Chapter 2

Choosing Eyepieces and Observing Strategies

In the marketplace today, there are literally many hundreds of eyepiece lines from which to choose. How can one possibly navigate such a large marketplace and ever hope to make a good decision? The answer is, of course, to arm yourself first with knowledge. When considering the choice and use of an eyepiece, it helps to first consider:

- Viewing comfort and usability considerations
- Visual impact considerations
- Observing strategies

Knowing these will provide the necessary insight to choosing and using eyepieces that will perform their best optically in your equipment for the celestial targets you most enjoy, provide you the ergonomic qualities that make them easiest to use, and give you strategies that will best leverage their full potential.

Viewing Comfort and Usability Considerations

The viewing comfort and usability of an eyepiece are primarily influenced by three characteristics, which when taken together are sometimes vital to the observer's impression of how much they "enjoyed" using the eyepiece:

- Eye relief
- Construction and mechanical features
- Size and weight

W. Paolini, *Choosing and Using Astronomical Eyepieces*, The Patrick Moore Practical Astronomy Series, DOI 10.1007/978-1-4614-7723-5_2,

There are many eyepieces in the marketplace that may provide less than the best images yet be highly ergonomic and enjoyable to use, whereas other eyepieces may provide the best optical performance possible and yet be very difficult or awkward to use. Experienced observers often find that the correct balance of both optical and comfort/usability factors are critical for an eyepiece to be a successful choice for long-term use. The balance of factors is also often quite unique to each observer, so while one observer may find an eyepiece highly enjoyable and capable, another observer can find that same eyepiece just the opposite. The reason for this is that an eyepiece is a highly personal part of the telescopic system, and finding the correct eyepiece involves not simply how well its optics will perform but is always dependent on the personal likes, dislikes, needs, and desires of each observer.

Eye Relief

Eye relief is a critical factor influencing comfort when using an eyepiece. It is the distance from the center of the top surface of the eye lens of the eyepiece to where the image is formed by the eyepiece. Eye relief is therefore the distance above the eye lens where the observer needs to place the eye to view the image. Eyepieces with shorter eye relief, requiring the observer to place the eye close to the lens, are generally less comfortable to use than those with longer eye relief. However, when the eye relief becomes too long, the eyepiece may also become difficult because of the problem many observers encounter trying to keep their eye positioned properly so far above the eyepiece. For many observers, an eye relief of about 20 mm is the maximum distance where proper eye position can be maintained without losing the view.

If an observer must wear eyeglasses when observing, then the eye relief of an eyepiece becomes the most critical factor of an eyepiece's performance. Observers who wear eyeglasses typically report that an eye relief not less than 13–15 mm is needed to see the entire field of view of an eyepiece when wearing eyeglasses. Luckily, it is often not necessary to wear eyeglasses when observing, since the eyepiece can simply be refocused to accommodate the needs of an observer's vision. Where an observer will need to wear eyeglasses for observing is if the eyeglass prescription corrects any astigmatism. Any refocusing of the lens will not correct for astigmatism. Observers whose eyes have astigmatism must either use longer eye relief eyepieces with 15–20 mm of eye relief so they can wear their eyeglasses while observing, or find eyepieces that have optional add-on accessories to accommodate correction of astigmatism.

One such accessory is the Tele Vue Dioptrx. The Dioptrx is made to fit on top of compatible Tele Vue eyepieces and is available in various prescriptions to accommodate different amounts of astigmatism. Although the Tele Vue Dioptrx is designed for Tele Vue eyepieces, there are some other eyepiece brands of long eye relief where this accessory can fit (Vixen LVWs, Baader Hyperions, and a few others).

Fig. 2.1 The Tele Vue Dioptrx for observers who have astigmatism (Image © 2013 Tele Vue Optics—www.TeleVue.com)

Construction and Mechanical Features

Although the optical performance of an eyepiece should of course never be overlooked, other considerations can sometimes be just as important, depending on the observer's personal preferences. The first and most obvious aspect of any eyepiece will be its construction and its mechanical features, as these are what will provide one's initial impression. The construction of the housing and the barrel provide the first impression. Housing construction usually varies from metal to various hard polymers such as Delrin. If the housing is metal, then it is typically either anodized some color, or coated with a durable paint. As a result of these differences, how the housing will wear over time will then vary. For housings made of solid materials that are of uniform color throughout, such as Delrin, any wear over time will simply show as a depression. If the housing is made of a coated metal, however, time will wear these surface coatings away, and the bare metal can eventually show. Anodized coatings are typically more resistant than painted housings.

Fig. 2.2 Eyepiece housings: Delrin (*left*), powder coated (*center*), anodized (*right*) (Image by the author)

Next, how the graphics on the housing are applied can cause them to wear away quite quickly when subjected to constant handling. Graphics and lettering are typically applied as surface painting, surface silk screening, or are engraved into the housing then filled with paint. The longest wearing, and most easily refurbished, application is the engraved one that is paint filled. Given that the paint-filled engraving is recessed from the surface, the paint is less prone to touch and wear, making it the most long-wearing. If the paint-filled engraving ever does loosen or wear away from age or use, it is an easy task to fix at home by simply filling with a same color paint. Of the other two common applications, silk screening and surface painting, silk screening generally resists wear slightly better than surface painting.

Fig. 2.3 Eyepiece housing graphics: surface silk screen (*top*) and paint-filled engraved (*bottom*) (Image by the author)

There are also housing features designed to improve secure gripping of the eyepiece. Many feel housings with smooth sides are aesthetically the best. However a diamond etching in the surface or a rubberized band will greatly aid in maintaining a secure grip on the eyepiece, especially when handled in colder weather when cold hands may make one's grip less tight or secure. Some eyepiece brands also place a rubberized material completely around the housing, or construct the housing entirely out of a sure grip material as an approach to maximize the grip-ability of the eyepiece. These types provide the most secure handling characteristics and are especially good in cold weather, as they never feel overly cold to the touch.

Fig. 2.4 Housing grips: smooth (*left*), rubber strip (*center*), completely rubberized (*right*) (Image by the author)

The final common feature of the housing is the eyeguard. Most eyepieces come with some sort of eyeguard to block external light from entering your eye when you use the eyepiece. However, there are still some brands where no eyeguard is provided or integrated into the housing. For some of these it is actually impossible to offer an eyeguard due to the short eye relief of the eyepiece, which would make it impossible to place your eye close enough to view the entire field.

Eyeguard construction comes in a variety of applications, from fixed non-adjustable ones to ones made of soft rubber that can be folded back, offering in effect two positions, to ones with "wings" on one side (very useful when the eyepiece is used in binoviewers) and to adjustable height eyeguards. For foldable eyeguards, the thickness and pliability of the rubber is important, as those made with very thin rubber can wear and crack along the fold points if folded often over time. For adjustable height eyeguards, the mechanisms to accomplish this are typically push-pull types or rotating types to adjust the height. Weak points to look for in these designs are their ability to stay in any adjusted position when pressure is applied on top. Once an eyeguard is adjusted for optimum viewing position, it is not desirable for the position to easily move when contacted during observing, or when removed or inserted into the focuser. Rotating mechanisms are usually less prone to accidental movement when in use. However some push-pull types have locking mechanisms so once the height is chosen if can be firmly locked in position (e.g., the Tele Vue Delos line of eyepieces).

Fig. 2.5 Eyeguards: none (*left*), folding rubber (*center*), adjustable (*right*) (Image by the author)

After the housing, the barrel is the next major construction element of the eyepiece. Most eyepieces have barrels that are chromed/nickel plated brass, polished aluminum or other base metal, or black anodized aluminum or other base metal. The chromed/nickel coated brass types are typical of older classic eyepieces. Today, however, more vendors are moving to the polished or anodized aluminum or base metals. In rare instances, some eyepieces may even have stainless steel used for the barrels (e.g., the discontinued Astro-Physics Super Planetary line). The chromed/nickel coated brass barrels, although having a nice heft and beautiful appearance, will wear over time from constant insertion into the focuser. After many years of heavy use, the wear can show as an area where the gold color of the brass shows through. Fortunately, it generally takes many decades of use for this to happen.

Similarly, barrels that are anodized can show wear of the anodized coating, revealing the color of the underlying metal. Although these types of wear result in cosmetic changes to the barrel, rarely do they affect the function of the barrel in any way. Solid metal barrels that are uncoated and only polished offer the longest wear with fewer cosmetic issues over time.

Another aspect of the barrel that some eyepieces possess is a safety feature to help prevent accidental slipping out of the focuser. For barrels with smooth sides, if the retaining screw of the focuser is not firmly tightened to hold these eyepieces in place, or if it loosens for any reason, then these eyepiece can fall out of the focuser if the telescope is placed into a position where the eyepiece is inverted.

To reduce the risk of this possibility, manufacturers have developed three different styles of a safety feature on the eyepiece barrel: a full undercut barrel, a beveled or tapered undercut barrel, and a tapered barrel. The full undercut types have widely milled bands around the barrel. When the focuser's set-screw or pressure ring is tightened into these milled inset areas of the eyepiece barrel, if it loosens for any reason then as the set-screw or the compression ring contacts the limit of the inset area the eyepiece will be stopped, preventing it from falling out of the focuser. The advantage with this feature is that it reduces risk of the eyepiece slipping out of the focuser, falling, and breaking if the focuser is inverted. The disadvantage of this feature is that many amateurs complain that the eyepiece often gets stuck or hung on this feature when removing it from the focuser. To reduce this tendency of getting stuck, the undercut style of some eyepieces has a bevel in the inset instead of being a sharp corner; these are called beveled undercut. The tapered barrel design, however, is probably the best design for reducing any annoying tendency for the eyepiece to sometimes get stuck when being inserted or removed. As small of a design feature as the undercut is on an eyepiece, it is often a hot topic on online astronomy boards, as many observers tend to have strong feelings one way or the other related to this feature.

