TELESCOPE 101

AN INTRODUCTION TO THE WORLD OF TELESCOPES

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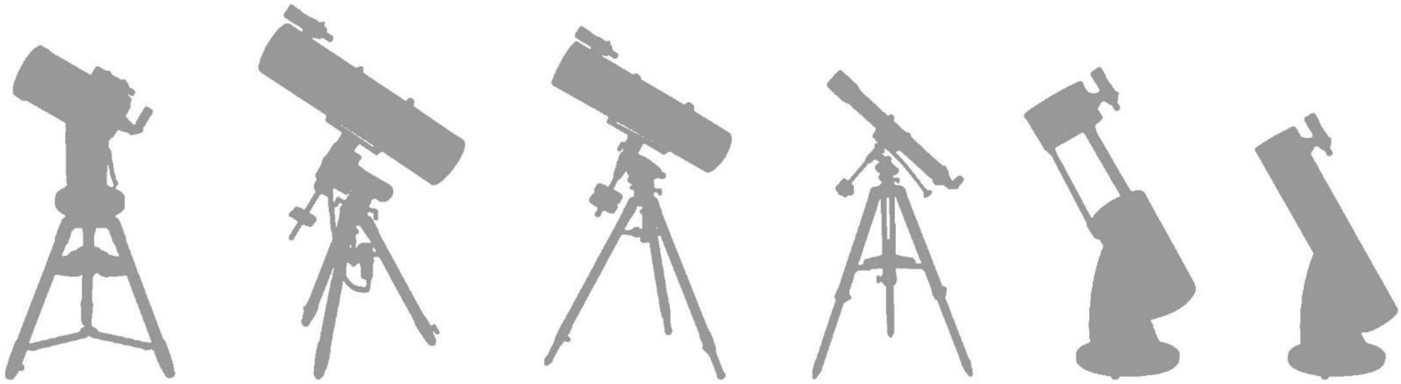
MARCUS SCHENK



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AN INTRODUCTION TO THE WORLD OF TELESCOPES

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Inhalt

Introduction

Anyone in the countryside away from city lights, or perhaps on a high mountain in the Alps, who has ever turned their gaze upwards on a clear night can perhaps understand why some people become so interested in the fascinating hobby of astronomy. Thousands of stars are visible, some thousands of light years away, as you stand with your mouth open trying to take in this natural showcase. Sometimes it is cold, with the wind whistling around your ears. But in the face of this wonder you could be in another world and you temporarily forget where you are. At first appearance the stars appear to be arranged more or less randomly - apparently chaos rules up there in the night sky. But once you have taken a closer look you will see that it's like a new place that you are unfamiliar with, where you first need a map to find your way around but gradually become more familiar with. Suddenly you can make out the figures of bears, lions, winged horses, hunters, hares and swans. These are all constellations: groups of stars that represent the shape of certain figures or animals. After having a taste of this naked eye astronomical lore, one is usually hungry for more. This involves assisting the performance of your own eye by artificial means.

After the sun has set on a clear day and the sky changes slowly from blue to deep black, they are ready. The people who have impatiently waited for the night, and who have travelled, heavily loaded with their peculiar-looking instruments, to a suitable site in the open air. Most of them are using red torches, as bright white light is a definite no-no. Then have set up large tubes directed at a steep angle into the sky. These are often festooned with all sorts of technology. Now they direct these instruments to particular locations in the night sky and take a look through them. These instruments are commonly

referred to as telescopes. Most of these people are quiet, not saying much as they observe. The rustle of the wind in the trees may be the only sound, but then sometimes there is an excited exclamation as one of these amateur astronomers (as they are called), suddenly observes some beautiful astronomical object. These people stargaze as a hobby and are typically passionately interested in the subject.

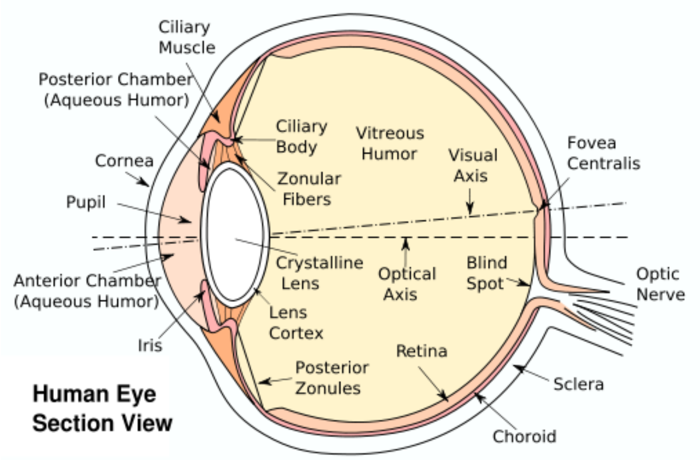
Fascination with astronomy

All of these people, with various levels of expertise, were once beginners in astronomy. They typically began by observing with just the naked eye, trying to find the Big Dipper and other well-known constellations. These were the first steps before they decided to really pursue astronomy as a hobby. Then, usually, they would want a telescope. A visual aid with which not only the stars, but also other objects can be observed - galaxies, planetary nebulae, emission nebulae, supernova remnants and the objects in our solar system. But almost everyone starts by being faced with a huge selection of telescopes and accessories and the question of which is the right telescope for their particular astronomical interests. In order to avoid the frustration of purchasing a telescope and then only later realizing that it is not the right instrument for you, it is strongly recommended to clarify what it is you actually need. For this reason, you should also know something about the various advantages and disadvantages of different types of telescope designs. To keep all this jungle of possibilities straight in your head, you will need clear information.
I want to help you find a path that is right for you. You can use the following pages to make yourself familiar with all the different telescope systems, the accessories available and the different types of observing.

Have fun!

NGC7331, CARLOS MALAGÓN

Tips for observation with the naked eye



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The Eye

Not only telescopes, but also the human eye itself is an observing instrument. Granted the eye is the smallest telescope that there is, but there is no better or more perfect telescope than the human eye (although even the eye does have some aberrations). Our eyes are always available of course and we can look exactly where we want. With telescopes, the larger the aperture is the more light it gathers. Our eye has an aperture in exactly the same way as a telescope - namely the eye's pupil.

The pupil in the human eye

The eye's pupil is an ingenious device. It is controlled by the iris and varies from a diameter of about 1mm to about 8mm. The maximum opening of the pupil is also dependent on the age of the person concerned. A typical 20 year old can manage a maximum pupil aperture of about 8mm, a 60 year old can only manage about 4mm. Thus, the eye of a 20 year old is much more sensitive to light than the eye of a 60 year old.

This fact is important for the observation of the night sky. A 20 year old will hence be able to detect fainter stars than older observers. When the eye's pupil is wide open, a lot of light can enter the eye – as already mentioned. However, with increasing aperture of the eye the visual acuity is reduced, but this is not important at night as then mainly the rods in the eye are sensitive enough to function. The rods have a poorer resolution than the cones, which are intended for daytime use.

The eye has the ability to separate two closely related points from a certain distance away. These points subtend a small angle in relation to the eye, and one can speak of the eye's resolution. Normally, the eye has a resolution of 1 arc minute (which corresponds to an optical acuity for the eye of V=1). At night it this is reduced to about 2 minutes of arc.

If we now consider being able to separate the individual components in a binary star system using the naked eye, then systems with stars of a few arc minutes separation or a little more can typically be resolved. A good test for the naked eye is the beautiful binary star system Alcor and Mizar (in the middle of the 'handle') in the Big Dipper.

The rod cells in the eye's retina come into use at night. These rods can only distinguish between shades of grey and are only suitable for vision in very low light conditions. As that is the case at night, we can hence only make out differences in light /dark or white/black at night. Resolution in comparison to daytime is also reduced. The part of the eye's retina that sees the sharpest is called the fovea (fovea centralis), and contains only cones for daylight vision. A huge number of cones - 130,000 - jostle for place in the fovea. That is as many cones as there are people living in Ingolstadt, the fifth largest city in Bavaria.

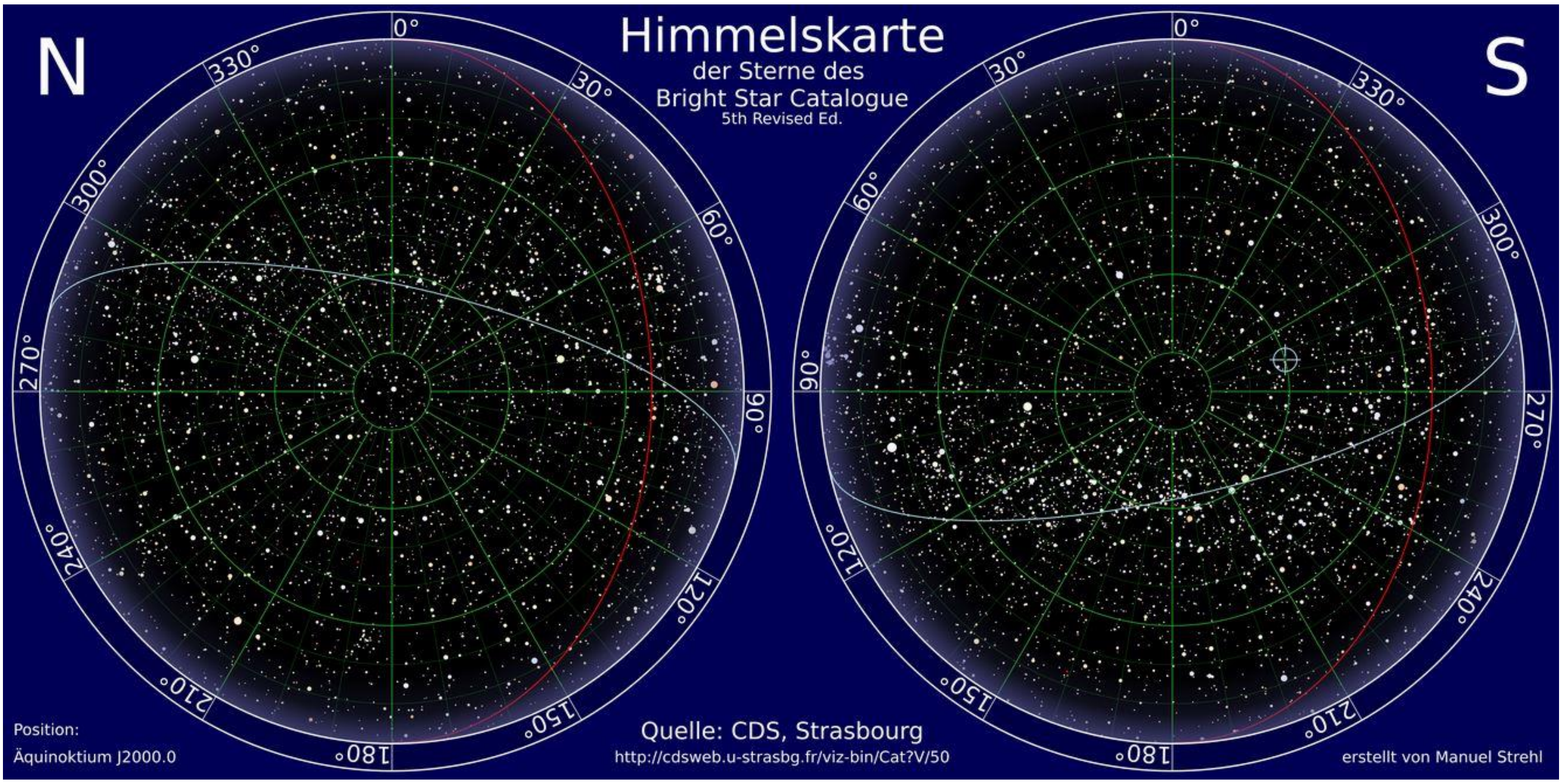
The fovea has no rods, meaning it does not come into use at night and of course is not used at all for astronomical observing. Outside the fovea, the number of rods gradually increases, but they are spaced somewhat further apart than the cones. The number and density of rods is greatest about 20° away from the fovea. That is hence also the part of our eye that we should use (at least for fainter objects) for our astronomical and telescopic observing.

