ORANGE COUNTY ASTRONOMERS

BEGINNERS CLASS NOTES

TELESCOPE BASICS

OPTICAL SYSTEMS

1. INTRODUCTION

Perhaps one of the toughest decisions confronting a beginner astronomer is to decide what is the best choice for a first telescope. The best advise perhaps is: **none,** at least for a while. Buying a telescope is like buying a car, you need to test drive it. Unfortunately, it is very difficult to find a salesman willing to take two or three telescopes out of the shop and spend the entire night, at a dark location, letting you to try them.

The best approach, in our opinion, is to join the local amateur astronomy club and attend its star parties. Amateur astronomers will let you look through their scopes gladly, and in this way you may be able to evaluate the quality and cost of the different types of scopes available in the market and then decide what you want to get. The dues of amateur astronomy clubs are usually a fraction of a scope price, and definitely cheaper than storing the telescope in the garage because what you bought so hastily does not stand to your expectations.

Still, whether you follow the above recommendation or not, it helps to know some basic facts about telescopes. This little paper describe the basic optical systems that are available in commercial telescopes. The telescope mounts are not described here (we hope to include information about mounts in future editions), however mounts are very important because an optical system of exceptional quality on a flimsy mount is virtually useless. In addition, the scope needs eyepieces. The type of eyepiece to choose depends on many factors. We are trying to prepare a separate paper on this important issue.

2. TELESCOPE BASICS

A telescope is basically a device that gathers light. The light gathered by the telescope is concentrated (focused) in a small area forming a small image of the object. This small image is then magnified by the eyepiece to a size that is convenient for observation.

The light gathering power depends on the diameter of the optical element (mirror or lens). The larger the diameter the bigger the light gathering power. In addition the diameter of the optical element determines the amount of detail that can be observed.

The relation between the diameter of the optical element and the light gathering power is not linear. For example, a telescope with a 8" mirror does not gather twice the amount of light what a 4" mirror would. The relation is the square of the proportion between the diameter of the mirrors. The proportion between 8" and 4" is 2, and the square of 2 is 4, therefore a telescope with a 8" mirror gathers four times more light than a telescope with a 4" mirror.

The pupil in the human eye, when fully adapted to darkness, has a diameter of approximately 1/4". If a telescope has a 8" mirror or lens it will gather 1,024 times more light than the human eye, as calculated below:

$$\frac{\text{Mirror diameter}}{\text{Eye pupil diameter}} = \frac{8"}{1/4"} = 32 \qquad 32^2 = \mathbf{1{,}024\ Times}$$

In the same way, the 400" Keck telescope at Mauna Kea would gather 2,560,000 the amount of light than the naked eye would.

3. TELESCOPE TYPES

Basically all telescopes are of two types: reflecting or refracting. The reflecting telescopes, or reflectors for short, gather and focus the light by means of a concave mirror. The refracting telescopes, or refractors, accomplish the same by means of convex lenses.

As a general rule reflectors need a second mirror (secondary or diagonal) to direct the light to the eyepiece. The most common types of reflectors are the Newtonian, the Schmith-Cassegrain and the Maksutov.

The Newtonian telescopes use a primary mirror shaped as a parabola to focus the light and a flat elliptical mirror angled 45^0 to direct the reflected light beam to the eyepiece as shown in Figure 1.