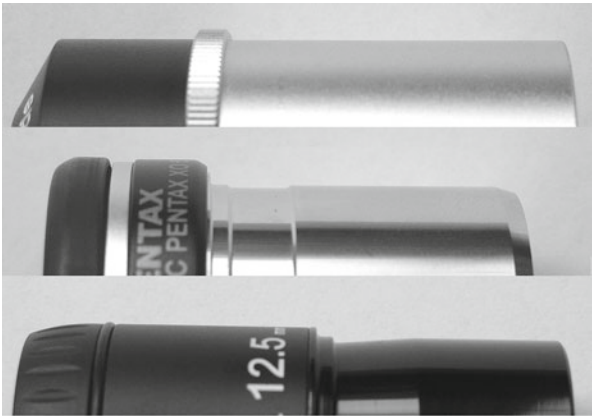

Fig. 2.6 Barrel safety features: none (*top*), undercut barrel (*center*), tapered barrel (*bottom*) (Image by the author)

The final construction element we will examine that is important to the best function of an eyepiece is how the eyepiece is baffled and if reflective surfaces are suppressed. Unfortunately, is not always feasible to inspect these without disassembling the eyepiece, which is not a recommended practice, as it may both void any warranty and cause damage if done improperly. What can be done, however, is to invert the eyepiece and look into its interior. When inspecting the interior of the barrel of an eyepiece, there should not be obvious highly reflective surfaces visible. All portions of the interior should be uniformly blackened with a flat anti-reflective paint or anodized flat black to minimize the possibility of stray light reflections entering the field of view. A well blackened interior is critical when observing brighter targets such as the Moon to eliminate flare within the field of view. Additionally, all visible parts in the interior should typically be made of metal and held in place mechanically with screwing threads rather than glue or pressure, as glued or the pressure-based method may not have the longevity of mechanical-based methods.

Fig. 2.7 Inside of barrels: well blackened (*left*), bare metal parts (*center*), plastic parts (*right*) (Image by the author)

Overall, the construction of an eyepiece should not be overlooked or deemed less important than the eyepiece's optical characteristics. Mechanical features and construction will often determine how well the eyepiece will wear and survive use over time. This is important not only for aesthetic reasons, but it can also be important for functional longevity of the eyepiece, as features such as rubberized grip panels and eyeguards can deteriorate over time if not robustly constructed, and the use of glue or plastics as construction elements can similarly deteriorate or be insufficiently robust.

Size and Weight

The physical size and weight of an eyepiece can also be important considerations, as these two characteristics affect many aspects of usability, including the balance of the telescope. Size, the most obvious feature, can be an issue for some observers when the eyepiece is too large or too small. Where this might also be an issue is related to ergonomics in use e.g., an eyepiece case of six or seven large eyepieces may not only require a large case to hold but may also be considered overly heavy if portability is a concern. Additionally, many eyepiece holders between the tripod legs of equatorial mounts will not accommodate more than one or two of the large format 2 in. eyepieces.

Fig. 2.8 Examples of size and weight variations of eyepieces. 40 mm Pentax XW (*left*) vs. 40 mm Meade 3000 Plössl (*right*) (Image by the author)

A usage area where the size of an eyepiece can be critical is in the width of the housing. This becomes important if the observer plans to choose eyepieces for use in a binoviewer. If the eyepieces are too wide, then an observer may not be able to move the two eyepieces close enough to each other in the binoviewer so that their eyes can be positioned over the center of the eye lenses. Therefore, if the intention is to use the eyepieces for binoviewing, then it is critical to know the distance between the pupils of one's eyes, called the interpupillary distance. Eyepieces for binoviewing must have a maximum housing width that is no greater (or slightly less preferred) than the interpupillary distance of the observer; otherwise the observer might not be able to effectively view through the eyepieces when used in the binoviewer.

Fig. 2.9 William Optics binoviewer with optical corrector adapter and William Optics eyepieces (Image by the author)

Since many times large eyepieces may be of significant weight, this can also impact the balance of the telescope. As an example, many Dobsonian telescopes do not have a tension adjustment for the altitude movement of the telescope's tube. Instead, these telescopes rely on the tube being balanced as it sits in its mount. If a very heavy eyepiece is placed in the focuser, this may then require the addition of weights near the base of the telescope's tube so the telescope will remain balanced and pointing where it is positioned. Alternatively, for those telescopes that have motorized tracking mounts, a heavy eyepiece may similarly cause an out of balance situation where additional weights must be used or the tube must be repositioned in its holder so the tracking accuracy is maintained.

Although not extremely critical, when choosing an eyepiece the observer should always be cognizant of its listed dimensions and weight to determine if these characteristics will be a problem for the telescope's balance, accessory holders, binoviewers, or portability needs.

Visual Impact Considerations

When observing, there are numerous characteristics of the eyepiece, both exclusive to the eyepiece and in combination with the telescope, that will influence the impact of the view for the observer. The better understanding of how these various characteristics visually impact the view through the eyepiece, the better choices can be made to ensure the eyepiece provides the best visual experience possible.

The primary characteristics that provide a substantial influence over the visual impact an eyepiece will provide include:

- Apparent field of view (AFOV)
- True field of view (TFOV)
- Magnification, brightness, and contrast
- Aberration control

Apparent Field of View (AFOV)

As was introduced earlier, the AFOV of an eyepiece is probably the most talked about aspect of eyepieces today. The AFOV is how wide the eyepiece's field of view appears when observing through the eyepiece (e.g., how large the "porthole" looks as you observe through the eyepiece). AFOV is important when choosing an eyepiece because it conveys the "experience" of viewing differently depending whether the AFOV is smaller or larger. Eyepieces that have narrower AFOVs tend to not engage the observer as prominently as eyepieces with larger AFOVs. Since a single human eye's vision is approximately 140° from left to right (and from 160° to more than 200° degrees when using both eyes together), the larger the eyepiece's AFOV the more natural it appears compared to our normal unaided eye's vision. This makes AFOV an important consideration.

In addition to how engaging the AFOV makes the view through the eyepiece, the AFOV size also directly impacts the true field of view (TFOV) attained by the eyepiece with the telescope (e.g., how large of a patch of sky will be visible). The illustration below demonstrates how the Great Orion Nebula, M42, appears in a 250 mm f/4.7 Dobsonian telescope using a 24 mm eyepiece. The eyepiece used for the field of view shown on the left has an AFOV of 68°, and the one on the right has an AFOV of 44°. The magnifications are exactly the same, but the eyepiece

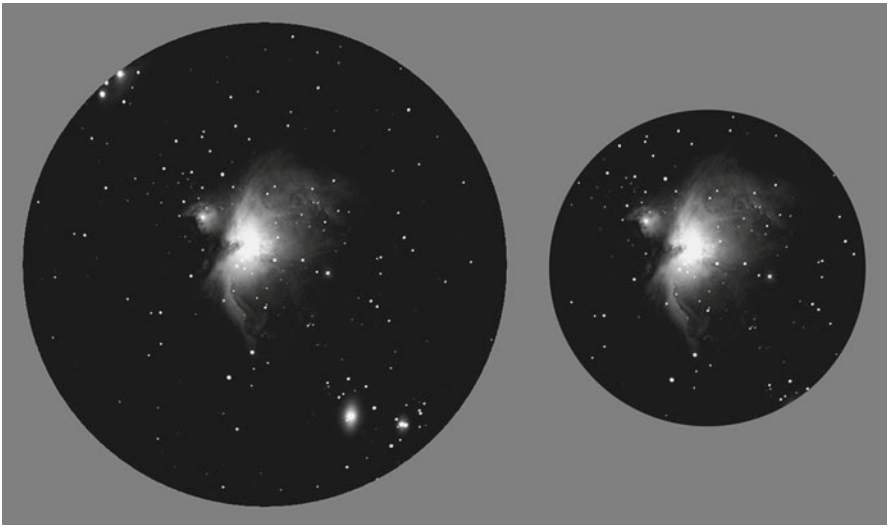

Fig. 2.10 AFOV-TFOV simulation: 24 mm 68° AFOV (*left*) and 24 mm 44° AFOV (*right*). Note how the larger AFOV eyepiece shows more TFOV around the object being observed (M42 astrograph courtesy of Mike Hankey, Freeland, MD, USA—www.mikesastrophotos.com)

with the larger AFOV allows one to see a more aesthetically pleasing larger patch of sky around M42 than does the eyepiece with the smaller AFOV.

Depending on the telescope used, especially for shorter focal ratio telescopes, the AFOV of the eyepiece is not only an aesthetic consideration, but is also a critical performance consideration. For some shorter focal ratio telescopes, the only way to obtain a large TFOV with the telescope is to use shorter focal length eyepieces that have the maximum AFOV size possible so the exit pupil of the eyepiece and telescope combination does not exceed the limit of the average human eye, which is approximately 7 mm (see the section on Calculating Exit Pupil under Observing Strategies later in this chapter for a more in-depth discussion of this limitation).

To illustrate, if you are using one of the new generation of ultra short focal ratio Dobsonian telescopes, such as the Webster 28 inch f/3.3 telescope, then a 23 mm eyepiece is the longest focal length that can be used without exceeding the 7 mm exit pupil limit of the typical human eye. Given this, it is preferable to use an eyepiece with the largest AFOV possible so the TFOV is maximized. In the case of our 28 inch f/3.3 telescope example, the 21 mm Tele Vue Ethos, with its 100° AFOV, would give us twice the TFOV compared to using a typical 20 mm Plössl. For short focal ratio telescopes a wider AFOV eyepiece is therefore sometimes necessary for TFOV capability. As a general rule, if the telescope being used has a focal ratio of f/5 or shorter, then at least one wide-field eyepiece with a 2 in. barrel will be required if one wants to maximize the TFOV capability of the telescope and keep the exit pupil smaller than the typical 7 mm maximum that the human eye can handle.

Although the AFOV of an eyepiece can be important for aesthetic reasons, or critical for performance reasons, this does not mean that eyepieces with larger AFOVs are necessarily better, or even preferable, to those with smaller AFOVs. For many observers, larger AFOV sizes can be more stressful or difficult to use, so they develop a preference for the smaller AFOV eyepieces. In some specialized observing tasks, such as double star or planetary observing, some observers prefer smaller AFOVs because a larger TFOV around these objects is generally of no advantage to the observation, either technically or aesthetically. Additionally, these smaller AFOV eyepieces typically need fewer glass elements for a well corrected view, can be made in smaller and easier to handle form factors, and are usually less expensive than the more complex wide-field optical designs. So although AFOV is an important consideration when choosing an eyepiece, individual observer preferences vary greatly, making larger AFOVs not necessarily better. The best advice is always to either borrow eyepieces of different AFOV sizes so observers can determine for themselves what works, or to participate in local astronomy club observing evenings to try different eyepieces that club members may be using with their telescopes.

