1

Parlez-Vous "Telescope"?

Before the telescope, ours was a mysterious universe. Events occurred nightly that struck both awe and dread into the hearts and minds of early stargazers. Was the firmament populated with powerful gods who looked down upon the pitiful Earth? Would the world be destroyed if one of these deities became displeased? Eons passed without an answer.

The invention of the telescope was the key that unlocked the vault of the cosmos. Although it is still rich with intrigue, the universe of today is no longer one to be feared. Instead, we sense that it is our destiny to study, explore, and embrace the heavens. From our backyards we are now able to spot incredibly distant phenomena that could not have been imagined just a generation ago. Such is the marvel of the modern telescope.

Today's amateur astronomers have a wide and varied selection of equipment from which to choose. To the novice stargazer, it all appears very enticing but also very complicated. One of the most confusing aspects of amateur astronomy is telescope vernacular—terms whose meanings seem shrouded in mystery. "Do astronomers speak a language all their own?" is the cry frequently echoed by newcomers to the hobby. The answer is yes, but it is a language that, unlike some foreign tongues, is easy to learn. Here is your first lesson.

Many different kinds of telescopes have been developed over the years. Even though their variations in design are great, all fall into one of three broad categories according to how they gather and focus light. *Refractors,* shown in Figure 1.1a, have a large lens (the *objective*) mounted in the front of the tube to perform this task, whereas *reflectors,* shown in Figure 1.1b, use a large mirror (the *primary mirror*) at the bottom of the tube. The third class of telescope, called *catadioptrics* (Figure 1.1c), places a lens (here called a *corrector plate*) in front of the primary mirror. In each instance, the telescope's *prime*

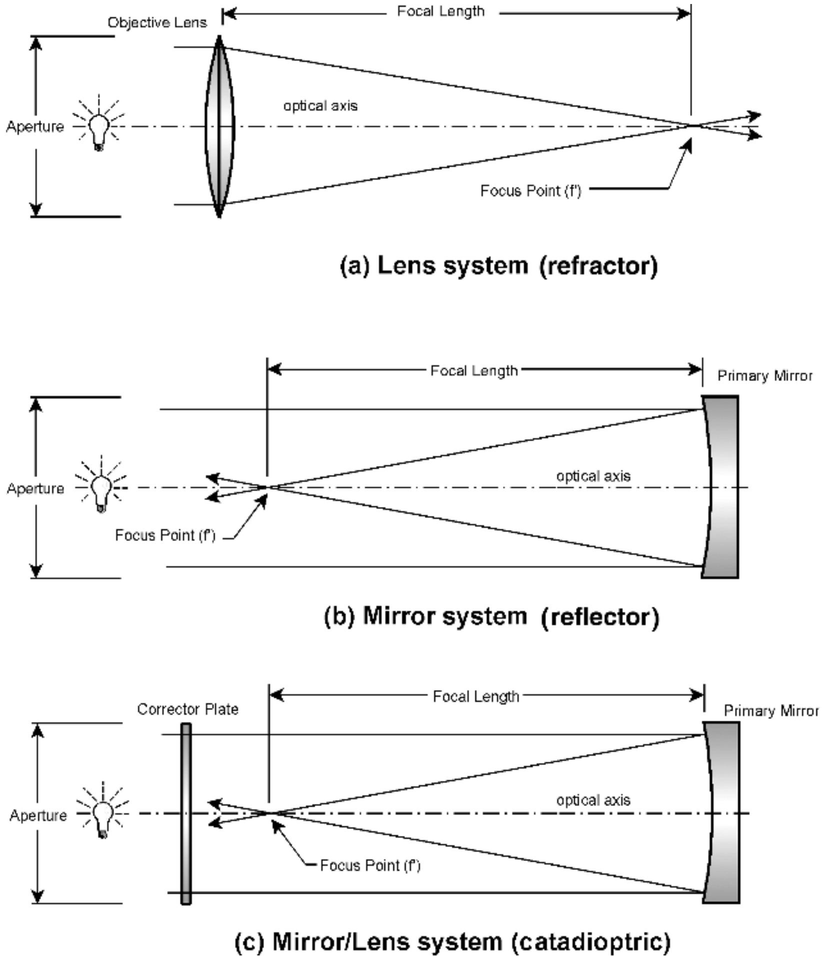

Figure 1.1 *The basic principles of the telescope. Using a lens (a), a mirror (b), or (c) a combination, a telescope bends parallel rays of light to a focus point, or prime focus.*

optic (objective lens or primary mirror) brings the incoming light to a *focus* and then directs that light through an *eyepiece* to the observer's waiting eye. Although chapter 2 addresses the history and development of these grand instruments, we will begin here by exploring the many facets and terms that all telescopes share. As you read through the following discussion, be sure to pause and refer to the telescope diagrams found in chapter 2. This way, you can see how individual terms relate to the various types of telescopes.

