Telescopes

Until Galileo built his telescope in 1609 and turned it to the night time sky, we have been peering at the night time sky with only our eyes. Since that time telescopes have gotten better in allowing us to see and photograph great detail on the moon, asteroids, sun and planets. In addition, we have been able to view and photograph other beautiful objects in our universe; stars, star clusters, nebula, and galaxies.

Telescopes are now available for everyone, not just professional astronomers. Amateurs can now see celestial objects almost as well as only the professional astronomers did a short time ago. Telescopes use either lens (refractor) or mirrors (reflector) to gather light from a far distance celestial object and magnify the image to allow greater detail to be seen.

The telescope lens or mirror area (area is a function of diameter squared) determines the amount of light that can be gathered and focused so we can see the celestial object with our eye or captured with a camera. Increasing the telescope diameter allows fainter objects to be seen. This is similar to increasing the diameter of a rain bucket to collect more rain in a given amount of time.

As the diameter of the telescope mirror or lens is increased additional detail can be seen in an object or the better the ability to see two stars that are close together. This is called telescope resolution. Look at the table to determine how the telescope diameter effects light gathering ability, the maximum observed stellar magnitudes (the larger the value the dimmer the star), and resolution compared to the human eye. For example, a 6 inch aperture has four times the light gathering power and twice the resolution of a 3 inch aperture telescope. Note that these values are theoretical only, and true performance will be limited by telescope and eyepiece optical quality, and atmospheric conditions.

Diameter (in)	Light Gathering	Stellar Magnitude	Resolution (arc-seconds)
1/4 (Eye)	1	5.8	18
2	64 X	10.3	2
3	144 X	11.2	1.5
4	256 X	11.8	1.1
6	576 X	12.7	0.8
8	1,024 X	13.3	0.6
10	1,600 X	13.8	0.5
12	2,304 X	14.2	0.4
18	5,184 X	15.1	0.25
20	6,400 X	15.3	0.23
25	10,000 X	15.8	0.18
400 (Keck)	2,560,000 X	21.8	0.01

Telescope Optics

Usually the first thing a person notices about a telescope is its diameter and length. A beginner may incorrectly decide that the best telescope is always the biggest and longest. They would be half correct, in that the larger the diameter of a telescope the more light it can gather and the better the resolution of the viewed image. However the length of a telescope does not really tell anything about the telescope unless the telescope type is known. There are many different types of telescopes, but we will start with the two general, basic types; reflectors and refractors. The only difference between a refractor and a reflector is how each collects light. The refractors use lenses, and the reflectors use mirrors (see figure 14).

Telescope performance is defined by the diameter of the aperture and the focal length (see figure 14). The focal length of a telescope is the distance from the lens or mirror to the image. A secondary design parameter is the f-ratio. The f-ratio is the focal length of the main mirror or lens divided by the diameter of the mirror or lens and this determines the size of the field of view. The lower the f-ratio the wider the field of view, which allows larger sections of the sky to be observed, as well as gather more light. The more light that is gathered the faster the optics or the less time it will take to expose a picture. At the higher f-ratios, the field of view decreases and the image becomes larger but less light is gathered and the image will lose brightness.

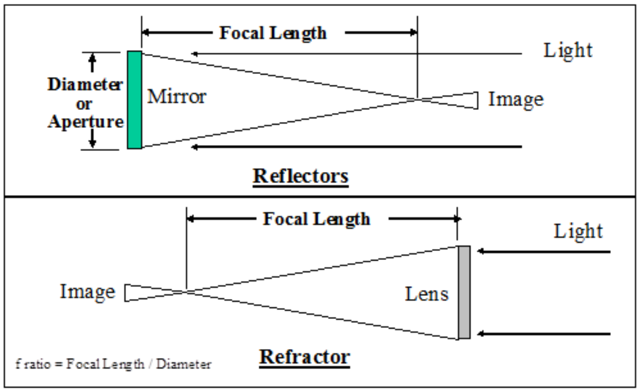


Fig. 14 Optic Basics

The detail of an object is a function of brightness and object magnification. Magnifying the image spreads the light over a larger area making the image larger, but also makes the image less bright. In practice, magnification is used only to make the object large enough to see as much detail as possible. It is possible to magnify the image to such an extent that it becomes so dim that it disappears. The only astronomical objects that can take high magnification are the moon and the planets. The other objects such as galaxies, nebula and clusters usually require only low to medium power.

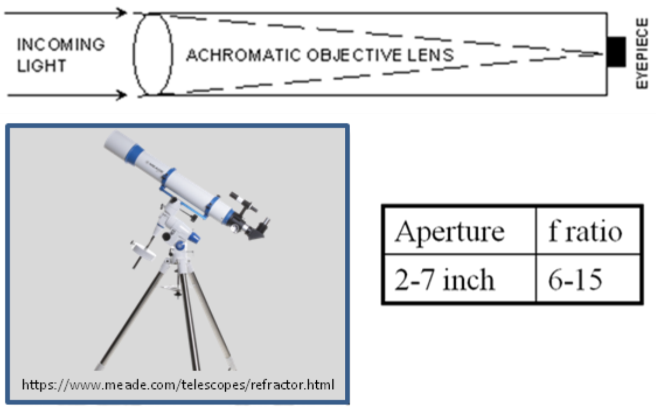
By common sense it should be apparent that the better the telescope optics the better the telescope performance. But how good does it have to be? Using the eye as a reference, the eye cannot see much better than a 1/4 wave optical tolerance. This is the traditional optical tolerances based on the criterion established by Lord Rayleigh. It means that images will be satisfactory as long as the longest and shortest optical path lengths to a selected focus do not exceed 1/4 wavelength of visible light. Note that to achieve the 1/4 wave optical tolerance the mirror surface must be of 1/8 wave or better.

A spherical shaped mirror with an f-10 ratio or higher meets this criteria. This is important because spherical mirrors are easier to make and usually less expensive. Below a f-10 ratio, the mirror should be of parabolic shape. These statements are general in nature, as you will see later different telescope types may differ in their optical design but will still meet the overall 1/8 wave criteria.

Optics with f-ratios of 4.5 to 6 is used for viewing deep sky objects such as nebula and galaxies. For planetary visual viewing, f-ratios of 14 to 20 are excellent because they produce larger images to see more detail. General purpose telescopes usually have f-ratios of 6 to 10.

Refractor Telescopes

Inch for inch of aperture the refractors (see figure 15) are generally considered the best. They are more likely to be perfectly collimated or aligned. The closed tube means cleaner optics and less air disturbance and it can be made nearly 100% glare proof. However, because of their length and weight they are generally limited to 4-inch aperture for portability, but they can be found up to a diameter of 7 inches.



https://www.meade.com/telescopes/refractor.html

Aperture	f ratio
2-7 inch	6-15

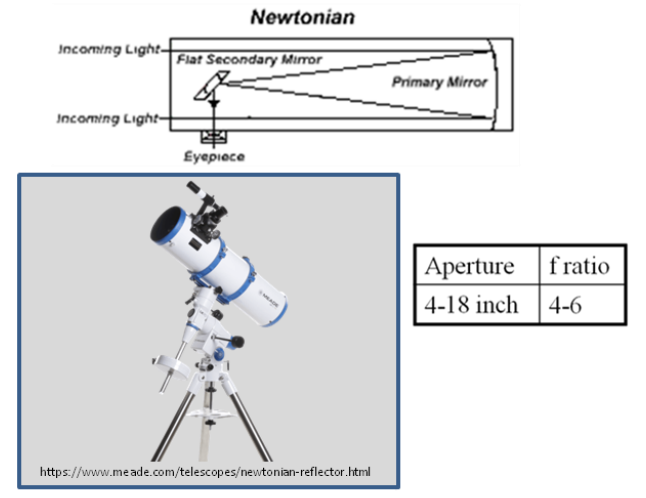
Fig. 15 Refractor General Characteristics

Refractors use lenses to magnify and form the image. The refractors have an unobstructed path to the incoming light and therefore produce images with higher contrast and sharper detail. Refractors are very good for bight objects such as the moon and planets, 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 wavelength, 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 was the reason that early refractors had very long focal lengths. The longer focal lengths allowed all the color of light to come to a focus easier. However, in several early telescopes they got to a length that they were useless.