True Field of View (TFOV)

The true field of view (TFOV), sometimes referred to as the actual field of view, is an angular measure, expressed in degrees, of the maximum amount of sky visible in the eyepiece from the furthest left to the furthest right of the field of view. It is useful because it gives the observer the ability to predict how well the selected eyepiece with telescope will frame the intended target. TFOV is not an attribute of

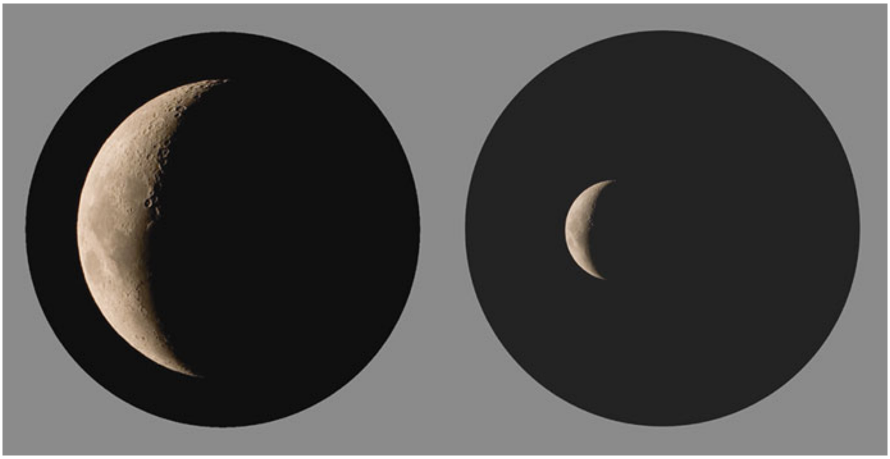

Fig. 2.11 The Moon as it would appear in a 24 mm Panoptic eyepiece in a 203 mm (8 in.) f/10 SCT (*left*) and with the same eyepiece in a 100 mm f/7.5 refractor (*right*) (Moon astrograph courtesy of Mike Hankey, Freeland, MD, USA—www.mikesastrophotos.com)

the eyepiece alone but varies depending on the focal length of the telescope, the focal length of the eyepiece, and the AFOV of the eyepiece used.

When considering the best eyepiece to use for a planned observing session for a particular target, it is often important to consider using an eyepiece that will provide a TFOV larger than the target itself to capture the surrounding context of the star field. For some targets, such as the Great Orion Nebula, Messier 42, the surrounding context of stars provides a richly rewarding view. The Great Orion Nebula M42 has an angular size of 0.6°, so an eyepiece that would show 0.6° of TFOV in the telescope would only "just" fit Messier 42 in the field of view. However, compare how differently the Great Orion Nebula appears in a TFOV that is over twice as large, at 1.3°. With M42's surrounding context of the entire Sword of Orion fully framed

Fig. 2.12 M42 in a higher magnification 0.6° TFOV (*left*) and in a lower magnification 1.3° TFOV (*right*) (M42 astrograph courtesy of Mike Hankey, Freeland, MD, USA—www.mikesastrophotos.com)

by the eyepiece, the observing experience of this target is completely different, and for many observers, preferred.

To calculate the TFOV of your eyepiece and telescope combination, you can use any of the several formulas that follow. Some calculation methods are more precise than others; however, even the least accurate methods are typically only 5–10 % less accurate. In the list of formulas below, the first set is an approximation-based method that will generally yield an answer several percent less accurate than the most accurate methods.

For calculating TFOV (in degrees) based on manufacturer provided data:

1.
$$\text{TFOV} \approx \frac{\text{AFOV}}{\text{Magnification}}$$

Notes: AFOV is the apparent field of view of the eyepiece in degrees. Magnification is the magnification produced by the eyepiece in the telescope.

2.
$$\text{TFOV} \approx \frac{\text{AFOV}}{(\text{FL [telescope]} \div \text{FL [eyepiece]})}$$

Notes: AFOV means the apparent field of view of the eyepiece in degrees. FL[telescope] means the focal length of the telescope in millimeters. FL[eyepiece] means the focal length of the eyepiece in millimeters. This method is only approximate, as any distortions in the eyepiece's field of view will make the results inaccurate by as much as 10 %.

For calculating TFOV (in degrees) based on drift time observations of a star:

3. $$\mathrm{TFOV} = \frac{\mathrm{DT[sec]}}{239}$$

Notes: DT[sec] means drift time in seconds; this method is only accurate when the star is near the celestial equator.

4. $$\mathrm{TFOV} = ABS(\mathrm{DT[sec]} \times .0041781 \times COS(\mathrm{DEC[star]} \div 57.3))$$

Notes: ABS means absolute value. DT[sec] means drift time across the entire field of view in seconds. COS means cosine. DEC[star] means the declination of the star in degrees. This method is accurate for any star chosen by drift time since the declination of the star from the celestial equator is taken into account.

For calculating TFOV (in degrees) based on field measures:

5. $$\mathrm{TFOV} = \frac{\text{Eyepiece Field Stop Diameter}}{\mathrm{FL[telescope]}} \times 57.3$$

Notes: Eyepiece field stop diameter is in millimeters. FL[telescope] means the focal length of the telescope in millimeters. COS means cosine; and DEC[star] means the declination of the star in degrees.

6. $$\mathrm{TFOV} = \frac{(\text{Tape Measure[observed]} \times 57.3)}{\text{Distance[telescope-to -tape measure]}}$$

Notes: Tape Measure[observed] means the number of inches (or millimeters) of the tape measure that are observed through the eyepiece in the telescope. Distance[telescope-to-tape measure] means the distance in inches (or millimeters) from surface of the objective of the telescope to the wall where the tape measure is mounted.

Formulas 1 and 2 are the easiest to use since all the needed information is provided by the manufacturers of your eyepiece and telescope. However, they only provide results close to the actual TFOV that will be produced. You can expect calculations using these two formulas to be accurate to within about 5 % or so of the actual TFOV. The reason these may be not as precise is due to distortions that may exist in the far off-axis of the AFOV of the eyepiece, particularly in wider AFOV eyepieces that typically have rectilinear and/or angular magnification distortions of several percent. If the eyepiece has several percent of these distortions in the off-axis affecting the AFOV, then the results of this TFOV calculation method will also be off by several percent. However, even with this imprecision, these are still fairly accurate and usable formulas, providing a quick and easy method.

Formulas 3 and 4 provide a method of calculating the TFOV without knowing any information at all about the eyepiece or the telescope. These are called drift-time methods and involve pointing the eyepiece and telescope at a star, placing the star just outside the field stop, then timing it with a stopwatch as it comes into view until it goes out of view at the other end of the field of view. If the star chosen is on or close to the celestial equator, then these formulae get simpler, less confusing, and produce more accurate results. (*Note:* The celestial equator is visible from almost everywhere on Earth.) The difficultly with this method is ensuring that the star crosses the exact center of the field of view during its transit. Since it is often difficult to ensure this, observers generally take the timings for several drifts and then average them for the most accuracy.

The first drift formula (3) provided is less accurate than the second (4) since it does not account for the declination of the star being observed. If the star is offset far from the celestial equator, then the constant in the denominator of the equation will be different. So this quick and easy drift formula is only very accurate when you choose a star very close to the celestial equator. However, an easy solution to this issue is to choose a star that you can identify, look up its declination, then use this in formula 4 for maximum accuracy. Since the declination of a star can be a positive or negative number, this formula uses the absolute value of the result, since it is only the declination's offset from the celestial equator that is important and not its direction of offset.

In formula 5, the TFOV is measured using the field stop diameter of the eyepiece. Although this is an excellent method, many current day wide field designs have the field stop within the main housing of the eyepiece set between some of the glass elements. Eyepieces of this design are generically called positive–negative eyepieces because the elements in the barrel are a negative group, like a Barlow. With these designs the physical size of the field stop is of no use because of the elements in the barrel of the eyepiece that are in part acting like a Barlow. For positive–negative design eyepieces, however, some manufacturers provide the "equivalent" or "effective" field stop measurements for their positive/negative designs. If these are supplied, then they can be used with formula 5 for accurate results. Otherwise, the other TFOV formulas will work just fine if the manufacturer has not provided what is often called the effective or equivalent field stop size for these positive–negative type eyepieces.

If the eyepiece is a classic design, where the field stop is visible in the barrel of the eyepiece below the field lens, a direct measure of the field stop size to use formula 5 will result in very effective results. Since field stops are usually small, a caliper or similar precision instrument is needed as a measuring device to accurately measure to a thousandth of an inch or a fraction of a millimeter.

If taking a direct measure of an eyepiece's field stop, be careful not to put too much pressure on the edges of the field stop because any dent or inadvertent etch in the knife-edge of the field stop will be seen as a notch at the edge of the field of view of the eyepiece when observing. The shorter the focal length of the eyepiece the easier it will be to see any inadvertent damage to the field stop's edge because of the increased magnification of short focal length eyepieces, so extreme care is always advised.

Once the field stop is measured, then simply plug this value into formula 5 to determine the TFOV that will be observed using that eyepiece with each telescope. To illustrate, assume the telescope is a 100 mm f/8 (800 mm focal length) refractor and the eyepiece is a 20 mm Plössl eyepiece that has a 50° AFOV. When measuring the field stop of this eyepiece, the caliper reads its diameter as 17.5 mm. For accuracy, repeat the measurement at least two more times. The next two measurements are: 17.1 and 16.7 mm. Taking the average of the three measurements the result is an average of 17.1 mm. Since the three measurements varied by 0.8 mm (e.g., maximum minus the minimum or $17.5-16.7=0.8$) the accuracy of the measurements is half of the variance or +/− 0.4 mm (or expressed as a percent it is variance/average $=0.4\div17.1$ +/− 2.3 %). Taking the average measurement for the field stop, use formula 5 to calculate the TFOV this eyepiece for the example's 100 mm f/8 telescope with its 800 mm focal length. To illustrate this example:

$$\begin{aligned}\text{TFOV} &= (\text{Eyepiece Field Stop Diameter}\times 57.3)\div\text{Telescope Focal Length}\\ &= (17.1\ \text{mm}\times 57.3)\div 800\ \text{mm} = 1.22^{\circ}\end{aligned}$$