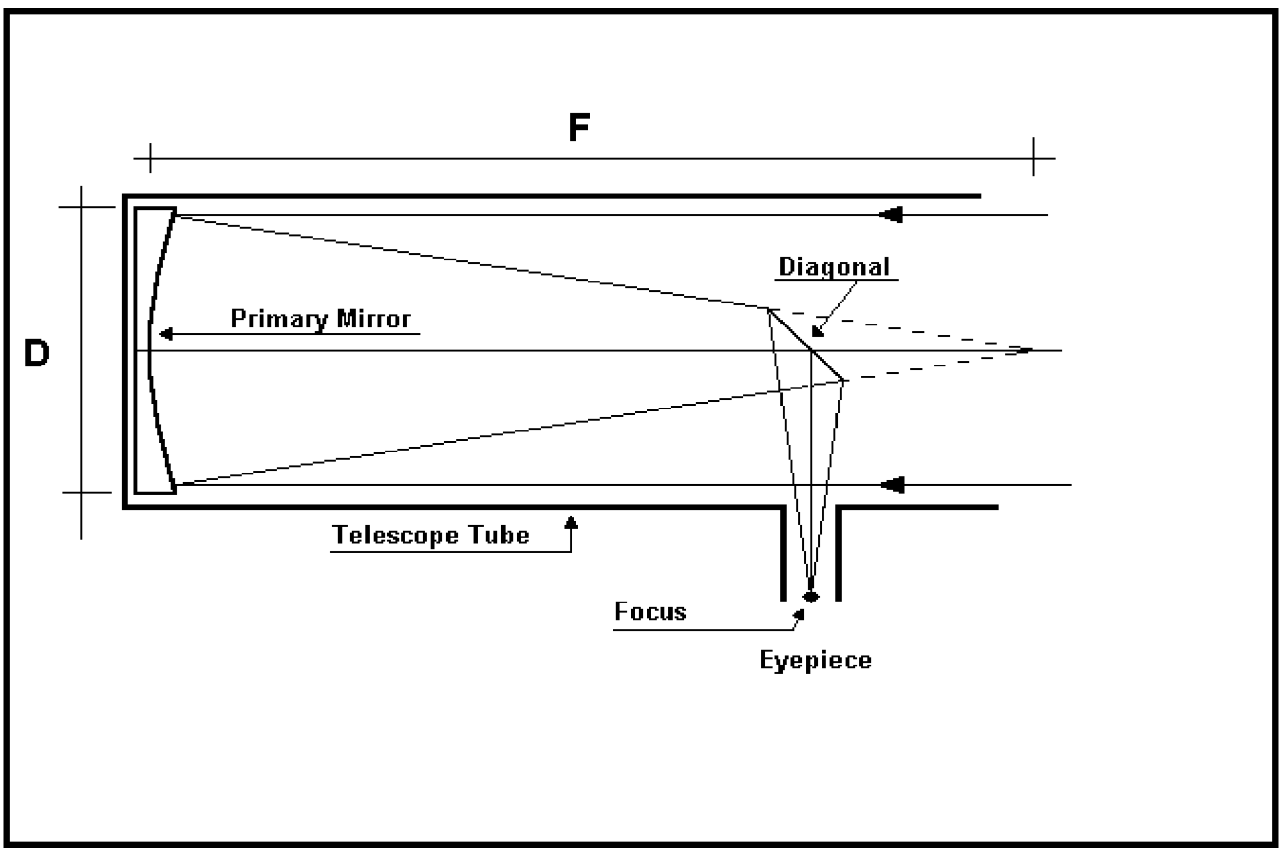


Figure 1. Diagram of a Newtonian Telescope

The Schmith-Cassegrain and the Maksutov telescopes have a secondary mirror that directs the light to a hole in the center of the primary mirror. In addition the Schmith-Cassegrain incorporates a corrector plate at the front of the telescope and the Maksutov features a curved convex lens at the same location. The secondary mirror in these types of telescopes us usually convex. Figure 2 shows a diagram of the mentioned telescope types.

