Bring up the topic of eyepieces with a group of seasoned observers and you better be prepared for a cascade of opinions. Comments about eyepiece designs, brands, and even costs are likely to surface along with opinions about such fundamentals as what range of magnifications is important for various types of observing. So, it's not surprising that eyepieces can be a confusing subject for someone new to the hobby of astronomical observing, especially given the huge variety of eyepieces available in today's marketplace. It's been awhile since we've run a general article on eyepieces, so what follows is a bit of an eyepiece primer mixed with some thoughts on how the conventional eyepiece wisdom I learned entering the hobby many decades ago has changed over the years.

Everyone knows that a telescope provides a magnified view of the world around us, be it terrestrial or celestial. And it's the eyepiece's job to create that magnified view of the image formed by a telescope's objective. An eyepiece's three fundamental attributes are its *focal length*, *angle of view*, and *eye relief*.

The focal length determines the magnification, and every beginning observer quickly learns that the simplest way to

Some Thoughts About Today's Eyepieces

Eyepieces are just as important as telescopes when it comes to visual observing, but some of the conventional wisdom about them has changed over the years.

calculate telescope magnification is to divide the scope's focal length by the eyepiece's focal length when both are expressed in the same units. For example, let's consider a refractor with a focal length of 500 mm used with an eyepiece having a focal length of 25 mm. The magnification will be 20× (500 ÷ 25 = 20).

There are two aspects of an eyepiece's angle of view. One is the true field, which is how much of the sky we are seeing through the eyepiece. The other is the apparent field, which is how big that circle of sky appears to our eye. Using an eyepiece with a small apparent field is a bit like looking through a paper tube, while one with a large apparent field is like stepping up to a porthole and viewing a scene so expansive that the edge of the field is almost out of our conscious view.

Up until the 1980s, most quality astronomical eyepieces had apparent fields no larger than about 50°. Since then, the field has been expanding (forgive the pun), and today there are excellent eyepieces with apparent fields of 100° and more. While observers don't usually think in these terms, the true and apparent fields are connected by magnification. Here's an example. To our unaided eye the Moon appears ½° in diameter. If we view the Moon at a magnification of 100×, it will appear to span an angle of 50° (½° × 100× = 50°). As such, an eyepiece yielding 100× on a telescope would have to have an apparent field of at least 50° to show us the whole Moon in a single view. If we switch to an eyepiece still yielding 100× but having an apparent field of 100°, the Moon will still appear the same size but now fill only half of the visible field. Flip that train of thought and you'll see that an eyepiece with a 100° apparent field will show the whole Moon at a magnification of 200× — an impressive increase in magnification from the eyepiece with a 50° apparent field. Note that it's just the apparent fields and magnifications that are important for these calculations, not any particular focal length for the telescope or eyepiece, only that the combination yields the desired magnification. I'll return to these thoughts in a bit since they are important.

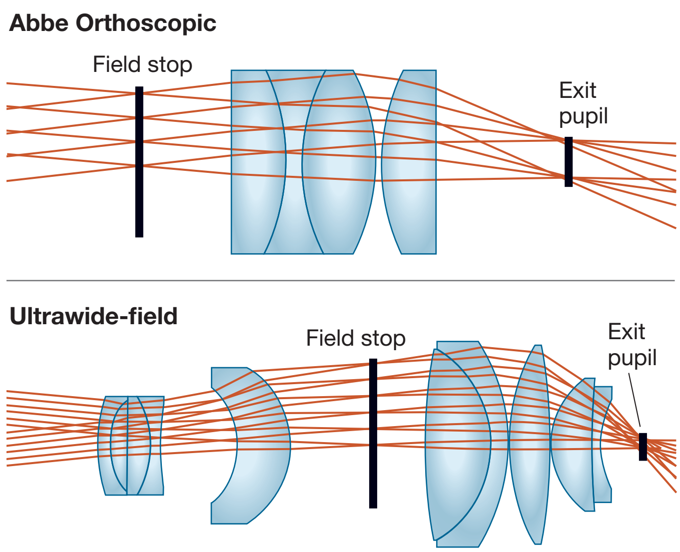
As the diagram at right shows, the bundles of light exiting an eyepiece cross at a point called the *exit pupil*. This is the point where you must place the pupil of your eye to see an eyepiece's full field, and its distance from the outer eyepiece lens is called the *eye relief*. Having sufficient eye relief is important when it comes to observing comfort. I could go on at length about the days of yore and the misery of having to cram an eyepiece almost into your eyeball to try to see the whole field of view. This was especially true of short-focal-length (high-magnification) eyepieces. Thankfully, most modern eyepiece designs have a generous amount of eye relief. Personal preferences vary, but most people who observe without wearing eyeglasses will be happy with an eye relief of at least 10 to 12 mm, and those with glasses will want between 20 and 25 mm. Having a long-eye-relief eyepiece is also beneficial for those of us who observe in cold temperatures since an eyepiece is less likely to fog up when our moist eyeball is kept farther from it.