Design improvements have changed very little since 1893, but the quality of the glass has dramatically increased. Today's "apochromatic refractors” now combines red and blue light on the same plane, reducing chromatic aberrations (color fringing) and spherical aberration (inability to focus to a perfect point). Also apochromatic refractors have objectives lenses, which contain fluorite, or extra-low dispersion (ED) glass which reduce aberrations even more - yielding razor sharp images and perfect color correction.

Reflecting Telescopes

There are generally two types of reflecting telescopes, Newtonian and Cassegrain. The Newtonian uses a parabolic primary mirror and a flat mirror(secondary mirror) of elliptical shape. The flat mirror allows the light path to be turned 90 degrees so the image can be viewed from the top and to the side of the telescope. They can be made in low f-ratios and are excellent for low to medium power in observing deep sky or dimmer objects.



https://www.meade.com/telescopes/newtonian-reflector.html

Aperture	f ratio
4-18 inch	4-6

Fig. 16 Reflector General Characteristics

The Cassegrain uses a parabolic primary mirror and a second mirror to direct the light back through a hole in the primary allowing viewing from the back of the telescope. This shortens the tube length over a Newtonian.

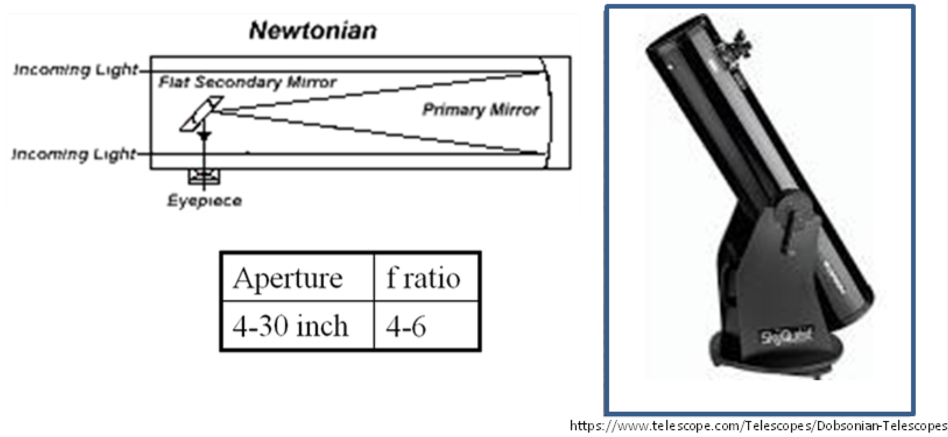
The reflectors, inch for inch are usually 1/3 the cost of refractors. They uses mirrors and therefore do not suffer from color distortion, however they suffer from coma. A mirror with coma causes images of stars near the edges of the field to lose their round shape to become fan tailed appearing more like a comet than a star.

The secondary mirror is usually either glued or placed in a mirror holder which attaches to the telescope with 1, 3 or 4 spider vanes. This structure partially obstruct the light path, slightly reducing the amount of light, and scattering the incoming light. This scattering reduces image contrast and decreases the amount of detail in the image.

There are many types of Newtonian and Cassegrain telescopes. Below are the descriptions of the more popular ones.

Dobsonian telescope

A Dobsonian telescope is an alt-azimuth mounted reflecting Newtonian telescope design popularized by the amateur astronomer John Dobson starting in the 1960s. Dobson's telescopes featured a simplified mechanical design that was easy to manufacture from readily available components to create a large, portable, low-cost telescope. The design is intended for visually observing "deep sky" objects, a requirement where the observer needs a large objective diameter (i.e. light-gathering power) combined with portability for travel to non-light polluted locations. Dobsonians are intended to be what is generally called a "light bucket" operating at low magnification, and therefore are not generally suitable to astrophotography or providing single axis equatorial object tracking capability. (https://en.wikipedia.org/wiki/Dobsonian_telescope)



Aperture	f ratio
4-30 inch	4-6

https://www.telescope.com/Telescopes/Dobsonian-Telescopes

Fig. 17 Dobsonian General Characteristics

Although in recent years, object tracking accessories have become available. Two digital encoders can be attached to each telescope axis. These encoders are connected to a handheld mini-computer that would direct the user to move the telescope to a selected object that is within the mini-computer object database after performing simple star alignments. Or the Dobsonian could be placed on an equatorial motorize platform allowing about 40-60 minutes of object tracking before having to reset the drive on the platform. And the top of the line, is on each telescope axis attaching an encoder, and a servo's or stepper motor's controlled by computer to provide a complete Go-to capability with object tracking.

"Classic" Cassegrain

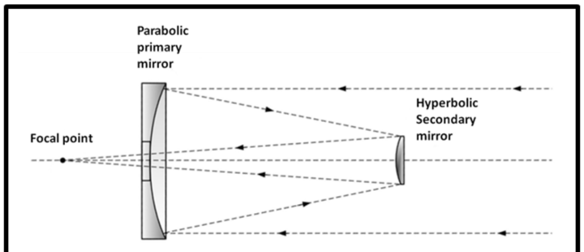


Fig. 18 Cassegrain Light Path

The "Classic" Cassegrain has a parabolic primary mirror and a hyperbolic secondary mirror that reflects the light back down through a hole in the primary. Folding the optics makes this a compact design, and therefore a tube shorter than a Newtonian. On smaller telescopes, and camera lenses, the secondary is often mounted on an optically flat, optically clear glass plate that closes the telescope tube. This support eliminates the "star-shaped" diffraction effects caused by a straight-vaned support spider. The closed tube stays clean, and the primary is protected, at the cost of some loss of light-gathering power. (**https://en.wikipedia.org/wiki/Cassegrain_reflector**)

There are other types of Cassegrain reflectors using different combinations of mirrors to obtain better images for different purposes. Several types are discussed below, including the catadioptric cassegrains which uses a corrector plate.

Ritchey-Chrétien

The Ritchey-Chrétien is a specialized Cassegrain reflector which has two hyperbolic mirrors (instead of a parabolic primary). It is free of coma and spherical aberration at a flat focal plane, making it well suited for wide field and photographic observations. Almost every professional reflector telescope in the world is of the Ritchey-Chrétien design. It was invented by George Willis Ritchey and Henri Chrétien in the early 1910s. (https://en.wikipedia.org/wiki/Ritchey-Chretien_telescope)

Dall-Kirkham

The Dall-Kirkham cassegrain telescope's design was created by Horace Dall in 1928 and took on the name in an article published in Scientific American in 1930 following discussion between amateur astronomer Allan Kirkham and Albert G. Ingalls, the magazine editor at the time. It uses a concave elliptical primary mirror and a convex spherical secondary. While this system is easier to grind than a classic Cassegrain or Ritchey-Chretien system, it does not correct for off-axis coma and field curvature so the image degrades quickly off-axis. Because this is less noticeable at longer focal ratios, Dall-Kirkhams are seldom faster than f/15. (https://en.wikipedia.org/wiki/Cassegrain_reflector)

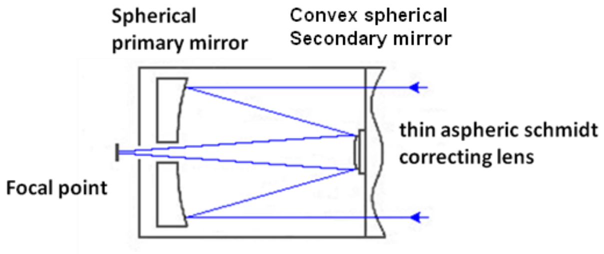
Off-axis configurations

An unusual variant of the Cassegrain is the **Schiefspiegler** telescope ("skewed" or "oblique reflector", also known as "kutter telescope" after its inventor), which uses tilted mirrors to avoid the secondary mirror casting a shadow on the primary. However, while eliminating diffraction patterns this leads to several other aberrations that must be corrected.