Although performing TFOV calculations for all eyepiece-telescope combinations can be tedious, the one place where performing TFOV calculations is the most important is to ensure that an eyepiece is available to adequately frame the largest celestial object you intend to observe. To illustrate, presume the intent for the evening's observation is to drive to a dark site with a 100 mm f/8 telescope, and that the largest object on the observing plan is Messier 45, the Pleiades Cluster. Assume that for this observing trip a 2 in. format eyepiece will not be taken to reduce the bulk of all eyepieces being taken for the observation. Will a 1.25 in. eyepiece that produces the most TFOV in a 1.25 in. barrel, such as a 32 mm 50° eyepiece, be sufficient to view Messier 45? Using the TFOV calculation methods just reviewed it is now possible to easily answer this question. Since Messier 45 is approximately 1.7° in size, to frame it better and get a little more context around the target the plan is to have an eyepiece that will produce about 1.5× more TFOV than the size of Messier 45, or $1.5\times1.7^{\circ}=2.6^{\circ}$. Will the planned 1.25 in. 32 mm 50° eyepiece provide the needed 2.6 in. of TFOV in the 100 mm f/8 telescope? Doing the calculations shows that this eyepiece only produces a TFOV of approximately 2.0°, much less than the 2.6° desired. To illustrate this example:

$$\begin{aligned}\text{TFOV} &\approx \text{AFOV}\div(\text{Telescope Focal Length}\div\text{Eyepiece Focal Length})\\ &\approx 50^{\circ}\div(800\ \text{mm}\div 32\ \text{mm})\approx 2^{\circ}\end{aligned}$$

Although in this scenario the plan was to not bring 2 in. format eyepieces, taking a little time to verify TFOV calculations revealed that our selected 1.25 in. eyepiece could frame Messier 45 tightly, but that it falls short of the 2.6° desired for extra context around the target. Knowing how to perform the TFOV calculations for an observation planning, particularly one that will be at a remote location where the observer might not have access to all his or her equipment, can be highly beneficial. In our scenario, bringing a 2 in. wide-field that will produce more TFOV than our 32 mm Plössl would be best to gain the extra context that a larger 2.6° provides for Messier 45. Repeating the above calculations for a 2 in. Pentax 30 mm XW with a 70° AFOV shows it will produce the more desired 2.6° TFOV when used with the 100 mm f/8 telescope.

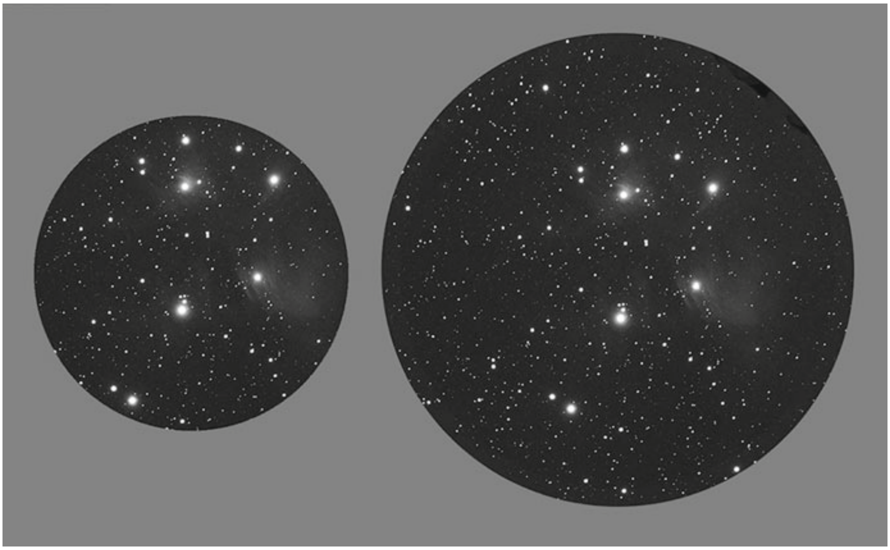

Fig. 2.13 M45, the Pleiades Cluster, in a 30 mm Plössl (*left*) and 30 mm Pentax XW (*right*) (M45 astrograph courtesy of Mike Hankey, Freeland, MD, USA—www.mikesastrophotos.com)

The final formula, 6, uses a method where the eyepiece and telescope are set up during the day, and direct measures of the size of the TFOV they produce are calculated based on measuring a target placed down field. This can be done outdoors or indoors, as long as your eyepiece and telescope can come to focus on the target. This method is highly accurate, as it is independent of any unmeasured or manufacturer provided data, such as the focal length of the eyepiece or telescope or the magnification being produced, etc. With this method, two direct measures are taken; then a simple trigonometric formula is used to calculate the TFOV.

To set up for this method, first mount a tape measure which is several feet long that has closely spaced measurement intervals (e.g., 1/16 in. tic marks) on a wall in the distance. Next place the eyepiece and telescope at a workable distance away so they can come to focus on the target, then measure the distance from the surface of the telescope's objective lens to the tape measure on the distant wall. Next, observe the tape measure in the field of view of the eyepiece and count the number of inches and fractions of an inch (or centimeters and millimeters) that is observed through the eyepiece from one end of the field of view to the other. Note that it is vital that the tape measure exactly bisects the field of view of the eyepiece so the measurement is taken from the widest part of the view from left to right. The unit of measure you choose is not relevant to the formula, as long as both measures are in the same unit of measure. Therefore, if you are counting the number of millimeters you can view on the tape measure across the field of view, then the distance from the telescope's main objective to the tape measure must also be in millimeters.

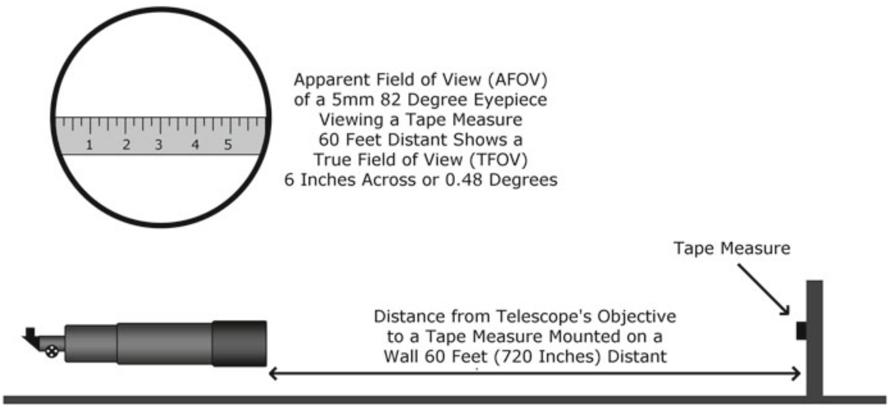

Fig. 2.14 Direct field measurements to determine the TFOV of an eyepiece and telescope (Illustration by the author)

To illustrate this method, assume the equipment used is a 100 f/8 telescope together with a 5 mm 82° AFOV eyepiece. The tape measure is placed on a wall that is measured as 60 ft (720 in.) from the front surface of the telescope's main objective. The tape measure is mounted on the wall from left to right so it is horizontal to the ground. Next place the 5 mm 82° AFOV eyepiece in the telescope and aim the telescope at the tape measure so the top of the tape measure is in the exact center (from top to bottom) of the eyepiece's field of view. Focus the telescope on the tape measure and assume for our example that a count of exactly 6 in. is visible from the furthest left of the field of view to the furthest right of the field of view.

Using the TFOV formula 6, TFOV = Observed Tape Measure Size × 57.3 ÷ Distance from Telescope Objective to Tape Measure, insert the measured and observed values into the formula. To illustrate this example:

$$\text{TFOV} = (6\text{ inches} \times 57.3) \div 720\text{ inches} = 0.48^\circ\text{ of TFOV}$$

The accuracy of any of these formulas can only be as accurate as the measure taken by the observer. It is therefore recommended that several measurements be taken and the average of the multiple measurements is used. When this is done the resulting answers can be provided with a level of accuracy based on the multiple measurements taken. The formulas to calculate this simple accuracy method is:

$$\text{Results} = \frac{(Value1 + Value2 + ValueN)}{\text{N}}$$

Notes: When taking field measurements, the measurement should be repeated several times, then the average taken using the formula for averages above. Once the average measure is calculated, then the formula for accuracy below can be used to express the accuracy of the average.

$$\text{Accuracy} = \pm \frac{(MaximumValue - MinimumValue)}{2}$$

To illustrate the above formulas, if the above TFOV measurement was conducted three times, where each of the measures was repeated and the three results were 0.43°, 0.48°, and 0.53°, then the result's average that would be reported is = (0.43° + 0.48° + 0.53°) ÷ 3 = 0.48°. The accuracy that would then be reported would be: (0.53°–0.43°) ÷ 2 = ± 0.05°.

Magnification, Brightness, and Contrast

Most people both inside and outside of the astronomy hobby understand the relationship between magnification and brightness—which is the greater the magnification the larger the image appears and the dimmer it appears. Some even understand the more exact relationship of brightness to magnification, which is that if you double your magnification then the image becomes only one quarter as bright. A more accurate representation of what is being observed is called the inverse-square law. Light follows what is called the inverse-square law, which for our use in visual astronomy with a telescope we would represent as follows:

$$\text{Brightness} = \frac{1}{(\text{Magnification2} \div \text{Magnification1})^2}$$

To illustrate, when observing the Moon at 100×, if the magnification is then tripled for the second observation to 300×, then using the formula above the brightness of the Moon through your telescope for the second observation would appear only 1/9 as bright:

$$\text{Brightness} = 1 \div (300 \div 100)^2 = 1 \div (3)^2 = 1 \div 9 = 1/9\times$$

Going the other direction, observing the Moon at 300×, if the magnification is reduced to 100× for the second observation, then the brightness of the Moon through the telescope would appear 9× as bright for the second observation:

$$\text{Brightness} = 1 \div (100 \div 300)^2 = 1 \div (1/3)^2 = 1 \div 1/9 = 9\times$$

Even though light follows this inverse-square law, using it will not always predict how the brightness will change when viewing through the eyepiece and telescope in certain circumstances. In our example of observing the Moon, this target does follow the inverse-square law faithfully, since the Moon will many times completely fill the field of view of the eyepiece, and as we further magnify the Moon its image will grow and become dimmer as expected. However, when observing stars things may start behaving much differently. Stars generally do not follow our expectations for the inverse-square law because for the typical observing magnifications stars will not enlarge with more magnification and they will remain a point of light. Because of this, all of the light energy coming from that star remains in that one point in the eyepiece's field of view, not growing larger, and consequently will not appear to dim. In fact, as the magnification is increased the stars may even appear brighter! Why?