Star maps

Before starting thinking about buying a telescope, you should know that it is also possible and fun to observe the night sky with just your eyes. There is the whole starry sky out there to see.

If you get yourself a rotatable star map (planisphere), you can use this to easily identify all the individual constellations currently visible. Getting to know the constellations in the night sky is a prerequisite for subsequently being able to find the other astronomical objects that you want to observe using a telescope. There are a number of different planispheres available. This is the very first thing you should buy. It will remain useful long after you have become familiar with the night sky: it not only shows you the night sky at any time, day or night all year round, but also shows you the position of the sun, the ecliptic (for planetary positions), sunrise and sunset times and much more.

The second important item to



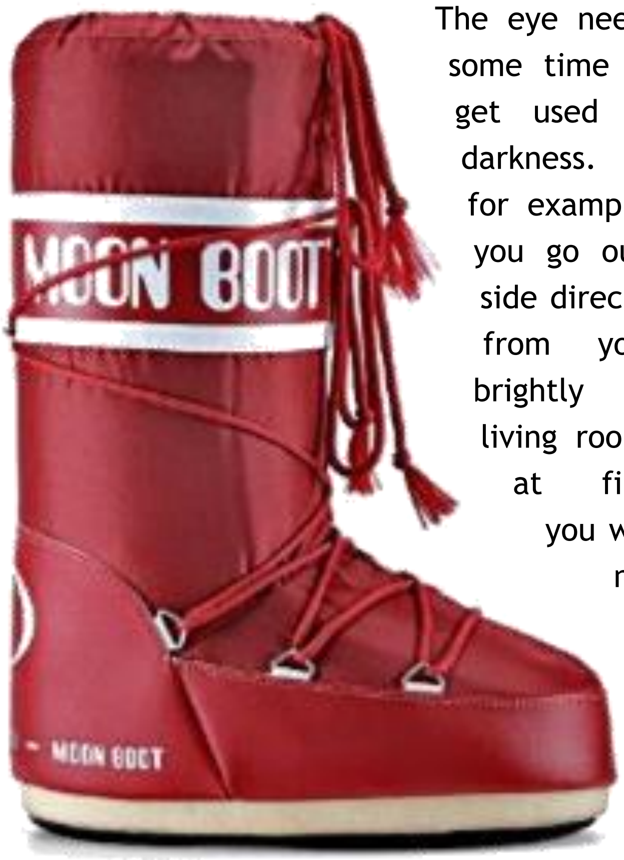
be recommended is an astronomical year book, such as Patrick Moore's Yearbook of Astronomy. This is a very popular astronomical yearbook which contains information about the planets, stars, meteors and objects to observe each month.

In addition to star maps and yearbooks, software (such as planetarium programs) is an ever greater part of astronomical publishing. Multimedia planetarium programs provide the observer with a complete overview of the night sky. Some programs have a whole raft of features which can show current or future astronomical events, allow you to 'fly' through the Solar System, or even contain a complete astronomy encyclopaedia. Some programs even allow you to control your GoTo telescope using your PC / laptop / tablet and slew the telescope automatically to designated astronomical objects. But for anyone who just wants to print out detailed finder charts so they can manually search for astronomical objects will also find this possible here.

One example of an excellent and comprehensive planetarium program is the famous 'Red Shift' software, which is now already available in its eighth version.

Now you can get started

You can now actually start observing. You have equipped yourself with a planisphere and yearbook and can't wait to get outside under a clear dark night sky. But wait, haven't you forgotten something? Of course! You should dress warmly before going outside to observe. Even summer days can turn into cool nights as the heat from the day gradually dissipates - it can become cold even in August. Warm shoes and a jacket are particularly important. And now, finally, you can get started...



The eye needs some time to get used to darkness. If, for example, you go outside directly from your brightly lit living room, at first you will not be able to see much. Your pupils are still contracted for seeing properly in brightly lit conditions. A little later the pupils star to dilate. This is initially a little faster and then becomes somewhat slower. It can take a good 45 minutes until your pupils are fully dilated. Of course you do not have to wait so long in the dark before you take your first look at the night sky. ;-)

Make sure that you cannot be blinded by nearby street lights, house lights or bright torches. If that happens too often, you can lose your eyes' dark adaptation. That is why astronomers do not use any white lights during their observing, but use a red light instead - often a dimmable red LED torch.

Once your eyes have adjusted to the darkness of a dark night sky, you will be able to see stars right down to the 6th magnitude. These are quite dim stars - about 100 times

fainter than stars of magnitude 1.
Magnitude 1 stars are among the brightest stars in the sky. Stars that are even brighter than these will have magnitudes of 0 or -1 for example. This system means stars become brighter with the decreasing number of the magnitude. The magnitudes of stars are generally referees to as 'mag'.

Using only your unaided eyes, you will already be able to observe several 'open clusters'. The Pleiades in the constellation Taurus are an example of this type of star cluster. You can even make out our nearest neighbour spiral galaxy as a small patch of blurry light: the Andromeda Galaxy. This fleck of light is more than 2.5 million light years away from us!

But what happens when you are no longer satisfied with observing only with your eyes? Then you will probably want to get yourself a telescope.

A short tale of frustration

After this brief introduction, we get to the actual instruments used to observe with, but first take a moment to imagine the following scenario:

Kurt, a 35 year old man (I'm assuming a man because, unfortunately, there are still more men than women interested in astronomy), has become interested in astronomy. When he was recently on holiday in Spain in Tenerife, he walked a few yards into the 'Pampa' next to his hotel. When he looked upwards, it took his breath away: He couldn't get over his astonishment, as he had never had been able to see such a beautiful dark star-filled sky. He could see thousands of stars and accidentally walked into a cactus, which he hardly even noticed. Back home in Germany he immediately bought a book on astronomy and devoured it outright. Of course, he soon decided he needed a telescope. A few days later some a leaflet from a well-known supermarket chain came through his letterbox which included details of an offer for a telescope with a 50mm aperture and 600X of magnification. Wow! He quickly went and bought one, admiring the superb photos of Saturn and Jupiter on the telescope' packaging (so that's what they would look like!). He put it together. It did, in fact, seem a bit wobbly. But probably it was supposed to be like that. On the next clear night, he rushed outside to set up the telescope and tried to find an object. He wrestled with it unsuccessfully for ages...

Then he finally found something. It was Saturn in the field of view, but it wobbled if he tried to get a better look and somehow he couldn't get it properly in focus. Frustrated beyond belief, he threw everything together and left the telescope on his balcony. He buried it next day in the garden, along with his astronomy book. For him, astronomy was dead and buried.

To avoid you having to go through a similarly frustrating experience, please use the following pages to learn about the different types of telescope systems available - with all their advantages and disadvantages. Every telescope has its use, but you must also consider many other factors before finding just the right telescope for you.

The different types of telescopes

The refractor

The refractor is the classic telescope design that most people are familiar with: A long thin tube that points to the sky with a focuser at the bottom end that you look through. There are basically two different types:

1. The Galilean telescope
2. The Keplerian telescope

Both of which, as regarding their construction, are in principle very simple systems. The Galilean system consists of a converging lens at the front and a diverging lens at the back. This type of system is used mainly in opera glasses. However, since the exit pupil lies inside the tube (i.e. in front of the diverging lens), it produces a small field of view which is rather diffuse at the edge. It is intended only for low magnifications. But the advantage is that it provides an upright image.

The Keplerian telescope

The Keplerian telescope is also referred to as an astronomical telescope. As with the Galilean system, it has a converging lens at the front. At the rear, however, it uses a converging lens instead. This serves as the eyepiece. The Keplerian telescope produces an upside-down image. It forms an intermediate image at the focal point. The focus of the lens coincides with the focal point of the eyepiece. The eyepiece, which consists of a single converging lens, produces an enlarged image of the intermediate image.

These 'normal' refractors that used to be used have one major drawback: they suffer from chromatic aberration. This means that the light of different wavelengths come to a focus at different distances. Blue light is refracted more strongly through the lens than red light for example. This produces irritating colour fringing around objects observed through the telescope. And if you want to magnify an image further, then this colour fringing will get even worse. This fringing also has an extremely detrimental effect on the image contrast of a refractor.

The optical solution to colour fringing

A method was discovered to minimize this effect by building a new design of telescope known as an 'achromatic'. An achromatic lens consists not of one, but two lens elements combined together, usually consisting of a crown glass element and a flint glass element, which work together as 'plus' and 'minus' elements and which are known together as an 'achromatic doublet'. These lenses consist of a convex (outer part) and concave (inner part) element.

The refraction index (by how much light is bent) and the dispersion (by how much light is scattered) of each lens element is different. This allows most colour aberrations to be cancelled out. Nevertheless, there is still a little colour fringing left, known as 'secondary spectrum'.

Optical designers subsequently developed the so-called 'apochromat', which employs a third lens element to eliminate the secondary spectrum. This means that these telescopes produce a nearly pure colour image.