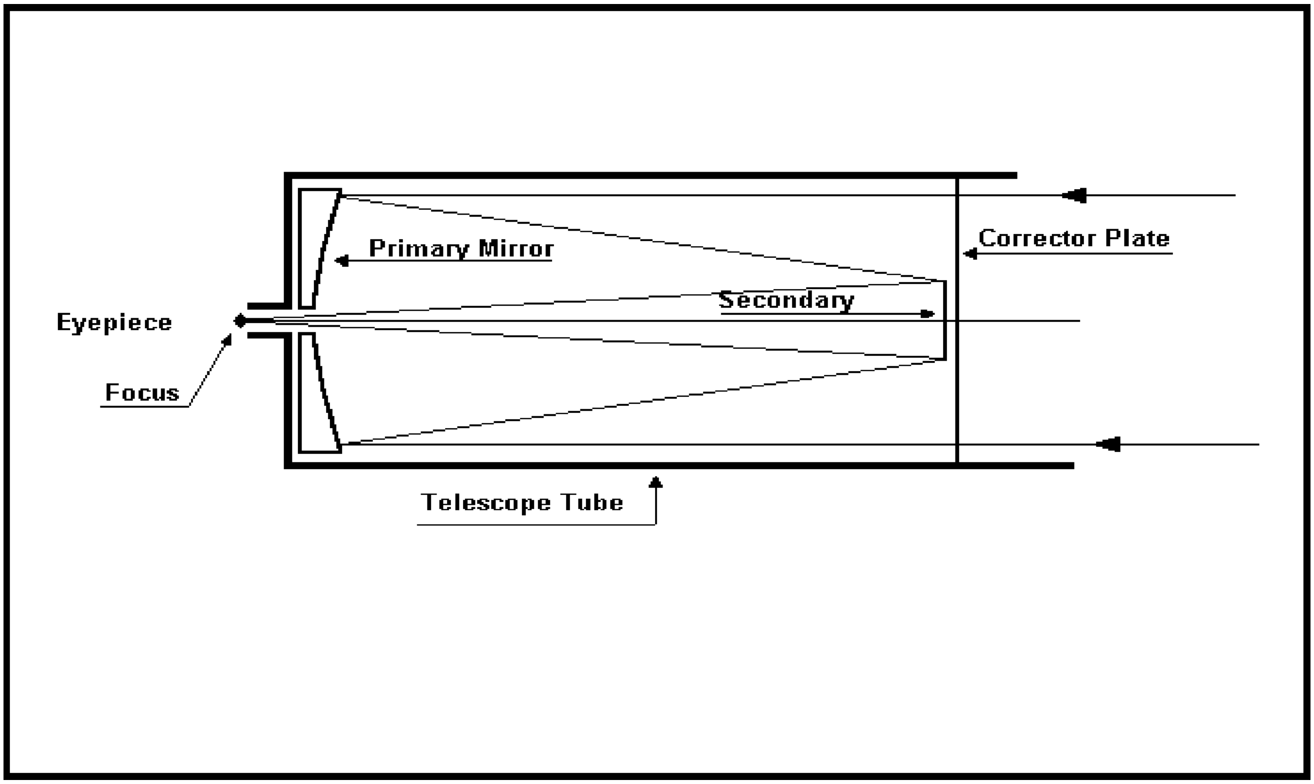


Figure 2. Diagram of Scmith-Cassegrain and Maksutov Telescopes

In these two telescope types the light path crosses itself twice, allowing to obtain large focal distances within a tube of limited length.

Refracting telescopes focus the incoming light by means of lenses. When the light enters a lens, it bends (refracts). If the lens has the proper curvature, all the incoming light will focus in a small area. Figure 3 shows the diagram of a refractor.

4. ADVANTAGES AND DISADVANTAGES OF TELESCOPE TYPES

The spider vanes and the secondary mirror holder in the reflecting telescopes obstruct partially the light path and scatter the incoming light. This scattering reduces image contrast and decreases the amount of detail in the image. The refractors on the other hand present an unobstructed path to the incoming light and therefore produce images with bigger contrast and sharper detail. Refractors are very good for moon and planetary observation, or when contrast and fine detail are required.

The refractors present a problem that is due to the physical nature of light. The white light is composed of seven basic colors, each with a slightly different wave length which bends (refracts) differently while crossing the lens. The result is that the light does not focus as a single point but as a series of concentric colored circles, producing images with colored fringes. This problem is virtually eliminated by combining several lenses made with different types of glasses. This solution, however, comes at a financial premium.

