A Short Guide to Choosing Eyepieces

by Neil Paterson

The following is a basic guide to some of the factors to consider when choosing eyepieces. It is based on my experience but also on conversations with and articles by other observers.

Eyepieces Terms

The choice of which eyepieces to purchase is almost as important as which telescope and mount to choose, eyepieces couple to our telescopes to give us our observing experiences and a bad choice of eyepieces will limit the experience as much as a bad choice of telescope. The best advice I can give to anyone contemplating a purchase of an eyepiece is to research it, read reviews of it and speak to people using one, go to an observing evening and try it out because an eyepiece will perform differently in each scope. The following is a list of terms used in relation to eyepieces and why they are used in eyepiece evaluation.

Focal Length

All eyepieces have a stated focal length in the same way as all telescopes have a stated focal length; focal length is the effective distance from the entrance of the eyepiece to its focal point. Focal length is important because the telescope focal length divided by the eyepiece focal length will give you magnification, all eyepieces will have the focal length imprinted on the eyepiece.

Field Stop

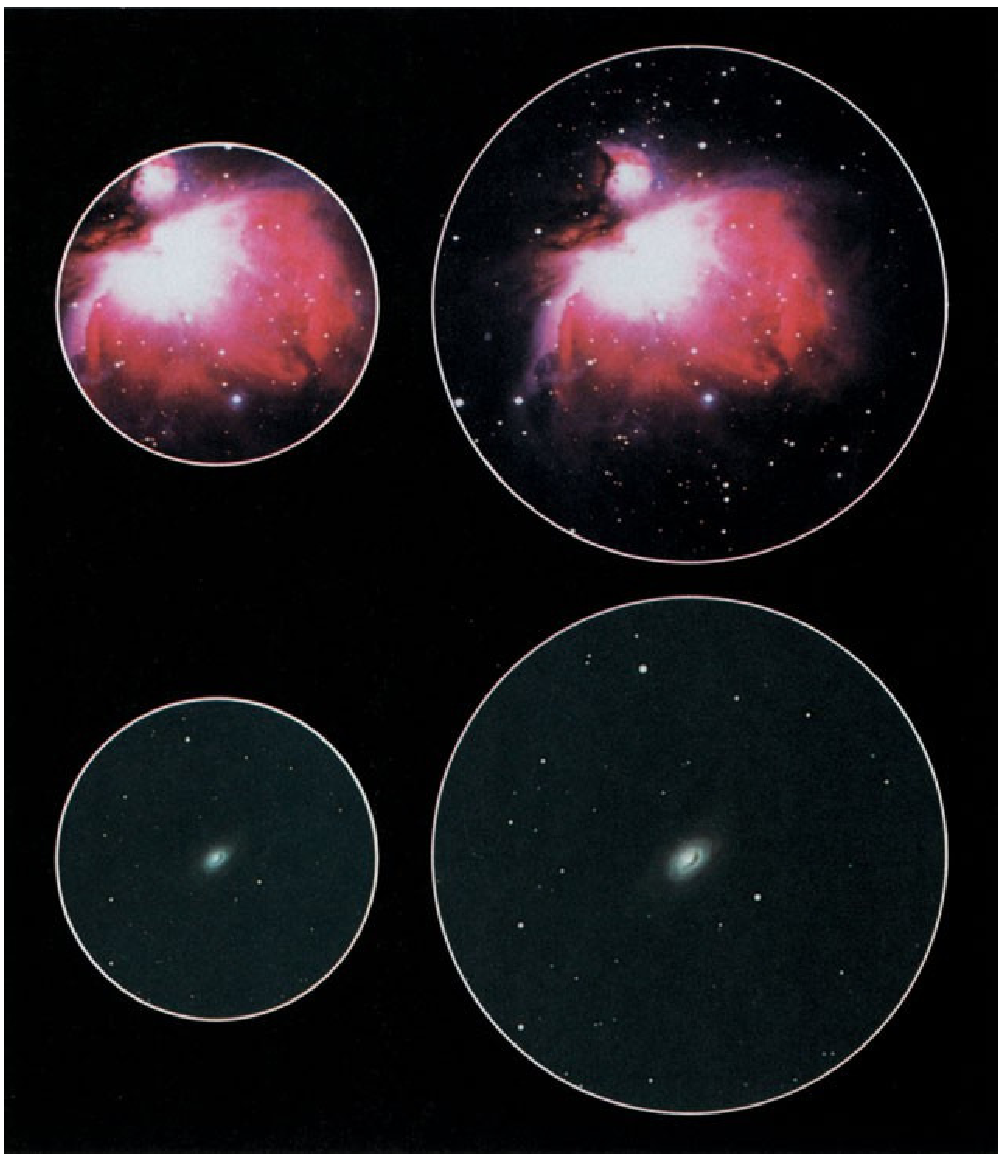
The field stop is a ring inside the barrel of an eyepiece that defines the edge of the field of view. In most eyepieces the field stop is not the inside of the barrel but a designer introduced ring inside the barrel, this is introduced to sharply delineate the edge of field of view and to prevent a gradual drop off in quality of view. In some reviews, the reviewers will state that the field stop in not properly placed; this usually means that the edge of the field of view is ‘mushy’ which detracts from the viewing pleasure. The field stop limits the Apparent Field of View (AFOV) and True Field of View (TFOV) of an eyepiece.

