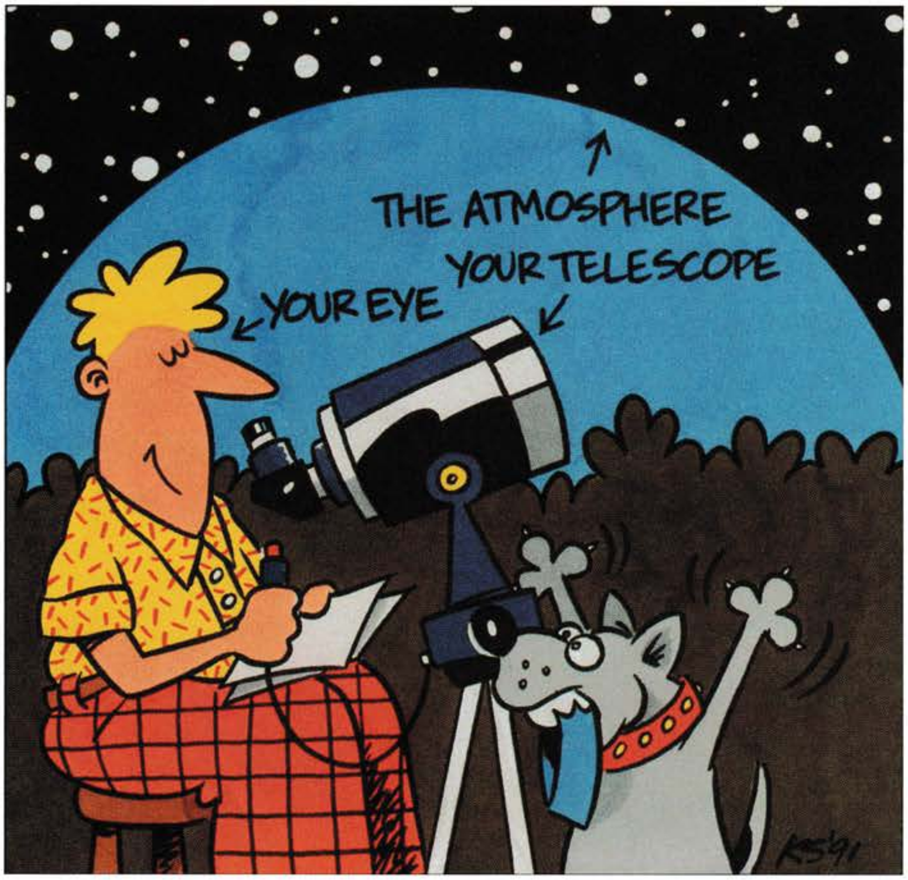


The complete observing experience involves several impediments that lie between the starry heavens and the view we have of them. These include the atmosphere, telescope optical system, and our eye. Cartoon by Kevin Sartoris.

Choosing Your Telescope's Magnification

How high can you get? How low can you go? The answers depend on many factors that combine to give each telescope a useful magnification range. This range is not fixed, however, and depends on the nature of eyesight, the telescope's aperture and optical design, atmospheric conditions, and even the type and size of the object looked at.

Consider the complete viewing experience: starlight passes through the atmosphere, through the telescope, and finally into your eyes. Each segment of the journey plays a role in determining the magnification range to use on a given night with a given telescope. Let's take up the segments separately.

OUR EYESIGHT

Eyesight is an engineering marvel. Think about it. Our eyes have an automatic iris, automatic focus, an aspheric lens, a curved image surface, a chemical image intensifier, a windshield washer-wiper, and a lens cover, all as standard equipment. And this is without mentioning the wonder of stereo vision!

While our eyes are not perfectly color corrected, our brain processes out the errors. Other defects vary from individual to individual. Fortunately, the common ones can all be compensated when one uses a telescope.

