

Second Session Part 4

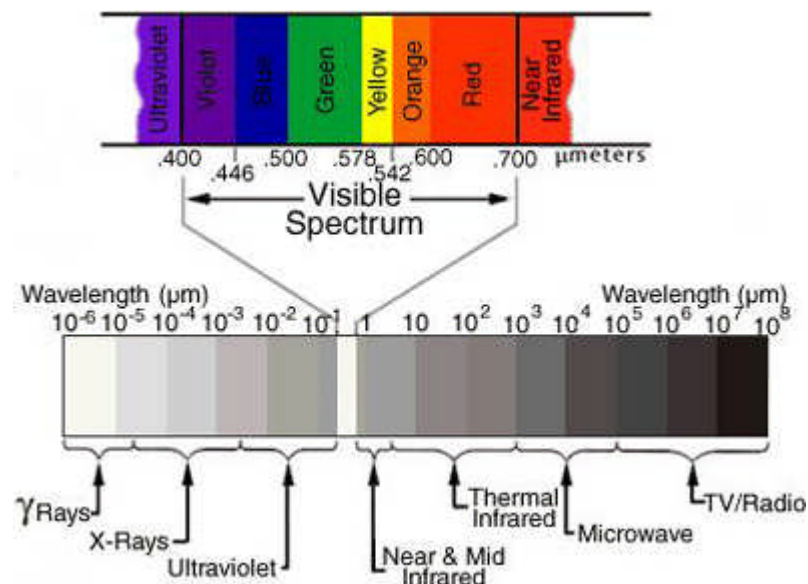
Before we discuss what telescope to buy and how to set it up let us discuss

Standard types of Telescopes, Eyepieces and Mountings¹

Of course, the next thing you want to know is how to set up your telescope so that you can find celestial objects as fast and easily as possible and track them without losing them out of sight almost as soon as you found them. Knowledge that you gained so far, most of all knowledge of basic geometrical features of the Alt/Az – and Equatorial systems will help you greatly.

However, let us pause for a while and discuss what kind of instrument you are using when you say that you are using a telescope.

As an amateur astronomer you are using an instrument which “aids in the observation of remote objects by collecting electromagnetic radiation” (Wikipedia: “telescope”) - such as light. (The word “telescope” comes from the Greek “tele” - “far, distant” - and “skopein” - “to view”). Other types of electromagnetic radiation (gamma ray/x-ray/ultraviolet/infrared/microwave/radio etc.) can also be observed using telescopes especially designed for this purpose; yet, amateurs mostly contend themselves with visible light and leave the rest of the electromagnetic spectrum to the professionals. Hence, optical telescopes are our domain.



But there are different kinds of optical telescopes. They are partly classified according to their optical design, partly by the kind of mounting on which they are mounted, partly by their specific purpose or way of functioning.

¹ All drawings of this section are taken from F.W. Price, *The Moon Observer's Handbook*, Cambridge: CUP 1988.

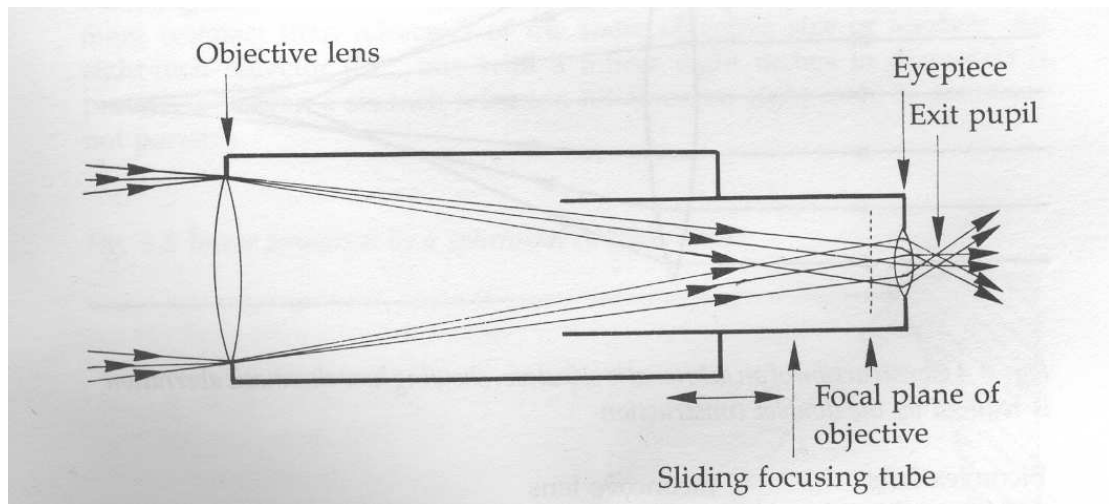
First of all, there are three basic optical designs of amateur telescopes: the **refractor**, **reflector** and the **catadioptric**.

The Refractor

It is commonly assumed that Jan Lippershey of Holland invented the “spy-glass” or telescope in 1607. He invented a refractor. Immediately afterwards, Galileo Galilei (1564-1642) built his own spy-glass and revolutionised our understanding of the universe with it. It had a very simple design. It was made of a convex objective lens with a focal length of roughly a meter, fixed to one end of a tube, and a concave lens – the eyepiece - at the other end. (When you stick out your tummy, it becomes *convex*; when you pull it in, it becomes *concave*; it “caves in”). The length of the tube could be adjusted for finding a reasonably sharp image. Point the telescope to an object, look through the eyepiece, adjust the length of the tube until you find a reasonably sharp image and, hey presto! Things come closer.

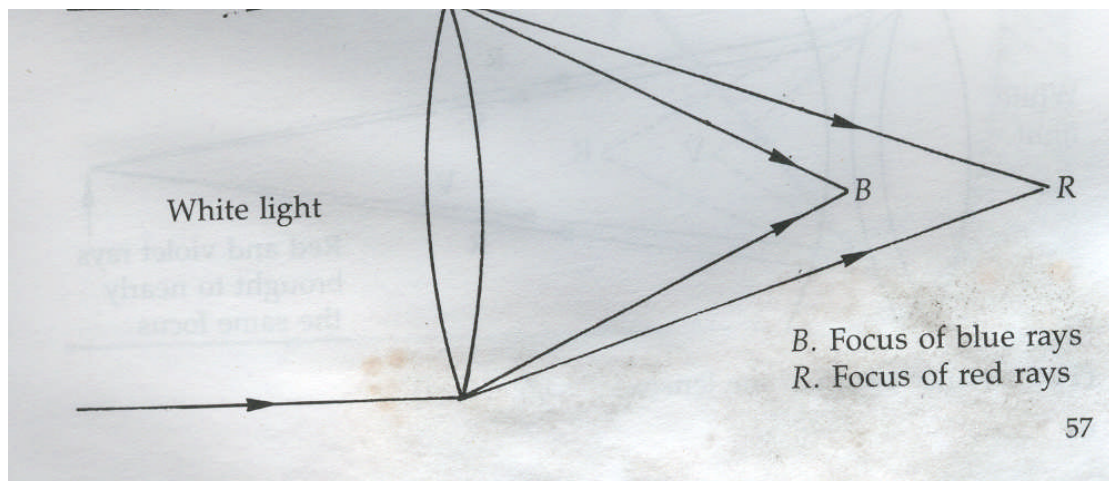


Picture of an Amateur Refractor



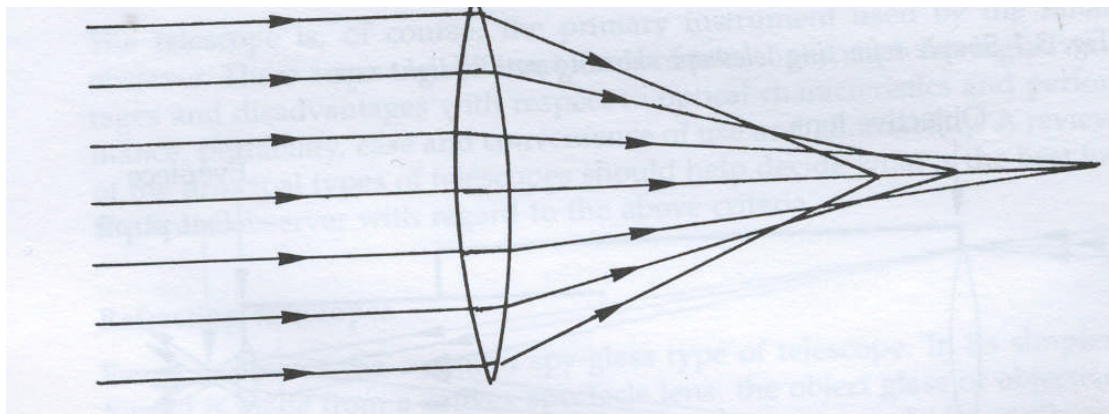
Drawing of optical design of refractor

However, this kind of refractor has at least two faults. The image formed by a single convex objective lens produces rainbow-coloured fringes around objects. The lens refracts light like a prism (splitting white light into rainbow colours) and causes *chromatic aberration*.



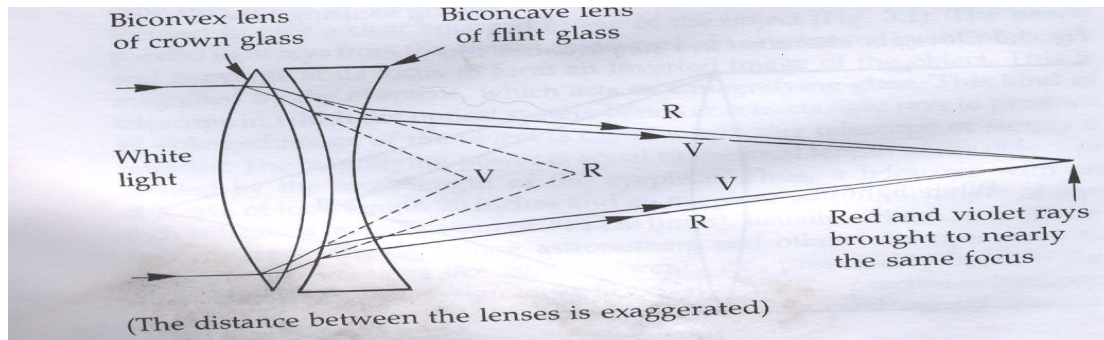
Drawing of optical path involving chromatic aberration

Also, the image is never really sharp because the lens refracts light in a way that its “rays” cannot coincide in a single joint focus. This is called *spherical aberration*.



Drawing of spherical aberration

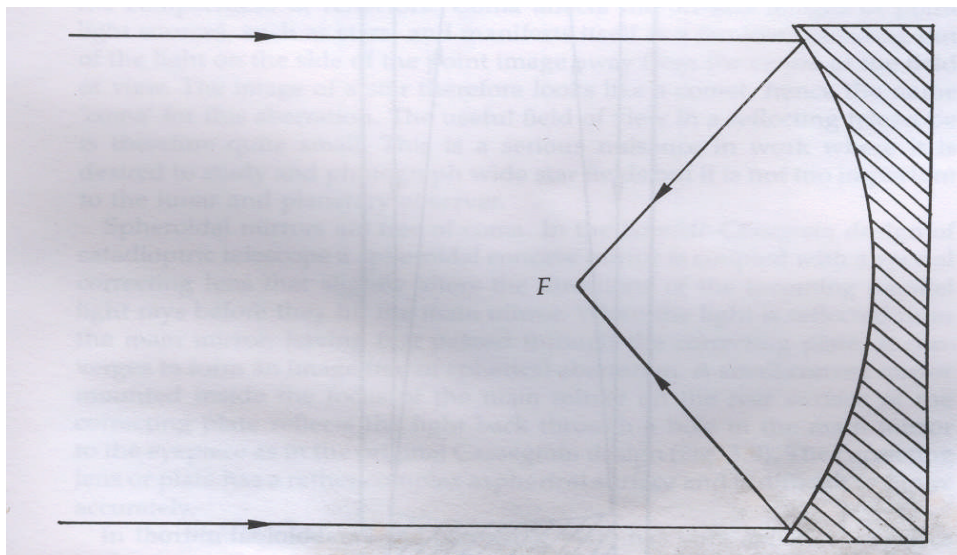
Both faults can be almost abolished if the front lens consists of a convex and a concave lens of different glass with different refracting properties - joined together. This is a *doublet*. It is called an *achromatic lens*. The telescope is called an *achromat*. Most amateur refractors are achromats (or apochromats).



The Reflector

In the 17th century, before Dollond invented the doublet objective lens, refractors suffered from severe chromatic aberration. Isaac Newton had the idea to use a (spheroidal) concave primary **mirror** for creating a magnified image of a distant object. Mirrors of this kind do not have chromatic aberration. If their focal length is long enough ($f/10 - 15$), i.e. the distance from the mirror in which the reflected image comes to a focus, spherical aberration can also be held at a minimum.

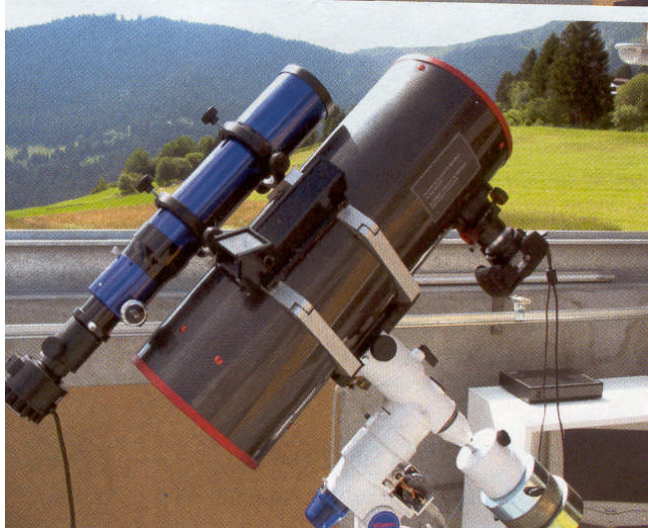
Image formation of such a mirror looks like this:



However, in order to see a distant object magnified, one would have to hold one's head near the focal point - which will obstruct the view almost entirely. We do not want our head to obstruct the view. Furthermore, we might wish to have a reasonably long focal length in order to get a decent image showing a lot of fine detail free of spherical aberration.

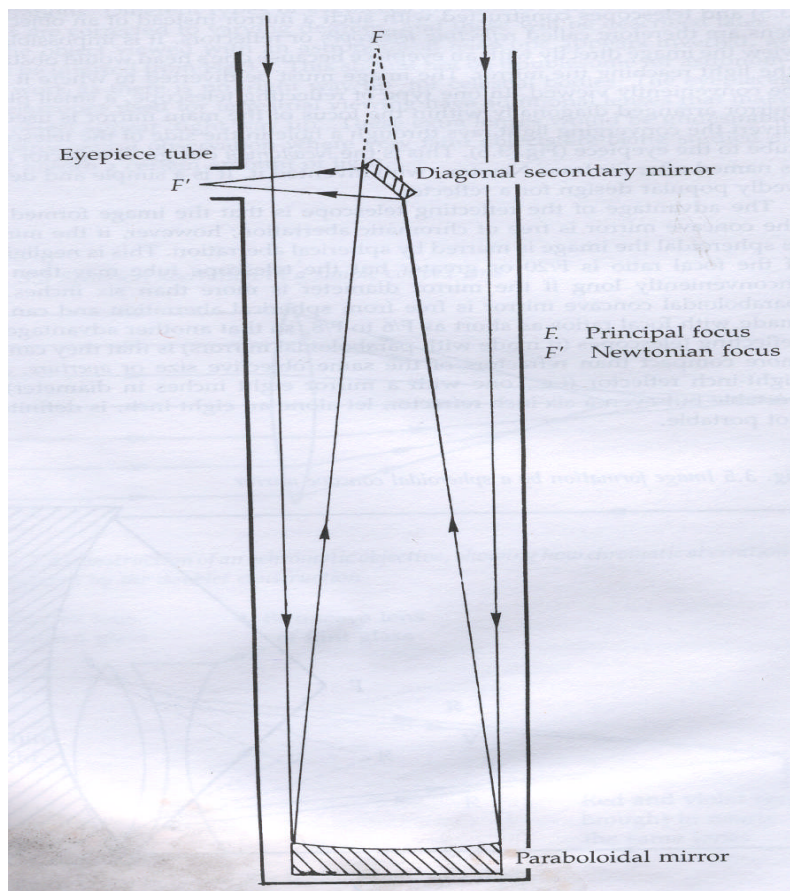
Newton had the idea of putting a secondary (flat) mirror into the optical path. It deflects the image in such a way that the focal point lies 90 degrees off the optical

axis. A magnifying eyepiece put into the eyepiece tube allows us to look at the image produced at the focal point.



An Amateur Newton reflector

This is its optical path:



Even reflecting telescopes are not perfect in spite of their advantages of having far less chromatic and spherical aberration, their tremendous light gathering power, their lighter weight and shorter length than refractors of the same aperture (diameter of the front lens/mirror). However, paraboloidal mirrors, frequently used in Newtonian telescopes of shorter focal lengths suffer from another kind of aberration called *coma* which makes stars at the edge of the field of view look like little comets. Of course, no one wants this kind of distortion either, particularly if you wish to take wide field images of the night sky. Spheroidal concave mirrors, however, are free of coma, although they need a correcting plate, in fact a kind of specially formed lens to slightly change the direction of the rays of light falling on the mirror.

Catadioptrics

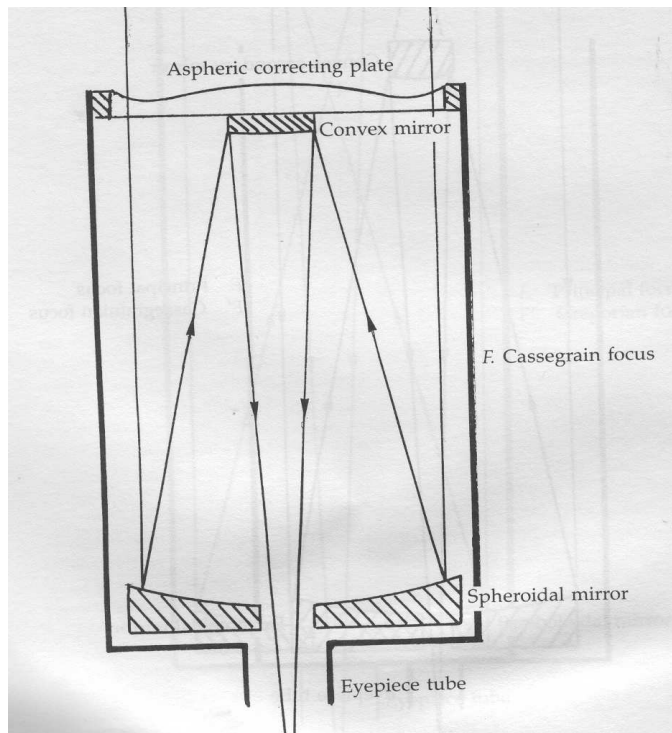
The third class of telescopes combines mirrors and lenses into a single optical system in the attempt to overcome all three kinds of aberrations. The two most popular telescopes of this kind are the Schmidt-Cassegrain- and the Maksutov-Cassegrain telescopes. They can have small focal ratios and, hence, wide fields of view free of coma, chromatic and spherical aberration, ideal for astrophotography.