When buying an apochromatic telescope today, you will find that there are two different types available:

1. Doublet ED apochromats
2. Triplet ED apochromats.

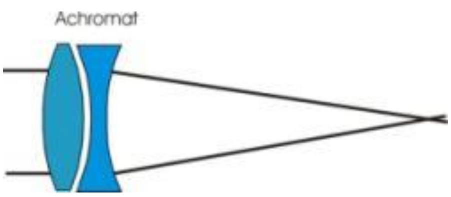
ED apochromats are come as instruments with two or three lens elements. One lens element will always made from

ED glass, which takes care of eliminating chromatic aberration in the entire lens system. Two lens ED apochromats correct for the majority of chromatic aberration, but cannot completely eliminate it. For this reason, some amateur astronomers refer to these telescopes as 'semi-apos'.

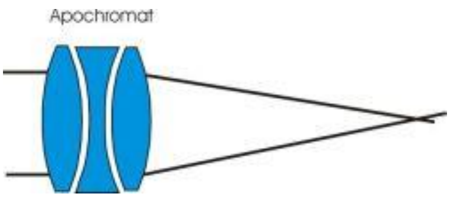
Three-lens ED apochromats eliminate colour aberrations almost completely. The image they produce is not only clear and colour-neutral, but also of very high contrast.

Lens telescopes in a nutshell:

Achromat: Consists of two lens elements - of flint and crown glass. These lenses are generally arranged so that there is an air gap, but there are also cemented systems.



ED apochromat: This system is basically an achromat, with one lens element made of ED glass. These also have an air gap. The colour aberration is almost entirely corrected for.



Fluorite-apo: This consists of two lens elements cemented together, one of which is made of fluorite. This produces a similar effect to using an ED glass element.

Apochromat: This system is a full apochromat, whereas the two preceding systems are both referred to as semi-apos. It typically consists of three lens elements. Chromatic aberration is virtually entirely corrected for.

For some time now, so-called 'superapochromats' have also been available. This type of refractor consists of five lens elements, generally arranged in two groups. The first group of three lens elements perform the same function as a triplet apochromat. The second group of two lens elements correct for field curvature with the aim of being able to producing perfect astronomy photographs.

The other solution

Another method of reducing chromatic aberration in refractors is that one designs refractors with the smallest possible aperture ratio. This means that these telescopes must have long focal lengths. This has the effect of also reducing chromatic aberration. A general rule of thumb states that the focal length of these achromats should be fifteen times their objective lens diameters in order to get a decently clean image colour. This would, however, with a 100mm refractor mean a focal length of 1500mm as f=1:15. In even larger refractors, the focal length would have to be even longer.

This would mean very long, unwieldy refractors, which would be unacceptable. Another acceptable formula would be: focal length in cm = aperture in cm². This is a compromise, but is still in order. A 100mm refractor would then have a focal length of 1000mm and a 120mm refractor would have a focal length of just under 1500mm.

Outwitting chromatic aberration

What should you do if you have a lens telescope which has chromatic aberration? Scrap it and buy a new one? No, you don't have go that far as, fortunately, there are ways of reducing this.

If a small amount of colour fringing irritates you, then you can, for example, use a minus-violet filter. This suppresses the blue colour fringe while increasing contrast. However, the image is not quite neutral, but appears slightly yellowish. Even so, detail is improved.

The minus-violet filter is a classical version, but there are now other filters that will also do the job. One specially developed filter is the Baader Fringe Killer. It blocks around 50% of the blue light

component, but allows the red and green light through. The intelligent design means that light loss is limited to only 12%. This hence allows you to confidently use this filter even with smaller refractors.

Another filter is the so-called Semi APO filter. This is a quite a cool product name, but does it do the job? Take a refractor with a short focal length - of perhaps 500mm. You can see a thick blue fringe around bright objects. What happens to the fringe if you screw a Semi APO filter into the eyepiece? The fringe around bright objects simply disappears. The image appears even more colour-neutral than with the Fringekiller. However, the light loss with the Semi APO filter is higher - approximately 30%. The advantage is that the image appears very colour-neutral with this filter. For smaller refractors it is better to use the Fringekiller, but with refractors from about 100-120mm the Semi APO filter is well worth the money.

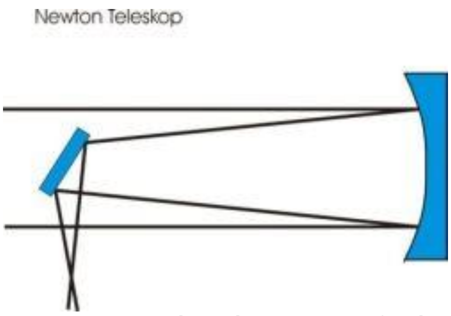
The refractor is a great instrument, if it is properly colour corrected. But large refractors, even though they collect a lot of light, are relatively expensive and bulky. So now let us take a look at mirror telescopes.

The Newtonian reflector

The Newtonian reflector is the classic mirror telescope design. The principle is straightforward yet ingenious. Isaac Newton first built this telescope in 1668. Actually, Newton was further developing an existing telescope design, as the physicist Zucchi had already constructed a telescope in 1616 which employed a mirror. Newton's idea was to install a flat deflecting mirror into the telescope tube. Just imagine: A telescope that was originally designed in 1668 is still one of the most popular and best-selling amateur telescope designs today, in the age of smart phones and iPads!

How a Newtonian telescope works

Light first enters the top of the telescope tube. At the lower end there is a primary mirror that is either spherical or parabolic in configuration. This mirror reflects the light back upwards. In order to prevent the image to be focused in front of the tube opening (and hence obscured by your head!), there is a secondary



mirror inside the top of the tube. This is a plane mirror which deflects the light beam by 90°, hence directing it out the side of the tube. The light enters the focuser here, into an eyepiece can then be inserted for observing. Focusing takes place by turning a focus wheel on the focuser so that the eyepiece is moved towards or away from the telescope tube.

The advantages

As opposed to a lens telescope, a reflector has no lenses. This means that the problem of colour fringing around bright objects is avoided with Newtonian reflectors. But that is not the only criterion for producing a good image. Equally important are the quality and reflectance of the mirrors - which can be very different, depending on the telescope. It is hence important to rely on well-known brands.

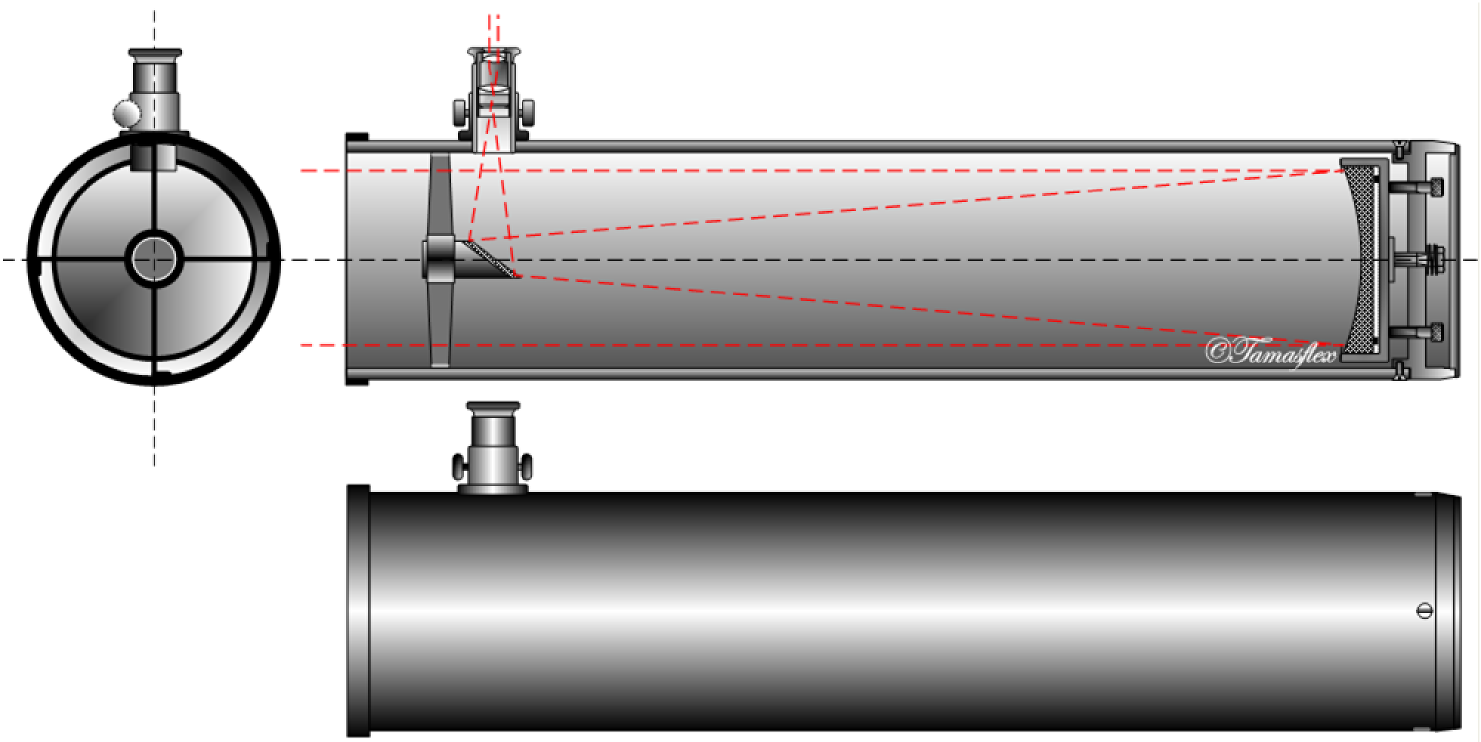
The aperture ratio of a telescope is the relationship between its aperture and focal length. A telescope with 100/1000mm has an aperture ratio of f/10. This means that the focal length is 10 times as large as the aperture.

Newtonian reflectors come in a relatively wide range of aperture ratios. Whereas refractors tend to have smaller aperture ratios (e.g. f/10, to reduce chromatic aberration), Newtonian telescopes can confidently be designed with optics of up to f/4. This means that Newtonian telescopes are optically 'fast' and have relative short focal lengths.

A major advantage with Newtonian telescopes is their affordable price. As compared to refractors and other telescope designs, such as Schmidt-Cassegrains, a Newtonian telescope is simply unbeatable in price. For relatively little money, you get optical performance for which you would have to pay significantly more for most other telescope designs.

