Before we begin our "study" of the telescope, let's try

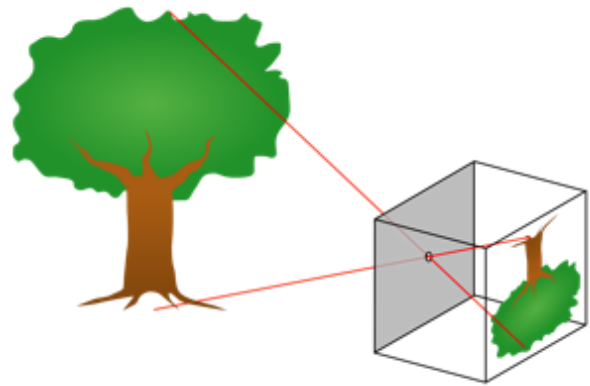
to understand the concept of pinhole projection. We will then turn our attention to the simplest form of telescope – the refractor. Once we understand how a refractor works, it's easy to generalize our knowledge to other telescopes.

The best way to gain an understanding of how a refracting telescope's main lens (the objective lens) produces an image for examination, is to examine a pinhole camera. Suppose a tiny box has a pinhole on one side and a sheet of wax paper has replaced the opposite side. Say you are standing in a darkened room during the daytime. If you were to see a tree outside your window, you could hold your pinhole camera up to the window and an inverted image of the tree would appear on the wax paper. It would be easy to see because you would be viewing it from within the confines of your much darker room.

The reason the tree appears inverted (flipped top to bottom and side to side) is because of the point-to-point mapping of the tree onto the waxed paper screen. The red lines in the image here show only two rays that would enter the box through the pinhole. Because light travels in a straight line, an inverted image is produced. Because the pinhole is tiny, only a faint image is produced. If a larger pinhole is created opposite the view screen, the image will be brighter but also blurrier due to the fact that there is no longer a point-to-point mapping between the tree and its projection.

The objective lens of a refracting telescope is in some ways like a pinhole. A lens will produce a brighter image though because it is larger. The shape and refractive index of the lens will bend rays, however, so that the point-to-

point mapping is maintained despite the fact that the aperture is no longer a pinhole.



One difference from the pinhole though is that there is a particular distance beyond the lens that an image will form. This is the so-called image plane. So, a lens will project an image of an object on the side of the lens opposite the object whose image is being created. The image literally “hangs in space” and an eyepiece can be used to view it.

Eyepieces are little more than glorified magnifying lenses. Recall that magnifying lenses produce erect images when held close to objects. The magnifying glass does not produce an inverted image; it only makes the object look bigger. So, when an eyepiece is brought together with an objective lens that produces a projected image, the eyepiece produces an enlarged view. Nothing could be simpler!

16. THREE POWERS OF A TELESCOPE

When people purchase telescopes, the only power they typically think about is magnifying power. Actually, that's probably the least important of the three powers of the telescope! Here I summarized the three powers and provide some guidance for purchasing a suitable telescope and eyepieces.

- 1. Light Gathering Power** – This power gives an indication of how much light a telescope will gather into one's eye. LGP is often given in comparison to the light-gathering ability of the human eye dilated to a certain diameter. Like a bucket's ability to collect rain drops in comparison with a test tube, the larger the aperture of a telescope (the size of its mirror or lens), the greater will be the LGP of a telescope. The LGP ratio between a telescope (*t*) and eye (*e*) is easily expressed in terms of a ratio of the light-gathering areas of the telescope and eye:

$$\frac{LGP_K}{LGP_L} = \frac{4\pi r_K^2}{4\pi r_L^2} = \left(\frac{r_K}{r_L}\right)^2 = \left(\frac{d_K}{d_L}\right)^2$$

As this equation implies, the LGP of a telescope with respect to the human eye increases with square of the diameter of the telescope objective (lens or mirror). For instance, an 11" telescope (36.4mm) telescope will gather nearly 1,600 times more light than will a human eye dilated to 7mm (280mm/7mm)².

This formula also can be used to compare the differences between telescopes as well. An 8" aperture telescope will gather four times (2²) as much light as will a 4". A 16" telescope will gather 16 times (4²) as much light as a 4" telescope.

The limiting magnitude, *LM*, of a telescope (the faintest *star* a telescope can show under 'average' conditions depending on a number of factors such as magnification, *M*, diameter of objective in mm, *D*, the transmission factor, *t*, which is usually 0.85 – 0.9, and even sky darkness which is associated with the magnitude of the faintest naked-eye star visible, *m*) is given by the following approximation:

$$LM = m - 2 + 2.5 \log (M \cdot D \cdot t)$$

18

+

An 11" telescope ($D = 280$) on an average night ($m_{\text{naked eye}} = 5.0$) used at a magnification of 87, and with $t = 0.9$ will have a limiting magnitude of about 13.8. This is 8.8 magnitudes fainter than the LM of the eye, and a brightness ratio of 3,300 times.

2. **Resolving Power** – Resolving power is the ability of a telescope to show fine detail. Ignoring, momentarily, the blurring of an image caused by atmospheric turbulence (seeing) and assuming no optical imperfections of the telescope, the ability to separate two stars with a telescope is given by Dawes limit as follows

$$\alpha = \frac{116}{D}$$

where α is the minimum separation between two distinguishable stars expressed in arc seconds, and D , the diameter of the telescope objective expressed in mm. The theoretical resolving power of my 11" CPC telescope is $116/280 = 0.4$ arc seconds – about the best that can be expected given even the best seeing conditions (addressed elsewhere).

This equation shows that, all else being equal, the larger the aperture, the better the angular resolution. Note that the resolution is not dependent upon the magnification of a telescope. Telescopes marketed by giving high values of the maximum power often deliver very poor images for a variety of reasons, not the least of which is due to imperfections in the optical system. As the aperture of telescopes increases, the resolution can drop because it is further limited by the turbulence of the atmosphere. Larger aperture telescopes gather light rays from a larger cross-section of the sky, and this increases the turbulence in the telescopic image degrading resolution. Sometimes, for instance, the best views of planets can be seen in telescopes of smaller aperture – say 4.25 to 8 inches in diameter. The best views of Jupiter the writer has ever seen were in a 6" reflecting telescope due primarily to the limits imposed by seeing. Aperture in relation to resolving then is a double-edged sword. The greater the aperture, the greater the theoretical resolving power but also the

greater the problems with seeing; the smaller the aperture the less the theoretical resolving power but also the smaller the problems with seeing. This explains, in part, why many amateur astronomers have telescopes of different aperture.

3. **Magnifying Power** – Magnifying power describes how much larger an object looks in an eyepiece in comparison to the object when seen with the unaided eye. At a magnification of 10X, for instance, an object will appear to be 10 times higher and 10 times wider in comparison to the view without magnification. Magnifying power, M , depends upon two aspects of a telescope: the objective's focal length (F) and the eyepiece's focal length (f). That is,

$$M = \frac{F}{f}$$

Consider once again an 11" telescope whose objective has a focal ratio (f) of 10, and an aperture of $D = 280\text{mm}$. The focal length is then found by multiplying the aperture by the f /number. That is,

$$F = D * f = 280\text{mm} * 10 = 2800\text{mm}$$

The magnification using an eyepiece with, for example, a 32mm focal length eyepiece is then calculated from the earlier equation as follows:

$$M = F/f = 2800\text{mm}/32\text{mm} = 87.5X$$

As stated earlier, magnifying power is among the least important factors in the use of a telescope. Why should this be? It's because by merely swapping one eyepiece for another, magnification can be changed. Longer focal length eyepieces produce lower magnifications (and typically wider angular fields of the sky) whereas shorter focal length eyepieces produce higher magnifications (and typically narrower angular fields of the sky). Because telescope eyepieces are quite varied in terms of focal length and apparent field of view (and many other factors), these are addressed in a separate publication.

17. LIMITING MAGNITUDE OF A TELESCOPE

With the recent acquisition of an 18-inch Obsession telescope, I have had the opportunity to compare how this telescope and my 2006 Celestron CPC 11-inch telescope perform in terms of limiting magnitude – the magnitude of the faintest stars visible at zenith through a telescope. I have during the past month taken several opportunities to compare telescopic views side by side and have come up with a number of findings. While investigating the limiting

magnitude of my 18-inch (for the purpose of generating better star maps), I was mildly surprised to find out that a large number of factors affect the limiting magnitude of a telescope. I'd like to share some of my thoughts and reflections dealing with limiting magnitude.

My first real question after acquiring the Obsession was, "What is this telescope's limiting magnitude?" More technically speaking, how faint a star can I see at zenith with

the telescope under varying conditions? I have been stunned by the observed differences between the 11- and 18-inch telescopes. Typical views through the 11-inch telescope match very nicely the star maps generated by my iPad's *SkyVoyager* (recently renamed *SkySafari*) program. That program shows stars down to about 12th magnitude. When looking at the same star field with the 18-inch, however, the difference is amazing! While only a few stars might be found in a given 11-inch field, many times more stars can be seen in the same 18-inch field of view.

Clearly, the larger a telescope's objective lens or mirror, the more light it can gather into the observer's eye. Considering the objective only, the amount of light that it can gather is directly proportional to its surface area. The ratio of areas tells the number of times more light a larger objective can gather in comparison to a smaller objective. Consider the relative light gathering powers (*LGP*) of my 11- and 18-inch mirrors:

$$\frac{LPG_{18}}{LPG_{11}} = \left(\frac{18}{11}\right)^2 = 2.68$$

The 18-inch objective (not considering the secondary obstruction and other factors) gathers some 2.68 times as much light compared to the 11-inch objective all other things being equal. This aperture difference alone will provide views of stars just over one magnitude fainter ($2.512^{1.01} = 2.68$). Clearly, this doesn't entirely account for the differences observed between my two telescopes. Many other considerations also apply, and it is these that account for the major differences in what I have observed.

Type of telescope: Reflecting telescopes have a mirror for an objective. Most reflectors (but not a Shiefspiegler for instance) have a secondary mirror that blocks a significant amount of light from hitting the primary mirror. Mirrors aren't perfect either; they don't reflect all incident light. These factors work together to reduce the limiting magnitude. (Recall that the fainter the object the higher the magnitude.) The refractor has a lens as its objective and is free from a central obstruction. Still, refracting telescopes can backscatter a significant amount of light from their surfaces if suitable anti-reflective coatings are not in place. Lenses can also absorb some of the incident light. The Schmidt-Cassegrain has a lens-and-mirror combination. It is subject to all these problems of reflectors and refractors.

Mirror reflectivity/lens transmittance: The reflectivity of the mirror and the transmittance of a lens will place a cap on limiting magnitude. Both mirror and lens coatings and optical cleanliness can affect limiting magnitude. For instance, old pure aluminum coatings on mirrors had only an 88% reflectivity. Two mirrors (primary and secondary) in series would have an effective reflectivity to only 77% (0.88^2). Modern "enhanced" coating on primary mirrors is typically 95% reflective and on secondary mirrors 98%

reflective with overall reflectivity of 93% (0.95×0.98). Similar considerations must be taken into account for refracting telescopes with and without anti-reflective coatings on critical surfaces. Also of concern with refractors is the clarity of the optical glass used to formulate the objective lens. The same is true with eyepieces. This article assumes the enhanced reflectivity of mirror coatings and the use of antireflective coatings. It is assumed that eyepieces do not play a direct role in terms of light reflection and absorption. Limiting magnitudes will be lower by approximately 0.2 magnitudes than those stipulated in this article if modern reflective coatings are not used on the surfaces of objectives and secondary mirrors (if employed). Poorly maintained (e.g., dirty or oxidized optical coatings) will further reduce the limiting magnitude of a telescope. "Clean optics" are assumed for the purpose of this article.

Magnification: The effect of magnification on limiting magnitude is surprisingly great. My recent experiences with observations of the planetary nebula Pease 1 in globular cluster M15 show that magnification is a major consideration. Higher magnification (e.g., 230X) with the 18-inch and a 9mm eyepiece shows disproportionately more stars in the same field of view than are visible at lower magnification (e.g., 52X) with the same telescope using a 40mm eyepiece. The higher magnification reduces the brightness of the background, making fainter stars visible. It's the higher contrast that makes the difference. Under stable atmospheric conditions, stars approximate point sources and cannot be magnified in size significantly; the background sky can be magnified, however, spreading its light over a wider surface area of the pupil and therefore reducing its intensity. This increases the contrast between sky and star. Greater contrast means greater visibility. (That's why you don't see stars during the daytime even though present in the sky – the contrast is too low.) So, limiting magnitude is clearly dependent upon magnification as well as aperture.

Atmospheric seeing: Seeing – essentially the turbulence of the atmosphere – can influence limiting magnitude. Seeing can be measured by determining the diameter of a star image. Stars, while large objects, are so distant that they normally appear only as point sources. The Earth's atmosphere can play havoc with starlight, making the images much larger. Point sources are not affected by dimming as a result of magnification; the same cannot be said when stars appear as disks. Disks of light can be magnified, thereby reducing their surface brightness. The more turbulent the atmosphere is, the greater will be the size of stellar disks. Stellar disks can easily vary from 0.5 arc seconds under ideal seeing conditions to several seconds of arc under poor seeing conditions. Poor seeing decreases the limiting magnitude.

Sky darkness: Pursuing a knowledge of limiting magnitude of a telescope further makes one realize that sky

darkness will also help to determine the number of stars visible in a telescope. This is analogous to the experience where more stars are visible in the sky on nights when it is especially dark. Anyone who has viewed the sky from both urban and country settings will clearly have a grasp on this. In an urban setting it is not uncommon to find a limiting magnitude at zenith of 3 or lower. Poor nights in the countryside will have a limiting magnitude of perhaps 4.5, typical nights of perhaps 5.5, and optimum nights of perhaps 6.5. A brighter sky will reduce limiting magnitude.

Sky transparency: Sky darkness and sky transparency are not to be confused. A sky can be extremely dark and yet stars cannot be seen if the sky is not transparent (e.g., overcast with clouds). High humidity, haze from forest fires and volcanic eruptions, dust from farm work, and thin layers of clouds can easily affect sky transparency. For the purpose of this article, high transparency is assumed. Low sky transparency will reduce the limiting magnitude.

Zenith distance and extinction coefficient: The path length that starlight must traverse through the Earth's atmosphere depends upon zenith distance. The closer to the horizon one observes, the greater the amount of atmospheric extinction one experiences. We are all familiar with the fact that the sun can appear appreciably dimmer when near the horizon than when higher in the sky. That dimming results from the increased path length that light must travel through the atmosphere to reach the eye. Overhead, the path length is unity. At the horizon light must travel through as much as 5 times the amount of atmosphere before reaching the eye. This added path length causes dimming which is related to the extinction coefficient. Typically, extinction coefficients range from 0.2 to 0.6 magnitudes per unit air mass. Observing closer to the horizon will reduce limiting magnitude. Atmospheric extinction accounts for the dimming of the sun near sunrise and sunset and can amount to several magnitudes if the sky is not transparent.

B-V color index (CI) of a star: CI in this article is defined as blue minus visual magnitude (B-V). The bluer a star, the smaller the value of CI is. The CI of stars varies considerably and affects visual acuity. We all know, for instance, that stars come in a range of colors from blue to white to yellow to orange to red. This color can affect one's ability to see a

faint star. We all know that we are relatively insensitive to red light (hence, the use of red light at night) and the much higher sensitivity to the blue-green portion of the spectrum (whose light can destroy dark adaption). Consider the following color indices: Regulus, bluish B7 spectral type, CI = -0.11; Sirius, whitish A0 spectral type, CI = 0.0; Sun, yellow G2 spectral type, CI = 0.63; and Betelgeuse, red M2 spectral type, CI = 1.85. The human eye is most sensitive to the yellow-green portion of the spectrum. Hence, observing faint stars outside this optimum color range will result in a reduced limiting magnitude.

Dark adaption: This article assumes complete dark adaption and good eyes...properly focused star images, etc. Dark adaption will allow for the eyes' pupils to dilate and for the chemical rhodopsin to form in the retina that sensitizes it to faint light. Clearly, people who are dark adapted will see more stars than someone who is not dark adapted – despite the fact that poorly dark-adapted individuals will often claim that the sky is much darker than it appears to a properly dark-adapted observer. Once fully dark adapted, an observer is more likely to see the sky glow in addition to the brighter stars.

Experience of an observer: Even the experience of an observer can affect limiting magnitude. Experience observers will use averted vision effectively. This helps to see dim stars, but this is a qualitative parameter and is not dealt with further in this article or the subsequent limiting magnitude calculations.

Limiting magnitude calculations: So, the limiting magnitude of a telescope is not a simple thing to determine. It depends on lots of optical factors, observing conditions, and observer characteristics. Using the following website whose code was written by Larry Bogan (1998), I have been able to develop a data set for my 18-inch telescope to which I have made adjustments to include the newest antireflective optical coatings.

<http://www.nature1st.net/bogan/astro/optics/maglimit.html>

Table 1 below shows what I have calculated to be the limiting magnitudes of my Obsession 18-inch telescope depending on varying conditions:

Magnification	Poor Conditions*	Typical Conditions*	Optimum Conditions*
52X	12.7	13.7	14.7
230X	15.1	15.9	16.6

Table 1. Limiting magnitudes of Obsession 18-inch telescope under varying conditions

So, what does this mean in terms of Milky Way stars in the observable range? Consider Table 2. Under typical conditions, my CPC1100 can reveal about 5.3 million stars at low power under typical conditions. My 18-inch

Obsession, on the other hand, can show nearly 380 million stars at high power under typical conditions – more than 70 times as many!

Magnitude	Range	Number of Stars in Range	Cumulative Number of Stars
12	+11.50 to +12.49	3,481,113	5,304,685
13	+12.50 to +13.49	10,126,390	15,431,076
14	+13.50 to +14.49	29,457,184	44,888,260
15	+14.50 to +15.49	85,689,537	130,577,797
16	+15.50 to +16.49	249,266,759	379,844,556

Table 2. Numbers of stars visible by magnitude

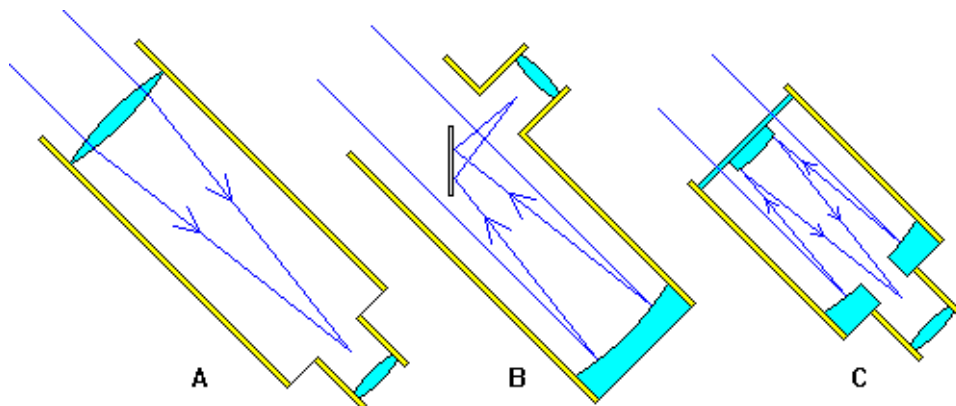
The next time someone asks you the limiting magnitude of a telescope, be certain to tell them that the old tried and true formulas (method 1: $ML = 3.7 + 2.5 * \log_{10}(D^2)$ where D = aperture in mm and taken from *Visual Astronomy for the Deep Sky* by Roger N. Clark; method 2: $ML = 9.5 + 5.0 * \log_{10}(D)$ where D = aperture in inches and taken from *The Observational Amateur Astronomer* by Patrick Moore) aren't really very accurate. For instance, method 1 gives 17.0 for my Obsession telescope and method 2 gives 15.8 under who knows what conditions. Clearly, it is difficult to say precisely what the limiting magnitude of any telescope actually is without a detailed analysis such as that provided by Bogan and slightly modified to account for new antireflective mirror coatings and such. For additional information about limiting magnitude, see the article by Bradley Schaefer who first calculated the limiting stellar magnitude an observer can expect under various conditions with various types and sizes of telescopes. The process is fully described in *Sky & Telescope* magazine, November 1989, page 522.