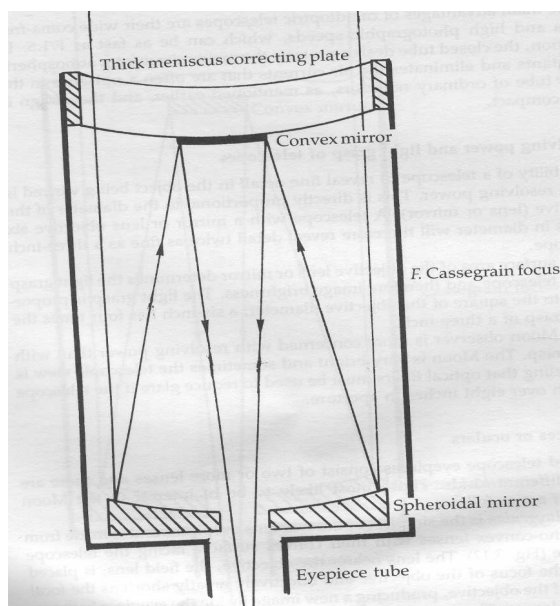
A Schmidt Cassegrain telescope

A Schmidt Cassegrain has a spheroidal mirror, combined with an aspheric correcting plate (lens). It also has a small convex mirror built into the rear centre of the

correcting plate facing the primary mirror. It reflects the light back into a central hole in the primary mirror which leads into the eyepiece tube.



A Maksutov telescope is very similar to a Schmidt Cassegrain. Instead of an aspheric correcting plate it has a spherical corrector which is not as thin as the one in the Schmidt Cassegrain but easier to manufacture. It is excellent, provided the glass for the corrector has no internal faults and does not absorb too much light.



Light grasp, magnification and resolving power

One of the most frequently asked questions by people who look through a telescope for the first time is: "What is its magnifying power?" They mostly assume that a telescope must be better, the higher its magnification is. Like myself when I started, you may have bought a small refractor or reflector from LIDL because you were told that it magnifies up to 200 times. Let us assume that you learnt to use it successfully to look at Saturn or Jupiter. Then you go to an observatory, look through a much larger telescope which also magnifies 200 times and you find that you see much more, more detail, more and fainter stars, even tiny and very faint galaxies. Obviously, magnification is not the major factor when it comes to assessing the quality of a telescope.

The most important piece of information about the "the power" of a telescope is its **aperture**, the diameter of its front lens or primary mirror. Its surface area determines the telescope's light grasp. It determines its image brightness. The larger the diameter, the more you will be able to see faint detail. Light grasp is proportional to the square of the objective/ mirror diameter. An 8 inch Schmidt Cassegrain is twice as big as a 4inch; but it has 4 times its light grasp. (Of course, the price of increasingly larger telescopes frequently increases in the same exponential way).

You can understand the relation between aperture and light grasp fairly easily if you think of your own eyes and how its pupils function. On a bright summer's day, your pupils may only open 1-2mm wide. You are almost blinded by the light. The pupil area for vision might just be 4 square millimeters. Incoming light has to be reduced in order for you to see clearly. If you suddenly step into a really dark room, you cannot see anything, of course. You are almost blinded by darkness. After some minutes, certainly after 20 minutes, your pupils will widen up to 8mm and, hence, you will see more and more again. Your pupil area for vision might increase roughly to 55 square millimeters. You are dark adapted because your light grasp was largely increased due to the increased diameter of your pupil.

Now compare the pupil area for vision of roughly 55 mm square with a small LIDL refractor with an objective lens of 60 mm. The surface area is already ca. 2800 mm square. This is 56 times larger than our widest pupil area.

Now compare this with the surface area of a 45 cm (16 inch) telescope. Its area for light grasp is 160 000 mm square which is 57 times the area of our 60 mm LIDL telescope. Moving from the surface area for light grasp of our pupil to a 60mm telescope is almost the same step as moving from a 60mm telescope to a 45 cm giant amateur scope! Higher light grasp is expensive, though, very expensive.

However, **magnification** is far from being irrelevant. Sometimes, higher magnification allows you to see fine detail in a relatively small field of view (FoV). Sometimes you want to look at large structures such as the Orion Nebula. In this case, you need a wider FoV and hence a lower magnification. Sometimes, the air is so turbulent (or the air in your Newton telescope) that you think that you observe as if being under water. Take a lower magnification and you get an image which remains relatively stable. But how do you determine magnification, anyway?

Let us take the example of a simple (biconvex) lens. Supposing you use it to look at an object which is far ("infinitely far") away. The lens images this object upside-down

a certain distance away from its own centre. The distance between the centre of the objective lens and the plane where the object is imaged (the focal plane) is its **objective focal length**. The image itself is generated in the **focus**. You can now use an eyepiece and look at the – upside-down –image, magnified by the eyepiece, in the focus of the objective lens. Of course, an eyepiece is another lens which also has a focal length, the **ocular focal length**. The magnification (V) of a telescope equals the ratio between objective focal length and ocular focal length:

$$V = \frac{\text{Objective focal length}}{\text{Ocular focal length}}$$

Examples: Your refractor has a focal length of 1000 mm. You are going to use an eyepiece with a focal length of 10 mm (it says it on the side of the eyepiece). Your magnification is 100 times. Since the objective focal length does not change (unless you use a focal reducer), you have to use different eyepieces with different focal lengths to get higher/lower magnifications: Using a 5mm eyepiece yields 200 times, a 20 mm eyepiece yields 50 times etc.

Higher magnification means higher sensitivity to atmospheric disturbances. Hence, a **maximum magnification** should not be overstepped. With small telescopes and favourable atmospheric conditions one should not use an eyepiece which yields a magnification higher than 1.5 – 2 times the diameter of its front lens/mirror in mm. Your LIDL telescope has 60 mm front lens; hence do not go beyond 90 – 120 times magnification. A 12mm eyepiece may be the highest you should use. Of course, you can use eyepieces with a higher magnification. You may use a 6mm eyepiece, for instance. It will give you a smaller, far dimmer and foggier image and will also not show any further detail!

There is also a **minimum magnification** beyond which magnification makes no longer any sense. It is normally calculated by dividing the aperture in mm by 6. A LIDL 60 mm telescope will thus have a minimum magnification of 10.

Another factor which becomes increasingly relevant when we wish to observe fine detail in celestial objects is the telescope's resolving power or **resolution**, its capacity to separate objects such as physical double stars. Resolution tells you the minimal distance between two objects detectable by your telescope. If the two objects are closer together than this minimal distance, they appear as one object.

There exists a simple formula telling you the minimal distance for your telescope in seconds of arc (the number 115 used here is a value based on experience):

$$\text{Minimal resolved distance} = \frac{115}{\text{Diameter of front lens/primary mirror in mm}}$$

If your LIDL telescope has a 60 mm front lens, then your resolution is roughly 1.9 seconds of arc. If your telescope has an aperture of 250 mm, then it should –

theoretically – resolve with a factor of 0.46 seconds of arc. Atmospheric problems with seeing may change this factor quite easily to the worse!
It may sound astonishing but it clearly is the case that **the resolving power of a telescope has nothing to do with its magnification.** It has a lot to do with aperture.

Another important piece of information concerning the “power” of a telescope is its so – called **f-ratio**. It is the ratio between the diameter of the front lens or primary mirror and its focal length. It is 1: f-number

$$\text{f- number} = \frac{\text{Focal length in mm}}{\text{diameter of front lens/mirror in mm}}$$

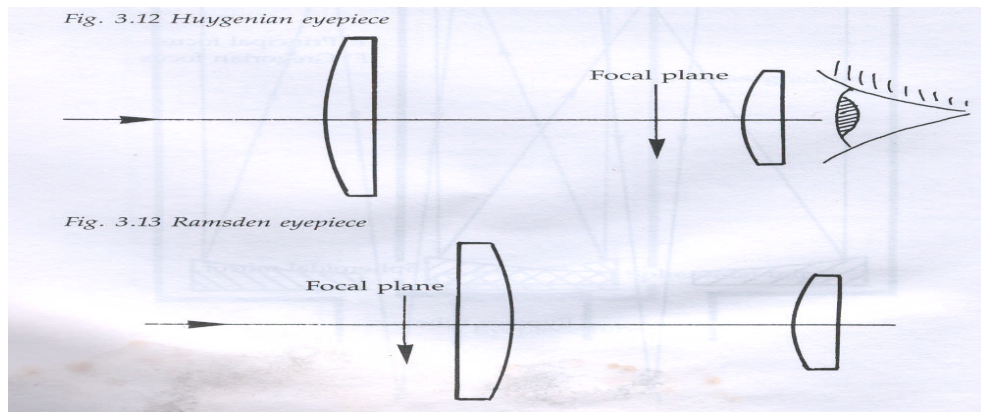
Your LIDL has a front lens diameter of 60 mm and a focal length of 1.000 mm. Hence, its f- number is roughly 16, its f-ratio is 1: 16.

The higher the f-number, the narrower the apparent field of view of a telescope, the lower the f-number, the wider the field of view. If you wish to photograph larger fields of the night sky, you will choose a telescope with an f-ratio of 1:5 rather than one with an f-ratio of 1:15. If you want to take images of a planet, for instance, you may prefer a telescope with a focal ratio of 1:15 rather than 1:5.

Eyepieces

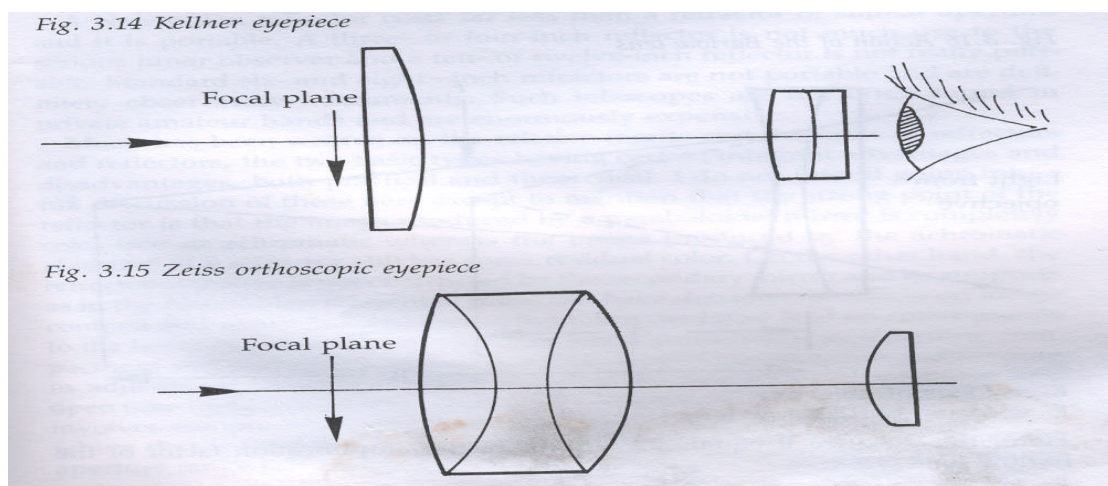
Eyepieces are also lenses and, hence, suffer from the same defects as front lenses of refractors. They can have chromatic aberration, spherical aberration or coma. Consequently, a simple lens will probably be not the best idea of a choice for an eyepiece. Eyepieces normally consist of a variety of lenses made of a variety of different kinds of glass to compensate for deficiencies and create a reasonably wide field of view. The lens next to your eye is the eye lens, the one directed to the front lens/primary mirror is the field lens.

The most elementary types which amateur astronomers use are the **Huygens-** and the **Ramsden** eyepieces consisting of two plano-convex lenses. They consist of two lenses only. The Huygens ocular has its convex parts turned to the front lens and has its focal point between its lenses; in the Ramsden, the convex parts of the plano-convex lenses face each other; it has its focal point outside its system, towards the front lens. (A Ramsden allows you to put a crosshair in the focal plane). The Huygens is useful for focal ratios higher than f/15, the Ramsden can be used for focal ratios down to f/6.



A better choice, although still not perfect when it comes to eliminating deficiencies is the **Kellner** eyepiece. They are used in many LIDL- type telescopes. They are Ramsden-type eyepieces except for the fact that their eye lenses are achromatic doublets. Unfortunately, they are known for creating ghost images due to internal reflections.

My favourites are **orthoscopic** eyepieces. They are brilliant in so far as they give you very crisp images up to the edge of the field of view free from major deficiencies, also at a reasonably low price. There are even better multi-lens eyepieces, of course **Naglers** and **Ploessls**, for instance, but their price increases considerably as well. Furthermore, the more glass you put between your eyes and the object you want to observe, the more light is absorbed by it!



Comparing types of amateur telescopes

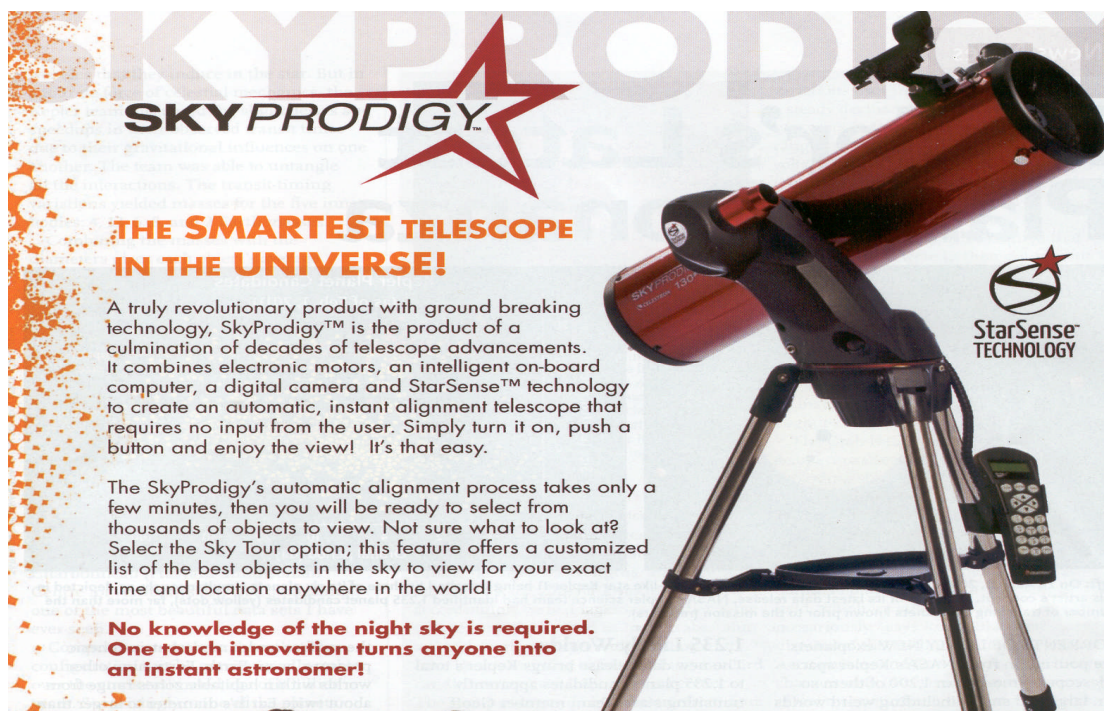
At the end of this session you may ask yourself: Which telescope is better for me – a refractor, a reflector or a catadioptric?

The answer depends partly on what you want to do with the telescope and how much money you are prepared to spend.

Let us assume, first, that the only thing you want to do is to find and admire the wonders of the universe, particularly the Moon, planets, comets, globular clusters, galaxies, double stars, nebulae or planetary nebulae - and that you want as wide a field of view as possible. Maybe you want to take the occasional short exposure image. Also, the telescope should not cost too much. The telescope you may want is either a so-called Dobsonian, possibly with a drive mechanism for Alt/Az, or a telescope which is definitely more expensive but finds its way in the sky almost automatically and may also tell you the story of what you are looking at.



If you want a telescope which is definitely more expensive but finds its way in the sky almost automatically, take this one:



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No knowledge of the night sky is required. One touch innovation turns anyone into an instant astronomer!

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A lot of amateur astronomers want to have telescopes that they can use for travelling and carry with them in their car. Ideally, however, telescopes should not be moved at all! They should be put on a permanent mount and aligned as precisely as possible to either an Alt/Az or – even better – to a polar position (explained in the next session). As a rule, however, refractors with front lenses larger than 4 inches become a real problem for transport and so do Schmidt Cassegrains or Maksutovs larger than 5 inches. They get rather heavy and clumsy, hardly manageable by one person only. 8 inch Schmidt Cassegrains with a focal length of f/10 combined with a focal reducer, reducing the focus to f/5 if required are, in my experience, the best overall compromise. They can still be transported, are excellent for observing and also for astrophotography.

Never forget to align your finderscope absolutely parallel to the optical axis of your telescope before observing! Otherwise you'll try to find a needle in a haystack! Choose a distant object – such as the top of a telegraph pole – with your telescope. Centre it in the field of view. Try to put the same object into the centre of the field of view of your finderscope. Try and try again until the object is both precisely in the centre of the finderscope and the telescope. Fix the finderscope so that it will not wobble! That's it. Whenever you center the object in the finderscope – which may have a FoV of 5 degrees – it will also be visible in the eyepiece of your telescope – which may have a FoV of less than 1 degree. Use a good star map to identify stars (on maps later).

Even though you may wish to be the proud owner of a telescope, never look down on a good pair of binoculars! With their large field of view (ca 3-5 degrees) they really open up the starry heavens for you, particularly when you have difficulties finding the objects you want to observe and the field of view of your telescope or its finderscope are vexingly small!

Telescope mountings

You will notice when using your binoculars that you can see much more detail in the night sky when you avoid wobbling and vibration caused by your hands or arms. Rest your arms on a wall or use a tripod. If you use higher magnification binos, your heartbeat may cause too much vibration! Things get even worse with telescopes. There simply is no good way of observing with them without putting them on a sturdy tripod or permanent mount which has to be vibration free and rigid. On the other hand, the telescope itself must be easily moved for tracking the celestial object of your choice. This object will apparently move permanently and uniformly. However, what you observe as permanent uniform motion is, for the most part, the earth's rotation. Most telescopes have drive motors to counteract this motion.

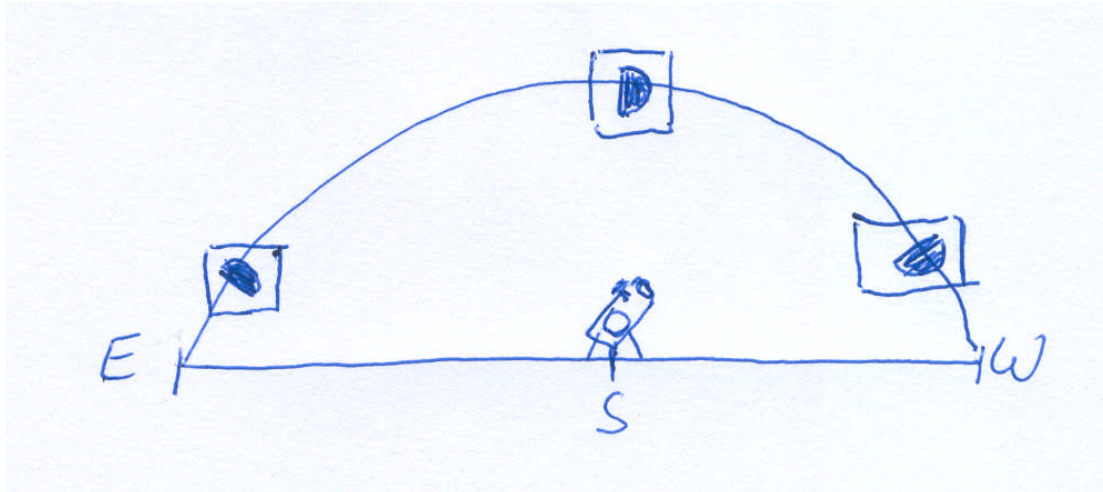
There are two basic types of mounts: the **altazimuth mounting** and the **equatorial mounting**.

