

Chapter 5

Reflecting Telescopes

Newtonian

The severe color aberrations of the early single-lens refractors soon led to the invention of the *Newtonian reflector* by Sir Isaac Newton. This form uses a concave parabolic (or spherical) primary mirror to collect light and bring it to a focus. Since the light never passes through the glass mirror but only bounces off of its reflecting surface, the image has no spurious color. The mirror is located at the bottom of the telescope tube rather than at the top, so the converging light cone is turned 90° by a small flat mirror (or diagonal) before it exits the tube and reflected through the side where it comes to a focus. All of the world's great observatory telescopes are reflectors of one form or another, including the famed 200-in. Hale reflector at Palomar and the twin Keck 400-in. reflectors in Hawaii. So too is the 94-in. orbiting Hubble Space Telescope. (And the two “monster telescopes” now on the drawing boards having apertures of 1,200 and 1,600 in. will also be reflectors!) This is partly because their huge mirrors can be supported from behind (instead of around the edge, as with refractors). It's also due to the fact that the glass itself does not need to be of “optical” quality, since the light merely reflects off its polished and coated surface rather than passing through the glass itself (again, as is the case with refractors) (Fig. 5.1).

While reflectors don't suffer from such *color aberration*, they do have a malady known as *coma*—a comet-like flaring of images the further from the center of the field of view they are. Focal ratios for Newtonians range from $f/4$ (and as low as $f/1$ for some professional instruments to keep them as short as possible) to $f/8$ or even $f/10$ in amateur scopes. The shorter the focal ratio, the worse is the coma. In the

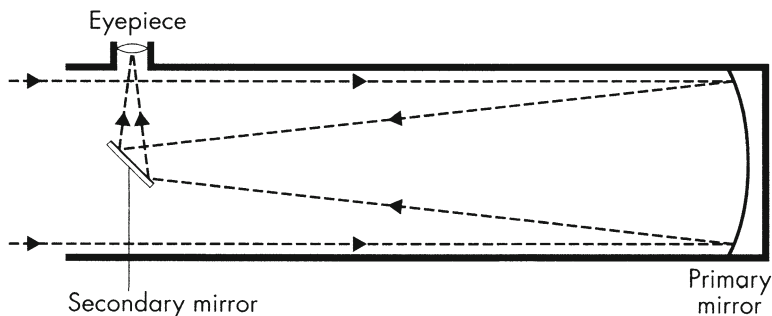


Fig. 5.1 The optical configuration and light-path of the classical Newtonian reflecting telescope. A parabolic primary mirror reflects the light onto a small flat secondary one, which directs it to a focus at the side of the tube. Most of the world’s large research telescopes are various forms of reflectors

longer lengths, it’s hardly noticeable over a typical 1° eyepiece field. Also, due to another optical defect known as *spherical aberration* (discussed in Chap. 4 under early refractors), the steeply curving surface of a short-focus primary mirror has to be parabolic in order to bring all the light rays it reflects to the same focus. But as focal length increases and the curvature of the mirror become flatter, the departure between a parabola and sphere are less distinguishable. Thus, at some point, the mirror may then be left spherical (a much easier optical surface to make) and give essentially identical optical performance to a parabolic one. It’s often stated that as a general rule the focal ratio should be $f/10$ for this to happen. But the actual value depends on—and increases with—aperture, optical theory requiring less than $f/8$ for a 4.5-in., around $f/9$ for an 8-in., and just under $f/10$ itself for a 10-in.

There’s often much discussion about the surface accuracy of telescope mirrors. To satisfy the well-known Raleigh Criterion for “diffraction-limited” performance (the point at which image quality is limited by the diffraction nature of light itself rather than optical quality) the *wavefront* errors must be $1/4$ th of a wavelength of light or less. Since light first enters and then leaves a mirror’s surface, surface errors are compounded—meaning the optics themselves must be figured to at least $1/8$ th-wave to achieve $1/4$ th-wave at focus (Wavelength accuracy in refractors is rarely mentioned. While there are four or more surfaces involved in their objectives—the front and back of each of the elements—the light traverses each of them only once. The surface errors averaged over the elements tend to cancel each other rather than being additive. Thus, a lens with surfaces figured to $1/4$ th wave will still meet the Raleigh Criterion for total allowable wavefront error.) (Fig. 5.2).

