ORANGE COUNTY ASTRONOMERS

BEGINNERS CLASS NOTES

TELESCOPE BASICS

TELESCOPE MOUNTS

1. INTRODUCTION

The optical system of a telescope is only a part of the overall system. The system must be installed in a mount that not only allows the scope to be moved easily around the sky, but also is solid enough to avoid vibrations.

Wind and touching of the telescope by the observer may induce vibrations in a scope. Since the telescope produces a magnified image, small vibrations will cause the image to jump wildly in the field of view. A good mount will reduce the amplitude of the vibrations and dump them quickly. A sturdy mount is crucial because an optical system of exceptional quality on a flimsy mount is virtually useless.

2. PURPOSE OF THE MOUNT

A telescope mount serves four purposes: Support, pointing, tracking and indexing.

2.1. Support

Support is the mount main job. As it is mentioned above, support not only means holding the scope, but also being able to avoid vibrations. To do this the mount structure must be rigid and properly designed.

The intuitive approach is to build massive mounts with very rigid materials such as steel and aluminum. Metals, however, are flexible and store vibrations efficiently. Mass can be detrimental unless it is carefully distributed and balanced.

Rigidity can be obtained with very simple, inexpensive and light materials, such as cardboard, plastic and wood. The principles behind rigidity are simple. Use triangles to avoid deformations, and do not use a mount that cantilevers large weights, which are prone to flexure induced vibrations.

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2.2 Pointing

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 aims at the desired location.

Each axis constitutes a bearing that, in turn consists of an axle held by two restrains. 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.

2.3. Tracking

Support and pointing are the two essential functions of a mount. Tracking is more of a convenience for visual observation, although it becomes a necessity for astro-photography.

As a consequence of the Earth revolution around its axis, the firmament seems 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. In the case of visual observation the scope can be moved manually to track the object, however this approach will not work for astro-photography.

Motor drives attached to the axes will match the rotation of the Earth and the scope, keeping the object stationary in the eyepiece or the objective lens of a photographic camera.

2.4. Indexing

The position of celestial objects can be determined by their right ascension and declination, or by their altitude and azimuth at any given time. By attaching indexed circles to the two axes of a telescope it would be possible to “dial” the position of a celestial object easily. These indexed circles are known as setting circles. This topic will be discussed with more detail later on this handout.

Effective use of setting circles requires careful alignment of the scope.

3. MOUNT TYPES

Telescope mounts come in two basic types, alt-azimuth and equatorial. These types correspond with the two types of coordinates commonly used in astronomy.

3.1. Alt-Azimuth Mount

The alt-azimuth mount works basically like an artillery gun. One axis of rotation is horizontal and allows the scope to move vertically from the horizon to the zenith. This constitutes the altitude motion which varies from 0 degrees (horizontal) to 90 degrees (vertical).

The other axis is perpendicular to the ground and allows pointing the scope around the horizon. This constitutes the azimuth motion that varies from 0 degrees to 360 degrees measured eastward from the North (0 degrees). By moving the scope in a combination of these two motions the observer can point the scope to any point in the sky.

The basic alt-azimuth design consists of a fork holding the scope. A horizontal axis thorough the fork allows the scope to move in altitude. The fork is supported by a vertical axis that allows the azimuth rotation of the scope. A pier or a tripod supports the vertical axis. Motion on both axes can be controlled with treaded rods and fixed into position with clamps.

This type of mounting is normally found in cheap department store telescopes and that is why this mount has a bad reputation. However, well-built alt-azimuth mounts, on a sturdy tripod or pier, with good slow motion controls, perform very well.