Another off-axis, unobstructed design and variant of the cassegrain is the 'YOLO' reflector invented by Arthur Leonard. This design uses a spherical or parabolic primary and a mechanically warped spherical secondary to correct for off-axis induced astigmatism. When set up correctly the yolo can give uncompromising unobstructed views of planetary objects and non-wide field targets, with no lack of contrast or image quality caused by spherical aberration. The lack of obstruction also eliminates the diffraction associated with cassegrain and newtonian reflector astrophotography. (https://en.wikipedia.org/wiki/Cassegrain_reflector)

Catadioptric Cassegrains

The Schmidt-Cassegrain was invented in 1940 by James Gilbert Baker as a modification of Bernhard Schmidt's 1931 wide-field Schmidt camera. As in the Schmidt camera this design uses a spherical primary mirror and a Schmidt corrector plate to correct for spherical aberration. In this Cassegrain configuration the convex secondary mirror acts as a field flattener and relays the image through the perforated primary mirror to a final focal plane located behind the primary.

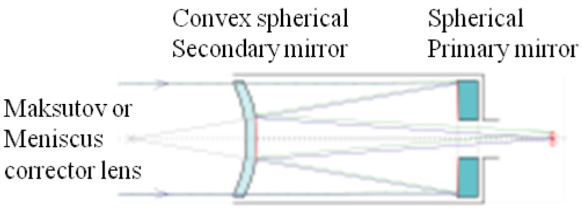


Aperture	f ratio
5-16 inch	10

Fig. 19 Schmidt-Cassegrain Light path

The Schmidt–Cassegrain design is very popular with consumer telescope manufacturers because it combines easy to manufacture spherical optical surfaces to create an instrument with the long focal length of a refracting telescope with the lower cost per aperture of a reflecting telescope. The compact design makes it very portable for its given aperture, which adds to its marketability. Their high f-ratio (f-10) means they are not a wide field telescope like their Schmidt camera predecessor but they are good for more narrow field deep sky and planetary viewing. Schmidt-Cassegrains are popular with amateur astronomers especially those wanting to do astrophotography. (https://en.wikipedia.org/wiki/Schmidt-Cassegrain_telescope)

The **Maksutov-Cassegrain** is a variation of the Maksutov telescope named after the Soviet/Russian optician and astronomer Dmitri Dmitrievich Maksutov who patented it in 1941. It starts with an optically transparent corrector lens that is a section of a hollow sphere. It has a spherical primary mirror, and a spherical secondary that in this application is usually a mirrored section of the corrector lens. (https://en.wikipedia.org/wiki/Cassegrain_reflector)



Aperture	f ratio
3-12 inch	12-15

Fig. 20 Maksutov-Cassegrain Light Path

The primary mirror is a low f-ratio and the secondary mirror is used to increase the f-ratio. The disadvantage is usually they only come in high f-ratios with narrower field-of-views. This configuration is good for use under medium to high power, and is best for viewing lunar and planetary images.

Eyepieces

Eyepieces magnify the image focused through the telescope mirror/lens system. As a result eyepieces are just as important as the mirror/lens on the telescope and serious consideration should be made before purchase. 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 wanted to accomplish. The eyepieces come with .965”, 1 1/4” and 2” barrels. Generally, the 0.965” diameter eyepieces are of poor quality and usually use plastic lenses. As a general rule these eyepieces should not be used. Note that there are good scopes that come with 0.965" eyepieces, but for some you can upgrade to a 1.25-inch diameter eyepiece configuration.

Besides the diameter, there are other factors to take into consideration: the focal length of the eyepiece (usually engraved on the barrel), the apparent field of view (written on the lens specifications), the eye relief, the exit pupil, the weight, and the price. Let's look at these in more detail.

The eyepiece focal length determines the magnification of the telescope. Compute the telescope magnification by taking the telescope focal length and dividing the eyepiece focal length into it. For example, if you have a 1000mm telescope and a 25mm eyepiece. The magnification would be 1000/25 or 40 magnification.

The apparent field determines the field of view through the telescope. Compute the telescope field of view by taking the eyepiece apparent field and dividing the eyepiece magnification achieved for the telescope/eyepiece combination. From the previous example the telescope/eyepiece combination provided a magnification of 40. If we assume an eyepiece apparent field of 60 deg and divide the magnification into it, we get a field of view of 60/40 or 1.5 deg. Generally eyepieces come in three favors; general, wide-field, and extra wide-field. The general or plossl eyepieces are usually 45-55 deg apparent field-of-view. The wide field comes in 60-68 deg apparent field-of-view. And the extra wide-field comes in with 80-100 deg apparent field-of-view.

The wide and extra wide field-of-view eyepieces are especially good for deep sky objects or dim objects. The plossl is a good general eyepiece. However, as the eyepiece focal length gets smaller special consideration need to take place. Since planet viewing usually occurs at high magnification it is important to consider an eyepiece with high contrast. Generally great eyepieces for planet viewing are unique and different than general viewing eyepieces.

The eye relief is a measurement of the distance the eye must be positioned from the eyepiece to keep the center of field fully illuminated. This is especially important for those who intent to observe through a telescope with eyeglasses. Note that it is better to not observe with glasses as your eyesight can in most case be corrected with the telescope focuser. If you must wear glasses because of astigmatism, you'll need at least 15mm of eye relief or longer if you want to see the full field of view with your glasses on. Note that high magnification usually results in smaller eye relief, which may prevent an eyeglass wearer from positioning the eye at the appropriate distance from the eyepiece. The eye relief is defined by the manufacture.

The exit pupil is important to size the eyepiece with the user's unique eye and telescope observing desires. The exit pupil of a telescope is the circular beam of light that leaves the eyepiece being used and is measured in millimeters (mm). Exit pupil can be used to determine the limiting useful magnification of a telescope by using the eye characteristics. Exit pupil larger than your eye is a waste of light, and it can be difficult to center your eye in the exiting light beam. An exit pupil that is smaller than your eye can produce a magnification that is not useful. Having eyepieces that produce exit pupils beyond your eye ability to perceive would not be optimum or cost effective.

The human eye can change its pupil diameter from about 0.5 mm to 7 mm. As we age the ability to obtain an exit pupil of 7 mm is diminished. As a rule of thumb the pupil may be only to dilate to 5 mm after the age of 50. Using the observer's pupil limitation, the useful telescope magnification and therefore the equivalent eyepiece focal length can be determined.

Table 2. Exit Pupil Limiting Eyepiece Focal Length vs. telescope focal ratio

	Exit Pupil Diameter (mm)		
	0.5	5	7
Telescope Focal Ratio (ND)	Limiting Eyepiece Focal Length (mm)		
4	2	20	28
5	2.5	25	36
6	3	30	42
10	5	50	56
12	6	56	56
15	7.5	56	56
20	10	56	56

To calculate exit pupil diameter, divide the aperture diameter (in mm) by the magnification created by the eyepiece being used. Or, you can calculate the exit pupil by dividing the focal length of the eyepiece (in mm) by the focal ratio of the telescope. For example, an 8" aperture telescope (203mm) used with a 20mm eyepiece is working at a magnification of 102 power and has an exit pupil of 2mm (203/102 = 2mm). In table 2 are the limiting eyepiece focal lengths that correspond to exit pupil diameters of 0.5, 5 and 7 mm for various telescope focal ratios. Note that the largest eyepiece focal length is assumed to be 56 mm in a 2 inch format.

The weight of the eyepiece should be suitable with the telescope size, and balance capability. Note that 2 inch eyepieces weigh a lot more than 1 ¼ inch eyepieces. The longer the eyepiece focal length or the higher the apparent eyepiece field-of-view, the heavier the eyepiece will be.

And last, the price needs to be considered as new eyepiece costs are from about $40 to over $1000 apiece. Generally the plossl are the least expensive, with the price going up with the wide-field and further with the extra wide-field eyepieces.

