

SOME PRELIMINARY NOTES
ABOUT TELESCOPES

One of the subjects we will cover in depth during this class is the subject of telescopes. There is a reason for this. Sooner or later you will want to get a telescope. Every year otherwise intelligent people go out and spend hundreds of dollars on a telescope with little or no knowledge about them or what they can and cannot do. Since your hard earned money is at stake I will try to arm you with facts you will need in order to make a wise choice. The following is a short table of the parameters relating to the more common apertures of telescopes you will encounter.

COMMON APERTURE	MAX. MAG. (60X IN.)	DAWES LIMIT	LIGHT GRASP (HUMAN EYE)
50mm. (2")	120x	2.28 arc/sec.	50.98
60mm. (2.4")	144x	1.90 "/"	73.44
76mm. (3")	180x	1.52 "/"	117.94
100mm. (4")	240x	1.14 "/"	204.20
114mm. (4.5")	270x	1.01 "/"	265.36
150mm. (6")	360x	0.76 "/"	459.24
200mm. (8")	480x	0.57 "/"	816.24
250mm. (10")	600x	0.46 "/"	1,275.20
300mm. (12.5")	750x	0.36 "/"	1,836.98

COMMON APERTURE	LIMITING MAGNITUDE	NUMBER OF STARS SEEN	????????? ?????????
50mm. (2")	10.3	324,000	//////////
60mm. (2.4")	10.9	870,000	//////////
76mm. (3")	11.4	1,200,000	//////////
100mm. (4")	11.9	1,950,000	//////////
114mm. (4.5")	12.4	2,270,000	//////////
150mm. (6")	13.1	5,000,000	//////////
200mm. (8")	14.0	8,000,000	//////////
250mm. (10")	14.8	13,000,000	//////////
300mm. (12.5)	15.9	32,000,000	//////////

Some of the common formulas for calculating telescope parameters are as follows:

Inches to Millimeters; 1 inch = 25.40 mm.

Magnification; $FT / FE = X$ where the telescope focal length in millimeters (FT) divided by the focal length of whichever eyepiece is being used (FE) equals the final magnification.

Maximum Useful Magnification; 60x per inch of aperture. Not always attainable but a few nights a year and in certain locations even this is no limit!

Maximum Practical Magnification; 50x per inch of aperture. This is the limit you will use most often at any given time and place. If it seems exceptionally good, push to 60x / in.

Dawes Limit (Resolving Power); 4.56 divided by aperture in inches. Results will be in seconds of arc (arc/sec).

F/ Ratio; the ratio of the telescopes aperture to its focal length. Sort of a telescopic shorthand. $FL / AP = F / ?$ where FL is the telescope focal length and AP is the aperture of the scope. Example: 8" scope with 48" focal length. $48 / 8 = F/6$.

Exit Pupil; $AP / X = \text{Exit Pupil (in mm.)}$. This is the circular beam of light which you see through the eyepiece. Its size affects how well you'll see an object. Also important if you wear glasses as the larger the exit pupil, the easier to see with glasses on. Aperture divided by the mag. equals exit pupil.

Always remember to use equivalent units in the calculations. In other words, don't mix inches and millimeters in the same formula.

There are, of course, other formulas for calculating such esoteric things as percentage of central obstruction which on reflectors will affect contrast levels, field curvatures, optical aberrations, etc. If and when you try your hand at telescope building or figuring optical surfaces, then you can learn the deeper mysteries of the art for they are nothing the casual or even the dedicated amateur will need or use with any regularity although there is nothing hard or forbidden about them. However, the above factors are the ones you will habitually use when you select, use and evaluate telescopes.