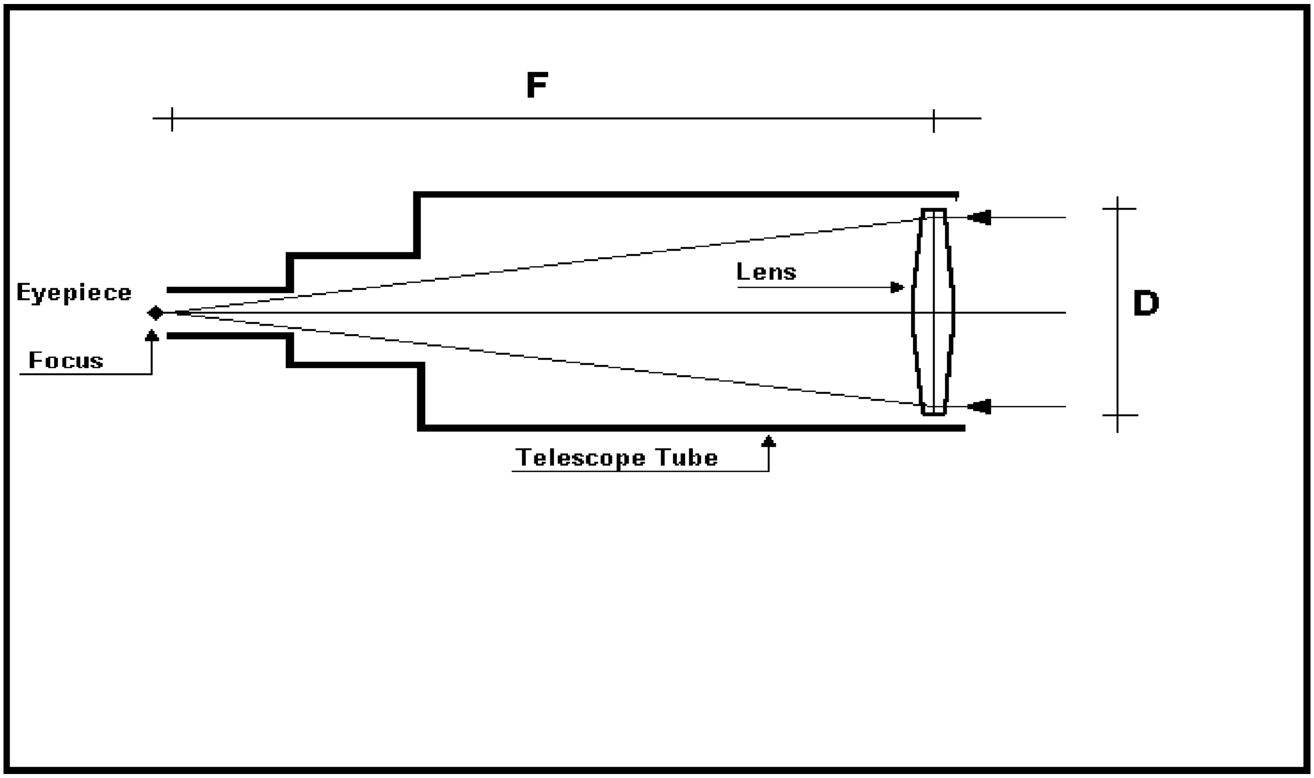


Figure 3. Diagram of a Refracting Telescope

Lenses also present the problem of sagging under their own weight. While a mirror can be supported on its entire back if necessary, the lenses of a refractor are supported only at their rim. If sagging of the lenses must be avoided, then the lenses have to be very thick. Casting a thick piece of glass without any internal imperfections is very difficult and costly, and that is why the large telescopes in the world are reflectors with very few exceptions.

5. OPTICAL SYSTEM PARAMETERS

The aperture of a telescope (diameter of the lens or mirror) and its focal length (distance from the mirror to the focus) are related by Formula 1

$$\textbf{(1)} \qquad F = \boldsymbol{f} D$$

where F is the focal distance, D is the aperture and f is called the f ratio. If two of these parameters are known, the third can be calculated with Formulas 2 and 3:

$$\textbf{(2)} \qquad D * \boldsymbol{f} = F \qquad\qquad \textbf{(3)} \qquad F = D\,\boldsymbol{f}$$

Aperture determines the light gathering and resolution power of the telescope. The focal distance, in combination with the characteristics of the eyepiece (to be discussed later on), determines the magnification and field of view. The ***f*** ratio (also called ***f*** stop) determines the length of photographic exposure. Small ***f*** ratios allow for shorter photographic exposure, although small ***f*** ratios do not provide brighter visual images. Brighter visual images depend on the telescope aperture. In telescopes with the same aperture, smaller ***f*** ratios will produce wider views.

Applying Formula 2 we can determine that a telescope of 12.5” aperture and f/4.8 will have a focal length of 60” calculated as follows:

$$D * f = 12.5 * 4.8 = 60''$$

Usually, the focal distance of a telescope is given in millimeters (mm.). Formula 4 gives the focal distance expressed in mm. :

(4) $D * f * 25.4 = F$

Applying Formula 4 to the above example we find;

$$D * f * 25.4 = 12.5 * 4.8 * 25.4 = 1{,}524 \text{ mm.}$$

6. APERTURE PERFORMANCE FEATURES

The following discussion is done on the assumption that either the mirror or lens are of good optical quality and have been well figured to the required shape.

The light gathering power was mentioned in Paragraph 2 of these notes and depends on the diameter of the lens or mirror (Aperture). The light gathering power results in the ability to see fainter objects. The faintest object (limiting magnitude) that can be seen with a telescope of aperture D is determined by the following formula:

(5) $M = 8.8 + 5 * \log D$

M is the magnitude of the object and log D is the decimal logarithm of the aperture in inches.

Table 1 lists the magnitude limits for different apertures as determined by formula (5). The values in Table 1 are the theoretical limits for different apertures, assuming perfect seeing conditions.

Aperture (in)	Magnitude Limit
4	11.8
6	12.7
8	13.3
10	13.8
12	14.2
18	15.1
25	15.8
400	21.8

Table1. Theoretical Magnitude Limits

The resolution power is the ability to separate detail and to separate very close objects. It is expressed in terms of the smallest angle between two stars that can be distinguished as separate objects.
An amateur astronomer called Dawes developed a formula which gives the resolution power of a telescope on the above basis. This formula is the following:

$$\textbf{(6)} \qquad R = \frac{4.56}{D} \text{ (in arc seconds)}$$

where R is the resolution expressed in arc seconds and D is the aperture in inches. If a telescope has a 10” aperture it will be able to split a binary star system with components as close as 0.45 arc seconds.

This formula assumes that the seeing conditions are ideal and that the two component stars are equally bright. In reality seeing conditions are not always good and therefore the resolution power will be smaller than its theoretical value. In addition, one of the components of a binary system can be many times brighter than the other, hiding the dimmer component in its glare. For example, Sirius is a binary system (Sirius is called the Dog Star and its dimmer companion very appropriately the Pup). The separation of its components varies from 3 to 11.5 arc seconds. This separation should allow a 2” telescope to split the pair. However Sirius is approximately 10,000 times brighter than the Pup. The result is that larger apertures with very good seeing are required to split the pair.