The usable magnification of a telescope is 30 to 300, depending upon telescope aperture and focal length. For small aperture telescopes you may not be able to use magnification above 100x to 150x. Don't be fooled by telescope advertisements that quote a telescope with 600 power. This is because the higher the magnification the dimmer the object becomes and the smaller the area of view. At high magnification mirror distortion, telescope vibration and atmospheric seeing become more apparent. In other words, don't spend your money on an eyepiece that gives much more than 300 magnification, you will probably have very little opportunity to use it.

Although in saying that, there is an exception. Several times a year, sometime during your observing session, for maybe only 20-40 minutes, atmospheric seeing can become extraordinary stable and clear. During these times you don't want to get caught without a capability to push the magnification to your telescope limit for the bright planets (i.e., Mars, Jupiter or Saturn). You may want to get one eyepiece just for this occasion or maybe purchase a Barlow eyepiece.

A special type of eyepiece is the Barlow lens. This lens is inserted in the telescope focuser prior to inserting the eyepiece. A Barlow lens increases the magnification beyond what would be achieved with only an eyepiece. Because of this magnification increase, the Barlow lenses are sometimes called telemultipliers. The majority of Barlows will increase magnification between 2 and 5 times. However, Barlows will dim the image somewhat, but they will maintain the eye relief of the eyepiece. The result is that a 10mm eyepiece with a 3X Barlow will produce the same magnification of a 3.33mm eyepiece. But while a 3.33mm eyepiece would have a very small and uncomfortable eye relief, the 10mm - Barlow combination will maintain the eye relief of the 10mm eyepiece. This, sometimes, may be the only way for glass wearers to use high magnification. The Barlow can double the number of eyepieces with its purchase, since each eyepiece can be used with the Barlow. However, this will only be true if your eyepiece collection does not have eyepieces with focal lengths as multiples of the Barlow magnification.

Also it is very convenient to have all eyepieces with the same shoulder or flange distance (parfocal) such that focus one and you focus all.

Telescope Optics Collimation

To obtain good images the telescope optics must be aligned or collimated. Generally, Newtonians need to be collimated more frequently than Catadioptrics or refractor type telescopes. A truss tube Dobsonian telescope due to assembly requirements needs to be collimated at each setup, and even several times an evening. As the telescope optics f-ratio gets smaller, the collimation must be more precise. Errors in optical alignment are dependent on the temperature of the optics compared to outside temperature, mirror cells that hold the mirror/lens firmly without binding, focuser alignment, and telescope tube rigidity.

There are three major collimation methods; 1) Visually using special collimator tools, 2) Laser Collimator/Barlow, and 3) Star Testing. Method 2) is the easiest and most expensive, with methods 1) and 3) as being the best method, though it takes a lot of experience/practice to use method 3) correctly and perform quickly.

Method 1) is very easy using the method discussed at www.garyseronik.com; Topics-Telescope Making, entitled “A Beginner’s Guide to Collimation”. This method requires a collimation cap or sight tube with cross hairs and that the center of your primary mirror is marked with, for example, a small paper doughnut. First insert the collimation tool into the focuser. The first step is to align the reflection of the little hole in the collimation cap that appears on the primary mirror with the center of the hole in the paper doughnut by adjusting the primary mirror collimation knobs. The second step is to center the secondary mirror reflection on the primary mirror by adjusting the secondary collimation knobs. And the third and last step is to repeat steps 1) and 2) until secondary and primary and all the reflections are centered.

Method 2) has had a lot of discussion regarding the alignment accuracy using only a laser collimator to align your telescope optics. Most articles suggest either first using a laser to align the secondary, then using a laser with Barlow or collimator tools to perform primary mirror alignment. The details will not be discussed here.

Method 3) has several options; the easiest star method was published in the October 2013 issue of the Sky & Telescope magazine, called the "No-Tools Collimation" method. This method is described in great detail on the "www.garyseronik.com" website under the topic of Telescope making. In summary, you first select a star that is around 2nd magnitude and center in your scope. Use an eyepiece that provides magnification about 25x per inch of telescope aperture. Adjust focus to see a central bright area surrounded by a series of faint rings. Move the out of focus star around the field-of-view by moving the scope until the central dark area of the star image is near the center, as close as you can get it. Using the telescope collimation adjustments move the star image to the center of telescope field-of-view. Now refocus to make the star image smaller and repeat the above process until the central dark area of the star image is at the center. Once you think you are done, slowing move focus in and out, the central dark area should stay in the center of the star image.

Determining Optical Quality using a star test

When you view a star in a properly focused telescope you are not going to see an enlarged image since stars, even at high power, should look like points of light rather than disks or balls. This is simply because stars are very, very far away. If you magnify a star's image by about 25x per inch of aperture and look carefully you may be able to see rings around the star. This is not the star's disk you are seeing but the effect of having a circular aperture in your telescope and due to the nature of light. Under close inspection, when the star is at the center of the telescope's field of view, this highly magnified star image will show two things; a central bright area called the airy disk, and a surrounding ring or series of faint rings called the diffraction rings. Doing this type of star testing with the telescope is the best method to determine the optical quality of a telescope, including whether your telescope optics is align properly. However, several conditions must be met to not misinterpret the results; 1) Atmospheric seeing must be good, 2) The telescope optics must be properly aligned; 3) The telescope optics must be about the same temperature as the outside air, and 4) Little or no air turbulence in the telescope tube. Under these conditions and good telescope optics the stellar image should appear like a series of concentric circles all aligned about a common center.

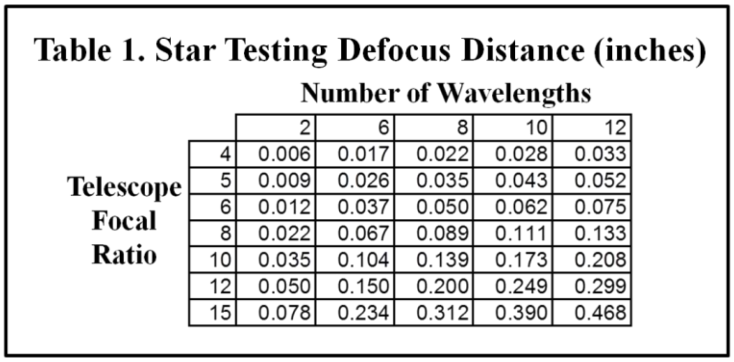


Table 1. Star Testing Defocus Distance (inches)

Telescope Focal Ratio	Number of Wavelengths: 2	6	8	10	12
4	0.006	0.017	0.022	0.028	0.033
5	0.009	0.026	0.035	0.043	0.052
6	0.012	0.037	0.050	0.062	0.075
8	0.022	0.067	0.089	0.111	0.133
10	0.035	0.104	0.139	0.173	0.208
12	0.050	0.150	0.200	0.249	0.299
15	0.078	0.234	0.312	0.390	0.468

To do this type of star testing with your telescope, you must compare the stellar images from both sides of the best focus. However, you must only move the focus no more than the distance shown in table 1. If the resulting star image does not look like a series of concentric circles all centered, then you may have a defective or less than optimal mirror or lens.

Telescope mounts

The telescope mount provides the support and stability necessary to find and track sky objects. This is extremely important if astrophotography is required. There are three general types of telescope mounts; equatorial, altitude-azimuth (Alt-Azimuth), and Dobsonian. Although technically, the Dobsonian is an altitude-azimuth mount.

The equatorial mount is a two axis system, but the telescope polar axis, or right Ascension axis, is aligned with the earth's rotational axis. This allows a sky object to be followed by moving one axis only. The axis tracking can be performed by manually using your hand, with a motor controlled hand pad or by a computer. The equatorial mount usually sits on a tripod or pier. This type of mount is best for astrophotography.

The altitude/azimuth mount is also a two axis system, in which both axes must be moved to follow a night time object. In the tripod variety, manual control cables can be used to precisely move the telescope in both axes. Digital encoders can be added to each axis and handheld computers can direct a user to move the telescope to a selected object. Motors can be attached to each of the axes and can be driven by a handheld computer key pad or by computers running planetarium programs point to any number of sky objects. The major disadvantage is that photography will be limited to short exposures due to field rotation. Field rotation is when the image rotates over time due to the telescope rotation axis not being aligned with the Earth's rotation axis. Although with additional processing the images can be rotated back using a computer to correct for the rotation.