 * "Poor conditions" consist of a 35° zenith distance, 4.5 zenith limiting magnitude, extinction coefficient of 0.6 magnitudes per atmosphere, dirty optics, seeing 2 arc seconds, and size of eyepiece exit pupil is less than size of observer's pupil. "Typical conditions" consist of a 35° zenith distance, 5.5 zenith limiting magnitude, extinction coefficient of 0.4 magnitudes per atmosphere, moderately clean optics, seeing 1 arc second, and size of eyepiece exit pupil is less than size of observer's pupil. "Optimal conditions" consist of a 35° zenith distance, 6.5 zenith limiting magnitude, extinction coefficient of 0.2 magnitudes per atmosphere, very clean optics, seeing 0.5 arc second, and size of eyepiece exit pupil is less than size of observer's pupil. These calculations also assume an "average" observer, neither expert nor novice, with well-adapted eyes and a properly focused telescope. Of course, the color of a star will also make a difference. Calculations are based on the presence of highly detectable A0 stars with a color index of 0 in the field of view.



18. COMMON TELESCOPE TYPES

Telescopes come in a variety of types with a myriad of variations as shown in the figure below. The three most common telescope types used by amateur astronomers today, however, are the classical refractor (A), the Newtonian reflector (B), and the catadioptric of the

Cassegrain design (C). Each type of telescope has advantages and disadvantages, and those looking to purchase a telescope should be familiar with each in order to make the best possible choice.





Telescope Type	Advantages	Disadvantages
 <p>A) Refracting telescopes...</p> <p>are probably the most common telescope around generally speaking. They use lenses instead of mirrors and the eyepiece is located at the bottom of the telescope. Their design is similar to binoculars and most spotting scopes. Astronomical refractors typically will have a diagonal prism or mirror just in front of the eyepiece to change the path of light by 90° making it possible to look down rather than upward through the eyepiece. With the use of a diagonal prism or mirror, images are semi-inverted due to the use of an odd number of reflecting surfaces. The objective lens must be either achromatic or apochromatic to avoid chromatic aberration. A single element lens is unsatisfactory for astronomical applications because of the resulting chromatic aberration that produces color fringes around celestial objects.</p>	<p>Easy to use due to the simplicity of design.</p> <p>Excellent for lunar, planetary, and binary stargazing.</p> <p>Sealed tube protects optics and reduces image-degrading air currents.</p> <p>Rugged, needs little or no maintenance.</p> <p>Its sealed tube partially protects the objective's surface from contaminants.</p> <p>Often come with "erector prism" that can reorient images of terrestrial objects so they can be seen properly (as with binoculars or a spotting scope).</p>	<p>Generally available only in small apertures, typically 2¼ to 6 inches, due to high expense of production.</p> <p>High quality refractors cost more per inch of aperture than any other kind of telescope.</p> <p>Smaller apertures mean poorer viewing of faint objects such as galaxies and nebulae.</p> <p>Heavier, longer, and bulkier than reflector and catadioptric telescopes of equal aperture.</p> <p>Objective lens is subject to dew and frost without the presence of a dew shield or lens heater.</p> <p>Most toy telescopes are of this design. Caveat emptor – let the buyer beware.</p>
 <p>B) Reflecting telescopes...</p> <p>use a mirror instead of a lens to gather light and form an image. The eyepiece is located at the side of the main tube near the top. Depending on the type of mount used, the eyepiece can sometimes appear below the telescope tube necessitating the observer to rotate the telescope in its mount to bring the eyepiece to the</p>	<p>Readily available in larger apertures and at low cost compared to other types.</p> <p>"Light buckets" usually have larger apertures providing excellent views of faint galaxies and nebulae.</p> <p>Short focal length systems can deliver larger fields of view and brighter images.</p> <p>A reflector costs the least per inch of aperture compared to</p>	<p>Generally, not well suited for terrestrial applications due to inverted images.</p> <p>The tube is open to the air, which means dust on the optics even if the tube is kept under wraps.</p> <p>Reflectors are more subject to optical misalignment than any other type of telescope and they require periodic collimation.</p>

<p>top. The problem is acute if an equatorial mount is used. Images are always fully inverted – flipped top to bottom and left to right – due to the use of an even number of reflecting surfaces. These telescopes are commonly available with computerized altazimuth mounts (above from left to right), manual German equatorial mounts, and Dobsonian push-to mounts. Mirrors must be parabolized to at least “¼ wave” in order to avoid obvious spherical aberration which results in the impossibility of completely focusing on an extended object.</p>	<p>refractors and catadioptrics because mirrors can be produced at a lower cost than lenses.</p> <p>The enclosed objective mirror is generally not subject to dew or frost while observing.</p>	
<div data-bbox="256 554 711 877" data-label="Image"> </div> <p>C) Catadioptric telescopes...</p> <p>use a combination of mirrors and lenses. Two of the more popular designs are the Schmidt-Cassegrain (left) and Maksutov-Cassegrain (right). The term Cassegrain refers to the fact that the light passes through a hole in the objective mirror and light exits the back of the telescope rather than the side. When these telescopes are used in conjunction with an altazimuth mount (left) the eyepiece in the same orientation to the ground no matter where in the sky the telescope is aimed. When used with a German equatorial mount (right), this is no longer the case. Diagonal prisms or mirrors are also used for visual observing to allow the observer to look down rather than up when peering through the eyepiece. Due to use of an odd number of reflecting surfaces in such cases, images are semi-inverted.</p>	<p>Most versatile type of telescope with excellent lunar, planetary and deep space observing plus terrestrial viewing and photography.</p> <p>Readily accommodates a telecompressor that permits the user to change the effective focal ratio.</p> <p>Best near focus capability of any type telescope.</p> <p>First-rate for deep sky observing or astrophotography.</p> <p>Closed tube design reduces image degrading air currents once the telescope as a whole has reached thermal equilibrium with the air.</p> <p>Compact and durable.</p>	<p>More expensive than reflectors of equal aperture.</p> <p>Corrector plate that holds the secondary mirror is subject to dew and frost. These telescopes almost always need to be used in conjunction with a dew shield or lens warmer.</p>

19. COMMON TELESCOPE TRAITS

Regardless of the design of telescope you own – refractor, reflector, Cassegrain, Schmidt-Cassegrain, Maksutov, Dall-Kirkham, or many others – there are three basic types of telescopes: reflectors, refractors, and composite telescopes. Composite telescopes are a combination of reflector and refractor. (See the handout **COMMON TELESCOPE TYPES.**)

Regardless of telescope type, there are certain telescope traits or other aspects that are common to most telescopes designs.

Aperture – The diameter, D , of a telescope’s objective mirror or lens constitutes its aperture. Because aperture determines to a large extent light-gathering power and theoretical resolving power, it is one of the most important traits of a telescope.

Focal length – The distance between the objective mirror or lens and its focal plane is known as the focal length, F . The focal length is directly proportion to a telescope’s magnification and true field of view with a given eyepiece. Longer focal length telescopes yield higher magnifications and smaller fields of view.

Focal ratio – The quotient of the focal length, F , and the diameter of the objective, D , constitutes the focal ratio. For instance, a telescope might have a focal ratio of 6. This is expressed as $f/6$. This does not mean “ f divided by 6”; the f merely stands for “focal” and the $/$ infers a ratio. Expressed mathematically, focal ratio $f/ = F/D$. Both F and D must be expressed in the same unit of measure to accurately determine the focal ratio. Consider the following example: $F = 2800\text{mm}$; $D = 280\text{mm}$; $f/ = F/D = 2800\text{mm}/280\text{mm} = 10$. Hence this is an $f/10$ system. What is the significance of the focal ratio? This ratio is used to describe the “speed” of a telescope. If $f/ < 6$, the telescope is considered “fast.” Such telescopes are ideal for low-power, wide-field viewing and for photographing dim objects. If $f/ > 8$, the system is considered “slow”. These telescopes are good for working with bright objects where high magnification is desired and narrow fields of view are acceptable such as in viewing the sun, moon, or planets. Focal ratios between 6 and 8 are considered general-purpose telescopes.

Barlow lenses – Barlow lenses are concave lenses that will effectively increase the focal length (and therefore focal ratio) of a telescope. A Barlow lens is placed between the objective and the eyepiece in order to increase the magnification of the system. It is typically attached to an eyepiece. For instance, a typical 2X Barlow lens will double the magnification of a given telescope eyepiece configuration. Barlow lenses effectively double the size of one’s eyepiece collection. If you had 40mm 32mm and 18mm eyepieces for example, adding a 2X Barlow to your collection would be like owning three additional eyepieces of 20 mm, 16mm, and 9mm focal lengths. A Barlow is much more cost effective, usually costing less than the price of one eyepiece.

Telecompressors – Many are the times when owners of high focal ratio telescopes (e.g. $f/10$ such as with most Schmidt-Cassegrain designs) are desirous of viewing with lower power and wider fields of view. This is made possible with the use of a telecompressor. Telecompressors are the opposite of Barlow lenses. They are convex lenses. Rather than extending the effective focal length of a telescope, they compress it. Typical telecompressor lenses reduce the focal ratio by a factor of 0.67. For example, an $f/10$ telescope effectively becomes an $f/6.7$ telescope with the use of a telecompressor. A Barlow lens can be thought of as a teleextender. An $f/4.5$ telescope effectively becomes an $f/9$ telescope with the use of a 2X Barlow lens.

Refractors with achromatic and apochromatic lenses – Quality refracting telescopes will have objective lenses that are either achromatic or apochromatic. Achromatic means that the optical elements of the objective lens (typically 2 elements) are matched in such a way as they provide good color correction at two points on the spectrum. Such lenses are less expensive than apochromatic lens (typically 3 elements) that are color corrected at three points on the spectrum. Apochromatic lenses are superior to achromatic

lenses, but they also cost considerably more. Apochromatic lenses give the truest colors to observed objects, while achromatic lenses do so less well. Lenses without chromatic (color) correction will produce images of stars with color fringes. Toy telescopes with plastic lenses are not commonly corrected for chromatic aberration. Manufacturers of such telescopes get around this problem by producing telescopes of longer focal length (larger focal ratio) where chromatic aberration is less of a problem.

Reflectors with parabolized mirrors – Parabolization ensures that light from all parts of the mirror produce all parts of an image on the same focal plane. Cheap toy reflecting telescopes commonly have spherical mirrors rather than parabolic mirrors. At shorter focal ratios especially ($f/ < 10$), spherical mirrors will not produce clear images. When examined with an eyepiece, various parts of the image (center versus edge) come and go out of focus as the eyepiece is racked in and out. Cheap reflecting telescopes get around this by having focal ratios of $f/ \geq 10$. At higher focal ratios the difference between parabolic and spherical lenses pretty much vanishes. This is why purveyors of toy telescopes promote higher magnification viewing. Their greater focal ratio (and, hence, longer focal length) instruments have less difficulty with the problem of spherical aberration.

Catadioptric telescopes – These telescopes have a front “correcting” lens like a refractor and a mirror system like a reflector. Perhaps the most popular type of catadioptric is the Schmidt-Cassegrain. These telescopes are very popular, very powerful. They tend to be longer focal length, typically $f/10$.

Corrected reflectors – Many more advanced systems are compounds with mirror systems capturing and focusing light, and then lens systems making corrections to the focal plane, such as with a corrected Dall-Kirkham.

Telescopes tubes and trusses – Tube or truss systems help hold the optical components in place. They vary in rigidity, thermal stability, and stray light trapping. Tubes are solid cylinders and can be heavy. Truss systems typically have 8 struts that can let stray light in. Tubes can be cardboard, composite materials, metal, etc. Trusses are typically built with metals. Ideally tubes and trusses have low coefficients of thermal expansion. High quality thermally stable tubes and trusses are composed of carbon fiber. Closed tube systems (refractor and catadioptric) can suffer from thermal currents in the tubes as the nighttime temperatures drop.

Light trapping – The insides of telescope tubes are painted flat black. Higher quality tubes have flocking paper. The struts of a truss system will most commonly be covered with a black shroud. Refractors often have several internal baffles. All these materials effectively capture stray light that has a strong tendency to reduce image contrast.

Paint – Traditionally portable telescopes have been painted white to make them more visible at night so as to

help observers avoid bumping into them. Such a highly reflective color can also help keep a telescope cooler if used for daytime observations.

Dew shields – Higher quality refractors typically have a section of larger diameter “tube” extending past the objective lens ostensibly to keep dew from condensing on the lens. Catadioptric telescopes will often be outfitted with a flexible, wrap around dew shield to keep the corrector plate from dewing. Closed-tubed reflectors already protect their objective from dewing and further precautions are not needed.

20. TELESCOPE MOUNTS AND PIERS

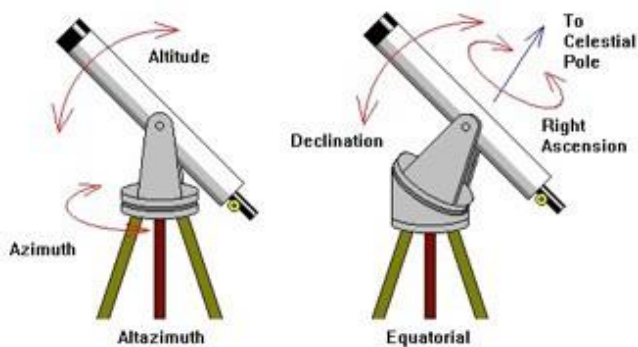
If you are in the market to purchase a telescope, you might want to seriously think about the type of mount and pier that will come along with the telescope of your choice. They are not all equal. Keep in mind that we are not talking about “junk” toy telescopes here with their over-powered telescopes, flimsy mounts, and spindly-legged tripods. There are several legitimate types of mount/pier combinations for you as a serious observer to consider when you buy a quality telescope. But first, let’s note the distinction between the terms ‘mount’ and ‘pier’ – terms that confuse some people. A mount is the device that is directly connected to the telescope and rests upon a pier. A pier is a single column or a

tripod that supports the mount. The mount allows for the telescope’s motion; the pier should be rock solid and should not flex. There are two fundamental types of telescope motion just as there two fundamental types of mounts.

Altazimuth mounts – These mounts – altitude/azimuth – allow telescopes to horizontally (side to side or in azimuth) with one axis and vertically (up and down or in altitude) in the other axis. This seems like a pretty reasonable way to mount a telescope until one realizes that stars don’t move in this fashion. Here in mid northern latitudes the stars in the eastern sky rise moving to the right as they do so. When in the south, the stars move from left to right. When in the west the stars set moving to the right as they do so. In order for an altazimuth mount to track the stars, they need to be moved in both axes at different and changing rates depending where in the sky the telescope is pointed. These are serviceable mounts, but the best among them are driven by computer-controlled stepper motors. These motors can direct the aim of the telescope at variable rates and in changing directions.

Equatorial mounts – Are a simple solution to the problems of altazimuth mounts. They have two axes of movement 90 degrees offset from the other just as in the case of the altazimuth mount. However, rather than having the horizontal rotation axis oriented vertically, it is inclined in such a way that is parallel to Earth’s rotation axis. Its right ascension or polar axis is aimed toward the north celestial pole near the North Star. This allows the telescope to be

Secondary mirrors – Non-refractor telescopes have a secondary mirror redirect the light forming the image to be observed. In the Newtonian version, the secondary mirror is usually held in place by four thin metal vanes that produce the “X” diffraction spikes often seen in astronomical pictures. The absence of the “X” means the telescope is either a refractor or a catadioptric. In some configurations the secondary mirror reflects the focused light at 90 degrees to the side. In others, it reflects it back down toward the primary mirror through a hole in the center of the mirror.



slewed east and west across the sky. So oriented, the telescope can follow celestial objects with the motion of one axis only. Only this axis need be motorized in order for it to follow celestial objects, and the speed and direction of motion is constant. The other axis, the declination axis, allows the telescope to be slewed north and south in the sky.

Now there are variations on these two types of mounts, and there is even a bit of overlap in the definitions of these two types under certain circumstances as well. Consider “what if” either of the two above mounts was used at either the North or South Pole of Earth. At these locations, an altazimuth mount would be no different from an equatorial mount as the celestial pole would be located overhead! The mount’s right ascension or polar axis would become an azimuth axis, and its declination axis would be its altitude axis.

The prior images show what is known as a **fork mount**. Due to problems with fork mounts and long telescope tubes (e.g., one can’t move all the way up to the zenith with the altazimuth mount nor all the way to the celestial pole with the equatorial mount), most telescopes that use a type of azimuthal mount today use a style designed by John Dobson out in California years ago. The advantage of the **Dobson mount** is that the telescope is kept low to the ground making it accessible to the smallest of viewers. It’s great for public observing sessions. Another advantage is that this style is easily and cheaply constructed. Many serviceable telescopes use this sort of mount. Unfortunately, this style

of mount is not readily motorized on the cheap. Yes, there are Dobson mounts with computer-controlled drive motors, but they tend to be rather expensive. Other variations of the fork mount can be seen in the Celestron CPC series of telescopes.



Much more readily motorized are the equatorial mounts. These come in several different types as well, two of which are worth mentioning. The **yoke mount** (an example of which is shown here) is rarely seen in the world of amateur astronomy nowadays. As the picture illustrates, the yoke has a real propensity for getting in the way when trying to view through the eyepiece. This design is perfectly acceptable for large telescopes such as the 200" Mount Palomar telescope, but that's because the observer can sit in a cage and view from within the telescope itself (though this isn't done today given recent advances in observing equipment).

An alternative to the yoke mount is the **German equatorial mount**. This mount is commonly found in

amateur telescopes today. The telescopes in the TCAA's Prairie Sky Observatory, for instance, are all on German equatorial mounts. Experts like these mounts, though many novices find them rather objectionable. In order to view the eastern sky, the telescope must be located on the western side of the right ascension or polar axis. When switching views to the western sky, the telescope must be "flipped" to the eastern side of the right ascension or polar axis. Another objectionable aspect of this mount is that there are large counterweights on the declination axis to counterbalance the weight of the telescope. This is because the motors driving the polar axis don't need to lift the telescope due to the counterweights.

A **pier** supports the mount that supports the telescope that allows it to move around the sky. There are essentially two types of piers in use today – vertical columns and tripods. Vertical columns are typically massive and are meant to stay in one place. Tripods are lighter and are designed for use in mobile situations. A generation ago it was possible to find vertical columns with three horizontal support legs associated with portable telescopes; that's no longer the case today. Good piers are heavy and solidly built; poor piers such as found with toy "junk" telescopes are light and typically quite spindly...

21. HOW TO BUY A TELESCOPE

Buying a telescope is an exciting prospect. Unfortunately, the purchase and use of a poor-quality toy telescope will result in difficulty, frustration, anger, and ultimately a loss of interest in sky viewing. It is important therefore to know how to purchase the right type of telescope before doing so. Avoid throwing money at the problem, and just buying the first thing that looks interesting – even if it is expensive. Many are the people who have purchased expensive, seemingly sophisticated telescopes only to end up with a useless piece of junk rather than an instrument that can serve their interest for a lifetime. The only legitimate way to enter amateur astronomy is to spend time learning about the subject and carefully reviewing what the experts have to say about which are the best telescopes to buy. This essay will give some basic information and will reference a number of other publications written for the TCAA's *Universe Sampler II* class. Please be certain to include suggested readings as you endeavor to purchase your "dream" telescope.

Terrestrial or celestial telescope? Telescopes designed for sky watching are often, but not always, different from those designed for terrestrial use. Telescopes come with two basic types of mounts. Terrestrial telescopes will always come with non-motorized altazimuth mounts where the movement is up and down and left and right. Unfortunately, celestial motions are not as simple as that. Astronomical telescopes are designed to track the motion of the stars and will either come with computer assisted altazimuth mounts

or equatorial mounts whose main rotation axis is aligned with that of Earth. Read about these mounts in the section **TELESCOPE MOUNTS AND PIERS**.

Reflector, refractor, or another design? Reflecting telescopes have mirrors that gather light and create an image for viewing with an eyepiece. Refracting telescopes use a lens to do the same. Combinations of reflectors and refractors – catadioptric telescopes available in various designs – use combinations of lenses and mirrors to produce images for viewing. Reflectors are relatively inexpensive in comparison to refractors. A high quality 8-inch reflecting telescope might cost in the range of \$1,000-\$2,000; the same size refracting telescope could easily run \$10,000 or more. When making a mirror for a reflecting telescope, there is only one optical surface to finish. The lens of a high-quality, color corrected (apochromatic) refractor will have 6 surfaces to finish, and the finishes much exactly match the adjoining lens' surface. The Schmidt-Cassegrain telescope (SCT) – a catadioptric – uses a single thin lens as a corrector plate and a modified mirror to accomplish the same task. The advantage of the SCT design is that one can compress a large telescope into a relatively small space. For example, a classic 8" f/10 reflector would have a tube over 7 feet long. A SCT with the same optical characteristics would be less than 2 feet long.