7. FOCAL LENGTH/EYEPIECE FEATURES

The focal length of the mirror/lens and the focal length of the eyepiece determine the magnification of the telescope by the following formula:

$$\textbf{(7)} \; Mx = \frac{F}{F_e}$$

where Mx is the magnification, F is the focal length of the mirror/lens and F_e is the focal length of the eyepiece.

Applying Formula 7 for a 1,524 mm. focal length mirror and a 28 mm. eyepiece we find:

$$Mx = \frac{1524}{28} = \mathbf{54.4 \text{ times}}$$

Higher magnification makes the images dimmer. The maximum theoretical magnification for a telescope is about 100 times its aperture in inches, however 50 times per inch is the useful limit of magnification for a telescope.

Once the magnification is known, the field of view can be calculated. The field of view is a measurement of how much sky can be seen and it is the relation between the apparent field of the eyepiece and the magnification, as per Formula 8.

$$\textbf{(8)} \; V = V_e \; Mx$$

In this formula V is the field of view, Ve is the apparent field of view of the eyepiece (specified by the eyepiece manufacturer) and Mx is the magnification calculated by Formula 7.

If the 28 mm eyepiece of the prior example has an apparent field of view of 62^o (degrees), the field of view of the telescope is calculated as follows:

$$V = V_e = \frac{62}{54.4} = \mathbf{1.14^o} \text{ (degrees) } Mx$$

The field of view becomes important while observing extended objects. M31 (the great Andromeda galaxy) spans more than 3^o from end to end, therefore requiring a wide field of view. Similarly, to observe M45 (the Pleiades cluster) and the Double Cluster in Perseus require a wide filed of view. The planets are small in comparison. Jupiter is about 1 arc minute and Mars at its biggest is about

20 arc seconds.

8. EYEPIECES

Eyepieces magnify the image focused by the mirror/lens. Eyepieces consist of an array of elements (lenses) arranged in different ways. The number of elements varies from three to eight depending on what goal the eyepiece designer wants to accomplish. The eyepieces come with .965”, 1 1/4” and 2” barrels (good quality telescopes never come with .965” eyepieces).

The choice of a particular eyepiece depends on the observer’s preferences, such as width of the field of view, magnification, etc. The price can range from $40 for a three element Kellner to $400 for an eight element wide angle.

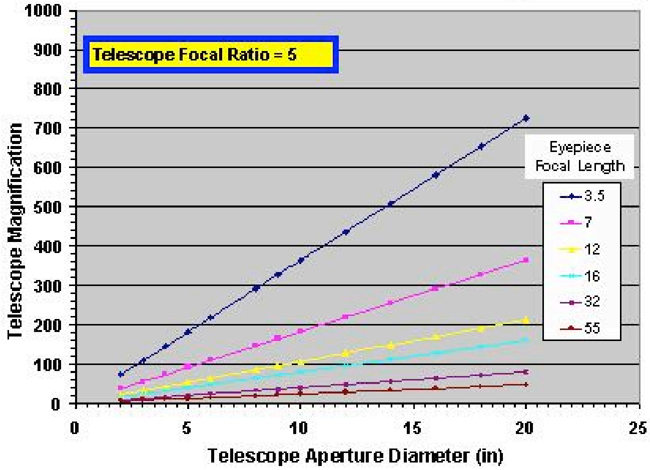
Although the best thing to do when deciding what eyepiece to buy is to consult with an experienced observer, however three factors to take into consideration are the focal length of the eyepiece (usually engraved in the barrel), the apparent field of view (written on the lens specifications) and the eye relief.

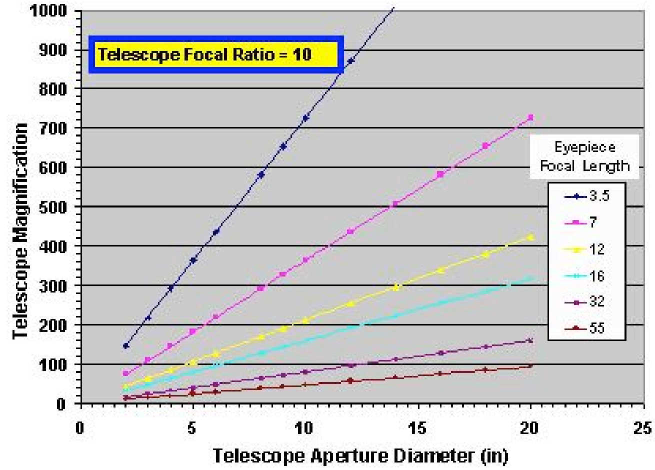
The focal length of the eyepiece determines the magnification and the apparent field determines the field of view through the telescope. If the observer’s intention is to observe the moon and planets, then an eyepiece that produces high magnification may be the choice. On the other hand if the observer is going to look at extended deep sky objects, the choice could be eyepieces that produce a wide field of view.