Entry level reflectors are available from a number of manufacturers in 3-, 4- and 4.5-in. apertures at prices in the \$100–\$300 range. Among these are Celestron, Edmund Scientifics, Konos, Orion and Pacific Telescope. Some have parabolic primaries and others spherical ones, in both cases providing acceptable views of the Moon, planets and brighter deep-sky objects. Unfortunately, some have less than



Fig. 5.2 Orion's AstroView classical 6-in. Newtonian reflector, shown here on a German equatorial mount. The traditional focal ratio for a 6-in. long-preferred by telescope makers and observers was (and for many still is) $f/8$. But in a bid to make telescopes more compact and portable, shorter ones have appeared on today's market—as in this case, which is an $f/5$ system. Courtesy of Orion Telescopes & Binoculars

ideal mountings, which can be quite frustrating to the beginner. As with refractors, a simple lightweight altazimuth is preferred over a heavier and often clumsy equatorial for casual stargazing. One noteworthy beginner's reflector that has received great reviews in the astronomy magazines is Orion's StarBlast 4.5-in., which sells for \$200. It has an easy-to-use table-top Dobsonian mounting (see below) and is provided with magnifications of $26\times$ and $75\times$ —ideal powers for casual stargazing. While designed primarily with young observers in mind, many older amateurs are finding it fun to use as well—especially as a highly portable second telescope. (Its short $f/4$ focal ratio actually qualifies it as what is known as a “rich-field” telescope,

covered below.) Orion also offers a 4-in. table-top SkyScanner reflector for \$100 and a tripod-mounted version for \$200. Another affordable scope is its SpaceProbe 3—a 3-in. altazimuth reflector which goes for just \$130. (Orion frequently runs sales on its entry level scopes which reduces their prices by as much as \$20.)

A new development in beginner's scopes since the first edition is the introduction by both Orion and Celestron of a 3-in. table-top reflector selling for just \$50! Called the FunScope by the former and FirstScope by the latter, these low-power little scopes offer optical quality adequate enough to see the craters on the Moon and Jupiter's four bright satellites at 15 \times , plus reveal Saturn's rings with a higher power eyepiece. Both appear to come from the same overseas factory, which is often the case with entry-level reflectors, refractors and even some catadioptric instruments. (Foreign-made telescopes at all levels come mainly from China and Taiwan today).

Three very affordable beginner's-level reflectors from the 1950s and 1960s need special mention here. Despite the fact that they are no longer being made, they gave many stargazers their very first views of the heavens, and are still occasionally to be found on the used market today. These were Edmund's 3-in. $f/10$, Sky Scope's 3.5-in. $f/10$ and Criterion's 4-in. $f/11.7$ Dynascope. All used very basic materials including bakelite or treated cardboard tubes and simple but adequate mountings, making it possible to offer reasonably good optical performance at an unbeatable price (in the case of the first two scopes just \$30, and \$50 for the third one!). They are much-sought-after collector's items today. Another such instrument was Criterion's famed RV-6 Dynascope—a complete equatorially-mounted 6-in. reflector with electric drive and superb optics. Selling for \$200, this was really the first mass-produced quality commercial telescope aimed at the amateur astronomy and education market. It met with immediate wide acceptance and many hundreds—if not thousands of them—were sold!