Among the most prevalent defects is astigmatism, which can be ameliorated with eyeglasses or by using only the small central area of our eye's pupil. To see an example of this, make a diamond-shaped aperture by pressing your thumbs and forefingers together. The harder you push them together, the smaller the aperture will become. Now place this opening close to your eye. You will probably see some improvement in resolution and depth of focus. (You may look silly to your companions at the dinner table, but it's great for reading the menu when you forget your glasses.)

Those who suffer near- or farsightedness can simply remove their eyeglasses to use a telescope, since the instrument can be focused to compensate for either defect. Floaters, those bits of debris in our eyes, are mainly a problem when we use magnifications that produce very small exit pupils that accentuate their visibility.

OUR TELESCOPES

There are six important factors to consider with a telescope. The first is **magnification,** and by this I mean angular magnification. We see the universe in terms of angles. A 50-power telescope will make the ½° disk of the Moon appear 25° wide.

To achieve low magnification, use long-focal-length eyepieces. Telecompressor lenses can shorten the effective focal length of some telescopes, lowering the magnification of a given eyepiece used with that telescope. High magnifications can be obtained by using short-focal-length eyepieces.

Barlow lenses (which can even be "stacked") allow even a short-focal-length telescope to achieve absurdly high magnifications. But beware: these high magnifications may not be what we want! The 600-power, 2.4-inch "department store" telescope is a prime example of a malicious turn-off to budding amateur astronomers — the resulting field at that high magnification is too small, too dim, too fuzzy, and too shaky to be of much use. I'll discuss optimum magnification later.

F/number is of little importance visually. A "fast" telescope implies a short focal length and a large field. Fast, however, is a term borrowed from photography (an f/5 telescope can take a photograph with one-fourth the exposure time of an f/10 instrument). *Visually,* well-made fast and slow telescopes of the same aperture have no difference in image brightness or resolution.

Many binocular users know this already. While aperture, magnification, and exit pupil are the key specifications for binoculars, manufacturers *never* give the f/number of the objective as a specification. It means nothing as far as visual image brightness is concerned! I find that photographers have the most difficulty understanding this concept, because their experience that a faster f/number means brighter images on film and in the view-finder is so ingrained.

Field angle is another confusing subject. The *true field* of a telescope is the amount of actual sky we see in the eyepiece. It is determined by the field-stop diameter (the ring inside the front of the eyepiece that defines the edge of the field) and the focal length of the telescope.

Here's some information on typical telescope maximum fields for reference:

Focuser size (inches)	500-mm focal length	2,000-mm focal length
1¼	3.1°	0.8°
2	5.3°	1.3°

Eyepieces of very long focus may use the inside edge of the barrel as a field stop. This is why 2-inch eyepieces can have much larger true fields than 1¼-inch eyepieces. The inside diameter of a typical 2-inch barrel is 1.7 times larger and has three times the area of the smaller barrels. Many eyepieces have field stops that are accessible for measurement by calipers. Others have field stops between the lens elements; such a stop's size cannot easily be used to determine the true field.

Regardless, you can find the true field of any eyepiece-telescope combination by the star-drift method. Point the telescope at a star near the celestial equator and, with the drive turned off, time the passage of the star centrally across the field. Since equatorial stars appear to move 15 arcminutes for each minute of time, you simply multiply the drift time in minutes of time by 15 to find the true field angle in arcminutes.

A rough approximation to the true field is obtained by dividing the apparent field of the eyepiece by the magnification. It's rough because eyepieces do not magnify linearly across the field, and a factor involving geometric "pincushion" distortion must be applied. Needless to say, this is usually known only to the designer. So use the star drift to determine true field accurately.

Apparent field is the angle perceived by your eye when the field stop is seen through the eyepiece. If you want to know which of two eyepieces is likely to have a larger apparent field, hold one up to each eye as if you were looking through binoculars. Position them so the field circles overlap, and it will be very clear which circle is larger.