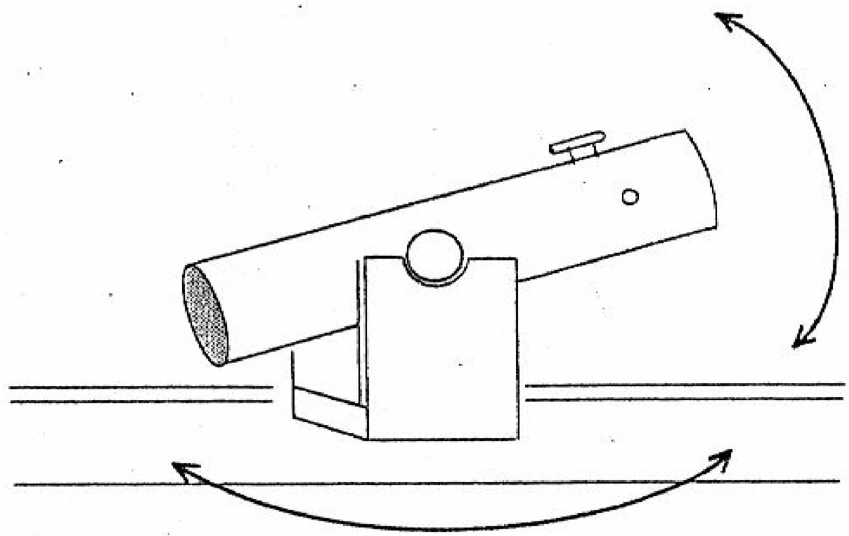


Figure 1. Alt-azimuth mount

The great advantage of well design alt-azimuth mounts is that they are very sturdy, because the center of gravity of the system always falls within the base of the scope, and there are no elements cantilevering out of the base that may cause flexure induced vibrations.

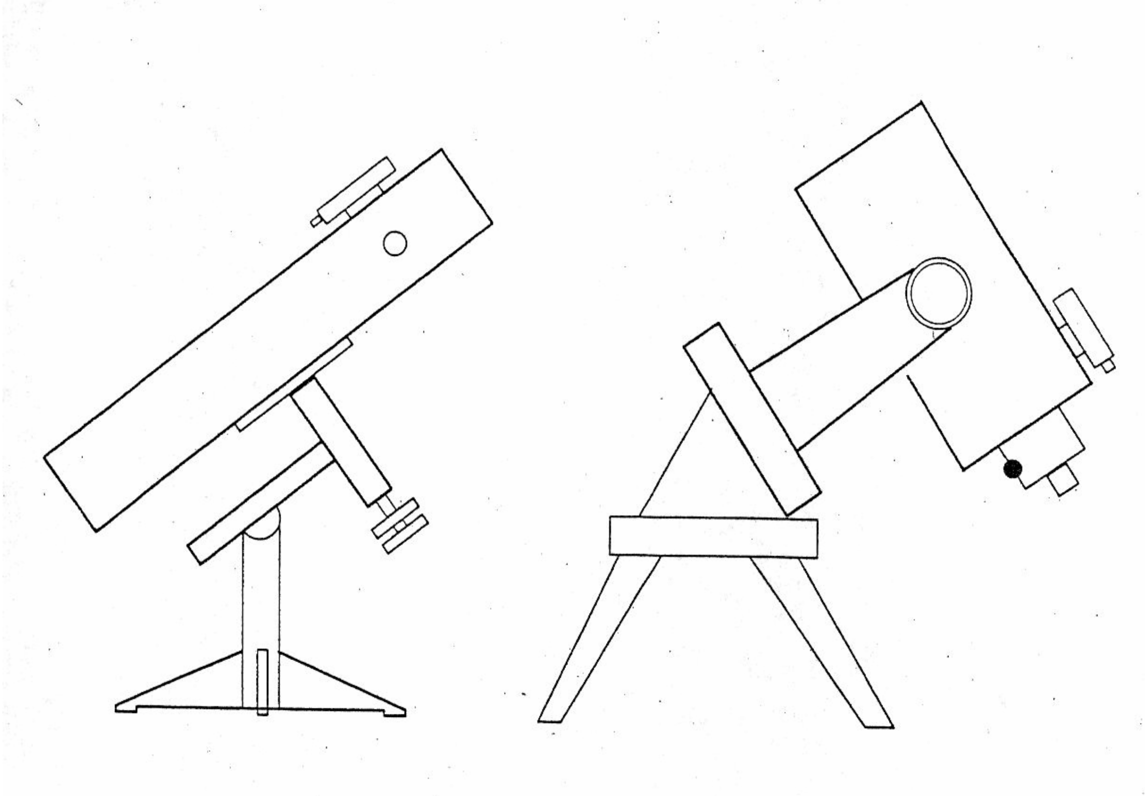
A very popular version of the alt-azimuth mount is the Dobsonian mount that was developed by John Dobson of the San Francisco Sidewalk Astronomers. This type of mount use inexpensive materials such as plywood and cardboard to make compact and very sturdy mounts favored for large aperture telescopes.

This type of mount does not require the use of bearings and precision machined shafts. Instead the Dobsonian telescopes use the friction between materials like Formica and Teflon to move with buttery smoothness and practically zero backlash.