Aperture

Let's begin with the basics. When we refer to the size of a telescope, we speak of its *aperture*. The aperture is simply the diameter (usually expressed in inches, centimeters, or millimeters) of the instrument's prime optic. In the case of a refractor, the diameter of the objective lens is cited, whereas in reflectors and catadioptric instruments, the diameters of their primary mirrors are specified. For instance, the objective lens in Galileo's first refractor was about 1.5 inches in diameter; it is therefore designated a 1.5-inch refractor. Sir Isaac Newton's first reflecting telescope employed a 1.3-inch mirror and would be referred to today as a 1.3-inch Newtonian reflector.

Many amateur astronomers consider aperture to be the most important criterion when selecting a telescope. In general (and there are exceptions to this rule, as pointed out in chapter 3), the larger a telescope's aperture, the brighter and clearer the image it will produce. And that is the name of the game: sharp, vivid views of the universe.

Focal Length

The *focal length* is the distance from the objective lens or primary mirror to the *focal point* or *prime focus,* which is where the light rays converge. In reflectors, this distance depends on the curvature of the telescope's mirrors, with a deeper curve resulting in a shorter focal length. The focal length of a refractor is dictated by the curves of the objective lens as well as by the type of glass used to manufacture the lens. In catadioptric telescopes, the focal length depends on the combined effect of the primary and secondary mirrors' curves.

As with aperture, focal length is commonly expressed in inches, centimeters, or millimeters.

Focal Ratio

When looking through astronomical books and magazines, it is not unusual to see a telescope specified as, say, an 8-inch f/10 or a 15-inch f/5. This f-number is the instrument's *focal ratio,* which is simply the focal length divided by the aperture. Therefore, an 8-inch telescope with a focal length of 56 inches would have a focal ratio of f/7, because $56 \div 8 = 7$. Likewise, by turning the expression around, we know that a 6-inch f/8 telescope has a focal length of 48 inches, because $6 \times 8 = 48$.

Readers familiar with photography may already be used to referring to lenses by their focal ratios. In the case of cameras, a lens with a faster focal ratio (that is, a smaller f-number) will produce brighter images on film, thereby allowing shorter exposures when shooting dimly lit subjects. The same is true for telescopes. Instruments with faster focal ratios will produce brighter images on film, thereby reducing the exposure times needed to record faint objects. However, a telescope with a fast focal ratio will *not* produce brighter images when used visually. The view of a particular object through, say, an 8-inch f/5 and an 8-inch f/10 will be identical when both are used at the same magnification. How bright an object appears to the eye depends only on telescope aperture and magnification.

Magnification

Many people, especially those new to telescopes, are under the false impression that the higher the magnification, the better the telescope. How wrong they are! It's true that as the power of a telescope increases, the apparent size of whatever is in view grows larger; but what most people fail to realize is that at the same time, the images become fainter and fuzzier. Finally, as the magnification climbs even higher, image quality becomes so poor that less detail will be seen than at lower powers.

It is easy to figure out the magnification of a telescope. If you look at the barrel of any eyepiece, you will notice a number followed by *mm.* It might be 25 mm, 12 mm, or 7 mm, among others; this is the focal length of that particular eyepiece expressed in millimeters. Magnification is calculated by dividing the telescope's focal length by the eyepiece's focal length. Remember to first convert the two focal lengths into the same units of measure—that is, both in inches or both in millimeters. (There are 25.4 millimeters in an inch.)

For example, let's figure out the magnification of an 8-inch f/10 telescope with a 25-mm eyepiece. The telescope's 80-inch focal length equals 2,032 mm ($80 \times 25.4 = 2{,}032$). Dividing 2,032 by the eyepiece's 25 mm focal length tells us that this telescope/eyepiece combination yields a magnification of 81× (read 81 *power*), because $2{,}032 \div 25 = 81$.