How big a mirror or lens? While one can save money by purchasing a small aperture telescope, it would constitute a waste of money not to buy the largest aperture

one can afford – up to a point. People who purchase small telescopes at the outset often come to regret it because before long they catch “aperture fever.” Larger telescopes do, in general, provide greater benefits. (See the handout **COMMON TELESCOPE TRAITS** for details.) As a general guideline, I suggest a telescope of at least 8” aperture for the serious would-be amateur astronomer. If you can afford it, an 11” aperture telescope would be even better. As an Astronomical League Master Observer with over 50 years viewing experience, I am very happy with my 11” SCT. Going larger – in light polluted Illinois – results in diminishing returns. If one views from the rural skies of Illinois, the sky is not adequately dark to take full advantage of a larger aperture. While large telescope mirrors do collect more light, they also collect more sky light, much of which is produced by artificial illumination. As a result of this problem, I recently sold a very high quality 18” telescope for which I paid nearly \$10,000 because the views it provided relative to my 11” telescope were not all that much better – certainly not worth the trouble of dragging it out into the countryside and setting it up.

What about eyepieces? Telescopes will sometimes come with several eyepieces providing a variety of magnifications and fields of view. These are commonly

inexpensive but serviceable. Still, experienced observers will typically want to replace these eyepieces with ones of higher quality. Higher quality eyepieces most commonly will provide larger fields of view at the same magnification. Certain other eyepiece will provide much better eye relief that makes them more useful for those who wear eyeglasses. Yet others are *parfocal* that means they can be exchanged with one another without requiring significant refocusing. A cluster of perhaps five good quality eyepieces along with a Barlow lens should be purchased with a quality telescope. Eyepiece focal lengths should span the range from minimum to maximum useful magnification. See the following section, **TELESCOPE EYEPIECE BASICS**, for additional information.

I’m not quite ready to purchase a telescope... That’s perfectly fine and might well reflect that fact that you need to spend time learning more about things of the night sky and the work of amateur astronomers.

Caveat emptor – let the buyer beware. Again, buy an honest-to-goodness optical instrument and avoid purchasing a toy telescope. If you are not yet ready to purchase a quality telescope, then consider starting off with a good set of binoculars. (See **BINOCULARS VS. TELESCOPES** to gain a better understanding of the difference.)

22. TELESCOPE EYEPIECE BASICS

Recall how a telescope works. An objective lens or mirror produces a real image that is then examined with a sophisticated magnifying glass known more commonly as an eyepiece. Eyepieces come in many different varieties, each with its own characteristics – pro and con. Nonetheless, there are several traits that all eyepieces have in common, and so our introduction to understanding eyepieces will begin here.

There are five phrases that can be used in association with every eyepiece used with a telescope. These phrases are focal length, apparent field of view, true field of view, exit pupil, and eye relief.

Focal Length – The focal length of an eyepiece is the distance from the principal plane of the objective to the focal plane of an eyepiece where parallel rays of light converge to a single point. It is fixed for a given (non-zoom) eyepiece. As a result, most amateur astronomers will have a variety of eyepieces of different focal lengths ranging from about 6mm to 40mm most commonly. Because magnification is defined as focal length of the objective, F , divided by the focal length of the eyepiece, f , different magnifications can be obtained using different eyepieces. That is, $M = F/f$.

Apparent Field of View – FOV_A is a characteristic of an eyepiece. Field of view is simply how wide an angle an eye can perceive looking through an eyepiece. While the human eye can span of field of view of nearly 180 degrees, eyepieces lenses – because their fields of view are confined

by the narrow tube - typically range from about 30° for inexpensive eyepieces to as much as 110° for truly expensive eyepieces.

True Field of View – FOV_T is a function of any eyepiece-telescope combination. It tells the angular size of the portion of sky that can be viewed through an eyepiece when used with a particular telescope. It is magnification specific and is typically between one tenth of a degree and two degrees (about four times the angular size of the full moon). FOV_T can be *approximated* from the following formula: $FOV_T = FOV_A/M$. The formula is accurate to 4% or better up to 40° apparent field of view and has a 10% error for 60°.

1¼” vs. 2” Eyepieces. Eyepieces (and some telescopes) come with three draw tube or barrel diameters – 0.965”, 1¼” and 2”. (The smallest standard barrel diameter is usually found in toy store telescopes and will not be addressed here.) Quality eyepieces are only of the 1¼” and 2” varieties. A 2” eyepiece is larger, heavier, and more expensive than a 1¼” eyepiece of the same focal length. Why then do some amateur astronomers purchase the larger-diameter eyepieces? It all has to do with the true field of view. A 2” eyepiece can provide a larger FOV_T than a 1¼” eyepiece. For an eyepiece designed with a given apparent field of view, the barrel diameter will determine the maximum focal length possible for that eyepiece. This is so because no field stop (the inner diameter of the draw tube in most cases) can be larger than the barrel itself. For example, a Plössl type eyepiece with a FOV_A equal to 45° in

a 1¼" barrel cannot have a maximum focal length greater than 35mm. Any longer focal length would require a wider barrel, or the view is restricted, effectively making the apparent field of view less than 45°. Amateurs purchase 2" eyepieces because, depending upon the optical type, they can obtain larger true fields of view for a given magnification.

Eyepiece Types – There are many eyepiece designs commonly used with telescopes these days. Each has its benefits and detractions. They differ in terms of price, eye relief, apparent field of view, achromatic characteristics, and field flatness to name just a few. While the differences are too complex to deal with here, the types of eyepieces commonly available today are as follows:

Orthoscopic or "Abbe"	König
Monocentric	RKE
Erfle	Nagler
Negative or "Galilean"	Ramsden
Convex lens	Kellner or "Achromat"
Huygens	Plössl or "Symmetrical"

Eye Relief – Eye relief is the distance one needs to place the eye from the eyepiece to see its full field of view. Short eye relief eyepieces require an observer to place the eye close to the outermost lens of the eyepiece. This can be a problem with lower-cost eyepieces, especially when they have short focal length. Shorter focal length usually translates to less eye relief. This isn't always a problem. An observer who wears eyeglasses for near or far-sightedness can remove them if desired to look through a telescope. The focus of the telescope can be adjusted to compensate for these eyes defects. However, if an observer wears eyeglasses for astigmatism, then he or she will need to use eyeglasses when looking through the telescope to obtain a sharp focus across the field of view. Short eye relief makes it harder to get one's eye close enough to the eyepiece for viewing – especially if using glasses. This is where the wise choice of eyepieces comes into play. Eye relief is a function



of eyepiece type and focal length. Some eyepieces provide more eye relief than do others. Without glasses, 10-20 mm of eye relief is good for comfortable observing. However, if you need glasses while observing (or simply prefer not to have to keep removing them), use eyepieces with at least 17-20 mm of eye relief.

Exit Pupil – *EP* is the diameter of the light beam that emerges from an eyepiece. The pupil of young adult's fully

dark-adapted human eye is about 7mm diameter (and decreases to about 5mm with increasing age). So, if an eyepiece has an exit pupil larger than 7mm, it passes more light than the eye can intercept and vignetting of the image results. When the exit pupil approaches 1mm diameter, so little light is passing through the eyepiece as to make viewing almost futile. Exit pupil is a function of magnification. These aspects suggest, then, that there are upper and lower limits to magnification, and so there are. Exit pupil (in mm) can be determined from the diameter of the telescope objective (also in mm) and the magnification: $EP = D/M$. For example, an 11" (280mm) diameter telescope used at 87X will produce an exit pupil of 3.2mm regardless of the type of eyepiece used. The maximum and minimum eyepiece focal lengths used with any telescope are then set by these criteria. $M = D/EP$

$$M_{\min} = 280\text{mm}/5\text{-to-}7\text{mm} = 40\text{X-to-}56\text{X}$$

$$M_{\max} = 280\text{mm}/1\text{mm} = 280\text{X}$$

Parfocal Eyepieces – Parfocal eyepieces come as a matched set from a manufacturer. When Parfocal eyepieces are switched out to obtain different magnifications, the image stays pretty much in focus. There is inevitably a small amount of focus error, but it is minimal. Such eyepieces are more of a convenience than a necessity.

Barlow Lens – The author would be remiss if he were not to mention the Barlow lens. The "Barlow" is a concave lens that effectively doubles (or sometimes triples depending on type) the focal length of an objective lens or mirror. In doing so, a Barlow will increase the effective magnification of a given eyepiece without reducing its eye relief significantly. A Barlow is sometimes used with a lower power eyepiece as a way of increasing magnification without decreasing eye relief.

Magnification and field of view are important traits in the selection of an eyepiece for viewing. Higher magnification means a smaller field of view with the same type of eyepiece. The first two images here show the effect of increasing the field of view at the same magnification. The third image in comparison with the first image shows the effect of using a higher power eyepiece with a wider field of view.




Finding the True Field of View – With the motor drive of your telescope turned off place a star on the celestial equator at the edge of a field of view. Position it so that the star drifts directly through the center of the field. Reposition the star just outside the field of view. Time how long it takes the star to move entirely across the field of view. Because Earth turns at a rate of about 15° per hour and 1° every four minutes, the true field of view can be determined by the time of passage. Say the passage requires 45s or 0.75 minutes. The field of view is then calculated from the standard formula "amount equals rate times time."

$$FOV_T = 1^\circ/\text{min.} \times 0.75\text{min.} = 0.75^\circ \text{ or } 45' \text{ of arc}$$

23. EYEPIECE FIELD ORIENTATION

It's not uncommon for the novice sky watcher to be surprised to find out that his or her telescope produces "upside down" images. Why does this occur? After all, binoculars and eyepieces both have objectives and eyepieces too. The reason binoculars produce upright or erect images is because they have prisms (roof or porro) between their objectives and eyepieces. These prisms invert images naturally produced by the objective lenses. When viewed with eyepieces, the images appear as they would to the unaided human eye, merely larger.

In space the meaning of up or down are lost. There is no up or down in space, so it doesn't matter which way an image appears in the eyepiece. Nonetheless, it is good to know how the introduction of additional mirrors in basic telescope designs affects the images. The table below provides a quick summary of what happens with different types of telescopes and various combinations of lenses and mirrors. Additional mirrors normally come into play with the addition of a diagonal (mirror or right-angle prism) just before the eyepiece.

Erect Image	Inverted Image	Reversed Image
		
As seen with eye or binoculars or a telescope with no mirrors and an image inverter.	As seen with a refractor with no mirror or with a reflector having an even number of mirrors.	As seen with a refractor using a mirror or with a reflector having an odd number of mirrors.

24. FINDER SCOPES

Traditionally, finder 'scopes are typically small telescopes that are attached to and optically aligned with the main telescope. They are used to aim the main telescope. Finder scopes are of short focal length, low magnifying power, and wide field of view. Most include crosshairs. These small auxiliary telescopes are used to find

objects and center them in the field of view. Once this is done, the main telescope should be pointing at or very close to the object that the observer intends to view.

Today this is a wide variety of finders, and not all are telescopes. Not all have magnification. Shown below are a number of finder telescopes, each with its pros and cons.



Finder A) Straight through finder



Finder B) With right angle prism and illuminated crosshairs



Finder C) Telrad with zero-power heads up display



Finder D) Red dot finder

Finder A. This is an all-too-commonly-found ‘cheap’ finder. It typically is a 6X30 monocular and is usually found on toy telescopes. It provides 6X magnification and has a 30mm aperture. While marginally adequate, it lacks basic features such as illuminated crosshairs. Focusing is often difficult (adjustment at the objective lens rather than the eyepiece), and the small aperture makes it difficult to see any but the brighter stars. Another drawback is its poor ability to align with the main telescope. The three setscrews on the side of the finder provide only a minimum of adjustment. This often makes it difficult to keep the finder properly aligned with the main telescope. Images are inverted, which is commonly the case with standard telescopes. This is not a problem, but it does take some getting used to. Push up to go down and left to go right. I do not consider this a ‘serious’ finder scope. Still, higher quality versions of this type of finder can be considered quite helpful.

Finder B. This is a more serious type of finder, but it is also fraught with difficulties in this configuration. It has a larger aperture that will reveal more stars and might even show the object you intend to observe. The illuminated reticle is a definite plus. This unit is much more substantially built and provides greater latitude for alignment with the main telescope. Once aligned, this unit probably will stay aligned. The problem really begins when looking through this telescope. If you thought that an inverted field of view was difficult in the case of the above finder, this one is somewhat worse. Introducing a mirror makes the eyepiece more accessible to the observer as it is now located at right angles to the telescope. Unfortunately, introducing the mirror produces a semi-inverted field of view. Depending on its orientation with respect to the sky one might push up to go up and push right to go left. Only one of the two directions is reversed but figuring out which one can be a real pain.

Finder C. I used to resist using this finder when I first started seeing them on other telescopes, but today wouldn’t observe without it. This is a Telrad finder. It’s a straight-through heads-up display with a set of finder rings instead of the traditional crosshairs. An LED projects three red rings (brightness adjustable with dimmer switch) onto

the heads-up display. The observer then sees the rings projected against the sky. The view of the sky is erect (not inverted or semi-inverted). The advantages are the ultra-wide zero-magnification field of view and the tremendous eye relief. One can place one’s eye several inches back from the heads-up display and still see the rings. The disadvantage is that without a light-gathering lens, it’s hard to see any but the brighter stars, and is difficult to use when trying to find faint objects without any brighter nearby stars. Another drawback is that the heads-up display is strongly subject to dewing.

Finder D. More commonly found on toy telescopes these days, this is typically a cheap knockoff version of the Telrad with a considerably smaller heads up display. Instead of a series of rings, a red dot is projected against the sky. To find objects in the main telescope, merely place the red dot over the area you intend to observe. In my opinion, this is not a serious finder either. Still, better quality versions do exist that some observers find quite useful.

Laser Finder-Pointer. A finder-related instrument is the laser pointer. This instrument is a plastic tubular housing in which a laser pointer can be mounted using two sets of three set screws each on opposite ends. The tube has a hole for accessing the laser’s on-off switch. It works by shooting a telescope-aligned laser beam into the sky. By pointing the laser beam at the object to be observed, the object can be readily found in the telescope eyepiece or in the surrounding area. It is a great way to point out to others where the object under observation is located in the sky.

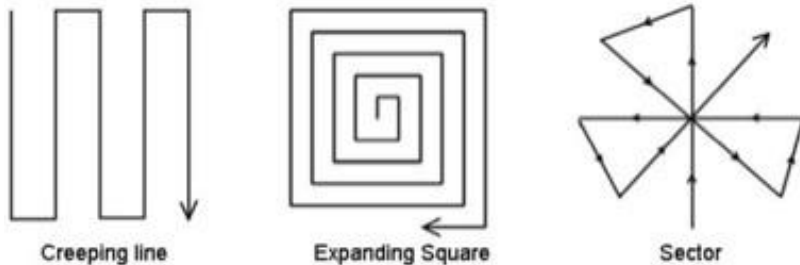


Which should I choose? The fact of the matter is that no one finder can satisfy all needs. For years, before I started using my goto CPC 11" telescope in 2006, I would use a combination of finder types A and C. I would use my Telrad (on the side of a 10" Coulter Odyssey telescope) to zero in on the area I was planning to observe. Once I did that I used my 7X50 straight-through finder to locate more precisely the object I was planning to observe. Then, when I looked through my main telescope, the object I was seeking was then in the main instrument's field of view.

I did as you said, and still can't see what I'm looking for. That's fairly common, but don't give up the search. I've had this happen to me hundreds of times. It's important to keep in mind that if you identified the star field properly and did the best you could to center the area of the object you are looking for, then the object is most likely just outside the field of view of your main telescope. You should execute a search pattern depending on the type of instrument with which you are observing. There are typically two or three

search patterns you can execute. I use all of them depending on the instrument I'm using. All three patterns below can be used effectively with push-to telescope (one that is not motorized and is free to move up and down and left to right). If using a telescope that is motorized, then the first two search patterns can be used most easily. Still, with practice even the sector search can be used with goto telescopes.

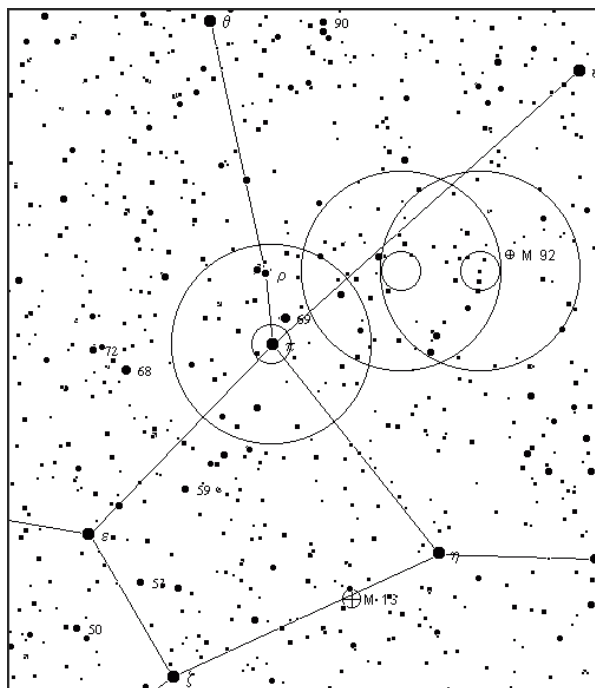
How do I align my finder? This is relatively easy, but it's a matter of using your finder and main telescopes in reverse. Chose a bright object like a faraway terrestrial object, the moon, a planet, or a star. Aim you telescope at the object and center it without using the finder. Then, adjust the finder so that the object is located in the center of its field of view. Check back and forth between the finder and the telescope to ensure that they are properly aligned with each other. Once you get the two instruments optically aligned, you'll not need to follow this procedure again.



25. STAR HOPPING

Star hopping is a procedure that can be used to find objects with binoculars or telescopes when the object is too dim to be found directly with the eye. The process is relatively simple and is illustrated below. Let's say that you want to find Messier 92 (M92) in the constellation of Hercules. While M92 is not possible to see with the eye or a small finder telescope, it can be observed with the use of the main telescope.

Using your finder scope, center the main instrument on the star labeled π (just below the star labeled 69). The field of view of your finder and main telescope are the large and small circles respectively. Note the arrangement of stars in the telescope's field of view (large circle), paying particular attention to the brighter star to the upper right of 69. Slowly move your telescope so that this star shifts to the left side of the field as shown in the second large circle. Note the "double" star to the lower right of the second field of view. Move your telescope again so that the binary is now to the lower left of the third field of view. M 92 will then be just to the upper right of the field of view of the main telescope. Move the telescope accordingly and you will have acquired M 92 for viewing.



26. SKY DARKNESS, TRANSPARENCY, AND SEEING

Not all nights are equal, even if they are equally dark. For instance, if the sky is entirely overcast at night, it might be dark, but you won't be able to see any celestial objects. Thin layers of stratus clouds and atmospheric haze due to high relative humidity can affect your observing sometimes for better (such as for some solar system objects) but most of the time for worse (star clusters, nebulae, galaxies). Another consideration is the stability of Earth's atmosphere. The turbulence of Earth's atmosphere makes it impossible to get a clear view of the sky. So it is with atmospheric turbulence. If the atmosphere is turbulent, we have poor seeing and vice versa. Poor seeing is the source of twinkling in stars. If the stars are violently twinkling, you might consider observing another night if you are seeking the most stable views.

All the light that's visible at night doesn't come from the stars, moon, planets, and Milky Way. Too frequently the night sky is illuminated by wasteful stray light from streetlights, parking lot lights, building lights, outdoor display advertising, illuminated billboards, and sports venues (e.g. driving ranges, stadiums, and arenas). Reducing the contrast between the stars and the background sky, light pollution makes it more difficult (if not impossible) to see the stars and Milky Way at night.

Just how many stars can be seen at night with fully dark-adapted eyes? That depends strongly on both sky darkness and transparency. If the sky is transparent, the more stars you will see the darker it is due to increased contrast between the sky and the stars. As the sky gets brighter, fewer stars are visible. At one extreme, the daytime sky is so bright as to make even the brightest stars impossible to observe without anything other than a high-powered telescope. At night, under a very dark and transparent sky, stars to the 6th magnitude or greater might be observed – depending on the observer.

Magnitude is a rating scale used by astronomers to compare the brightness of stars. Very roughly put, the brightest stars are typically of 1st magnitude (though some are brighter with 0 and even –1 magnitude). The next groups of increasingly dimmer stars are of the 2nd, 3rd, 4th, 5th, and 6th magnitude. Stars of the 6th magnitude are the dimmest visible under good dark-sky conditions with fully dark-adapted vision. This historic six-step magnitude system is a qualitative measurement based upon the logarithmic response of the human eye to light. If measured with a modern light-sensing device, stars of the 1st magnitude are 100 times brighter than stars of the 6th magnitude. Each stellar magnitude represents a brightness difference of about 2.512 times ($2.512^5 = 100$). Sirius, the Dog Star in Orion, the brightest star in the night sky (note that it's NOT Polaris the North Star – the 49th brightest star in the sky) is so bright that it has a magnitude of *negative* 1.44. Stars like Vega in Lyra the Harp, Arcturus in Boötes the Bear Driver, and Capella in Auriga the Charioteer are bright enough to qualify as zero-magnitude stars. Aldebaran in Taurus the Bull, Spica in Virgo the Maiden of the Harvest, and Antares in Scorpius the Scorpion qualify as 1st magnitude stars. Relatively speaking, very few 2nd magnitude stars and those dimmer are known by their proper names.