The altazimuth mounting owes its name to the directions in which it moves the telescope, one in altitude – up or down – and one in azimuth – side to side. For the most part, the telescope itself is mounted on a fork mount in which it can move up or down. The fork mount itself rotates on its vertical axis. The “natural” celestial coordinate system for alt/az mounted telescopes is the Alt/Az System.



Dobsonian telescopes (shown before) also have alt/az mountings.

During an observing session an altazimuth telescope has to be continuously readjusted in both of its axes, in azimuth and also in altitude. Some telescopes like the ones shown here have motors which do this for you. Even then you may run into problems due to field rotation when you use it for astrophotography.



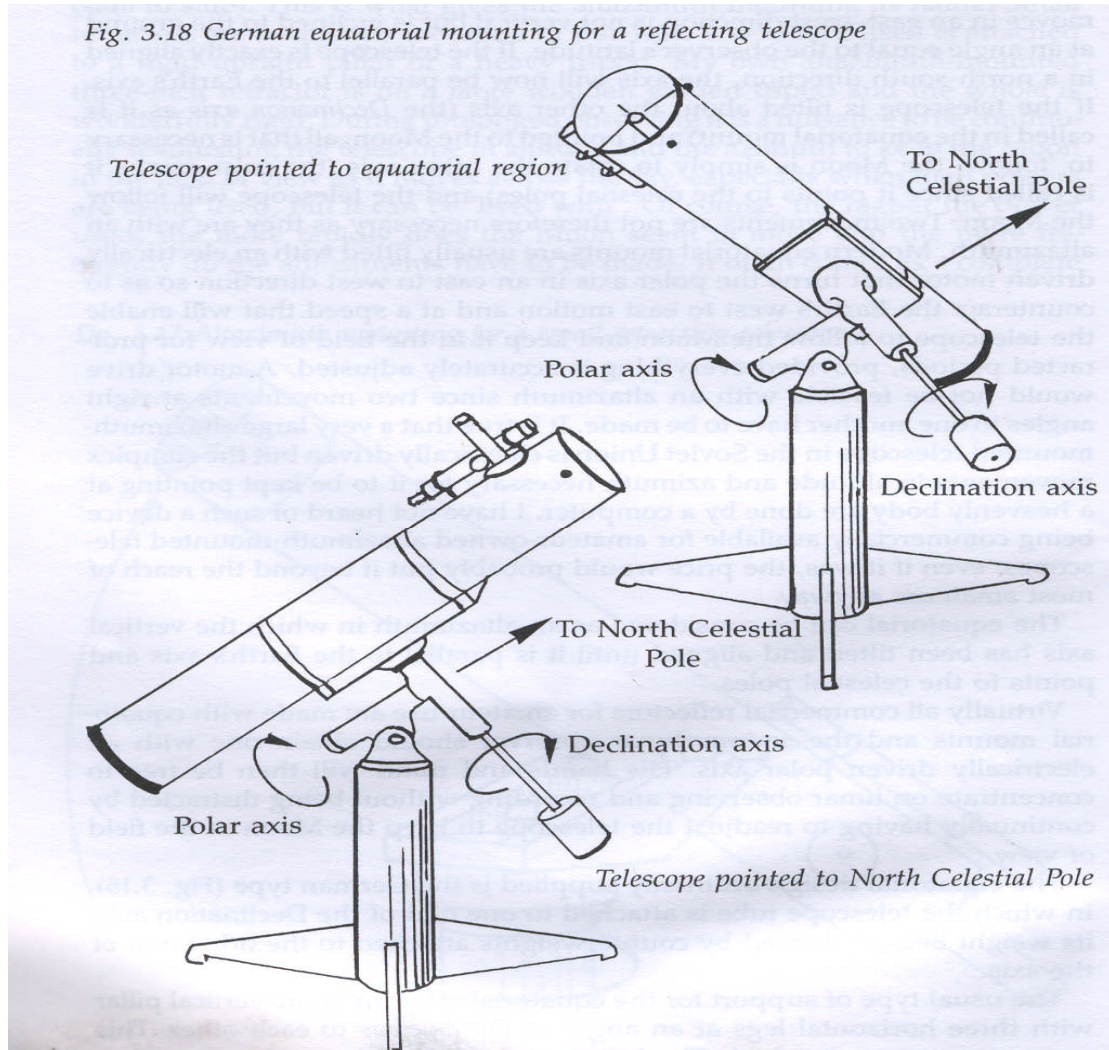
Let us assume that you want to image a distant galaxy using exposure times of more than a minute. Let us also assume that you want to stack several images of the same object using appropriate software. The images you are taking, perfect though they may be, show the object rotating slightly over time. They have to be de-rotated before being stacked, either by software or by a de-rotator to counteract this motion.

You'll run into far less trouble – in the end – if you use an **equatorial mounting** (some telescope mountings can be used either way). The major difference is that the axis in which the equatorially mounted telescope moves in an east-west direction is not vertical as it is the case with alt/az mountings. It is inclined to the ground at an angle which is the same as the latitude of the observer (roughly 53 degrees for Galway). Provided that you align the telescope precisely in a north/south direction, this axis will point (almost) to the Pole star Polaris and will be parallel to the Earth's axis. It is the **polar axis**. The telescope can be moved up and down around its second axis, the **declination axis**. After you found the object you want to observe, simply lock the declination axis and follow the apparent motion of your object by moving the telescope around its polar axis. The telescope, in this case, will follow the earth's rotation, no field rotation occurs nor do you have to adjust the telescope in both axes all the time!

The most common types of equatorial mounts are the **German equatorial** or the **equatorial fork mount**. In the German equatorial the telescope tube is attached to one side of the declination axis and balanced out with a counterweight. In a fork mount, the telescope is mounted between the two prongs:

A. A German equatorial:

Fig. 3.18 German equatorial mounting for a reflecting telescope



B. A Schmidt Cassegrain on an equatorial fork mount:



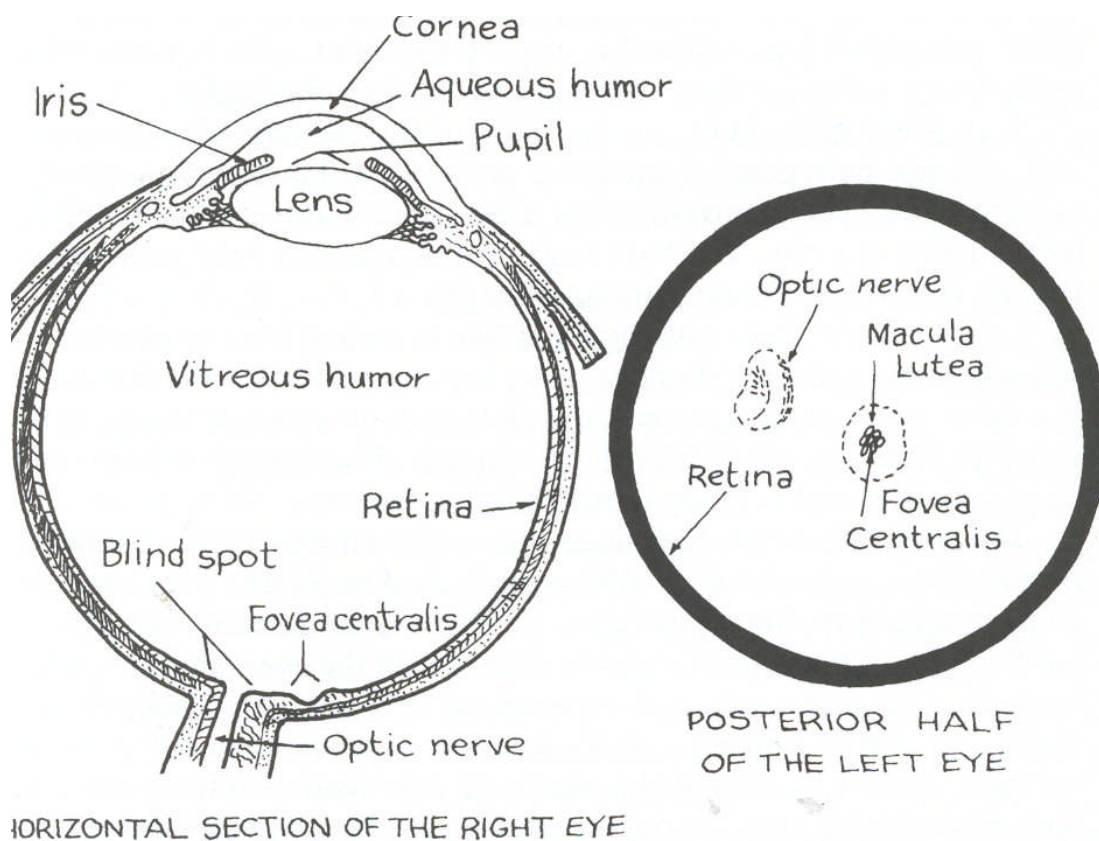
Don't Forget Your Basic Instrument: The Eye

Of course, the pride and joy of every amateur astronomer is his or her telescope. It is used for gathering light. We often forget, however, that its function presupposes the effective use of a much more basic instrument which gathers light for us in the first place, our eyes! And eyes have some peculiarities which we should know and understand in order to understand what we are doing when we are looking through our telescope or pair of binoculars. So let us pause again a little and think about our eyes.

Imagine, you are looking through your telescope at a light source such as the Sun which is so bright that it will definitely damage your eyes, possibly even turn you blind. (Never even **think** of doing it except for thinking – merely thinking – of it now). Now imagine that you are looking at a light source which is the dimmest that you can still see. It is roughly a hundred trillion times dimmer than the original bright source! Hence, the eye has an enormous range of light gathering power. It can also adapt relatively easily and fast to different levels of brightness on this 100 trillion

scale. As a rule, we have no problems, for instance, adapting from daylight to night vision and vice versa.

In both bright daylight and night's moon- or starlight, light passes through the transparent outer leathery covering of the eye (**cornea**) and then through the black **pupil** (our shutters, small in bright light, large in dim light) through the **lens**. The lens focuses the incoming light on the **retina** at the back of the eye. The light-sensitive cells of the retina are triggered by light to send electrical impulses. They travel to the brain via the optic nerve.



Muscles in the **iris** (the coloured section of the eye) contract or dilate the pupil – from roughly 2mm diameter in very broad daylight (for people younger than 30 years of age) to 8mm at night. Later in life, these figures change, I am afraid, and also the transparency of the cornea. Gaining experience and skills of observing, however, compensate quite well for the deficiencies which occur in the course of your life.

Most importantly of all for observing stars is the fact that your retinal cells triggering the transmission of electrical impulses to the brain are of two different kinds. They respond quite differently to different lighting conditions. The ones which work well in bright light are called **cones**, the ones working well in dim light are called **rods**. **It is via the cones that you can distinguish colours, not by rods! When you look at celestial objects at night (such as the Orion nebula) through binoculars/telescopes, they appear to be “grey” rather than coloured, quite different from the splendid images you normally see in magazines or books. This**

is due to the deficiency of retinal cones at night and the working of retinal rods used by the eyes under dim light.

However, your retinal rods are obviously the most important sensors as far as astronomical observation is concerned which still involves your eyes as observing instruments rather than cameras. These rods work using a chemical with the name of *rhodopsin*. It is commonly called “visible purple”. Rhodopsin is bleached out in bright light but quickly redevelops in darkness. It may take about 20 minutes for re-development – the time you need to dark-adapt your eyes from daylight (room) vision to night vision. Only after your eyes are dark-adapted will you be able to see fainter stars, the Milky Way, or objects such as the Andromeda Galaxy or the h and chi double cluster with your naked eyes.

You can spoil your night vision and that of others by using a torch for trying to find additional equipment or looking at a star map in the darkness of the night. Things get even worse when you try to observe near street lights or leaving the lights of your car on. Astronomers are night-active animals and see best in the dark. If you have to use a torch at all, make sure that you glue a dark-red and transparent piece of plastic film in front of the light. The rods in your eyes are least sensitive to red light. Consequently, you do not lose your night vision by using red light.

There is a technique of seeing, well established among amateur astronomers, which you ought to learn because it allows you to see objects which are so faint that you are not able to see them by looking at them directly – because you can’t. This is **averted vision**. Direct your gaze a little bit away from the object you assume to be there. All of a sudden you can see it from the corner of your eye! How is this possible? The structure of your retina and the areas of distribution of rods and cones in it are the answer.

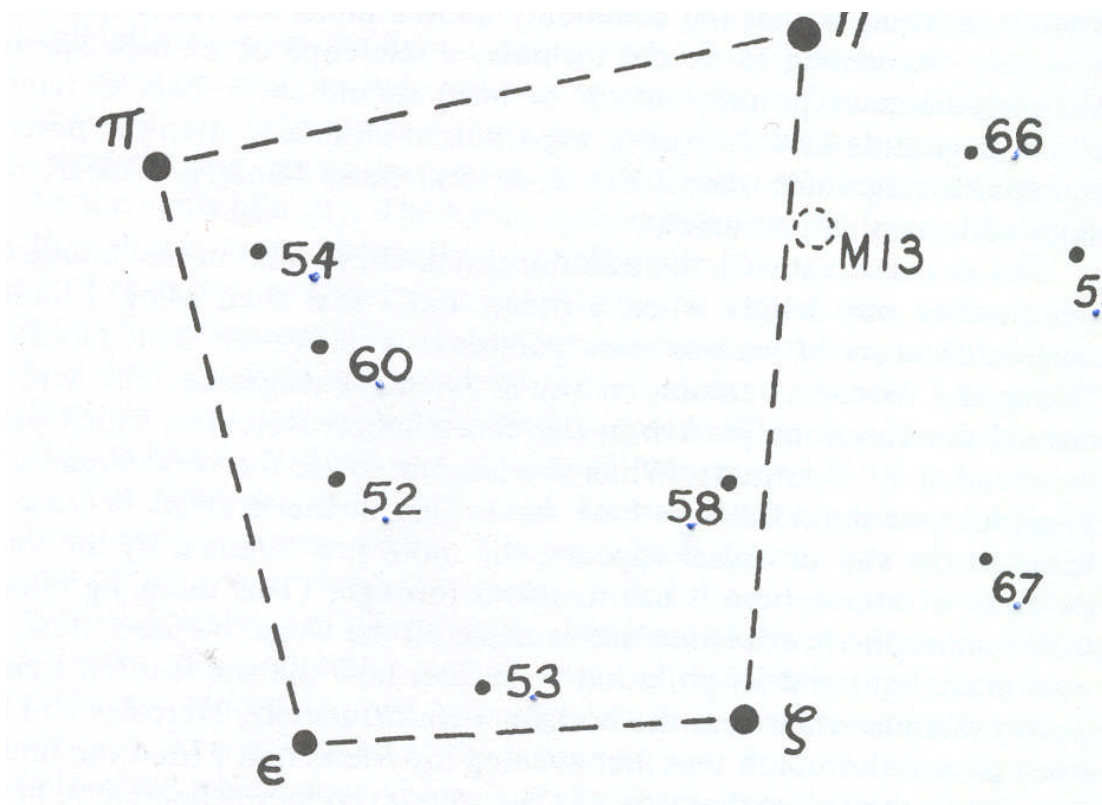
Almost all cones but none of the rods are concentrated in a tiny area (**fovea centralis**) of the retina. It is the centre of your field of vision where you see sharpest when light falls on it. It is very small, taking up only one and a half degrees of the eye’s field of view! Since cones are not made for night vision, you can see dim objects only badly with this part of your eye.

Not so for the rods. Although they are spread fairly loosely across the retina, they are none the less concentrated in a narrow oval band surrounding the *fovea centralis* a slight distance away from it. It is here where the eye is most sensitive to dim light. Using averted vision means that light coming from dim objects can hit this area which, in turn, allows you to see things that you only guessed were there before!

What is Magnitude?

It is generally held that the faintest object that you can see in the night sky determines your **limiting magnitude**. Since the time of the Greek astronomer Hipparchus (162 – 127 BC) who produced the first star catalogue in antiquity, the limiting magnitude for people with excellent eyesight is 6.5 mag. What magnitude means, in fact, is a crucial datum not only for visual astronomy. Let me explain by giving you a task to solve.

1. Compare two *really bright* stars A and B (Arcturus/Capella). Let us assume for the moment that both stars are equally bright, having (roughly) a brightness (magnitude) of 0 mag. Hence, there is no immediately apparent difference in magnitude between A and B.
2. Use one of these stars (A) as a comparison star, comparing the brightness of other stars you can see with A's brightness.
3. Choose a star that you can *barely* see because it is so dim, the dimmest star that you can detect in the sky. You may use the constellation of Hercules to find both a very dim star and a star that lies at the very limit of your seeing capability:



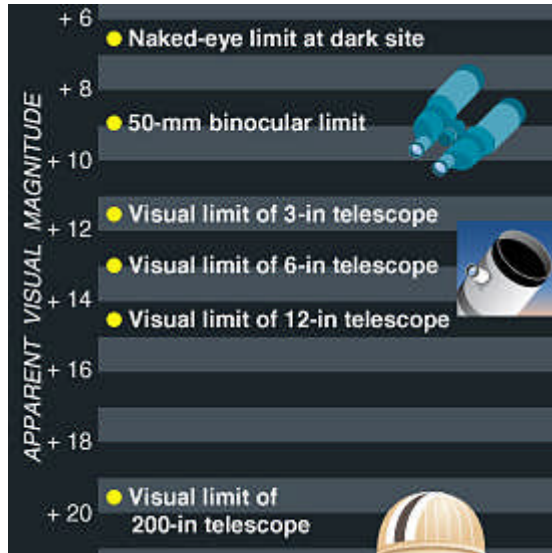
Part of the Constellation Hercules

Can you see the star with the magnitude 5.3 ? (It is clearly a bit brighter than the star with the number 6.6 mag which you may only be able to see under almost ideal seeing conditions, if at all. The 5.3 mag star is a bit dimmer than Epsilon Herculis, which is 3.9 mag). The 5.3 mag star is a little more than 100 times dimmer than your original star A!

How do I know?

Hipparchus used to rank his stars in **descending order of brightness**. The brightest stars he could see (forget about the Sun for a moment and planets which are not stars) he called “of the first magnitude”. Slightly dimmer stars he called “of second magnitude” and so down to stars “of sixth magnitude” which could barely be seen. This system of classifying stars according to their apparent brightness worked well until Galileo found that he could see an uncountable number of stars with his telescope even dimmer than 6th magnitude. Hence, the scale of Hipparchus had to be extended. Moreover, the bigger the telescopes became and the more fainter stars

became visible, the more the Hipparchus scale had to be extended. It is extended in the following way:



(Taken from *Sky and Telescope* Nov. 2011)

Some theory not really necessary – but useful to know - for a beginner

Research in Psychology (Fechner and Weber) in the 19th century showed that visual sensation of brightness is logarithmically proportional to its stimulus. (The same is supposedly the case with hearing). A constant difference in brightness corresponds to a constant ratio in intensity of the stimulus. If you take m to be the magnitude (visual sensation) of the star, and I the intensity (stimulus), then you can describe the difference $m_1 - m_2$ between descending magnitudes of two stars A and C as a result of the ratio I_1/I_2 :

$$m_1 - m_2 = -2.5 \log (I_1/I_2)$$

The constant (2.5), the so-called Pogson ratio, is empirically based. It relates to the ratio between the intensities of two subsequent magnitudes. The 19th century astronomer N.R. Pogson found this out. He suggested - quite reasonably yet not really exactly - that the difference of five magnitudes should be defined as the ratio of 100 to 1. One magnitude, therefore, corresponds roughly to the fifth root of 100, which is roughly 2.5. This ratio explains fairly well why Hipparchus had chosen his own scale. It is not too far off the way we experience differences in brightness in objects such as stars.