Another thing you will encounter when shopping for optics are the terms "Diffraction Limited" and fractions of "Wave Length". Both these terms are related and refer to the exactness of the optics to their theoretical ideal. The minimum acceptable tolerance is 1/4 wave length AT THE FOCUS which is sometimes known as Rayleigh's criterion. This means that the COLLECTIVE aberrations of all the optics in a system must not depart from the ideal shape such that the final image is within 1/4 the length of a wave of light, i.e; 5 1/2 MILLIONTHS of an inch! This will bring the scope to the point where it is only limited by the physical laws of light, the so-called "Diffraction Limit" and will then produce an image which is imperceptible from a "perfect" image to the eye. As the wave front numbers get smaller (1/8, 1/10, etc.) the quality gets theoretically better. However, any single surface must be BETTER than 1/4 wave since each surface the light encounters in a reflective system is additive and the final focus must be 1/4 wave or better. For a refractor the degree of accuracy can be slackened a bit because the light passes through the lenses of this type of

scope and angles each surface once unlike the reflector where the light is angled off of each surface twice. Consequently, the reflector surfaces need to be "more perfect" than refractor surfaces but the glass in refractors needs to be better than in reflectors since the light actually passes through the glass of the refractor but only bounces off the reflective first surface of the reflector and for most scope designs does not enter the glass at all. SO THE TERM "DIFFRACTION LIMITED" SIMPLY MEANS THAT A SCOPE WILL FUNCTION AS WELL AS THE NATURE OF THE DESIGN AND THE LAWS OF PHYSICS ALLOW!

One factor of wave length measurements which is seldom covered is which frequency or color is used to make the determination of the wave front error. If the reference source against which the optics are tested uses red light, which are long waves, then the errors will be worse than if they were corrected relative to a blue light reference source which has a physically shorter wave length. A pit, hill or any other error which is 1/4 of a long light wave will be more extreme than one which is 1/4 of a short light wave. By using shorter wave lengths the error will be physically smaller for the same per cent of error and the image will be better. The standard is to use the green light of Mercury at 546.0 nanometers (5460 Angstroms) which is in the middle of the visual spectrum. Optical systems corrected to 1/4 wave green light at the focus give very well corrected images.

It has been said that terms like those described above are a gold mine for manufacturers and a mine field for the prospective customer since they sound impressive without really telling the customer anything important! Is it 1/8 wave at the focus or at each surface in a seven surface system? And what was the wave length of the reference source? If each surface is 1/4 wave the result will still be by definition "Diffraction Limited" since it will only perform as well as the laws of physics IN THE SYSTEM will allow! But as the light reacts with each 1/4 wave surface, the errors build up to where the light will be in error beyond one wave length at the focus. And if the test reference was a light source toward the yellow or red spectrum, then the physical errors can be larger but the surface will still be 1/4 wave. A telescope such as this will be a miserable performer.

For the most part, however, all the telescopes on the market will do the job to some extent but when buying, evaluate with an eye on substance and quality. If a telescope is built cheap and flimsy, chances are it will perform accordingly. If well made it will deliver the goods. Also, well made scopes have warranties by companies that care about their reputations. With telescopes as with just about anything else, follow the time tested axioms; "Let the buyer beware" and "You get what you pay for".

Everyday folks go out into the shopping world and pay upwards of \$300.00 for telescopes which have 60mm. (2.4") objective lenses and which the ads say will magnify to "450 power" thereby equating magnification with quality or desirability. Magnification is but one of several factors used to evaluate telescope optics and not necessarily the most important! The six common factors are;

1. Light Grasp.
2. Resolution
3. Contrast.
4. Limiting Magnitude.
5. Airy Disk.
6. Magnification.

All of these factors except the last is a function of aperture; that is, the diameter of the light collecting surface whether lens or mirror. This is what you pay for in ANY telescope and why the professional astronomers use such huge instruments; they are trying to gather as much precious, faint light as possible. Magnification is somewhat related to aperture but is more a function of focal length; the distance the light travels from the objective (again a lens or mirror) to the focus.

LIGHT GRASP.