3.2. Equatorial Mount

If we tilt an alt-azimuth mount in such a way that the vertical (azimuth) axis points to the celestial pole the mount becomes equatorial. An equatorial mount, in summary, is a mount in which one of the axes is aligned (pointed) to the North celestial pole. The two axis of an equatorial mount are called right ascension and declination axis. Since all the celestial objects move in circles around the pole, tracking is easily achieved by rotating the scope around a single axis, the ascension axis.

Equatorial mounts for amateur scopes come mainly in two types, german equatorial and fork mounts. Other less common amateur equatorial mount is the split ring equatorial. Figure 2 illustrates the german and fork mounts.



a. German Equatorial b. Fork Mount

Figure 2. Equatorial Mounts

There are other types of equatorial mounts used primarily in large observatories, such as the horseshoe type of mount used in Mount Palomar.

Good quality equatorial mounts require precision machining of their elements and relatively heavy components because the center of gravity of the system normally cantilevers away from the base, creating flexure induced vibrations.

4. TRACKING

As the Earth rotates on its axis it continually changes the direction any telescope points in space. This causes celestial objects to drift out of the field of view of the scope. The higher the telescope power, the faster objects drift out of the field of view. To maintain any celestial object in the field of view the of scope, the scope has to be moved slowly to keep the object in sight.

Unfortunately, objects do not move in a single altitude or azimuth motion. As the time progresses both the altitude and azimuth of an object change, thus requiring continuous adjustments in both axes to track the object. The equatorial mount was designed for this reason. All celestial objects revolve in circles around the celestial poles, so if one axis of the scope is precisely aligned with the celestial pole, it is possible to track the object by turning the scope only around this axis, which is called the right ascension axis.

In alt-azimuth mounts the object is kept in the filed of view by realigning the scope manually, specially with dobsonian mounts, although some alt-azimuth mounts come fitted with slow motion gears and knobs. Equatorial mounts normally come fitted with slow motion gears and knobs.

The rotation rate of the Earth is practically constant, therefore if an accurate clock drive were attached to the right ascension axis of an equatorial mount, the telescope would track any object in the field of view.

The same principle could be applied to alt-azimuth mounts. If one motor drive is attached to each axis of an al-azimuth mount it would be possible to track any object in the sky. However alt-azimuth drives present the difficulty of variable rates of speed in both motors as the time goes. The azimuth change is practically zero when an object is rising on the east, while the altitude movement is very high, however when the same object is culminating, the altitude virtually does not change, while the azimuth moves at its fastest rate. For this reason, motor drives for alt-azimuth mounts were not practical until the advent of fast computers. The computer calculates the rate of speed for each motor several times per second and controls the motors accordingly. The majority of large telescopes in the world use alt-azimuth mount now.

Motor tracking is essential for astrophotography. For astrophotography, alt-azimuth drives have a problem due to the rotation of the field of view. While the center of the field remains fixed, the edges of the field rotate slowly. Visually this is not a problem, but in photography it would result in the objects at the edge of the field trailing. This problem has been corrected also with what is called field de-rotators controlled by the same computer that controls the tracking.

5. SETTING CIRCLES

Each celestial object, except for the Solar System objects, has a virtually fixed position in the sky. This position is determined by the right ascension and declination of the object. If we fit an equatorial mount scope with graduated dials (circles) in each of its two axes, and if we align it accurately to the celestial pole, it would be easy to find any object by dialing its coordinates. This graduated dials are called setting circles.

In addition, each object also has an alt-azimuth position in the sky. The fundamental difference is that while the right ascension and declination remain virtually constant over time, the altitude and azimuth change constantly with each second that goes by. Therefore, should an alt-azimuth telescope be fitted with setting circles, the coordinates of an object would have to be calculated for the precise time of the observation, and recalculated for each subsequent observation.

5.1. Mechanical Setting Circles

Mechanical settings circles consist of graduated dials attached to each axis of a telescope. Mechanical settings circles are the domain of equatorial mounts almost exclusively. There are several provisos required for setting circles to be effective in finding objects. The first and foremost is their quality. The small setting circles found in the department store type telescopes is almost invariably useless. Setting circles must be large, in the range of 5” diameter or bigger, to be effective. The divisions must be very clear and sharp. If right ascension divisions that cannot be estimated with an accuracy of 5 minutes or better, chances are that the object will not be within the field of view after dialing its coordinates. Divisions should not be cluttered; it is better to have clear and sharp 15-minute divisions than trying to mark 5-minute divisions very close to each other.

