Know your telescope

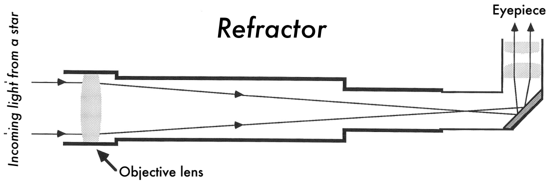
Galileo discovered the four major moons of Jupiter (forever after called the Galilean satellites *in his honor); he was the first to see the phases of Venus and the rings of Saturn; he saw nebulae and clusters through a telescope for the first time. In fact, a careful checking of his observations indicates that he even observed, and recorded, the position of Neptune almost 200 years before anyone realized it was a planet. He did all this with a 1" aperture telescope.*

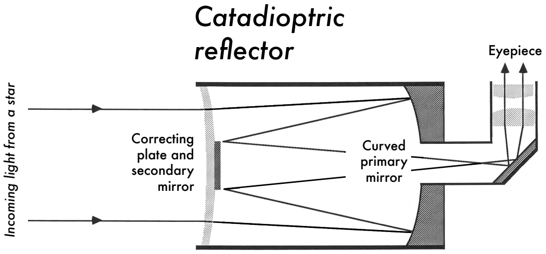
Charles Messier, who found the hundred deep-sky objects in the catalog that bears his name, started out with a 7" reflector with metal mirrors so poor that, according to one account, it was not much better than a modern 3" telescope. His later instruments were, in fact, 3" refractors.

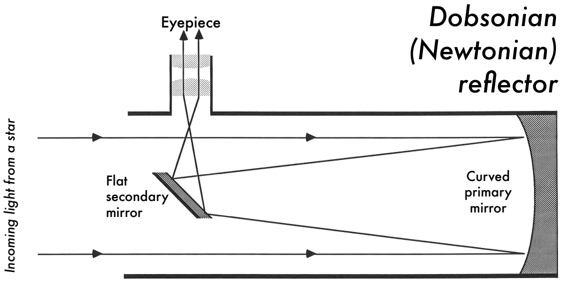
The point is this: there are no bad telescopes. No matter how inexpensive or unimpressive your instrument is, it is almost certainly better than what Galileo had to work with. It should be treated well. Don't belittle it; don't apologize for it; don't think it doesn't deserve a decent amount of care.

Get to know your optics

An astronomical telescope has two very different jobs. It must make dim objects look brighter; and it must make small objects look bigger. A telescope accomplishes these jobs in two stages. Every telescope starts with a big lens or mirror called the *objective*. This lens or mirror is designed to catch as much light as possible, the same way a bucket set out in the rain catches rainwater. (Some astronomers refer to their telescopes as "light-buckets.") Obviously, the wider this lens or mirror is, the more light it can catch; and the more light it catches, the brighter it can make dim objects appear. Thus, the first important measurement you should know about your telescope is the diameter of the objective. That's called the *aperture*.


Refractor


Catadioptric reflector


Dobsonian (Newtonian) reflector

If your telescope uses a lens to collect light, it's called a *refractor*; if it uses a mirror, it's called a *reflector*. In a refractor, the light is refracted, or bent, by a large lens called the objective lens. In a reflector, the light is reflected from the primary mirror, sometimes called the objective mirror, to a smaller mirror sitting in front of the objective, called the secondary mirror. In both cases, the light bent by the objective is further bent by the eyepiece lens, to make an image that can be seen by your eye.

A reflector where the light is sent back through a hole in the main mirror is a *Cassegrain* reflector. *Catadioptric* reflectors have, in addition, a lens in front of the primary mirror that allows the telescope tube to be much shorter. A specific catadioptric design that works well for amateurs is one called the *Maksutov* reflector; bigger Cats often use a slightly different design, called a *Schmidt*.

A reflecting telescope in which the secondary mirror bounces the light sideways through a hole near the top of the telescope tube is a *Newtonian* reflector. The most popular amateur version of the Newtonian design nowadays is the *Dobsonian*, a Newtonian with a simple but elegant alt-azimuth mount invented by John Dobson.

The primary mirror (or, in a refractor, the objective lens) bends the light to concentrate it down to a small bright image at a point called the *focal point*. The light has to travel a certain distance from the objective until it is fully concentrated at this point; this distance is called the *focal length*.

The small, bright image made by the objective seems to float in space at the focal point. Put a sheet of paper at that spot (or piece of film, or a photographic CCD chip, or a slice of ground glass) and you can actually see the little image that the objective makes. This is what's called the *prime focus* of the telescope. If you attach a camera body there, with the camera lens removed, you can take a picture. The telescope is then just a large telephoto lens for the camera.