The Dobsonian mount is an altitude/azimuth mount that also requires two-axis tracking. This mount in the simplest form is simple, inexpensive and can be homemade. The Dobsonian is controlled by grabbing the end of the telescope tube and moving it to the desired viewing direction. Digital encoders can be added to each axis and handheld computers can direct a user to move the telescope to a selected object. The latest option is adding motors with digital encoders to each axis and controlling the mount by phone, tablet or hand controller. This method also allows the mount to track a user defined RA/DEC coordinate. This will keep the object in the eyepiece or camera field-of-view.

A telescope mount serves four purposes; Support, Pointing, Tracking, and Indexing. Each will be discussed in the following paragraphs.

Support

A telescope mount must "Support" the optical tube assembly and varying attached accessories, such as a finderscope, focuser, eyepiece, and camera's as the telescope is moved, at rest or in windy conditions. The mount needs to be rigid to minimize vibration caused by wind, adjusting the focuser, switching eyepieces or moving the telescope either by hand or by computer. Mounts can be light if the telescope optical tube assembly is light and photography is not a priority. Or they can outweigh the optical tube assembly by several times if photography is required.

Pointing

A telescope mount allows "Pointing" of the telescope to find objects in the sky. Every telescope, whatever its type, must be rotated around two perpendicular axis. Pointing is then a matter of rotating the scope around these axes until the scope is aimed at the desired location. Pointing of the telescope can be done by 1) Manually grapping the telescope tube to move the telescope, 2) Manually using Slow-motion control knobs which allows the telescope to be moved precisely, 3) Pushing buttons on a hand paddle which controls motors that move the telescope, or 4) Pushing keys on Computer keyboard providing pointing commands which tells the computer how to control the motors on the telescope

Each telescope axis consists of an axle held by two restrains or bearings. The purpose of the bearing is to restraint unwanted movements allowing only rotation. A well-designed telescope mount will have smooth and regular movements and will not have any “looseness” in the system.

Tracking

As a consequence of the Earth’s rotation around its axis, the sky appears to rotate. The result is that if the scope is kept stationary, celestial objects will drift across the field of view and will eventually disappear. With a telescope field of view of one degree, an object will only been seen for 4 minutes. However, with motor drives attached to the axes, the Earth’s rotation can be matched, keeping the object stationary in the eyepiece. This can be done using manual hand controls, a computer or a computer/CCD camera with auto-tracking. Any of these methods can be used to maintain an object in the telescope’s field of view. Tracking is a convenience for visual observation, but it is a necessity for astrophotography. To record very faint objects, a camera can be used to obtain photographs using film or a CCD by collecting the light from the object over a long period of time. To prevent object smears or tails from appearing on the photograph the telescope tracking must be precise for the duration of the photograph.

The following can affect the ability to maintain long term tracking; 1) Telescope balance, 2) Clock drive backlash, power supply errors and periodic error, 3) Perpendicular of the drive axes, and 4) Polar Alignment Error.

Telescope Balance

If the telescope is not properly balanced on the mount, the telescope optical tube assembly can slip or move affecting the ability of the telescope to point and track accurately. Not properly balancing the telescope on the mount can damage the axis clamp locks or in a worse case cause the motor to jump or slip, and over time possibly damage the motor or gears. The causes of poor telescope balance can be, 1) Adding heavy camera without rebalancing the telescope, 2) Using heavy eyepieces without rebalancing the telescope, 3) Too heavy of a finder-scope or other accessory, 4) Telescope drive clutch is too loose, 5) Telescope balanced in only one axis, and 6) not having sufficient weights to balance the loads on the telescope.

Clock drive backlash, power supply errors and periodic error

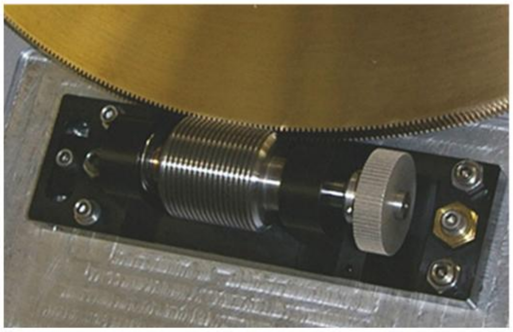


Fig. 21 – Example of a gear and a worm drive in a telescope mount

http://www.mathis-instruments.com/Design/DriveGears.html

The telescope clock drive generally consists of a gear and a worm drive. Because of mechanical errors in this type of drive, unless the gear is forced to be in contact with the worm drive at all times a backlash or movement is observed any time the drive is not driving the gears. This is usually prevented in the telescope mount drive design with springs, gravity or motor design. The more expensive mounts have this feature. Also due to either poor design or gear wearing over time errors can occur that interferes with precise tracking. This can be minimized by ensuring the telescope optical tube assembly is balanced on the mount at all times. Large power supply ripple or fluctuations can cause the motor to speed up or slow down. To minimize this affect, direct current (DC) is usually the choice for telescope power. Periodic error is an inherent problem in all telescope drives. In any drive system, that has circular gears, the gears are not perfect and during one rotation of motion a very slight wobble can be observed over time that repeats. The more expensive mounts try to minimize this error in the circular gears during manufacture or by means of electronics - Periodic Error Correction (PEC). The principle of PEC is based on recording tracking corrections made by observer by star tracking during one period. This tracking correction is then applied during normal mount use.

Perpendicularity of the drive axes Error

If the two telescope drive axes or rotation axes are not exactly perpendicular then as the telescope moves it will slowly cause tracking or pointing errors.

Polar Alignment Error

Polar alignment error is similar to “Perpendicularity of the drive axes” errors, however it can be corrected. If the telescope’s rotation axis is not precisely aligned with the Earth’s Rotation Axes, the star or object will slowly drift out of the telescope’s field of view. The larger the polar alignment error, the faster the star or object will appear to move. This error can be reduced with a polar alignment finder scope with reticule when used with a pole star location program (“http://myastroimages.com/Polar_FinderScope_by_Jason_Dale/“). And further reduced with a polar alignment scope in the mount, or almost completely eliminated by using the star drift method of polar alignment or use of Polar Alignment software with a camera that helps in the identification and correction of polar alignment errors.

Star Drift Polar Alignment Method for Equatorial mounts

The star drift method can be used to align your telescope to any accuracy. It takes approximately 10-40 minutes to complete depending upon how good an alignment is required. For astrophotography, the longer the exposure the better your alignment needs to be.

Procedure

1. First, level your tripod and orientate it to Polaris (not necessary, it just helps). If you have a Polar alignment finderscope or reticule, use it to obtain a good polar alignment.
2. Look at a star near the Equator in the direction of South. Track the star in RA only, and look if the star goes up or down in your eyepiece (supposing you are looking straight at south with your head vertical). Rotate the azimuth of your telescope to adjust it until the star is not moving.
3. Continue until the star does not move for the expected time of your exposure
4. Next, move to a star at East (West works also). Do the same as before, but adjust the latitude this time (the angle between your telescope axe and the horizon plane). By switching several times from South to East (West), you should be able to adjust your polar alignment quite quickly. Of course, the first time you will spend a lot of time; take notes of what you are doing, and it will be much quicker the next time you do it.
5. Continue star drift process until the star does not move for the time you want to take an exposure or view an object without correction.

Polar Alignment for Alt-Azimuth mounts

The only manual method to polar alignment an Alt-Azimuth mount is by performing a star alignment. This is completed by pointing and centering the telescope on one or more known stars and let a computer determine the direction of the Earth’s rotation axis. An alignment error is due to the accuracy of the computer program algorithm, the encoder accuracy and the user’s ability of centering the alignment stars in the telescope and telling the computer which star is being observed. Only method to improve performance is lots of practice.

For the more expensive scopes, GPS, encoders, star databases and cameras are used to perform the star alignment. You don't even have to know the stars!