Eye Relief

Eye relief is the distance above the eyepiece we place our eye to see the entire field of view of the eyepiece. Eye relief affects our comfort when we observe, if the eye relief is too small our eye is too close to the lens, indeed in some eyepieces the relief is so short that, if we blink, our eyelashes touch the lens. If you are a spectacle wearer and need to observe with the glasses on you will probably need 18mm or more of eye relief, however if you remove your glasses or do not need glasses 8mm is enough eye relief to be comfortable. Too much eye relief can be as frustrating as too little as it makes the ideal placement of your eye difficult and you can feel disconnected from the eyepiece, extended eye cups can remove this problem.

Apparent Field Of View (AFOV)

The apparent field of view is the field of view advertised by eyepiece suppliers. It's the angle your eye sweeps out when you look at one edge of the field in the eyepiece and then look to the opposite edge. The greater the AFOV the more of the sky you will see, many of today's most highly regarded eyepieces are ones with a large AFOV, this is because it gives a more immersive feeling to the observer. With a larger field of view it also enables higher magnification to be used and still encompass quite large objects, the picture below show two views at the same magnification, the one on the left has a 50° AFOV the one on the right an 80° AFOV, as can be clearly seen the one on the right frames the subject better.



However, the main problem associated with getting a wide AFOV is the cost. To get a wide field of view, that is well corrected, requires numerous lenses to be incorporated in the eyepiece. Every additional lens impacts light transmission, so to limit the impact of these lenses they must be of top quality and well coated and this raises the cost. Many of today's best wide field eyepieces are prohibitively expensive for the average amateur astronomer. Eyepieces can be roughly divided into four categories around AFOV: -

Narrow Field 30°-45° (some specialist eyepieces appear in this category, notably some specifically designed for planetary observation where a large field of view is not necessary but maximum transmission is)

Normal Field 50°-60° (there are many good quality, fairly inexpensive eyepieces with this AFOV)

Wide Field 65°-72° (there is an increasing number of eyepieces appearing in this category and the prices are decreasing while quality is increasing)

Ultra Wide 78°+ (the number of lenses needed to provide a well corrected field of view this size make it difficult to produce eyepieces of this AFOV cheaply so most are quite expensive)

True Field of View (TFOV)

The True Field of View (TFOV) is the actual amount of the sky we see when we look in the eyepiece. To work out the exact True Field of View requires you to know the exact size of the field stop. This information is, in most cases, not readily available. However the exact True Field of View is not really necessary for most observers, a god approximation of the TFOV can be obtained by dividing the stated AFOV by the magnification being used.