Most books and articles state that magnification should not exceed 60× per inch of aperture. This is true only under *ideal* conditions, something most observers rarely enjoy. Due to atmospheric turbulence (what astronomers call *poor seeing*), interference from artificial lighting, and other sources, many experienced observers seldom exceed 40× per inch. Some add the following caveat: never exceed 300× even if the telescope's aperture permits it. Others insist there is nothing wrong with using more than 60× per inch, as long as the sky conditions and optics are good enough. As you can see, the issue of magnification is always a hot topic of debate. My advice for the moment is to use the lowest magnification required to see what you want to see, but we are not done with the subject just yet. Magnification will be spoken of again in chapter 5.

Light-Gathering Ability

The human eye is a wondrous optical device, but its usefulness is severely limited in dim lighting conditions. When fully dilated under the darkest circumstances, the pupils of our eyes expand to about a quarter of an inch, or 7 mm, although this varies from person to person—the older you get, the less your pupils will dilate. In effect, we are born with a pair of quarter-inch refractors.

Telescopes effectively expand our pupils from fractions of an inch to many inches in diameter. The heavens now unfold with unexpected glory. A telescope's ability to reveal faint objects depends primarily on the area of its objective lens or primary mirror (in other words, its aperture), not on magnification; quite simply, the larger the aperture, the more light gathered. Recall from school that the area of a circle is equal to its radius squared multiplied by pi (approximately 3.14). For example, the prime optic in a 6-inch telescope has a light-gathering area of 28.3 square inches (since $3 \times 3 \times 3.14 = 28.3$). Doubling the aperture to 12 inches expands the light-gathering area to 113.1 square inches, an increase of 300%. Tripling it to 18 inches nets an increase of 800%, to 254.5 square inches.

A telescope's *limiting magnitude* is a measure of how faint a star the instrument will show. Table 1.1 lists the faintest stars that can be seen through some popular telescope sizes and is derived from the formula*:

$$\text{Limiting magnitude} = 9.1 + 5 \log D$$

where D = aperture.

Trying to quantify limiting magnitude, however, is anything but precise. Just because, say, an 18-inch telescope might see 15th-magnitude stars, it cannot see 15th-magnitude galaxies because of a galaxy's extended size. A deep-sky object's visibility is more dependent on its surface brightness, or magnitude per unit area, rather than on total integrated magnitude, as these numbers represent. Other factors affecting limiting magnitude include the quality of the telescope's optics, seeing conditions, light pollution, excessive magnification, and the observer's vision and experience. These numbers are conservative estimates; experienced observers under dark, crystalline skies can better these by half a magnitude or more.

Table 1.1 ***Limiting Magnitudes***

Telescope Aperture		
Inches	**Millimeters**	**Faintest Magnitude**
2	51	10.6
3	76	11.5
4	102	12.1
6	152	13.0
8	203	13.6
10	254	14.1
12.5	318	14.6
14	356	14.8
16	406	15.1
18	457	15.4
20	508	15.6
24	610	16.0
30	762	16.5

*There are many formulas for calculating a telescope's limiting magnitude. In practice, I have found this one, from *Amateur Astronomer's Handbook* by J. B. Sidgwick, to be closest to reality. Sidgwick's formula is based on a naked-eye limiting magnitude of 6.5.

Resolving Power

A telescope's *resolving power* is its ability to see fine detail in whatever object at which it is aimed. Although resolving power plays a big part in everything we look at, it is especially important when viewing subtle planetary features, small surface markings on the Moon, or searching for close-set double stars.

A telescope's ability to resolve fine detail is always expressed in terms of *arc-seconds*. You may remember this term from high school geometry. Recall that in the sky there are 90° from horizon to the overhead point, or zenith, and 360° around the horizon. Each one of those degrees may be broken into 60 equal parts called *arc-minutes*. For example, the apparent diameter of the Moon in our sky may be referred to as either 0.5° or 30 arc-minutes, each one of which may be further broken down into 60 arc-seconds. Therefore, the Moon may also be sized as 1,800 arc-seconds.