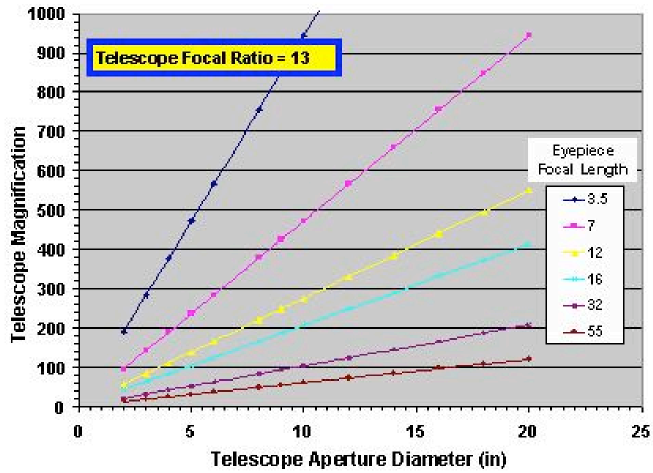
The eye relief is a measurement of how apart the eye must be positioned from the eyepiece. High magnifications usually result in smaller eye relief which may prevent an eyeglass wearer from positioning the eye at the appropriate distance from the eyepiece. Ask the eyepiece manufacturer the eye relief if you need to wear eyeglasses and intend to use high magnification.

A special type of eyepiece is the Barlow lens. This lens is inserted in the focuser prior to inserting the eyepiece. The result of using a Barlow lens is to increase the magnification which the eyepiece alone would otherwise produce. Because of this magnification increase, the Barlow lenses are sometimes called telemultipliers. The normal range of the Barlows is between 2 and 3, meaning that the magnification will be increased between 2 and 3 times. Barlows dim the image somewhat, however they maintain the eye relief of the eyepiece. The result is that a 10 mm. eyepiece with a 3X Barlow will produce the same magnification that a 3.33 mm. eyepiece, but while a 3.33 mm. eyepiece would have a very small and uncomfortable eye relief, the 10 mm. - Barlow combination will maintain the eye relief of the 10 mm. eyepiece. This, sometimes, may be the only way for glass wearers to use high magnification.