Dobsonian

Another type of Newtonian that has become immensely popular with both telescope makers and observers alike in recent years is the *Dobsonian reflector*. Named after the famed "Sidewalk Astronomer" and telescope-maker John Dobson, a "dobsonian" is a type of mounting rather than a form of optical system. Essentially a basic altazimuth, homemade versions typically make use of simple materials such as plywood for the stand and Teflon strips for the bearings, as well as heavy cardboard tubing for the telescope itself. But there's more to Dobson's brainchild than this. He pioneered the use of very thin mirrors—typically only an inch or two thick and made of plate glass (he originally used ship portholes)—to make very large-aperture reflectors ranging all the way up to 24-in. This is a size unheard of in amateur hands until Dobson appeared on the scene! Another distinguishing feature of Dobsonians is their short focal ratios—typically $f/4$ to $f/5$, making them very compact for their huge apertures (Technically, this also qualifies them as rich-field telescopes—or RFT's, discussed below.) (Fig. 5.3).



Fig. 5.3 A fine example of a commercially available Dobsonian reflector—this one the 10-in. Starhopper by Celestron. These affordable instruments offer the most aperture-per-dollar and as such are immensely popular with stargazers today. Courtesy of Celestron

Dobsonian reflectors are now widely available commercially in sizes from as small as 4-in. all the way up to 36-in.! Coulter Optical Company introduced the first such instrument to the market in 1980 with their 13.1-in. f/4.5 Odyssey 1 for under \$500, followed by both smaller and larger models (including a 17.5-in. and a 29-in.!). Sadly, this firm is no longer in business, but many of its bulky but economically-priced telescopes remain in use today. Entry level “Dobs” are available from many sources including Celestron, Hardin, Orion and Sky-Watcher in apertures up to 12-in. with prices starting for under \$300 for a 6-in. Premium Dobsonians are offered by among others Discovery, Obsession and Starsplitter up to 30-in. in size and at prices as high as \$5,000. The views of deep-sky wonders like the Orion Nebula (M42/M43), the Hercules Cluster (M13) and the Andromeda Galaxy (M31) through a large-aperture Dobsonian (even a 10-in.) are quite spectacular, while those in 14-in. and bigger sizes being absolutely breathtaking! (Fig. 5.4)

A number of optical companies over the years manufactured traditional equatorially-mounted Newtonian reflectors in sizes up to 12.5 in. (and even larger upon special order), one of the best-known being Cave Optical Company and its famed Astrola series. The wide availability of relatively inexpensive, large-aperture



Fig. 5.4 Orion’s line of SkyQuest IntelliScope Dobsonian reflectors feature Push–Pull-To computerized technology to locate objects. The hand controller (seen here on the 8-in. model) indicates the location of a desired object while the observer moves the telescope until a “null” reading appears on the LCD display. Courtesy of Orion Telescopes & Binoculars

Dobsonian’s today has seen most of these firms either switch to other more compact forms of the reflector or discontinue making them altogether. Meade Instruments, for example, (mainly known for its catadioptric telescopes) used to offer a line of equatorially-mounted reflectors. It has since changed over to its highly-portable “LightBridge” Truss-Tube Dobsonians, with a 10-in. $f/5$ selling for \$700.

Rich-Field

As for refractors, *rich-field reflectors* provide the widest possible field of view for their aperture.

This is again achieved through very short focal ratios (typically $f/4$), which translate into low magnifications and expansive views. Two of the best-known such instruments on the market today are Edmund Scientifics’ 4.25-in. $f/4.2$ Astroscan-Plus (the upgraded Astroscan) and Orion’s 4.5-in. $f/4$ StarBlast (discussed above)—both having study table-top mountings at prices of \$290 and \$200, respectively. The former gives a 3° field at $16\times$ and the latter about a 2° field at $26\times$. The optics of both scopes are