Indexing

The purpose of indexing is to be able to find sky objects. The position of celestial objects can be determined by their right ascension and declination coordinates or by their altitude and azimuth at any given time. By attaching accurate indexed circles to the two axes of a telescope (equatorial, alt/azimuth or Dobsonian) it would be possible to easily "dial" the position of a celestial object. These indexed circles are known as setting circles. Digital setting circles are now available that are far more accurate than the use of mechanic setting circles. Effective use of setting circles requires careful star alignment of the scope. And by merging the digital setting circles or encoders with a computer and a planetarium program this task is simplified and easy.

Portion of this section was extracted and edited from a 2005 Orange County Astronomers (https://www.ocastronomers.org) Beginner's Class handout written by Antonio Miro

In the past few years, a new version of a telescope has arrived, called the Go-To telescope. These telescopes combine a computer, a sky planetarium program, and control motors to move the telescope to a user-defined object found in the sky planetarium database. The user first enters the time, then performs a one, two or three star alignment, selects the desired object in the computer database and the computer will maneuver the telescope the object's sky location. The higher cost Go-To telescopes have even eliminated the need for the user to provide time or to perform the star alignments. Even the Dobsonian telescope now has Go-To capability.

For the Dobsonian or telescopes without encoder or digital setting circles, indexing uses your brain, eyes, hands, star maps and sighting equipment. The sighting equipment may be a finderscope, red dot reticule, a telerad, laser pointer, or an eyepiece that provides a very wide field-of-view.

1. The finderscope is the best choice for those telescopes that can support the weight. It has a larger field of view (usually about 5 degrees) than your telescope (usually about 1 deg) making it easier to point the telescope at a star or sky object. The most common sizes are 6x30, 7x50 or 9x50. The first number defines the magnification over using just

your eyes, and the second number represents the diameter of the aperture in millimeters. As a generally rule, unless the telescope cannot support it, chose at a minimum the 7x50 finderscope. They come in either right angle or straight thru versions. Choose the one that makes it easier on your back!

2. The red dot pointer provides a red dot centered in a sight tube that allows the user to sight down the tube to put the red dot on the object that is of interest by moving the telescope. It has no magnification, but is very light weight. Pointing accuracy is at the size of the red dot.

3. The Telerad is basically a telescope Heads-Up-Display(HUD). It places two red circular reticules in the center of a sight tube, allowing the user to sight down the tube and place the object of interest in the center of the circles by moving the telescope. The telerad works best when sighting on dimmer objects. To help in this, a circuit can be added to cause the reticule to blink on and off that improves your ability to center the dimmer objects. It does not have any magnification.

4. The laser pointer provides a dot in the sky to point your telescope on the intended object. A green laser is preferred. But beware of an airplane along the intended viewing area as it is a federal offense to point a laser at an airplane.

5. An eyepiece that provides a very wide field-of-view can also be used for very light weight telescopes with a short focal length. Remember to be an effective finderscope the field-of-view should be 3-5 degrees wide. But with practice you can get this down to one degree by performing a little spiral search.

Note that in using any of these methods, except the eyepiece method, they require the sighting device to be aligned with the telescope to achieve the intended results.

The previous paragraphs describe the equipment needed to index or find a sky object, but a star map is required to know where to point your telescope. There are plenty of star maps available. Just a few years ago star maps were printed in paper catalogs, but today with computers and mobile devices there are plenty of mobile device apps and computer software planetarium programs that provide star/object locations or maps. To be able to find your way around the apps and computer programs you will see that objects are categorized in by different methods using constellations, or specific star/object catalogs. Three of the more popular catalogs are the Messier (M) catalog, New General Catalog (The NGC) and the index catalog (IC).

The Messier catalogue consists of a list of 110 objects catalogued by the French astronomer Messier (1730-1817) in the 18th century. Messier was a comet hunter and in his search for comets he came across a number of “fuzzy” comet-like objects. When he realized that those objects were not comets, he prepared a list of them to help other astronomers to avoid confusion if they came across the same objects. The Messier catalogue is very often the first observing goal of beginners. The catalogue includes star clusters, nebulas and galaxies, and they are all within reach of a 90-100 mm scope.

https://en.wikipedia.org/wiki/Charles_Messier

The New General Catalog was updated from the General Catalog first created by Sir William Herschel (1738-1822), his sister, Caroline and his son, John. Their catalog consisted of 2514 objects, including star clusters, nebulas and galaxies that were far dimmer than those in the Messier catalog. William Herschel had the best telescopes in the world (6in diameter with 7-foot focal length, 12in and 18.7in diameter, both with a 20foot focal length) at that time so was able to see further into the cosmos. Herschel is most famous for the discovery in 1781 of the planet Uranus, along with its two major moons, Titania and Oberon, and also discovered two of Saturn’s moons. The General Catalog was first published in 1786, with updates in 1789, 1802 and a final update in 1864 by John Herschel.

https://en.wikipedia.org/wiki/William_Herschel

In 1888, John Dreyer (1852-1926) edited the general catalog, supplemented with discoveries by many other 19th century astronomers and published as the New General Catalogue with 7840 deep sky objects.John Dreyer published two supplements to the New General Catalogue, the first in 1895, containing 1520 objects, and the second in 1908 containing 3866 objects. The supplements were called the Index Catalogue (IC) and contained a total of 5386 objects.

https://en.wikipedia.org/wiki/New_General_Catalogue

https://en.wikipedia.org/wiki/John_Louis_Emil_Dreyer

Another popular, newer catalog is the Caldwell catalog complied by Sir Patrick Caldwell-Moore, better known as Patrick Moore, as a complement to the Messier catalog. It was first published in Sky & Telescope magazine in 1995. Many of today's popular deep sky objects were not included in the original Messier catalog, so Moore edited the Messier catalog to come up with a 109 object list to complement that of Messier.

https://en.wikipedia.org/wiki/Caldwell_catalogue

https://en.wikipedia.org/wiki/Patrick_Moore

There are galaxy catalogues such as the PGC (Principal Galaxy Catalogue), the UGC (Upsala General Catalogue), the MPG (Morphological Catalogue of Galaxies) and some others. The PGC alone lists over 100,000 galaxies. Then there is the Hikson catalogue, for groups of galaxies, The Aarp catalogue for galaxies, the Terzan Globulars, the PK catalogue for planetary nebulas to name a few. Many objects are listed in several catalogues at the same time. M31 for instance is listed in the Messier, NGC, PGC, UGC and MPG catalogs. http://messier.seds.org/xtra/supp/cats.html

If you use a Dobsonian or a telescope without computer assistance, a "Star Hopping" technique is needed to improve your ability to find dim objects. Star hopping consists in locating an object by "hopping" from star to star that are easy to recognize, and by following patterns and shapes in the sky. Let's try a very simple example. Almost everyone knows how to locate Polaris, the North Star. First find the two end stars (beta Ursa Majoris (Merak) and alpha Ursa Majoris (Dubhe)) that make up the bucket of the big dipper. Follow an imaginary line passing through these stars and going toward north. Extending this line about five times the distance between Merak and Dubhe (called for this reason the Pointer Stars) we find Polaris. It is possible to hop in this way to many objects, even if they are not visible with the naked eye.