Exit pupil is the image of the objective formed by the eyepiece. It's where you place your eye to view the entire field. Its diameter is equal to the objective diameter divided by the magnification. Binocular makers indirectly specify the exit pupil by always specifying the magnification and the aperture. The exit pupil may also be defined by the objective's f/number. For example, an eyepiece of 35-millimeter focal length, when used on an f/5 telescope, will give a 7-mm exit pupil. There is no single best exit pupil for low power or high power. As we shall see, it depends on many factors.

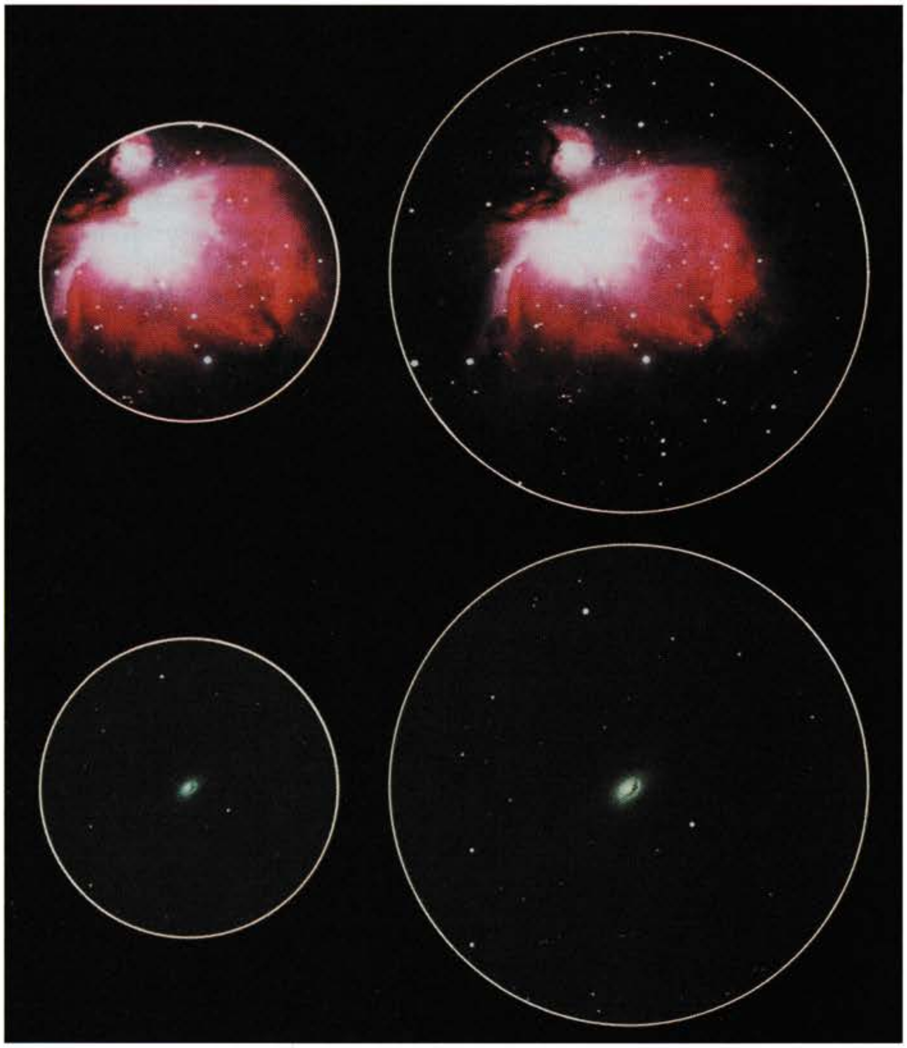
Resolution can be defined in many ways. By tradition, telescope manufacturers use the *Dawes limit* as a specification. During the 19th century in England, Rev. William R. Dawes observed with small refractors and found that he could just distinguish the components of faint double stars of equal magnitude when their separation was equal to 4.56 arcseconds divided by the aperture in inches. Of course it's just a guideline, since much larger or smaller scopes differ somewhat in performance. Furthermore, resolution is poorer when double stars have components of differing magnitudes.