Low Magnification

There are a variety of ways to approach assembling a set of eyepieces depending on the type of observing we want to do. For many newly minted observers, however, a modest eyepiece set that spans a range from low to high magnification is a good start. Let's begin with the low end of the range.

Back when I started observing and quality eyepieces had apparent fields of around 40°, the concepts of low power and wide field went hand in hand, and it was easy to fall into the mindset that a lower magnification always meant a wider field of view. But the real goal wasn't low magnification, but rather a wide field showing a big expanse of sky. And the fact is that it will always be better to have such a view with the highest possible magnification. Since most of us observe under some amount of sky glow, increasing the magnification darkens the apparent sky background and improves the contrast and the visibility of faint stars, which, at the magnifications were talking about, are not dimmed by increased magnification. Unlike stars, deep-sky objects, such as galaxies and nebulae, do not get a boost in contrast as the magnification increases, but they often become easier to see because they appear larger and we can resolve more details. I know it sounds weird, but having more "low-power" magnification is always a good thing.

So what about that wide field? The amount of true sky we see in an eyepiece is set by the diameter of the eyepiece field stop, which can't exceed the diameter of the eyepiece barrel. The maximum field-stop diameter is about 27 mm for a 1¼-inch eyepiece and 46 mm for eyepieces with 2-inch barrels. An easy way to calculate the true angle of sky seen



▲ **EXPANDING FIELD** The Abbe Orthoscopic eyepiece with a roughly 45° apparent field of view is one of the most enduring astronomical eyepiece designs of the 20th century. But modern glass types and high-transmission coatings have helped usher in a new era of eyepiece designs that have apparent fields of 100° and more, and these designs have revised some of the conventional wisdom that surrounded older designs. The field stop and exit pupil are explained in the accompanying text.