If observing from a location that has any light pollution, the background sky itself will have a small glow that is seen through eyepiece. The background in the field of view of the eyepiece will be dark, but not completely black when observing from light-polluted locations. This is especially evident when using lower magnifications. However, when magnification increases the background glow of the sky will be magnified and dim faithfully according to the inverse-square law, just as the Moon dims. So with more magnification when observing stars, the background field of view in the eyepiece will grow darker while the stars will appear to have the same brightness. This increase in contrast between a dimming and darkening background, and a constantly bright star point, makes the stars in the field appear more distinct and brighter to our perceptions. In addition, as the background field of view darkens more and more stars in the eyepiece's field of view will actually appear, as these dimmer stars will no longer be hidden by the bright background. This latter situation is why the limiting magnitude of stars visible to a telescope of a given aperture is also dependent on both the prevailing light pollution of the observing site as well as the magnification used to observe, and not just the aperture of the telescope.

The lesson of magnification in astronomical observing is therefore that for some targets, such as the Moon and planets, they will appear dimmer as magnification is increased. However, for other targets, such as stars, open clusters, globular clusters, and even nebulae and galaxies, these become easier to see as magnification is increased (up to a point), since the background field of view will dim and darken, allowing the stars to stand out more distinctly. Understanding the intricacies of these relationships and experimenting for yourself will aid greatly in an observer's ability to use eyepieces most effectively.

Aberration Control (Telescope Dependencies)

As discussed earlier, there are numerous optical designs, each of which has distinctive optical characteristics and performance capabilities. When choosing an eyepiece, optical designs become an important consideration, depending on the telescope that is used with the eyepiece. Where the optical design of the eyepiece becomes important is when the focal ratio of the telescope is short, particularly for telescope focal ratios of f/5 or less. As an example, if the intent is to use a wider field eyepiece, like one based upon the König design, then the majority of the off-axis of the field of view will have moderate to severe aberrations if the telescope's focal length is much shorter than f/8. So star points will show as aberrations in the off-axis, and the view will not appear pleasing to many observers. However, place that same König eyepiece in an f/10 telescope, and the majority of the field of view will show beautifully sharp and well defined.

As a general rule-of-thumb, simpler optical designs, those with five or fewer elements, should not be expected to perform well off-axis if they have AFOVs wider than 55° and are used in telescopes with focal ratios shorter than f/6 or f/7. This is not to say that it is impossible for these simpler designs to perform well off-axis in short focal ratio telescopes, but it should simply raise a warning flag that the observer is best advised to seek observers knowledgeable with the eyepiece in question prior to committing to any purchase. As observers become more familiar and experienced with the various eyepiece designs, they will begin to get a fairly accurate intuitive feel for which may perform better in the various telescope designs and focal ratios.

With the more modern and complex optical designs using specialized glass types and/or many more optical elements, there are some of these that have a distinct reputation for performing well in telescopes with f/6 and shorter focal ratios. Some of these include the Plössl, the Abbe Orthoscopic, the TMB Planetary, and the Tele Vue Radian for narrower AFOV eyepieces. For wide fields, check out designs branded as Tele Vue Ethos, Tele Vue Nagler, Tele Vue Panoptic, Tele Vue Delos, Explore Scientific 100/82/68 Series, Meade 4000 and 5000 SWA/UWA, Pentax XL/XW, and Nikon NAV.

Choosing an eyepiece for a short focal ratio telescope requires a considerably greater expenditure in time and research (as well as money) to ensure the eyepiece will perform up to expectations, particularly when the focal ratio is shorter than f/5. A best practice is to first borrow the eyepiece from a friend if feasible; otherwise conduct online research and ask fellow amateur astronomers to get as many opinions as possible. After this, make sure the return policy of the store is fully understood if expectations are not satisfied so the eyepiece can be returned.

In the end, since there are many factors that contribute to perceived aberrations, from the human eye to the eyepiece to the telescope and to the atmosphere, it is impossible to predict the exact performance of any eyepiece in a unique optical chain to a great degree of accuracy. Instead, only a ballpark prediction is usually feasible. Therefore, as in so many other circumstances, it is best to seek advice from others who have similar telescopes and the eyepiece in question to get their impressions, or to attend a local club's evening observing session to get first-hand experience.

Observing Strategies

The average observer approaches astronomical observing as taking a broad range of eyepiece focal lengths out to the telescope, then simply switching eyepieces in and out of the telescope until they see a view they consider good. Although there is nothing wrong with an approach to observing where an extensive range of eyepiece focal lengths are purchased and used in a trial-and-error process for all possible observing needs, there are a number of observing strategies that can also be employed instead of the trial-and-error method. Each of the strategies listed have their own distinct strengths and weaknesses, but they all provide the observer with more considered methods of choosing eyepieces to be used that can result in an improved view and less labor intensive method than the trial-and-error method. Some of these effective time-tested strategies are:

- Focal length choices (or magnification strategies)
- Exit pupil
- High magnification
- Intended targets
- Comparing one eyepiece to another

Focal Length Choices

Amateur astronomers use a variety of different strategies when choosing eyepiece focal lengths to build a range of needed capability with their telescope. A very time honored and popular strategy is to choose focal lengths that produce magnifications of 50×, 100×, and 150× in the telescope. Some amateurs extend this rule and say it should also include focal lengths to obtain 200×, and even 250× or 300×. This strategy is actually a highly practical approach, as observing conditions rarely allow magnifications above 300× for most locations. Another nice aspect of this is that the eyepiece collection can be fairly small and still give an excellent range of magnifications. Basically, three eyepieces and one 2× Barlow are all that are needed to implement this strategy and have a full range of magnifications.

With just three eyepieces that produce 50×, 100×, and 150×, plus a 2× Barlow to enable the eyepieces that produce 100× and 150× to generate 200× and 300×, this small collection can provide all the capability the average observer will need for the vast majority of situations. Minimalist sets such as this are often praised by observers as being "freeing," since it takes their focus away from the myriad of choices when there are too many eyepiece choices, and instead allows more concentration on the act of observing. For the beginner, this strategy excels because it requires the least amount of equipment and expense, and for the seasoned observer it is highly effective because it allows greater attention to observation versus the equipment.

A second popular strategy is to have the eyepieces provide jumps in magnification in approximately 1.4× or 1.5× increments. To illustrate, if the first eyepiece produces a magnification of 50×, then using the 1.4× rule the second selected would produce $1.4 \times 50 = 70\times$, then the third would produce $1.5 \times 75 = 98\times$, and so on. This method can be calculated using only the eyepiece focal length instead of magnifications and have the same results. To do this, divide the focal length of the eyepiece by 1.4× magnification jump factor instead. When using this method with eyepiece focal lengths instead of magnifications, one must necessarily start with the longest focal length eyepiece they desire. To illustrate, if the lowest magnification eyepiece desired is a 20 mm wide field, then the next eyepiece focal length needed is 20 mm ÷ 1.4 = 14 mm, followed by 14 mm ÷ 1.4 = 10 mm, and so on. As can be seen, these focal lengths actually represent what some manufacturers provide (e.g., the Pentax XW line's 1.25 in. eyepieces come in focal lengths that have 1.4× separations: 20 mm, 14 mm, 10 mm, 7 mm, 5 mm, and 3.5 mm). The advantage of thinking of this rule in terms of eyepiece focal lengths is that, regardless of the telescope used, these focal lengths would produce magnification jumps in the same 1.4× increments, and if it is not possible to find eyepieces in the exact focal lengths dictated by the rule, simply choose an eyepiece with a focal length that is possible.

Fig. 2.15 The Pentax 1.25 in. XWs made in 1.4× focal length increments (Image by the author)

A third strategy, one touted by amateur astronomer Don Pensack from Los Angeles, California, is the 1×/2×/3× rule. With this rule the value of "x" in the rule varies based on the aperture of the telescope; for 6–8 in. aperture x = 50, for 10 in. aperture x = 60; for 12.5 in. aperture x = 70, and for 18–20 in. x = 80. The uniqueness of this rule is that it defines a nice minimalist set of magnifications that are also tuned to the magnification potential of each aperture class of telescope. Using this method, with a 10 in. 'scope where x = 60, the three eyepieces that result provide the following highly useful range of magnifications:

$$1 \times (60) = 60 \times$$

$$2 \times (60) = 120 \times$$

$$3 \times (60) = 180 \times$$

If the telescope was a 1,200 mm focal length 250 mm (10 in.) f/4.7 Dobsonian, like those offered by Orion Telescopes and others, then to calculate the focal lengths needed for this 1×/2×/3× rule simply divide the focal length of the telescope by the magnifications specified by the rule. Since the rules says that a 10 in. would use x = 60, the 1×/2×/3× magnifications are: 1 × 60 = <u>60×</u>, 2 × 60 = <u>120×</u>, and 3 × 60 = <u>180×</u>. The eyepiece focal lengths required then become:

$$1200 \div 60\times = 20 \text{ mm}$$

$$1200 \div 120\times = 10 \text{ mm}$$

$$1200 \div 180\times = 6.7 \text{ mm}$$

Since these strategies are more optimized to produce a minimal set of eyepieces to satisfy a broad range of observing, they work best when special attention is paid to the longest focal length eyepiece. In the above example, using the 250 mm (10 in.) f/4.7 Dobsonian telescope, if the 20 mm eyepiece chosen was a 50° AFOV Plössl, then much of the maximum TFOV potential of the telescope would be lost. A 250 mm (10 in.) f/4.7 telescope with a 2 in. focuser has a maximum TFOV potential of approximately 2.2°, whereas the example 20 mm 50° AFOV Plössl would only give 0.82° TFOV. So with these methods, the longest focal length should be a quality ultra wide-field eyepiece so the capability exists for observing larger celestial objects (e.g., a 20 mm 82° AFOV eyepiece would produce 1.3° TFOV and a 20 mm 120° AFOV eyepiece would produce 2°, close to the maximum potential of the telescope).

Another strategy to use in choosing eyepiece focal lengths is to select them based on the specific exit pupils that are generally considered optimum for the basic observing situations (the section that follows this continues with an in-depth discussion on exit pupil). An example of this method is to choose focal lengths that produce exit pupils within the following categories so at least one eyepiece is available that is optimized for that category of observing:

- Maximize image brightness—6 mm (light-polluted observing site) / 7 mm exit pupil (dark site)
- General observing exit pupil—4 mm to 5 mm exit pupil
- Optimum deep sky object (DSO) exit pupil—2 mm to 3 mm exit pupil
- Optimum planetary exit pupils—0.75 mm, 1 mm, and 1.5 mm exit pupils
- Filler focal lengths if a transitional magnification or TFOV capability is desired between the major categories

Fig. 2.16 Example of how strategically using a Barlow allows almost no focal length overlap. No Barlow—35 mm, 25 mm, 17 mm, and 12.5 mm. With 2.8× Barlow—12.5 mm, 8.9 mm, 6.1 mm, and 4.5 mm (Image by the author)

The final strategy that observers use is the trial-and-error method. This strategy is very simplistic, popular, and unfortunately the highest cost option. It involves simply purchasing as many focal lengths as possible, from long focal lengths for widest TFOV to a number of special high magnification focal lengths for planetary observing. When at the telescope, since the observer has a large selection of eyepieces in many focal lengths, the process is simply to experiment with the different focal lengths until one is found that best portrays the target being observed. The advantage of this method is that no pre-planning is required, making the observing session simple and intuitive. The disadvantage is that an optimum focal length eyepiece may not be available for the particular target, or even known since no planning was conducted to best exploit the capabilities of the telescope. A further disadvantage is that many eyepieces are needed that complicates set-up of the equipment, especially if it is at a remote location. However, even though this strategy is more of a "brute force" approach, it still is a highly successful approach that is used by many observers.