The Dawes limit tells us nothing about the effects of contrast on resolving planetary details. It also ignores the fact that telescopes with apertures larger than about 9 inches can seldom achieve their theoretical ½-second or better resolution because of bad atmospheric seeing. Also, if the naked-eye resolution is 1 arcminute (for people with the best eyesight), you only need 120 power to see the resolution limit imposed by either Dawes' formula or the atmosphere. In practice, two or three times that magnification is more comfortable. Any magnification is possible, but I don't believe extraordinarily high powers reveal more than using 300× to 500× on any telescope.

Aperture gain will give you an idea of the faintest stars visible with a telescope. For example, the area gain of a 70-mm aperture over our eye's 7-mm aperture is 100 times. That's equal to a five-magnitude difference, so if 6th-magnitiude stars are visible with the naked eye, then 11th-magnitude stars should be seen in the 70-mm telescope. This reasoning ignores light loss in the optics.

THE ATMOSPHERE

When a deep blue, breezy afternoon turns to a dark and clear night, with stars



The large *apparent field* (the angular "opening" perceived by the eye) of modern eyepiece designs has interesting implications for observers. Compare these examples of eyepieces that have apparent fields of 50° *(left)* and 80° *(right)*. The upper images show the difference between eyepieces that have the same focal length and thus the same magnification on a given telescope. Here the larger apparent field translates into a larger true field showing more area of sky. The lower images cover the same field, but this is achieved by using a shorter-focal-length (higher-magnification) eyepiece with an 80° apparent field.

twinkling brilliantly, we have a night of high *transparency*. The dark sky and high contrast afford ideal conditions for viewing galaxies, nebulae, and faint stars. Unfortunately the other side of the coin — air turbulence — is often present. On such nights the *seeing* is often poor. A small telescope shows twinkling stars jumping about playfully, but large apertures average out the motions, giving us steady blobs. Many novice observers are unaware that transparency and good seeing usually avoid one another. The hazy summer doldrums often produce the best seeing and are excellent for revealing double stars and planetary details.

Another factor we must all confront is encroaching light pollution combined with atmospheric haze from industrial pollution. While everyone should pitch in to make our planet cleaner, the immediate answer for an observer is to pack the car and travel to a remote site. It is no coincidence that very portable telescopes, big and small, are becoming more popular, and that star parties are popping up at dark-sky sites all over the country.

OUR TARGETS

Before selecting a viewing magnification, consider carefully what it is you are going to be looking at. If you want to see small and faint galaxies, globular clusters, and faint stars, there is no substitute for aperture. Years ago, big heavy mirrors and long focal ratios were the rule. Eyepieces back then couldn't handle fast f/ratios well. Today, with modern, highly corrected eyepieces and coma correctors, large and compact Dobsonian telescopes can perform as never before, and they're really portable. With 13- to 25-inch Dobsonians, you can use all the power the atmosphere and optical quality will permit. Subject brightness is rarely a limit.

A subject's contrast is sometimes as important as its brightness. Often small refractors outperform larger reflectors because of superior contrast. Increasing the magnification of any telescope will reduce the size of the exit pupil and darken the background sky. This is why the faintest stars are always seen best with moderately high magnifications. The contrast of extended objects such as galaxies and nebulae is fixed relative to the sky background and only looks better as you boost magnification because details become more visible. In general you can increase the magnification to darken the sky (the field stop is a good reference for "black") as long as there is still sufficient sky showing around the object of interest to provide contrast. This appears to contradict the old adage about using big exit pupils when viewing nebulae. Don't worry; trust your eyes and experience.