The disadvantages

One disadvantage of Newtonian telescopes, as compared with refractors, is the shadow produced on the incident light by the secondary mirror. Depending on the size of the secondary mirror, a lesser amount of light gets to the eye than originally enters the

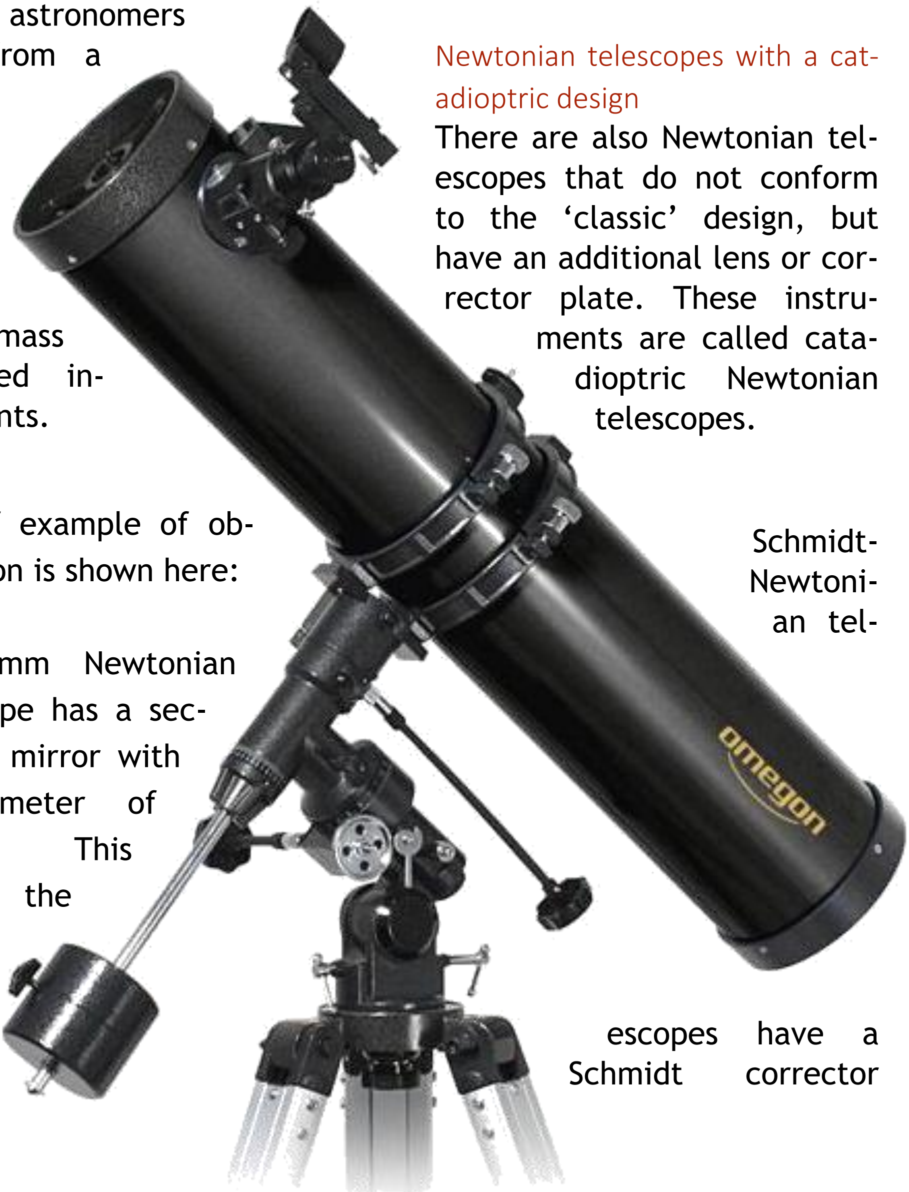


telescope tube. This is also known as 'obstruction'. In comparison, a refractor has no components in the light beam's path and thus has no obstruction. This means that a refractor of a given aperture will always provide more light and more contrast than a reflector of the same size.

But larger refractors are too expensive for most amateur astronomers and, from a certain size, are not even available as mass produced instruments.

A brief example of obstruction is shown here:

A 200mm Newtonian telescope has a secondary mirror with a diameter of 50mm. This means the obstruction is 25%. A 200mm Newtonian reflector with a 50mm secondary mirror would have an effective aperture of 193mm. However, it would have the same contrast performance as an unobstructed telescope of 150mm in aperture.



Newtonian telescopes with a catadioptric design

There are also Newtonian telescopes that do not conform to the 'classic' design, but have an additional lens or corrector plate. These instruments are called catadioptric Newtonian telescopes.

Schmidt-Newtonian telescopes have a Schmidt corrector plate mounted in front of the telescope. This plate provides a closed system which also means that there is always the same air in the tube, which ensures that it does not quickly change in temperature. Another advantage is that this plate corrects aberrations arising from the primary mirror. The secondary mirror is mounted behind the Schmidt plate, and so its spider vane mounting does not interfere.

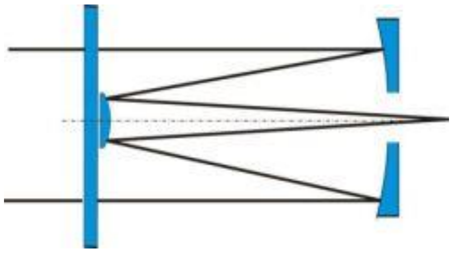
But there are other catadioptric Newtonian telescope designs that do not have a Schmidt plate. They occur mainly in the lower price range and have a Barlow lens (or a similar lens) incorporated into the light beam's path to increase the focal length. This allows the overall telescope tube length to remain short and the focal length can be made as long as possible.

A Barlow lens is always a component with a diverging lens which increases the focal length. These telescopes have the disadvantage that their optical imaging quality can be adversely affected by the Barlow lens. But a far greater downside is that these systems are relatively difficult to collimate. This is because you have to be able to see a reasonably large image of both the primary mirror and secondary mirror when collimating a Newtonian telescope, and their design makes this very difficult with these telescopes. Since such telescopes are also often used by beginners, it can be especially difficult for them to carry out this adjustment. However, some of these telescopes have the advantage that you can unscrew the Barlow lens for this purpose.

Based on the above facts we recommend that beginners stick to the classic Newtonian telescope design, without built-in lenses.

Schmidt-Cassegrain Telescopes

A very popular system is the Schmidt-Cassegrain telescope design. Many amateurs swear by these telescopes as they are both very compact and easy to transport. They provide a very short tube length together with a long focal length. A primary mirror with a central hole throws back the incoming light and starts to focus it. The light then strikes a secondary mirror, which reflects the light back again, with it finally passing through the central hole into the focuser at the back of the telescope. A Schmidt plate is mounted at the front for correction. The Schmidt-Cassegrain design can be described as a true all-round telescope as you can do with virtually everything with it. Nevertheless, this telescope does have some disadvantages: The small aperture ratio, of 1:10 or less, means that type of telescope for excellent for visual observing. However, if you want to take photographs with it, you will encounter problems due to this low aperture ratio: The telescope will need to be tracked at high precision.



The Schmidt plate protects the interior from dust and other contaminants. However, in such closed systems the cool-down time - until the telescope has adapted to the outdoor temperature – can be relatively long.

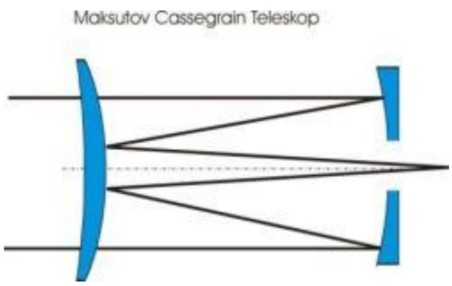
The long focal length also produces a relatively small field of view. A Schmidt-Cassegrain telescope also has the drawback that it shows field curvature. There may be some edge ring in photog tography. Other aberrations are so small that they remain within the diffraction disk and are not no-

ticed.

Maksutov-Cassegrain telescopes

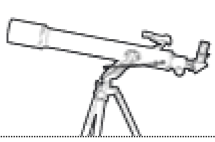
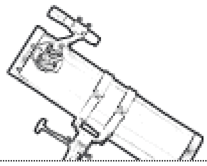
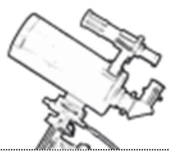
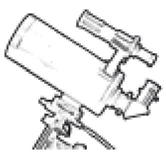
Maksutov telescopes are another variant on Cassegrain optics. In principle, they work just the same as a Schmidt-Cassegrain telescope. They have a spherical primary mirror and a secondary mirror. This design is the same. The difference to the Schmidt-Cassegrain with the Maksutov is in its meniscus-shaped lens at the front aperture and no Schmidt plate. This lens goes back to the Russian optical engineer Dmitry Dmitriyevich Maksutov. The constant thickness of the lens means that the system only has a small amount of chromatic aberration. It also corrects the spherical aberration produced by the main mirror. The secondary mirror of the system is a metal coating vapour-deposited onto the back of the meniscus lens. So the design dispenses with spider vanes which could degrade the image. Due to the relatively small secondary mirror obstruction can be kept small. The optics provide very good contrast, coming close to that of a refractor.

Although this telescope has many advantages, there are



some downsides of course, as no optical design is perfect in every respect. It also has a long cool-down time. This telescope design has a relatively high weight due to the lens. Similarly to the Schmidt-Cassegrain, the Maksutov has a small field of view with its aperture ratio of between 1:10 and 1:13. Fast optical systems are not possible with Gregorian systems (employing a hole in the primary mirror), as existing aberrations are amplified.

The pros and cons of different telescope designs in a nutshell

		Advantages	Disadvantages
Refractor		+ great classic design + no obstruction + good contrast + collimation almost never necessary + no thermal degradation	- expensive at larger apertures - unwieldy with large refractors - chromatic aberration and blurring if it is not corrected
Newtonian		+ cheap to manufacture + large apertures possible + no chromatic aberration + good contrast + obstruction is fairly low + light + many variants are available + Dobson construction possible	- image aberration dependant on aperture ratio - lower contrast than a refractor of the same aperture due to obstruction - thermal air currents are possible as the system is not enclosed, affecting the image - needs regular collimation - more prone to being affected by dirt than a closed system
Schmidt-Cassegrain, ACF and Edge HD		+ short length + very practical handling + portable + viewing is always comfortable + the SC thread allows a wide range of accessories to be connected + instruments with a fork mount can be set up extremely rapidly	- more expensive than a Newtonian of comparable aperture - larger secondary mirror than with a Newtonian telescope
Maksutov		+ short overall length + almost no chromatic aberration + closed system, therefore no thermal degradation + good correction of spherical aberration + very good contrast + no spider vanes + inexpensive models available	- heavy due to the meniscus lens - long cool-down time - larger apertures (above 8") are rather expensive - obstructed by the secondary mirror - small fields of view due to aperture ration of about f/13

Basic considerations in your choice of telescope

Which telescope should I buy?

