CHAPTER FIVE

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 its reflecting surface, the image has no spurious color. The converging light-cone reflected from the primary mirror at the bottom of the telescope tube is turned 90 degrees by a small optical flat (or diagonal mirror) before it exits the top and is reflected through the side, where it comes to a focus. All the world's great observatory telescopes today are reflectors of one form or another, including the legendary 200-inch Hale reflector at Palomar and the twin Keck 400-inch reflectors in Hawaii (and the famed Hubble Space Telescope). 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).

While reflectors don't suffer from color aberration, they do have a malady known as *coma* – a comet-like flaring of images that is more noticeable further from the center of the field of view. 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 the coma. In the longer lengths, it's hardly noticeable over a typical 1-degree eyepiece field. Also, because of another optical defect known as *spherical aberration* (discussed in Chapter 4 in connection with early refractors), the steeply curving surface of a short-focus primary mirror has to be parabolic in order to bring all

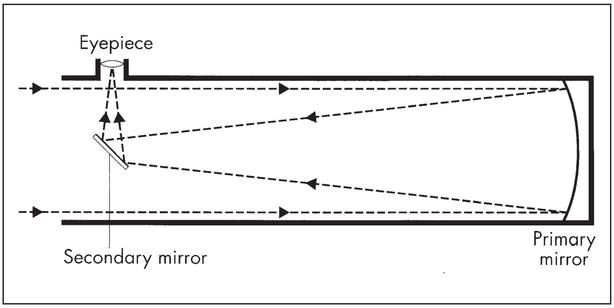

Figure 5.1. The optical configuration and light-path of the classical Newtonian reflecting telescope. A parabolic primary mirror reflects the light onto a small flat secondary one, which directs it to a focus at the side of the tube. Most of the world's large research telescopes are various forms of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

the reflected light rays to the same focus. But as focal length increases and the curvature of the mirror become flatter, the difference between a paraboloid and a sphere is less distinguishable. Thus, at some point, the mirror may then be left spherical (a much easier optical surface to make) but give an optical performance essentially identical to a parabolic one. It's often stated as a general rule that 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-inch, around f/9 for an 8-inch, and just under f/10 itself for a 10-inch.

There's often much discussion about the surface accuracy of telescope mirrors. To satisfy the well-known Rayleigh Criterion for diffraction-limited performance (the point at which image quality is limited by the wave nature of light itself rather than by optical quality), the *wavefront* errors must be $\frac{1}{4}$ of a wavelength of light or less. Since light first enters and then leaves a mirror's surface, surface errors are compounded – meaning that the optics themselves must be figured to at least $\frac{1}{8}$-wavelength to achieve $\frac{1}{4}$-wavelength at focus. (Wavelength accuracy in refractors is rarely mentioned. While in an achromat there are four surfaces – the front and back of each element – and six in a typical apochromat, the light transverses each surface only once. Surface errors averaged over the various elements tend to cancel each other out rather than being compounded. As a result, a lens with surfaces figured to $\frac{1}{4}$-wavelength will still meet the Rayleigh Criterion for total allowable wavefront error.)

Entry-level reflectors are available from a number of manufacturers in 3-, 4-, and 4.5-inch apertures at prices in the \$100 to \$300 range. Among these are Bushnell, Celestron, 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, they often have less than 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-inch, which currently sells for around \$175. It has an easy-to-use tabletop

Figure 5.2. Orion's AstroView classical 6-inch Newtonian reflector, shown here on a German equatorial mount. The traditional focal ratio for a 6-inch, 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.

Dobsonian mounting (see below) and provides magnifications of 26× and 75× – ideal powers for casual stargazing. While it was designed 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 a rich-field telescope or RFT, which is covered below.)

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. They were Edmund's 3-inch f/10, Sky Scope's 3.5-inch f/10, and Criterion's 4-inch f/12 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 a truly unbeatable price (in the case of the first two scopes just $30, and $50 for the third one!).

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 – essentially a basic altazimuth – rather than

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

a form of optical system. Home-made versions typically use 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 reflectors with very large apertures ranging all the way up to 24 inches. 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 RFTs, as discussed below.)

