Optimizing Observations of Deep Sky Objects

TCAA Guide #8

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ABOUT THIS GUIDE:

This *Optimizing Observations of Deep Sky Objects* guide – the 8th in a growing number of such TCAA Guides – was first published as a 3-part series of articles by that name appearing from February through April 2009 in ***The OBSERVER***, the newsletter of the Twin City Amateur Astronomers of Bloomington-Normal, Illinois. A subsequent article, *Limiting Magnitude of a Telescope*, was added to this group after it was published in the November 2010 issue of that same newsletter. Additional content about the use of go-to telescopes and Astronomical League observing programs, was added to bring this Guide to completion.

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, a 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 continued to teach physics and physics education courses for an additional seven years. He also taught astronomy and physics lab science almost continuously at Illinois Wesleyan University from 1982 to 2001. He fully retired from Illinois State University in 2014 after nearly 40 years of university-level teaching.

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. In 2017 he was recognized by the Astronomical League with the Mabel Sterns Newsletter Editor Award. He is a lifelong honorary member of the TCAA and is a member of its G. Weldon Schuette Society of Outstanding Amateur Astronomers. Carl is currently Chair of the North Central Region of the Astronomical League (2017-2019).

OPTIMIZING OBSERVATIONS OF DEEP SKY OBJECTS

~ By Carl J. Wenning, Twin City Amateur Astronomers ~

A number of factors determine the quality of one's telescopic views of deep sky objects. 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 what one perceives in the eyepiece. If one is to optimize telescopic observations, then one needs to understand various factors interact to produce the best (and worst) telescopic views. To a considerable extent, this Guide is a primer on how telescopes work, so don't be surprised to be reading about such things as magnifying power and so forth.

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 2800*mm.* When used with an 18*mm* eyepiece, I get a magnifying power of 2800*mm* ÷ 18*mm* = 156X; with the use of a 32*mm* eyepiece, I get a magnifying power of 88X. 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 that 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 eyes pupil is coincident with the eyepieces exit pupil. If the diameter of ones fully dilated eye pupil is less than the telescopes 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 7.5*mm,* whereas someone who is 70 years of age will have a dark-adapted pupil diameter on the order of 3*mm.* A simple formula relating average pupil diameter of the eye to the adult observers age (≥ 20) is given as follows:

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

Hence, in my case (65 years old) selecting a low power eyepiece-telescope combination that produces an exit pupil of greater than about 3.5*mm* 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 (4.2*mm* x 10) or 42*mm.* Using an eyepiece in this range (say a 40*mm*) 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 40*mm* 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 (70^2). 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 nebulas, 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:

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

So, by this criterion the optimal highest power for my 11” telescope will be approximately 103X (6.2 x 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 27*mm* (2800*mm*/103X) 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.

Eyepiece Filters

While telescope aperture and magnifying powers are critical components for optimizing views of extended deep sky objects (dark, emission, reflection, and planetary nebulas 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 nebulas 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.

Dark Adaptation

This guide 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 others whose eyes are 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.

Eyes typically take about 30 minutes to reach most of their dark adaptation, but observers will notice increased 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. It is best, therefore, to expose one's eyes to bright sunlight prior to a night of observing if hoping to optimize observations of deep sky objects.

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.

Averted 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 say 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.

The Atmosphere

Heightened sky transparency will also increase the visibility of extended deep sky 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 sky objects that are most often diffuse.

Twilight

Amateur astronomers are often anxious to begin observations of celestial objects as soon as possible after sunset. However, in order to optimize observations of deep sky objects, observers should wait until the end of astronomical twilight when sunlight is no longer illuminating the night sky. This occurs at astronomical dusk when the sun's center is 18^{o} below the western horizon. Other types of twilight (civil twilight when the sun's center 6^{o} below the horizon and nautical twilight when the sun's center is 12^{o} below the horizon) are not conducive to obtaining the best views of deep sky objects. Both morning and evening twilight intervals should be kept in mind during observing. Astronomical dawn begins when the sun's center is 18^{o} below the eastern horizon.