Magnification

Magnification is the relative change in angular size of an object, though we usually think of magnifying as making something bigger. In astronomical observing the magnification is worked out by dividing the focal length of the telescope by the focal length of the eyepiece being used. So in practice the shorter a focal length eyepiece being used the higher the magnification.

One of the most common questions asked about magnification is "what magnification should I use to view ……………………." and the answer is usually the totally unsatisfactory "it depends". When observing, magnification is relative to the telescope being used and depending on the size of aperture what is deemed high magnification in a small telescope may only be medium power in a larger telescope. So for observing terms we tend to talk about magnification ranges as per inch of aperture and the following are just loose guidelines and many: -

Low Power – up to 10X per inch of aperture

Useful for finding objects, viewing open clusters, viewing faint nebula, viewing large galaxies

Medium Power – 10 to 20X per inch of aperture

Useful for smaller deep sky objects e.g. galaxies, planetary nebula, some globular clusters, planets with moons

High Power - 20 to 30X per inch of aperture

Useful for planets, moon, double stars, globular clusters

Very High Power – 40 to 50X inch of aperture

Useful for closer double stars, planetary and lunar detail

Extreme Power – 50 – 75X inch of aperture, this range of power is rarely used as atmospheric conditions and eye problems will overwhelm the view, to use this power needs nights of excellent seeing.

On most observing nights it is likely that atmospheric conditions will limit the amount of useful magnification to <300X, using anything above this will result in a larger but fuzzier image. As we increase magnification the object being viewed will become dimmer (except for stars) and is more affected by atmospheric and equipment issues, even a light wind and a shaky mount make high power observing impossible. When deciding on magnification a good rule of thumb is: - for low power subjects use the highest power that frames the subject and provides enough sky for contrast, for high power use the lowest magnification that lets you see the details you are looking for. Observing subjects using different magnifications is very rewarding as different powers change the view. Experiment with magnification. There is no best magnification to view any subject.

Exit Pupil

The Exit Pupil is the size of the image formed from the eyepiece, it is very closely tied in with magnification in that higher magnifications give smaller exit pupils and lower magnifications give larger exit pupils. Exit pupil is worked out by dividing the eyepiece focal length by the focal ratio of the telescope being used.

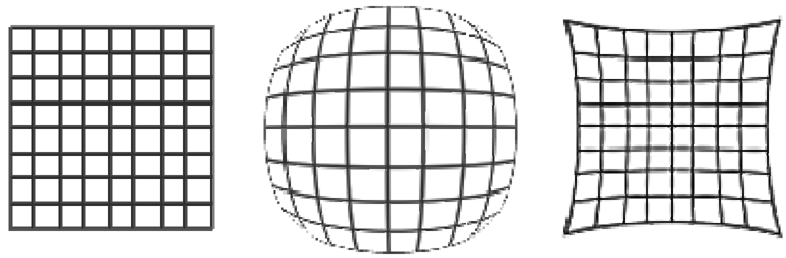
Exit pupil is a factor in choosing eyepieces because of the limitations of the Human eye, at best the human eye dilates to 7mm so an exit pupil greater than 7mm means you are not seeing the whole image i.e. you are not utilizing the full aperture of the telescope. If you are using a refractor this is the only reason not to use an exit pupil greater than 7mm, however, if you use a reflector there is another reason not to use a larger exit pupil than 7mm. All reflectors have a secondary mirror which forms a shadow on the primary mirror, we usually talk about this central obstruction as a percentage of aperture and the obstruction is always in the centre of the image, normally this is not noticeable but if the exit pupil is increased so is the effect of the central obstruction until it can become apparent as a black spot in the centre of the image. To find the longest focal length eyepiece to use multiply your focal ratio by 7 and this will give you the eyepiece focal length which will produce a 7mm exit pupil. The minimum exit pupil will be decided by our eye, for even the best sighted person an exit pupil of less than 0.5mm will reveal defects in the eye such as 'floaters'.