Dobsonian reflectors are now widely available commercially in sizes from as small as 4 inches all the way up to 36 inches! Coulter introduced the first such instrument to the market in 1980 with its 13.1-inch f/4.5 Odyssey-1 for under $500, followed by both smaller and larger models (including a 17.5-inch and a 29-inch!). Sadly, this firm is no longer in business, but many of its bulky but

Figure 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-inch model) indicates the location of a desired object while the observer moves the telescope until a "null" reading appears on the LCD display. Courtesty of Orion Telescopes & Binoculars.

economically-priced telescopes remain in use today. Entry level "Dobs" are available from many sources, including Bushnell, Celestron, Hardin, and Orion, in apertures up to 12 inches and with prices starting for under $300 for a 6-inch. Premium Dobsonians are offered by, among others, Discovery, Obsession, and Starsplitter up to 30 inches in size and at prices as high as $5,000. The views of deep-sky wonders such as the Orion Nebula (M42/M43), the Hercules Cluster (M13), and the Andromeda Galaxy (M31) through a large-aperture Dobsonian (even a 10-inch) are truly spectacular, while those in 14-inch and bigger scopes are absolutely breathtaking!

Rich-Field

As with 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

Figure 5.5. The 4.25-inch 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 16x eyepiece provides a wide 3-degree 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.

Figure 5.6. Orion's highly popular 4.5-inch 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! Courtesy of Orion Telescopes & Binoculars.

of the best-known such instruments on the market today are Edmund's 4.25-inch f/4.2 Astroscan and Orion's 4.5-inch f/4 StarBlast (discussed above) – both having sturdy tabletop mountings and prices under $200. The former gives a 3-degree field at 16× and the latter about a 2-degree field at 26×, and the optics of both scopes are good enough to support higher magnifications for viewing the Moon and planets. The Astroscan features an optical window that seals the tube and supports the diagonal mirror. Its unique 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 pounds, and can be picked up and taken anywhere at a moment's notice. Note, however, that their tabletop mounts do require a sturdy support on which to place them, such as a picnic table. (The Astroscan is tripod-adaptable as well.)

Two other rich-field reflectors deserve mention. If you're on a budget, Bushnell's 4.5-inch f/4.4 Voyager goes for about $130 on a tabletop mount. On the premium end is Parks Optical's 4.5-inch f/5 Companion, which sells for about $800. Among other upgrades included is a tripod altazimuth mount (which brings the total weight up to 30 pounds). Despite the coma inherent in all these short-focus reflecting systems, sweeping the heavens – especially the star-clouds of the Milky Way – and viewing big star clusters such as the Pleiades (M45) or Beehive

(M44) is quite thrilling. Moreover, 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 comets.

Cassegrain

Very soon after the reflecting telescope was invented by Newton, Guillaume Cassegrain introduced a modification now called the *Cassegrain reflector.* Instead of a flat diagonal mirror reflecting the light to the side of the tube, this arrangement substitutes a convex secondary that 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 shape 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 five, resulting in an instrument with very long focal length but 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 inches in aperture, I have never been impressed with their image quality. Not only do they have limited fields of view because of 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, well-contrasted 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–Chrétien form discussed below. Among the exceptions are Parks, which makes these systems in apertures of 6 to 12.5 inches with prices ranging from $2,000 to $5,000, and Vixen with an 8-inch for under $2,000. Optical Guidance, which is best-known for its Ritchey–Chrétien systems, offers a line of research-grade classical Cassegrains ranging from 10 to 32 inches in aperture with prices beginning around $8,000. Another source is Parallax, which offers a 10-inch at under $5,000, and 12.5-inch and 16-inch models with prices in the $10,000 to $20,000 range.