A Word about Visual Magnitudes

The first column in the table below gives magnitude names. The second column gives magnitude ranges. The third column gives the number of stars within a particular magnitude range. The fourth column gives the total number of stars visible by limiting magnitude – the magnitude of the faintest star visible. The higher the limiting magnitude, the more the stars there are visible to the unaided eye.

Magnitude	Magnitude Range	No. of Stars in Range	Cumulative No. of Stars
–1	–1.50 to –0.51	2	2
0 (0 th)	–0.50 to +0.49	6	8
+1 (1 st)	+0.50 to +1.49	14	22
+2 (2 nd)	+1.50 to +2.49	71	93
+3 (3 rd)	+2.50 to +3.49	190	283
+4 (4 th)	+3.50 to +4.49	610	893
+5 (5 th)	+4.50 to +5.49	1,929	2,822
+6 (6 th)	+5.50 to +6.49	5,946	8,768

Numbers of stars visible as a function of limiting magnitude.

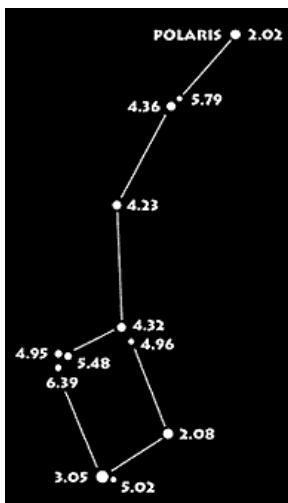
On a dark, clear night with no moon, no light pollution, and fully dark-adapted eyes, the limiting magnitude is about +6.5. Under such conditions 8,768 stars are potentially visible. Because about half of these stars will be below the observer's horizon at any one time, and those near the

horizon will be dimmed by Earth's atmosphere, it's easy to understand why we will see only about ½ of that number or some 2,500 – 3,000 stars at any one time. By the time the limiting magnitude reaches +3.5 (say in a small rural town), the number of stars visible drops to less than 100. In small

cities (Springfield, Bloomington-Normal, Decatur, etc.) the limiting magnitude is often +2.5, and the number of stars visible is reduced to only about 30. In larger cities (Peoria, Rockford, and metropolitan Chicago) where the limiting magnitude is often +1 or brighter, the number of stars visible drops to 7 or fewer.

Limiting magnitude will vary by proximity to outdoor light sources as well as weather conditions. The closer one is to outdoor lighting, the lower the limiting magnitude and the fewer the number of stars visible. (Recall that the higher the magnitude number, the dimmer the star.) As a result of this, it's not unusual to find "light domes" from nearby towns and cities when observing from a rural setting. Few stars might be visible in the light dome, but other parts of the sky will be less light polluted and more stars visible there. Sky transparency also plays a role in the number of stars visible. It is possible to have a pitch-black night and not see a single star because the sky is covered with clouds. The greater the relative humidity and the amount of dust suspended in the air, the lower the transparency and the smaller the number of visible stars regardless of sky darkness.

Assessing Sky Darkness



One of the easier methods for assessing sky darkness is to determine the faintest star visible by unaided eye in the Little Dipper. The Astronomical Society of the Pacific suggests the use of the chart to the left to assess sky darkness. Record the visual limiting magnitude (not to be confused with telescopic limiting magnitude) as the magnitude of the faintest star visible to the unaided eye.

Alternatively, today there are several free apps that can be used to physically measure sky brightness. For instance, The Dark Sky Meter (available for iPhone) helps one measure the night sky brightness with the press of a button.

Assessing Sky Transparency

Sky transparency varies with clouds, altitude, relative humidity, the presence of pollutants (e.g., volcanic ash, pollen, smoke from fires, etc.) and auroras. A suitable transparency scale suggested by the American Association of Amateur Astronomers is as follows:

0. **Very Poor** – Mostly cloudy.

1. **Poor** – Partly cloudy or heavy haze. 1 or 2 Little Dipper stars visible.
2. **Somewhat Clear** – Cirrus or moderate haze. 3 or 4 Little Dipper stars visible.
3. **Partly Clear** – Slight haze. 4 or 5 Little Dipper Stars visible.
4. **Clear** – No clouds. Milky Way visible with averted vision. 6 Little Dipper Stars visible.
5. **Very Clear** – Milky Way and M31 visible. Stars fainter than mag 6.0 are just seen and fainter parts of the Milky Way are more obvious.
6. **Extremely Clear** – Overwhelming profusion of stars, Zodiacal light and gegenschein form continuous bands across the sky, the Milky Way is very wide and bright throughout.

Assessing Seeing

Astronomical seeing can be quantified separately. According to Jeff Beish of the Association of Lunar and Planetary Observers (A.L.P.O.), a workable seeing scale makes reference to the size of stellar images viewed through a high-power eyepiece and references a bright star's diffraction pattern (the Airy disk) which is visible on only nights of best seeing. A star's interference pattern consists of concentric rings of light decreasing in intensity from the central point to the edge. (87% of the light is concentrated in the central dot.) As the atmosphere becomes more turbulent, this pattern is disrupted and begins to "seethe and boil." One scale of Astronomical Seeing is based on Airy Disk appearance of a star viewed at high power and goes as follows:



- I. Stellar image tends toward a planetary appearance
- II. Diffraction rings weak or absent
- III. Diffraction rings broken and central spots have undulating edges
- IV. Complete diffraction rings visible crossed by moving ripples
- V. Perfect images without visible distortion and little agitation.



Visual planetary viewers will use a slightly different and *reverse* characterization (as far as the numbering goes) to similar effect (the Antoniadi scale):

1. **Perfect seeing**, planet seen without a quiver.
2. **Slight undulations**, with moments of calm lasting several seconds.
3. **Moderate seeing**, with larger air tremors.

4. **Poor seeing**, with constant troublesome undulations.
5. **Very bad seeing**, scarcely allowing the making of a rough sketch.

Other seeing scales ranging from 1-10 are also available, as are estimates made by assessing the ability to split close double stars. These methods are a bit of overkill as far as the novice amateur astronomer is concerned.

Keep in mind that transparency and seeing will change as a function of location in the sky. Close to the horizon one is viewing through about five times the air mass as

compared to viewing an object directly overhead. Transparency and seeing will therefore be considerably worse near the horizon as compared to the zenith.

Also, keep in mind the transparency and seeing are time dependent. An evening might start out with lower transparency and poorer seeing, but with the passage of time both can improve remarkably. These changes can occur in very short periods of time and the differences in the view obtained quite noticeable.

27. DARK ADAPTATION

Dark adaption is necessary for viewing dimmer stars and other faint objects of the Milky Way. The adaption process is two-fold. When one enters a darkened place, the pupil automatically dilates or becomes wider thereby admitting an increased amount of light to the eye. In addition, the retina – the light sensing region at the back of the eyeball – begins producing a substance known as visual purple or rhodopsin. This substance sensitizes the eye to light, making it possible for one to see better under darker – but not pitch black – conditions. There must always be a small amount of ambient light in order for someone to see. No matter long how long a person sits in a dark cave, for instance, he or she will never be able to see. Vision always requires the presence of at least a minimum amount of light.

It takes about 30 minutes for the eyes to become

reasonably well dark adapted, though additional time in the darkness will aid with improving dark adaptation.

If you intend to observe at night, it is best to avoid direct sunlight during the daytime hours. This will enhance your dark adaptation. Keep in mind, too, that diets severely deficient in vitamin A (carotene) can result in night blindness – the inability to adapt to the darkness.

Also keep in mind that light in colors other than red will destroy rhodopsin and ruin dark adaptation. Nowhere is this more evident than when one leaves a movie theater on a sunny day. Walking outside can result in a painful sensation in the eyes. This occurs because the shorter wavelengths of sunlight (yellow, green, blue) are breaking down the rhodopsin. This results in ionization of the substrate, and it produces the sensation of pain.

28. THE ART OF ASTRONOMICAL OBSERVING

There is more to looking through a telescope than putting one's eye up to the eyepiece. Having observed the heavens for more than 50 years now, I can tell you that there are things that an observer can do to improve what one sees. Kind mind, though, that you'll never see Hubble quality images. Most of us humans will be restricted to viewing celestial objects from the confines of Earth while peering through its turbulent atmosphere. Astronomical viewing is much akin to bird watching conducted from the bottom of a swimming pool! The ripples of the water make it difficult to see things clearly. Be that as it may, there are many things that one can do to optimize views obtained through the eyepiece.

Plan your observing session. If you set up your telescope under the stars without a plan for observing, you'll be surprised by how little you will end up seeing. Yes, there's the moon and planets, but then what? Unless you have a catalog of celestial objects to observe in your head, your viewing will be quite limited. I've been observing the sky for over 50 years, and I'd still be limited to viewing a

handful of representative objects were it not for the fact that I pursue observing programs. Consider pursuing first and foremost the Messier objects. Here you'll have a list of 110 objects you can observe throughout the year. At any one time about half of these objects are above the horizon at any one time. They generally constitute the best and brightest clusters, nebulae, and galaxies. The Astronomical League has many such observing programs you should consider.

Acquire a quality "goto" telescope. Nothing opened up the sky for me like my CPC 11" goto telescope. I had observed for years but was getting tired of the struggle to find "faint fuzzies" using a finder scope all the while bending and twisting my body like a contortionist. After seeing the ease with which event faint objects can be found using a goto telescope, I had to have my own. It was the best money I ever spent on amateur astronomy and accounts – at least in part – for why I get out to observe so much. On any given evening I can see several dozen objects I have never seen and would not have seen were it not for my goto telescope.

Get an observing aid. Even with a goto telescope, you'll be pleasantly surprised by how much an observing application can enhance your experience of looking through binoculars or telescope. I frequently use my iPhone, iPod, or iPad while observing. My favorite application – *SkySafari Pro* – helps control my telescope (when I care to do so), but always provides critical observing information like where a faint object is located relative to brighter stars. I used to make observing cards, but today they are instantly available to me through the *SkySafari* application. Also, I can find information immediately about the size or distance of an object.

Establish and maintain your dark adaptation. Once you have achieved dark adaptation, work to maintain it. Use faint red lighting to provide illumination as necessary. Red light – no matter how intense – does not have sufficient energy to break down rhodopsin whereas blue light does.

Seek to observe rather than merely see. There is a difference between these two acts. One can see things merely by looking at them. An observer – someone who looks carefully – will note things that the casual viewer will otherwise miss. Viewing with intent is the best way to see fine detail. Knowing what to look for also markedly improves what one views. It's no wonder that experienced observers will see things that casual observers overlook.

Take observing notes. It is helpful to make written descriptions during observing. Keep track of atmospheric transparency and seeing, sky darkness, weather conditions (temperature, humidity, and winds), telescope used, the eyepiece and magnification, filters used, observing location, date/time, relative difficulty of viewing, and so forth. Refer back to your notes when re-observing an object. Compare this time with prior observing sessions and learn how different conditions affect what you see.

Make eyepiece sketches. You will be surprised at how much more detail you perceive when you make drawings at the eyepiece. When viewing an object pay attention to and record such things angular size in relation to the eyepiece's field of view, elongation, image brightness, density, and color. Record field stars in such a way that depicts star density, counts, and locations accurately. Consider partitioning the field of view into quarters and draw each quarter separately if helpful.

Know the details for which to look. You will be amazed at how much detail you can actually perceive if you know what to look for. For instance, I never really "saw" the Dumbbell Nebula until I started comparing a photograph of the object with the view in my eyepiece. Study your objects patiently and try to see every detail visible to your eye.

Use averted vision. Looking out "the corner of one's eye" can improve what one sees when looking through an eyepiece. The color receptors in the center of the retina are not well suited to dim light conditions and don't work well at night. This is why things appear in shades of gray rather than in living color. The eyes' rods, however, distributed

around the eye but concentrated outside the fovea where most color perceiving cones are located, are very sensitive to subtle differences in lighting. Learn how to avert your vision and use the rods to observe faint celestial objects. Avoid, however, averting your eye toward the bridge of your nose as the eyes' blind spots (where the optic nerve connects the eye to the brain is attached) will then be at the center of your field of view.

Jiggle the image. A "trick" you can employ for seeing finer detail is to "jiggle" your telescope while viewing the object in question. Tap the side of the telescope, and the object in the field of view will rapidly oscillate back and forth. For reasons still somewhat unclear, one can see more detail in an object in motion than one that is completely stationary – at least in a telescope.

Remember transparency and seeing. Recall that not all nights are the same. When the sky is perfectly clear it has high transparency. When the sky is completely overcast, it has low transparency. Observe on nights when the sky is as cloud and haze free as possible. Also, despite a completely transparent sky, the sky can also be very turbulent with poor seeing. When stars near the horizon are twinkling violently, keep in mind that seeing is probably not very good and so objects that tend to show fine detail such as the moon and planets will not likely show it on nights when the seeing is poor.

Use a proper observing stance. If you prefer to stand while observing, your approach to the telescope should be carefully considered. Ergonomics suggests a particular observing stance. Do



not, for instance, look through the eyepiece as shown in the illustration to the right. Imagine the neck and back strain if a person were trying to view something much higher up in the sky. The person would need both to bend over more and throw the head back further. This can lead to terrible back and neck pain that few observers can long endure. Consider changing your observing stance. Avoid lining up your body with the telescope as shown. Rather, stand with your body at a 90° angle to the optical axis and turn your head left or right to the eyepiece. Rest your hands on your knees for additional support. So positioned, an observer can easily spend several minutes comfortably viewing object even when they are much higher in the sky than shown.

Employ comfortable seating. Ergonomics is the name of the game when looking for yet another way to increase observing prowess. Experienced observers know that the best views to be obtained through the eyepiece are obtained when the observer is comfortably positioned and relaxed. Using a good observing chair can satisfy the need better than an observing stance alone. Many observers use firm chairs and even step stools for sitting while observing. Specially designed observing chairs can be more readily

adapted to the changing height needs while viewing. Regardless, any sort of seating can help observers avoid neck, back, foot, and leg strain while observing.

Seek the darkest observing location possible. Seek out the darkest location you can if you hope to see things at their best. Perhaps the most expensive lesson I ever learned was purchasing an 18" telescope. When viewing side-by-side with my 11" telescope, I found that the views were not really all that different. Yes, a larger telescope collects more starlight and shows more details, but it also collects more atmospheric light. Large telescopes used for visual observing perform best when used under truly dark sky conditions. Unfortunately, central Illinois rarely has truly dark observing locations due to light pollution emanating from nearby cities. Still, the darker the observing location the better because the contrast between celestial objects and the background sky is much better. Higher contrast means better views. Note that poor contrast between celestial objects and the bright background is the very reason why we don't see stars during the daytime.

Use the best eyepieces you can afford. Most telescopes come with eyepieces that typically are of lower quality. Depending on the manufacturer, you will normally receive tolerably good eyepieces, but they cannot provide the stunning views that more expensive eyepieces can. The apparent fields of view of inexpensive eyepieces might only subtend 40° or 50°. Your more expensive eyepieces (for instance, of Nagler design with a number of manufactures such as TeleVue and Orion) can provide fields of view on the order of 82°, 100°, or even 120°! These ultra-wide apparent fields of view give larger true fields of view and the impression of "falling through the eyepiece" as the edges of the field of view often extend into the regions of peripheral vision where they are barely noticed.

Consider using eyepiece filters. Eyepiece filters come in quite a variety. Some of the more common are the Skyglow and UHC (ultra-high contrast) multi-band pass light pollution filters, the neutral density moon filter, broadband filters such as red, green, blue, orange, and yellow, and narrowband filters such as OIII, SII, and H α . The broadband filters are good for heightening contrast when observing planets, whereas the narrowband filters are good for enhancing contrast between the sky and certain nebulae. There are numerous other types of filters besides. Broadband filters often come in sets and are rather inexpensive. Narrowband filters are sold individually due to their varying appeal and the fact that they are quite expensive.

Maintain the cleanliness of your telescope and eyepieces. Cleanliness is one of the most important things to consider when maintaining your telescope and eyepieces. The need for cleanliness should be obvious. A lens or mirror coated with dirt, dust, and oil from one's hands will not be a good reflector of light. Cleaning lenses and mirrors is beyond the scope of this handout, but you

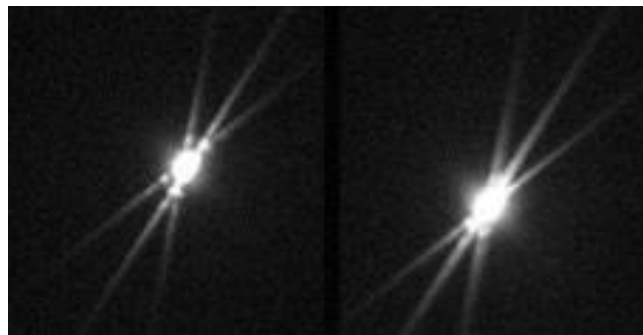
can consider using a good quality lens cleaner and cloth to clean up your lens surfaces. Do NOT spray lens cleaner on your optics; rather, spray it on the lens cloth so excess fluid doesn't leak through and get between lens surfaces. Once that happens, you'll have no choice but to disassemble your eyepiece. This is not something recommended for the novice.

Maintain good telescope collimation. Establishing the proper optical alignment of lenses and mirrors in your telescope system is critical to proper views. Poor collimation results in stars appearing out of round and produces scattered light. More of a problem with reflectors than refractors, collimation should not be done the first time without the advice of an expert. Novices often make things worse rather than better when trying to collimate optics when they have little or no experience doing so. A poorly collimated telescope cannot be properly focused because the image plane is no longer perpendicular to the telescope's optical axis.

Be certain you have the sharpest focus. Focus is generally at its best when stellar images are as small as possible. By turning your telescope's focusing knob back and forth, you can obtain the best focus. Still, you might want to consider using a



Bahtinov mask for focusing telescope to achieve the best possible focus. This screen – placed over the objective end of the telescope – produces diffraction patterns as shown in the pair of star images shown here. In the leftmost star image, the diffraction lines do not cross at a single point; the telescope is not in focus. In the right star image, the lines do intersect at one point; the telescope is in focus.



Watch out for dewing and frost. When the air temperature drops to the point of condensation (a.k.a. the dew point), either dew (if $T > 32^\circ$) or frost (if $T \leq 32^\circ$) will begin forming on your observing equipment. This is a significant problem with SCTs and refracting telescopes whose corrector plate or objective, or a reflector's mirror used with an unshielded truss system, is not protected by any sort of a shield such as a screen or tube. It's amazing how quickly condensation of some sort can occur on your equipment. Check for it regularly, but especially on evenings

when the temperature is dropping quickly, and the wind is calm. There are two approaches to dealing with this condensation: (1) either prevent it, or (2) treat it. In the former case, consider using a dew shield on exposed optics or get a heater for your telescope. In the latter case, you can purchase a heated electrical strip that is placed around the telescope's optics to keep them warmer than the night air or use a low-wattage hair dryer to evaporate the condensation. If you don't have heating equipment – aim your telescope toward the ground and leave it in that position for a while. Infrared radiation from the ground will slowly evaporate the condensation (though frost will take longer than dew to evaporate). When all else fails and you just can't keep up with the rate of condensation, it's best just to pack up and go home.

Ensure thermal equilibrium of your equipment.

Telescopes yield the best views if their optical systems are in thermal equilibrium with the air. As the temperature of optical and mechanical components rises and falls, these items will expand or contract respectively. Different parts of a lens or mirror will cool at different rates due to variations in thickness, so while temperature change is taking place the physical features of the optical shapes and surfaces change. Such changes reduce the quality of views provided by these telescopes. If you keep your telescope shaded and outside, you generally won't have to wait for it to come to thermal equilibrium with the air. If, however, you keep your telescope in a colder house or warmer vehicle, you might need to set it up and wait for at least an hour for it to reach thermal equilibrium with the air. Some of the more expensive telescopes come with built-in fans to increase the rate of thermal exchange with the air.

Avoid unnecessary air currents. Choose your observing site carefully. There are many factors to keep in mind when choosing an observing site. If you set up on a hard surface such as concrete or asphalt, you won't have to worry much about your feet getting wet due to dew formation. However, you will have to worry about air currents caused by thermal convection. Asphalt due to its dark color tends to absorb heat from the sun during the day and give it off at night. This produces convection currents to form over the observing spot. Your best views are obtained when the atmosphere is stable. Convection currents cause images to shimmer thereby reducing the quality of the view. Concrete is much the better choice for viewing on a hard surface. It is lighter in color and therefore does not absorb and give off as much heat as asphalt. Viewing from a grassy spot is even better, but there is a problem with dew. In a similar vein, avoid viewing through an open window or viewing objects located not far above rooftops. Thermal currents form due to convection in both situations.