The main distinction when buying a telescope is deciding between reflectors or refractors. Despite the pros and cons of each telescope type, there are some basic facts that you should consider when choosing a telescope. The first question you should ask yourself before buying a telescope is: "What do I actually want to observe?" Or more specifically: "Do I want to mainly observe planets or mainly observe deep sky objects such as faint galaxies?"

If you are clear on this issue, you can proceed directly to step two: the actual choice of telescope. Not every telescope is suitable for all purposes. The ultimate telescope that meets all your observing requirements does not exist, but you can get very close to it.

Light gathering power

An important property of telescopes is their ability to gather light, as the more light a telescope can collect, the fainter the objects that can be seen in the night sky. And there are a lot of these faint objects out there in the depths of the universe. Ignoring the observing of the Moon, the Sun and the bright planets, the aperture of a telescope is its most important feature. This does not mean that small telescopes cannot have a decent performance, as every telescope has its use.

The larger the aperture of a telescope, the ‘faster’ it is. The following is a comparison of the various apertures:

Light, aperture and faint stars

The smallest telescope is the human eye, which has a maximum aperture of 7mm. With a 7mm aperture we can observe stars down to a limiting magnitude of 6. The magnitude of a star is a unit indicating its brightness: the smaller the number, the brighter the star. Stars of magnitude 1 are among the brightest stars. A 6th mag star is 100 times fainter than a mag 1 star. One can see from this that our eye can see relatively poor light sources. But it is nowhere near sensitive enough to observe fainter astronomical objects.

If we assign a light collecting ability of 1 to the human eye, you can marvel at how this ability increases with increasing aperture. A telescope with a 50mm aperture has a light collecting ability of 51 times, and a lens with a 100mm aperture collects 204 times as much light as the human eye.

Also important and of interest is the magnification of a telescope. The small telescopes sold in supermarkets are often advertised as providing a magnification of 500 times or more. The most amazing astronomical images are also shown on their packaging, giving the impression that you hold a small Hubble telescope in your hands. These are promises that do not hold up and you would be quickly 'brought back to earth'.

In general, one can say that the maximum useful magnification of a telescope is twice its lens aperture in millimetres. So a telescope with a 150mm aperture should support a maximum magnification of 300 times and a 200mm aperture telescope a maximum of 400 times. If you increase the magnification any further, you risk a dimmer and more blurred image. The magnification of a telescope is not the most important thing, but rather its aperture and the resolution it can achieve thereby.

It is also extremely important to consider the mount when buying a telescope, as even the best instrument is useless if the mount does not do its job in keeping the telescope stable. If the mount is undersized for the weight of the instrument, then it will be very vulnerable to vibration and the result will be that you will have no real fun using your telescope. If you intend to do astrophotography, then the mount you use must be even more capable and be even more stable.

The influence of the aperture

One of the most important characteristics of a telescope is its objective diameter, which is referred to as its aperture. The larger the aperture a telescope has, the 'faster' it is.

The naked eye has a light-gathering power that can just make out stars and other astronomical objects down to the 6th magnitude. Anything fainter cannot usually be seen. Most objects in the sky are fainter than this, so you need a telescope with an appropriate aperture as a 'light amplifier'.

A telescope with a 100mm aperture can image much fainter stars and deep sky objects. Under really dark skies, this size of telescope can see stars that are a 1000 times fainter than the naked eye alone.

A telescope with a 200mm aperture can image stars 3900 times fainter than the faintest which can be seen with the naked eye alone.

Resolution

The resolving power of a telescope is another very important factor. It increases with increasing aperture. If the telescope has a high resolution, fine detail can be seen in non-stellar astronomical objects. The resolution is defined as the ability to individually and recognizably image two closely spaced objects.

In practice this means that two individual stars in a double star, separated by a certain angular distance, can be separated. So imagine: You are trying to observe a double star and to see two fine stellar points directly next to each other.

If the resolution is not sufficient for this particular star, then you would just see a single point or perhaps a slightly elongated structure.

The narrower the angle of a double star or the closer together the details on a planet, the more aperture is required to achieve a higher resolution, and be able to separate the objects. The separate resolution of two objects is often called their separation or 'minimum separability'.

The resolving power of the naked eye is about one minute of arc during the day and about 2 minutes of arc at night. You can even separate quite a few double stars with the naked eye, such as the 'Horse and Rider' in the Big Dipper.

Perhaps your optician mentioned the term visual acuity? Opticians are happy when you achieve optimal visual acuity, and will speak of a visual acuity of 1.0. This value corresponds to a resolution of one minute of arc.

However, some people do not achieve such a high resolution while others even achieve a slightly higher resolution - which is in the nature of things and is completely normal.

The large apertures of telescopes mean they can achieve a very high resolution. While a 50mm telescope has a resolution of about 2.7 arc seconds, a 200mm telescope has a resolution of 0.7 seconds of arc. With these resolutions, these telescopes can cleanly separate two stars that have these separations. One factor in the resolution is the size of the Airy disk resulting in the telescope. The higher the resolution of a telescope is, the smaller the size of the Airy disk appearing in the telescope. The resolution is relatively easy to calculate:

A = 138 / Obj

A= Resolution, Obj= Aperture of the telescope [in mm]

This calculation is a formula according to Rayleigh and gives the separation which, for example, a binary star system can still clearly be split into its individual stars.

Aperture of the telescope	Resolution according to Rayleigh
60mm	2,3"
80mm	1,7"
100mm	1,3"
120mm	1,15"
150mm	0,92"
200mm	0,69"
250mm	0,55"

Of course these are theoretical values that are not 100% the same in practice. This is because, usually, the resolving power of a telescope is limited by the turbulence in the atmosphere to about 1 arc second. This means that telescopes that have an aperture of more than about 120mm bring no real benefit in this area.

Obstruction

A telescope is a light trap which brings together all the light into a bundle and presents you, the observer, with an image. In reflecting telescopes (Newtonians) is a primary mirror is used for this, which starts to focus the image towards the front of the telescope tube. Objects can be observed through the eyepiece on the side of the telescope tube, via a secondary mirror (a 45° plane deflecting mirror), mounted at the top of the telescope tube mounted on spider vanes, which brings the light bundle into the eye via the focuser.

This secondary mirror creates a shadow in the telescope, which reduces the performance of the telescope with respect to contrast and effective aperture. Every component which is located in the beam path of a telescope creates a shadow - the obstruction. This is basically the case for all reflecting telescopes (an exception is the 'Schiefspiegler'). Only a refractor has an obstruction of 0% because no component interferes with the light arriving at the eyepiece.

Obstruktion 0%

Obstruktion 40%

(Bilder generiert mit Aberrator mit Genehmigung von Cor Berrevoets)

The illustrations show how the image is diffracted by an obstruction, resulting in a loss of contrast. The larger the secondary mirror in a telescope, the greater the obstruction. To work out the contrast performance, or the loss of contrast, for a reflecting telescope, you can directly subtract the secondary mirror diameter from the primary mirror diameter. This gives you the effective 'contrast aperture' that would have been available in a telescope without the obstruction.

A Newtonian reflector telescope with a 200mm diameter mirror and a 50 mm diameter secondary mirror diameter would provide the same contrast performance as a refractor with a 150mm aperture. So if you measure the secondary mirror diameter, you can calculate the effective contrast.

It is somewhat different story regarding the light gathering ability. Of course it is also reduced by the obstruction too, but not to the same extent as we have seen with the contrast.

The magnification

For beginners, this is often regarded as a very important factor when buying a telescope. It is, however, not the most important characteristic of a telescope, but rather plays a subordinate role. Much more important are the light intensity and how stable the telescope is held by its mount.

Basically a telescope, depending on the curvature of the mirror or lens, focuses incoming light at a focal point. The focal length means a certain magnification factor is already achieved. But one needs an additional eyepiece to view the resulting image. This basically works like a magnifying glass which enlarges the image accordingly.

The achievable magnification depends on the ratio of the focal length of the telescope to the focal length of the eyepiece. If divide the focal length of the telescope (fob) by the focal length of the eyepiece (fok) you get the magnification achieved.

$$V = fob \, / \, fok$$

If, for example, you use a telescope with a 1000mm focal length and a 5mm eyepiece, you will get a magnification of 200 times. Theoretically, one could increase the magnification ever higher. But, as this is related to the aperture of the telescope, there is a limit to sensible magnifications. An important role is played by the exit pupil, the beam that exits the eyepiece and enters the eye. More on this in a moment.

There are not only limits set on the maximum magnification set by the aperture size, but also on the minimum magnification. The exit pupil should never be greater than seven millimetres. This is usually also the maximum aperture achievable by the pupil of the eye; and only then in absolute darkness at night. If you now divide the telescope aperture by the diameter of the maximum aperture of the pupil, it will give you the minimum useful magnification.

At this magnification, a beam of seven millimetres diameter will still pass completely through the eyepiece and into the eye. Now if the exit pupil were to be even larger at a lower magnification, then the remaining light will be lost as the eye's pupil starts to block the outer region of the light bundle.

Vmin = Aperture (mm) / 7mm

For a telescope with a 200mm aperture, the minimum useful magnification would hence be about 28X. If the aperture of the telescope were larger, then the minimum magnification would also be higher; and with a smaller telescope lower accordingly.

The normal magnification of a telescope is approximately that of its aperture in millimetres. The normal magnification will give an exit pupil of about 1mm. This magnification lets an observer use the achievable resolution of the telescope. This means that considerably more detail, e.g. on planets, is visible.

A telescope with a 100mm aperture would have a normal magnification of100X and a 200mm telescope 200X. The maximum useful magnification can be calculated using this rule of thumb:

Vmax = lens aperture (in millimetres) x 2

The exit pupil is here reduced to 0.5 mm:

telescope aperture / maximum magnification = 0.5.

If higher magnifications than this are used, then the image will become dim and blurry.

The normal magnification is always usable. Problems often arise at the maximum magnification due to the Earth's atmosphere, meaning it is not always possible to go to the maximum limit. The reason here due to different layers of hot and cold air that lie over each other in the atmosphere. This phenomenon is also called the 'seeing' and is often dependent on meteorological aspects. Through the telescope, bad seeing makes itself felt as stars twinkling. When you select a high magnification, the air turbulence cells are also enlarged. If you have ever observed Jupiter shortly after it rises in the east, you may have noticed that the image appears somewhat unsteady and blurry. But wait for a couple of hours and observe again when it has risen higher and you will find that the image is much more sharp and steady. The seeing is always worse on the horizon and it makes sense to use lower magnifications when observing here.

There is a general rule which one should consider when choosing the magnification for observing astronomical objects: For nebulae and other large objects it should be rather low (up to 100X) and for planets be somewhat higher (more than 150X).