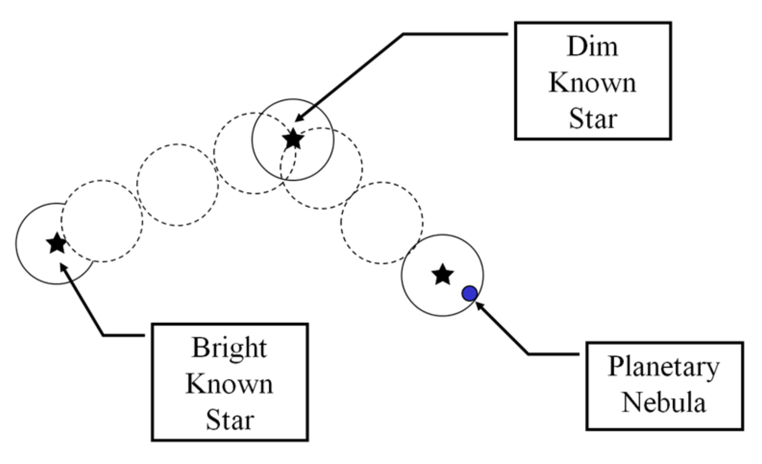


Fig. 22 – Star Hopping Example

Now let's do an example of finding a dim object using a finderscope on a telescope. Let's assume we want to find a small Planetary Nebula. Looking at our star catalog or device we determine that it is near a known named or bright naked eye visible star (star 1). We first center the known naked eye visible star (star 1) in the finderscope. If we don't know the finderscope field-of-view, we must determine it by using the manufacture value or measuring it. Remember, the earth rotates 1 deg in 4 minutes. Looking at the star catalog or device we notice that a dim star (star 2), that is only visible in the finderscope, is 3.0 finderscope field-of-view diameters away going in the north east direction. So we move the telescope to first place the naked eye visible star(star 1) on the edge of the finderscope field-of-view. Then we move the telescope/finderscope toward the north east 3.0 finderscope field-of-view diameters until we find the dim star(star 2). Then, center the finderscope on that star (star 2). Again looking at our star map or device we notice a dim star (star 3) right next to the planetary Nebula 2.5 finderscope field-of-view diameters away toward the south east from where we are currently looking. So as before, first place the current star(star 2) at the edge of the finderscope field-of-view, then move the finderscope/telescope toward the south east 2.5 finderscope view-of-views until we find our next dim star (star 3). Then, center the finderscope on that star (star 3). According to our star map or device the planetary nebula is now within the telescope field-of-view. In the best case, it is visible in the finderscope, if not then we have to look in the telescope eyepiece to find the planetary nebula.

Of course in the case, where the planetary nebula is outside the telescope field-of-view while centered on the 3rd star, you have two choices. The first choice would be to move the finderscope from the 3rd star toward the direction and distance of the planetary nebula and hope it is within the telescope field-of-view. Or the second choice would be to determine the distance to the planetary nebula using the telescope field-of-view, put the 3rd star at the edge of the telescope field-of-view and move toward the direction of the planetary nebula the calculated telescope field-of-view value

Star hopping may sound complex, but after a little patience and practice, practically any object can be located. Soon you will be a star hopper expert!

To be able to align your go-to telescope or perform a star Hop, a little more definition is required to bridge the gap between catalogs and finding stars/objects. This includes star names, star magnitude, and coordinate system definitions.

Star Names

In ancient times, only the Sun and Moon, a few hundred stars and the most easily visible planets had names. The majority of the alignment stars necessary for today's computer telescopes are named, so these are fairly easy to find within a constellation. However, as stars become dimmer the number of star increase and a different method is required to designate a star. The most common is the Bayer designation for stars. In 1603, Bayer published a list of stars that were assigned lower case Greek letters to each of the brightest stars in every constellation. For each constellation, Alpha was assigned to the brightest star, beta the second brightest and so forth. However the Bayer designation very quickly runs out of Greek letters to cover all the visible stars of a constellation. In the 1700's, Flaamsted suggested to assign numbers to the rest of the stars not designated by the Bayer system. Stars that are too faint to be designated by either the Bayer or Flaamsted designations are designated by other catalogues such as the SAO, Hipparchos, GSC, PPM, Tycho catalogues to name a few.

https://en.wikipedia.org/wiki/Astronomical_naming_conventions
https://heasarc.gsfc.nasa.gov/W3Browse/all/hipparcos.html
https://www.iau.org/public/themes/naming/

Star Magnitude

All objects in the night sky can be described by their apparent brightness or also known as a stellar magnitude. Many centuries ago stellar magnitude was defined that the brightest star was magnitude zero and the dimmest star that could be seen with the human eye was magnitude 6. Today photometric measurements are used, and that equates to a first magnitude star being 100 times brighter than a sixth magnitude star. That means a one magnitude change in a star brightness, is equal to being 2.5 times brighter or dimmer. According to http://www.skyandtelescope.com/astronomy-resources/how-many-stars-night-sky-09172014, under good seeing conditions about 9,096 stars are brighter than magnitude 6.5. This includes the moon, the planets, except Neptune and the dwarf planets, and some deep sky objects, like Andromedia galaxy (M31), M8, gobular cluster (M13), the Double Cluster in Perseus, and another few deep sky objects.

Coordinate frames

All sky objects use a coordinate system to accurately define its location in the sky. With these coordinates any celestial object can be found. There are many coordinate systems, horizontal (local), Earth, and Celestial or Astronomical. In addition, telescopes have their own equivalent coordinate system.

The **horizontal coordinate** system is a celestial coordinate system that uses the observer's local horizon as the fundamental plane. It is expressed in terms of altitude (or elevation) angle and azimuth. The horizontal coordinate system is fixed to the Earth, not the stars. Therefore, the altitude and azimuth of an object in the sky changes with time, as the object appears to drift across the sky with the rotation of the Earth. In addition, because the horizontal system is defined by the observer's local horizon, the same object viewed from different locations on Earth at the same time will have different values of altitude and azimuth. https://en.wikipedia.org/wiki/Horizontal_coordinate_system

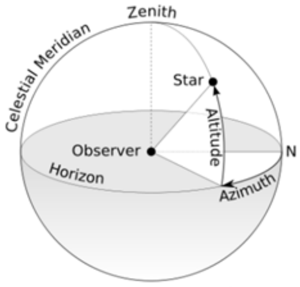


Fig. 23 – Horizontal Coordinate System

- Altitude or elevation angle is measured upward from the horizon. Zero degrees would be pointed at the horizon, and 90 degrees would be pointed straight up (zenith). A negative value indicates the object is below the horizon.
- Azimuth angle is measured eastward from North in degrees. North is 0 degrees, East would be 90 degrees, south is 180 degrees, and west is 270 degrees.
- On telescopes this is known as an Alt-Azimuth coordinate system

A precise Earth location can be defined using latitude, longitude and altitude, which is defined as Earth coordinates.. Latitude is the angle in degrees measured up from the Earth’s equator. Zero degrees would be on the equator, and 90 degrees would be at the North Pole, and -90 degrees would be at the South Pole. Longitude is the angle in degrees measured eastward from the Greenwich meridian. Altitude is measured from a reference earth model (GPS or geodetic) or can be defined as from sea level. This distinction is important when entered your location into a computerized telescope.

Celestial objects use a coordinate system similar to Earth coordinates of latitude and longitude. Declination is use instead of latitude, and Right ascension is used instead of longitude. Positive declination is measured upward from the celestial equator from 0 to 90 degrees. Negative declination is measured downward from the celestial equator from 0 to a negative 90 degrees. Right ascension is measured eastward along the celestial equator from a zero reference point call the vernal Equniox. Since the Earth is turning and the stars are not, a time is used when defining the location of a celestial object observed from an Earth location. Therefore, Right Ascension is measured as an angle in time (hours, minutes and seconds) and since the Earth turns once in a 24 hour period, one hour of right ascension is equal to 15 degrees at the celestial equator. Note that these celestial coordinates are only valid for one instance of time or epoch. Currently the epoch used for defining celestial coordinates is J2000 or January 1, 2000 noon UTC. The prefix "J" indicates that it is a Julian epoch. (https://en.wikipedia.org/wiki/Right_ascension)

According to http://calendars.wikia.com/wiki/Vernal_equinox#Names, the vernal equinox occurs when the sun can be observed to be directly above the Earth's equator. This occurs about March 20 of every year and signals the start of spring. Unlike the zero longitude reference in the Earth's coordinate system that is essentially fixed, the vernal equinox or the zero right ascension reference varies every year. The reason for this is similar to the effects observed in a child's spinning top; the top's top follows a circular path. This is call precession. Since the Earth is spinning, it acts like a top and will also have precession due to gravity of the Sun and Moon. Although the child's top precession period will be measured in seconds, the Earth's precession period is about 26,000 years as shown in Fig. 24. It takes 26,000 years for the Earth's axis to complete one precession period of 360 degrees. The precession speed is therefore about 50 arc-seconds of angle in a year. This doesn't seem like much but over a 30 year period the vernal equinox will moved about 25 arc-minutes, or 0.4 deg. If not accounted for, the ability to point a telescope at a set of celestial object coordinates would be in error. However in the age of computers, computer planetarium programs compensates for the changing vernal equinox.