The duration of astronomical twilight varies over the course of the year. The sun appears to move across the sky at a rate of about 15 degrees per hour (an average of 360° per sidereal day), but sunrise and sunset typically occur at oblique angles to the horizon and the actual duration of any twilight period will be a function of that angle. The more parallel the sun's apparent path is to the horizon, the longer the duration of twilight. This angle of the sun's motion with respect to the horizon changes with both latitude and time of year (declination of the sun).

In mid-northern latitudes, the duration of twilight is greatest around the time of summer solstice and can easily last two hours. The shortest duration of twilight is around the time of winter solstice. Most apps for computers, tablets, and cell phones will do the calculations to show the end of astronomical twilight for you. Nonetheless, if you want to calculate it yourself, you may use the following formulae:

Duration of twilight = $\frac{1}{15}(H' - H)$ where H' and H are defined as follows:

$$H = cos^{-1}[-\tan(\phi) * \tan(\delta)]$$

and

$$H' = cos^{-1}\left[\frac{-\sin(18°) - \sin(\phi) * \sin(\delta)}{\cos(\phi) * \cos(\delta)}\right]$$

Where ϕ is the observer's latitude and δ is the declination of the sun.

The shortest duration of astronomical twilight, 1 hour and 10 minutes, occurs at the Equator, where the sun rises and sets at right angles to the horizon throughout the year. The longest twilight occurs at the poles; it lasts for about six weeks before the annual sunrise and after the annual sunset. In summer, astronomical twilight will last all night, for any place with latitude above 48.6° North.

Airglow

Experienced observers can tell you that even after the end of astronomical twilight the sky will continue to darken. This is so due to airglow. Airglow (also called nightglow) is a faint emission of light due to the de-excitation of air molecules. During the day, the sun excites the gases that make up Earth's atmosphere. After sunset the gases naturally de-excite, giving off light as they do so. As a result of airglow, the night sky of Earth will never be completely dark. Fortunately, the effect of airglow is considerably reduced an hour or two after the end of astronomical twilight.

Have you ever noticed that when you pack it in after an evening of viewing the sky seems darker than before? I've noted that nearly every time I've gone out observing. It's because airglow is much reduced from earlier in the evening. Also, do you know that saying, "It's darkest before dawn?" That saying is true and stems from the airglow phenomenon. In the hour or two before the beginning of astronomical dawn, the sky truly is at its darkest, all other things being equal.

Skyglow

Skyglow is the result of light pollution. Due to uncontrolled outdoor illumination at night, the brightness of the night sky in a built-up area will result is poor observing conditions for observing deep sky objects. We are all familiar with the problems presented by light pollution. Perhaps the best way to avoid skyglow today is to view far from light-polluting communities – the farther the better. Those with restricted access to a sky free from skyglow should consider the use of light pollution filters with their telescopes. Commercially available skyglow filters block the most common wavelengths of light pollution for increased contrast and improved views. Such filters can significantly improve the quality of one's deep sky observations so long as observations are made from locations that are only moderately light polluted.

Zenith Distance

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 be 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. Personally, I rarely observe objects when they are less than 30 degrees above the horizon (or have a zenith distance of greater than 60 degrees).

To get the best views of extended deep sky objects, be certain to view them when they are higher up in the sky. The best views occur when an object is observed when near the zenith – the overhead point in the sky. Efforts to obtain the best possible view when objects have a minimum zenith distance. This will occur when an object is crossing the observer's meridian moving from east to west.

Telescope Optics

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 assemble and that following on a secondary mirror.

Limiting Magnitude of a Telescope

With the 2012 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 through a telescope at zenith. 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. In many ways I have been surprised by these findings. 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?" That is, how faint a star can I see with the telescope under varying conditions? I have been stunned by the difference between the 11- and 18-inch telescopes. The 11-inch matches very nicely with the star maps generated by my iPad's *SkyVoyager* 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 a only a few stars might be found in an given 11-inch field, many times more stars can be seen in the same 18-inch field of view. 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 great number of factors affect the limiting magnitude of a telescope.