The exit pupil

We discussed this briefly above.

It is the light beam which exits the eyepiece and enters the eye. This exit pupil (EP) should never be larger than 7mm. This value lets you calculate the minimum magnification that should be used with a telescope. If the EP is larger than 7mm, then light is being lost and wasted. In elderly people, the maximum opening of the eye's pupil is somewhat smaller as it continuously decreases with increasing age. A 60 year old can achieve a pupil diameter of 4-5mm. You should therefore consider the choice minimum magnification best suited to your age.

The stronger an eyepiece magnifies (and smaller its focal length), the smaller the exit pupil will be. A 200/1000mm telescope gives an EP of about 7mm when used with a 35.7mm. A 10mm eyepiece will give an EP only 2mm in diameter.

The individual parts of a telescope

The telescope mirror

An important component of reflecting telescopes is the main mirror. It collects the light from the night sky and reflects it, usually to a secondary mirror. It is very important that the large primary mirror is of high quality. In addition to the optical surface quality, the mirror substrate is also very important.

There are various materials used that differ primarily in the fact that they have different coefficients of expansion. A mirror made of window glass case undergoes significantly greater expansion or contraction than a mirror made of Pyrex for example. The following materials are common mirror materials:

- Window glass
- BK7
- Pyrex
- Zerodur

Window glass has the largest coefficient of thermal expansion and Zerodur the smallest. Basically, it is only this factor that is important in the mirror material and possibly the density and not so much to do with the quality of the image. This can be just as good with a window glass mirror as with one made from Zerodur glass.

Types of glass such as window glass, BK7 or Pyrex are commonly used in telescopes manufactured in large batches. Zerodur, a development by Schott, is relatively expensive and so is rarely used. Why is Pyrex more often preferred to the slightly cheaper BK7 glass?

BK7 mirror glass has more than twice the thermal expansion of Pyrex. This means in practice that Pyrex delivers a much better image than BK7 the in the cool-down period. A mirror is ground to a specific aspheric or parabolic shape. This shape should be maintained and not change. As the mirror shape will distort with large changes in temperature, BK7 is more problematic here. Pyrex does not distort to anywhere near the same extent and retains its shape better. The cool-down time is only slightly different and may vary according to thickness of the glass. The air temperature can also change in the course of the night, and Pyrex (or other borosilicate glass) mirrors are hence also superior here.

But Pyrex mirrors often only first come into use with larger telescopes, as it is here particularly important that the mirror material is not so temperature sensitive. Another advantage of Pyrex is also that it is harder than the other materials used and can therefore be ground more precisely.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The mount

This is a very important part of a telescope, whether it is on a refractor or reflector. If the mount is no good, you can have the best optics in the world but will have absolutely no fun observing. Simply put, a mount is something that holds the optics rock steady so that you can observe objects comfortably through the optics.

The altazimuth mount

One of the simplest types is the altazimuth mount.

This allows you to move the telescope in *alt*itude (height) and in *azimuth* (horizontally) and hence point at any desired object. With most cheap telescopes, you will find the telescope mounted onto a small fork. In addition, the telescope has on one side a small metal rod which is connected to the fork mount (this applies mostly to the smallest telescopes). This lets you fix the elevation of the telescope. The other telescope axis can usually be rotated 360° horizontally and can be fixed in position with a small screw.

Thus equipped, you can use this type of mount to point at and observe any object in the sky. This design has the advantage that it is very light to carry and requires no great technological knowledge to operate it. When observing astronomical objects, you must constantly correct the telescope in the two axes to compensate for the rotation of the Earth.

You will not have to make the same size of correction on both the axes: The Earth's rotation means that a star will ‘move’ in the sky by about 0.25° per minute. Objects appear in the east, rise in a circular path, reach their highest point in the south at the meridian and finally sink again until they set in the west.

So you will need to keep ‘recapturing’ objects with the altazimuth mounts again and again as they drift out of the field of view of the eyepiece after quite a short time. This is not easy when the telescope has a very simply built mount in which no fine position adjustment is possible. Such a mount in any case absolutely unsuitable for astrophotography, as a photographic object must always remain precisely stationary in the field of view. In addition, altazimuth mounts are affected by field rotation.

However, there are also easy to operate altazimuth mounts. These have two knobs called ‘slow motions’, one for each axis, and enable fine control of the movement of the telescope. This allows you follow astronomical objects much more precisely. If you are planning to buy a telescope with an altazimuth mount, I would advise you to get one with the ‘slow motions’.

The equatorial mount

This astronomical mount is known as an equatorial, or occasionally a parallactic, mount. It is almost a must for meaningful astronomical observation and available in two different versions:

- German Equatorial Mount (GEM)
- Fork mount

These mounts look very different, but the principle is the same. Each mount consists of two slewable axes.

- The right ascension (RA) axis
- The declination (Dec) axis

The RA axis is aligned with the north celestial pole, so that it is parallel to the rotational axis of the earth. The Dec axis is at ninety degrees perpendicular to the RA axis. The shaft extension on this axis holds the counter-weights which compensate for the weight of the telescope so that it remains stable even when not locked in position. This is important, among other reasons, for the smooth functioning of motor controls of the telescope.

The horizontal plane of the telescope mount can be adjusted to match the latitude at the observation site. The Pole Star has an angular elevation which exactly corresponds to the geographical latitude here.

These two axes are responsible for the co-ordinate system used for the sky. Imagine the celestial coordinate system as simply a projection onto the celestial sphere. It consists of many curved vertical and horizontal lines which together form the intersections of many ‘boxes’.

Dec indicates the altitude of an object above the celestial equator in a scale going up to 90°. The RA coordinates are responsible for the changing hour angle, the celestial equivalent to terrestrial longitude. This is measured eastward, in hours and minutes, from its zero point in the vernal equinox in the constellation of Pisces.

When you have located a specific object in your telescope, you can now follow its coordinates on a planisphere (rotatable star map). Dec is always fixed and corresponds to that specified on the planisphere (e.g. 50° North). The RA, however, can be adjusted and you can set the hour angle on a rotating coordinate ring. You can rotate the RA scale on the telescope mount until the indication corresponds to the star map. Now you can just pick out any object from the star map and adjust the mount according to the coordinates of the object.

Once the equatorially mounted telescope is aligned on Polaris, you can point the mount (and hence the telescope) at any object you want to observe. You have now only to compensate for Earth’s rotation by using the RA slow motion knob to keep an object in the centre of the field of view. You do not need to do anything about the declination.

Everything becomes much easier with motors on the axes, as then you do not even have to compensate for the Earth's rotation manually, but can simply let the motors do the work. In general, there is also a control box provided with which you can make any corrections needed.

When used for astrophotography, the mount must be somewhat more precisely set up than simple alignment on Polaris. This is because the North Celestial Pole is not located precisely at Polaris, but about 0.5° away. This will lead slightly inaccurate tracking if not aligned on correctly. The best way to align on the North Celestial Pole with high precision is to use a polar finder scope. This is included as an option with many mounts.

The Dobson Mount

A particularly ingenious but simple idea is the Dobsonian mount. The idea behind this invention was to put as large as possible s telescope onto a very inexpensive mount. This goal was actually achieved.

How does a Dobsonian mount work?

A Newtonian telescope sits on a wooden box which allows it to move freely in azimuth (horizontally) and in altitude (vertically). The construction of the box is really quite simple: it consists of only a few parts that are assembled rather like an Ikea flat pack. To ensure ease of movement, the telescope and box are connected via sliding and rotating bearings. This allows the telescope to be moved in any direction with very little effort.

20 years ago and even earlier, large telescopes could be acquired for unbeatably low prices. A Dobsonian is also more easily transportable than virtually any other instrument. Simply lift the telescope tube (OTA) off the rocker box and you have two separate parts in front of you for transportation. The telescope is also reassembled again just as easily.

Whether in the field or on your own doorstep, set up is quick and easy - that is the simplicity of a Dobsonian mount.

Of course there are not only advantages but also disadvantages with this type of telescope mount design, as with as any other design. Astrophotography is not possible with a Dobsonian telescope. Also at very high magnifications, for example when planetary observing, it is quite difficult to keep the object in the field of view. However, there are 'Dobsonnauts' who have found the optimal technique for high-magnification planetary observing.

These telescopes polarise the preferences of the amateur astronomy community.

Some swear by Dobsonian telescopes while others would never have anything other than a super-heavy German Equatorial Mount in the house.

Eyepieces

There are a flood of eyepieces of various designs on the amateur astronomical supply market which you can use for your own observing. You will hear strange-sounding names, terms such as field of view, focal length, exit pupil and then still not really know which eyepiece is it the right one for your observing. In order to remedy this somewhat, I have listed the various designs with their advantages and disadvantages below.

Basically, eyepieces are like a magnifying glass used to magnify the view of the intermediate image produced by the telescope itself. In principle, such an 'eyepiece magnifier' could consist of just a single lens element. Since however different eyepieces also want to produce different fields of view, an eyepiece has a combination of lens elements at various fixed spacings. But achieving longer eye relief and the correction of image aberrations are also reasons for this. The 'holder' which keeps all these lens elements in place is also known as the eyepiece 'barrel'.

Huygens eyepieces

These eyepieces are a simple two lens element design which provides a relatively small apparent field of view. The lenses are not cemented together and therefore well suited for solar projection through a telescope. These eyepieces are among the oldest designs and are only rarely found among telescopes accessories. Their field of view is about 40°.

Kellner eyepieces

Kellner eyepieces are composed of three lens elements and have a field of view of around 45°. Since the two eye lenses are cemented and constitute an achromatic doublet, only a little chromatic aberration is produced. Kellner eyepieces can be used for higher magnifications with telescopes having an aperture ratio of up to 1:10. The limit with Newtonian reflectors is at an aperture ratio of 1:5, and here it is better to resort to Ploessl eyepieces.


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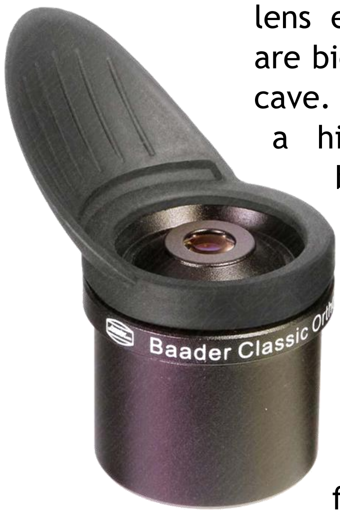
Orthoscopic eyepieces



These eyepieces have four lens elements, two of which are biconvex and one is biconcave. These eyepieces provide a high level of sharpness both at the centre as well as at the edge of the field of view. They are therefore also of interest for planetary and double star observing. They feature a flat image field. The low absorption exhibited by these lenses due to their use of only a few lens elements and accordingly good lens coatings is another plus for these eyepieces. Their field of view is about 40° to 45°.