Choose your observing location carefully. Sky darkness is only one factor in choosing an observing location. Observatories built in the flatlands of the Midwest are frequently built near lakes and reservoirs. Have you ever wondered why? This is so because water has much higher thermal inertia (it takes a lot of heat to change the temperature of water substantially) than land, and the water temperature changes very little over the course of day and night. Less heat being emitted from a lake at night means that air over it is less likely to experience the thermal effects commonly seen over soil whose temperature can range widely over the course of day and night.

29. Optimizing Observations of Deep Space Objects

A number of factors determine the quality of one's telescopic views. The stability of the atmosphere (seeing), the transparency and darkness of the sky, filter use, dark adaptation, the size and quality of one's telescope (including the mount), and even the powers of one's telescope can adversely affect one's view of the heavens. If one is to optimize telescopic observations, then one needs to understand how these factors interact to produce the best (and worst) telescopic observations.

Telescopes have three "powers" – light-gathering, resolving, and magnifying. Bigger objectives, if well made, produce brighter and sharper images that can be viewed with the use of an eyepiece. The choice of an eyepiece can be critical in optimizing the view.

Perhaps the least understood of the powers of the telescope is magnifying power. I've been reflecting on this aspect of telescopes for several months now and have resolved to cast some light on this particular power and provide some implications for eyepiece selection.

Magnifying Power – The magnification of a telescope – the size of an object seen in an eyepiece compared to the size of that same object seen in the sky with an unaided eye can be determined with a simple expression:

$$\text{Magnifying Power} = EFL_t \div FL_e$$

Because the effective focal length of a typical telescope (EFL_t) remains fixed (unless, say, one inserts a telecompressor or Barlow lens into the optical train to change the effective focal ratio of an instrument from f/10 to f/6.3 or from f/8 to f/16 respectively), one varies the magnification by using eyepieces of different focal lengths (FL_e). My f/10 configured CPC 11" telescope has a focal length of 2800mm. When used with an 18mm eyepiece, I get a magnifying power of $2800\text{mm} \div 18\text{mm} = 156\times$; with the use of a 32mm eyepiece, I get a magnifying power of $88\times$. The shorter the focal length of the eyepiece, the higher the magnifying power it will provide.

Drawbacks of High Magnifying Power – Many people misunderstand magnifying power. They think “the more the better.” Not so. First and foremost, increased magnification reduces image brightness. A telescopic image magnified 50X will appear 2,500 times (50²) dimmer than the image obtained with the unaided eye. Granted, this is offset somewhat by the light-gathering power of a telescope, but telescopes rarely provide increased image brightness. This is the province of some of the lower powered binoculars with large objective lenses. Higher magnifying powers also amplify the rate of motion of celestial objects through a field of view and reduce the field of view making things harder to find. Higher powers also can negatively affect image quality as perceived by the eye as well. If a telescope mount is wobbly, any vibrations will be similarly magnified.

Exit Pupil – Before moving on to lowest and highest useful magnifications for a particular telescope-observer combination, I need to mention a bit about the exit pupil. The exit pupil is the diameter of the small disk of light emanating from an eyepiece. For optimal viewing at lower powers, an observer must place his or her eye at such a position that the eye's pupil is coincident with the eyepiece's exit pupil. If the diameter of one's fully dilated eye pupil is less than the telescope's exit pupil, the observer will see a vignetted image, wasting much of the light-gathering power of the telescope. (This effectively reduces the aperture of a telescope.)

The diameter of the exit pupil of the telescope is dependent on the aperture of the objective and the magnification, and they are related in the following manner:

$$\text{Eyepiece exit pupil diameter} = \text{Aperture} \div \text{Magnification}$$

As the equation shows, lower magnifications produce larger exit pupils, and higher magnifications produce smaller exit pupils. In order to obtain the best low-power views in a telescope, the exit pupil of the eyepiece-telescope combination must match the maximum pupil diameter of the observer's eye. Now, the pupil diameter of the typical adult human eye is mostly a function of age. Young adults on the order of 20 years of age will have a fully-dilated pupil diameter of as much as 7.5mm, whereas someone who is 70 years of age will have a dark-adapted pupil diameter on the order of 3mm. A simple formula relating average pupil diameter of the eye to the adult observer's age (≥ 20) is given as follows:

$$\text{Average pupil diameter} = (-0.09\text{mm/yr}) \times \text{Age} + 9.3\text{mm} \\ (\text{Age} \geq 20\text{yr})$$

Hence, in my case (56 years old) selecting a low power eyepiece-telescope combination that produces an exit pupil of greater than 4.2mm probably would not be advisable.

Lowest Useful Magnification – As a result of the exit pupil considerations addressed last month, there actually is a lowest useful magnification that an observer can use to achieve the brightest possible image for viewing with direct

vision – at least if that observer expects to use the entire aperture of the telescope. It is convenient to express the optimal lowest power eyepiece (OLPE) in terms of its focal length, which happens to depend on a telescope's focal ratio and the maximum diameter of the fully dilated pupil of the observer's eye. The expression is:

$$\text{OLPE Focal Length} = \text{Exit Pupil Diameter} \times \text{Focal Ratio}$$

For example, in my case the OLPE focal length for direct vision will be (4.2mm x 10) or 42mm. Using an eyepiece in this range (say a 40mm) will provide me with the brightest views of celestial objects given my telescope's characteristics and my observing eye's maximum dilation. The resulting magnification will allow for the best possible direct-vision views because I am then dealing with the brightest possible image for a given telescope-observer combination. My optimum low magnification with a 40mm eyepiece in my CPC 11" telescope would be 70X.

A Common Misconception – It is often said that telescopes make celestial objects brighter so the observer can see them. This is a common misconception, and in the vast majority of cases patently false. Almost all astronomical telescopes will dim celestial objects rather than make them brighter. Consider that my 11" telescope gathers about 3,500 times more light than my eye (taking into account the presence of the secondary mirror, and the loss of light due to absorption and reflection). Using my telescope at a magnification of 70X will actually reduce the brightness of the image by some 4,900 times (70²). Hence, when observed with this combination of telescope and eyepiece, the image in the eyepiece is about 70% (3,500/4,900) as bright as it would be seen with the unaided eye. Only some binoculars with larger apertures (e.g., 50mm) and lower powers (e.g., 7X) will actually increase the apparent brightness of an object – assuming, of course, that the exit pupil criterion is met. Observers see more details in telescopes merely because extended objects appear larger and more resolvable than when observed with the unaided eye.

Two Highest Useful Magnifications – As any experienced observer knows, the best way to view fainter objects is with the use of averted vision. Direct vision is fine if an object is bright enough to stimulate the cone receptors in the fovea of the eye. If an object is very dim, it is best viewed with the use of averted vision. In such situations the observer views a dim object “out of the corner of the eye.” This allows light to fall on the much more sensitive rod receptors located outside the fovea of the retina.

From a practical standpoint, there is a highest magnification one might use with averted vision to see the maximum detail in an extended, non-stellar object. Historically, a general rule of thumb has been given that states that the highest useful magnification is about 50X per inch of aperture. This rule is based on the ability of an observer to visually separate binary stars in close proximity

to one another, but it does not take into account other limiting factors such as poor atmospheric steadiness, inferior optics, a shaky mount, or getting an eyepiece with adequate eye relief (the distance from the outer surface of the eyepiece and the focal point of the image). In addition, this 50X rule is too “simplistic” to the extent that it does not apply meaningfully to extended deep-space objects such as nebulae, supernova remnants, and galaxies.

Research conducted by H. Richard Blackwell (Contrast thresholds of the human eye, *Journal of the Optical Society of America*, Vol. 36, No. 11, November 1946) showed that there are better ways to maximize the human ability to see fainter objects using averted vision, and this is subject to both illumination and image size. Work using Blackwell’s data, represented graphically by Roger N. Clark in *Visual Astronomy of the Deep Sky*, 1990, can be summarized with a simple formula that takes into account the use of averted vision in relation to optimal highest power (OHPE). It is given by the following formula:

$$\text{OHPE} = 6.2 \times \text{Aperture} + 35 \quad (4'' \leq \text{Aperture} \leq 16'')$$

So, by this criterion the optimal highest power for my 11” telescope will be approximately 103X ($6.2 \times 11 + 35$). Converting this into focal length of the eyepiece using the first equation in this article series, the OHPE focal length for me would be approximately 27mm ($2800\text{mm}/103\text{X}$) when viewing extended objects using averted vision. While this is the highest power for seeing maximal detail using averted vision, it is not necessarily the highest power one might want to use. One may safely double this optimal magnification with a minimal reduction in the averted vision visibility index according to Blackwell’s work. The increased magnification might dim the object, but the trade-off is acceptable. It will make extended objects larger and more resolvable to the human eye as a result even with the loss of brightness.

When I’m observing certain planetary nebulae on the AL observing club list, I must push the magnification far beyond the OHPE condition so that I can resolve a nebula’s near stellar image. Higher powers will allow me to distinguish the nebula from field stars that do not grow in size with increasing magnification (unless the seeing is poor). Because telescopes, observers, and observing conditions vary so much, it’s really up to the observer to decide when a certain magnifying power is too much. When increasing the magnification makes an image worse rather than better, then an observer knows that he or she really has surpassed optimum highest power.

While telescope aperture and magnifying powers are critical components for optimizing views of extended deep space objects (dark, emission, reflection, and planetary nebulae as well as galaxies), they are not the only considerations. Another way to enhance visibility of these celestial objects is to increase their contrast relative to the background sky. This can be achieved in two different ways:

(1) observing celestial objects from a location with a darker sky, and (2) using filters that transmit only certain wavelengths of light while blocking others. Additional considerations also apply, and these include: (3) observing only with dark-adapted eyes, (4) using averted vision properly, (5) observing only when the sky is very transparent, (6) maintaining your optics, and (7) observing objects only when they are higher up in the sky.

Enhancing the contrast of extended celestial objects relative to the background is most easily accomplished by observing from remote dark-sky locations (e.g., mountain tops, Chile, or in some years the Illinois Dark Sky Star Party). Even viewing from sites not terribly far removed from cities (e.g., Sugar Grove Nature Center) enhances the views over those obtainable by observing under urban skies. Also, observe when the moon is not present in the sky to achieve maximum darkness. When the night sky is at its darkest, the celestial objects are viewed at their best.

Increasing the contrast between an extended celestial object and the sky also can be accomplished with the use of narrow-band filters such as the OIII (doubly ionized oxygen), UHC (ultra-high contrast), Skyglow, and so on. Anyone who has observed with me recently and seen the North American, Veil, or Helix nebulae knows the “power” of the OIII filter to improve visibility of these objects, especially on nights when the contrast between the object and the sky is low. As experience has shown, these objects are essentially invisible from SGNC with my telescope without the use of the OIII filter no matter what the conditions.

Another way to get a good view of extended deep space objects is to allow your eyes to properly adapt to the dark. Eyes will typically take about 30 minutes to reach most of their dark adaptation, but observers will notice additional adaptation after several hours in darkness. Note that subjecting your eyes to very bright daylight can affect your ability to dark adapt for several days.

Using a dark red-filtered flashlight of low intensity is one way to maintain your dark adaptation. Red wavelengths of light do not have sufficient energy to destroy the chemical rhodopsin that is created by the retina as a means of adapting to the dark (the other means is to dilate the pupil). Deep red LED flashlights with dimmers are the ideal. (I have found the Orion *RedBeam* II LED variable-brightness astro flashlight to be ideal.) When observing, don’t let nearby lights or passing headlights of cars ruin your night vision. Close your eyes and look away when a car is approaching an observing sight. While observing, some observers will employ hoods that cover the observer’s head and extend all the way the telescope eyepiece. Failing that, some observers will cup their hands around the eyepiece providing for a bit darker situation. Such approaches can perceptibly improve and preserve one’s night vision.

Be certain to use averted vision to see additional detail. The cones at the back of the eye are color receptors, but don’t work very well under dim light conditions (explaining

why we tend to see things in shades of gray at night). The rods surrounding the fovea's cones at the back of the eye are more sensitive to subtle differences in lighting. Look at extended space objects "out of the corner of your eye" if you'd like to see more detail. This method requires and improves with practice, as the eye's peripheral vision rods are not attached to the brain in the way the direct vision cones are. Too little attention is paid to this important observing technique and, frankly, I was using improper technique for years. Don't turn your eye toward your nose when using averted vision due to the blind spot at the back of the eye. Directing light into this blind spot will reduce an object's visibility rather than enhance it.

Projecting and maintaining your optics will lead to improved visibility. Scattered light, dust, and dew can destroy image quality, brightness, and contrast. If observing with a truss-tube assembly, be certain to cover the open parts of the optical tube assembly with a shroud. Also, be certain that stray light cannot strike the secondary mirror. Keep your optics clean. Dust can scatter light making for a more diffuse image. Watch out for dew, but especially if you are using a refractor or Schmidt-Cassegrain where the corrector plate is not protected by a tube assembly. On nights when water vapor is condensing (or freezing) on exposed optics, be certain to either use a dew shield to prevent or a low-wattage hair dryer to evaporate condensation.

Dew shields provide an added benefit in that they reduce the presence of scattered light in the optical tube assembly and that following on a secondary mirror.

Heightened sky transparency will also increase the visibility of extended deep space objects. The best views occur on cold winter nights and following the passage of cold fronts at other times of year. Often associated with these weather conditions is enhanced twinkling. Fortunately, the twinkling phenomenon doesn't tend to strongly influence the quality of views of extended deep space objects that are most often diffuse.

Lastly, to get the best views of extended deep space objects, be certain to view them when they are higher up in the sky. Personally, I rarely observe objects when they are less than 30° above the horizon. When looking close to the horizon, one is peering through a thicker layer of atmosphere than when an object is viewed higher up in the sky. The light of objects close to the horizon travels through as much as five times as much atmosphere as objects viewed overhead. To get the best views of celestial objects, be certain to observe them when they are transiting the meridian, crossing from east to west across the north-south line in the sky.

Two recent developments have more strongly influenced my "ability" to observe deep space objects than anything else. They are the advent of "go-to" telescopes and the Astronomical League's observing programs. When I first heard about go-to telescopes in the early part of this

decade, I wasn't quite sure what to expect. I shortly thereafter observed with Michael Rogers as he used his 8-inch Meade go-to telescope and fell in love with the concepts of "auto finding" celestial objects. Thanks in part to Michael, I moved to the next stage of amateur astronomy.

I was tired of seemingly crawling around on the ground on my hands and knees in order to keep seeing the same objects. I rarely took the time to observe any object that required me to search using approaches such as sweeping and star hopping. I especially hated bending over my telescope or contorting my body to use the straight-through finder to locate object nearly overhead. Astronomy was quickly getting older than me, and literally quite a pain in the back. The prospect of finding celestial objects at the push of a button held great appeal.

After using the SGO's 12-inch Meade LX200 go-to telescope for the first time under the tutelage of William Carney, I was hooked. A few weeks later, I was immediately convinced of the good of my own go-to telescope after finding 60 celestial objects with the SGO telescope in just over one hour. In the summer of 2006, I purchased my first go-to telescope. That Celestron CPC 11-inch now makes finding deep space objects a breeze and has increased my viewing pleasure immensely. I just align the telescope on two bright stars and start observing by pushing a few buttons. Nothing could be easier.

Using a go-to telescope has effectively increased the visibility of celestial objects in a most impressive fashion. Deep space objects of every type are now eminently more accessible. I now can spend much more time observing deep space objects, and much less time searching the heavens for them. I have used my CPC 11-inch to glimpse (I really can't call this observing!) more than 100 galaxies in a two-hour time span. While the cost of a high quality go-to telescope can be in the thousands, trust me, it is well worth it.

Equipped with a powerful go-to telescope, one can really take a tour of the universe. Having an observing program improves viewing almost immeasurably but is often NOT thought of as way to improve "visibility." I assure you it is. Had the Astronomical League's observing clubs not existed, I would never have viewed 100 features on the moon, 110 Messier objects, 400 Herschel objects, 100 Urban objects, nearly 60 planetary nebulas and 50 globular clusters (to date)! Neither would I have found curious individual objects such as comets, asteroids, and deep red carbon stars.

So, folks, there you have it, how to optimize observations of deep space objects. I hope that you have been as inspired as I have by the four-part series and will spend some time out under the stars this summer. Now, let's start putting this knowledge to use.

Note: Portions of this article are based on "The virtual observer: A new breakthrough technology for the visual observer" by Roger Blake appearing in *Astronomy Technology Today*, Volume 2, Issue 9, September 2008.

30. THE USE OF OBSERVING FILTERS

While a telescope can enhance your observations in comparison to the unaided eye, eyepiece filters and filters that fit over the objective of a telescope can enhance what you see through the eyepiece. There are three basic types of eyepiece filters with which we will concern ourselves here and now – broadband filters, narrowband filters, and other. Broadband filters typically pass a wide range of wavelengths; narrowband filters typically pass only a limited range of wavelengths; other filters can be used to reduce the brightness of an image across all wavelengths or to detect polarization. Filters can be further subdivided into the following classifications: lunar, planetary, nebular, cometary, and light pollution filters.

Lunar filters utilize polarization to adjust the brightness of images for better observing. They consist of two polarizing planes mounted in a rotating cell. They vary the light transmission from 3% to 40%. The light transmission can be adjusted depending on the phase of the moon.

Planetary filters come in a very wide range of colors. Each is designed to pass certain wavelengths and block others. This tends to enhance the contrast of features on the planetary bodies. Each of these colored filters makes use of the visible light transmission (VLT) scale. The lower the VLT number, the dimmer the object observed will appear. VLT numbers of 40% or lower are not typically used on small aperture telescopes because the images they yield are simply too dim. Consider the following common Wratten filters and their uses as described by *telescopes.com*:

- #8 Light Yellow (83% VLT) helps to increase the detail in the maria on Mars, enhance detail in the belts on Jupiter, increase resolution of detail in large telescope when viewing Neptune and Uranus, and enhance detail on the moon in smaller scopes.
- #11 Yellow Green (78% VLT) helps to bring out dark surface detail on Jupiter and Saturn, darkens the maria on Mars, and improves visual detail when viewing Neptune and Uranus through large telescopes.
- #12 Yellow (74% VLT) help greatly in viewing Mars by bringing out the polar ice caps, enhancing blue clouds in the atmosphere, increasing contrast, and brightening desert regions. Yellow also enhances red and orange features on Jupiter and Saturn and darkens the blue festoons near Jupiter's equator.
- #21 Orange (46% VLT) helps increase contrast between light and dark areas, penetrates clouds, and assists in detecting dust storms on Mars. Orange also helps to bring out the Great Red Spot and sharpen contrast on Jupiter.
- #25A Red (14% VLT) provides maximum contrast of surface features and enhances surface detail, polar ice caps, and dust clouds on Mars. Red also reduces light glare when looking at Venus. In large telescopes, a red

filter sharply defines differences between clouds and surface features on Jupiter and adds definition to polar caps and maria on Mars.

- #56 Light Green (53% VLT) enhances frost patches, surface fogs, and polar projections on Mars, the ring system on Saturn, belts on Jupiter and works as a great general-purpose filter when viewing the Moon.
- #58 Dark Green (24% VLT) increases contrast on lighter parts of Jupiter's surface, Venusian atmospheric features, and polar ice caps on Mars. Dark green will also help bring out the cloud belts and polar regions of Saturn.
- #80A Blue (30% VLT) provides detail in atmospheric clouds on Mars, increases contrast on the moon, brings out detail in belts and polar features on Saturn, enhances contrast on Jupiter's bright areas and cloud boundaries. A blue filter is also useful in helping to split the binary star Antares when at maximum separation.

Nebula filters come in a wide variety of types, but the most useful are the Oxygen 3 (OIII), Hydrogen alpha (H α), Sulfur 2 (S2), and Ultra High Contrast (UHC) filters. OIII in particular has a broad applicability in that it can be used to enhance the contrast between the various regions of an emission nebula and help observers distinguish tiny planetary nebulas from surrounding stars. OIII also increases the contrast of these objects with the night sky rendering them more visible to the observer. SII and H α filters can be use similarly if not as effectively by visual observers. UHC filters are particularly useful for revealing nebulosity. This is achieved by passing three nebula emission lines – two doubly ionized oxygen lines (496 and 501 nm) and the H-beta line (486 nm) – while blocking light-pollution and sky glow.