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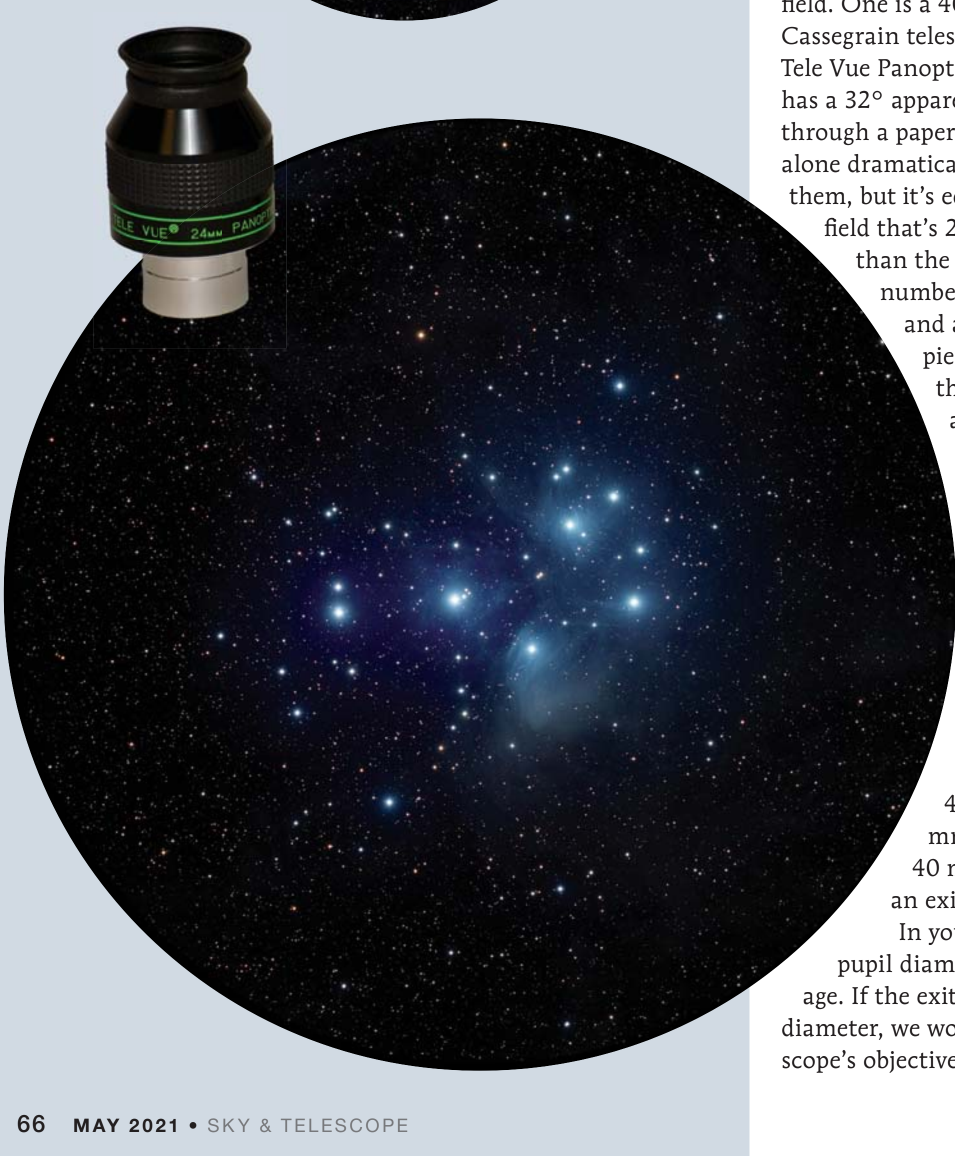
▼ **NOT SO SIMPLE** For a given telescope, lower magnification by itself does not mean a wider field of view. These simulated views are scaled to show the relative magnifications and true sky areas shown by two of the author's 1¼-inch eyepieces used with a telescope having a 500-mm focal length. The view below is with a 40-mm Kellner eyepiece from the early 1970s with a 32° apparent field, while that at the bottom is with a Tele Vue 24-mm Panoptic with a 68° field.



M45: SEAN WALKER / MDW SKY SURVEY (2)

in a telescope is to multiply 57.3° by the eyepiece's field-stop diameter and divide the result by the telescope's focal length using the same units of measurement for both. For the telescope mentioned above with a focal length of 500 mm, the maximum possible field for a 1¼-inch eyepiece will be 3.1° (57.3° × 27 ÷ 500 = 3.1°) and 5.3° for a 2-inch eyepiece.

But the majority of eyepieces don't have field stops that are as large as the barrel diameters permit. They are usually smaller, and in many cases significantly so. Some manufacturers give the field-stop diameter in their eyepiece specifications, but others do not. Lacking the field-stop size, you can still get a reasonable approximation of the true field visible in an eyepiece by dividing its apparent field by the magnification of the set up. Recall the Moon discussion above in which an eyepiece with a 50° apparent field working at a magnification of 100× will just fit the Moon's ½° diameter into the field of view (50° ÷ 100× = ½°). In a perfect world this formula would be exact, but optical distortions, especially those in very wide-angle eyepieces, can alter the numbers a bit.