Plössl eyepieces

Ploessl eyepieces are the astronomical standard lens and anyone who does not want to spend a lot can afford these eyepieces. Often one finds these Ploessl design lenses in complete accessories kits for beginners.

These eyepieces always consist of four lens elements in two pairs. These lens element pairs are cemented together and each form an achromatic doublet meaning there is virtually no chromatic aberration. But short focal length Ploessl eyepieces have a problem with their eye relief. This means that the eye lens elements are so small that you have to position your eye very closely to the eyepiece. Your eye is glued to the eyepiece, so to speak. Other eyepiece designs are therefore preferable at short focal lengths.

Their apparent field of view is about 50°.

Erfle

You cannot find Erfle eyepieces in modern accessory catalogues as this type is no longer directly available. However, many eyepieces can be found among astronomical accessories that have the basic features of this design. Many modern eyepieces are actually a development of the Erfle design.

Erfle eyepieces have five lens elements and apparent fields of view of up to 68°. They are especially useful for use as wide-field long focal lengths eyepieces. The eye relief is not optimal at shorter focal lengths and they are therefore not recommended under 20mm.

Long eye relief eyepieces

These eyepieces have become especially popular in recent years. If you look at the eyepieces used by any amateur astronomer, you will probably find at least one of this type. These eyepieces cannot be assigned to any one particular design, but rather have long eye relief as a dominant feature.

They always have long eye relief of around 16-20mm, even at short focal lengths, and are hence especially comfortable to use.

These eyepieces are ideal for spectacle wearers, but also people who do not wear glasses appreciate the benefits.

Nagler

Nagler eyepieces are an in-house development from the eyepiece manufacturer Tele-Vue. The main elements of these eyepieces consist of a number cemented doublets. Most of these eyepieces have seven lens elements, but there are also variations using fewer elements. These eyepieces you provide one with a fantastic impression of the night sky. They almost make you feel as if you are floating in space. This is due largely to their enormous apparent field of view of 80°.

These eyepieces also reduce image errors such as coma and distortion. In practice, this means that you observe sharp stars right out to the edge of the fields of view, even in 'fast' telescopes.

2 inch eyepieces

Are you perhaps currently thinking of buying a telescope? Then you should also consider one with a 2" focuser, as this could give you a completely new perspective on the night sky. Or does perhaps your telescope already have a 2" focuser?

So far, we have only discussed 1.25" eyepieces - eyepieces that fit into any telescope. But with somewhat larger telescopes, from apertures of around 150mm, you also find 2" focusers fitted. But what are the benefits of 2" eyepieces?

Firstly, these eyepieces are significantly larger and heavier than their smaller 1.25" relatives. But the key feature is their much larger field stop, which does not limit the light bundle to the same extent as the smaller eyepieces hence allowing a much larger field of view. This means you can even find 2" eyepieces providing a more than a 100° apparent field of view. Observing though such an eyepiece seems limitless; it appears as if there is simply no end to the star-speckled blackness. Only when you move your eye will you eventually reach the edge of the field of view. Another advantage of these eyepieces is their very comfortable viewing, with the huge eye lens ensuring very relaxed observing.

For which objects are 2" eyepieces suitable?

In general, the longer focal length 2" eyepieces are of most interest - for example in the range 20-40mm. At the telescope, this will give you low magnifications and very wide fields of view. This makes these eyepieces especially interesting for deep sky observing. So observing faint galaxies or extended nebulae with 2" eyepieces is a real joy. But there is an additional benefit: Imagine you want to find a particular galaxy with your telescope. Despite your finderscope, you are not sure if it is actually in the field of view because you simply cannot see the faint galaxy with your naked eye. Luckily, you are now using your 2" wide angle eyepiece, covering perhaps two degrees (that is four full moon diameters!) of the night sky. Thanks to the wide field of view, you can see the galaxy directly in the eyepiece and can now set the galaxy in the centre of its field of view.

Field of view

The field of view which can be achieved with an eyepiece is a crucial factor. If you look at the eyepieces available today, you will find fields of view ranging from 45° to 110°.

Here, this means the 'apparent field of view' (AFOV) of the eyepiece - that is the angle that can be seen by means of the eyepiece. But these large fields of view can be misleading. This is because the AFOV is very far from the field of view that you can actually see in the sky.

A very important criterion here is the telescope used. Different actual or true fields of view (TFOV) will be achieved, depending on the magnification used. If you know the AFOV of the eyepiece, then you can relatively easily calculate TFOV in the sky.

The magnification of the eyepiece in the telescope:

M = focal length of telescope / focal length of eyepiece

Example: You use a telescope with a 1000mm focal length and a 10mm eyepiece. 1000mm/10mm = 100X magnification

Calculation of the true field of view (TFOV):

TFOV = AFOV / magnification

As an example we take a Super Ploessl eyepiece with 52° AFOV:

TFOV = 52°/100X = 0.52° = ~30'

The field of view in the sky now has a size of 0.5° or *30 arc-minutes.

For comparison, the moon has a diameter of ~30 arc-minutes.

For comparison, here is a table with the different fields of view:

How do you calculate the AFOV of an eyepiece if it is not provided?

Measure the diameter of the field stop at the bottom of the eyepiece. To do this, unscrew the eyepiece barrel, allowing you to easily determine the diameter of the free passage of light. The second value you need is the focal length, which can be found printed on the eyepiece. The following inverse tangent function allows you to calculate the AFOV:

AFOV = half the field stop diameter / eyepiece focal length tan-1

Not the whole field stop, but only half is used.
The result is then multiplied by 2.

Example:
I measure a field stop of 12mm with a 12.5mm focal length Ploessl eyepiece. These two pieces of information are now put into the formula with, however, only half the diameter of the field stop, i.e. 6mm:

6mm/12.5mm tan-1 = 25.6 x 2 = 51°

Okular	Eigengesichtsfeld	Vergrößerung	Wahres Feld
Kellner	40°	120x	0,3°
Plössl	50°	120x	0,4°
Super Plössl	52°	120x	0,43°
Ultra Wide Angle	66°	120x	0,55°
Panoptic	68°	120x	0,56°
Nagler	82°	120x	0,68°

Originally (bitmap) uploaded to English Wikipedia: File:Lens-sphericalaberration.png Created by DrBob as claimed on en:User:DrBob SVG conversion and translation: Frank Murmann at de.wikipedia [GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons

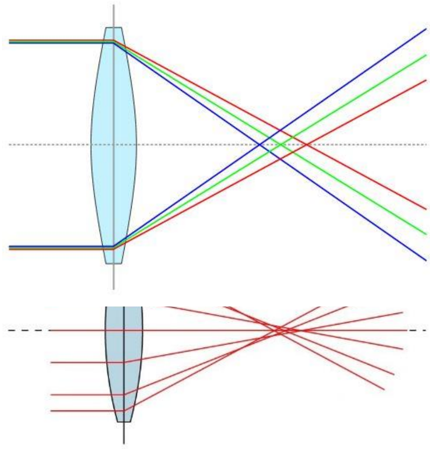
Optical Aberrations

Unfortunately, there is no telescope or of any type of other optical instrument that is completely free of image aberrations. The perfect telescope does not exist. Even the eye has some aberrations. But it is always possible to develop optical systems which correct for particular aberrations. Often, it is also a matter the observer's attitude: i.e. whether he accepts an optical system with certain aberrations, or whether he demands a high-end instrument which produces a virtually perfect image.

Explanations of the most important aberrations in astronomical telescopes can be found on the following pages.

Spherical aberration

Spherical aberration is an aberration that may occur in both the case of lens and mirrors. Here, light rays nearer the optical axis are refracted, or reflected, differently, from light rays further away from it. This means there are different focal planes for the various rays. In the case of a



spherical lens, or a spherical mirror, this spherical aberration occurs because the angle of incidence further away from the optical axis is considerable higher than that close to the optical axis. In telescopes, this aberration is seen as a blurring of the image. The aberration is more serious at shorter focal lengths than at longer focal lengths. This aberration can be reduced by use of an aspherically curved lens or a parabolic mirror This means that the angle of incidence are not as high and therefore the light beams come together in one focal plane.

Von Andreas 06 (Own work) [Public domain], via Wikimedia Commons

When the Hubble Telescope was first launched into space, it was found that it suffered from spherical aberration and provided blurry images. A pair of 'spectacles' had to be made and fitted to it in space to correct for this error.

Chromatic aberration

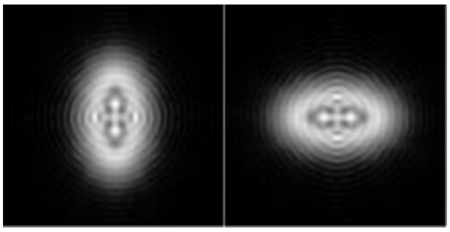
Chromatic aberration is a problem which lens, or refracting, telescopes suffer from. Light strikes the lens elements and is refracted by them - perhaps you can still remember something about this from physics lessons at school. Refraction is essential for the formation of an image. Blue light is refracted more than, say, red light. This means that the different wavelengths have different focal lengths. The refractive index of blue light is greater than that of red light.

If one imagines the effect of this on the formation of an image of an object, then the blue light will be found at a different location than the red light. This means that the image produced is blurred. But not only that, it also means a difference in the magnification of different colours. In plain language, this means that the different image distances for the respective colours cause different image sizes for them. This means the production of annoying colour fringes in the image.

Chromatic aberration can be quite well corrected by use of an achromatic doublet. Here, a positive biconvex lens is combined with a negative lens located behind it with greater dispersion. Thus partially compensates for the chromatic aberration. But even then there is some residual chromatic aberration. This residue is referred to as 'secondary spectrum'.

Also this secondary spectrum can be corrected, in which you can still inserts an additional lens (usually again a plus lens). In reflecting telescopes occurs no chromatic aberration.

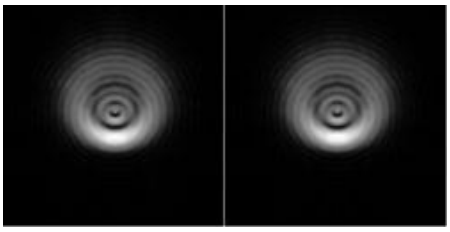
Coma



Coma is another image error caused mainly by the incident light beam falling obliquely, away from the optical axis. It is often produced by the combination of spherical aberration and astigmatism. Astigmatism is partly due to asymmetric light rays. In the diagram, the light beams generate asymmetric images. This gives rise to stars at the edge of the field of viewing exhibiting distortions that resemble comet tails. These have a fuzzy appearance and cannot be focused.