Eyepieces Issues

When choosing eyepieces it is also important to be able to understand what issues may be prevalent in the eyepiece design. If you are researching which eyepieces to purchase, you will sometimes read about defects or aberrations in a certain eyepiece. Often the reviewer will state what problem they found e.g. "there is rectilinear distortion present". This is only useful if you know what rectilinear distortion is and how it affects the view through an eyepiece. The following is a list of the more common defects/aberrations that effect eyepieces and a short explanation of what might be seen through the eyepiece if they are present.

Rectilinear Distortion

As this is mentioned above I will start with it. When there is rectilinear distortion present reviewers quite often write of the 'fishbowl effect', the picture below illustrates the issue.



The illustration on the left depicts a field of view without any rectilinear distortion, the illustration in the middle depicts a form of rectilinear distortion usually called 'barrel distortion' and the illustration on the right depicts a form of rectilinear distortion usually called 'pincushion distortion'. For most of us when observing this issue has little impact, what it means is the stars are not in exact position relative to each other. However, if your observing involves lots of sweeping the sky, say as a comet hunter, as you move your scope the stars will not move across the field of view in straight lines they will bow one way or the other giving the 'looking through a fishbowl effect', some observers find this difficult to tolerate and some even find it nauseating.

Field Curvature

Field curvature is not constant with every telescope, an eyepiece may present field curvature in one scope but not in another, this is because all telescopes and eyepieces have a slightly curved focal plane (in scopes it is usually convex but in eyepieces it can be either convex or concave). It is the interaction between the two focal planes that can cause field curvature to be present, if the two planes are a perfect match the concave plane of the eyepiece will exactly counteract the convex plane of the scope resulting in a perfect flat field. Our eyes can compensate for a degree of field curvature so we will not notice slight field curvatures (the ability of our eyes to accommodate for field curvature lessens with age so older observers are bother more by this than the younger observers).

Field curvature is recognized by stars at the edge of field being out of focus, slightly blurred when the central stars are in focus. If it is field curvature that is causing this you will be able to focus the stars at the edge of the field by either out-focusing (then the curvature is concave) or by in-focusing (then the curvature is convex) but of course the central stars will now be out of focus. As I stated field curvature is not purely a result of the eyepiece but as a result of the interaction of scope and eyepiece so if a reviewer states that field curvature was present this does not mean that in your set-up you will experience a similar issue.

Astigmatism

Astigmatism is widely regarded as the most 'annoying' aberration to be present in an eyepiece and the one that most people find unacceptable (usually a degree of rectilinear distortion is introduced by the designer to counteract astigmatism). Astigmatism is caused by the vertical curvature of eyepiece field being different form the horizontal curvature of the field. Astigmatism is seen when the stars in the centre of the field of view are in sharp focus the stars at the edge of the field are usually like crosses or some say they look like bats at the edge of the field. Astigmatism is quite often present in inexpensive eyepieces, especially if they have a larger AFOV. And the shorter the focal ration of the scope being used the more apparent this will become.

Angular Magnification Distortion

An angular magnification distortion is where the degree of magnification differs slightly from the centre of the eyepiece to the edge. The impact of this on most observers if negligible, indeed most observers will never know if it exists in an eyepiece. The only real impact is if an observer is carrying out star drift timings, i.e. timing a star moving across the field of view in an un-driven scope, then the timings will be slightly off as the speed with which the star moves across is not constant (it will move faster across the centre than at the edges).

Spherical Aberration of the Exit Pupil

A spherical aberration of the exit pupil is caused by different bits of the exit pupil having different best focus points. This is often referred to "kidney-beaning" in reviews. This is a particular annoying defect in an eyepiece as it results in a black spot or kidney bean floating around the view depending on where you place your eye and it will be very difficult to view the entire field of view.