The purpose of a telescope is to gather light to a focus and there examine the image. To do that, we use light collectors of glass. The larger the collector, called the objective or aperture, the more light we gather to examine. The fully dark adapted human eye has an aperture of 7 to 8 mm. in diameter. As we get older, this number will decrease to 5 or 6 mm. in diameter. So even a pair of 35mm. binoculars will grasp more light than the eye alone. This allows us to see fainter objects beyond our normal capabilities and dim objects will appear correspondingly brighter. Increase of light grasp is computed as the square of the increase in aperture. For example, a 6 inch scope does not gather twice the light of a 3 inch scope; it gathers FOUR times as much light. A mirror twice as big gathers four times as much light.

RESOLUTION.

This is the ability of a telescope to see fine detail. As the aperture becomes larger, more detail is seen. A related factor but not quite the same thing as resolution is RESOLVING POWER or the ability to separate closely spaced point sources of light such as double stars. These factors are measured in "seconds of arc". One arc/sec. is $1/3600$ of a degree, (there are 60 arc/seconds to an arc/minute and 60 arc/minutes to a degree and, of course, 360 degrees in a circle) a very small angle, indeed. To put it into perspective, the type you are now reading subtends an angle of around 2000 seconds of arc to your eye. Try to imagine two thousand stars piled one on top of the other and you'll get an idea of just how small one arc/sec. separation between the visual images of two stars really is! Resolving power is figured roughly by a formula called "Dawes Limit". Dawes was an amateur astronomer during the middle of the last century and he determined that a one inch scope would just separate two EQUALLY bright stars by 4.56 arc/sec. Conversely, a 4.56 inch scope will separate two equally bright stars one arc/sec. apart. To find the resolving power of a telescope in arc seconds, simply divide 4.56 by the scopes aperture in inches.

CONTRAST.

This is the same as contrast for a television or computer monitor, a clean separation between light and dark detail. High contrast will make this difference obvious while low contrast makes seeing this difference difficult. Contrast is most affected by the seeing conditions of the air at any particular time but the optics do play a big role. Refractors tend to have the best contrast because of their unobstructed light path, the light is simply collected by the objective lens and travels the length of the tube to the focus. Reflectors and Catdioptric scopes have secondary mirrors that actually lay in the path of the incoming light blocking

some of this light from reaching the primary mirror. This does result in some light loss, decrease in contrast and the introduction of some light scattering called diffraction. However, these negative factors tend to be more imperical then practical and in reality, a well made reflector or "Cat" will give very high quality images with good contrast.

AIRY DISK.

Without going into the gory physics of optical theory too deeply, when we look at a star in a telescope we do not see a magnified image of the stars "disk" as with a planet. The largest star is a mere 1/20 of an arc/sec. in diameter and if they were not self luminous generating so much energy they would be invisible. Due to the nature of light and the fact that telescopes have round apertures, the light is concentrated into a very small area but not into a "point". This area is called the Airy Disk named after Sir George Airy, the Astronomer Royal in the middle 1800's and a great optical theorist who first quantified this effect. The Airy Disk will appear at high magnification to have a definite size disk surrounded by a ring or series of rings called diffraction rings. Indeed, prior to Airy's description of the effect, many earlier astronomers spend long, tedious hours measuring the diameters of these disks in the mistaken belief that they were in truth the actual disks of the stars. We now know that it is merely an effect of the optics. However, as the aperture increases, the size of the Airy disk decreases by a factor of four putting more light into a more compact area. Doubling the aperture of a telescope will double the resolution, increase light grasp by a factor of four and reduce the Airy Disk by a factor of four resulting in an increase of the stars brightness by a factor of SIXTEEN!

LIMITING MAGNITUDE.

Objects in the heavens are listed as being "so" bright. The scale adopted is a rather random scale dating back into Hellenic Greece. The brightest stars started at 0 magnitude and the faintest were 6th magnitude. We have revised the older estimates since the invention of better instrumentation. Currently, the brightest star (Sirius) is -1.4 magnitude while the faintest star visible to a dark adapted eye from a dark site is around +6.2 mag. The Moon is magnitude -12 when full while the Sun is magnitude -26. Limiting magnitude is simply the faintest star visible in any particular telescope under excellent conditions. Objects fainter then 6.2 are telescopic and the larger the telescope, the fainter the limiting magnitude visible in that telescope. The chart way back at the beginning of this novel has the limits of magnitude already figured out for you for the size scopes you will more then likely encounter.