In a bid to have 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 pricey, since you're essentially getting two telescopes in one. An example is Takahashi's CN-212 (for Cassegrain–Newtonian), which is an 8.3-inch (21-mm) f/12 Cassegrain with a replaceable secondary mirror that converts it into an f/4 Newtonian, and which goes for over $10,000. Another manufacturer is Parks Optical, which offers f/3.5–f/15 Newtonian–Cassegrains in apertures ranging from 6 to 16 inches at prices from $2,000 to over $16,000. Again, in all cases in which I have used such hybrid instruments, the views at the Newtonian focus were far superior in terms of image sharpness and field of view to the views at the Cassegrain one.

As an aside here, you may wonder why I didn't mention glare-stops and light-baffling when 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 Chapter 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 cloth 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. (I was a consultant in the development and marketing of Edmund's Astroscan, often referred to as the "red bowling ball." It has an all-red exterior for just this very reason!)

Ritchey–Chrétien

In an effort to improve the imaging quality of the classical Cassegrain reflector for photographic work, George Ritchey and Henri Chrétien jointly developed a marvelous new system in the early 1900s known as the *Ritchey–Chrétien*. Typically operating at effective focal ratios of f/8 or f/9, its hyperbolic primary and secondary mirrors give it both a larger and a flatter field than that of an ordinary Cassegrain, with total freedom from coma. And while it was originally developed for photographic (and more recently CCD) imaging, modernized versions 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-inch reflectors at the Keck Observatory (currently the world's largest optical telescopes) and the Hubble Space Telescope itself.

Among the first to offer Ritchey–Chrétien reflectors commercially for the serious amateur astronomer and small-observatory market was Optical Guidance, with apertures from 10 to 32 inches, as for its classical Cassegrains. Focal ratios are around f/8 to f/9 and prices range from $10,000 to over $20,000. Its chief competitor is RC Optical, whose line runs from 10 to 20 inches in size in focal ratios of f/8 to f/10, with costs in the same range as those of Optical Guidance. Its popular 12.5-inch f/9, for example, sells for around $14,000. At the time of writing, Meade had just introduced its line of "optically-enhanced" f/8

Ritchey–Chrétien telescopes in apertures from 10 to 16 inches and prices ranging from $6,000 to over $16,000.* 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 such as *Sky & Telescope* over the past several years – some of which rival those taken with large research telescopes – were taken by amateur astronomers using Ritchey–Chrétien 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 an elliptical primary and a spherical secondary mirror, which are easier to figure than those in a standard Cassegrain, thus 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 noticeable curvature of field. Dall–Kirkhams are not widely available on the commercial telescope market, but one source is Takahashi. Its Mewlon series offers 7-inch, 8-inch, and 10-inch models at hefty prices running between $5,000 and $10,000.

Modified Cassegrain

Several variations on the Cassegrain arrangement have appeared over the years. One is the *coudé* system, widely used by professional observatories in conjunction with both Cassegrain and Ritchey–Chrétien reflectors. Here, a small flat tertiary (third) mirror located 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 scope 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, this is usually located right above the balance point where the tube joins the axes). Both the coudé and modified Cassegrain modes eliminate the need to perforate the primary unless desired. This is the system used on the famed 100-inch 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, speculum-metal-mirrored, 20-inch 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-inch 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, currently no commercial coudé or modified Cassegrain telescopes are available other than custom-made ones. The modified Cassegrain form has been employed on catadioptric telescopes (see Chapter 6) as well as on reflectors. Fecker's superb 6-inch f/15 Celestar Maksutov–Cassegrain from 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 having reflective coatings on glass, which came much later. In order to reduce 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 the eyepiece was positioned. This form of unobstructed or *off-axis reflector* is known as the *Herschelian*. Several other designs using tilted primaries and additional flat 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 of them 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-inch, f/13.6, modified version of the Herschelian. Instead of having an image that is viewed directly with an eyepiece at the top of the tube, as Sir William did (here quite impractical because of the small aperture), a flat mirror outside the incoming optical path reflects the light across the tube and outside it to a standard focuser. The complete telescope goes for about $1,000 and the optical-tube assembly by itself is available for under $700. Another source is DGM, which offers models ranging from 4- to 9-inch in aperture, with 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 here 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.

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*Since the optical enhancement is achieved using a full-aperture corrector plate, technically these systems can be considered catadioptrics.