<u>Objective aperture:</u> Clearly, the larger a telescope's objective lens or mirror, the more light it is able to 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. The light gathering ability is proportional to the areas of the mirrors and, stated in a different way, to the square of the diameter.

$$\text{LPG}(18'')/\text{LGP}(11'') = (18''/11'')^2 = 2.68$$

The 18-inch objective (not considering the secondary obstruction and other factors) gathers about 2.68 times the amount of light gathered by the 11-inch objective all other things being equal. This aperture difference alone will provide views of stars just over one magnitude fainter ($2.512^{1.01} = 2.68$).

<u>Type of telescope:</u> Reflecting telescopes have a mirror for an objective. Most reflectors (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. 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. Lens 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.

<u>Mirror reflectivity/lens transmittance:</u> The reflectivity of the mirror and the light 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 sequence would reduce the reflectivity to only 77% (0.88^2). Modern "enhanced" coatings on primary mirrors is typically 95% reflective and secondary mirrors is 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” – both mirrors and lenses (including diagonal, eyepieces, and glasses if any) – are assumed for the purpose of this article.

Magnification: The effect of magnification on limiting magnitude is great. My recent experiences with observations of the planetary nebula Pease 1 in globular cluster M15 show that magnification is also a consideration. Higher magnification (e.g., 230X) with the 18-inch shows disproportionally more stars than are visible at lower magnification (e.g., 55X). The higher magnification reduces the brightness of the background, making fainter stars visible. The higher contrast makes more stars visible. 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. So, limiting magnitude is clearly dependent upon magnification as well as aperture.

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 6.5. Twilight glow from the sun and airglow can also contribute to a less than ideal sky darkness.

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, 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.

B-V color index (CI) of a star: CI is 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.

Atmospheric seeing: Seeing can be measured by determining the diameter of a star image. Stars, while large objects, are so distant that they 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 rather than point sources. Disks of light can be magnified, thereby reducing their apparent 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.

Experience of the 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.

Liming 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 more modern considerations.

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

Here is what I have calculated to be the liming magnitudes of my Obsession 18-inch telescope depending on varying conditions using the following definitions:

“Poor conditions” consist of a 35-degree 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-degree 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-degree 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.

Magnification	Poor Conditions	Typical Conditions	Optimum Conditions
55X	12.9	13.9	15.0
230X	15.1	15.9	16.6

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

So, 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: $M_L = 3.7 + 2.5 * \text{Log}_{10}(D^2)$ where D = aperture in mm and taken from *Visual Astronomy for the Deep Sky* by Roger N. Clark; method 2: $M_L = 9.5 + 5.0 * \text{Log}_{10}(D)$ 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. For additional information about limiting magnitude, see the article by Bradley Schaefer who first calculated the limiting stellar magnitude an observer can expect to see with various types and sizes of telescopes, and under various conditions. The process is fully described in *Sky & Telescope* magazine, November 1989, page 522.

Go-to Telescopes

Two recent developments have more strongly influenced my “ability” to observe deep sky 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 a fellow club member who used his 8-inch Meade go-to telescope and fell in love with the concepts of “auto finding” celestial objects. Thanks in part to this observing companion, I moved to the next stage of amateur astronomy – but more about that later.

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 TCAA’s 12-inch Meade LX200 go-to telescope for the first time, 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 sky 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 sky objects of every type are now eminently more accessible. I now can spend much more time observing deep sky 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.

So, folks, there you have it, how to optimize observations of deep sky objects, and knowing what the limiting magnitude is of those objects you can observe with your telescope. Now, let's start putting this knowledge to use.

Astronomical League Observing Programs

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 (and so on and so forth)! Neither would I have found curious individual objects such as comets, asteroids, quasars and deep red carbon stars. One can even complete an informal 300-object observing program known as the Astronomical Bucket List prepared by the author, Carl Wenning. You may contact him at carlwenning@gmail.com if interested in completing the unofficial observing program (no certificates, no pins).

To immerse yourself in one of the Astronomical League's many excellent observing programs. Go to the following URL to find out more about them: https://www.astroleague.org/observing.html

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[*] Note that a go-to telescope may not be used with the Astronomical League's Messier observing program.