The second proviso is that the scope has to be accurately aligned to the pole for the setting circles to be effective. Polar aligning a telescope can be a tedious process, although many scope manufacturers offer polar alignment scopes as part of the standard equipment. Polar alignment scopes simplify aligning the telescope to the pole.

5.2. Digital Setting Circles

Digital setting circles consist of devices called optical encoders attached to each axis of a telescope. The encoders send a signal to a hand held computing device, which processes the signal and determines where the telescope is pointed. Digital setting circles are used mainly for alt-azimuth mounts although the can be used also for equatorial mounts.
The main advantage of digital setting circles, unless used in an equatorial mount, is that they not require polar alignment. To align the scope you simply lock the scope in two stars of known coordinates. The computer calculates the sidereal time and

latitude of the point of observation using the two stars coordinates and the relative angle between them.

Normally these setting circles are provided with a database of thousands of objects. To point to one object, that object is selected from the database; the computer indicates the direction to move the scope and the scope is moved until the display reads 0. The object should be in the field of view.

The main problem with this type of setting circles is that they are very sensitive to mechanical imperfections in the manufacture of the scope. If the axes are not perfectly perpendicular or if the altitude trunions are not perfectly round there will be errors in the pointing.

6. EYEPIECES

Except for prime focus photography, eyepieces are required to see images through a telescope. An eyepiece works as a microscope to enlarge the image formed at the focus by the main mirror or objective of the scope.

All eyepieces consist of several lenses (elements) mounted inside a tube of metal or plastic. The quality of an eyepiece depends or its design and the quality of the glass of its elements. In addition there are another features that enhance the quality of the eyepiece such as coating of the glass surfaces. Often times, coatings are applied to the elements to eliminate ghost reflections and enhance light transition. Coatings can be single or multi-layer. Coatings may be applied in single or multiple layers to all or some of the elements' surfaces.

Also the edge of the elements may be blackened to avoid spurious reflections; the tube supporting the elements may be baffled to increase contrast, and so forth.

Choosing an eyepiece involves consideration of several things, such as price, intended use, etc… but in general three or four wisely chosen eyepieces will fulfill the observing needs of an amateur astronomer.

6.1. Eyepiece Features

6.1.1 Focal Length

The focal length of an eyepiece determines the magnification obtained by using this eyepiece. The focal length of the eyepiece is expressed in millimeters and it is engraved in the barrel of the eyepiece.

6.1.2 Barrel Size

Barrel size is the diameter of the tube that holds the elements. Eyepieces come in three different barrel sizes, 0.965", 1 ¼ " and 2". The 0.965" are the eyepieces normally supplied with department store scopes. Their field of view is very restricted and normally suffers from excessive vigneting.

6.1.3 Flatness of Field

The field of view in poor quality eyepieces appears to be sinking or going away at the edges, giving the impression that the center is closer to us than the edges. Good quality eyepieces do not suffer from this problem.

6.1.4 Apparent Field

The apparent of an eyepiece is a feature that, in conjunction with the magnification, determines the real field of view (how much sky is seen through the eyepiece).

6.1.4 Exit pupil

The exit pupil is related to the focal ratio of the scope and the focal length of the eyepiece. The exit pupil is the thickness of the light beam coming out of the eyepiece. The exit pupil is important to know because ideally the maximum size of the exit pupil should not be bigger than the size of the eye pupil fully adapted to darkness.

The pupil of an adult measures approximately 0.25” when fully adapted to darkness. If the light beam coming out of the eyepiece is bigger than 0.25” then we cannot take the entire field of view in the eye and we have to keep moving our eye around to see the field in its entirety.

In the quest to obtain bigger fields of view, amateurs buy eyepieces of large focal length (32 mm and bigger) without realizing that what it is gained in field of view is lost in exit pupil. When the exit pupil exceeds 0.25” by a big amount, not only it is not possible to see the entire field without moving the eye around, but also many times the spider and the secondary holder become visible through the eyepiece making the viewing uncomfortable. As a practical rule the maximum focal length, **FLe**, in millimeters for a scope of focal ratio ***f*** can be found by the formula:

$$\mathbf{FLe} = 6.35 * \boldsymbol{f}$$

6.1.5 Eye Relief

The eye relief is the distance from the eyepiece to where the eye must be placed to see the image. Eyepieces with big eye relief make observing easier.

6.2. Eyepiece Types

Eyepieces come in a wide range of types and features. Eyepieces can be also an expensive part of the observing gear. Normally three or four wisely chosen eyepieces should be enough to fulfill the observing needs of an amateur astronomer.