Fig. 5.5 The 4.25-in. aperture Edmund Scientifics Astroscan is one of the best-selling small reflectors ever made and it remains one of the most popular RFTs (richest-field-telescope) on the market today. It's 16 \times eyepiece provides a wide 3 $^\circ$ field of view (or 6 full-Moon diameters of sky), and its unique optical window protects the system from dust as well as supports its diagonal mirror. Courtesy of Edmund Scientifics

good enough to support higher magnifications for viewing the Moon and planets. As mentioned earlier, the Astroscan features an optical window that seals the tube and supports the diagonal mirror. Its famed ball-shaped housing sits on an aluminum base with three support pads, creating in essence a very stable “universal joint” that easily points anywhere in the sky. Both telescopes weigh just 13 lb, and can be picked up and taken anywhere at a moment's notice. Note, however, that their table-top mounts do require a sturdy support on which to place them, such as a picnic table or car hood (The Astroscan-Plus is supplied with a thick circular rubber mat to protect the surface of whatever it's placed on. And it's also tripod-adaptable as well.) (Figs. 5.5 and 5.6).



Fig. 5.6 Orion's highly popular 4.5-in. StarBlast reflector, which is a Dobsonian-mounted RFT. While designed for table-top use by young stargazers as seen here, it's also being widely used by seasoned observers as a highly-portable second telescope! A 6-in. model is also now available. Courtesy of Orion Telescopes & Binoculars

Despite the coma inherent in all these short-focus reflecting systems, sweeping the heavens with them—especially the starclouds of the Milky Way and viewing big star clusters like the Pleiades (M45) or Beehive (M44)—is quite thrilling. And their low powers are still enough to see the Moon's surface features, the four bright Galilean satellites of Jupiter and other solar system wonders such as bright comets.

Cassegrain

Very soon after the reflecting telescope was invented by Newton, Guillaume Cassegrain introduced a modification called the *Cassegrain reflector*. Instead of the light being reflected to the side of the tube by a flat diagonal mirror, this arrangement substitutes a convex secondary which directs the converging light cone back

down the tube through a hole in the parabolic primary, where it comes to focus. But the light is not just folded upon itself—the secondary’s hyperbolic figure changes the angle of the converging beam as if it were coming from much further away. This increases the effective focal ratio of the primary by as much as a factor of 5, resulting in a very long focal length instrument compressed into a very short tube. This results in high magnifications for viewing (or imaging) the Moon and planets, and for other applications where a large image scale is desired.

As with refractors, Cassegrains must be carefully light-baffled in order to prevent the field of view from being flooded with light. The “glare stops” here are actually carefully machined and fitted flat-black tubing, mounted in front of both the secondary mirror and the central hole in the primary mirror. Having used classical Cassegrains ranging from 6- to 30-in. in aperture, the author has never been impressed with their image quality. Not only do they have limited fields of view due to their long effective focal lengths combined with strong field curvature, but the images themselves often seem to have a “softness” about them—certainly not like the crisp, sharp contrasty images of a refractor or a Newtonian reflector.

Many of the optical companies that traditionally offered Cassegrain reflectors commercially to the amateur astronomy market have switched instead to the Ritchey-Chretien form discussed below. Among the exceptions are Vixen Optics which makes models ranging from a 3.5-in. for \$300 up to a 10-in. for \$3,700. Optical Guidance Systems, which is best-known for its Ritchey-Chretien telescopes, offers a line of research-grade classical Cassegrains ranging from 10- to 32-in. in aperture. Prices begin around \$15,000 and their 24-in. goes for a whopping \$84,000. A third source is Parallax Instruments, which offers a 10-in. for \$6,000 up to a 16-in. for \$15,000. Note that in all three cases, prices quoted are for optical tube assemblies (OTA’s) only—no mounting being provided. Optical Guidance and Parallax can supply essentially custom-made mountings at significantly higher additional costs.