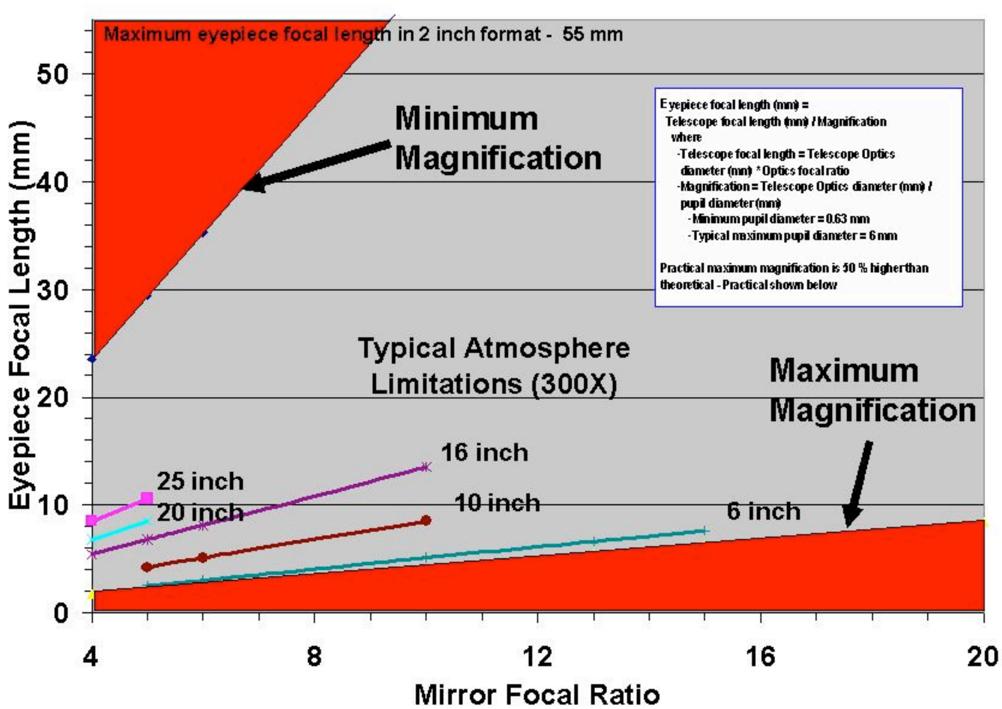
Telescope Optics Sensitivities



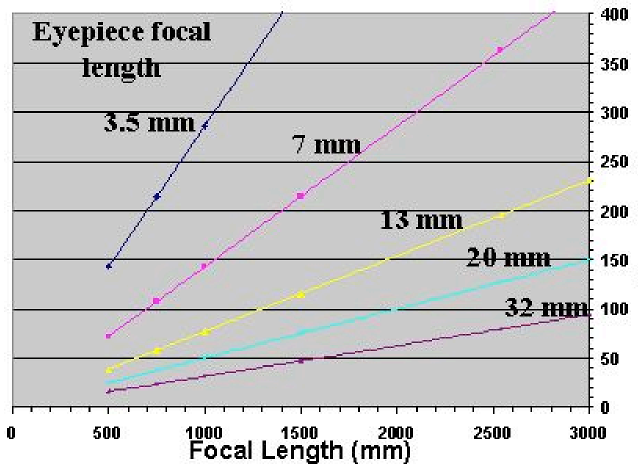


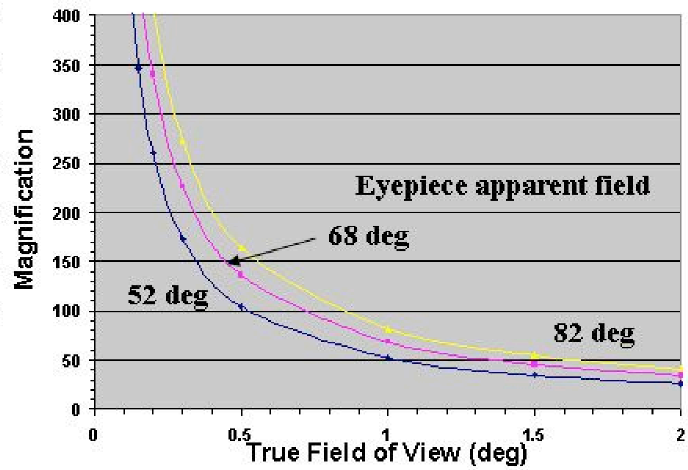


Telescope Magnification Limitations

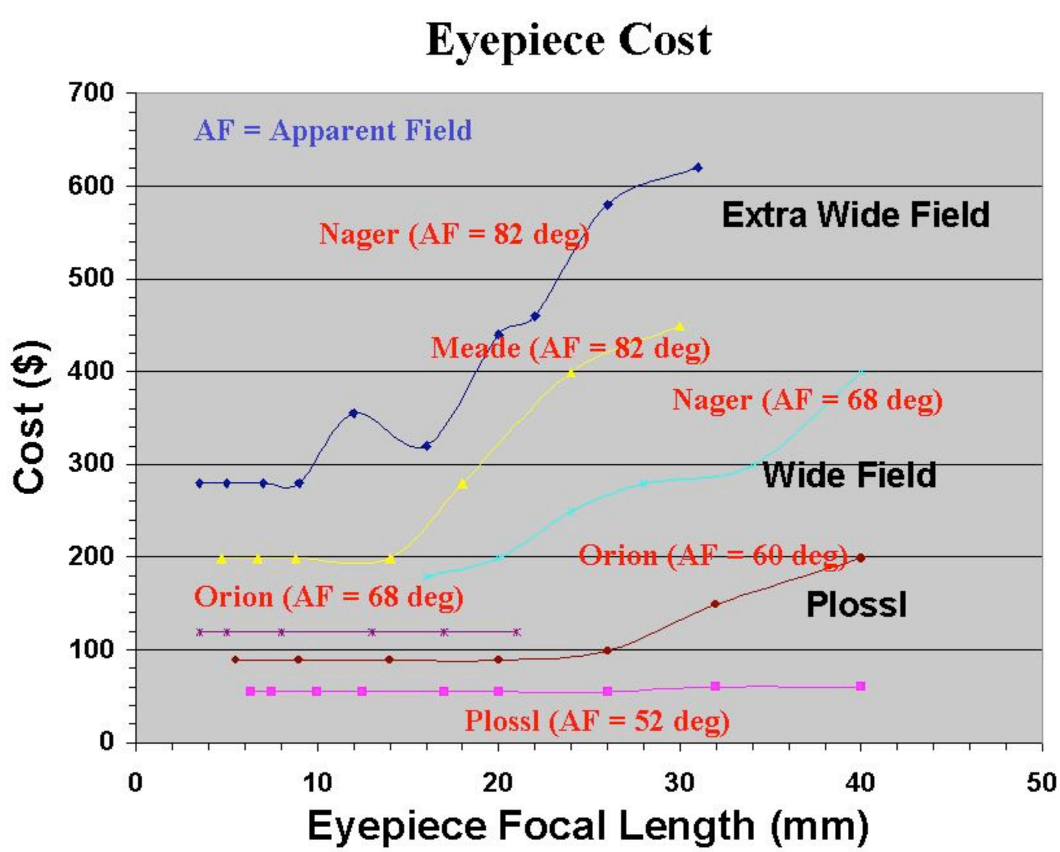