Regardless of the size, quality, or location of a telescope, stars will never appear as perfectly sharp points. This is partially due to atmospheric interference and partially due to the fact that light is emitted in waves rather than mathematically straight lines. Even with perfect atmospheric conditions, what we see is a blob, technically called the *Airy disk,* which was named in honor of its discoverer, Sir George Airy, Britain's Astronomer Royal from 1835 to 1892.

Because light is composed of waves, rays from different parts of a telescope's prime optic (be it a mirror or a lens) alternately interfere with and enhance one another, producing a series of dark and bright concentric rings around the Airy disk (Figure 1.2a). The whole display is known as a *diffraction pattern*. Ideally, through a telescope without a central obstruction (that is, without a secondary mirror), 84% of the starlight remains concentrated in the central disk, 7% in the first bright ring, and 3% in the second bright ring, with the rest distributed among progressively fainter rings. Figure 1.2b graphically presents a typical diffraction pattern. The central peak represents the bright central disk, whereas the smaller humps show the successively fainter rings.

The apparent diameter of the Airy disk plays a direct role in determining an instrument's resolving power. This becomes especially critical for observations of close-set double stars. Just like determining a telescope's limiting magnitude, how close a pair of stars will be resolved in a given aperture depends on many variables, but especially on the optical quality of the telescope as well as on the sky. Based on the formula*:

$$\text{resolution} = 5.45 \div D$$

where D = aperture in inches.

Table 1.2 summarizes the results for most common amateur-size telescopes.

Although these values would appear to indicate the resolving power of the given apertures, some telescopes can actually exceed these bounds. The nineteenth-century English astronomer William Dawes found through experimentation that the closest a pair of 6th-magnitude yellow stars can be

*Also from *Amateur Astronomer's Handbook* by J. B. Sidgwick.

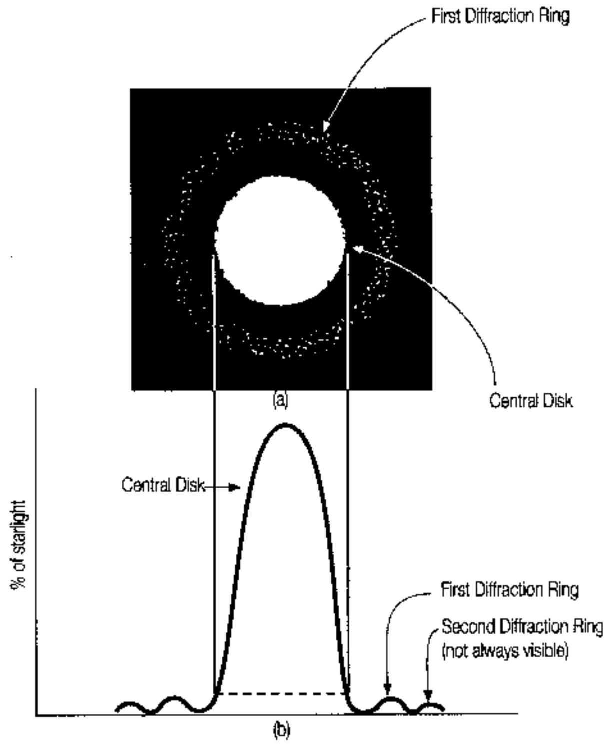

Figure 1.2 *The Airy disk (a) as it appears through a highly magnified telescope and (b) graphically showing the distribution of light.*

Table 1.2 ***Resolving Power***

Telescope Aperture		Resolution Threshold
Inches	Millimeters	(theoretical) arc-seconds
2	51	2.7
3	76	1.8
4	102	1.4
6	152	0.91
8	203	0.68
10	254	0.55
12.5	318	0.44
14	356	0.39
16	406	0.34
18	457	0.60
20	508	0.27
24	610	0.23
30	762	0.18

to each other and still be distinguishable as two points can be estimated by the formula:

$$4.56 \div D$$

where D = aperture in inches.

This is called *Dawes' Limit* (Figure 1.3).