Regardless of the strategy one may choose, seasoned observers realize that it is not necessary to have a large number of eyepieces for enjoyable and productive observing. Some amateurs use as little as only two or three eyepieces with a Barlow and never find themselves wanting. Whatever strategy is selected, it is important to take into account the maximum practical magnification for the telescope, and also how much magnification the typical sky conditions at the observing locations will permit. Many suburban observing sites do not allow magnifications greater than 200× regardless of the aperture of the telescope, whereas other observing sites have typical sky conditions that are more stable, allowing magnifications of 400×, 500× and more.

For the seasoned observer, eyepiece focal length choices typically involve assessment of the following factors: (a) the telescope's limits, (b) the TFOVs needed to best frame the anticipated celestial targets, and (c) the prevalent sky conditions of the intended observing site. For beginners, however, until they gain several years of experience, choosing eyepiece focal lengths that will produce 50×, 100×, 150×, together with a 2× Barlow accessory to attain the less used 200× and 300× magnifications, may be the soundest approach.

Calculating Exit Pupil

In the previous section in the discussion of eyepiece focal length/magnification strategies, the concept of taking advantage of exit pupils for observing strategies was introduced. As was learned, the exit pupil is not a property of an eyepiece by itself but is actually a combined property of both the eyepiece and the telescope.

There are at least five common situations where calculating exit pupils can be a beneficial strategy for observing. These situations range from maximizing the potential of the telescope's capability to finding exit pupils that work best on various celestial objects:

1. Equalizing image brightness between telescopes
2. Planetary high magnification improvement
3. Matching exit pupil to the eye's dark-adapted state
4. Darkening the background sky under light-polluted skies
5. Optimizing the search for deep sky objects

1. <u>Equalizing Image Brightness Between Telescopes</u>
   When an eyepiece is in the telescope and the image is brought to focus, this image is formed within a small circle above the eye lens at the eye relief point of the eyepiece. All the light gathered from the telescope is then contained in the circle of this image. Therefore, when the diameter of the exit pupil is the same in two different telescope-eyepiece combinations, this indicates that the brightness of the image produced by both telescopes is the same. Even though the two telescopes may have completely different aperture sizes, when eyepieces are chosen for each

telescope that produce an identical exit pupil, this means the image in each telescope will appear just a brightly. The magnifications may be different due to the apertures and focal lengths of each telescope, but the brightness will be the same when each eyepiece produces the same size exit pupil. Since the exit pupil is a measure of brightness that is “independent” of the aperture of the telescope, it becomes a valuable tool that the seasoned observer can use to their advantage.

To calculate the exit pupil of an eyepiece and telescope combination, either of the following formulas will provide equally accurate results:

a. $$\text{Exit Pupil} = \frac{\text{FL[eyepiece]}}{\text{FR[telescope]}}$$

Notes: FL[eyepiece] means the focal length of the eyepiece in millimeters. FR[telescope] means the focal ratio of the telescope, which is the focal length of the telescope in millimeters divided by the aperture of the telescope in millimeters.

b. $$\text{Exit Pupil} = \frac{\text{APERTURE[telescope]}}{\text{Magnification}}$$

Notes: APERTURE[telescope] means the diameter of the main objective of the telescope in millimeters. Magnification is the magnification produced by the eyepiece in the telescope, which is the focal length of the telescope divided by the focal length of the eyepiece.

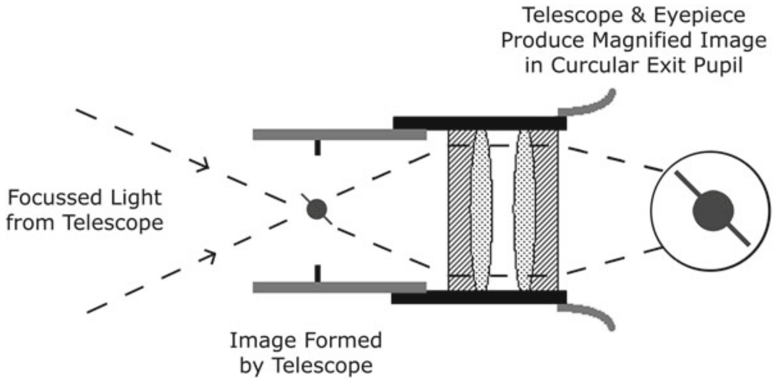

Fig. 2.17 Exit pupil circle (Illustration by the author)

To illustrate exit pupils in action, let’s use formula 1 with two different eyepiece and telescope combinations. Assume that telescope “A” has an aperture of 200 mm, a focal ratio of f/6, a focal length of 1,200 mm, and has an eyepiece with a focal length of 12 mm. Using the formula to calculate magnification, this eyepiece will produce a magnification of 1,200 mm/12 mm or 100× in telescope "A." What will the exit pupil size be of the 12 mm eyepiece in our 200 mm f/6 telescope? Using formula 1 we would calculate it as the eyepiece focal length, or 12 mm, divided by the focal ratio of the telescope, which is f/6. So the exit pupil is 12 mm ÷ 6, or 2 mm. The 12 mm eyepiece in the 200 mm f/6 telescope will therefore produce a 2 mm exit pupil at a magnification of 100×.

If telescope "B" is a 100 mm f/8 telescope, what eyepiece is needed that would produce the same 2 mm exit pupil so its view will appear just as bright as it was in telescope "A"? Again, formula 1 can be used for this, but it needs to be rearranged so it solves for eyepiece focal length instead of exit pupil. To illustrate:

$$\text{Exit Pupil} = \text{Eyepiece Focal Length} \div \text{Focal Ratio of Telescope}$$

solved for eyepiece focal length becomes…

$$\text{Eyepiece Focal Length} = \text{Exit Pupil} \times \text{Focal Ratio of Telescope}$$

Inserting the values we have for our example's 100 mm f/8 telescope "B" in the above formula becomes:

$$\begin{aligned}\text{Eyepiece Focal Length} &= \text{Exit Pupil} \times \text{Focal Ratio of Telescope}\\ &= 2\ \text{mm} \times \text{f}/8\\ &= 16\ \text{mm}\end{aligned}$$

Performing the exit pupil calculations we have discovered that the image observed in the 200 mm f/6 telescope "A" with a 12 mm eyepiece will appear just as bright as the image observed in the 100 mm f/8 telescope "B" using a 16 mm eyepiece. The magnifications will be different, 100× in telescope "A" and 50× in telescope "B," but their brightness will appear the same. For observers who have multiple telescopes, or who wish to purchase new telescopes, the exit pupil calculations can be invaluable in gauging how the brightness of the view will compare for their favorite targets.

2. Planetary High Magnification Improvement

Another area where knowing the exit pupil becomes particularly important is in planetary observing. Observers typically find that when the exit pupil gets smaller than 0.75 mm, most of the primary planets such as Jupiter, Saturn, or Mars begin to appear dim and lack the high contrast necessary to show many of their fainter details. So regardless of the telescope's aperture, exit pupil calculations allow the observer to determine the optimum eyepiece and telescope combination to produce what will essentially be the highest magnification where brightness and contrast are at an optimum level for planetary observing.

To illustrate, assume that an observer has a 100 mm telescope and feels that once the magnification get above 150× planets generally appear too dim to the eye. So with a 100 mm telescope he or she prefers 150× as a maximum planetary magnification, where details are most pleasingly bright and shown in high contrast. After many years with the 100 mm telescope, a more powerful planetary telescope is wanted that could view planets at 225× and have the image appear just as bright and with just as much contrast as is currently enjoyed with the 100 mm telescope at 150×. What aperture telescope would provide this capability? To answer this, we use the exit pupil calculation.

What is required first is to calculate the exit pupil of the current 100 mm telescope when observing planets at maximum preferred magnification. Knowing the aperture of the telescope, 100 mm, and the magnification, 150×, using exit pupil formula 2 to calculate the exit pupil of this telescope at 150× becomes:

$$\text{Exit Pupil} = \text{Telescope Aperture} \div \text{Magnification}$$

$$= 100\text{ mm} \div 150\times$$

$$0.67\text{ mm exit pupil}$$

We now know that a 0.67 mm exit pupil is the observer's personal preference for maximum magnification when planetary observing with their 100 mm telescope. Using exit pupil calculations, what aperture telescope should observers upgrade to if their goal is to observe planets that will appear just as brightly at 225×? Again, exit pupil formula 2 can be rearranged to solve for the unknown aperture as follows:

$$\text{Exit Pupil} = \text{Telescope Aperture} \div \text{Magnification}$$

Solved for aperture the above formula becomes…

$$\text{Telescope Aperture} = \text{Exit Pupil} \times \text{Magnification}$$

$$= 0.67\text{ mm} \times 225\times$$

$$= 151\text{ mm aperture telescope}$$

Using exit pupil calculations gives the observer the flexibility to remove much of the guesswork from situations like these, and therefore permit more considered decisions. In the scenario just presented, understanding how to use exit pupil calculations allows the observer to predict outcomes without having to resort to trial and error experiments. Instead, using exit pupil calculations, they are able to reliably predict that a 151 mm aperture telescope will provide them their goal to view planets at 225×, instead of at 150×, and they will appear just as bright and high contrast as their current 100 mm telescope performs at 150×.

A note of caution, though. Exit pupil analyses such as these work best when the compared telescopes have the same overall transmission efficiency. That is, both telescopes are of the same optical designs, such as two doublet refractors or two Newtonians with both using similar anti-reflection technologies on their optics. A 151 mm SCT telescope at 225× producing a .67 mm exit pupil would not show its image as brightly as a 100 mm refractor at 100× producing the same .67 mm exit pupil. The reason for this is that mirrored surfaces do not transmit light as efficiently as glass surfaces. To adjust these exit pupil calculations to account for the different transmission efficiencies of typical telescope designs, consult a trusted resource on telescope optics, an online astronomy forum, or members of a local astronomy club for assistance.