Resolution — how much do you need? Most large reflectors exhibit better resolution when used with an off-axis aperture mask. This is because you can wait with frustration for those magic, fleeting moments when the atmospheric seeing allows high-resolution glimpses with a large aperture, or you can reduce the aperture and trade off some resolution for much more time when the view is satisfying. Once again, a small aperture gives a sharp image that jumps around in bad seeing, while a large aperture often averages the image into a fuzzy blob.

If you consider astronomical viewing as a supremely rewarding, aesthetic experience, then the universe is your painting and your telescope is the palette. Frame the subject properly. Open clusters in particular can be blown out by too much power — you may not even recognize what you're viewing. I don't think seeing Alcyone and a few stars in the Pleiades at 300× compares with a good sharp view at 20× to 60×. Leave plenty of breathing room around the subject so it appears in context with its surroundings. One advantage of a short-focal-length telescope is that you have field to spare for all your framing needs. You can always go up in power with these instruments. Long-focal-length telescopes, on the other hand, are limited when wide fields are needed.

Low-power subjects are those 1° or more wide. Open clusters, large galaxies, diffuse nebulae, and the Milky Way star fields are examples. The Beehive Cluster is 1° across, the Pleiades about 2°, and the Hyades 5°. The Veil Nebula is great at low and high power, but the North America Nebula needs at least a 3° field to show its distinctive shape.

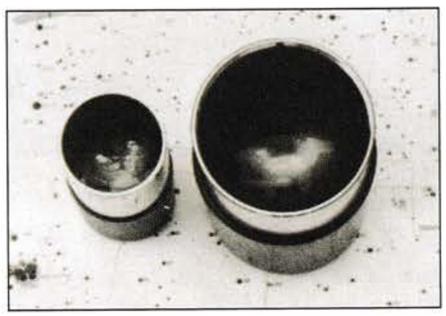
Now comes the question of how low you can go. First, consider the exit-pupil limits of refractors and reflectors. The 7-mm diameter of the dark-adapted eye's pupil seems to be a popularly enshrined value among astronomers. It is promoted by the 7-mm exit pupil of so-called night binoculars and corresponds to the exit pupil of a telescope used at a magnification of 3.5× per inch of aperture.

What we can physically fit into our eye as an exit pupil and what is appropriate may not be the same. Furthermore, they differ for reflectors and refractors. A refractor has no limits on how low the power can go and how large the exit pupil can be. This idea is heresy to many, so let me explain. Consider a 4-inch f/4 refractor with a 55-mm eyepiece. The exit pupil has a diameter of about 14 mm. Since you can use only about 7 mm, some would say that half the aperture is wasted and are you really using a 2-inch telescope. They would say you are wasting light and wasting resolution.

However, the truth is that while you are wasting potential aperture, you are *not* wasting light because your eye is fully illuminated, and you have the brightest possible image that you can ever have at that low magnification. Think of using 7 × 50 binoculars in the daytime when your eye's pupil is only 3.5 mm. Does the image appear dimmer than it does in 7 × 25 binoculars, which have a pupil that matches your eye's? Of course not. Also, the resolution reduction for a 2-inch scope compared to a 4-inch is totally invisible at that magnification.

If a 14-mm exit pupil at 8× doesn't cost you anything in brightness or resolution does it have any benefits? Sure. At 8×, a 2-inch eyepiece will produce a true field 6° or more in diameter. If you want that large a field to view the Milky Way, for example, why not have it! I'm not arguing that it is particularly wonderful to have an 8× scope, but the concept is valid.

Does the same argument hold true for reflecting telescopes? No! The central obstruction that exists with conventional reflectors places a much stricter limit on the situation. Central obstructions run from



It may seem *only* a small increase to go from a 1¼-inch to a 2-inch eyepiece barrel, but the latter has an opening 70 percent larger in diameter and almost three times the area of the former. This sets a limit on the *true field* (the amount of sky) visible with a telescope.

less than 20 percent of the objective diameter for some Newtonians, to 45 percent or more on some Cassegrain telescopes. A 14-mm exit pupil on the latter would have a black spot in its center more than 6 mm in diameter. While this is an extreme case, it points out the value of reflectors with small secondary obstructions and keeping the exit pupil to about 7 or 8 mm. Large secondaries also limit your visual performance by blacking out the center of your eye's pupil, which is the sharpest part.