Light Pollution Reduction (LPR) filters are designed to selectively reduce the transmission of certain wavelengths of light, specifically those produced by artificial light. This includes mercury and both high- and low-pressure sodium vapor lights. In addition, they block unwanted natural light caused by neutral oxygen emission in our atmosphere. As a result, LPR filters darken the background sky, making deep-sky observation and photography of nebulae, star clusters and galaxies possible from urban areas. LPR filters are not used for lunar, planetary or terrestrial photography. The SkyGlow filter enhances deep-sky observations in moderately light-polluted skies. It is a broadband filter blocks the most common wavelengths of light pollution for increased contrast and better views. The filter improves views of nebulas, galaxies as well as open and globular star clusters.

Filter wheels are a great way to manage a collection of eyepiece or photographic filters. The image below is a housing that holds five filters of the viewer's choice. Instead of constantly screwing and unscrewing filters into the end

of an eyepiece, filters can be rotated manually into and out of the optical path of a telescope's eyepiece. This makes changing filters quick and easy. No need to drop filters or eyepieces while fumbling around with them in the dark.



Solar filters fall into two basic types: optical Mylar (shown in the left image below) and coated glass (shown in the right image below). The solar image through Mylar is a pale blue; through the glass filter it is orange. Sunspots and faculae are readily observed when viewed in the usual optical spectrum despite the type of filter used.

Filters either can be purchased for the full aperture of the scope, or smaller and used off-axis. The glass filters are more expensive, but more durable. If scratches or pinholes appear on these filters, you can simply cover them over with a black waterproof felt-tip pen. This will in no way diminish light transmission.

Never use a solar filter that screws into an eyepiece. The telescope's objective will focus an intense beam of heat and light on the dark absorbing lens sometimes causing it to explosively shatter. Solar retinopathy can result from the eye being subjected to full, un-attenuated light of the telescope.



The **Herschel wedge** is another form of solar filter rarely used today. They are merely plates of glass that transmit most of the sun's visible, UV, and IR light, and an eyepiece (often with a neutral density filter) is used to view the reflected image.

31. RECORDING YOUR OBSERVATIONS

It's good practice to record your observations. This will provide a "look back" record should you wish to review what it was that you observed on any particular night. In addition, it will provide critical information necessary for

completing observing programs such as those available through the Astronomical League.

Observing records should contain at a minimum the following information shown in this sample observing record.

Object:	Date:	Time:	Notes:
	Instrument:	Eyepiece:	
	Seeing:	Power:	
	Transparency:	Location:	
	Limiting Mag:	Filter:	

A completed record might look something like this:

Object: M42	Date: 2/27/16	Time: 9:31pm	Notes: The nebula shows an incredible amount of detail and is so bright I can even see a greenish coloration throughout without a filter. The Trapezium is clearly visible at the center of the nebula. The OIII filter really brought out the detail.
	Instrument: CPC11	Eyepiece: Plössl	
	Seeing: 3/5	Power: 87X	
	Transparency: 4/5	Location: SGNC	
	Limiting Mag: 5.5	Filter: OIII	

An observing record might also include room for drawings. Each such record might include one or two sketch templates (high versus low power or filtered versus non-filtered views) for information about the true field of view as well. Amateur astronomers can create their own

observing record templates using a word processor. Running off multiple copies can aid with making a professional-looking record.

Something to keep in mind, however, is the utility of a tablet application like *SkySafari* that have built in observing

records plus a tremendous amount of other information available at the observer's fingertips. Serious observers will definitely want to consider purchasing such a device and application. Even an older cast off can be readily employed.

Cell phone versions of the application are similarly available, but with the small screens can be hard to work especially under colder conditions.

32. MOON PHASES AND THEIR EFFECT ON OBSERVING

The causes of the moon's phases are well understood, though many people hold to the mistaken belief that the phases are caused by Earth's shadow falling on our nearest neighbor. Nothing could be farther from the truth. When that occurs, we are experiencing lunar eclipse and such eclipses can occur only during full moon phase.

The moon takes 29.5 days – and about 389° of angular motion as seen from Earth – to exhibit the complete set of phases. However, the period of time required for the moon to orbit Earth once with respect to the stars once is only about 27.3 days – its sidereal period. The longer period of time required to exhibit a complete set of the moon's phases – its synodic period – exceeds its sidereal period by about 2.2 days. This results from the sun's $0.9856^\circ/\text{day}$ eastward motion along the ecliptic over the course of time ($360^\circ/365.25$ days). The moon takes 2.2 additional days to catch up with the sun in order to exhibit the next new phase.

The moon moves eastward among the stars and constellations at a rate of about 13.2° per day due to its orbital motion around Earth. As a result, the moon travels about 97.2° to move from new to first quarter and from first quarter to full phase, and so forth. Hence, the time between phases is about $7\frac{1}{2}$ days on average.









The moon's phases can have a pronounced negative effect on certain aspects of astronomical observing. Moonlight is a naturally occurring form of light pollution. When the moon is present, the air scatters its light. This brightens the sky, thereby reducing the contrast between the sky and celestial objects. This is generally not a problem when viewing planets or star clusters because these objects are much brighter than the moonlit sky; a problem does exist with viewing such things as comets, nebulas, and galaxies when the moon is present in the sky.

One of the more surprising things about the moon is that its brightness is not directly related to the amount of lunar surface illuminated. For instance, the moon's apparent magnitude at full phase is -12.7 whereas at the two quarter phases it is less than 10 percent as bright. If the

moon's surface were perfectly smooth, the moon at a quarter phase would be half as bright as it is at full phase. This doesn't happen though, and the reason has to do with the rugged lunar landscape – especially in the regions near the day/night edge (the terminator). The lunar landscape is riddled with holes and shadows cast by mountain, boulders, and even tiny grains of the lunar regolith (soil). In addition, the moon's face has dark, splotchy regions known as lunar maria. The result of the interaction between the sunlight, the terminator, and these lunar features and colors is that at quarter phases the moon appears much dimmer than would be expected. Believe it or not, the moon is only half as bright as the full moon a mere 2.4 days before or after full phase. Even though 95% of the moon is illuminated at this time (and most casual observers would think the moon was entirely full), its brightness is roughly 0.7 magnitudes less than at full phase making it appear only half as bright.

The moon also can vary in brightness due to the changes in Earth-Moon and Earth-Moon-Sun separations. The full moon, for instance, appears brightest when it is closest to Earth. Its brightness will increase even more if the Earth-Moon system is nearer the sun. This gives rise to the so-called "supermoon" phenomenon that is readily perceptible in both brightness and size to the experienced observer.

As a result of the moon's non-uniform changing brightness, the best times for observing will occur between waning and waxing crescents when the moon is near the sun in the sky and rises shortly before or sets shortly after the sun and in the twilight hours. Between first quarter and waxing gibbous, and between waning gibbous and third quarter, the observer needs to carefully time observations to avoid the moon's presence in the sky, unless of course one wants to observe the moon. During full moon the moon rises at sunset, sets at sunrise, and is in the sky all night long. The following table will help the reader better understand the relationship between moon phase and optimal viewing times.

Moon Phase		Approximate Rise Time*	Approximate Set Time*	Optimal Viewing Times
New Moon		6 AM Std 7 AM DST (sunrise)	6 PM Std 7 PM DST (sunset)	Moon not visible. Best viewing from after to sunset to before sunrise.
Waxing Crescent		9 AM Std 10 AM DST	9 PM Std 10 PM DST	The dim moon is low in the west after sunset. Moon doesn't significantly interfere.
First Quarter		12 PM Std 1 PM DST (noon)	12 AM Std 1 AM PDT (midnight)	The moon is in the south at sunset and now interferes; best views after midnight.
Waxing Gibbous		3 PM Std 4 PM DST	3 AM Std 4 AM DST	The bright moon is in the southeast after sunset. Best views before sunrise.
Full Moon		6 PM Std 7 PM DST (sunset)	6 AM Std 7 AM DST (sunrise)	The moon rises in the east at sunset and sets in the west at sunrise. No best times.
Waning Gibbous		9 PM Std 10 PM DST	9 AM Std 10 AM DST	The moon rises sometime after sunset. Best viewing during the early evening hours.
Last Quarter		12 AM Std 1 AM DST (midnight)	12 PM Std 1 PM DST (noon)	The moon rises around midnight. Best viewing conditions up to midnight hours.
Waning Crescent		3 AM Std 4 AM DST	3 PM Std 4 PM DST	The dim moon rises a few hours before sunrise. Moon doesn't significantly interfere.

* "Std" refers to standard time; DST refers to Daylight Saving Time

The times of rising and setting in the above table are at best approximate as there is a significant seasonal variation for a given location. For instance, near the September equinox we experience the harvest moon phenomenon. The full to near-full moonrises at this time are delayed by only about 30 minutes from night to night whereas the average delay in moonrise time averages 50.2 minutes per

day over the course of a year. Moonrises around the March equinox are delayed by as much as about 70 minutes from night to night.

To get precise moonrise and moonset times it is best to use a computer/tablet/cellphone application. Also, check out the following very useful and helpful URL: http://aa.usno.navy.mil/data/docs/RS_OneYear.php

Location: W088 59', N40 29'

BLOOMINGTON, ILLINOIS
Rise and Set for the Sun for 2016
Central Standard Time

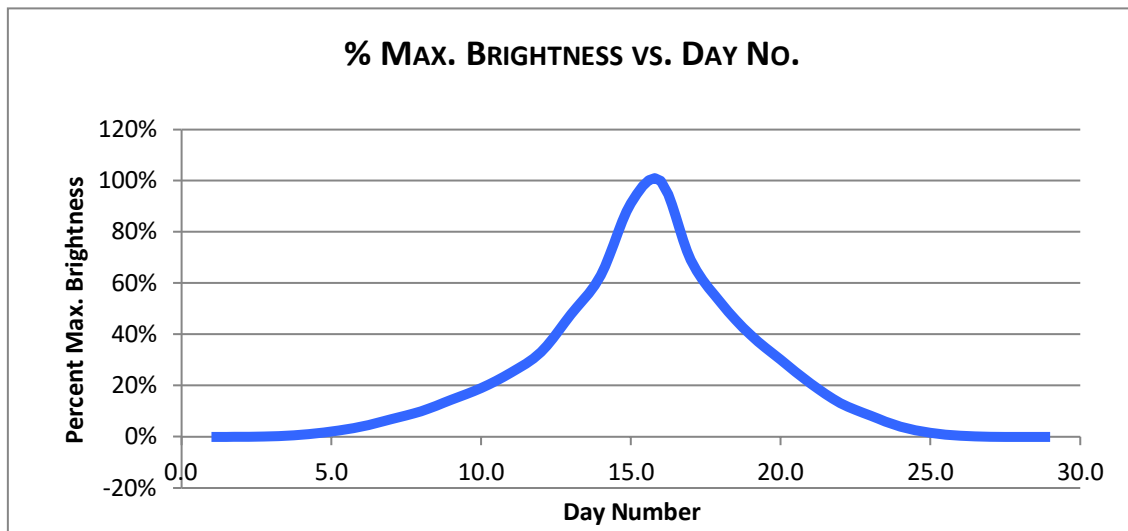
Astronomical Applications Dept.
U. S. Naval Observatory
Washington, DC 20392-5420

	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
Day	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set	Rise	Set
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
01	0719	1640	0706	1714	0629	1748	0539	1821	0454	1852	0428	1921	0430	1930	0454	1910	0524	1827	0553	1737	0626	1652	0700	1630
02	0719	1641	0705	1715	0627	1749	0537	1822	0453	1853	0427	1921	0430	1930	0455	1909	0525	1825	0554	1736	0628	1651	0701	1630
03	0719	1641	0704	1716	0626	1750	0536	1823	0452	1854	0427	1922	0431	1930	0456	1908	0526	1824	0555	1734	0629	1650	0702	1629
04	0719	1642	0703	1717	0624	1751	0534	1824	0451	1855	0426	1923	0431	1930	0457	1907	0527	1822	0556	1732	0630	1649	0703	1629
05	0719	1643	0702	1718	0623	1753	0532	1825	0450	1856	0426	1923	0432	1929	0458	1906	0528	1821	0557	1731	0631	1648	0704	1629

33. MOON PHASE VERSUS BRIGHTNESS

Have you ever wondered about the relationship between the moon's phase and its brightness? You can find out by examining the chart below. This chart shows the moon's brightness as a function of day number relative to the brightness of the full moon for June 2016. It is plotted specifically for Central Illinois. In order to determine the

relationship between phases and brightness, one merely needs to know that in June 2016 the first quarter phase occurs at approximately day number 7.22; that is, 7.22 days past new moon. Full phase occurs around day number 15.33, and last quarter phase around day number 22.64. New phase occurs on days 0 and 29.5.



With the above chart we can see that on day 8 (just past first quarter phase) the moon is only about 10% of maximum brightness. On day 12 the moon is only 33% maximum brightness; on day 13 it's just under 50% of maximum brightness. Of course, maximum brightness occurs near but not always on the date of the full moon. This might seem curious, but keep in mind that the moon's orbit around the Earth is not circular, and that the motion of the observer on the spinning Earth also changes the distance between the two. When the moon is closer to the observer it looks brighter and vice versa.

To further understand this curious light curve, we must be cognizant of the fact that the moon does not have a smooth surface; rather, its surface is littered with craters ranging from hundreds of kilometers in diameter to smaller than can be seen with the unaided eye from close up.

Additionally, the lunar surface has many high mountain ranges and cliffs such as the Straight Wall. The lunar surface is also composed of different types of rock and regolith (soil), each with its own reflectivity. Part of the lunar surface is dark (the lunar maria for instance) and part of the lunar surface is bright (the lunar highlands for instance). These topographic differences are spread irregularly over the moon's surface.

When the moon is at full phase, all shadows on the lunar surface disappear giving the surface its maximal brightness. When the moon is at any other phase, the lunar surface has many shadows due to its irregular surface and the lower elevation of the sun as seen from the moon. These factors, in combination with the changing lunar phases, give the moon strangely varying brightness verses day number curve.

34. DEALING WITH WEATHER

There is a myriad of legitimate excuses for NOT getting out to observe, and among them is the weather. It's said that nothing can put a damper on observing like an overcast sky. That's true, and there is nothing that can be done about it. The other complaints are that it's too hot or too cold. Fortunately, we can do something about these if but to a limited extent. The advantage that winter observing has over summer observing is that there are more things that can be done to overcome the cold than the heat. Let's look at a few guidelines for dealing with the cold and heat while observing.

COOL AND COLD WEATHER OBSERVING

- * **Dress in layers.** Dressing so allows air to get trapped between layers of clothing where it serves as an insulator. It is better therefore to suit up in several thin layers of loose fitting clothing than in one thick layer. The advantage of doing so is that you can add or subtract layers of insulation should you get too warm.
- * **Keep your core body temperature up.** The best way to keep your hands and feet from getting cold during observing is to maintain your core body temperature. When your torso is warm, extra blood is shunted toward to extremities as a way of cooling off. If the core body temperature drops, the blood flow is reduced, and hands

and feet will rapidly become intolerably cold. To help keep your hands and feet warm, keep your core body temperature up. Proper attire and hot refreshments can help ward off that chill.

- * **Avoid alcoholic drinks.** While consuming an alcoholic beverage might seem to be a good way to keep warm, it is a double-edged sword. Shortly after imbibing, alcohol's byproducts sometimes cause a flushing effect. This can make the skin feel warmer – at least temporarily. This is achieved when capillaries open and warm blood moves to the skin where it then rapidly cools. Cool blood then returns to the body's center where it drops the core

temperature that is the opposite of the effect we intend to achieve.

- * **Start with a high calorie snack.** Eating a healthy, high calorie snack prior to observing can fortify an observer against the heat loss that is to come. When one loses heat, the body's cells will produce it by burning energy supplies.
- * **Take periodic warming breaks.** There's nothing to take the chill off an observer like periodic warming breaks. Sitting down in a warm location (your running vehicle or a building) can help you maintain your core body temperature and fight the effects of heat loss. It is best to take warming breaks before you get so cold that you start picking up a "chill" and begin shivering. When this occurs, the battle against the cold is lost. It's time to pack up and go home.
- * **Don't delay dressing up.** Dress warmly before you start observing. If you wait to get cold before dressing properly, it will be very difficult for your body to catch up when sustaining constant heat loss. The time to dress warmly is before you start feeling cold. When you step out of your vehicle to start observing on a cold night, it is fine to be uncomfortably warm so long as you are not beginning to perspire. Perspiration will have an unwanted cooling effect.
- * **Wear gloves.** If your body core temperature is maintained, the blood coursing through your hands will be maintained. If your core temperature is maintained, even thin gloves will keep your hands warm. Bare hands can get cold when touching metals that can more rapidly conduct heat away from your hands than can still cold air. A similar situation occurs with blowing wind and the accompanying wind chill. Your body might not be able to keep up with excessive heat loss even with a well-maintained core body temperature. If you are using electronic equipment while viewing such as a cellphone or tablet, consider getting a set of touch screen gloves that are electrically conductive and permit you to use these devices while your hands are covered.
- * **Cover your head.** More heat is lost from the head and around the neck than from any other parts of the human body. Lots of blood flows close to the surface here, and the face tends to get directly exposed to the air whereas other parts of the body are frequently covered. A hat with ear covers and good insulating properties can dramatically reduce this heat loss.
- * **Wear a hood, hoodie, scarf, cowl, or balaclava.** Wrapping or otherwise protecting the neck and face

Warm and Hot Weather Observing

- * **Remain fully hydrated.** Observing on hot, muggy nights can be exhausting if not downright debilitating. Be certain to remain hydrated because you can lose a lot of water through evaporative cooling (sweating). Consider

drinking cold, non-alcoholic beverages that can help reduce your core temperature and prevent dehydration. The best material for doing so is micro fleece fabric. Micro fleece is a thin poly fleece fabric that is a light but highly effective insulator that wicks moisture away from the skin. The fabric is soft against the skin, not scratchy like wool. Be certain to avoid trapping breath (as with a neck gaiter) as this results in condensation around the lower portion of the face and can lead to discomfort and evaporative chilling. The best hoods, hoodies, and hood scarves are those with flexible draw cords that can hold the fabric close to your face and reduce contact of your skin with the cold night air.

- * **Consider a Micro Fleece vest or jacket.** Micro fleece is so effective in keeping the observer warm that it keeps making its appearance among these recommendations. It can be one of your multiple layers.
- * **Consider a coat with a draw cord at the bottom.** Draw cords are elastic bands that can be used to close off areas of undesirable wind flow such as around the wrists, waist, and neck regions.
- * **Wear thick pants.** Avoid wearing thin pants during cold weather observing. Blue jeans provide better protection. You might also want to consider the use of thermal underwear.
- * **Wear insulating socks and shoes.** Avoid thin socks and dress shoes. They provide little defense against heat loss to the cold ground. Better are thick-soled work boots worn with thicker cotton socks. Avoid, however, tight socks as these can restrict blood flow to the feet.
- * **Consider augmented heating.** There are actually electric gloves and socks that an observer might consider. Also, chemical-based hand warmers kept in each of two coat pockets can provide an added boost if electric gloves are out of the question.
- * **Stay out of the wind.** Wind chill can have a devastating effect upon the observer. When a cold air passes over human flesh it conducts away heat faster than if there were no wind at all. This produces a wind chill factor. The wind chill temperature is the effective temperature the exposed skin experiences. Staying out of the wind will all but eliminate the wind chill factor.
- * **Consider remotely controlling your telescope.** One of the most difficult tasks when viewing under cold weather conditions is spending large amounts of time searching for things using finder scopes or star hopping. Consider acquiring a "goto" telescope that can find objects for you with a few taps of a keypad.

drinking cold, non-alcoholic beverages that can help reduce your core temperature and prevent dehydration.

- * **Dress lightly.** Clothing is a form of insulation that causes the body to retain heat. During warmer months, wear

lightweight, loose fitting clothing preferably of white or off-white color. Insects like mosquitoes are less likely to be attracted to light-colored clothing as animal sources of “nutrition” are usually darker in color.