The corresponding differences in brightness are as follows

Difference in mag	Difference in brightness
0	1 to 1
0.1	1.1 to 1
0.2	1.2 to 1
0.3	1.3 to 1
0.4	1.4 to 1
0.5	1.6 to 1
1.0	2.5 to 1
2	6.3 to 1
3	16 to 1
4	40 to 1
5	100 to 1
10	10,000 to 1
20	100,000,000 to 1

After a little bit of practice, you will be able to distinguish relatively easily between a star of 0 magnitude, one of 2nd and one of 5th magnitude. Experienced observers of variable stars, after some years of practice, can even distinguish between stars whose difference in brightness is even as small as 0.1 mag! None the less, they never really reach below 6.5 mag.

Astronomy has made great progress after Galileo. The bigger the telescopes, the more we are able to see fainter and fainter stellar objects. “Fifty-eight magnitudes of apparent brightness encompass the things that astronomers study”, says *Sky and Telescope* Nov. 2011, “from the glaring Sun to the faintest objects detected with the Hubble Space Telescope. This range is equivalent to a brightness ratio of some 200 billion trillion.”

You may wonder what magnitude the full Moon or the Sun have, since they are far brighter than bright stars in the sky, but also *very* bright stars such as Sirius, Rigel, Capella, Arcturus and Vega. The magnitude scale should obviously be extended beyond “the first magnitude” if you want to put them on the same scale! Consequently, Rigel, Capella, Arcturus and Vega are magnitude 0 mag, Sirius is – 1.5 mag, the planet Venus reaches – 4.5 mag, full Moon is – 12.5 mag, the Sun is – 26.7 mag! Vega is now – in all wavebands – the standard star defining 0 mag.

Things are getting even more complicated when the camera, chemical photographic emulsions of films and CCD cameras and their electronic chips replace our eyes as receptors of light. Photographic emulsions of a black and white film are, as a rule, more sensitive to blue light than to red light compared to the human eye. Hence, two different scales were devised, one called **visual magnitude** (m_v), one called **photographic magnitude** (m_p). However, the difference between a star’s ($m_v - m_p$) magnitude, called the **colour index**, was a good measure of the star’s colour, showing how hot (and possibly old) it is! This colour index is positive for increasingly “cooler” (older) stars of yellow, orange, red, and increasingly negative for hotter (younger) stars of blue to white. Compare this change of colour with the colour of iron heated up in a blazing fire. The hotter iron is, the brighter is its colour.

Today, the colour index (B-V) of a star is defined as the difference between its magnitude measured through a calibrated B-filter (Blue) minus its brightness measured through a Visual-filter (Visual). A really white star has a B-V of about 0.2, Betelgeuse, orange-red, has a B-V of 1.85, the Sun, yellow, has 0.64 and the bluest star has a B-V of -0.4 .

You may well object that all these measurements of brightness and their scales refer to the brightness of stars **as they appear to us** but not **how bright they are in themselves!** Hence, the question remains how much total energy they are sending to Earth at all visible and invisible (infrared/ultraviolet) wavelengths taken together, what their **bolometric magnitude** (m_{bol}) is. Obviously, the star's distance from Earth will have to be taken into account and also whether or not gases or dust clouds interfere with our measurements. However, bolometric magnitude is still a magnitude of a star's radiation **as seen from Earth**. Can there be a measure which is even independent of this particular point of view?

Hence, astronomers wanted to find something like an **absolute** measure for a star's brightness. They found it by constructing a scale which assumes that all stars can theoretically be put at the same distance (of 10 parsecs = 32.6 light years) in relation to us. How bright would our Sun be, for instance, if it were put at a distance of 10 parsecs compared to Rigel, for instance, put at the same distance? Our Sun would be a rather pale object of 4.85 mag, whereas Rigel would be as bright as the quarter Moon (-8mag)!

For the most part, amateurs are happy enough to determine the visual magnitude, the photographic magnitude and the colour index of a stellar or non-stellar object (such as a galaxy or a nebula). Training yourself by trying to determine magnitudes with your naked eyes and comparing what you guessed with data from a stellar catalogue such as **Sky Catalogue 2000.0** is a crucial first step.

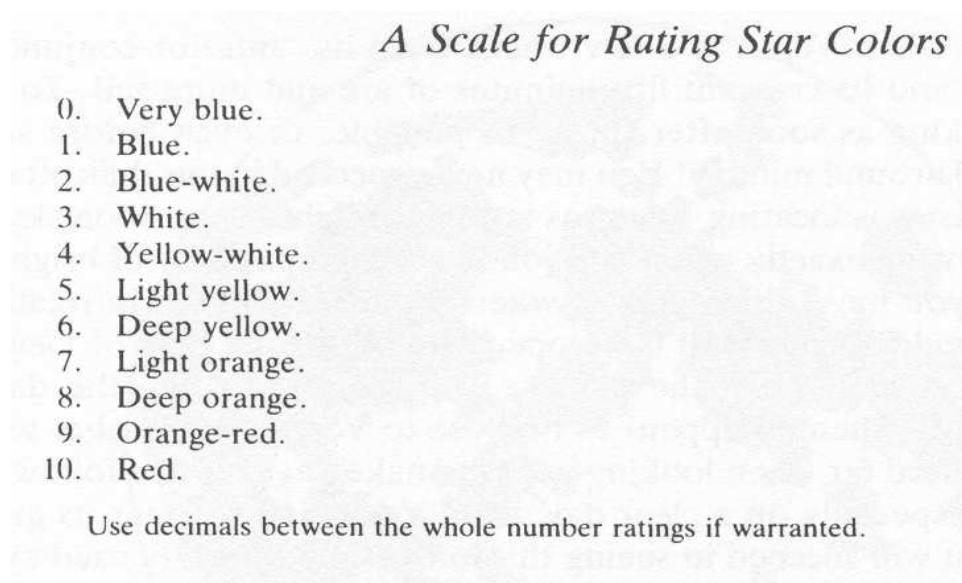
Detecting and Rating Star Colours

Still using your naked eyes as your instruments you will not only learn to distinguish different magnitudes of stars but also their different colours and that some of them change their brightness over time (variable stars). You have not lost your colour vision entirely at night!

Start with the brightest stars in the sky, Betelgeuse in Orion, for instance (in late autumn/winter) and compare its colour with that of Rigel, also in Orion. Betelgeuse is a comparatively cool star, shortly before becoming nova, Rigel is a very hot, young star. Betelgeuse will appear as orange-yellow, Rigel as bluish-white. If you use a telescope, look at double star Polaris or look at stunningly beautiful double star Albireo in the Swan (in summer) showing orange in one component and blue in the other.

You may use the following scale for getting a feeling for (and roughly quantifying) colours of stars. When using this educational rather than scientific scale, however, one has to keep in mind that the brightness of a star, its position in the sky and different atmospheric conditions may have a distorting influence on our perception of its

colour. The brighter the star, the more pronounced its colour. This is particularly important when stars of different brightness and colour are compared:



Of course, we cannot see stars shining in the ultraviolet; nor can we see them in the infrared. The limits of our vision are the violet on one end of the visible spectrum (roughly 400 nanometers) and the red on the other (roughly 700 nanometers), which defines a really tiny window within the bandwidth of total electromagnetic radiation.

Second Session Part 5

How to Set Up Your Telescope

Congratulations! You bought a telescope and now you are its proud owner who begins to wonder where, when and how to set it up. You may want to set it up in your living room in broad daylight, open the window and start observing using an eyepiece with the highest magnification. You want to know, of course, how powerful your new instrument is. The Sun seems a good object to start with. Using the living room seems particularly suitable in winter when it is cold or whenever it is raining. Also, you may easily find the Sun through your telescope. **STOP!!!** and think what you are doing before you do yourself (or even the telescope) permanent harm!

The basic rule is: **NEVER LOOK AT THE SUN THROUGH A TELESCOPE** (unless you know how to use special SOLAR FILTERS and know how to install them safely)!!!!

Rooms in your house or flat are probably the most unsuitable place for beginning to observe since they do not have the same darkness, temperature and air currents as the outside air. Its air currents – and particularly the air currents inside your Dobson or Newtonian – may make the image you are looking at blurred and quivering. **Looking at the Sun through your telescope, even for a very short period of time, may burn holes into your retina or cause any other permanent damage to your eyes up to permanent blindness.**

Check collimation

No optical system works properly if its component optical parts are not aligned properly having one and the same optical axis. Normally, the company producing your telescope aligns (**collimates**) it so that you can use it almost immediately. However, Dobsonians and Newtonian reflectors in particular may easily be misaligned when they are bumped around in cars or handled roughly. They ought to be treated like raw eggs. Fortunately, their optical components can usually be re-adjusted relatively easily – with a certain amount of patience and practice. For present purposes, I shall concentrate on collimating a Newtonian system.

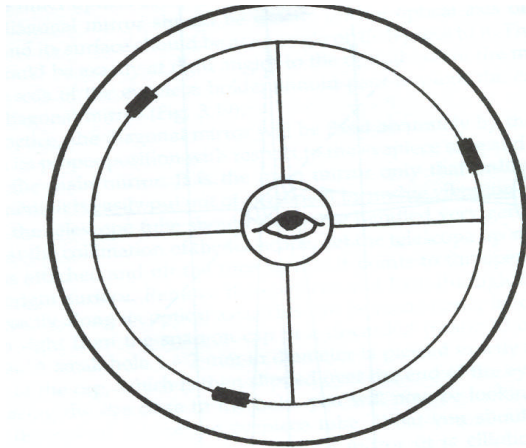
Here is a description of a perfectly collimated Newtonian system:

The centre of the secondary mirror is exactly centred on the centre of the primary mirror (you see the centre of the primary mirror exactly in the centre of the secondary mirror) and tilted by 45 degrees in relation to the primary mirror so that the central light “rays” reflected in the primary and secondary mirrors are deflected by 90 degrees through the eyepiece tube and come to a focus in front or inside the eyepiece (depending on which kind of eyepiece you are using). However, for the purpose of centring the mirrors don’t use the eyepiece yet, just look through the eyepiece tube.

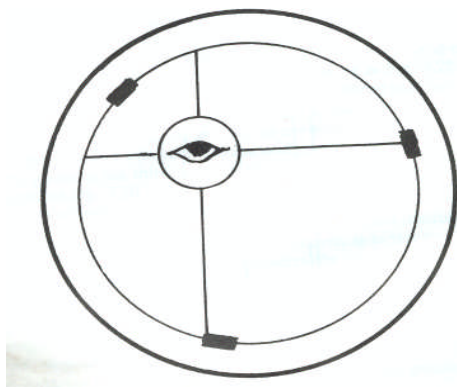
In order to get the optical axis of the whole optical system centred in the primary and the secondary mirrors and finally in the eyepiece, it is advisable to start by *very* carefully putting a tiny black spot into the centre of the primary mirror. (I use one of those round bits made by a paper puncher and fix it on the surface of the primary mirror without doing any further damage. This spot will not reduce the performance of the mirror). It should be visible exactly in the centre of the image when you look through the eyepiece tube.

It is useful to insert a **collimator** or a **Cheshire eyepiece** into the tube to find the exact centre. Otherwise, take the little canister of a film roll, poke a tiny hole into the centre of its bottom, insert the canister into the eyepiece tube and peep through the tiny hole. Ideally, you should see the apparently round shape of the secondary mirror/**diagonal** (which *really* is oval shaped) in the centre, and the image of the round shaped primary mirror filling almost your entire view as a kind of circumference. If you also see the walls of the telescope tube, make sure that this “circumference” is exactly centred. In the middle, you should also see an image of your eye in the image of the diagonal, with the pupil right in the centre. Right in the centre of your pupil should also be the image of the small dot you put on the primary mirror. Pointing inwards from the circumference image of the primary mirror to the circumference of the secondary mirror you can see the spider vanes that hold the

diagonal in its central place inside the telescope tube. These vanes – pointing to the centre - should have equal length.



If you see them having different lengths holding the image of the diagonal not in the centre but somewhere off-centre, you have to re-align the system.



Otherwise, each star that you may see through your telescope will appear to be a small comet, a distorted smudgy oval or something even worse.

Let us assume that the manufacturer has fixed the secondary mirror in its proper position. In this case, you only need to adjust the position or tilt of the primary mirror.

You will find three adjusting screws at the end of the tube in the mount of the primary mirror. Carefully give one of the screws a quarter turn and see what happens to the image which you can see through your collimation eyepiece. If turning the screw centres all the things that you can see, you are lucky. Otherwise, try to carefully turn the other screws one by one and check constantly if the image is thereby centred or moves away from the centre. If it moves away, carefully turn the screw back again and turn it slightly in the opposite direction. Initially, finding the right adjustment may take some time of trial and error. After some practice, however, collimation will not

take more than a few minutes. Nonetheless, these minutes may be decisive for the quality of your telescope's optical performance.

Once you have done this *preliminary* collimation, wait for a clear night when the atmosphere is calm, take a high powered eyepiece (9mm – 6mm) and focus on a star so that it forms a single bright point.

De-focus it slightly (*in*) and you will see diffraction rings of the image of the star instead of a sharp point of light. These rings may not look as if they are concentric. Again, very gently use the collimating screws for your primary mirror and make the rings look as concentric as possible.

Re-focus and de-focus (*out*) until you can clearly see the diffraction rings. They should be fully concentric by now. If not, adjust the primary mirror again and re-try the whole procedure. Check collimation whenever you set up or take down your scope, particularly after a bumpy journey with a car.

Schmidt Cassegrains are collimated similarly by using the collimation screws connected with the secondary mirror in the centre of the front corrector plate. However, you have to collimate this scope without using the star diagonal. Collimate it by looking straight through the eyepiece holder.

As a rule, refractors and Maksutovs do not have to be collimated since they are properly collimated by the producer.

Adjust your finderscope

The optical axis of your finderscope which is usually attached near the upper end of the telescope tube, has to be strictly parallel to the optical axis of the main telescope. Only when these axes are parallel, you will be able to look through the finderscope when trying to point the scope to a stellar object, put the object in the centre of the crosshairs of your finder and, as a result, find the object also centred in the eyepiece of your main telescope. You save yourself a lot (!) of frustration if you adjust it properly because, otherwise, you may have found the object of your desire in the finderscope (with a field of view of roughly 5 degrees) but you are far from having centred it in the eyepiece (with a view of – say – less than 30 minutes of arc). The better you succeed in adjusting your finderscope, the easier it gets for you to find objects in your telescope. A lot of amateur telescopes are abandoned because of lack of adjustment of their finderscopes. Hence, it is worth spending some time on it:

Make sure that the telescope does not move. Focus on a distant pointed object in the eyepiece of your main telescope – such as the top of a chimney, a mast or an areal. Put the tip of the mast or areal into the centre of your field of view.

Insert the finderscope into its holder. Focus on the same object putting the tip of the mast or areal into the centre of the crosshairs. Fix the finder *firmly* in this position. This is it.

At last: Setting IT up properly

Choose a dark site – without city lights, away from lights coming from houses, cars or street lamps, sheltered from prevailing winds and chimney smoke. Look for an unobstructed view to the southern part of the heavens extending as far as possible to the east and west. If you put up your telescope in your back garden, it may be best to use a location on the east side of the house with an open view south.

Putting up a telescope properly varies depending on the type of mount and telescope you are using: Altaz Dobsonians, German Equatorials, fork mounted Altaz Schmidt Cassegrains or equatorially mounted Schmidt Cassegrains or Maksutovs (using a wedge) are most frequently used by amateurs.

Dobsonians:

These very popular telescopes are relatively easy to transport and particularly suited to beginners, to starparties or occasional viewing. Since they move in Azimuth and in Altitude rather than equatorially in Right ascension and declination, they only need a fairly level ground to be set up, with their 0 degree Azimuth position pointing North. The telescope tube has to be properly balanced in its cradle, the optical system collimated and the viewfinder aligned with the optical axis of the scope. Finding fainter celestial objects may become increasingly difficult, however, the more the observer depends on stellar atlases based on aequatorial system data.

Again, continuous practice is the key to your success! Just as you need time, patience and practice to drive a car, so you need time, a lot of patience and practice to “drive” a telescope. Observing is a skill which will have to be acquired. Quite often, telescopes are buried in the scullery after having been used three or four times because the process of learning and practicing involved, here, seems too frustrating at the initial stage. On the other hand, the reward for practicing is tremendous. The sky is the limit!

German Equatorials:

Set up your tripod on a hard and even ground. Fix all the screws on your tripod so that it is absolutely sturdy and the telescope on it cannot wobble at all. It also makes sense to have one leg of your tripod pointing North. Use a compass if you cannot see the Pole Star. Use a spirit level to make sure that the top plate of the tripod or the system supporting your mount/telescope tube is level in all directions.

Fix your mount on the tripod (this does not apply if you have a permanent mount, of course) and make sure that the telescope remains firmly fixed on the mount - although it may not be properly balanced yet.

Find the “Home” position of the telescope in which case the polar axis (Right Ascension Axis) should be parallel to the Earth’s axis and the telescope should point to the Pole Star with the Declination Axis (the one with the counter weights) pointing down and the telescope on top and parallel to the polar axis (see drawings on p. 49). Hence, adjust your polar axis to the local latitude – its higher end pointing North - and point it to Polaris or, even better, to celestial North. Looking through the eyepiece of your finderscope, you should see Polaris *almost*, yet not entirely in the centre of your finder. **Use the freeware PolarFinder to determine where in your finderscope Polaris should be located for you to put Celestial North right in the middle.**

Rotate your telescope around the polar axis and see whether or not the stars that you can see in your finder revolve around a joint centre. This centre – which, unfortunately, you cannot see directly – should be moved into the centre of your finderscope. If it is not in the centre, very gently try to move the mounting on your tripod in azimuth and/or the polar axis in altitude by constantly keeping Polaris near the centre of the field of view of the finderscope until you are fairly satisfied with the result. Remember: the better you align your telescope to celestial North, the easier it will be to keep celestial objects fixed in the field of view of your telescope.

If your telescope is driven by electric motors, one of which continuously drives it in right ascension (see “equatorial system”), your scope will rotate slowly in the direction opposite to the daily rotation of the Earth with the effect that whatever celestial object you look at in the scope, it will remain stationary in the field of view and not drift – provided that all the other adjustments are correct. This is a necessary prerequisite if you wish to take images with your camera using your telescope. Otherwise, any images you take will show bright lines instead of point-like stars. It also helps tremendously if you observe for a longer period of time.

Once this is done, rotate the declination axis by 90 degrees, put the telescope tube in a horizontal position and balance the tube so that it neither tilts down at the front nor at the back when you let go. Tighten the telescope tube in this position of balance.