In a bid to offer the best of both worlds, a few manufacturers offer a combined Newtonian-Cassegrain system. An interchangeable or “flip” secondary mirror typically provides $f/4$ or $f/5$ wide-field, low-power performance in the Newtonian mode and high-power viewing at $f/10$ to $f/15$ or more in the Cassegrain form. These dual instruments tend to be quite pricy, since you’re essentially getting two telescopes in one. An example is Takahashi’s CN-212 (for Cassegrain-Newtonian), which is an 8.3-in. (212 mm aperture) $f/12$ Cassegrain with a replaceable secondary mirror that converts it into an $f/4$ Newtonian, that goes for over \$10,000. Another manufacturer is Parks Optical, which offers $f/4$ to $f/12$, $f/15$ or $f/18$ Newtonian-Cassegrains in apertures of 10-, 12.5- and 16-in. at prices of \$6,000, \$8,500 and \$32,000, respectively. Again, in all cases in which the author has used such hybrid instruments, the views at the Newtonian focus were far superior in terms of image sharpness and field of view than through the Cassegrain one.

As an aside here, the reader may wonder why glare stops/light baffling was not mentioned in discussing Newtonian reflectors. This is because in a Newtonian, the observer is looking into the darkened tube wall across the optical axis rather than

along it, as with refractors and Cassegrains. In other words, you are not looking skyward—which is where stray light enters the telescope. However, there’s an important point to be borne in mind in this regard when using a Newtonian. As you look into the eyepiece, you are also looking peripherally at the outer surface of the telescope tube as well, which typically has a glossy-white finish. Unfortunately, this makes it an excellent reflector of stray light from around the telescope, thereby reducing the dark adaptation of the eye (see Chap. 10). A flat-black screen made of poster board or other material placed around the focuser/eyepiece area is one solution. Another is to use a photographer’s cape to cover the head and the viewing end of the telescope. Actually, the best color for a telescope tube is red (or no color, i.e. black), which preserves the eye’s dark adaptation just as reading star charts with a red light does. (The author was involved as a consultant in the development and marketing of Edmund Scientifics’ Astroscan—and also the upgraded Astroscan-Plus—which is often referred to as the “red bowling ball.” It has an all-red exterior for just this very reason!)

Ritchey-Chretien

In an effort to improve the imaging quality of the classical Cassegrain reflector for photographic work, George Ritchey and Henri Chretien jointly developed a marvelous new system in the early 1900s known as the *Ritchey-Chretien*. Typically operating at effective focal ratios of $f/8$ or $f/9$, its hyperbolic primary and secondary mirrors give it both a larger and flatter field than an ordinary Cassegrain with total freedom from coma! And while it was originally developed for photographic (and more recent times CCD) imaging, a modernized version allows for excellent visual observing as well. Initially used by only a few select professional observatories, it has since become *the* system of choice for all major research telescopes built over the past several decades—including the giant twin 400-in. reflectors at the Keck Observatory and the Hubble Space Telescope itself.

Among the first to offer Ritchey-Chretien reflectors commercially for the serious amateur astronomer and small observatory market was Optical Guidance, with apertures from 10- to 32-in., as for its classical Cassegrains. Focal ratios are around $f/8$ to $f/9$ and prices range from \$15,000 to over \$84,000. Its chief competitor is RC Optical, whose line runs from 12.5- to 32-in. in aperture in focal ratios of $f/7$ to $f/9$, with costs in the same range as those of Optical Guidance. These premium telescopes are definitely for the affluent stargazer desiring an observatory-class instrument! Many of the most spectacular photographic and CCD images gracing the pages of the various astronomy magazines like *Sky & Telescope* over the past several years—some of which rival those taken with large research telescopes—have been obtained by amateur astronomers using Ritchey-Chretien systems. And visually, image quality is noticeably improved over that of a classical Cassegrain.

Dall-Kirkham

Another variation on the classical Cassegrain reflector is the Dall-Kirkham, invented by the optician Horace Dall in 1928 and subsequently promoted by the amateur astronomer Allan Kirkham. This form uses elliptical primary and spherical secondary mirrors, which are easier to figure than those in a standard Cassegrain, accounting for its popularity among amateur telescope makers. Its long effective focal ratios (typically $f/12$ or more) are great for lunar and planetary observing, but the system suffers from coma and strong curvature of field. Not widely available on the commercial telescope market, one source for Dall-Kirkham's is Takahashi. Its Mewlon series offers 7-, 8- and 10-in. models at hefty prices running up to \$10,000 and more.