3. Matching Exit Pupil to the Eye's Dark-Adapted State

If an observer wishes to determine the eyepiece that will have an exit pupil with the lowest practical magnification for the telescope, the general rule of thumb is to keep the maximum exit pupil produced by the eyepiece-telescope combination at 7 mm or smaller to match the dark-adapted human eye. A 7 mm exit pupil is recommended, since popular wisdom advises that the average dark-adapted human eye can open to approximately 7 mm in diameter. This collective experience holds well with multiple studies that generally report that for a range of individuals with normal vision between 20 and 70 years of age, the average measured dark-adapted pupil dilation varies by age between 7.5 and 5.5 mm (*Note:* This was the average range; a very few individuals had a maximum opening as high as 9 mm and as low as 4 mm). Therefore, if the eyepiece and telescope are producing an exit pupil larger than 7 mm, then a portion of the light from the telescope is blocked by the eye's pupil if the observer is an average individual with a maximum pupil opening of 7 mm.

To illustrate the issue with eyepiece-telescope combinations producing overly large exit pupils, if the eyepiece-telescope combination is producing an exit pupil of 8 mm, and the observer's eye can only open to 7 mm, then 1 mm of the light cone is being blocked, which represents a full 23 % loss in the available brightness of the image.

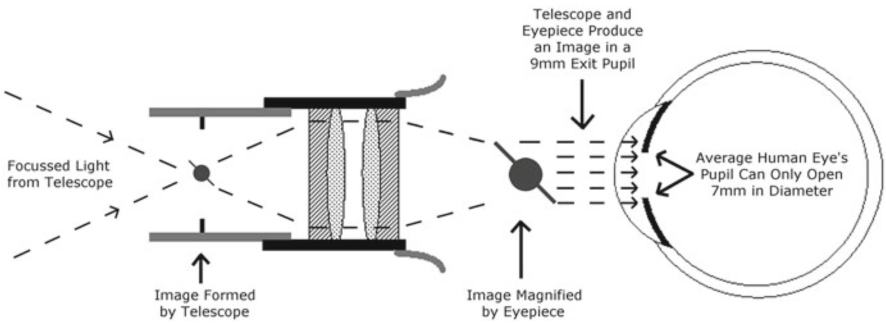

Fig. 2.18 Human eye blocking light when the eyepiece-telescope exit pupil is too large (Illustration by the author)

Another way to think about the potential light loss from excessively large exit pupils is to equate how this light loss would compare to telescope aperture. Since the area of a 7 mm diameter circle is approximately 23 % less than the area of an 8 mm diameter circle, this means that the observer is potentially losing 23 % of their telescope's light-gathering capability if they are using an eyepiece that produces an 8 mm exit pupil and their dark-adapted eye only opens to 7 mm. If they were using a 100 mm telescope, the brightness loss by using an eyepiece producing an 8 mm exit pupil would make it appear that the image was only as bright as what they would see in a telescope of approximately 88 mm. If they were observing with a 250 mm (10 in.) aperture telescope with an 8 mm exit pupil then it would be like their telescope was only 226 mm (8.9 in.) instead.

Because the pupil of the average dark-adapted human eye may only open to a maximum of 7 mm, does this mean larger exit pupils should never be used? The answer to this is "No," as using larger exit pupils than recommended only means that the observer should expect the image to appear dimmer than might be expected. If an observer desires to use an eyepiece-telescope combination that produces an exit pupil larger than 7 mm to obtain a view with wider TFOV, then this is a perfectly acceptable practice. It is actually a common practice by many observers to use exit pupils larger than 7 mm, as the brightness of star points are generally not perceived to dim nearly as much as with faint objects such as nebulae and galaxies.

Therefore, a large and bright cluster such as the Pleiades will show just as spectacularly using an 8 mm exit pupil as it does when using a 7 mm exit pupil. However, targets like the great Orion Nebula will appear much dimmer with less nebulosity visible at an 8 mm exit pupil than it does at a 7 mm exit pupil. So it is best to use an eyepiece-telescope combination that produces exit pupils larger than the eye can accommodate wisely; acceptable if the goal is to see the widest amount of sky possible, not recommended if the goal is to observe fainter objects, as they may appear dimmer than desired.

4. <u>Darkening the Background Sky under Light-Polluted Skies</u>
   To determine the eyepiece-telescope combination that will have the largest "practical" exit pupil when observing under brighter light-polluted skies, many observers feel that keeping the largest exit pupil to 6 mm or even 5 mm is a best guideline. Since the background sky appears brighter with larger exit pupils, using an eyepiece that generates a 5 or 6 mm exit pupil will make the background sky in the eyepiece appear darker and richer. This darker background then allows the stars to show themselves with more contrast against the darker background than with an eyepiece that produces a larger exit pupil. Observers should experiment for themselves if they routinely observe from sites with light-polluted skies, as they may find that a shorter focal length eyepiece that has a wider AFOV and produces a 5–6 mm exit pupil proves an aesthetically improved view with little practical loss in TFOV if they choose the widest AFOV eyepiece available. This is a primary reason why eyepieces such as the Tele Vue 31 mm Nagler, Explore Scientific 30 mm 82 Series, William Optics 28 mm UWAN, Explore Scientific 25 mm 100 Series, and the

Tele Vue 21 mm Ethos have become more popular choices, producing smaller exit pupils in telescopes than the longer focal length eyepieces such as the 56 mm Plössl.

5. Optimizing the Search for Deep Sky Objects
Finally, to determine the low magnification eyepiece that will be most effective for hunting faint deep sky objects, many observers recommend using an eyepiece that will produce an exit pupil between 2 and 3 mm. At these smaller exit pupils the background sky appears very dark, providing a higher contrast between the background sky and the faint deep sky object. This higher contrast then allows these faint deep sky objects to be more easily seen. In addition to the higher contrast of the view, if the observer also plans to use this eyepiece to "hunt" for deep sky objects, it is best for him or her to use one with as wide of an AFOV as possible so a larger portion of the sky is visible (i.e., a larger TFOV).

To illustrate the importance of maximizing the eyepiece AFOV when hunting for deep sky objects using smaller 2–3 mm exit pupils, let's calculate the numbers using an operative example. Let's assume the observer is using a popular variety of the 203 mm (8 in.) f/6 Dobsonian telescopes available today. With that type of telescope, an eyepiece that would produce a 3 mm exit pupil would need to have a focal length of 18 mm (exit pupil = eyepiece focal length ÷ telescope focal ratio). Performing the calculations for magnification, an 18 mm eyepiece in this telescope would produce 67×. At that magnification, the TFOV of an 18 mm Plössl with its 50° AFOV would only be about 0.75°, which is quite small. If an 18 mm 82° wide-field eyepiece was used instead, the TFOV visible would be 60 % larger (e.g., 1.2°), allowing coverage of a larger region of the sky and improving chances of finding elusive targets.

Exit pupil calculations add more complexity to the observing experience, and as a result many observers dislike taking advantage of what they can provide. However, if an observer possesses a full range of eyepiece focal lengths from 40 mm to 4 mm, then it is certainly easy enough to simply find the eyepiece that provides the best exit pupil for observing through trial and error without doing any calculations. The disadvantage of trial and error is that it can be time consuming, and many observers find knowledge of exit pupils and skill in applying that knowledge when planning an observation can actually allow them to devote more time to observing. Regardless of whether an observer chooses to use an exit pupil methodology or not to guide their observing, exit pupils remain a valuable tool for the amateur astronomer.

High Magnification

Rarely is magnification discussed in the context of an observing strategy. More often, magnification, especially high magnification, is discussed in the context of what may be maximum magnification limits for a particular telescope. There are also many excellent books and online communities where the many aspects of what affects the magnification capabilities of a telescope are detailed (e.g., Dawes limit, the Rayleigh criterion, the mean transfer function, the seeing and transparency of the atmosphere, and the thermal acclimation of the optics to the outside environment). In the context of the eyepiece, however, the considerations are not what magnifications can be achieved but more about how eyepiece features can be advantageous or disadvantageous when conducting high magnification observing.

The four primary attributes of an eyepiece that impact its usability for high-magnification observing are:

- Eye relief
- Apparent field of view (AFOV)
- Off-axis performance (e.g., lack of aberrations/distortions that reduce sharpness of the image)
- Transmission and contrast

Each of these attributes are more or less important when using the eyepiece, depending on the particular observer, the target they are observing at high magnification, and the stability and tracking capability of the telescope's mount.

Eye relief becomes important from the standpoint of comfort during long observing sessions. Typically, as the eyepiece's focal length becomes shorter, so does the eye relief. This is especially true for the classical designs that use a minimum number of elements such as the Plössl, Abbe Ortho, König, Brandon and similar simple designs. As an example, a typical modern 25 mm Abbe Ortho eyepiece has an eye relief of about 20 mm. However, the same eyepiece design in a 4 mm focal length will only have an eye relief of only about 3.5 mm. These designs, with their minimum eye relief, are considered by many observers to be best for short duration observing tasks only. When a high performing eyepiece that contains the least amount of glass to maximize perceived brightness and contrast is the advantage to leverage, then these classic designs excel. However, if the task requires long observation time, such as when studying an object in detail or when sketching, the short eye relief can be counterproductive to the objectives of the observation. Optimizing eye relief for high magnification observing is therefore dependent on the exact type of observing task planned, and can vary with long eye relief being an advantage, or short eye relief being acceptable.

The second attribute to consider when using a high magnification eyepiece is apparent field of view. This attribute is important depending on the target being observed. If the target is a planet or double star, as an example, then there is little to be gained by using an eyepiece with a wide AFOV, since there is rarely any context around these objects to observe. In fact, many observers comment that they prefer the smaller AFOV eyepieces for these type targets, as they provide fewer distractions to observing the primary target. However, if the plan is to conduct high magnification observations of other targets, such as globular clusters, then it may be an advantage to use a high power eyepiece that also has a wider AFOV. An example of this situation is when observing globular clusters. These objects often have stars extending a significant distance from their core, so a wider AFOV is a distinct advantage when observing them at high magnification. The wider AFOV eyepiece affords a distinct advantage in this circumstance, as the greater TFOV around the object is preferable to have in the field of view of the eyepiece.