I have two 1¼-inch eyepieces in my collection that nicely illustrate the point above about magnification and true field. One is a 40-mm Kellner that came with a Schmidt-Cassegrain telescope in the early 1970s, while the other is a Tele Vue Panoptic 24 mm introduced in 2002. The former has a 32° apparent field (it really is like seeing the world through a paper tube), while the latter has a 68° field. This alone dramatically alters the perception of looking through them, but it's equally startling that the 24 mm shows a star field that's 28% wider with a magnification 66% greater than the 40 mm when used on the same telescope. The numbers for the 500-mm telescope above are 12.5× and a true field of about 2.6° for the 40-mm eyepiece and 20.8× and 3.1° for the 24-mm. Banish the thought that lower magnification by itself always means a wider field.

There are also practical considerations involving the exit pupil when it comes to picking a low-power eyepiece. For a given telescope, as magnification decreases the diameter of the exit pupil increases. Two easy ways to calculate exit-pupil diameter are to divide a telescope's aperture by the viewing magnification or divide the eyepiece's focal length by the telescope's f/ratio. Let's give our 500-mm telescope a 100-mm aperture, making it an f/5 instrument. The 40-mm eyepiece will then yield an exit pupil 8 mm in diameter (100 mm ÷ 12.5× = 8 mm, or 40 mm ÷ f/5 = 8 mm), and the 24-mm will yield an exit pupil of 4.2 mm.

In youth our dark-adapted eyes have a maximum pupil diameter of around 7 mm, and it decreases with age. If the exit pupil of an eyepiece exceeds our eye's pupil diameter, we won't have all the light collected by the telescope's objective enter our eye. In such cases the eye's pupil is effectively stopping down the usable aperture of the telescope and thus "wasting" light. But wasting isn't quite the right mindset, since we are actually using the maximum objective diameter possible for the given magnification. In the example above, the 8-mm exit pupil may be too big for our eye, but we're still seeing the brightest possible image for a 12.5× magnification. Regardless, the 4.2-mm exit pupil with the 24-mm eyepiece will pump all the light from the 100-mm aperture into even older eyes, thus showing fainter stars. Score more points for the higher-magnification eyepiece.

All of this makes a solid case for using the highest magnification we can that still gives us the true field we want to observe, and that points us toward eyepieces with large apparent fields. But what's a good true field? There are certainly spectacular celestial objects that can take advantage of fields of view at least 2° or 3° across — the Pleiades, the Andromeda Galaxy, the Orion Nebula, the Lagoon Nebula, and the Veil Nebula to name a few. But that list is still short compared to the countless open and globular star clusters, galaxies, and nebulae visible in backyard telescopes. Personally, I've found that a true field between ½° and ¾° in diameter is excellent for this type of "low-power" deep-sky observing. With eyepieces having a 50° apparent field, that means selecting eyepiece focal lengths that yield between 70× and 100× on a given telescope. With an 85° apparent field, the magnification becomes 120× to 170×, and with 100° eyepieces focal lengths that give 130× to 200×. And for me those higher magnifications possible with the 100° eyepieces really do offer big advantages in my suburban skies.

High Magnifications

If the discussion on low-power eyepieces seems long, you may want to avoid the details when it comes to picking high-magnification eyepieces. Part of the reason is that high magnifications are critical for planetary observing, in which there

◀ **CIRCULAR MATTERS** Some eyepieces have field stops near the front of the eyepiece barrel and are easy to measure for the calculations mentioned in the text. Many modern designs, however, have internal field stops that aren't accessible, and their diameter must be obtained from manufacturer specifications or estimated by other means.

is a wealth of subtleties that go beyond just the eyepiece. But there is a shorter version of the story for those of us who fall into the category of casual high-magnification observers.

At first glance it would seem that wide-field eyepieces offer little advantage for most high-magnification observing. Even if magnified 400×, Jupiter has an apparent diameter barely approaching 5° in the eyepiece, and it would fit well within even the smallest apparent fields of view. But today's wide-field eyepieces often have long eye reliefs that make high-magnification observing very comfortable. And larger apparent fields mean larger true fields at a given magnification, and for anyone using a telescope without a tracking mount that means a longer viewing period before having to nudge the telescope to center the object again. So eyepieces with large apparent fields do offer some benefits.