Modified Cassegrain

Several variations on the Cassegrain arrangement have appeared over the years. One is the *coude* system, widely used by professional observatories in conjunction with both Cassegrain and Ritchey-Chretien reflectors. Here, a small flat tertiary or third mirror above the primary intercepts the converging light cone from the convex secondary and directs it down the telescope's polar axis. This makes it possible to keep the focal position fixed no matter where the telescope is pointed in the sky, and to feed the light into spectrographs and other instrumentation too large and heavy to be supported by the telescope itself. Also, extremely long effective focal lengths (ratios of $f/30$ or more) can be achieved while keeping the size of the telescope itself manageable.

Another variation is the *modified Cassegrain* form itself. Here, the third flat mirror directs the light out to the side of the tube near the bottom (with a fork mounting, usually located right above the balance point where the tube joins the axes). Both the *coude* and modified Cassegrain modes eliminate the need to perforate the primary unless desired, which is the system used on the famed 100-in. Hooker reflector at Mt. Wilson Observatory, which has no central opening in its huge mirror. By positioning the tertiary mirror in a fork mounted telescope so that it sends light through and just outside one of the axes themselves, it's possible to keep the eyepiece at a fixed elevation no matter where the instrument is pointed. Invented by James Nasmyth for use on his altazimuth-mounted 20-in. speculum-metal mirrored Newtonian-Cassegrain, this form is referred to as the *Nasmyth focus*. It's being extensively used today on many huge altazimuth fork-mounted observatory telescopes, including the two 400-in. Kecks, where light is fed into heavy instrumentation located just outside the fork arms. While a number of amateur telescope makers have built such systems in order to have a telescope at which they can remain seated comfortably while observing, there are currently no commercial *coude* or modified Cassegrain telescopes (other than custom-made ones) available. The modified

Cassegrain form has also been employed on catadioptric telescopes as well as reflectors. Fecker's superb 6-in. $f/15$ Celestar Maksutov-Cassegrain of the late 1950s was one such instrument, which sold for around \$500.

Off-Axis

All early reflectors used mirrors made of speculum metal rather than reflective coatings on glass, which came much later. In order to save light loss from the diagonal mirror in his reflectors, Sir William Herschel tilted their primary mirrors to direct the focus off to the side of the optical path at the top of the tube, where it was examined with an eyepiece. This form of unobstructed or *off-axis reflector* is known as the *Herschelian*. Several other designs using tilted primaries and extra mirrors to bring the light to a focus without having a secondary in the way have been devised by modern-day amateur telescope makers, one of the more unusual-looking being the so-called *Schiefspiegler*. All off-axis instruments must of necessity have long focal ratios (typically at least $f/10$) in order to tilt their primary mirrors sufficiently for this purpose.

In 2004, Orion introduced a 3.6-in. $f/13.6$ modified version of the Herschelian, where instead of viewing the image at the top of the tube directly with eyepiece in hand as Sir William did (quite impractical due to the small aperture), a flat mirror outside the incoming optical path reflects the light across the tube and outside of it to a standard focuser. The complete telescope sold for about \$1,000 and the optical tube assembly by itself for under \$700. But it has been dropped from its line apparently due to lack of interest by observers. Another source is DGM, which offers models ranging from 4- to 9-in. in aperture and focal ratios averaging around $f/10$. Their optical arrangement is similar to Orion's, but with the secondary mirror mounted off-axis right under the focuser itself rather than across the tube from it. Prices range from below \$1,000 to over \$3,000. Off-axis, unobstructed telescopes offer observers refractor-like performance with the color fidelity of a reflector—but at a significantly higher cost than for a basic Newtonian of similar aperture.