In addition to the context of the surrounding field of view of the target being observed, another important reason to use an eyepiece with a wider AFOV for high magnification observing is when the telescope's mount does not track the object automatically, or if it is not stable. When using very high magnifications, the TFOV visible in the eyepiece naturally becomes smaller. Consequently, if the telescope's mount does not automatically track, the target will drift through the field of view in just a view seconds, potentially resulting in only a very brief observation. Use of a larger AFOV eyepiece means that the object takes longer to drift through the field of view and therefore the observation can be longer. In addition, if the mount is not stable, then higher magnification observing can accentuate this instability, and with a narrow AFOV eyepiece even the simple act of focusing may cause the target to severely jitter or even move completely out of the field of view. Therefore, if the telescope's mount is not stable or if it does not have automatic tracking, then a wider AFOV eyepiece is generally a better choice if high magnification observing is planned.

The third consideration for high magnification observing is the performance of the off-axis of the eyepiece with the telescope. Like one of the AFOV considerations, off-axis performance is generally more important if the telescope's mount does not have automatic tracking. In these circumstances, since the target will drift rapidly through the field of view at high magnifications, it is customary to place the target at one end of the field of view so observing time can be maximized as it drifts across the entire field of view. If the eyepiece chosen has an off-axis with aberrations and distortions (i.e., field curvature, astigmatism, lateral color, etc.), these will reduce the sharpness of the image, further limiting the time during the drift that the object will appear sharp for a productive observation. Therefore, for high magnification observing it is important to understand how the off-axis of the eyepiece chosen will perform in a telescope that does not have a tracking mount.

As an example, the TMB Monocentric eyepiece, one of the very best performers for high magnification planetary observing, has a poor performing off-axis in short focal ratio telescopes. In a short f/5 Dobsonian, as much as 50 % of TMB Monocentric's field of view may be out of focus. Although this eyepiece is an excellent choice for a short focal ratio telescope with tracking, where the planet is maintained in the center of the field of view, this eyepiece becomes a poor choice for short focal ratio non-tracking telescopes.

The last characteristic we will highlight that can be an important consideration when conducting high magnification observations is the perceived transmission and contrast performance of the eyepiece. It is important to note that these characteristics of an eyepiece are very difficult to assess; therefore these performance characteristics are usually only found in the field observing reports sometimes provided by other amateur astronomers. Where the transmission and contrast characteristics of an eyepiece come into play is for the most part in two very specialized areas of observing: planetary observing and faint galaxy/nebula observing. For those observers where planetary or detailed observations of faint deep sky galaxies/nebulae are a passionate pursuit, finding and using eyepieces that perform best on these targets is a never-ending quest. For these observers it is a constant challenge to attain the best possible eyepieces for the task, scrutinizing all new entrants to the field that could possibly render these targets a little bit better when viewed through their favorite telescopes.

For the general observer, however, this nuance of eyepiece performance is not always that important of a consideration because most modern eyepieces perform at exceptional levels of transmission and contrast, so having the best-of-the-best is not a passionate pursuit. Therefore, only for those observers who depend on very small gains in brightness and contrast to bring out the most challenging aspects of a planet, galaxy, or nebula will these difficult to assess characteristics of an eyepiece become important.

When considering an eyepiece's transmission, we know from a theoretical standpoint that each air-to-glass interface in the optical design loses a small portion of light. Therefore, those eyepieces with more glass groupings in the design will theoretically have a lower transmission than those with fewer lens groups. As an example, a Plössl design has four elements of glass in two groups. These two groups then have four air-to-glass interfaces. When compared to another eyepiece that has more than two groups in its design, the Plössl will transmit a little more light (as long as the anti-reflection coatings and glass types in each eyepiece are the same). Therefore, the general assertion one often hears is that eyepieces with simpler designs, having less glass, will be brighter, transmitting more light.

This is actually very true from a theoretical standpoint. As long as all other aspects of the eyepieces are the same (e.g., level of polish of the lenses, coatings, internal baffling, etc.) eyepieces with fewer lens groups will transmit slightly more light and also have slightly higher contrast. However, although this may be true from a theoretical standpoint, it cannot be reliably extended to production eyepieces because each manufacturer builds its eyepieces using coatings of different efficiencies, spending more or less cost on internal baffling and polishing of the glass, etc. Even a same line and focal length of eyepiece can have different levels of anti-reflection coating efficiency if the manufacturer upgraded the coatings over time. It is therefore impossible to generalize that an eyepiece with less glass will actually be better in terms of transmission and contrast, or that even the same brand eyepiece of different production vintages will have the same transmission and contrast.

Given these difficulties, how can the transmission and contrast characteristics of an eyepiece be determined? Unfortunately, manufactures do not indicate the test results for transmission and contrast from their production eyepieces, so there are no quantitative reference sources to determine a particular eyepiece's transmission or contrast characteristics. However, there is a wealth of qualitative information on these attributes for eyepieces—the multitude of user reports and reviews on how select eyepieces performed when used in specific telescopes observing specified targets. Over the years, based on a predominance of observer reports and reviews, several eyepiece lines have gained a strong reputation as being top performers, providing views that are perceived by the observers as having slightly improved levels of both brightness and contrast. These reports, as with any observation report, do not tell if the actual transmission or contrast of an eyepiece is different, but they can convey an observer's subjective perception of image brightness and perceived contrast. And these reports also cannot tell if it was solely the eyepiece responsible, as it is nearly always impossible to separate characteristics of the telescope from the eyepiece.

So when reading observation reports understand that they are, in reality, optical "system" reports instead of "eyepiece" reports, since the entire optical chain is involved in the observations being noted by the observer and not just any one element. However, with all these caveats in place, over many years there were developed a handful of eyepieces that have consistently obtained accolades from observers related to how sharply they are perceived to perform, their lack of perceived scatter, their perceived brightness, and their perceived contrast. Examples of these are the Zeiss Abbe Orthos (ZAO) versions I and II, the TMB Supermonocentrics, the vintage Carl Zeiss Jena (CZJ) Orthos (.965 in. barrels only), the Pentax SMC Orthos (.965 in. barrels only) and Pentax XOs, and the Astro-Physics Super Planetary (AP-SPL). This elite group of eyepieces have the reputation of providing the brightest, highest contrast, and most detailed views for both planets and many faint deep sky objects. The optical designs for all these eyepieces, coincidentally, fall into the "less glass" variety, with all of them being two or three group designs with only five or fewer glass elements. These eyepieces also, coincidentally, fall into the class of having extremely high quality builds, with premium optics and premium prices.

Although the elite planetary group of eyepieces are considered the best-in-class, this does not mean that there are not more complex optical designs that do not come very close to the performance of the elite planetaries. It is worth it to note that many observers today report that a select few eyepiece lines with many more optical elements than the elite planetaries can come very close in performance. These eyepiece lines include the Docter UWA, the Leica VARIO 25 50× Aspheric Zoom, the Pentax XW, the Tele Vue Delos, and the Tele Vue Ethos, all of which are optical designs incorporating as much as 10–12 glass elements. Many observers report superb planetary and faint object deep sky performance from these very complex optical designs, demonstrating that when a manufacturer pays special attention to every aspect of an eyepiece's design and build, even the most complicated designs using many elements can rival the best-in-class minimum glass specialty eyepieces.

Fig. 2.19 Premium classic planetary eyepieces (Image by the author)

Since there is no single eyepiece design that fully maximizes all the eyepiece attributes of eye relief, apparent field of view, off-axis aberration and distortion control, and brightness and contrast performance for high magnification observing, many observers choose a path of maintaining multiple short focal length eyepieces. This approach is centered on treating the eyepiece as what it is, a tool for a highly specific task. Taking this approach means it can be advantageous to maintain several eyepieces in overlapping focal lengths to best match the eyepiece's unique characteristics to the task at hand. An observing situation that illustrates this is when the evening's observing is to include some lengthy observation of a planet such as Jupiter. For this target, given that it is a planet, the AFOV of the eyepiece to choose would normally not be important. However, during this evening Jupiter's moons happen to be positioned widely apart from the planet, so a wider AFOV high magnification eyepiece will be more appropriate. Finally, since the plan is to conduct some lengthy observing and sketching of this single target, an eyepiece with comfortable eye relief is required as well.

During the course of the observation, it is noted that there is a hint of a structure called a barge on the edge of one of Jupiter's main equatorial cloud belts. Unfortunately this barge is faint and of low contrast, so the comfortable, wide-field eyepiece being used is just not showing the barge decisively or distinctly. In this situation, if the observer maintains specialized eyepieces for specialized tasks, he or she would then turn to a specialized high quality, narrow field, tight eye relief, minimum lens count eyepiece to determine if this highly optimized design better shows the suspected barge. In this scenario a TMB Supermonocentric eyepiece could be an appropriate choice.

Although the observer can no longer see all of Jupiter's moons because of the eyepiece's narrow AFOV, and its very short eye relief means the viewing is uncomfortable and not suited for extensive sketching, in our scenario (and as reported in real observation reports), this specialized eyepiece showed the barge very distinctly! After enjoying the "catch" of this elusive barge, the observer can then continue using the high magnification eyepiece with more comfortable eye relief to observe other aspects of this wonderful planet and continue sketching. This is an example of a real-life scenario that observers have encountered and demonstrates that when observing extremely challenging aspects of a target, the slight edge a highly optimized eyepiece can provide can be worth the extra expense when an observer is passionate in particular observing tasks. Of course, this approach is not appropriate for all, and for other observers who do not need to go to these extremes to satisfy their observing goals, a better solution could certainly be the more comfortable and larger AFOV design of a quality wide field.

High magnification observing is a specialized niche in astronomical observing. Whether the goal is tracking down challenging features on planets, going as deeply as possible into the cores of globular clusters, trying to tease out as much definition as possible in the spirals arms of distant galaxies, or trying to split a difficult double star, sometimes these tasks can be done best when using multiple eyepieces of the same focal length that have demonstrated themselves to perform best in certain very narrow observing circumstances. The more care an observer takes to fully understand and exploit the unique aspects of an eyepiece, its design, and its operational characteristics, the greater rewards are there to be found. Although there is no “best” eyepiece or eyepiece design for high magnification observing, what is “best” is when the particular strengths of a given eyepiece or eyepiece design can best match the needs of the observer for the specific observing task he or she wishes to pursue.

http://www.springer.com/978-1-4614-7722-8

Choosing and Using Astronomical Eyepieces
Paolini, W.
2013, XVIII, 442 p. 268 illus., 51 illus. in color., Softcover
ISBN: 978-1-4614-7722-8