The bottom line for low power is to frame the subject. In fact, the best view occurs with the highest power that comfortably includes the target object. As mentioned before, higher powers darken the background sky, reveal fainter stars, and show more detail. The resulting smaller exit pupil also minimizes the effects of eyesight defects and reduces the size of the dark spot

TELESCOPE FORMULAS

$$\text{Magnification} = \frac{\text{Objective focal length}}{\text{Eyepiece focal length}}$$

$$\text{Magnification} = \frac{\text{Objective diameter}}{\text{Exit pupil}}$$

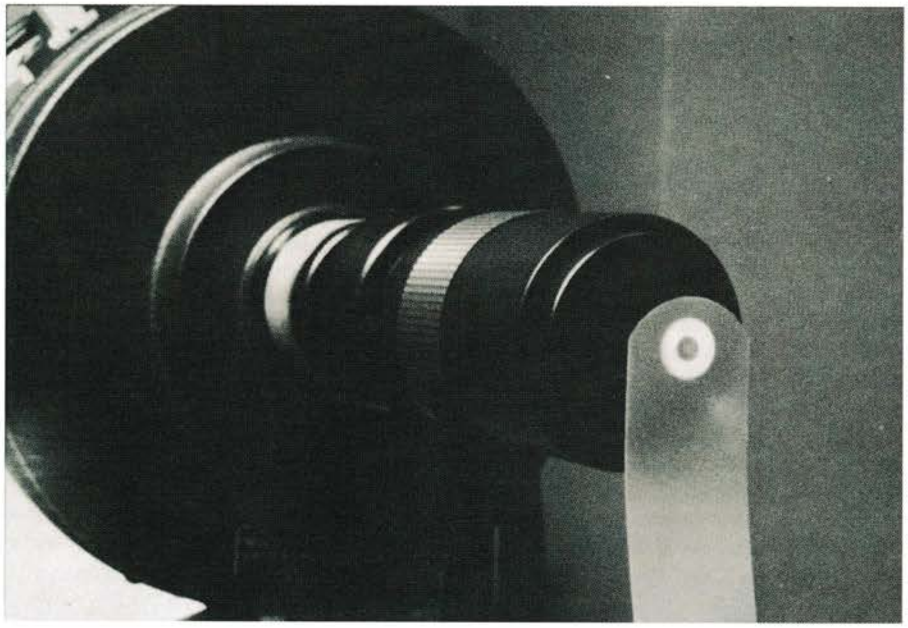
$$\text{f/number} = \frac{\text{Objective focal length}}{\text{Objective diameter}}$$

$$\text{True field} = \frac{\text{Eyepiece field stop}}{\text{Objective focal length}} \times 57.3^\circ$$

$$\text{Exit pupil} = \frac{\text{Eyepiece focal length}}{\text{Objective f/number}}$$

$$\text{Dawes limit} = \frac{\text{4.56 arcseconds}}{\text{Objective diameter (inches)}}$$

$$\text{Aperture gain} = \left(\frac{\text{Objective diameter}}{\text{Eye pupil diameter}}\right)^2$$



As explained in the text, there is no practical limit to the low magnification that can be used with a refractor. But the secondary obstruction found on most reflectors does set limits, because the shadow spot it forms in the exit pupil grows as the magnification is reduced. Consider this extreme example of an exit pupil formed by an 8-inch Schmidt-Cassegrain with a central obstruction equal to 43 percent of the aperture's diameter. A telecompressor lens and long-focal-length eyepiece give 14× magnification. While the central shadow remains 43 percent of the exit pupil's diameter, it is now 6.2 millimeters in diameter and would nearly fill the 7-mm pupil diameter of the dark-adapted eye.

caused by a reflector's central obstruction.