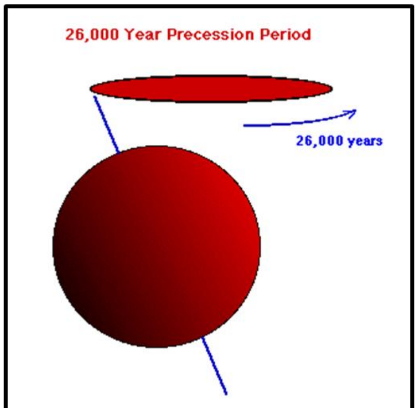
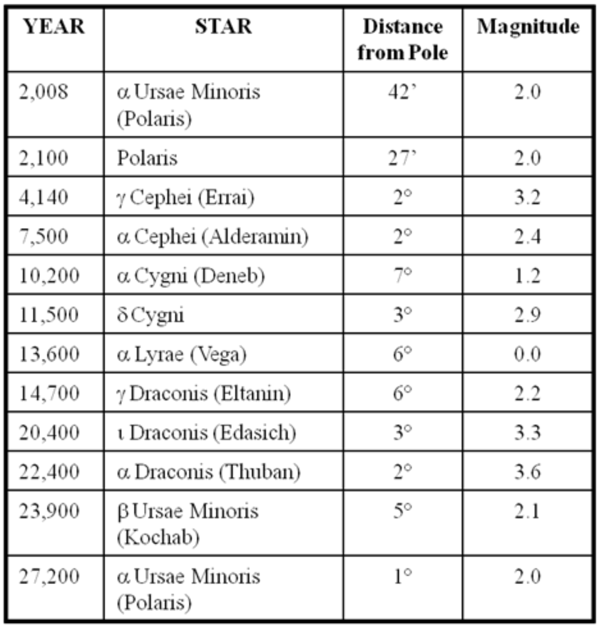


Fig. 24 – Earth's Precession Period

http://www.crystalinks.com/precession.html

Another interesting fact about the 26,000 year procession cycle is that Polaris, the pole star, will not always be the North Star. In about 8,000 years Deneb will be in the pole star position, and in about 12,000 years, Vega will again be the pole star.

Fig. 25 – Future Pole Stars



YEAR	STAR	Distance from Pole	Magnitude
2,008	α Ursae Minoris (Polaris)	42’	2.0
2,100	Polaris	27’	2.0
4,140	γ Cephei (Errai)	2°	3.2
7,500	α Cephei (Alderamin)	2°	2.4
10,200	α Cygni (Deneb)	7°	1.2
11,500	δ Cygni	3°	2.9
13,600	α Lyrae (Vega)	6°	0.0
14,700	γ Draconis (Eltanin)	6°	2.2
20,400	ι Draconis (Edasich)	3°	3.3
22,400	α Draconis (Thuban)	2°	3.6
23,900	β Ursae Minoris (Kochab)	5°	2.1
27,200	α Ursae Minoris (Polaris)	1°	2.0

Taken from Sky & Telescope article in March 2008 issue by Andre G. Bordeleau

How to Select a Telescope

Perhaps one of the toughest decisions confronting a beginner astronomer is to decide which telescope is the best choice for a first telescope. The best advice 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 let you 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 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. Also you can watch the scope being setup to determine any negative or positive items to consider. 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 up to your expectations.

Also, Subscribe to a Astronomy type magazine to get familiar with telescope manufactures. Some manufactures have material and videos describing their telescopes. Get familiar with the night time sky and try visual astronomy using binoculars. You can see Planets, Moon, star clusters, multiple stars, and a few galaxies through binoculars. Binoculars are a good first choice because they are less expensive than a telescope, larger field-of-view to find objects, and can be used during the day time.

After you have done the above and are ready to purchase a telescope, consider the following. As discussed earlier, Aperture (diameter of the lens or mirror) is the single most important factor in choosing a telescope. The larger the aperture, the more light it collects and the brighter (and better) the image will be. At any given magnification, the larger the aperture, the better the image will be. Greater detail and image clarity will be apparent as aperture increases. For example, a globular star cluster such as M13 is nearly unresolved through a 4" aperture telescope at 150 magnification but with an 8" aperture telescope at the same power, the star cluster is 16 times more brilliant, stars are separated into distinct points and the cluster itself is resolved to the core.

Besides aperture, astronomy knowledge, observing goals, portability, storage and budget are of equal importance. Let's discuss each item in detail.

Astronomy knowledge

What is your level of astronomy and astronomy equipment knowledge? If you are just a beginner and don’t know if astronomy is a passion, it doesn’t make sense to spend thousands of dollars on equipment. Choose first at the lower end of telescopes, and as your passion grows, you can always upgrade your equipment at a later time.

Observing goals

What type of observing do you plan to do? Do you want to see bright objects/planets or deep sky objects or both? Do you want to record your viewing objects using photography, or do you want to do only high-end photography?

- Visual only is the least expensive as it doesn’t require expensive cameras, computers, computer software or mounts. Dobsonian telescopes are good choices as they are the largest aperture for lowest cost. Another option is the current selection of small telescopes that have Go-to capability. They come in both refractors and reflectors versions. Select at least a 60 mm aperture, although a better choice would be in the 80-90mm range for a refractor, or a 4" aperture in a reflector.
- Refractors are the best choice if only bright objects are desired. Newtonian telescopes are best choice if Deep sky objects are desired as larger apertures are available over

what a refractor can provide.

- Photography capability requires a more stable and expensive mount, including a camera, and generally a computer to store and process the images using image processing software. A lot more time is required to process the images. Web or video camera, or a standard digital single reflex (DSLR) camera can be used for bright objects and almost any telescope can be used. Photographing Dim objects (and usually smaller objects) will require a more specialized and expensive astrophotography CCD camera and a better mount. A Schmidt-cassegrain telescope with focal reducer is a good choice for general photography use. Note that if whole sky photography is desired a telescope is not required.
- High-end photography requires an even more stable, heavier, and expensive mount along with a better camera, auto guider, and a lot of software programs. There are two choices, wide field and narrow field. A small 80-100mm refractor on a stable mount is excellent for wide field photography. For narrow field photography an even better mount is required to allow tracking with longer focal length telescopes. A Ritchey-Chrétien cassegrain telescope would be a good top choice here.

Storage

The basic question here is "Where is telescope going to be stored when not in use?" Remember the larger the telescope, the larger the storage area.

Portability

How is telescope going to be transported? Is your car or truck large enough to transport, spouse/friends, kids, camping gear, and telescope equipment? How much can you lift and feel comfortable assembling in the dark without help? Will i always need help? A modular telescope reduces the maximum weight that needs to be lifted at the cost of longer assembly or setup time.

Cost

How large is your budget for a telescope and equipment? Don’t forget the cost of eyepieces and accessories. Before you buy know minimum prices, whether you plan on buying a telescope on-line or not, check internet prices including shipping. If you plan on purchasing a telescope at a dealer, always offer a lower price than marked…..dealer can only say no.

Remember a local dealer may not be able to match internet prices, so be prepared to offer at least the internet price plus shipping. If your offer is not accepted, ask if they will throw in a good quality eyepiece, for example a 26 mm focal length possl eyepiece. Used telescopes are a good alternative, but don't buy unless you look through it first or have consulted an experienced observer before committing to purchase. And last look for deals.

After you have decided on the above choices, select the largest telescope aperture that is within budget, can be lifted, transported and stored, and within your astronomy knowledge.

This section on telescopes originally came from two 2005 Orange County Astronomers (https://www.ocastronomers.org) Beginner's Class handouts written by Antonio Miro (The original handouts are no longer available). David Pearson reproduced and edited portions of these handouts, and added material as reference.

Keck telescope picture was taken by the author