Keeping the telescope tube in the horizontal position, loosen the clamp usually tightening the telescope on the polar(right ascension) axis and see if you can keep it in balance - or if it swings in the direction of the counterweights or the tube instead as soon as you let go of it. Adjust the counterweights so that the scope also keeps its balance around the right ascension axis. When everything is balanced, stand back and admire your piece of work before using it for the real fun, for observing.

Fork mounted Schmidt Cassegrains/Maksutovs:

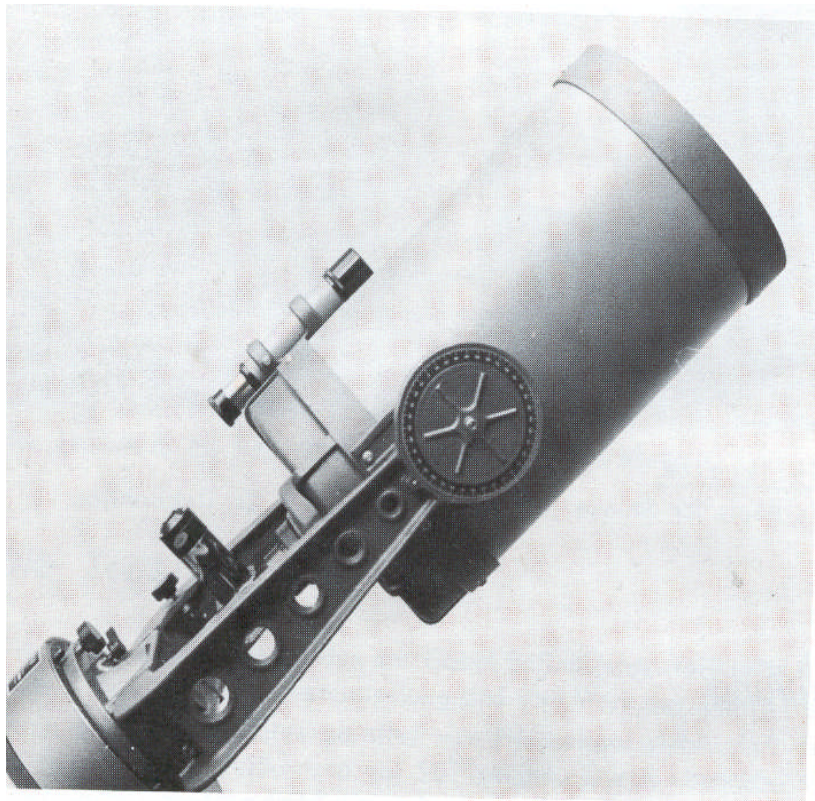
Set up your tripod on a hard and even ground. Fix all the screws on your tripod so that it is absolutely sturdy and the telescope on it cannot wobble at all. It also makes sense to have one leg of your tripod pointing North. Use a compass if you cannot see the Pole Star. Use a spirit level to make sure that the top plate of the tripod or the system supporting your mount/telescope tube is level in all directions.

If you have a Schmidt Cassegrain/ Maksutov which is to be driven in altaz mode, things are relatively easy, at least initially. Fix your mount on the tripod (this does not apply if you have a permanent mount, of course) and make sure that the telescope remains firmly fixed on the mount. Balancing the scope is not necessary unless you have added additional hardware to it (such as a second scope or a camera). In this case balancing is a Must. Find the “Home” position of the telescope, i.e. the telescope tube pointing North (= 0 deg. azimuth), and parallel to the floor (0 deg. altitude).

Now you can start observing.

If you have a Schmidt Cassegrain/ Maksutov which is to be driven equatorially (in right ascension and declination), you have to fix an **equatorial wedge** on the tripod with the plate for fixing the telescope mount tilted at an angle equivalent to your local latitude and pointing North (the highest end of the plate points South).

Fix the telescope mount on the wedge. Its fork will point North. The fork is parallel to the central axis of your mount which is its polar axis now. Find the “Home” position of the telescope by pointing the telescope to the Pole Star (declination roughly 90 deg.).



Home position pointing to celestial North

Looking through the eyepiece of your finderscope, you should see Polaris *almost*, yet not entirely in the centre of your finder. Polaris is less than 1 degree distant from Celestial North. **Use the freeware PolarFinder to determine where in your finderscope Polaris should be located for you to put Celestial North right in the middle.** Rotate your telescope around the polar axis and see whether or not the stars that you can see in your finder revolve around a joint centre. This centre should be moved into the centre of your finderscope. If it is not in the centre, very gently try to move the mounting on your tripod in azimuth and/or change the angle of your equatorial wedge by constantly keeping Polaris close to the centre of the field of view of the finderscope.

How good is your telescope – some simple tests

Although you may be happy having come so far successfully, it may still be worth checking your telescope for spherical aberration, astigmatism and coma. You may also want to know how good it is as far as resolution is concerned. Of course, it is also worth getting your eyes checked since you cannot blame the telescope for any

deficiencies of your eyes. It does not matter, however, if you are short sighted or long sighted since you can adjust it with your focuser. Things are different with astigmatism in which case point-like objects are no longer points on your retina!

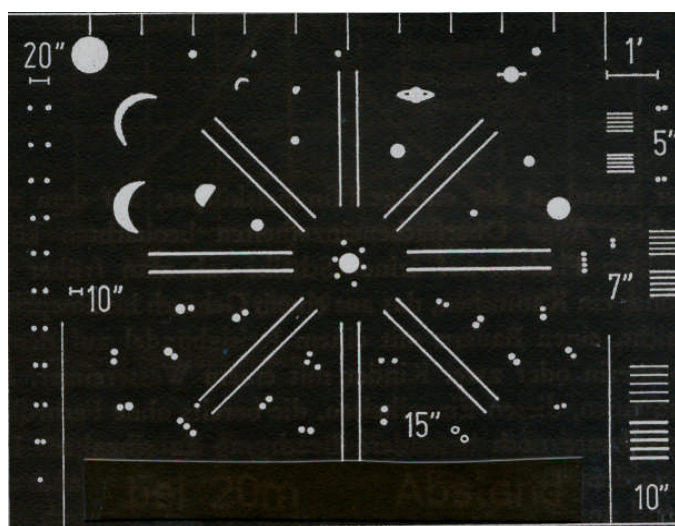
How can you find out whether your eyes are astigmatic or your telescope?

Focus on a star. De-focus your telescope slightly so that you can see the star as a disk with its diffraction rings. If you see an elliptical shape instead of a disk (or any other distortions of the image), it is likely that your telescope has astigmatism. If your eye is astigmatic, the largest diameter of the disk-ellipsoid will move when you turn your *head* around the optical axis. Your telescope has astigmatism when the largest diameter of the disk-ellipsoid moves when you turn the *telescope* around its optical axis. If your telescope has astigmatism, I recommend sending it back to the shop.

Take an exact copy (same format!) of the image shown below and place it at a distance of 20 metres away from your – small – telescope (5' or less). It is an image of double stars separated by 2" (bottom left) to 20" (top left) and some lines separated by 5" (top right) to 10" (bottom right). It also shows images of planets such as Venus and its phases, Saturn or Jupiter, or brighter stars.

Focus on the image and see if you can separate the two dots at the bottom left, for instance. If you can see two dots instead of one, you can say that your telescope is capable of separating objects which are 2" apart from each other. Keep in mind, however, that looking at this image represents almost ideal conditions of seeing. Atmospheric disturbances which you would have to take into account under normal conditions do not obtain, here. Hence, don't be disappointed that looking at a real double star may not show any separation at all. In that case, you will have to wait for better weather conditions and/or choose double stars which are blue and equally bright rather than yellow or red. Try Polaris or the double-double Epsilon Lyrae for a start.

Apart from separation you can also test your telescope for astigmatism or coma using the same image!



Spherical aberration may also be a problem – apart from astigmatism. This is how you find out:

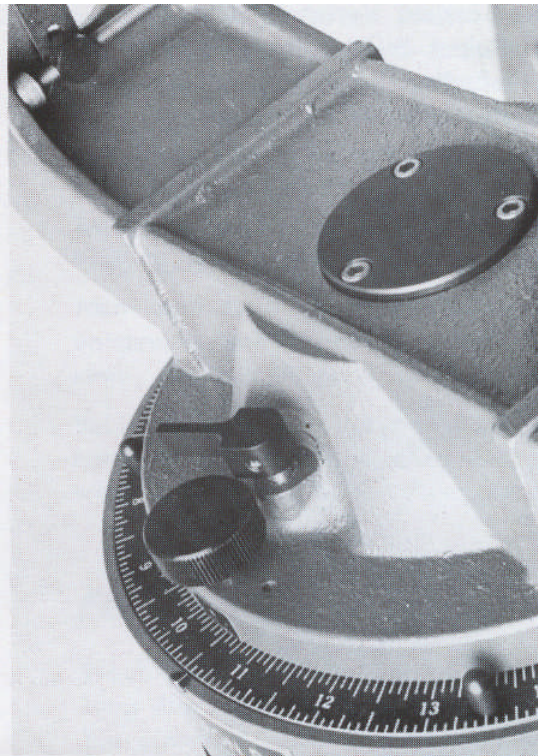
Wait until your telescope mirror has the same temperature as the surrounding area. Focus on a star. De-focus your telescope slightly so that you can see the star as a disk with its diffraction rings. Concentrate on the defraction rings and see if they have the

same width and brightness. If the outer ring appears wide and bright in the *extrafocal* position but small and dim in the *intrafocal* setting, you have a case of over-correction of spherical aberration. The mirror is too 'deep'. It is more hyperboloidal than paraboloidal. If the outer ring in the extrafocal position appears small and dim and bright and wide in the intrafocal setting, your mirror is undercorrected. If your telescope has spherical aberration, I recommend sending it back to the shop where you bought it.

Finding celestial objects with Setting Circles

Setting circles on your (German) equatorial mount (for your refractor, reflector or catadioptric) permit the location of faint celestial objects, too faint to spot through your finderscope. If you know the right ascension and declination of any celestial object from a star atlas, setting circles will help you point your telescope precisely in its direction, provided you have set up your scope properly.

There are setting circles for declination (Dec.), following celestial 'latitude', and right ascension (R.A.), following celestial 'longitude'. Setting circles for Dec. are measured in degrees, arc minutes and arc seconds; setting circles for R.A. are not measured in degrees. The reason for it is easily understood. The Earth rotates by 15 degrees in longitude in one hour. It takes roughly 24 times 15 degrees (24 hours) to cover 360 degrees, a full rotation. Hence, co-ordinates of the heavens are both indicators of degrees as well as of time. (We might say the same of longitudes on Earth).



Right Ascension circle



Declination circle

With the equatorially mounted telescope pointed at the Celestial North Pole (roughly Polaris), the Dec. circle should read +90 degrees. Pointing the telescope at 0 degrees will point it to the celestial equator. Pointing it below 0 degrees will point to objects with minus declination coordinates.

Finding faint celestial objects

You have to learn **starhopping**: Find a bright star near the object you wish to observe and centre it in the scope. Use a star atlas such as *Sky Atlas 2000* or *Uranometria 2000*, identify your bright star and your fainter celestial object in the atlas and see what stars lie between your bright star and the object you wish to observe. Move the telescope from star to star, making sure that you make no mistake, first with your finderscope, then with the telescope itself, until you find what you want to see. Lock the declination and right ascension axis and guide the telescope with your drive motors or manually. Here is an example showing you how to find the Whirlpool Galaxy M51:

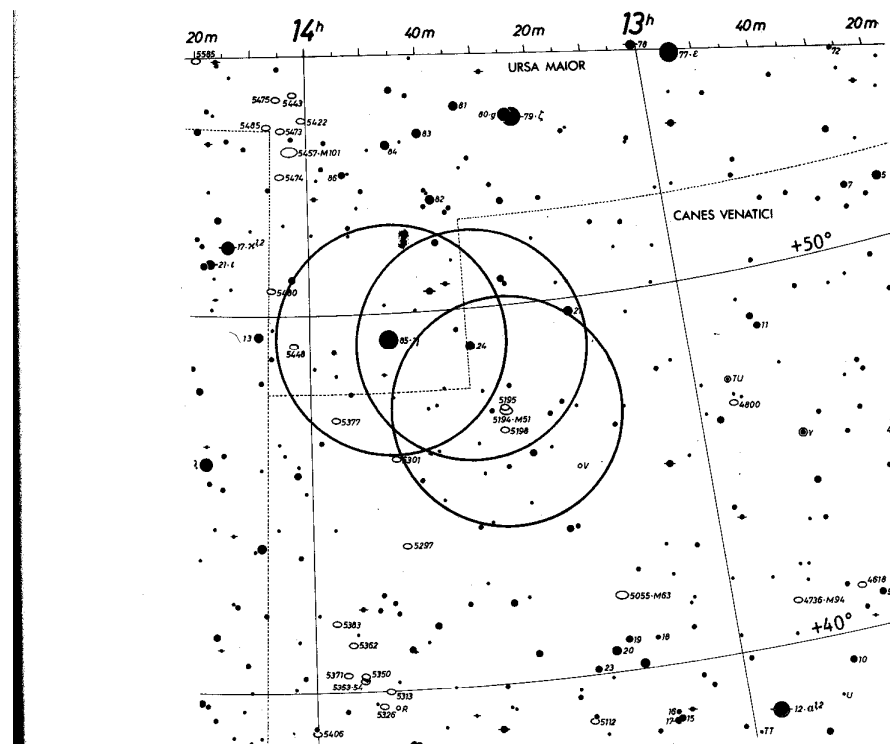


Figure 3.10c. M51, the Whirlpool Galaxy, is a favorite of amateur astronomers. Finding it is not too difficult as it lies near the end star of the Big Dipper (Eta Ursa Majoris). Start by centering the finder on that star. Move west nearly half a finder field to center the 5th-magnitude star 24 Canum Venaticorum. Now move south about a third of a field and

west a little. M51 is just west of a 7th-magnitude star. Note the many other galaxies in this region, and how one would star hop to them. The brightest galaxies are the Messier objects: M51, M63, M94, and M101. Chart reproduced from *Sky Atlas 2000.0* by W. Tirion.

After you found your object (M 51) in the scope, find its right ascension and declination data in your star atlas. Move the mark for right ascension (of M 51) on

your right ascension setting circle to the right ascension marker on your mounting and its declination to the declination marker and fix them in this position.

If you wish to move from your object to neighbouring objects, loosen the right ascension and declination clamps, move the telescope in right ascension and declination to the data of your new object (M 63, say) on the setting circles without touching them and fix the scope in the new position. The new object should be in the field of view of the finder – provided your scope was set up properly.

With a bit of training you will be able to find almost anything in the sky; hence it is well worth spending considerable time practicing this method.

(To be continued)

Second Session Part 6 (incomplete)

Free Software to Help You

General Cartographic Software

Google Earth

Not only a phantastic atlas of the Earth but also a planetarium, a lunar atlas with top images of the Moon, and a Mars atlas

Stellarium

A Planetarium for Windows or Linux, can also be used for controlling your telescope

Cartes du Ciel

Free star-mapping and telescope control

Virtual Moon Atlas

Detailed atlas and rich source of basic data of lunar features

General Purpose addresses

Astronomy Picture of the Day Archive

Stunning pictures of latest events in the optical universe

Space Weather

Daily space news, highly recommended

Heavens Above

Daily space news

Special Purposes addresses

NASA – Solar Dynamics Observatory

A must for solar observation

Near Earth Objects Group

A must for everyone interested in potentially threatening NEOs

Imaging Software

Gimp 2

Image processing software

Deep Sky Stacker

Stacking and processing software for Deep Sky Objects taken with a DSLR camera

Registax

Stacking and processing software for lunar and planetary images taken with a webcam

Software for running your telescope

PolarFinder

Software to help you find Celestial North in your finderscope

Basic information systems for the advanced amateur/researcher

Simbad

Superb astronomical database

Second Session Part 7

How to Observe the Moon

(For **BASICS** concerning the Moon's motions and lunar or solar eclipses see **Second Session Part 2**)

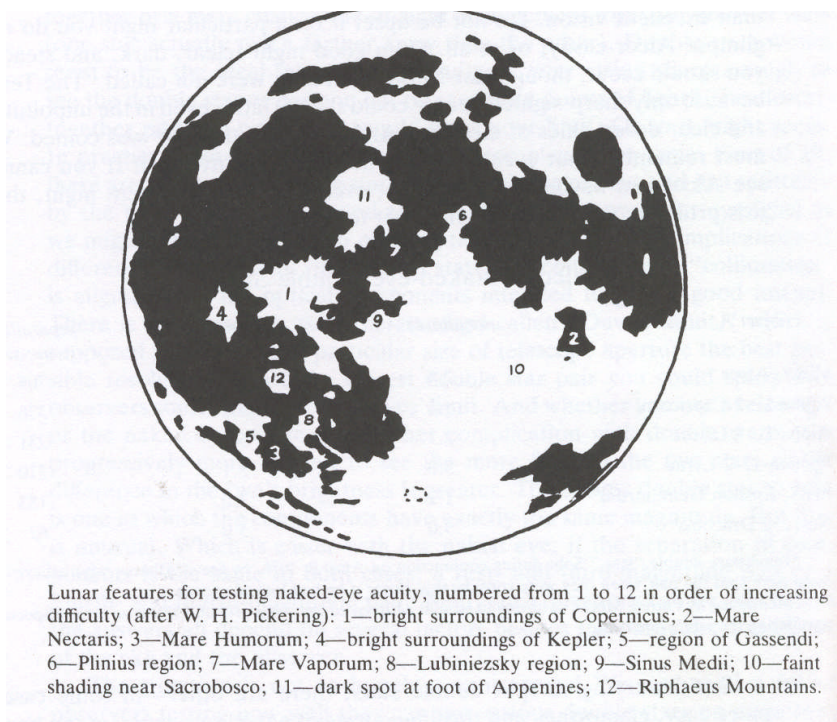
You must be extremely gifted if you can see - with your naked eyes - any detail of the surface of a celestial object except for the Earth itself (which is trivial) and the Moon (which is less trivial). Maybe you can also see sunspots in desert sandstorms on your holidays or under special atmospheric conditions. When you look at the Moon, you are looking at an object from a distance of roughly 400.000 km.

Looking at the Moon's darker areas, people used to see a Man on the Moon a rabbit, a funny face, a farmer with a bundle of twigs on his shoulders, an old woman weaving or children holding a water bucket.

All of this is a friendly kind of nonsense, of course, but very useful indeed for getting small children (or lovers) interested in the Moon.

So what can you see on the Moon with your naked eyes?

W.H. Pickering, a well known American astronomer at the beginning of the 20th century, used increasingly hard to see features on the surface of the full Moon as a kind of scale useful for testing the sharpness of your own vision. Congratulate yourself if you are able to see all the features he mentions when you observe the Moon on a clear night:



Lunar features for testing naked-eye acuity, numbered from 1 to 12 in order of increasing difficulty (after W. H. Pickering): 1—bright surroundings of Copernicus; 2—Mare Nectaris; 3—Mare Humorum; 4—bright surroundings of Kepler; 5—region of Gassendi; 6—Plinius region; 7—Mare Vaporum; 8—Lubiniezsky region; 9—Sinus Medii; 10—faint shading near Sacrobosco; 11—dark spot at foot of Appenines; 12—Rhipaeus Mountains.

The full Moon, however, may not be the best phase for observing our satellite. A beautiful aspect visible with our naked eyes which we can have of the Moon is its appearance in the light reflected from Earth. We call it the **Ashen Light (Earthshine)**. Try to distinguish features on the Moon in its ashen light!