We will list here the most common types of eyepieces and describe their qualities and problems.

6.1.1. Older Types

These include the Ramsden and Huygenian eyepieces. These are very simple two element eyepieces that have been around for centuries. They come normally in 0.965" barrels and come with the department store telescopes. They have a very narrow filed of view and very small eye relief. They are virtually useless.

6.1.2. Kellner and RKE

The Kellner eyepiece is a three-element eyepiece. It has an apparent field of view of 40 degrees and provide acceptable performance for medium and low power. Their price is low around $35. The RKE is an improvement of the Kellner developed by Edmund Scientific. It is also a three-element eyepiece providing better performance than the Kellner, especially at medium to high power. The price range is $40-$45.

6.1.3. Orthoscopic

This is a four-element eyepiece that eliminate virtually optical aberrations, and for many years they were the finest available. They have an apparent field of view of 45 degrees and they are excellent for medium and high power especially in planetary observation. The price range is $60-$80.

6.1.4. Plossl

The Plossl is another four-element eyepiece. Plossl eyepieces are in many ways superior to the types mentioned before. They provide remarkably sharp images with a slightly bigger field of view (50 degrees) than the orthoscopic. They are very versatile being suited for low, medium and high power observation. Their price is range is $75-$80 although very good "house-brand" Plossls are offered by several telescope companies for about $50.

6.1.5. Erfle and Konig

These are eyepieces with a relatively large apparent field of view of about 62 degrees. They have five to seven elements and are suitable for low and medium power viewing. They range in price form $115 to $150.

6.1.6. Wide Angle.

These eyepieces incorporate 5 to 7 elements and have an apparent field of view of about 68 degrees. They are normally used for medium to high power, although low power eyepieces of these type are available at very high prices. They provide breathtaking views of the sky, extremely sharp through the filed of view. Meade Super Wide Angle and Televue Panoptics are examples of these eyepieces. They are expensive ranging from $200 to $300.

6.1.6 Extra Wide Angle

These eyepieces incorporate also 5 to 7 elements and have an apparent filed of view of 82 degrees. They are normally used also for high to medium power. As the Wide Angle eyepieces they provide impressive views of the sky. They are expensive, in the $300 range. Meade Extra Wide Angle and Televue Nagler are extra wide-angle eyepieces. They are heavy due to the amount of glass they have, and they can tip the balance of small scopes. They are also expensive, specially the low power ones. The price ranges from $250 to $300 and the Televue Nagler 32mm sales for almost $600.

6.1.7 Barlow Lenses

Barlow lenses are used to increase the magnification of other eyepieces. They are also called telemultipliers. A Barlow lense normally increases the power by a factor of 2 or 3, although Televue manufactures a Barlow with a multiplying factor of 5. Barlow lenses dim somewhat the brightness of the image. A good quality Barlow sells for about $80.

6.1.8. High Eye Relief Eyepieces

These eyepieces are designed to provide at least 20 mm. eye relief. They are 6 to 7 element eyepieces. One of the elements is made with the rare earth lanthanum. They are available in a normal apparent filed of view (50 degrees) and wide angle (68 degrees). They range in price for $125 t0 $200 depending on the apparent filed of view. These eyepieces sometimes are the only solution for observers that need to wear glasses all the time.

6.1.9. Zoom Eyepieces

These eyepieces are supposed to provide a continuum of focal lengths in a single eyepiece. They do not perform well at any power.

7. FINDERS

The field of view of a telescope, even under low power, is normally very narrow. With the exception of the so-called rich field telescopes, normally the field of view will be about 1 degree, or the equivalent of two moon diameters. Trying to find any object pointing at it directly with the telescope is a very difficult task. The purpose of telescope finders is to show a bigger field of view, thus facilitating the search for astronomical objects.

7.1. Magnifying finders.

These finders are nothing more than low power, wide-angle telescopes. They normally are small refracting telescopes, although sometimes small Newtonian type reflecting scopes are used as finders.

The field of view of these finders can be as much as 6 degrees, which results in showing 36 times as much area of the sky as compared to the 1 degree field of view of a scope, thus making it easier to find objects that are not perfectly centered in the field of view. They magnify 6-10 times.

There are two basic types of magnifying finders, straight view and angled. The main limitation of a straight viewfinder is that sometimes their position becomes awkward for observation. This is the main reason for the angled finders. In these a star diagonal allows the observer to look through them comfortably.