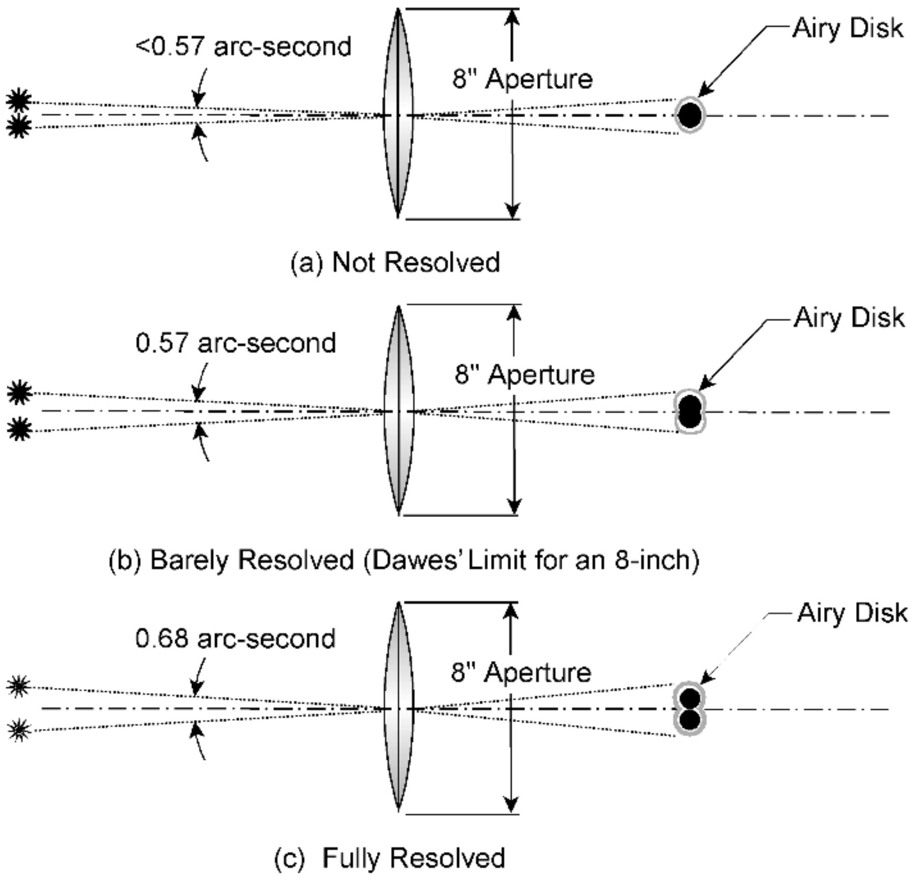

Figure 1.3 *The resolving power of an 8-inch telescope: (a) not resolved, (b) barely resolved, or the Dawes' Limit for the aperture, and (c) fully resolved.*

Table 1.3 ***Dawes' Limit***

Telescope Aperture		Resolution Threshold
Inches	**Millimeters**	**(theoretical) arc-seconds**
2	51	2.3
3	76	1.5
4	102	1.1
6	152	0.76
8	203	0.57
10	254	0.46
12.5	318	0.36
14	356	0.33
16	406	0.29
18	457	0.25
20	508	0.23
24	610	0.19
30	762	0.15

Table 1.3 lists Dawes' Limit for some common telescope sizes.

When using telescopes less than 6 inches in aperture, some amateurs can readily exceed Dawes' Limit, while others will never reach it. Does this mean that they are doomed to be failures as observers? Not at all! Remember that Dawes' Limit was developed under very precise conditions that may have been far different than your own. Just as with limiting magnitude, reaching Dawes' Limit can be adversely affected by many factors, such as turbulence in our atmosphere, a great disparity in the test stars' colors and/or magnitudes, misaligned or poor quality optics, and the observer's visual acuity.

Rarely will a large aperture telescope—that is, one greater than about 10 inches—resolve to its Dawes' Limit. Even the largest backyard instruments can almost never show detail finer than between 0.5 arc-second (abbreviated 0.5″) and 1 arc-second (1″). In other words, a 16- to 18-inch telescope will offer little additional detail compared with an 8- to 10-inch telescope when used under most observing conditions—although the larger telescope will enhance an object's color. Interpret Dawes' Limit as a telescope's equivalent to the projected gas mileage of an automobile: "These are test results only—your actual numbers may vary."

We have just begun to digest some of the multitude of existing telescope terms. Others will be introduced in the succeeding chapters as they come along, but for now, the ones we have learned will provide enough of a foundation for us to begin our journey.