Vignetting

Vignetting is caused when a lens of an eyepiece is not able to field all the lights rays coming through the previous lens. Vignetting presents itself as a noticeable darkening of the field of view towards the edges.

Chromatic Aberration

Chromatic aberration is caused because no lens no matter how well configured or made can focus all colors of light at exactly same point. It is not that common for an eyepiece to be severely effect by CA but if an eyepiece suffers from CA it will be noticed, usually, at the edge of the field of view where a bright star, planet or the moon would have a false color fringe.

There are other terms often used in reviews to describe flaws in eyepieces but in most cases the effects of these are self explanatory e.g. light loss, light scattering, ghost images.

Choosing the correct eyepiece or selection of eyepieces is very important to maximizing your observing experiences, when contemplating an eyepiece it is very important to consider the above factors. Getting informed about any potential eyepiece purchase will protect against the disappointment of spending good money on something that is unsuitable to your requirements, in this I definitely speak from bitter experience. Reading reviews, speaking to fellow observers and trying out various eyepieces will enable you to make good choices for your eyepieces.

Common Astronomical Formulas

$$\text{Telescope Focal Ratio} = \frac{\text{Objective Focal Length}}{\text{Objective Diameter}}$$

$$\text{Magnification} = \frac{\text{Telescope Focal Length}}{\text{Eyepiece Focal length}}$$

$$\text{Magnification} = \frac{\text{Objective Diameter}}{\text{Exit Pupil}}$$

$$\text{True Field of View} = \frac{\text{Eyepiece Field Stop}}{\text{Objective Focal Length}} \quad {}^{*}57.3\text{degrees}$$

$$\text{Approximate True Field of View} = \frac{\text{Eyepiece AFOV}}{\text{Magnification}}$$

$$\text{Exit Pupil} = \frac{\text{Eyepiece Focal length}}{\text{Telescope Focal Ratio}}$$

$$\text{Aperture gain} = \frac{\text{Objective Diameter}}{\text{Eye pupil Diameter}} \quad \text{Squared}$$

$$\text{Dawes Limit} = \frac{\text{4.56 arcseconds}}{\text{Objective Diameter (inches)}}$$

Planetary Filters

Planet	Filter	Benefits
Mercury	#23A Light Red	Useful in twilight or daylight to reduce the brightness of the sky
	#25 Red	Useful in twilight or daylight to reduce the brightness of the sky
	#47 Violet	Useful In large telescopes to help in detecting faint features
Venus	#12 Yellow	Helps with low contrast surface detail
	#23A Light Red	Useful in twilight or daylight to reduce the brightness of the sky
	#25 Red	Useful in observing the terminator
	#47 Violet	Useful for enhancing upper atmosphere
Mars	#12 Yellow	Can help in observing Martian Clouds
	#15 Deep Yellow	Useful for observing the Martian Polar caps
	#21 Orange	Useful in observing the Maria

	#23A Light Red	Useful in observing the Maria
	#25 Red	Useful in observing the Maria
	#56 Light Green	Useful in observing the polar caps
	#58 Green	Useful in observing the polar caps (especially in larger scopes)
Jupiter	#12 Yellow	Useful for observing the red and orange features
	#21 Orange	Useful for sharpening contrast on the belts and great red Sot
	#80A Blue	Useful for overall observing of Jupiter helps with contrast in cloud belts and in bringing out the Great Red Spot
	#82A Light Blue	Useful for enhancing the low contrast features
Saturn	#12 Yellow	Useful for observing the red and orange features of belts and zones
	#21 Orange	Useful for observing the polar regions
	#23A Light Red	Useful for observing the polar regions
	#47 Violet	Can be some help in observing the rings in larger scopes
	#80A Blue	Useful for enhancing detail in belts and polar regions
Uranus	#8 Light Yellow	Can be useful in improving detail but needs a large scope
Neptune	#8 Light Yellow	Can be useful in improving detail but needs a large scope