High-power subjects include the Moon, planets, globular star clusters, planetary nebulae, small galaxies, small open clusters, and double stars. Here the power is limited by the atmosphere, telescope aperture and optical quality, the quality of your eyepieces and Barlows, and the stability of the telescope mounting.

A steady atmosphere is a prerequisite for effective high-power observing. Look for a minimum of star twinkling and try to observe subjects high in the sky. Well-made apochromatic and fluorite refractors produce excellent planetary images, and so do traditional long-focus refractors and reflectors with relatively small diagonals. Telescopes of fast focal ratio require complex (and expensive) eyepieces and good-quality Barlows for best results. Barlows can improve image quality and provide more eye relief for comfortable, relaxed high-power viewing.

Also, don't neglect the telescope mounting's rigidity or the smooth drive that is necessary for high-powered observing. A shaky mount can ruin the benefits of an optically excellent instrument. Dobsonians are inherently stable, but they must be moved frequently at high magnifications. This situation can be minimized by using wide-angle eyepieces, which extend the viewing time before having to reposition the instrument.

When magnification gets *too* high; subjects become dim and lose contrast. They are also more affected by atmospheric seeing and any misalignments and defects in the optics. When using high power, use the "lowest" high power possible.

IMAGE SHARPNESS

How sharp can you get? As I noted earlier, Dawes based his resolution limit on his practical viewing experience. But why does a limit exist? Light consists of electromagnetic waves. Just like ripples on a pond when we toss in a few stones, light waves that interact can reinforce in some places and cancel in others. Circular telescope apertures diffract light so that it forms a series of bright and dark rings surrounding a star's image. These are most pronounced if we view the image with the eyepiece slightly inside or outside of focus.

In focus a star's image becomes a small dot with one or more faint diffraction rings around it. Imperfect telescopes and atmospheric turbulence make it difficult to see this pattern. In a perfect image the central dot, called the Airy disk, contains 84 percent of the light collected by the aperture. The first ring has about 7 percent, and the rest is distributed in successively fainter rings.

The 19th-century English physicist Lord Rayleigh established a slightly more lenient resolution limit than Dawes' for double stars. In his view, two stars are just resolvable if the center of one star's Airy disk lies in the first dark ring of the other's diffraction pattern. This Rayleigh limit equals 5.5 arcseconds divided by the telescope aperture in inches. Once you have enough magnification to see the diffraction pattern clearly, further magnification is "empty."

Experienced planetary observers use 20× to 30x per inch of aperture to see the most planetary detail. Double-star observers go higher, up to 50× per inch (which corresponds to a ½-mm exit pupil). Beyond this, telescope power and eye limitations degrade the view.

The atmosphere limits our sharpness. It is rare to find atmospheric conditions that allow *any* telescope to perform at more than two or three times the resolution capability of a good 4-inch. Sharpness is not exactly the same as resolution. Spherical aberration, defocusing, or adding a central obstruction subtracts light from the Airy disk and adds it to the diffraction rings. With a 50 percent central obstruction the Airy disk is only 10 times as bright as the first ring, compared to 50 times as bright for an unobstructed telescope. The obstructed system may still split double stars at the Rayleigh limit, but just a touch of atmospheric defocusing will really mess things up.

The shift in light from the Airy disk to the diffraction rings also reduces contrast, rendering planetary details less sharp. Planetary observers using Newtonian reflectors want the smallest possible secondary mirrors for exactly this reason. Owners of large Dobsonians find that, for the finest resolution and contrast, an off-axis aperture mask (best placed near the mirror to minimize tube currents) gives the best of all possible worlds — unobstructed, color-free images. A 17-inch mirror can have a 6-inch unobstructed aperture.