If you look at the small sickle of the waxing Moon in the West shortly after sunset (shortly after New Moon) or of the waning Moon in the East before sunrise (shortly before New Moon), you can still see the part of the Moon which is not illuminated directly by the Sun shining faintly in sunlight deflected on the Moon by the Earth's atmosphere. The Earth-caused ashen light of the Moon is particularly strong around New Moon because this is the time when an astronaut, standing on the Moon, would see FULL EARTH showing its maximum reflecting surface area to the Moon. New Moon for us means Full Earth for lunarians!

Full Moon is the time, of course, when we see most of the lunar surface. However, it is so bright that it is about the worst time for observing it with binoculars or a telescope. Fine detail of the lunar surface simply vanishes. This is partly due to its total brightness at the time. Furthermore, it may become quite painful for your eyes to observe it with a telescope at this stage, unless you use special lunar filters absorbing some of the light. Since the Sun shines almost perpendicularly on the lunar surface, there are hardly any shadows and, consequently, not sufficient contrast for distinguishing detail on its topography. Full Moon also scatters so much light all over the sky that it makes it very difficult to observe deep sky objects at the same time. Full Moon, in other words, is not the best time to put up your telescope!



Full Moon showing Maria and Terra areas, the crater Tycho with its ray system and bright Copernicus.

The best time to use your telescope is the time when the Moon has phases so that you can see fine detail, particularly near the terminator, i.e. the edge of sunlight on the lunar surface. Also, the best positions of lunar phases in the sky are when the Moon stands highest: First quarter Moon is highest in the sky around Spring equinox, last quarter Moon is highest around Autumn equinox. Due to atmospheric extinction near the horizon positions of lunar phases in the sky when they are lowest are the worst, i.e. Last quarter Moon around Spring equinox, first quarter Moon around Autumn equinox.



First quarter Moon showing (from top of terminator) Herschel (the small crater) on top of Ptolemaeus, with Albatagnius on the right (East), Alphonsus with a small central mountain, Arzachel with a massive central mountain, Purbach, Werner, Walter, Maginus

When you look at the Moon, you are looking at a spherical body with a diameter of roughly 4.500 km, a body with no atmosphere. The Earth's equatorial diameter is

roughly 14.000 km. The Moon's soil (**regolith**) is a mixture of loose, sticky dust, fragments of rock and stones forming the Moon's crust. Roughly 70 km below it is the lunar mantle enclosing an iron-rich core, 500-900 km in diameter, which may be partly liquid because it is hot (ca. 1000 degs).

You have to consult **WIKIPEDIA** as a start to find more detailed information about lunar structure. We are only dealing with Earth-based visual observation, here, suitable for amateur astronomers. However, you may even visit the Moon in your lifetime. Who knows?

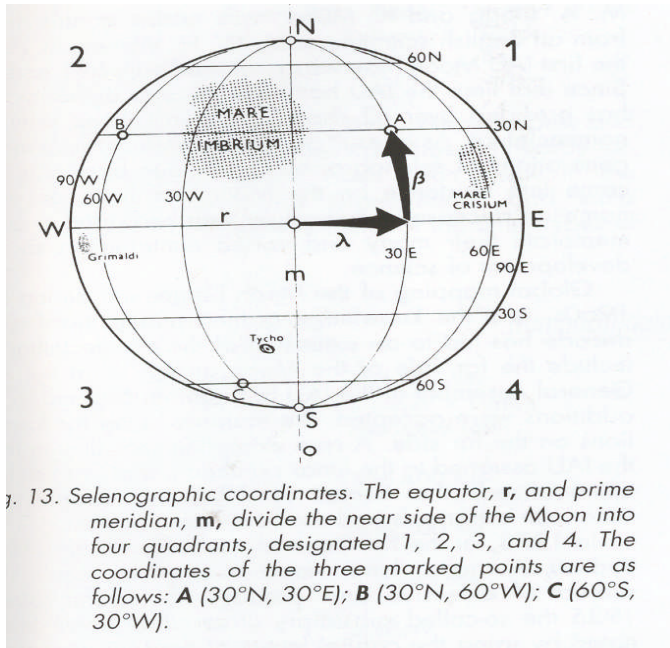
If you use **Google Earth's** planetarium, you'll also find superb satellite images of the lunar surface. Compare them with what you can see through your telescope or your pair of binoculars!

How to Start: Use your Eyes and a Pair of Binoculars before Using Your Telescope!

Most of us use an 8x50 or 10x50 pair of binoculars for looking at objects relatively close to us (50 is the diameter of its two front lenses in millimeters, 8x or 10x is the binocular's magnification). Binoculars are excellent for finding your way around in the starry heavens, particularly if you can put your pair on a tripod using an adapter (ask your photo shop in town). They are also excellent for getting familiar with the basic lunar formations such as "Maria" (planes), "Lakes", "Marshes", "Bays", or "Terra"- regions filled with craters, rilles, ridges, walls, domes, mountains, valleys or ray systems. Keep in mind that the lunar surface changes its appearance constantly due to the changing angle of light falling on it from the Sun. The Moon's bound rotation is the cause of it. Don't be surprised, therefore, that the same crater which you admired so patiently an hour ago will look very different when you look at it again!

Your Primary Practical Task: Find out and learn what's on the Moon

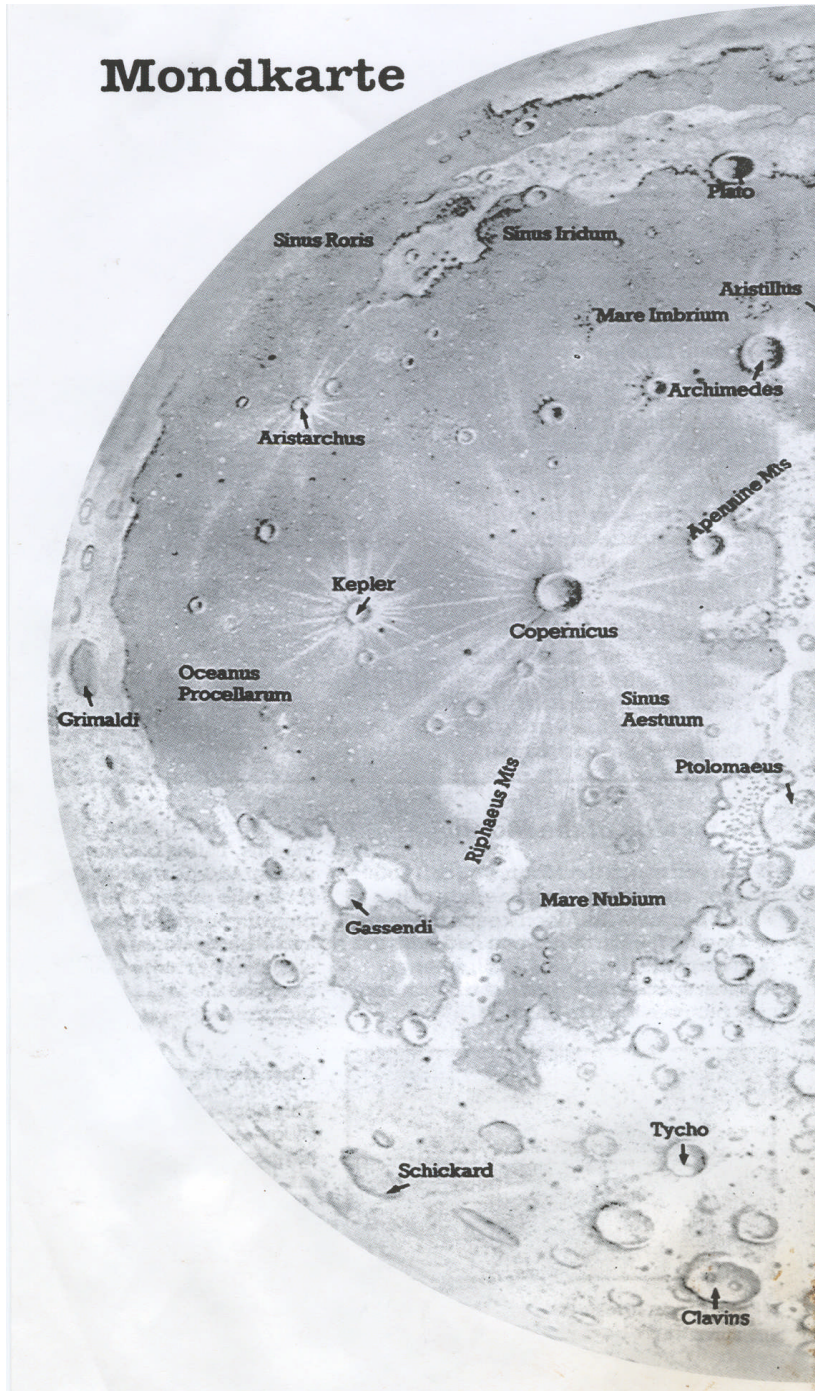
Here is a rough guide showing what's on the Moon. It shows the Moon in 2 parts which you have to stick together. It shows the Moon as you will see it with your naked eyes or small binoculars. If you use the IAU (International Astronomical Union) convention of defining lunar (selenographic) coordinates, North is up, South is down, West is on the left, East is on the right. With this system of coordinates in mind, you will be able to locate and identify any larger object using a lunar atlas.

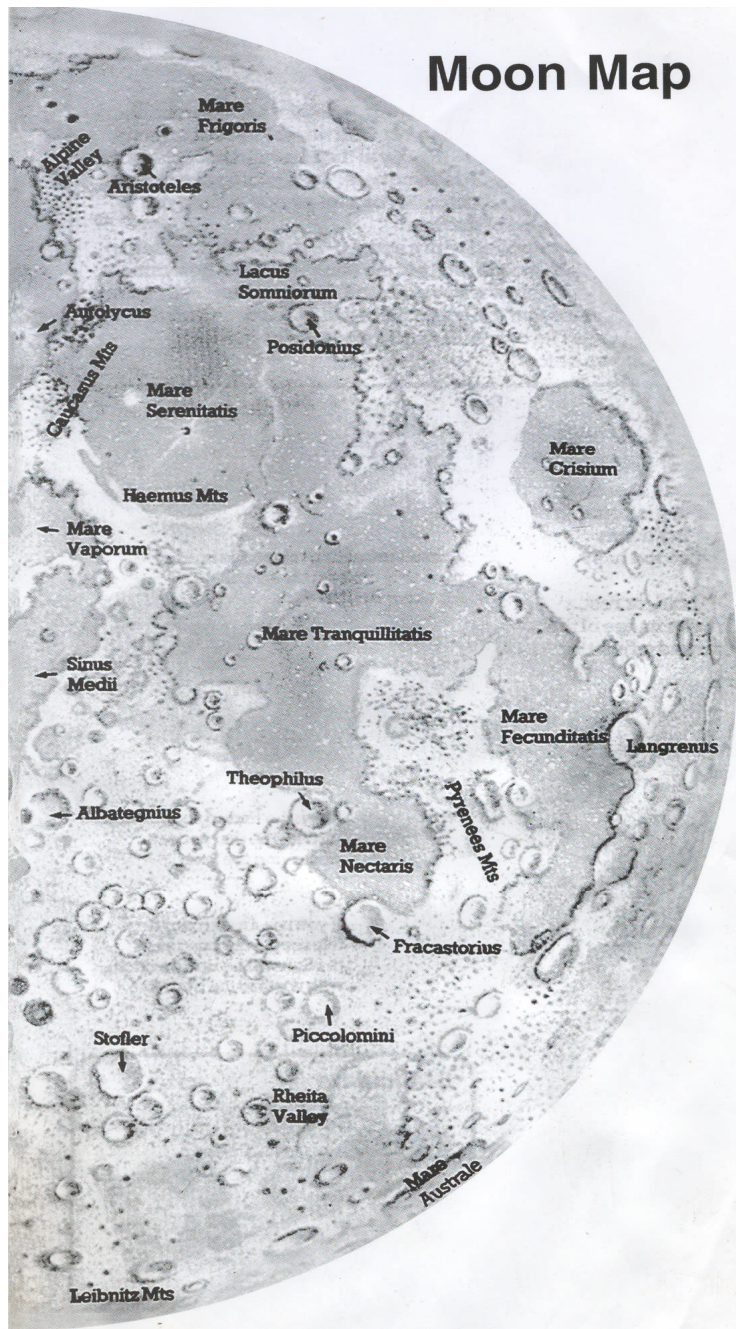


Most (Keplerian-type) telescopes produce an inverted (upside down) image, though! In this case, North is down and South is up. Some telescopes using diagonals such as Schmidt Cassegrains may show an image which is erect but West and East are swapped. This sounds confusing but you get used to it with increasing practice of observing.

Before you go outside to study the Moon, try to memorise some of the names and locations shown below. Start with names of Maria:

Mondkarte





Using your computer and the **Virtual Moon Atlas** freeware as a guide or an excellent book such as **Antonin Ruekl (ed. by Gary Seronik), Atlas of the Moon, Sky Publishing Corp., Cambridge/Mass. 2004**, take your binoculars before using your telescope and try to find some of the objects listed below. (You may also try the **Google Earth** programme, switched to the Moon, to find objects. When you put in the name of your object (say “Birmingham”) into the Fly-to box and click on the magnifying glass next to it, it will guide you there).

However, it is best to check *beforehand*, using a map of the Moon and information about lunar phases, what you may be able to see, given the phase of the visible Moon on your day of observing:

{NOTE: These lists are far from complete. They also do not include craters at the very edge of the visible Moon, for instance}.

Here are major lunar structures well worth finding:

1. *Maria* (Seas)

Maria are regions which the Ancients thought were vast seas. Of course, if they were seas of water, sunshine would be reflected in them quite brilliantly. This is clearly not the case. They are large grey areas. Smaller areas of mare-type grey material are called lakes or marshes. Maria frequently have circular or sometimes somewhat rectangular shapes. Others are elongated or quite irregular.

Maria best visible in greater detail at times when the Moon is waxing – leading to first quarter Moon – have optimistic names such as Sea of Tranquillity (Mare Tranquillitatis), Sea of Fecundity (Mare Foecunditatis), Sea of Nectar (Mare Nectaris). Maria best visible in detail when the Moon is waning have gloomy names such as Sea of Rains (Mare Imbrium), Sea of Clouds (Mare Nubium) or Ocean of Storms (Oceanus Procellarum). An old “wisdom” for predicting the weather seems to provide the reason why this change of attitude comes about: “When the Moon is waxing, the weather will be fine, and when the Moon is waning, the weather will be cloudy, rainy and stormy”. Maybe one has to get very old indeed to find out if this is really true.

Mare Crisium
 Mare Vaporum
 Mare Nubium
 Mare Imbrium
 Mare Humorum
 Oceanus Procellarum
 Mare Aestatis
 Mare Serenitatis
 Mare Anguis
 Mare Foecunditatis
 Mare Nectaris
 Mare Tranquillitatis
 Mare Frigoris

(There are also some Maria which are situated at the very edge of the fully visible Moon, sometimes only visible under special circumstances of libration or nutation. They need particular expertise to find. Forget them for the moment).

2. *Lacus and Paludes* (Lakes and Marshes)

Palus Somnii
 Lacus Somniorum
 Lacus Mortis
 Palus Nebularum

Palus Epidemiarum
Palus Putredinis

3. *Sinus (Bays)*

Sinus Medii
Sinus Iridum
Sinus Roris
Sinus Aestuum

4. Major Ring Structures (craters)

There are about 300.000 craters larger than 1km on the near side of the Moon only! The largest, with diameters between roughly 60 km – 300 km (e.g. Bailly, Clavius, Ptolemaeus), used to be called “walled planes”, craters of 20 – 100 km showing high terraced walls were called “ringed mountains” (e.g. Tycho, Copernicus, Theophilus). Here are just some of them:

Petavius	Hipparchus
Vendelinus	Albategnius
Langrenus	Alphonsus
Furnerius	Ptolemaeus
Janssen	Sacrobosco
Piccolomini	Arzachel
Fracastorius	Purbach
Catharina	Regiomontanus
Cyrillus	Stoefler
Theophilus	Maurolycus
Cleomedes	Maginus
Messala	Clavius
Posidonius	Blancanus
Atlas	Longomontanus
Endymion	Tycho
Aristoteles	Deslandres
Plato	Wilhelm
Archimedes	Schiller
Copernicus	Schickard
Walter	

5. Mountain Ranges

Alps
Altai scarp
Apennines
Carpathian Mountains
Cordillera Mountains

Haemus Mountains
 Harbinger Mountains
 Pyrenee Mountains
 Spitzbergen Mountains
 Riphean Mountains
 Ural Mountains
 Teneriffe Mountains

Also try to find isolated mountains such as Mt. Argaeus, Mt. Blanc, Mt. Bradley, Mt. La Hire

6. Clefts and Valleys

Hyginus cleft
 Ariadaeus cleft
 Triesnecker clefts
 Cauchy rilles
 Sabine and Ritter clefts
 Goclenius Clefts
 Cleft in Petavius
 Mersenius clefts
 Archimedes clefts
 Alphonsus clefts
 Posidonius clefts

7. Bright Ray Systems

Tycho
 Copernicus
 Kepler
 Langrenus
 Aristillus
 Aristarchus
 Archimedes
 Proclus

Personal Highlights for Observation depending on Phases of the Moon (from New Moon to Full Moon)

Find out at what lunar phase individual formations can be seen best. For this reason, let us begin **three days** after New Moon when the Moon's crescent is very thin, shining in the West shortly after sunset.

Half way down the crescent you will see a section of Mare Crisium and Mare Foecunditatis at the terminator. Above Mare Crisium – in an inverted telescope – you

can see Langrenus, Vendelinus, Petavius and Furnerius forming a chain of four large walled planes. Petavius is a **MUST SEE**. It has a complex wall consisting of several ring walls and a massive central mountain! Also find clefts and rilles connected with it. Don't forget to look at the Moon's cusp, pockmarked with craters, to be seen at the top of an inverted telescope.

Four days after New Moon Mare Foecunditatis is in full splendour. Also try to find Proclus, one of the brightest objects on the Moon.

On the **fifth day**, Mare Tranquillitatis and Mare Nectaris become visible. Mare Nectaris has a crater called Rosse, a reminder of the Third Earl of Rosse from Birr, Co.Offaly and his Leviathan of Parsonstown, the largest telescope in the world between 1848 and 1917. The crater Posidonius is also a **MUST SEE**. Spare me the detail; look at it.

On the **sixth day**, you can see a remarkable group of three craters (Catharina, Cyrillus and Theophilus. Theophilus has a multiple central mountain rising about 2.000 metres above its floor. Also, try to find the Altai scarp near Cyrillus whose highest peak rises up to 4.300 m. Near the Lacus Mortis you'll find a classical pair of ancient philosophers: Eudoxus and Aristoteles.

The **seventh and eights days** give you the most spectacular views, particularly along the terminator. From the 8th day on, the Moon's terminator is no longer convex or straight but convex; it has become **gibbous**. It is the time around first quarter (half) Moon and one of the most suitable times to get to know the visible Moon. (The other optimal time is around day 21, the time of the last quarter Moon). Look at craters such as Maginus, Walter, Prubach, Arzachel, Alphonsus, Ptolemaeus, Albategnius, Herschel, Hipparchus, Triesnecker, Archimedes, Alpetragius, Autolycus, Aristillus, Cassini, Bond, Meton and enjoy their structure using a higher magnification eyepiece. Also study the fine detail of the Apennine Mountains, the Caucasus Mountains or the Alps. You may even want to make a drawing of some of these phantastic formations. The free Software Virtual Atlas of the Moon will provide you with an abundance of information for each of them! One of my great favourites since I began watching the Moon is the Straight Wall (Rupes Recta), an almost straight cliff of a length of about 100km. It is a **MUST SEE**. Also a **MUST SEE** is the crater Plato (about 100km in diameter) between the Mare Imbrium and the Mare Frigoris. Plato at lunar sunrise is particularly spectacular since you can first see it as a shining oval standing out in blackness and then you can see long pointed shadows developing on its floor also showing small craterlets.