Nevertheless, the central idea of high-magnification observing is to make visible the finest details that we can see with a given telescope. In the mid-19th century the English double star observer Reverend William R. Dawes determined that a telescope could just resolve a pair of equal-magnitude stars if their separation measured in arcseconds was equal to 4.56 divided by the telescope aperture in inches (or 116 divided by the aperture in millimeters). Telescope optics, however, are not the only issue since distortions introduced by Earth's turbulent atmosphere typically limit any telescope's

▶ **OCULAR PROGRESS** More than a half century of eyepiece evolution is represented by this collection of oculars that all have 9-mm focal lengths and thus yield exactly the same magnification when used on a given telescope. The eyepiece at far left, supplied with a 60-mm refractor in the early 1960s, has an apparent field of just 36°. Continuing clockwise around the arc the respective fields increase, expanding to 83° for the Tele Vue model at far right, and finally culminating with 100° for the Explore Scientific eyepiece in the foreground that shows nearly 9 times the area of sky in a single view than the eyepiece from the 1960s.

visual resolution to about 1 arcsecond on even good nights. But for the sake of argument, let's take a more-demanding resolution of ½ arcsecond, which the Dawes limit states can be resolved with a 10-inch telescope if the atmosphere cooperates. People with excellent eyesight can resolve about 1 arcminute with their unaided eyes, which means they could resolve that ½-arcsecond angle if it were magnified just 120×. But let's make it even easier on our eyes and double the magnification to 240×. Most of us don't think of that as extremely high magnification for a telescope, but it should be more than enough to show us all the detail that can be seen in a 10-inch or larger telescope, and certainly for smaller instruments and even the best "average" seeing conditions.

That 240× works out to a magnification of just 24× per inch of aperture for the 10-inch telescope or 40× per inch for a 6-inch instrument. These values fit well with the 25× to 50× per inch of aperture often suggested by experienced planetary observers. Furthermore, many of the great planetary observers in the late 19th and early 20th centuries rarely found an advantage to using maximum magnifications greater than 400× to 500× with even with the largest professional telescopes. Last October I was among the legions of observers viewing Mars. There was never a night when magnifications above 300× offered a better look at the planet with telescopes between 6-inch and 18-inch aperture, and most of the time my best views were at magnifications between 155× and 220× with a 6-inch refractor, which experienced acceptable seeing conditions far more often than the larger instruments.

Final Thoughts

Armed with the above information, this is what I consider as a good set of eyepieces for a new telescope. At the "low-power" end of the spectrum I'd aim for an eyepiece giving the highest magnification and still providing the true field of view I want. And this would be the one that most warrants the investment necessary for one of today's eyepieces with a truly wide apparent field of view. My choice for a high-power eyepiece would be one delivering around 200×. And rounding out a basic set would be a third that delivers a magnification between these two. Rather than another eyepiece, my next addition would be a quality 2× or 3× Barlow that, when coupled with the three eyepieces, gives different magnifications than what's available with any of the eyepieces alone. The result would be a range of six magnifications that covers virtually everything I'd ever want for a typical night under the stars. Your mileage may vary.

■ **DENNIS DI CICCO** says old habits die hard, and he still occasionally catches himself reaching for a lower-power eyepiece rather than one that offers a wider field of view.

ON THE TEST BENCH Using equipment from his shop, the author set up a system for accurately measuring an eyepiece's apparent field of view. It works by using a paper target to position the exit pupil of an eyepiece attached to a refractor directly over the axis of a rotary table, and measuring the angle needed to sweep the crosshairs of a small finderscope (which provides a magnified look at the eyepiece's field of view) from one side of the field stop to the other. Of the dozens of eyepieces examined over the years, the measured fields rarely deviated by more than 1% or 2% from that specified by the manufacturer, and more often than not were exact.