The second stage of the telescope is the eyepiece. One way to describe how the eyepiece works is to think of it as acting like a magnifying glass, enlarging the tiny image that the objective lens makes at the focal point. Different eyepieces give you different magnifications. The shorter the eyepiece focal length, the higher the magnifying power – but with a fainter image, and a smaller field of view. You'll find yourself using high power less often than you might think.

Get to know your tripod

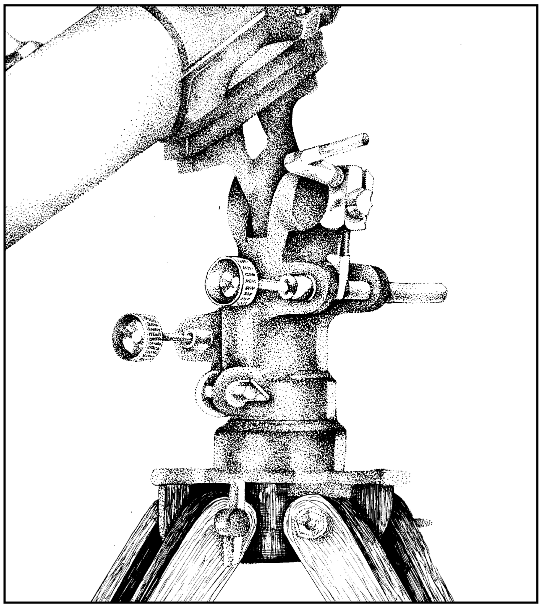
Small telescopes often come on a tripod similar to a camera tripod, which lets you tilt the scope up and down or turn it left and right. The up–down direction is the *altitude*; swiveling left and right moves you through the *azimuth*. Such a mount is called an *alt-azimuth mount*. For a small telescope, this is a perfectly reasonable sort of mount. This type of mount is lightweight, requires no special alignment, and it's easy to use since all you have to do is point the telescope wherever you want to look.

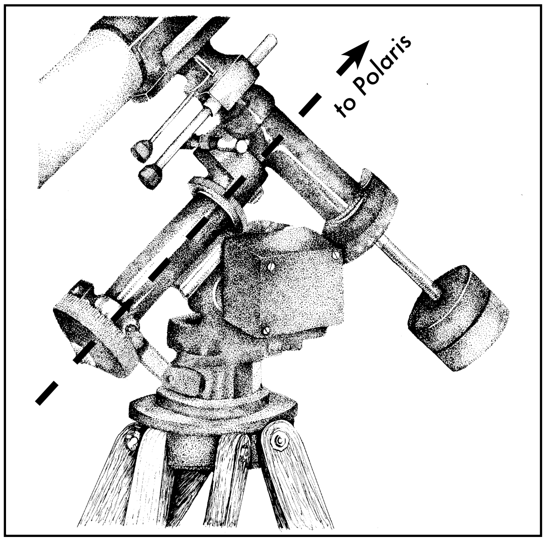
A popular, inexpensive variant of the alt-azimuth mount is the *Dobsonian*. Instead of a tripod supporting the center of the telescope tube, a Dobsonian is mounted near the bottom, where the mirror sits. Two design features keep the telescope from tipping over: the base is made especially heavy (and the heaviest part of the telescope itself is the mirror, which is already down at that end in a Newtonian design) and the tube is made of some lightweight material. Also adding to the low cost and simplicity of use, the two axes that the telescope moves about to point at stars have Teflon friction pads, which (when they're tightened just right) let you move the telescope from position to position, but hold it in place when you let go. (For more about Dobs, see page 245.)

Once you're focused in on an object in the sky, you'll discover that the stars move slowly out of your field of view. Using an alt-azimuth mount, you have to constantly correct in both directions; as the object you're looking at goes from east to west, it also moves higher or lower in the sky. With a little thought it's not hard to understand why. The stars are rising in the east and setting in the west, and so they're slowly moving across the sky. What's really happening, of course, is that the Earth is spinning, carrying us from one set of stars to another.

To correct for this motion, a fancier type of mount can be found (usually on bigger telescopes), called an *equatorial mount*. This can be thought of as an alt-azimuth mount, only tipped over. The axis that used to be pointing straight up now points towards the celestial north pole. (It is tilted from the vertical at an angle of 90° minus the latitude where you're observing.) It's called the *equatorial axis*. With this sort of mount, you can just turn the telescope about this tipped axis in the direction opposite to the Earth's spin, and so keep the object you're observing centered in the telescope.