Don't forget to look for the crater (or what is left of it) called **Birmingham** near Mare Frigoris since it owes its name to an Irish 19th century astronomer from Milltown/Tuam whose story you can find on the Galway Astronomy Club's website.

On the **9th and/or 10th days** you will be able to see Clavius (roughly 180km across), one of the most beautiful great wall depressions on the Moon. Tycho should also not be missed. Its system of bright rays is one of the most prominent features on the Moon. Copernicus, also to be seen on this day, is the second largest centre of bright rays.

On the **11th day** look at the clefts in Gassendi or Hippalus.

On the **12th day** look at the sunrise on Schickard (roughly 160km across).

On the **13th and 14th days** you may look at clefts in Hevelius, find Galilei, Darwin or Bailly. Bailly is more than 200 km across, having peaks on its walls of up to 4.500m. However, in order to look at Bailly properly, you will need favourable libration.

The 15th day is full Moon. Although you may find the full Moon almost too bright to look at through the telescope and rather disappointing as far as detection of fine detail is concerned, it is well worth identifying and remembering major features still prominent. You may need to identify them when it comes to a lunar eclipse – when the Earth's shadow obstructs the sunlight illuminating the Moon. You can time the progress of the eclipse by timing when the Earth's shadow meets the objects concerned. Ruekl's **Atlas of the Moon** (p. 25) gives you a list of objects that can be used for this purpose.

Good luck with your observing. Keep in mind that any lunar feature cannot be said to be observed adequately before it has not been studied under a variety of different conditions of illumination.

Third Session

Part 1

How to Observe the Sun

A rich field for observing and beginning to understand the daily lives of stars is the observation of our nearest star, the Sun, **provided we take the necessary precautions**. Precautions may equally be necessary when the rising or setting sun is very low above the horizon and we think we are safe by just looking at it.

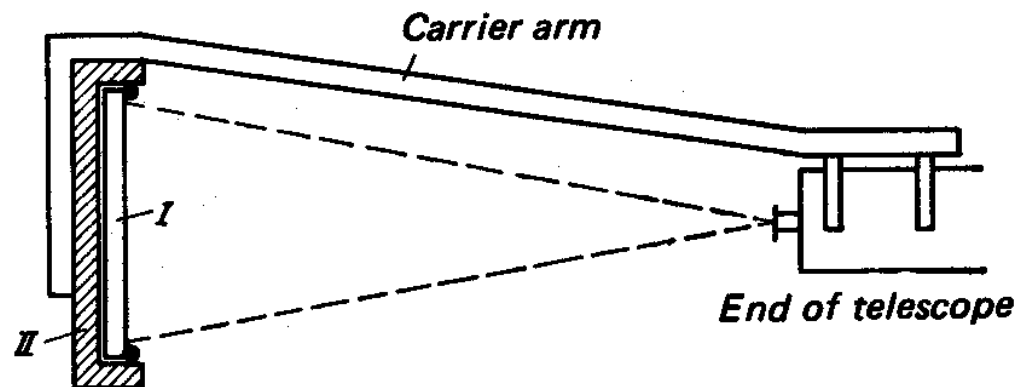


We can observe the Sun during the day. This is *very* convenient for those of us couch potatoes who prefer to sleep at night and stay awake during the day, instead of walking around like zombies after a long night of stargazing. Moreover, you can even do a bit of astronomy during your lunch break. Also, our Sun is so bright that we can easily observe it from the centres of cities whose night sky appears to vanish altogether the more street lights prevent us from seeing truly dark skies. Finally, the Sun reveals details of phenomena in its photosphere (and chromosphere) which can be observed even with relatively small instruments and with the use of appropriate filters.

Then it turns out that the sun looks different almost every day! You can trace how sunspots develop and move, what their often intricate structure is, how frequently they occur and how they are distributed. You can observe faculae, flares, protuberances or wonder about the grainy surface of the photosphere. After you gained some observing experience and with a little bit of help from the internet (Space Weather, for example) or a simple, homemade magnetometer you may even be able to predict Northern lights (**aurora borealis**) or potential disturbances of our radio and telecommunication or electronic systems.

You may (1) observe the Sun with the help of a telescope which projects the solar image on a screen. This is a very safe method because it cannot harm your eyes. Furthermore, you can build the screen yourself without any extra cost. **However, do not forget to cover your finderscope when observing with any of the methods mentioned, here.**

A screen of 10 to 15cm diameter should be fixed on an aluminium tube of changeable length connected to the draw-out tube of the telescope (see drawing).



Extending the distance from the eyepiece will change the size of the solar image, adjusting the image with the draw tube will focus it. Putting a cover on the front lens every few minutes will also prevent over-heating. On the other hand, heat may none the less develop within the telescope and particularly near the focal point, potentially damaging the eyepiece in a prolonged observing session unless it is a Huygens-, Mittenzwey- or Ramsden eyepiece. They produce useful images when they are sufficiently distant from the focus. Hence, proceed with caution.



A much more satisfactory way (2) of observing the Sun which reveals more surface detail than a mere projection is its observation with a white light solar filter made of specially coated glass or solar foil which only allows 0.1% - 0.01% of solar light to pass through. It is fixed in front of the front lens or opening of the scope.



Most glass filters produce a very pleasant orange image of the Sun, whereas foils show the Sun in brilliant white.

Also (3), one may safely use a specially designed prismatic eyepiece, the Herschel prism. It deflects most of the solar light and provides beautifully crisp images of solar photospheric detail.



There is another, extremely risky way of observing the Sun (4). Small solar filters for small and cheap telescopes may still be on the market which can be screwed into normal eyepieces rather than covering the front lens or opening (4). They used to come – and may still come - with telescopes offered in supermarkets or toy shops. **These filters heat up rapidly and tend to break suddenly. Any observer will be blinded by the sudden burst of light hitting the eye and permanent damage is more than likely to occur.**

Available on the amateur astronomy market for solar observation (5) are also specially designed telescopes equipped with Hydrogen-Alpha solar filters to show you flares, prominences, spicules, filaments, plages, coronal mass ejections, and more – not just the sunspots you see through a conventional white light solar filter or projected on a screen. With such a telescope, you see the dynamic, living face of the Sun changing as you watch.



A Hydrogen Alpha Solar Telescope



A lot of what you can observe depends, of course, on the quality of the earth's atmosphere and that of your instrument. It is definitely worth keeping a record of the quality of what you can see. You may judge it according to the steadiness (*r*) and the sharpness (*s*) of the image you are looking at by using this scale:

r = 1: solar limb perfectly quiet
r = 2: solar limb a small amount disturbed
r = 3: solar limb disturbed
r = 4: solar limb strongly disturbed, wavy

s = 1: solar limb clearly defined, granulation clearly visible
s = 2: solar limb and granulation diffused
s = 3: solar limb ragged, granulation not visible, umbras of spots diffuse
s = 4: limb almost completely diffuse, very diffuse spots.

What to observe on the Sun

1. Sunspots

It is mind-blowing to imagine that even the smallest visible sunspots are – in reality – many times larger than the Earth. Moreover, they seem to change their appearance every day, even every few hours. No wonder that sunspots are the most commonly observed and fascinating objects for amateur solar astronomers. They can take seemingly unclassifiable shapes and forms. The Swiss Observatory Zurich, for instance, developed a classification which has become standard among European amateur astronomers. The classification corresponds roughly with the development (A to I) of a very large group of sunspots:

A: represents a small single spot without a penumbra;

B: a group of small spots without a penumbra;

C: a group of spots with a single penumbral spot which, for the most part, is to be found on the western edge of the group, i.e. the preceding side of the direction of solar rotation;

D: a group with at least two penumbral spots which, for the most part, are to be found on the western and the eastern side of the group. They form a bi-polar group.

E: A somewhat larger bi-polar group containing several smaller and larger penumbral spots;

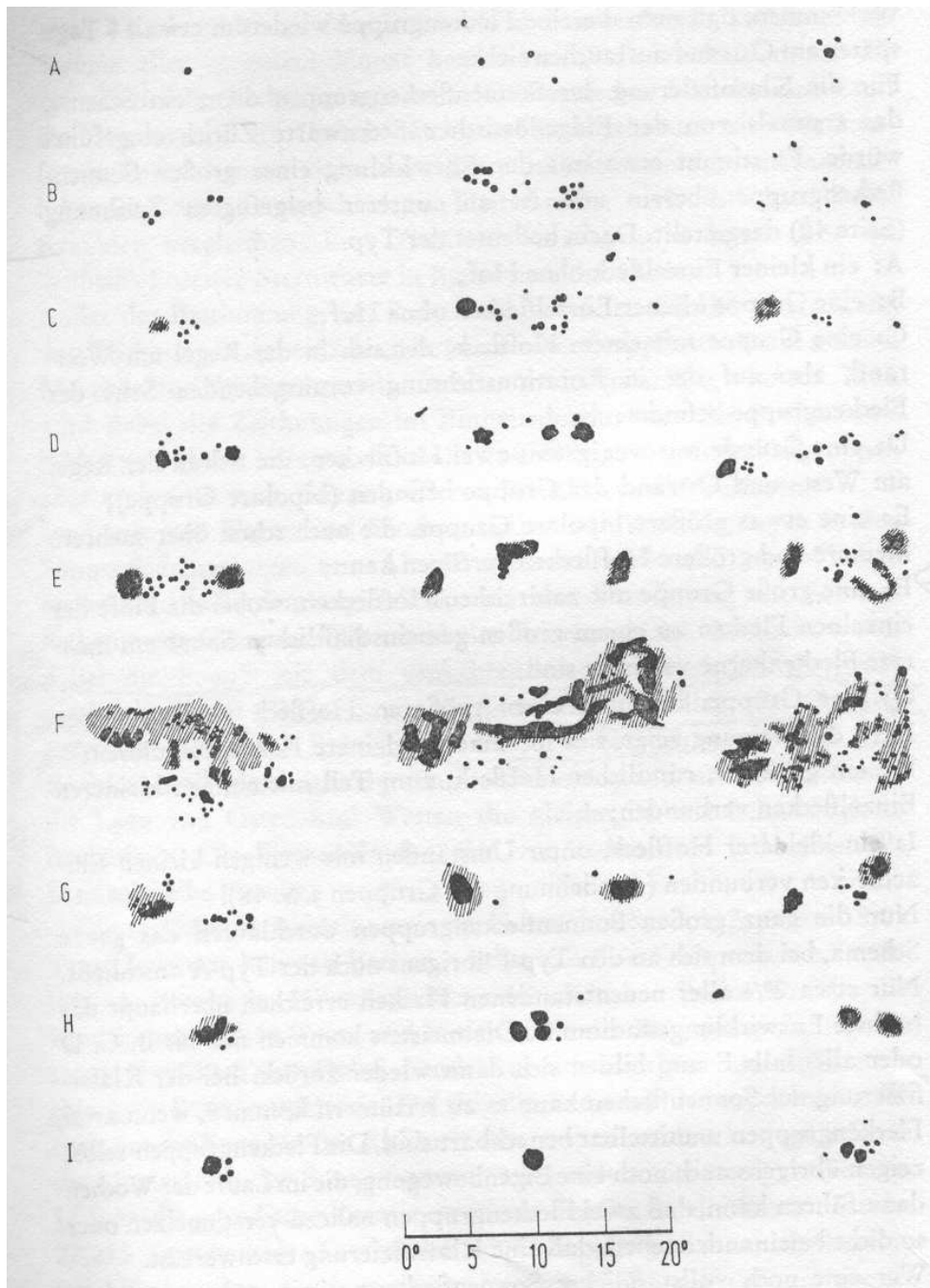
F: a large group with several penumbral spots where the penumbrae are joined together by a seam around several spots. F represents the maximum development, reached by only 2% of new spots;

G: a group with a large penumbral spot whose centre shows a tendency to dissolve into smaller spots;

H: a large, roundish penumbral spot, partly connected with smaller separate spots;

I: a small penumbral spot, sometimes connected with a few small separate spots.

Compare the map:



Of course it is easy to make mistakes in the attempt of classifying sunspots, particularly when two groups are in close vicinity to each other. Since groups of sunspots also have their own proper motion it may well happen that two groups merge and thus make it impossible to classify them as clearly as the Zurich classification appears to demand.

Determining the sunspot number

It is well worth trying out your scientific instincts by counting separately individual sunspots and groups of sunspots every sunny day of the year. It needs a bit of patience but that's what pays off in the end. What you gain in the end is a diagram representing the development of solar (sunspot) activity during a day, a month, a year, and beyond. You will even be able to determine solar cycles by yourself – if you are patiently continuing to observe and to write down your data for more than 25 years! Some amateurs do it! Information such as this is becoming increasingly important in the debate on climate development and change, for instance. How do you proceed? The first step is to determine the daily **sunspot number (Wolf Number)**. This only takes a few minutes per day.

However, there is a problem which was noticed first (as far as I know) by Rudolph Wolf in 1848: Suppose you look at the Sun through a pair of binoculars (with solar filters, please) - you may see one or two large spots. An astronomer observing through a solar telescope might see 10 or 20. A space-based observatory will see even more -- say, 50 to 100. Hence, which is the correct sunspot number? You can circumvent this problem by comparing your data with the official daily Boulder Sunspot Number and find out (calculate your own personal "variable scaling factor". Having done this you may find that your observations are not far from what the "official" result is.

There are two official sunspot numbers in use, differing in their measurements, the "International Sunspot Number," published daily by the Solar Influences Data Center in Belgium, and the daily "Boulder Sunspot Number," computed by the NOAA Space Environment Center. Both use a formula devised by Wolf but use different observatories for their collected data:

$$R = k (10g+s),$$

where **R** is the sunspot number; **g** is the number of sunspot groups on the solar disk; **s** is the total number of individual spots in all the groups; and **k** is a variable scaling factor (usually <1) that accounts for observing conditions and the size of the telescope (binoculars, size of telescope, seeing etc.). The smaller the instrument is, the larger is **k**, and vice versa.

For your own purposes follow these steps:

Step 1: count the number of sunspot groups using the Zurich classification (=g)

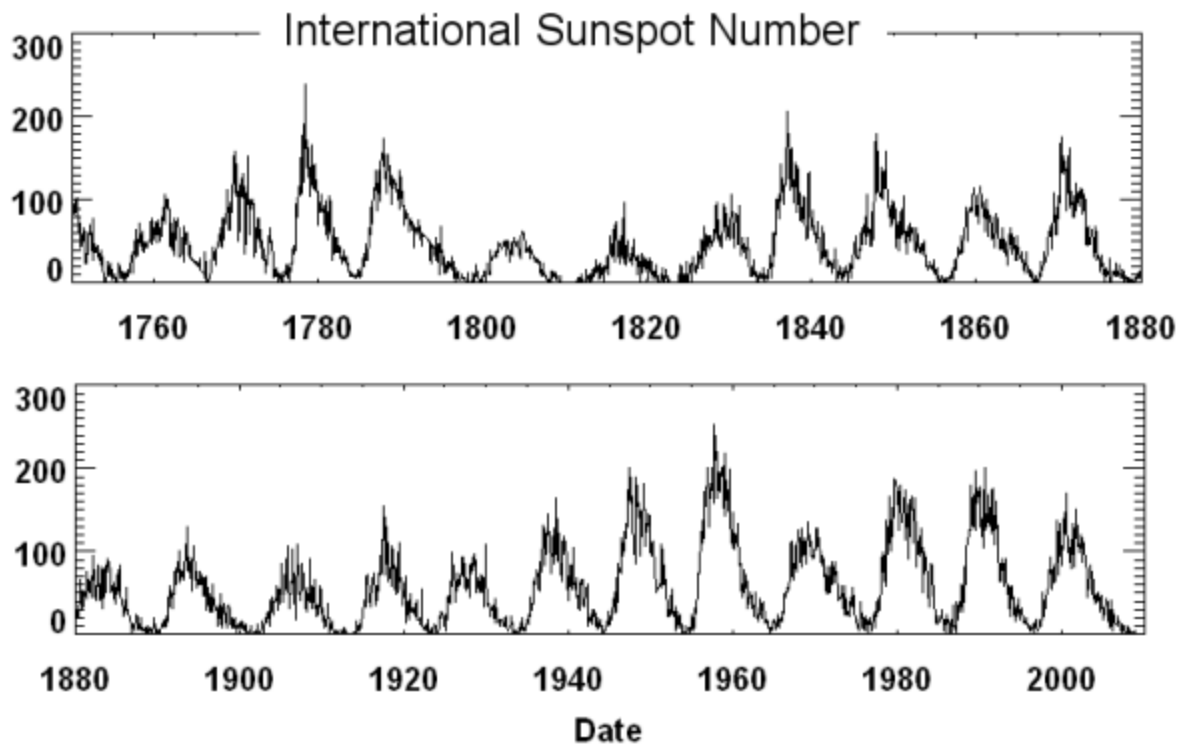
Step 2: multiply this number by ten (=10g)

Step 3: count all individual spots in all groups (=s)

Step 4: add up 10g+s

Step 5: compare your result with the official Boulder Sunspot number and average the differences daily for about a month. Add the numbers and divide them by the number of days of effective observing. From this average calculate your own variable scaling factor that you may use for future comparison. To begin with, you may start with $k = 1$.

Result: A sequence of sunspot numbers which can be represented in a diagram in which the x-axis represents the number of days and the y-axis indicates the sunspot number for each day. Connect the points in the diagram to result in a curve representing the development of sunspot activities over a period of time. Of course, you will not be able to construct a diagram such as the one shown here, representing the overall development of sunspot activity between 1760 and 2000, clearly showing the periodic change of maxima and minima. None the less, you will be able to represent a small section of it yourself, perhaps even a whole cycle of roughly 11-12 years!

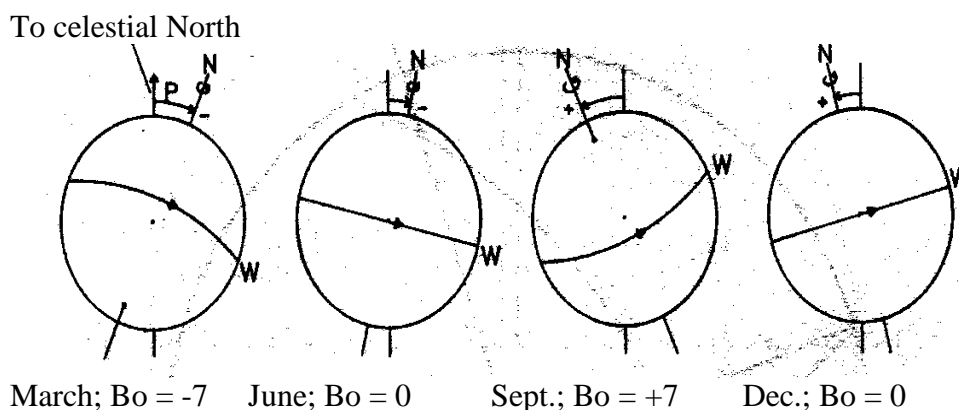


As a rule of thumb, if you divide the official sunspot number by 15, you'll get the approximate number of individual sunspots visible on the solar disk. Assuming that there are no sunspots to be seen, and disregarding the scaling factor k , 0 should be the result for the Wolf number, immediately followed by the number 11 if only one spot can be detected.