Telescope Magnification and True Field of View

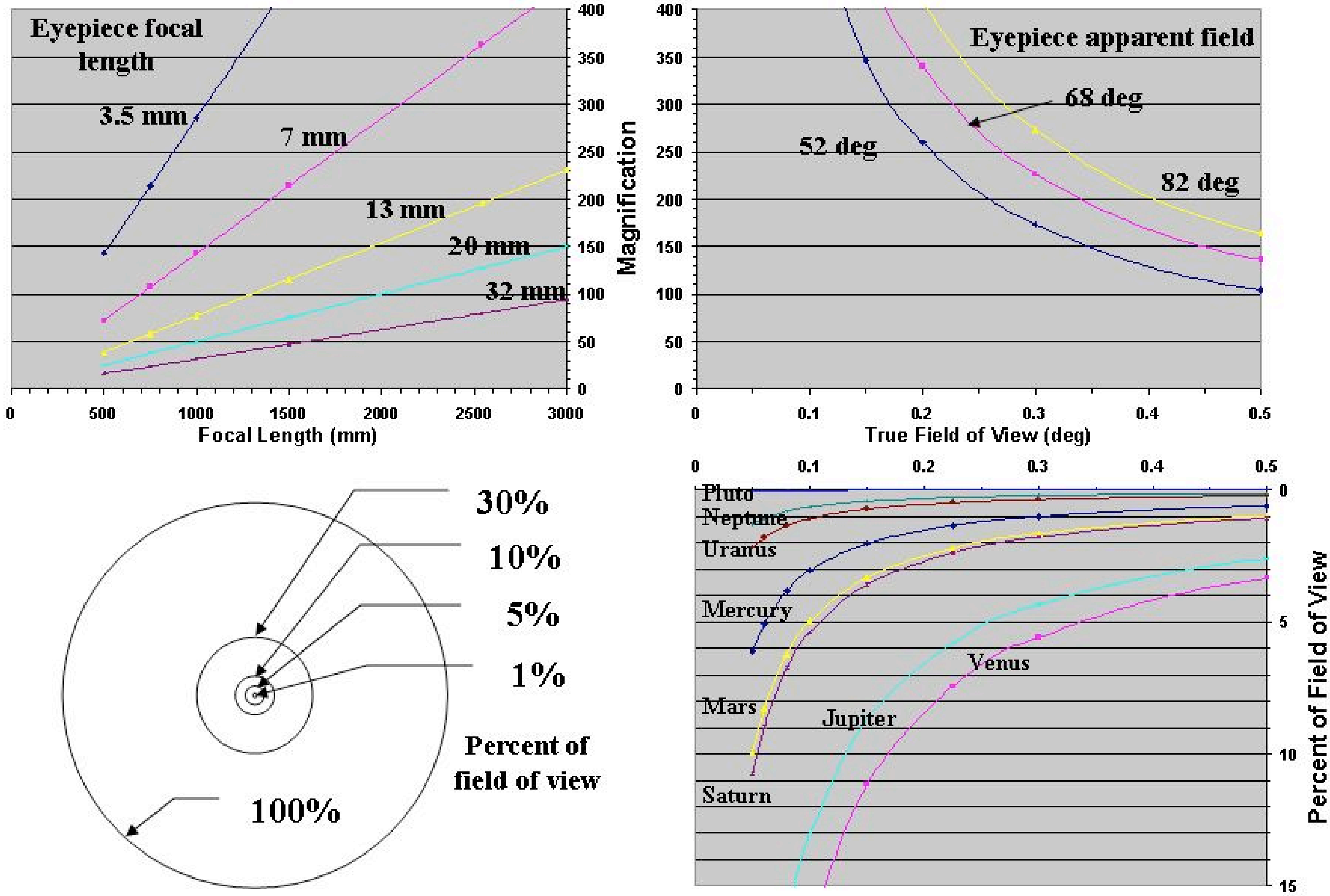




Apparent Field	General Eyepiece Category
52 deg	Plossl
68 deg	Wide Field
82 deg	Extra Wide Field



Apparent Diameter of Planets



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