Telescopes with large aperture ratios tend to suffer particularly badly from coma. These are telescopes with aperture ratios of 1:4 or 1:5 up to about 1:7. In other words, the aberration appears worse with particularly fast optics. Long focal length telescopes, with their smaller aperture ratios (e.g., 1:10), suffer much less from coma. Also, this error can be minimized if the lens is stopped down. It is always possible to use a coma corrector to achieve sharp images with fast optics however.

Astigmatism



Astigmatism can be caused by the incident light beam hitting the telescope obliquely (oblique astigmatism). It can also occur due to distortions of the main mirror. But it is often caused by two different curvatures of mirrors or lenses generating different focal lengths. One bundle of rays would then be perpendicular to the other. Astigmatism can be seen in the Airy disk as an image distortion where it is longer in one axis than that perpendicular to it. The aberration can be minimized by stopping down the telescope.

Field Curvature

Field curvature is related to oblique astigmatism.
The image is formed on a curved surface, rather than on a flat pane, meaning you can never get the image focused simultaneously at both the centre and the edge. Stopping down the lens can also mini-

mize this aberration.

Other astronomical accessories

Star diagonals – mirror and prism versions

When you point a refractor telescope, Schmidt-Cassegrain telescope or Maksutov telescope at the night sky, one stands out: The focuser points downwards.

This means that higher the telescope is pointing in the sky, the more awkward it is to look through it, and indeed sometimes you need to be virtually lying on the ground!

To avoid a trip to an orthopedic surgeon after buying your telescope, there in an ingenious accessory available called a star diagonal.

This uses either a prism or a mirror to deflect the light by 90°. Simply slide the star diagonal into the focuser of a refractor, Schmidt-Cassegrain or Matsutov and your observing becomes immediately much more relaxed.

The prism variant has a triangular shaped prism, like the roof of a house. The base of this 'roof' is positioned at 45° so that the shorter faces are perpendicular to the incoming and outgoing light. Now, when a light beam hits the longer side it is deflected by 90° and into the eyepiece. A star diagonal using a mirror works in a sim-

ilar way. It consists of a mirror which is oriented in the housing in exactly 45°. So the prism and mirror versions both have the same effect.

The light path in the prism is slightly longer and poor quality prisms are prone to chromatic aberration. With mirror star diagonals however, it is important that they have a high reflectance. There are now so-called dielectric mirrors that reflect up to 99% of the incident light. Compared to ‘normal’ mirrors, these provide a brighter and higher contrast image.

The only telescope that does not need a star diagonal is the Newtonian reflector. The focuser points sideways out of the top of the telescope, so that you never have to crane your neck with this type of telescope.

Anyone who has ever looked through a refractor without a star diagonal will probably have noticed something odd: The refractor provides an image that is upside down. Using a star diagonal puts the image the right way up again.

Inverted images can be quite irritating when you are trying to find an object in the night sky. You tend to move the telescope in the wrong direction. These orientation problems become easier as one gains experience with handling a telescope and it eventually is no longer a problem.

The image produced by a refractor is quite different from that seen in a Newtonian reflector. In order to clarify this confusion, take a look at this list:

Typ	Bild
Refractor with a straight focuser and with no star diagonal	Image is inverted and left-right correct
Refractor with 45° Amici prism	Image is upright and left-right correct
Refraktor with a 90° star diagonal	Image is upright but left-right reversed
Newtonian Telescope	Image is (no star diagonal possible) on the head is inverted
Newtonian Telescope with erecting lens	Image is upright and left-right correct
Schmid-Cassegrain and Maksutov-Cassegrain telescopes	Image is inverted
Schmid-Cassergrain and Maksutov-Cassergrain	Image is upright but left-right reversed

with 90° star diagonal

In order to obtain an upright and left-right correct view with a refractor or Schmidt-Cassegrain, you will need an Amici prism. This accessory has a roof prism, which sets the image the right way up. This type of prism can also be found in binoculars for example. The Amici prism usually has a viewing angle of 45°, but they are also available as 90° prisms.

The erecting lens

An erecting lens has a very similar effect to an Amici prism. The erecting lens turns an upside-down image the right way up again, allowing you to use an astronomical telescope for terrestrial viewing. This lens is often not a single lens, but a system consisting of several lens elements. It usually has four lens elements, in which two lens elements are cemented together. The cemented systems consist, for example, of a plano-concave and a bi-convex lens. A defined separation of elements generates a magnification factor of 1.5X in addition to the re-inverting of the image. The most serious chromatic aberration is also corrected for.

However, an erecting lens is a compromise. The image scale is often changed adversely. Also, these lenses are usually not coated so that one has to reckon with some light loss. However, there are also high-quality systems whose optical quality is particularly good and where the lenses are fully coated. One should stick to buying these high quality lenses.

The Barlow lens

A Barlow lens is an optical device which is usually inserted between the eyepiece and the focuser. Inside is a negative lens that increases the focal length of the telescope artificially. A Barlow is often not a single lens, but a system of lens elements. This is usually employed to reduce chromatic aberration and, in this case, the lens is often referred to as an achromatic Barlow. Standard Barlows have a 2X magnification factor.

The function of such a lens can be best explained using an example: Let us look at a 200/1000mm Newtonian reflector, such as the Omegon Advanced Telescope. An eyepiece with 6mm focal length is used for this purpose. The magnification formula results in a 166X magnification. A Barlow with a magnification factor of 2X extends the focal length of the telescope from 1000mm to 2000mm. Using the same eyepiece, this results in double the magnification, i.e. 330X.

With an eyepiece and a Barlow lens provides you with two possible magnifications. Of course you will have a much better range of magnifications available if you take care to match the eyepieces to the Barlow when first buying your eyepieces.

But there is a problem:

A Barlow is an additional component, containing lens elements. Each lens element reflects light from its optical surfaces and also absorbs light internally. This means that less light finally arrives at the eye. That is why you should really consider when a Barlow lens is useful. A Barlow lens should not be used as a substitute for a good eyepiece if at all possible. Of course, there are now really high quality Barlows that provide a good image. However, these Barlows are usually in higher price range. Another application where using a Barlow makes sense is in webcam astrophotography.

Barlow lenses are really necessary in this type of astrophotography. As you usually photograph planets with webcams, using a Barlow with a high magnification factor makes sense. These lenses are available with a 3X or 5X magnification factor.

Reducer lenses for shortening the focal length

In addition to Barlows, there are also lenses which shorten the focal length of the telescope. This type of lens was previously mainly known as a Shapley lenses, but today they are known as a 'reducer'. While a Barlow uses a diverging lens system for the magnification effect it causes, a reducer works in the other direction. It is equipped with a converging lens and the positive power of this lens decreases the focal length of the telescope.

This component also often consists of more than one lens element and these working together have an overall positive, i.e. converging, effect. They often have three lens elements, with two converging and one diverging lens element, which are cemented together.

These lenses are used mostly useful in Cassegrain tele-

scopes and their Schmidt-Cassegrain or Maksutov-Cassegrain variants. These telescope systems all have a relatively long focal length. The aperture ratio is usually 1:10 or more. A 250mm Schmidt-Cassegrain telescope has at an aperture ratio of 1:10, meaning a focal length of 2500mm. This may be a too large for some purposes. Long focal lengths produce very small fields of view with astrophotography, and one has virtually no chance of capturing extended objects on the camera chip without the use of such a reducer.

However, there is no universal reducer. They are mostly designed for a particular design of telescope. Possible disadvantages are greater image aberrations and possible vignetting in photos.

Filters used in astronomy

Visible light is emitted in a range of about 380 to 780 nanometres: from the short wavelength blue-violet end to the long wavelength red end. When observing a particular astronomical object in a telescope, you can often improve contrast by the use of an appropriate filter. The filter achieves this by blocking certain regions of the visible spectrum and letting others through. There are filters in all conceivable colours that are often used for Lunar and planetary observing. You can make specific details on the surface of planets stand out more via their use.

Moon filter

A neutral, grey or moon filter is used to lessen the intensity of bright moonlight and to slightly increase contrast. Anyone who has ever been to an observatory and looked at the Moon through a large telescope without a filter will vividly remember the experience and know why this filter is so important. Observing the moon without a filter will not cause any damage, but it is so bright that it really dazzles you. If you then turn away from the

telescope and look into the darkness you will often still have a ghostly afterimage of the moon in the eye you observed with. Although this afterimage will gradually fade, it is still very irritating.

Of course these filters are available in different light reduction levels. They range from a light transmittance of about 8% up to 50%. The filters with a high transmittance are suitable for the smaller telescopes and those with a low transmittance are suitable for larger telescopes.

Adjustable polarizing filters are the luxury version of Moon filters. This is not just one, but two filter elements, which are connected to each other. Rotating one filter element relative to the other continuously adjusts the amount of darkening. Most polarizing filters allow light transmission levels from 1% to 40%. They can be used to set the optimal balance between light level and contrast for the size of telescope you are using.

Nebula filter

There are also special filters available for deep sky observing. These are quite complex and costly to produce. They consist of multiple dielectric layers which are vapour-deposited onto high-quality optically flat glass. They have the task of only passing a well-defined range of the light spectrum, depending on the type of observing the filter is to be used for. As a rule, spectral regions which are of no interest are absorbed and the spectral regions in which the objects mainly radiate are allowed through. The image seen in the telescope is darkened slightly.

All nebula filters block the spectral regions where streetlights radiate in. This is, for example, the case above 530nm and extends to about 630nm. When you look at the transmission curve of any of these filters, you will notice that there is a significant drop in transmittance in this area and the curve only rises again above 630nm. These filters are enormously effective as they block the street light while, at the same time, increasing contrast in the object being observed.

Using filters with a telescope

Using a filter with a telescope is quite simple: you have a choice between using 1.25" or 2" filters. These sizes correspond to the eyepiece format on your telescope and all you have to do is to screw your filter onto the thread in the eyepiece barrel provided for it. You then put the eyepiece, including the filter, into the focuser of the telescope and you can start observing immediately.

There is a huge range of astronomical accessories out there, and this book only covers a small selection – those which are of interest to beginners in amateur astronomy. But have a look at our online shop at Astroshop.de to discover other accessories, ranging from those for solely for visual observing to special astrophotography equipment. You can also find out about other accessories in our comprehensive glossary. And if you have a question you would like answered in person, then ring our experts or send us an email – we would love to hear from you.

On behalf of Astroshop.de, I wish you much enjoyment in your new hobby of astronomy. The universe is out there, just waiting to be discovered by you!