Observational astronomy is an aesthetic pursuit for most amateurs. It seems presumptuous to try to quantify how high or low we can go, given the variety of instruments, subjects, atmospheric conditions, and eyesight that exists. I think, however, that two generalizations are valid: For the best low-power views, use the highest power that frames the subject. For the best high-power views, use the lowest power that reveals the detail you're looking for.

AL NAGLER
Tele Vue Optics, Inc.
32 Elkay Drive
Chester, NY 10918

The sky is filled with objects that lend themselves to viewing with a wide range of magnifications. Consider, for example, the brilliant Pleiades star cluster, which is spectacular in a field of 1° or more in diameter. Higher magnifications and narrower fields are fine for examining the delicate wisps of nebulosity seen here around Merope and other stars. California astrophotographer Kim Zussman made this 2½-hour exposure on gas-hypered Kodak Technical Pan 2415 film with a Celestron 11 telescope. (The diffraction spikes that protrude from the brightest stars are normally not present on photographs made with Schmidt-Cassegrains, but this telescope was modified.)

COMMON TELESCOPE MYTHS

Through the years, many myths (or, if you prefer, misconceptions) have become woven into the fabric of amateur astronomy. The following is a selection that involves telescope magnification. A number of the answers described here are further explained in the accompanying text.

Myth #1: A 7 mm exit pupil gives the lowest useful magnification.

Not so! With a refractor there is no limit on the size of the useful exit pupil. Use whatever is necessary to get the field you need to frame the subject. A reflector's low-power limit is reached when the black spot in the exit pupil (caused by the secondary obstruction) becomes obtrusive.

While a 7-mm exit pupil, by matching that of the eye, does give the *brightest* views of deep-sky objects, it does not necessarily give the *best* ones. Higher magnifications, despite their smaller exit pupils, will reveal more details, maintain contrast, show fainter stars, and help bypass defects in the eye itself.

Myth #2: Exit pupils larger than 7 mm waste light and resolution.

With refractors, larger pupils do waste aperture. But the magnification is so low that the wasted aperture is of little concern: both image brightness and resolution are as great as possible at that magnification. With reflectors, however, larger pupils do waste light, but primarily because the black spot in the pupil caused by the secondary obstruction becomes larger. Both light loss and field shadowing occur with reflectors, but as with refractors there is no resolution loss because of the low power.

Myth #3: Faster telescopes show brighter images.

This is a misconception carried over from photographic use, where the fast f/ratios do mean brighter images and shorter exposures for extended objects. Telescopes with equal apertures and equal magnifications have the same visual image brightness, regardless of the objective's f/number.

Myth #4: Long-focal-ratio telescopes give higher-contrast images.

In general, refractors offer the potential for higher contrast because mirror coatings, by their nature, tend to scatter more light. But when comparing well-made, highly corrected refractors, there is no gain in contrast with instruments of long focal ratio.

Reflectors too, if well made and having the same size of secondary obstruction, will have the same contrast at the same magnification regardless of the f/ratio.

Myth #5: The highest useful magnification is 50× per inch of aperture.

What is "useful"? Although small telescopes little affected by the atmosphere may give pleasing images even up to 100× per inch of aperture, no more detail is seen than at 50× per inch. On the other hand, large instruments, more affected by atmospheric seeing, may top out at 20× or 30× per inch. In practice, a 3- or 4-inch refractor may work well at 200×, but it is rare indeed that any size instrument benefits from more than two or three times that magnification.

Myth #6: Barlow lenses degrade image quality.

There may have been some truth to this when Barlows were made with low-index glasses and not specifically designed for use with modern eyepieces. Modern, high-index Barlows actually improve eyepiece performance by reducing astigmatism at the edge of the field. Furthermore, using a Barlow reduces the effective f/number of the objective and permits using longer-focal-length eyepieces (with their longer eye relief) for high-magnification viewing.