You can even attach a motor to turn the telescope for you. The motor is called a *clock drive;* it turns the telescope about the tipped axis at half the speed of the hour hand on a clock. Thus, it makes one rotation every day (actually, every 23 hours 56 minutes, since the stars rise four minutes earlier every night).





There are two basic types of mount, the alt-azimuth (top) and the equatorial (bottom). The equatorial mount is effectively an alt-azimuth mount which has been tilted so that one axis turns with the Earth.

The extra tip of the equatorial axis can make it awkward at first to find what you're looking for, however. And, depending on the design of the mount, it may shove the telescope off to one side of the tripod. The telescope's weight then has to be balanced out by heavy counterweights. That makes this sort of mount quite burdensome to lug around.

If your telescope does have an equatorial mount, the first thing you must do when you go observing is to make sure you set up the tripod in the right direction; the equatorial axis must be lined up with the spin axis of the Earth. Conveniently for folks in the northern hemisphere, the Earth's axis has pointed (for the past thousand years or so) at a spot very close to a bright star called Polaris. So all you have to do is make sure that the equatorial axis of your tripod is pointing straight at Polaris. But remember, every time you set up the telescope you've got to line it up again!

(Southern-hemisphere observers are out of luck; there is no south polar star.)

If you are planning to use your telescope with a motorized drive to take time-exposure astrophotographs, you'll need more careful alignment. But for casual observing, lining up on Polaris is quite good enough.

Basic telescope math

Learning to calculate the magnification, resolution, or other properties of your telescope is a great way to get to know in detail what it is capable of doing. But be sure you use consistent measurement units: divide millimeters by millimeters, or inches by inches; don't mix them up!

A = **aperture** of telescope (mm): the diameter of the primary mirror of a reflector or the objective lens of a refractor

L_T = **focal length** of telescope (mm): the distance from the main mirror or lens of a telescope to where light from a star is focused to a point

L_E = **focal length** of eyepiece (mm): the distance from the eyepiece lens to where distant light is focused to a point

f = **focal ratio** of telescope = L_T/A

M = **magnification** = L_T/L_E

R = **resolution**, the smallest angle (in arc seconds) the telescope can see

V_A = **apparent field of view**: the angular size (in degrees) of the circle of light you can see when you hold an eyepiece to your eye

We measure the sizes of astronomical objects in arc seconds, arc minutes, and degrees. One degree is sixty arc minutes, written 60'; and each arc minute is 60 arc seconds, or 60". The full Moon is half a degree (30', 30 arc minutes) in size. The planetary nebulae in this book are typically about one arc minute across. An easy double star like Albireo has a separation of about half an arc minute, or 30" (30 arc seconds).

Resolution

$$\begin{aligned} R &\approx 120/A \quad (A \text{ in mm}) \\ &\approx 4.5/A \quad (A \text{ in inches}) \end{aligned}$$

Resolution is the measure of how much detail your telescope can make out. It determines how far apart two members of a double star must be before you can see them as individual stars, and limits how much detail you can see on the surface of a planet.

Resolution is measured in terms of the smallest angular distance (in arc seconds) between two points that can just barely be seen as individual spots in the telescope image – for example, the separation of a close "cat's-eyes" pair of double stars.

There is a theoretical limit (resulting from the wave nature of light) to how much detail any telescope can resolve, which is approximated by the formula given above. Assuming good conditions, a telescope with a 60 mm wide objective mirror should be able to resolve a double star with a separation of 2 arc seconds. In practice, of course, you'd need very steady skies to do so well.

By this formula, an 8" Dobsonian should have a resolution limit of just over half an arc second. But in reality, that never happens. The general unsteadiness of the sky, even on the best of nights, means an amateur observer generally can't expect to do better than a 1 arc second resolution.

In some cases, the human eye is clever enough to get around this resolution limit. The eye can pick out an object that is narrower than the resolution limit in one direction, but longer than that limit in another direction, especially if there's a strong brightness contrast. The Cassini Division in the rings of Saturn is an example.

You can identify double stars that are a bit closer than the resolution limit if the two stars are of similar brightness; the double will look like an elongated blob of light. On the other hand, if one star is very much brighter than the other, you may need considerably more than the theoretical separation before your eye notices the fainter star. Experience helps.

The easiest way to determine a focal length is simply to find the numbers written on the side of your telescope or eyepiece. The eyepiece to the left has a focal length of 25 mm; the lens/mirror combination of the Maksutov telescope on the right has a combined effective focal length of 1000 mm. It's important in any calculations to use the same unit of length – usually millimeters – for all lengths.