- * **Use insect repellents.** Because humans produce carbon dioxide, they will always attract mosquitoes at night no matter how they dress. Insects like mosquitoes are attracted by the CO₂ in human breath. Because of the growing number of diseases carried by mosquitoes (Zika, West Nile, Dengue fever, etc.), it is important to defend yourself with the use of an effective insect repellent. Many people suggest applications including DEET.
- * **Defend yourself from ticks.** Be cautious in tick-infested areas. Dog ticks are common in Illinois, and the smaller deer tick is becoming so. Deer ticks are of a greater concern because they can carry Lyme disease. You are less likely to encounter ticks if you observe from, say, a parking lot. If, however, you are walking through vegetation to reach your “safe” observing site, the chances of picking up a tick increase. You need not actually brush against a plant to pick up a tick. Ticks will literally jump from their resting location to any nearby moving object – including legs and arms. Check yourself if you experience a “crawling” feeling on your skin. Also, carefully check yourself upon returning home.
- * **Avoid chiggers.** While some observers like to lay on their backs at night just to soak up starlight, avoid doing it directly on the ground no matter how enticing the grass might appear. The grass is often full of chiggers. Chiggers are mites that latch on to people the same way ticks do. Chiggers are most numerous in early summer. After they attach to humans, they feed on the skin, often causing itching and other forms of irritations. These relatives of ticks are nearly microscopic, measuring 0.4mm and have a metallic orange color.
- * **Choose your observing site wisely.** Avoid setting up your observing site near still, stagnant water. Ponds, discarded tires, watering tanks, dump sites, and roadside and agricultural ditches can become infested with mosquito larvae.
- * **Consider a slightly breezy location.** Sometimes amateurs will set up their telescopes in out of the way places to avoid a breeze. If you are not doing astrophotography, then choosing a slightly breezy location can actually pay dividends. A breeze can have a cooling effect. In addition, a breeze can keep optics from dewing and mosquitoes at bay when they are present.
- * **Work to prevent dewing.** When the relative humidity of air is high, objects that cool faster than the air will experience the accumulation of dew. When the temperature of moist air decreases, relative humidity increases, and condensation occurs. Consider a glass of ice water on a warm day. Note how quickly the cold glass causes condensation to occur on the exterior. Telescope optics can radiate heat more rapidly than the air and are subjected to this condensation. Be certain to use a dew shield or an electrical warmer on lenses and mirrors to keep this condensation from occurring.
- * **Take cooling breaks.** If you have access to a cooler location (air-conditioned vehicle or building), you might want to consider taking a cooling break from time to time. Short cooling breaks can be refreshing on a hot, humid night.
- * **Protect your feet from the dew.** If you have the habit of viewing from a grassy location, consider placing a tarp or some other sort of mat on the ground prior to setting up your telescope. Grass will quickly gather dew as the temperature drops and your feet will soon get soaked. This can lead to a very uncomfortable viewing condition.

35. CELESTIAL OBJECTS TO OBSERVE

Now that you have access to a telescope and know how to use it, what will you observe? There is considerable variety among celestial objects worth viewing and many observing programs to help you find them in a systematic fashion. Consider the types of objects that you can observe with a telescope:

Solar System Objects: *The sun and objects within its environment. Each is commonly known by a proper name.*

- **Sun** – Visual and narrowband views such as H α . Requires special filters. Caution: The sun can be extremely dangerous to observe due to the intense sunlight. Seek out expert advice before attempting to view the sun.
- **Moon** – Often overlooked because it is a natural form of light pollution, the moon shows more detail than any other celestial object.
- **Planets and their moons** – Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and Neptune. Most of the outer planets (Jupiter through Neptune) have moons that can be observed with a good size amateur telescope.
- **Dwarf planets** – Don’t forget Pluto and Ceres. Both are easily observed with suitable telescopes. Ceres was once considered to be the largest of asteroids but was reclassified about the time the Pluto was demoted from planet status.
- **Asteroids** – There are literally hundreds of asteroids that can be observed over the course of several years as they range widely in brightness over time. They look like slow-moving stars where motion can easily be observed from night to night.
- **Comets** – These are visible much of the time, but most are faint and require telescopes to view. They, like asteroids, tend to have readily observed motions. Some comets pass

near Earth and their motion can be noted after only a few minutes.

Deep Space Objects: *Objects beyond the solar system often identified by Messier (M), New General Catalog (NGC), or Index Catalog (IC) numbers.*

- **Open clusters** – Loose gatherings of stars of tens or hundreds of stars “recently” formed from dust and gas clouds in space. More than 10,000 are known.
- **Globular clusters** – Tightly packed groups of stars numbering in the tens or hundreds of thousands. These are among the oldest stars in the Milky Way galaxy. About 140 are known to cluster around the Milky Way galaxy.
- **Novas** – When the least massive stars end their lives, they die in “quiescent” explosions in which they cast off their outer layers of atmosphere. More of a “puff” than an explosion, these stars brighten enough to be seen with the naked eye. Most are observed within our Milky Way galaxy.
- **Planetary nebulae** – The remnants of low mass stars that have ejected their outer envelope of gas. More than 100 are readily visible in modest-sized amateur telescopes.
- **Supernovas** – When the most massive stars end their lives, they die in titanic explosions that can allow them to

become nearly as bright as a galaxy of stars. Most frequently seen from Earth in distant galaxies.

- **Super nova remnants** – The remains of massive stars that have exploded leaving neutron stars or black holes in their wake. A few are visible in amateur telescopes.
- **Emission nebulae** – Clouds of gas that are forced to glow as a result of hot stars in their vicinity. These are abundant, but not all are bright. Perhaps a couple of dozen are readily viewed with amateur telescopes.
- **Reflection nebulae** – Clouds of dust and gas that merely reflect starlight from cooler stars in their vicinity. Their number and visibility are much like that of the emission nebulae.
- **Dark nebulae** – Clouds of dust that obscure stars and bright nebulae located behind them. Sometimes they are so dark that they appear like “holes in the heavens”.
- **Galaxies** – Islands in the depths of deep space consisting of whirling masses of hundreds of billions of stars. Many varieties such as spiral, barred spiral, elliptical, spherical, and irregular. Some – the Seyfert galaxies – have intensely bright interiors and are some of the most remote.
- **Quasars** – The most remote objects you will ever see with your telescope. Only a handful are visible through moderate sized telescopes. Thought to be protogalaxies forming during the dawn of time powered by massive black holes.

36. Astronomical League Observing Programs

Observers are encouraged to begin regular observing programs, specifically Astronomical League observing programs. As noted on the Astronomical League website... (see <https://www.astroleague.org/observing.html>)

The Astronomical League provides many different observing programs. These programs are designed to provide a direction for your observations and to provide a goal. The programs have awards and pins to recognize the observers’ accomplishments and for demonstrating their observing skills with a variety of instruments and objects.

As a quick reference, you can compare the programs in these lists:

- Alphabetical Listing with images of the pins.
- Listing of the requirements for each program in a grid format.
- Listing of programs showing observer level (beginner, intermediate, advanced).
- Listing of programs showing equipment needed (naked-eye, binocular, telescope).

Programs offer a certificate based upon achieving certain observing goals and completion is recognized with a beautiful award pin. You are required to observe a specific number of objects from a list or of a specific type (meteors, comets, etc.) with a specific type of instrument (eyes,

binoculars, telescope). Some programs have multiple levels of accomplishment within the program, and some permit observations of different types (manual vs. go-to, visual vs. imaging) and note this on your certificate. There is no time limit for completing the required observing (except for the Planetary Transit Special Awards), but good record keeping is required.

The programs are designed to be individual effort. Each observer must perform all the requirements of each program themselves and not rely on other people to locate the objects. This is called “piggy-backing” and is not acceptable for logging objects for any of the programs. You are allowed to look through another observer’s telescope to see what the object looks like, but you still need to locate and observe the object on your own.

When you reach the requisite number of objects, your observing logs are examined by an appropriate authority and you will receive a certificate and pin to proclaim to all that you have reached your goal. Many local astronomical societies even post lists of those who have obtained their certificates as does the Astronomical League.

When you complete a program by yourself, you should feel a sense of pride and great accomplishment for what you have just completed. Each program is designed not only to show you a variety of objects in the sky and to learn some science related to those objects, but to also familiarize you

with your telescope and how to use it, night-sky navigation (the ability to find the objects in the vastness of space) and

to learn some observing techniques that will enhance your viewing of the objects in the programs.

ADVANCED TOPICS:

37. CLEANING YOUR OPTICS

Whether a telescope sits in a closet for years or gets used under the night sky on a fairly regular basis, there is one thing for certain – the optical surfaces of your telescope and eyepieces eventually will have to be cleaned. Even with the judicious use of dust caps, mirrors and lenses will get dirty. Consider for instance eyepieces.

With repeated use eyepieces will collect dust and pollen carried on the wind and oils from contact with eyelashes and other body parts. The hands of the amateur astronomer will sometimes inadvertently touch eyepiece lenses, and this results in fingerprints. At other times observers – generally novices – viewing through the telescope in the dark will actually touch an eyepiece’s optical surface with their noses leaving an oily smear. Despite our best efforts to protect our eyepieces, they will get soiled. Objective lenses, mirrors, and corrector plates are similarly subject to becoming soiled through a variety of similar means.

How should one clean such optical surfaces? The answer to this question is important, for if an improper procedure is used, the optical surface can be scratched and/or left with residues that will negatively affect performance.

The choice of a cleaning fluid is important. While most optical surfaces that have anti-reflective coatings (lenses) or silicon monoxide over coatings (mirrors) are pretty durable, no liquid short of a corroding agent is going to damage them. Nonetheless, the incorrect cleaning fluid can leave a film that will deteriorate the performance of the optical components.

Some observers prefer Windex or Glass Plus as a cleaning fluid. Others like to use isopropyl alcohol or pure methanol. (The author prefers “No-Glare Lens Cleaner” available through the Wal-Mart’s vision center.) Once a suitable cleaning fluid has been obtained, one must be very careful with its use. Always apply the cleaning fluid to the cleaning tissue (Microfiber works well – avoid using facial tissue that often contain softeners such as aloe) rather than to the optical surface, but especially with eyepieces. If the cleaning fluid is applied to the surface of an eyepiece, it will often seep around edges where it can become lodged between optical surfaces.) Methodology is more important than almost anything else.

Before applying a cleaning tissue or cloth to an optical surface, it is best to use a camel’s-hair brush, compressed air, or a bulb-type puffer to blow away any particles adhering to the surface. Gently does it. Particles, if not removed with a gentle touch, can abrade the optical surface when a cleaning rag is used that applies more pressure to the optical surface. If a brush or air does not remove surface particles, gently blot the surface with the cleaning cloth without rubbing. After a few minutes, try the brush or air once again. That should dislodge any abrading agent.

Once the optical surface has been cleared of potential abrading agents, the surface can then be cleaned with the cleaning tissue. Remember to apply the cleaning agent to the tissue or cloth sparingly – perhaps using a mister. Do not soak the lens or tissue because if you do, excess fluid will break away from the cleaning cloth leaving spots when it dries. Sweep gently (do not rub) from the center to the edge of the optical surface. Use a new tissue or portion of cleaning cloth with each pass. This will prevent any contamination removed during an earlier sweep from reappearing on the optical surface. Use a *dry* Q-tip to clean areas near the edge of an eyepiece’s surface lens. If you use a wetted Q-tip, capillary action could draw the liquid into the gap making it nearly impossible to reach.

Keep in mind that the cleaning of a telescope’s objective sometimes means taking a telescope apart. If you should ever do this, you will have to carefully re-collimate your telescope before it will work properly once again.

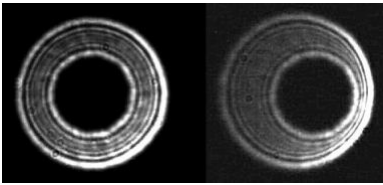
Amateur astronomers should be vigilant about maintaining clean optics. Proper storage using objective covers and eyepiece cases would seem to be a reasonable first step.

N.B. If after you have cleaned your telescope’s optics and still seem to get a “greasy” looking view, check your glasses if you were them. They often become smudged with body oils and this can cause images to look as they are smeared across the field of view. If you do not wear glasses, consider getting checked for cataracts. Cataracts can diffuse light passing thorough a telescope just as easily as oil on bifocal lenses. If you are still uncertain about the cleanliness of your optical system, look through your “non-observing” eye. The can speak volumes.

38. CHECKING THE COLLIMATION OF YOUR TELESCOPE

Collimating a telescope can be one of the most daunting tasks an amateur astronomer can encounter. The collimation process itself depends heavily on the type of telescope and the approach used and is beyond the scope of this publication. Rather than attempting to explain this complicated process, it is advisable that the novice satisfy himself or herself with assessing the collimation of his/her telescope. Consulting with an expert about the collimation process would be best at this stage of the game.

Testing the collimation of a telescope can be done using a variety of means. There exists one general approach, however, that can be used to assess the collimation of any telescope. It is the eyepiece test.



When a telescope is perfectly collimated, stars will appear in the eyepiece as point sources and extended objects such as planets will be as clear as atmospheric seeing and the diffraction of light permits. If a telescope is un-collimated, stars will appear unfocused even though their image size has been reduced to a minimum. The image above shows what to expect with a telescope unobstructed by a secondary mirror.

To check the collimation of your telescope, it is best to choose a bright star near the zenith and view it with a high-

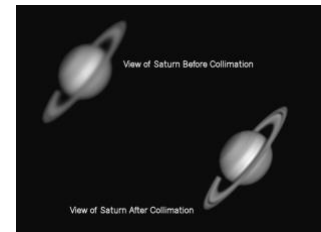
magnification eyepiece placed slightly out of focus – either inside or outside of best focus. When this is done, the star's diffraction pattern is made more readily discernable.

In a properly collimated telescope with a secondary mirror, the star will appear as a tightly spaced series of concentric bands of light as shown to the left in the accompany



image. The banding is caused by diffraction associated with interference of wave fronts as they pass through the telescope. When a telescope is not collimated properly, these bands will not be uniformly distributed, and the shadow of the secondary mirror will be offset from the center.

Don't confuse the consequences of poor collimation with bad seeing. When bad seeing occurs, the air will from time to time hold steady enough for clear images of stars or planets to be seen. When image quality is degraded as a result of improper collimation, then the image will never come into clear focus.



39. CHECKING YOUR OBJECTIVE'S OPTICS

Not all telescopes are equal. While most telescopes are supposedly "figured to $\frac{1}{4}$ wave or better" (required to perform on a "diffraction-limited basis"), sometimes objective mirrors and lenses have defects that reduce their ability to perform up to expectations. This is more commonly true with toy telescopes than more advanced instruments made for experienced amateur astronomers. Still, if your telescope is not operating up to expectations after it has been properly collimated, one needs to start looking for evidence of problems with the objective.

The image to the right shows how various defects in an objective affect in the diffraction patterns of bright stars viewed at higher magnification. The images here are for unobstructed telescopes such as an ordinary refractor or Schiefspiegler (a reflector with no secondary mirror). The central column shows what is expected under various defects when a star is at best possible focus. The left column shows what to expect when the eyepiece is racked inside focus. The right column shows what to expect when the eyepiece is racked outside of focus.

The following errors are thus illustrated:

Row 1: *Astigmatism*. The images are not radially symmetric. The focal length is different along different axes.

Row 2: *Coma*. More of a problem with short focal ratio telescopes and stars near the edge of the field. Most commonly observed at very low power where the field of view is larger.

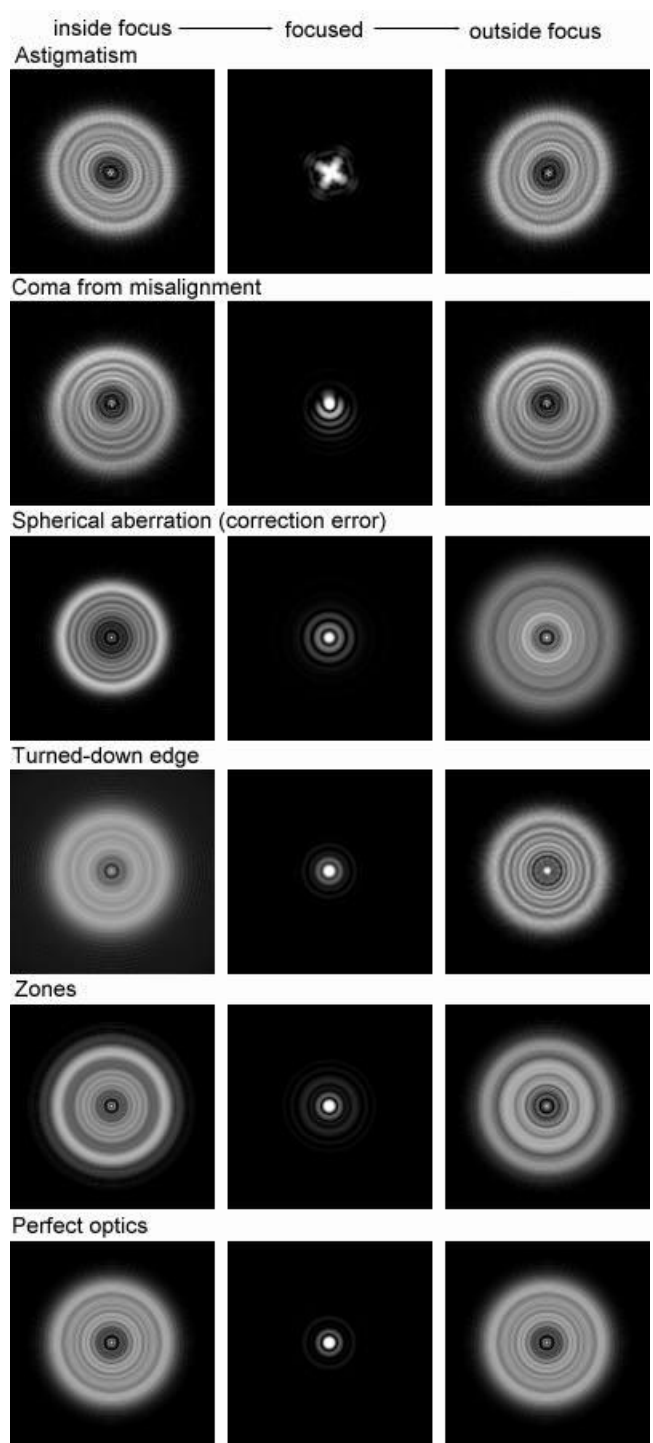
Row 3: *Spherical aberration*: The results from the failure to completely parabolize a mirror or lens. Mirrors are produced with a spherical form and then parabolized. Sometimes the process is incomplete.

Row 4: *Turned down edge*. Resulting from a failure to properly parabolize a mirror. The focal length near the edge of the objective is longer than zones nearer to the center.

Row 5: *Zones*. This is a variation of the turned down edge. Again, the focal lengths of various concentric zones on a mirror or lens are not the same causing light to be defocused at certain points in the image resulting in dimming and, in comparison, brightening in other zones.

Row 6: *Perfect optics*. Here we see an in-focus diffraction pattern with 84% of the light in the central peak and just under 16% in the first diffraction ring. Not be confused with the consequences of the turned-down edge. In perfect optics, the diffraction images are the same inside and

outside of best focus. With turned-down edge, the asymmetry of inside and outside focus images is quite noticeable.



Unless you are a telescope maker, if you have a poorly made objective, you will have to live with these problems. The best way to avoid having to live with such problems is to make certain that your telescope is performing up to expectations when you purchase it. If it does not, then the best thing to do will be to return the telescope while under warranty to the distributor and ask for a different telescope.

40. BALANCING YOUR TELESCOPE

No matter the type of telescope and mount you have, there is one critical concern for viewers – that the telescope be balanced. This is of particular concern if you wish your telescope is of a “push to” kind with un-lockable friction pads and you want it to remain in place after you’ve directed it to a particular location in the sky. There is nothing worse than looking for a faint object, finding it, and then rapidly losing it as an unbalanced telescope swings out of place after one’s hand is removed. The problem is readily resolved by balancing your telescope.

German Equatorial Mount (GEM). Most high-quality telescopes will arrive pretty much in balance – at least when the counterweights are set into proper position. However, when observers move things about or modify a telescope by switching to a heavier class of eyepieces or putting a new finder into place, the telescope becomes quickly unbalanced. Every amateur should therefore know how to balance a telescope regardless of the type.

To be properly balanced, a GEM’s balance must be ensured along two rotation axes – the polar (or right ascension axis) and the declination axis – if the telescope is to remain in place after it is moved to position. This will also reduce the amount of load the motors will have to move in order to slew or track the stars.



Steps for Balancing a Telescope on a German Equatorial Mount

It is important to balance the *declination axis first!* A common error is to reverse these steps.

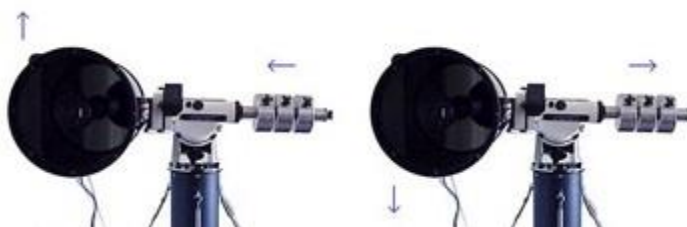
- 1) Begin by loosening the polar axis and rotating the unit until the declination axis connecting the telescope and the counterweight bar is parallel to the ground as shown to the right. Tighten the clutch mechanism on the polar axis so the declination axis remains horizontal. Carefully loosen the clutch of the declination axis and see if the telescope is front-heavy or rear-heavy. Push the front of the telescope up and down gently to see if it will stay in place when it comes to a stop. If the front or back continues to fall or rise, then the telescope is ether front-heavy or back-heavy respectively. This imbalance normally can be corrected by moving the telescope forward or backward in its carriage.