The advantage of these finders is that they allow the observer to see fainter objects, and the magnification they provide may help locate extended objects. However, the same laws that apply to telescopes govern the light grasp of a finder. Therefore the finder chosen for a particular scope must be of sufficient size to show the type of objects the observer wants to find. For instance, the typical 30 mm finder supplied with small scopes will only show, under the best circumstances, objects brighter than magnitude 9.5. On the other hand if an observer is targeting objects brighter than magnitude 11 he or she will need an 80mm. finder, and a 4 ¼" finder will be limited to objects of magnitude 12 and brighter.

A disadvantage of magnifying finders is that they will show an inverted image of the sky, unless they are provided with an erecting prism. This problem makes difficult correlating a chart with the view through the finder. The problem is not that big with straight viewfinders, because turning the chart around 180 degrees will take care of the problem. However the finders with a star diagonal not only invert the image 180 degrees, but also invert it right to left like a mirror. The only way to correlate a chart with the view through the finder would be to look at the chart on a mirror.

All magnifying view finders are supplied with crosshair lines to help center the object in the filed of view. An option is illuminated crosshair reticules that allow to see the crosshairs when looking at dark regions of the sky.

7.2. No-magnifying Finders

During the last years a type of finders that show the sky as it is seen with the naked eye, without magnifying the view, have become very popular. These finders consist of a transparent window that projects a bull's eye or a lighted dot into the sky. Perhaps the best known of these finders is the Telrad.

The advantage of these finders is that they show the image as seen in the charts, and they show the entire sky. Magnifying finders show a limited portion of the sky limiting start hopping to the stars shown in the field of view, while the Telrad-like finders show the entire sky, making star hopping easier, specially in areas of the sky with few bright stars.

Many observers use a combination of magnifying and non-magnifying finders to locate objects, however a Telrad-like finder used by an experienced observer can be extremely effective in finding objects, especially those of magnitude 12 and fainter that would require finders in the 5" – 6" aperture range.

The main problem with Telrad-like finders is that sometimes the guiding stars are hidden by the glare of the bull's eye if the stars are faint, however the problem can be corrected by fitting the finder with an inexpensive blinking device. As a matter of fact, Rigel Systems supplies a Telrad-like finder with a blinking device as a standard option.

7.3. Finder Alignment

Needless to say, both the finder and the telescope have to point in the same direction. It is easy to align a finder, just center the telescope on a distant object, such as a church spire, a mountaintop, or a electric pole, and then tweak the finder mounting screws until the crosshairs are centered on the same object. Check the alignment of the viewfinder frequently.

8. FILTERS

Filters are elements of glass or Mylar, colored or coated with different media, which are placed between the object and the eyepiece. There are several types of filters with specific uses. The purpose of filters is to enhance the observation of astronomical objects.

8.1. Planetary Filters

Planetary filters are used to enhance viewing of the planets. The filters are designated by their Wratten number and they are screwed at the bottom of the eyepiece. They are inexpensive costing around $15 and when bought in sets they can sell for as little as $10.

8.2. Moon Filters.

These filters are very similar to the planetary filters and they are used to reduce the Moon glare and increase contrast. They are in the same price range than planetary filters.

8.3. Solar Filters

They are used to look at the Sun safely. There are two basic types, glass and Mylar. Both are placed at the front of the scope two reduce the Sun's glare. They are more expensive than planetary filters and their price is related to the aperture of the telescope. They can range from $50 to $150.

There are filters used to observe solar flares. They are specialized filters that are quite expensive.

8.4. Light Pollution Filters

Dark skies are becoming more difficult to find these days. As cities and towns grow, light pollution encroaches further into areas that had pristine dark skies only a few years ago. Light pollution filters are specialized filters that eliminate some of the light wavelengths produced by mercury, sodium and fluorescent light. They are supplied into two types, narrow and broadband, depending on how broad is the spectrum of the light wavelengths eliminate by them. They attach to the eyepiece like a planetary filter, and they darken the sky and increase the contrast, allowing the observer to look at objects that otherwise could not be seen. They range in price from $75 to $125.

8.4 Special Purpose Filters

These filters are designed to allow some of the wavelengths to pass the filter. They are used for many different purposes. The most common ones are the nebula filters and the OIII filters. The nebula filters enhance the view of diffuse nebulas, while the OIII filters are used to increase the contrast in planetary nebulas. The are other filters with very specific uses like the hydrogen alpha and beta filters used to see objects such as the Horse Head Nebula. This filters attach to the eyepiece like planetary filters and they are quite expensive costing well over $100.