MAGNIFICATION.

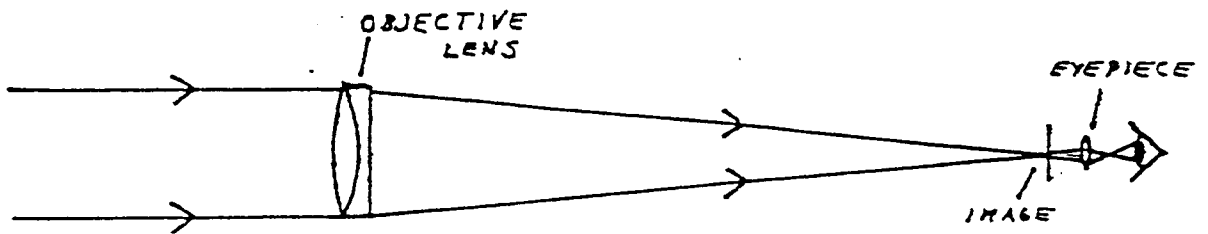
Telescopes focus the light they gather to what is erroneously called the focal point. In reality the focus of a telescope is a plane or area of real size. In fact, you can point a telescope at the Moon and by putting a piece of paper at the focuser, an image of the Moon is easily visible projected onto the paper. By putting a magnifier in place of the paper, we can make the image larger and easier to see. An eyepiece is simply a magnifier. Magnification is a factor of the telescopes focal length and the focal length of the eyepiece used and is determined by dividing the

focal length of the telescope by the focal length of the eyepiece. If you have a focal length of 1000mm. and you are using a 10mm. eyepiece, the magnification would be 100x. If you use a 6mm. eyepiece, the magnification will be 167x and so on. There is no limit in theory to the magnification one could use but practically there is a limit of 60x per inch of aperture under IDEAL conditions and a more normal maximum of 50x per inch. A 3 inch can go to 180x maximum and a 6 inch to 360x and so forth. Above 60x per inch the image becomes distorted by optical limits (the amount of light available becomes insufficient), air turbulence, heat from various sources, airborne dust, etc. Always remember that we live at the bottom of an ocean of air and to see out into space we have to look through that ocean. When looking through a telescope we are not only magnifying the object observed but all of the intervening material as well!

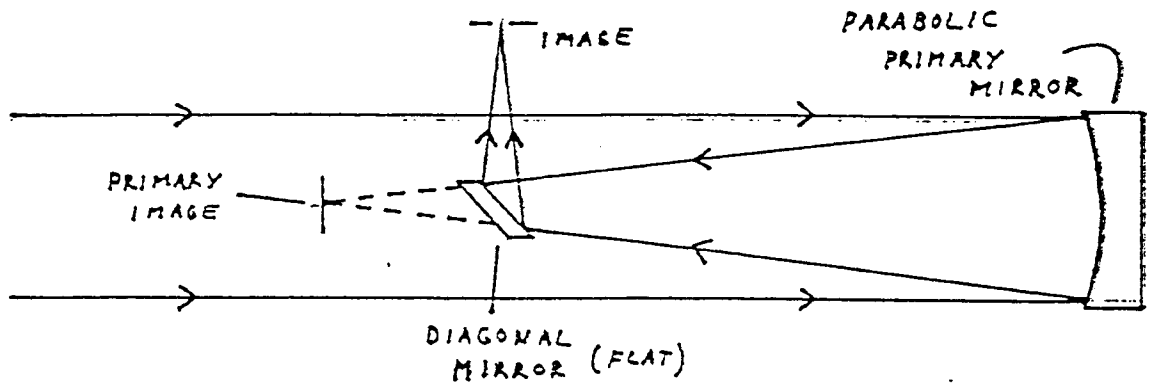
As you can see from these parameters, a telescope has a lot to do in order for you to see as much as possible. While telescopes are fairly simple in concept and surprisingly not at all difficult for regular people to build from scratch, all the above factors must be taken into account in order to achieve the best image possible.