- 2) Loosen the clutch on the polar axis. Move the telescope around this axis until it is directly over the mount and aimed north. Slide the telescope forward or backward in its carriage to achieve proper balance. If the telescope is front-heavy, then slide the tube backward on its mount. If the scope is rear-heavy, then slide the tube forward on its mount. Return the telescope to its former test position and retest. Continue to make small adjustments as necessary. If moving the telescope backward and forward in its carriage is not possible, then add a counterweight to the opposite of the heavy side.



- 3) Return the telescope to the horizontal position once it has been balanced in its declination axis. Slowly and carefully release the clutch of the polar axis to see if the setup is telescope- or counterweight-heavy. Be careful not to let the telescope go into “free fall.” If the arrangement is telescope heavy, the telescope could crash into the pier. If the arrangement proves heavy toward the counterweight end, slide the counterweights up the shaft toward the telescope. If the telescope is heavy toward the telescope end, slide the counterweights down the shaft away from the telescope.



Balancing a Telescope on an Altazimuth Mount

The procedure for balancing a telescope on an altazimuth mount is simpler than that of a GEM. When the altazimuth mounted telescope moves around its vertical axis (in the directions of the red circle in the figure shown below) it cannot be out of balance. When imbalance occurs, it always occurs in the horizontal axis that allows the telescope to be aimed either higher or lower in the sky. If the telescope is front heavy, either weight must be removed from the front or added to the back. If the telescope is back heavy, either weight must be added to the front or removed from the back.



Because friction plays an important role in maintaining the balance of a telescope in the Dobson type mount shown here, it is important to address the problem of friction. Ideally, when a telescope is pushed to a given position, it will stay exactly where it was directed. This will not always be the case with a Dobson mount as stresses build up under friction and distort the wooden support box like a spring. Once this stress – caused by moving the telescope – is released, the telescope springs backward driving the telescope off target. It is therefore very important in this type of mount that the surfaces on which the telescope glides are of very low friction. This low friction situation will then require good balancing in the vertical direction.

41. POLAR ALIGNING AN EQUATORIAL MOUNT

Polar alignment is the process whereby the polar axis of a mount is made parallel with Earth's rotation axis. It is necessary if one uses a German equatorial mount (GEM) or a fork mount on a wedge and intends to track the motion of the stars with rotation about a single axis of that mount. When Earth's and a mount's rotation axes are parallel, it is possible for a telescope to track the motion of the celestial objects by turning about only the polar axis. If an equatorial mount is not properly aligned, then adjustments must be periodically made in both the right ascension and declination axes to keep an object centered in the eyepiece's field of view. The greater the misalignment of these axes, the greater the amount of adjustment required.

If one is casually observing and observations are not of long duration, then a marginally aligned equatorial mount will keep the object in the eyepiece's field view for a reasonable period of time before it drifts out of view. If one is using the telescope's ability to find objects one after another, then the more precisely aligned the two axes are the easier it will be to find subsequent objects.

If photographic observations are the goal, then proper polar alignment is crucial. If the telescope's polar axis is non-parallel with Earth's rotation axis, not only will objects drift out of the field of view with the passage time, but the field of view will also appear to rotate. Trying to take a time exposure of an object moving so will result in curved star trails rather than the pinpoint images for which one might be hoping.

An equatorial mount should not be used unless it is at least roughly polar aligned. If it is not, it will be next to impossible to track objects in the sky. An equatorial mount can be roughly polar aligned as follows:

1. The telescope pier is set up on either a level surface or its legs are so adjusted so that the shaft of the pier is oriented vertically, pointing straight up toward the zenith. Pier leveling is assessed with the use of a tool such as a bull's eye spirit level (best) or a tubular spirit level used along two axes 90° from each other.
2. With the inclination of the polar axis is set equal to the observer's latitude, the mount is placed upon the pier with the top end of the polar axis aimed toward geographic (not magnetic) north and the general vicinity of the North Star.

This two-step process is adequate for visual observing where each object is found by hand one after the other. If, however, a succession of objects is to be viewed using the hand screws or motor drives of the telescope after "syncing" on a star, then polar alignment must be ensured if finding new objects is to be expected.

There are several ways to polar align a telescope with varying degrees of precision. More precise methods are used with telescopes that are permanently mounted. Two of these more methods are described here: first a modern method and second a "traditional" method. Computerized goto telescopes have their own methods to compensate for misalignment and are not within the scope of this publication.

The first of the more precise methods involves the use of a polar sighting telescope. These telescopes can be used to either peer through the center of a hollow polar axis of a telescope or are precisely aligned with the polar axis in some fashion. These telescopes have an illuminated reticle, which must be rotated to match the current time, date, and geographic location. This rotation must be determined from an external source. Smartphone



applications are a convenient way to know how to make this adjustment, as they typically provide all three pieces of information. Polar alignment is then achieved by maneuvering the mount in such a way that the North Star appears in the proper position in the sighting telescope. If you have one of these sighting telescopes, see the manufacturer's instructions for use.

An even more precise approach – the declination drift method – allows an observer to get a more accurate polar alignment still. This method requires that the observer monitor the drift of selected stars. The drift of each star helps assess in which direction a telescope's polar axis is pointing away from the celestial north pole. Although the method is simple and straight forward, it requires a time and patience to complete. The declination drift method should be done only after any one of the previously mentioned methods has been completed.

To use the declination drift approach, you need to choose two bright stars. One should be in the eastern sky and one due south near the meridian. Both stars should be near the celestial equator (i.e., 0° declination). You will monitor the drift of each star – one at a time – in declination only. While monitoring a star on the meridian, any misalignment in the east-west direction of the telescope's polar axis is revealed. While monitoring a star in the eastern sky, any misalignment in the north-south direction is revealed. It is imperative to have an illuminated reticle (crosshair) eyepiece to help recognize any drift. For very close alignment, a Barlow lens is also recommended for use with the illuminated reticle because it increases the magnification and reveals any drift more clearly.

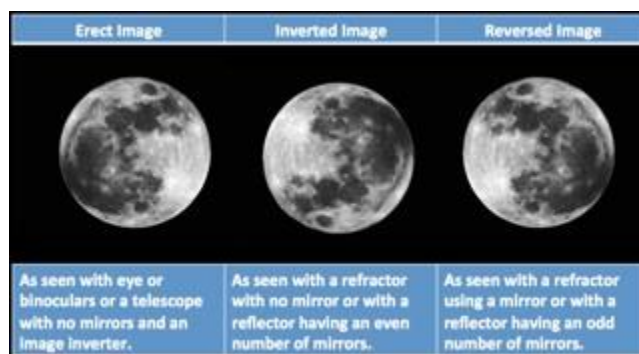
With the telescope level and facing due south, insert the diagonal so the eyepiece points straight up. Do NOT rotate the diagonal in relation to the optical tube assembly at any time during or between the following steps. (The reason will become clear momentarily.) Insert the crosshair eyepiece and rotate the eyepiece until one crosshair is parallel to the declination axis and the other is parallel to the right ascension axis. Sighting on any bright star, move your telescope manually in R.A. and DEC to check parallelism. When the telescope is moved in each direction,

the star should stay on or move parallel to each of the crosshair lines.

Next, choose a star near where the celestial equator and meridian meet. A star map, cell phone app, or a good planisphere will be helpful in making this selection. The star need not be very bright but should be within $7\frac{1}{2}^\circ$ of the meridian ($|\text{hour angle}| < 30$ minutes of right ascension) and within 5° of the celestial equator ($|\text{declination}| < 5^\circ$). Center the star in the center of the eyepiece's cross hairs and monitor the motion after turning off the motor drive if one is being used. Look for any drift in declination as the star moves out of the field of view.

- If the star drifts south relative to the left-right crosshair, the polar axis is too far east.
- If the star drifts north relative to the left-right crosshair, the polar axis is too far west.

Now, keep in mind that in a telescope the prime focus image produced by the optical system (either lens or primary and secondary mirrors in combination) will be inverted (flipped top to bottom and from side to side). Also keep in mind that this orientation will change when a diagonal is introduced. See in the accompanying diagram what happens when an extra mirror is introduced.) A telescope with a diagonal mirror will produce a reversed image where north is up, and south is down.



To get straight in your mind which way is which in your eyepiece, move the telescope northward and then southward in declination and note the direction the star appears to move in the eyepiece. Take notes or draw a sketch. It's very easy to get confused on this.

Make the appropriate adjustment to your telescope's polar axis to eliminate drift. If you make a correction and the drift gets worse but on the same side of the crosshair, the chances are very good you corrected in the wrong direction. If the drift switches sides of the crosshair, then you've probably over-corrected. Repeat the process until you are sure you have eliminated the declination drift.

Once you have eliminated all the drift, aim the telescope to the star in the east-southeastern sky. Again, do NOT move the diagonal in any way relative to the optical tube assembly. The star should be about 30° above the horizon and within 5° of the celestial equator. (A star nearer

the east horizon still is preferred, but refraction can also cause problems.) NOTE: If the eastern sky is blocked, you may choose a star in the western sky, but you must reverse the polar high/low error directions given below.

- If the star drifts south relative to the up-down crosshair, the polar axis is too low.
- If the star drifts north relative to the up-down crosshair, the polar axis is too high.

Again, make the appropriate adjustments to the polar axis to eliminate any drift. Repeat as necessary. Unfortunately, the latter adjustments interact with the prior adjustments ever so slightly. So, repeat the process again to improve the accuracy checking both axes for minimal drift. Once all drift has been eliminated, the telescope is accurately aligned.

Careful drift alignment is capable of achieving excellent polar alignment – within tens of arc seconds of the celestial pole – provided adjustments on the mount are capable of that kind of precise movement. All this comes at the cost of time. It can take a half hour or more to achieve precise alignment.

Bear in mind that other factors affect your polar alignment. For instance, settling of the tripod into a grassy lawn or a careless bump in the dark can adversely affect your ever so carefully aligned polar axis. Most polar alignment scopes are capable of good alignment to within a few arc minutes. This is almost always good enough for visual observation, and generally good enough for most astrophotography applications. There's nothing more frustrating than spending an hour minutes getting a great polar alignment, and then tripping over the mount's power cord. Don't let polar alignment spoil the night. Perfection is not necessary. Generally speaking, good enough often is good enough.

Cautionary note: This method works well for objects in either the eastern or western parts of the sky. When a German equatorial mount is "rolled over" the meridian, the telescope can be out of alignment once again due to orthogonality error. (The telescope's optical axis and the mount's right ascension axis are not parallel.) This error typically requires shimmiing of the telescope reducing the misalignment in right ascension by half and then realigning the polar axis.

SUGAR GROVE OBSERVATORY:

Club members working with volunteers constructed Sugar Grove Observatory in 2000. It is a 3-story domed structure that today houses several telescopes on the highest level, a work space on the middle level, and a "welcome center" on the ground level. TCAA members who qualify for the use of the observatory (normally by completing this *Introduction to Amateur Astronomy* course) will be provided with a sub master key (a key holder fee applies) that will allow for open access to SGO. Members may use all three floors of this structure in their pursuit of the hobby of amateur astronomy.

42. Operating SGO's 10' Ash Dome

SGO is capped with a 10'-diameter rotating dome with a shutter that can be opened and shut. The shutter opens providing an unobstructed view of the heavens from zenith to horizon. The shutter cover has two sections, a short lower section and a long upper section. Both should be opened when observing.

To Open the Sliding Upper Dome Shutter: If necessary, obtain the crank shaft that looks a bit like a shepherd's hook hanging in the stairwell just before entering the last flight of steps into the dome. Use the crankshaft to open the dome shutter. Be sure to keep the crank shaft is roughly in line with the rotational axis of the eye on the gearbox while turning to minimize wear. Don't stand directly underneath the eye to crank the slit open as this produces wear on both the hook and the eye (not easily replaced). Return the crankshaft to storage during observing.

To Open the Lower Drop-Out Shutter: A hand crank for

raising and lowering the drop-out shutter is mounted on the right side of the dome slot. The drop-out shutter can be lowered using the crank, but only after the upper dome cover has been moved up enough to free the watertight flange and seal of the drop-out shutter. The drop-out shutter does drop all the way down to horizontal without contacting the roof so that the dome can be rotated fully without concern of the shutter contacting the roof.

When the dome slot is fully open, the CPC 11" telescope can point from all the way down to the horizon to 15° beyond the zenith giving an unobstructed 105° view. The drop-out shutter need not be opened if viewing will be focused on the upper portion of the sky (say 30° above the horizon or more). The drop-out shutter may be left in place to be used as both a wind and light screen if preferred.

To Rotate the Dome: A left-right control switch is used to move the dome in clockwise and counterclockwise directions. After turning on the power switch, throw the control switch to the left if you want to move the dome slot

to the left, and right if you want the dome slot to move to the right. Always allow the dome to come to a complete stop before reversing the direction of its motion to avoid damage to the drive mechanism.

To Close the Shutter: If open, close the lower drop-out shutter first. When closing the drop-out shutter, make sure that the upper lip contacts the dome but do not over tighten the hand crank. If the top part of the drop-out shutter does not contact the dome, the upper slot cover will not slide down over the lower shutter's flange and seal and might cause damage.

Next, close the upper sliding shutter just the opposite of the way it was opened – keeping the crank shaft parallel to the rotational axis of the gearbox eye to reduce the wear

on the hook and eye mechanism. Don't compress the seal between the dome slot covers too tightly to avoid damaging the seal. When finished, you may return the crankshaft to its storage location or leave it in place for the next observer.

To Park: Ash Manufacturing Co. suggests that when the dome is not in use the shutter should be turned into the prevailing wind. This practice minimizes the possibility of blowing dust, fine snow, or driving rain from entering the dome. It is best therefore to direct the dome shutter toward a westerly direction when in parked position. Southwest might be best during the summer and northwest during the winter, and west during spring and autumn. Avoid placing any opening in the dome over the motor to avoid damage due to possible leakage.

43. Operating SGO's Celestron CPC 11" Telescope

The following steps essentially constitute a cheat sheet for using the CPC 11" telescope. Please follow these procedures when preparing to use SGO and starting up the CPC 11" telescope. Nothing can substitute for a detailed knowledge of how the mount works. To better understand the mount and to take advantage of the many features not included here, download the Operator's Manual at the following URL:

https://s3.amazonaws.com/celestron-site-support-files/support_files/CPC-Master.pdf

1. Turn on lights in dome.
2. Open dome slot, top and bottom.
3. Power up dome rotation motor.
4. Remove dust cover mounted on front of the telescope.
5. Turn on the telescope using the rocker switch at the bottom of the yoke mount. (If it doesn't turn on, check the rocker switch on the power strip; someone might have turned it off.)
6. Turn on Telrad finder.
7. Press **ENTER** on hand control to begin. (All future commands refer to the hand control.)
8. Use key 6 or 9 to scroll up or down a set of offerings and stop at **Auto Two Star**
9. Press **ENTER**
10. Set time hh/mm/ss using the number pad; be sure to use a 24-hour format (e.g., 8 PM = 20 hours) Use **UNDO** to move backward if necessary.
11. Press **ENTER**
12. On **Daylight Saving Time** press **ENTER** (If not Daylight Saving Time, the use the 6 or 9 key to go to **Standard Time** then press **ENTER**.)
13. On **Central USA** press **ENTER**
14. Set date mm/dd/yyyy using the numeric keypad. Use **UNDO** to move backward if necessary.
15. Press **ENTER**
16. Use the 6 or 9 key to scroll to first star to be used for alignment. (You need to know and be able to find this star in the sky.)
17. Select for instance Arcturus (not suitable for winter).
18. Press **ENTER**
19. Use the up-down, left-right arrow buttons on the keypad to slew telescope to Arcturus (or other). When found in the inner ring of the Telrad (and supposedly in a low-power/wide-field eyepiece of the telescope), press **ENTER** to change from slew rate (fast) to guide rate (slow).
20. Starting with the star in the lower left "corner" of the telescope eyepiece, center the star and press **ALIGN**. (This approach is important because it will account for any gear backlash, so the telescope aims perfectly; otherwise, finding objects later could become a problem.)
21. The telescope will automatically pick a second finder star automatically, Vega in this case.
22. Press **ENTER** to accept Vega as second calibration star and watch telescope slew to this star.
23. Using the left-right, up-down arrow keys, center Vega in the Telrad and press **ENTER** to begin guide rate

24. Starting with the star in the lower left "corner" of the eyepiece, center star and press **ALIGN**.
25. The telescope responds with **Align Success** (If not, you made a mistake; start over.)
26. Turn off the Telrad; you'll no longer need it.
27. Press **UNDO** until the hand controller reads **CPC Ready**.
28. Find first object, say M5, by press M (key 1) and then 005. (Note that some keys have double functions determined by when they are pressed.)
29. Press **ENTER** and watch as telescope slews perfectly to M5
30. To move to next object, say M78, press **UNDO** and hand controller reads **CPC Ready**.
31. Press M (Key 1) followed by 078 and press **ENTER**

Follow this routine until you have completed observing. When finished, press **UNDO** until hand controller reads **CPC Ready**. Press **RATE** followed by the 9 key (fastest). Using the arrows, point the telescope to the southern horizon, install the dust cover, and power down. Make sure the Telrad has been turned off. Cover telescope with the blue tarpaulin. Close dome. Power off dome motor and turn off lights. Lock observatory upon exit. Phone Carl Wenning at (309) 830-4085 if you have any problems or questions.

44. Personal, Observatory, and SGNC Safety

Since the beginning of the TCAA's observations at SGNC in the late 1990s, no one has ever had a serious personal run-in with safety concerns. There have been no thefts or assaults, and the only perceived threats have been skunks, opossums, raccoons, deer, and coyotes. There have been reports of Sasquatch in Funks Grove, but we have never seen them. No UFOs have dropped down out of the sky to abduct an observer as of yet. There is always a first time, so it doesn't hurt to give personal, observatory, and SGNC safety some thought.

To increase your personal security when using SGO, feel free to keep the observatory door locked when you are inside. When leaving the observatory unattended at night, please shut the door. If unattended for more than a few minutes, lock the door when you exit. Uninvited "guests" have been seen entering the SGO after midnight when the door was left unlocked after an observer stepped outside. It was a couple who had had a bit too much to drink but had no malicious intent. There can be quite a bit of traffic at SGNC sometimes, even early in the morning. It's almost always harmless, but there's a first time for everything.

McLean Sheriff's deputies who have noted the presence of our cars have stopped to make sure we were authorized to be at SGNC at night. The deputies have let us know that we are always free to phone them on their non-emergency number (309-888-5030) if we become uncomfortable with something going on out there. If there is an emergency, of course, 911 is the correct action to take.

Note that beginning in 2015 and continuing to the present day we have an infrared surveillance camera working 24/7. While this will not protect observers in any direct sense, it does provide a record of who was in and around the observatories should anything untoward happen.

If you have opened the nature center building for any

reason, it is your responsibility to lock it again. Do not assume someone else will do so. The SGNC graciously allows us use of their building as need arises at night, but that permission can be withdrawn. Be sure the lights are off, doors locked, and any trash you may have generated has been properly disposed of before leaving. Few things generate an email from the director quicker than them finding the door unlocked or trash in their building when they come in the morning after a clear night. They know where it came from.

On occasion you may find the SGNC is unlocked for no apparent reason. If none of the SGNC staff is in the building, you should turn off the lights and lock the doors assuming you have access to a building key. (Your observatory key will not work in the nature center lock.) Not only does this help keep the building secure, but it avoids the situation of them finding the building unlocked in the morning and thinking it was our doing.

When leaving the SGO for the night, check the following:

1. All equipment turned off
2. Dome slot is closed
3. Interior lights are off
4. Clean up after yourself
5. Doorknob and deadbolt locks are locked
6. During the cold months, any space heaters should be physically unplugged

The SGNC staff has let me know several times how comforting it is to know that we're often out there in the evening and at night. They're aware of the amount of traffic there, and to have us pulling night watchman duty helps them not worry so much.

45. Reserving SGO for an Observing Session

There currently is no formal way to reserve SGO for an observing session. An online approach has been tried in the past, but it resulted in failure. As a result, use of SGO is pretty much “catch as catch can” and use is on a first-come, first-served basis.

However, in order to reasonably ensure its use, it is best to place a notice of “intent to use” SGO on the TCAA Yahoo listserv. See any recent astronomy club newsletter for details about the listserv. We encourage sharing observing time if two or more observers arrive on site at the same time.