Determining coordinates of sunspots

You may also wish to determine the **position of sunspots on the solar disk** in order to keep track of their movement within a solar day or month. They move from the eastern to the western edge of the solar disk. If you observe the sun through a refractor which turns the image upside down, East is on the right, West on the left, South is up, North is down. However, if you project the image on a screen, East remains on the right, West on the left, but North is up and South is down. Hence, sunspots move over the solar disk from the right to the left!

One relatively simple way of determining positions of sunspots on the solar disk is to project it on a screen with a solar coordinate grid which allows for an image of the Sun of 10 - 15cm (I am using an image of 10cm). Stonyhurst disks, easily downloaded from the internet and copied, provide a set of different grids. They differ depending on the changing heliographic latitude of the centre of the solar disk, i.e. its distance from the solar equator during the year - which can be used for this purpose. They have to be different disks because due to the differing tilt of the solar axis in relation to our axis of view from Earth different grids have to be used during the year.



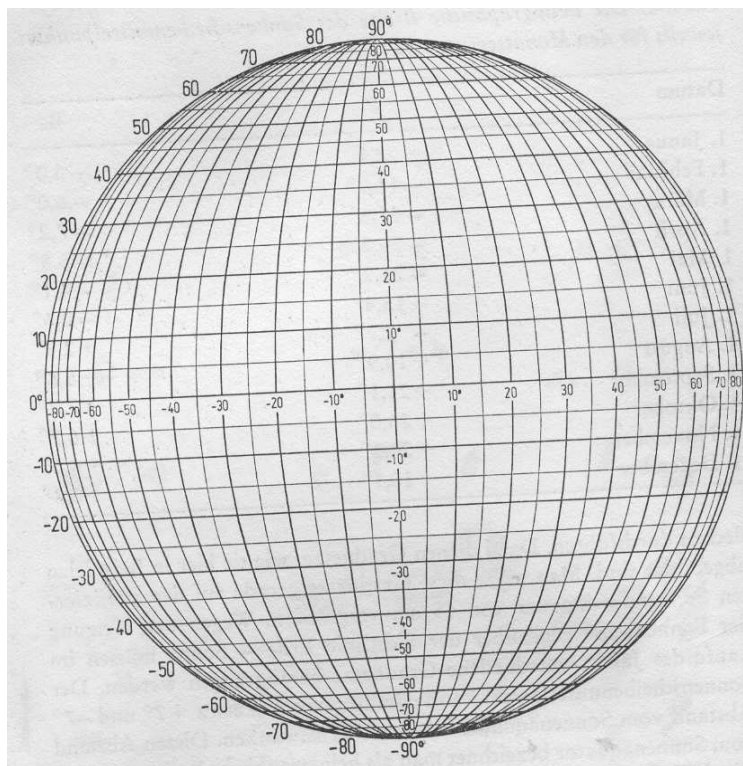
The centre of the solar disk (Bo) can vary by +7deg to -7deg from the solar equator. Also, the position angle of the Sun's axis of rotation (P) in relation to North/South changes during the year. The axis may be more inclined to the West (+) or to the East (-).

Here are the different values for the first day of each month:

<i>Date</i>	<i>P</i>	<i>Bo</i>
1. January	+ 2.5deg	- 3.0deg
1. February	-11.9	-6.0
1. March	-21.6	-7.2
1. April	-26.2	-6.5
1. May	-24.2	-4.1
1. June	-15.4	-0.6
1. July	-2.7	+2.9
1. August	+10.9	+5.8

1. September	+21.1	+7.2
1. October	+26.0	+6.7
1. November	+24.5	+4.3
1. December	+16.1	+0.8

Example of a solar grid:



Grid for $B_0 = 0^\circ$, suitable for June

Steps for adjusting the grid on the projection screen:

Step 1: Mark the East/West direction with a pencil line

Step 2: Project an obvious sunspot on the screen and bring it to the eastern edge of this line. Do not move the telescope (motors turned off).

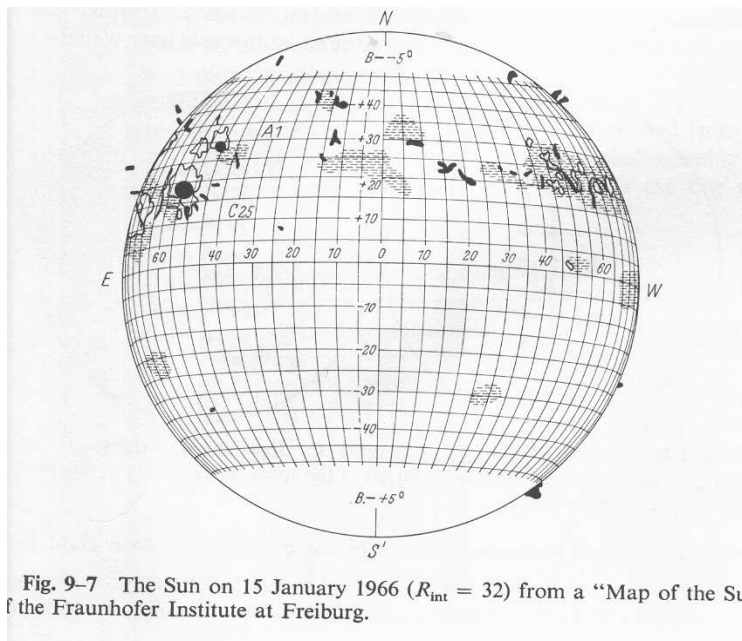
Step 3: Allow the spot to move West and observe if it deviates North/South

Step 4: Move the grid into a direction such that the spot moves exactly on the Pencil line

Step 5: After steps 1-4, the position angle (P) of the Sun's rotational axis has to be accounted for. At the edge of the projection screen should be a ring larger than the solar grid indicating angles from North (= 0°) to 26° West to 26° East corresponding to the maximum deviation from North/South of the position angle of the solar rotational axis during the year. If $P = -24^\circ$, for instance (May), turn the northern edge of the grid on the projection screen by 24 degrees to the East (to the right). If $P = +24^\circ$ (November), turn the northern edge of the grid anti-clockwise by 24 degrees.

Result: Provided that the correct grid was chosen - depending on the value for B_0 , the coordinates of the sunspots can be determined fairly exactly. Of course, attempting to determine the position of a group of sunspots, the centre of the group has to be chosen.

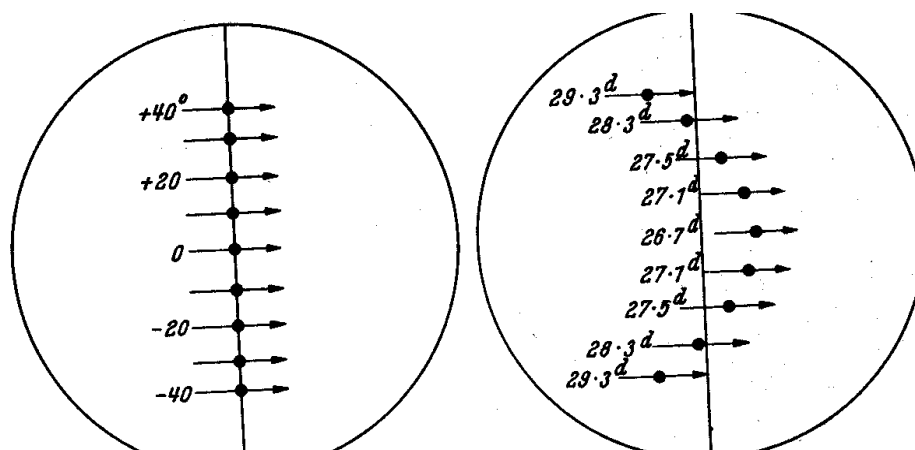
Positions of spots are to be related to their distance from the solar equator and from the central meridian running North/South. A group may have the coordinates 22deg N 17deg W, for instance, which may be read almost directly from the grid.



Determining solar differential rotation

As seen from the Earth, the Sun completes a full rotation in about 27 days. A sunspot moves roughly 13deg longitudinally per day, moving from east to west, crossing the disk in roughly 13 days. Since the Sun does not rotate as a rigid body, there are different rotational periods for spots nearer the polar regions compared to the region of the solar equator.

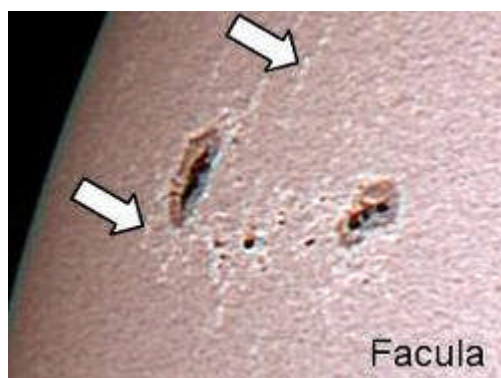
The solar surface rotates differentially. At the solar equator, the (sidereal) rotational period is 25.03 days, whereas it is much slower near the northern or southern rotational poles where it amounts to more than 30 days. At 16 degrees latitude North or South it already amounts to 25.38 days. Since the Earth moves in the direction of the solar rotation, these differential motions – as seen from Earth – appear even to be slowed down a bit more (synodic period). Consequently, the synodic rotational period of the Sun at 16 degrees latitude is 27.275 days. Hence, a new sunspot group appearing on the Eastern edge will take about 13 days to disappear behind the Western edge. It will take about a fortnight before it may re-appear over the Eastern edge.



To follow these movements of sunspots is well worth observing because it allows the amateur solar astronomer (you) to measure the rotational period of the Sun as well as differences of rotational periods.

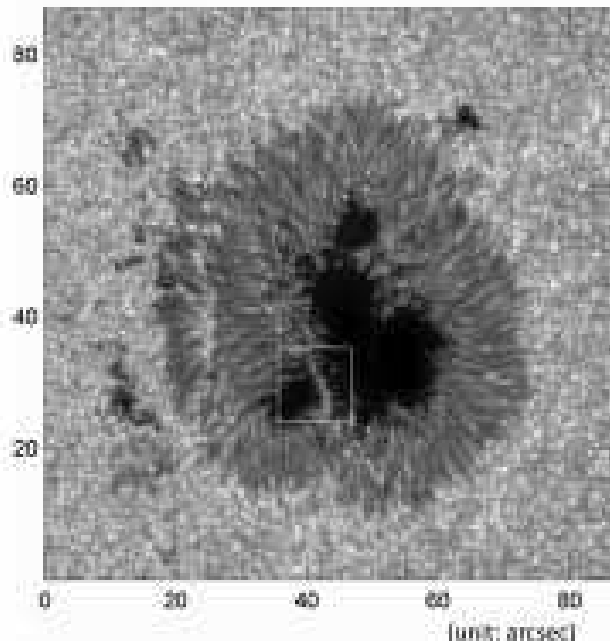
2. Solar Faculae, Light Bridges, Flares and Prominences

Occasionally you can see bright irregular lines, more or less broad, visible near the solar limb. These are almost certainly **solar faculae**. They frequently indicate the beginning of new spots although faculae surround almost all spots or sunspot groups anyway.

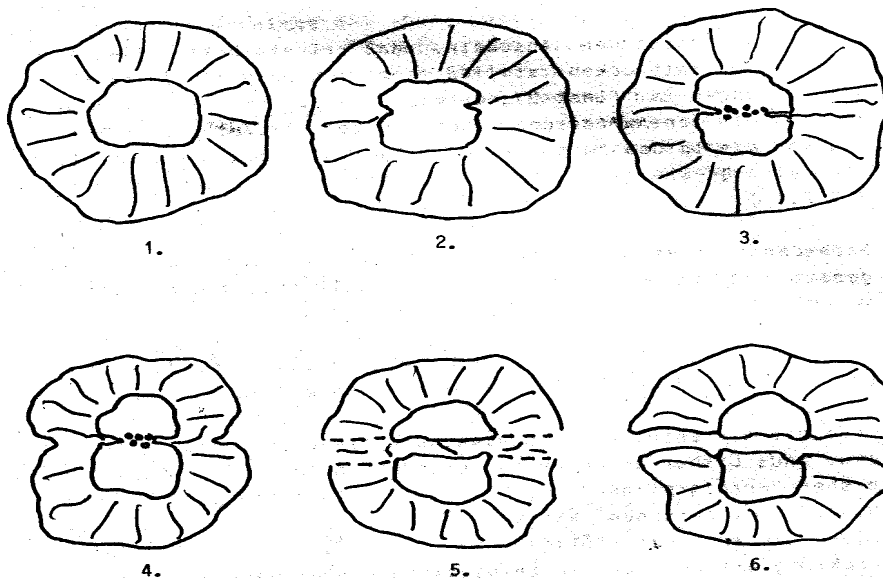


Apart from attempting to make drawings of them it is worth estimating their extension using a measuring grid like the ones used for coordinates. Their intensity may also be estimated using a scale ranging from 1 (very low) to 5 (extremely bright). The point of these estimates is that they sharpen your observing skills and sense of visual discrimination far more than simply looking at these amazing structures could ever teach you.

Even small telescopes (of 70mm front lens diameter, for instance) may reveal bright areas *within* sunspots having an umbra and, possibly, a penumbra. These are **light bridges**.



Although light bridges look as if they split sunspots, they may not do this in reality but simply indicate that changes in the magnetic field of the spot are happening. They frequently follow a pattern of development which may be characterised by the following six steps:



However, these steps may not follow each other necessarily. Each one of them may terminate in itself and then dissolve. None the less, it is worth noting this development and to compare your findings with images shown of sunspots by professional solar observatories such as NASA – Solar Dynamics Observatory (see website):

Step 1 represents a sunspot with penumbra having no light bridge.

Step 2 indicates that a light bridge may be starting because some brighter filaments from the penumbra appear to move into the umbra, possibly from opposite sides of its edges.

Step 3 shows that these filaments have advanced into the umbra, isolating some granules.

Step 4 shows further advance.

Step 5 indicates an apparent separation of the sunspot with some remaining filaments from the penumbra in the bridge.

Step 6 represents a fully developed light bridge.

Prominences essentially radiating in the light of hydrogen are best observed by the amateur using a solar scope especially geared to observing the solar chromosphere with filters for observing the hydrogen alpha line of 6563 Angstrom (see picture on page 87).



Of course, this is a highly specialised area for a beginner. However, there is hardly a solar phenomenon more fascinating and magnificent for observation. Unfortunately, solar telescopes are not exactly cheap because of their filters. Buying one of them frequently means that you may have decided to dedicate yourself specifically to observing the Sun.

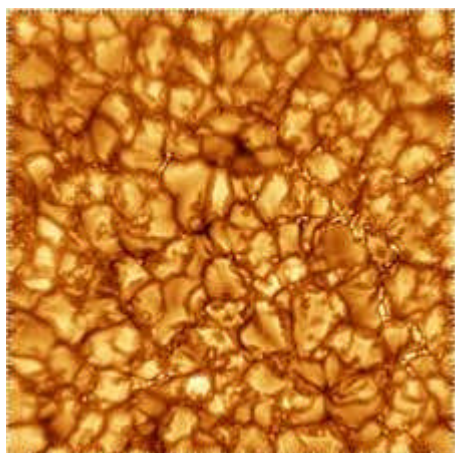
Solar flares are sudden eruptions of radiation, mostly within the solar chromosphere, detectable in H alpha. Very rarely they are even visible in the photosphere (white light flares). In this case, they become visible for amateur astronomers using a normal white light filter for their telescope. They remind of lightning, lasting only for some seconds to a few minutes, much brighter than their surroundings, sometimes connected with large sunspot groups.

The energy emitted by such eruptions is so high that it can affect the Earth's magnetic field, radio communication or Northern lights. No wonder that major solar observatories monitor these events closely. Hence, it is especially exciting to detect them and to be able to predict possible auroral activity for the following nights!



3. Granulation

The solar surface has a grainy appearance which becomes visible for an amateur astronomer with a small (LIDL) telescope only under very favourable atmospheric, transparent and calm observing conditions. They look like large, bubbly formations, similar to a huge layer of stratocumulus cloud seen from above. Each granule has the size of a whole country, however, undergoing complete change within a few minutes.



Fascinating as it may be to follow the development of granules it may be more advisable to take a series of images of the same area and compare the development of granules photographically provided that the atmospheric conditions allow for it.

4. Solar Eclipses

There is hardly an event in a solar observer's life which is as beautiful and dramatic as a total or an annular eclipse! When the Moon is near its closest approach (**perigee**) to Earth and in line with the Sun as seen from the observer and an eclipse is going to happen, it is going to be total since the Moon's apparent diameter is large enough to cover the whole solar disk. In reality, the solar diameter is about 400 times the diameter of the Moon.

When the Moon is almost furthest away from the Earth (**apogee**) at the event of an eclipse, the lunar disk will not cover the entire solar disk. Hence, a bright ring of solar surface surrounding the lunar shadow will remain. An annular eclipse will occur.

Here is an image of a total solar eclipse:



This is an image of an annular eclipse:



However, observing a total or annular solar eclipse from one's own home is extremely rarely possible. To live in the path of the fast moving umbral lunar shadow which is not very wide at all may happen only once every 450 years, although eclipses occur every one and a half years. Moreover, most of the time eclipses happen over the oceans. Therefore, it is reasonable to prepare yourself for a long travel with a group of astronomy enthusiasts to experience it and hope for the best that the weather (clouds) will not spoil the view in the last minute. None the less, having witnessed it is an unforgettable experience!

An eclipse occurs in the southern sky (for us living under Northern skies) when the fast-moving Moon approaches the Sun from the West. Its first stage (**first contact**) occurs when the lunar limb appears before the solar disk.

Immediately before the beginning of totality the umbral shadow of the Moon appears on the horizon, looking and moving like a fast, threatening storm. Its shadow rushes across the countryside with at least 1700 km/h. Daylight will appear harsh compared with the light normally associated with dusk. Animals will behave as if they are going to sleep. A strange wind will arise across the countryside. The air temperature sinks. The sky darkens and the phenomenon known as Baily's Beads can

be seen along the lunar limb. Bright points of sunlight thread their way through the Moon's mountainous terrain.

At **second contact** true totality begins. It never lasts longer than 7 minutes and forty seconds. For those observing near the central line of the shadow's path the beads disappear, replaced by the Sun's ghostly chromosphere since the light of the solar photosphere is now blocked by the lunar disk. If any prominences are present, they can also be seen in the chromospheric corona. Narrow and broad rays from the Sun may also be seen, related to magnetic storms. This corona extends to distances up to nine million km from the Sun. A truly impressive sight!

At **third contact** totality vanishes as suddenly as it came. Shortly before it ends, Baily's Beads will re-appear. From then on, it will look like a partial eclipse, coming to a fast end. Eventually, the lunar disk will disappear from the Sun's eastern limb, marking the **fourth contact**.

After the Sun:

How to observe Planets

Major planets, minor planets, asteroids, transits

How to observe stars

General, double stars, Variable stars, clusters, novae etc

How to observe non-stellar objects
General, Galaxies, nebulae, comets etc

How to observe meteorites, northern lights, sun halos, moon halos, rainbows,
moonbows etc.