Note that this telescope also tells you its aperture – 90 millimeters, hence the name "C 90" – and the f *ratio, f/11, which is (roughly) 1000 divided by 90. Using the 25 mm eyepiece in this telescope would give you a magnification of 40× (i.e. 1000 ÷ 25).*

Magnification

$M = L_{\text{telescope}}/L_{\text{eyepiece}}$

To find the magnification you get with any of your eyepieces, take the focal length of your objective lens, and divide it by the focal length of the eyepiece (usually written on its side).

Be sure both numbers are in the same units. Nowadays, most eyepieces list their focal length in millimeters, so you must also find the focal length of your objective lens in millimeters.

For instance, with a telescope whose objective has a focal length of 1 meter (that's 100 cm, or 1000 mm), an eyepiece with a focal length of 20 mm gives a power of 1000 ÷ 20, or 50× (50 power). A 10 mm eyepiece would give this telescope a magnification of 100×. When you're making this calculation, don't confuse focal length with aperture!

$$M_{\max} \approx 2.5 \times A \quad (A \text{ in mm})$$
$$\approx 60 \times A \quad (A \text{ in inches})$$

Maximum useful magnification is a consequence of your telescope's *resolution*. The image formed by a telescope's primary lens or mirror is never perfect, so there is a limit to how big you can magnify that image and see anything new. Looking through a telescope at extremely high magnification won't help any more than looking at a photograph in a newspaper with a magnifying glass lets you see any more detail. (A newspaper photo is made of little dots; a magnifying glass just shows the same dots looking bigger.) Once you've reached the limit of resolution in the original image, further magnification won't give you any more detail. Of course, even for a bigger telescope, the sky's unsteadiness limits your useful magnification to about 400×.

$$L_{\text{eyepiece}} < 7 \times f$$

Longest useful eyepiece: Low power eyepieces (the longer ones) gather light from a wider area of the sky. The lower the power, the wider the circle of light that comes out of the eyepiece: the "exit pupil." But the width of your own eye's pupil is about 7 mm (it gets smaller as you get older). An exit pupil wider than your eye's pupil is a waste, if your goal is to take advantage of your telescope's full aperture. Thus the longest useful eyepiece is just your eye's pupil diameter (i.e. 7mm) times the focal ratio (f) of the telescope.

Of course, there can be reasons to go to an even lower power, for instance to bring more of a large nebula into your field of view. However, in a Dob (or any reflector) if the power is too low, the shadow of the secondary mirror becomes visible as a dim spot in the middle of your view.

Focal ratio *f*

$f = L_{\text{telescope}} / A$

Focal ratios for refractors are typically large, *f*/12 to *f*/16. Catadioptric reflectors typically have *f*-ratios of *f*/8 to *f*/12. Newtonians, including Dobsonians, commonly have low *f*-ratios of *f*/4 to *f*/7.

The low *f*-ratio of Dobsonians is generally a good thing; it allows for large aperture in a relatively compact package, and it makes it easier to get beautiful views of diffuse deep-sky objects. But telescopes with low *f*-ratios have much greater problems with a field distortion called *coma*, which turns stars near the edge of the field from sharp points into blurry "v"shapes. Also, when *f* is small you need a more expensive eyepiece with a shorter focal length to get high magnifications to observe planets or double stars. And there is a limit to the longest useful eyepiece (minimum useful magnification) for small-*f* telescopes.

Field of view

$V = V_A / M$

The *field of view V* tells you how wide an area of the sky you can see in your eyepiece. When you hold a typical inexpensive eyepiece up to your eye, the field of view appears to be about 50° (the *apparent field*). Since the view through a telescope is magnified, the part of sky you can actually see using this eyepiece is equal to the eyepiece apparent field, divided by the magnification. Thus, a typical low-power eyepiece, about 35× or 40×, shows you roughly 80' of the sky; a similar medium power eyepiece (75×) gives you a 40' view, while a high power eyepiece (150×) should show you 20'. These are the values we assumed for our circles of low-power, medium-power, and high-power telescope views in this book.

Nowadays, most eyepieces that come with telescopes have apparent fields of view of about 50°. But even some modestly-priced eyepieces can range up to 70° apparent field, and special (expensive) designs give apparent views of up to 100°.

Thirty years ago, apparent fields of about 40° were more common. Thus, if you have an older eyepiece, you will see less of the sky than what we indicate here.

To estimate the field of view of an eyepiece, take it out of the telescope, hold it to your eye, and look through it at a bright lamp in a dim room. Move your head so that the lamp (looking like a blurry bright spot) appears at the edge of your field of view, then turn until it sweeps across to the opposite side of the eyepiece view. The angle you turn through is the eyepiece's apparent field of view.