In addition, personal training enters into the picture. One person may be able to distinguish fainter objects than another person whose eyes are not quite as sensitive or who has not had the training or experience of another. That person would be able to see more objects in a faint cluster, separate closer double stars and observe more planetary detail and yet both may be using the same size and type of telescope or even the very same instrument. The so-called "personal equation" should be taken into account when evaluating telescope performance based on personal testimony. But the list of parameters at the beginning of this article is less empirical and more analytical in arriving at the answers so it may safely be trusted to give a truer picture of telescopic performance than mere hearsay. The formulas listed have been time tested in some cases for centuries and can be relied upon to guide you unfailingly toward the size and type of telescope which will best suit you, your lifestyle and observing.

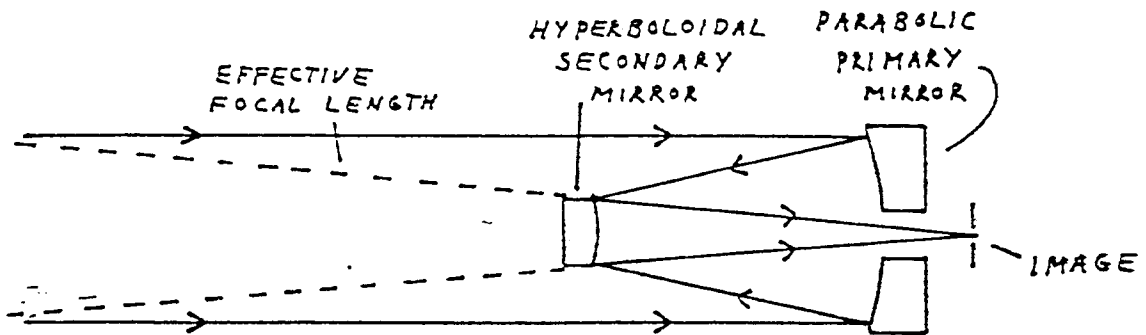
OPTICAL CONFIGURATIONS OF
COMMON ASTRONOMICAL TELESCOPES



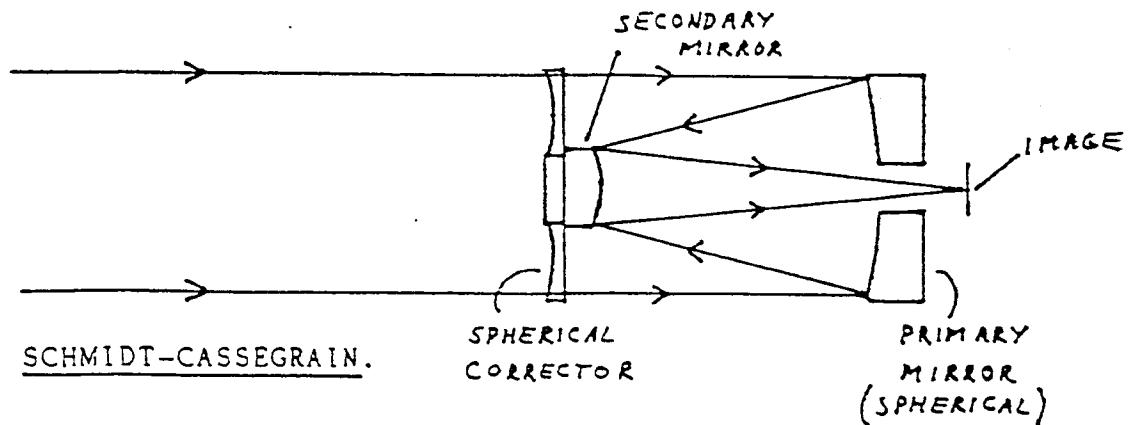
REFRACTOR.



NEWTONIAN REFLECTOR (Incl. DOBSONIAN).



CASSEGRAIN REFLECTOR.



SCHMIDT-CASSEGRAIN.