

Equipment

2.1 Telescopes

Before the telescope

Year	Event
3000 BC	Glass first appears, in Egypt
1500 BC	Oldest known glass vessels made
425 BC	Optical properties discussed
1000 AD	Atmospheric refraction explained
1278 AD	Glass mirror invented
1285 AD	Spectacles invented

Refracting telescopes

Refraction is the bending of light as a result of it passing from one medium (such as air) to another (such as glass). A refracting telescope makes use of this property by using a lens with curved surfaces. As light goes from air to glass and then back to air, its path is deviated toward the optical axis of the lens. If the surfaces of the lens are shaped properly, the light is brought to a focus.

The first telescope was constructed by the Dutch spectacle maker Hans Lippershey (1570–1619), who, on 2 October 1608, filed a patent application for “an instrument for seeing faraway things as though nearby.” This was a tube with a convex lens at the front and a concave lens in the rear, which one would look through. The device magnified objects approximately 3×. At the time, there was some contention as to who first invented this device so a patent was never granted.

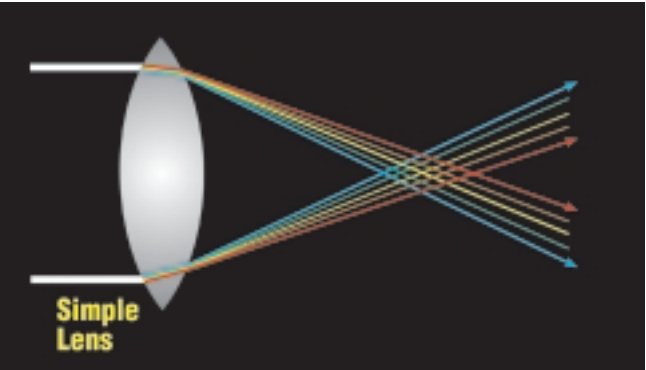
The Italian inventor Galileo Galilei (1564–1642) built his own telescopes beginning in 1609. Galileo was the first to use the new device to study celestial objects and what he saw revolutionized astronomy forever.

You probably know that the earliest telescopes had very poor optical quality. The lenses had many and varied aberrations. Telescope makers found that if they made their systems with a large focal ratio they could at least minimize the optical defects. The most famous of these inventors were the Dutch astronomer Christiaan Huygens (1629–1695) and the German astronomer Johannes Hevelius. Huygens constructed loosely connected telescopes with focal lengths of 3.6, 7, and 37.5 meters and made significant discoveries with them, including being the first to correctly identify the nature of Saturn’s rings. He also reduced the color problems of the objective lens and used optical stops (in his smaller telescopes) to reduce light reflected by the telescope’s walls.

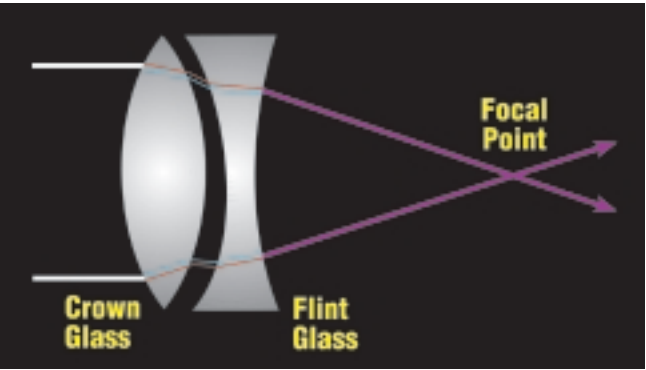
Hevelius made telescopes with focal lengths of 18, 22, and

46 meters! These were much more massive units in wooden frames, coupled by pulleys and moved about with the help of a team of assistants. In addition to being difficult to point accurately, they were essentially useless if there was any wind.

One of the problems with early lenses was a defect known as chromatic aberration. White light is made up of all colors. Unfortunately, the colors, when passed through a simple lens, do not focus at the same point. Blue light is refracted more than red light.



Chromatic aberration. A simple lens will not bring all colors to focus. (Illustration by Holley Y. Bakich)



A two-element achromatic lens dramatically reduces chromatic aberration by bringing the red and blue wavelengths to the same focus. (Illustration by Holley Y. Bakich)

In 1729, Chester Moore Hall (1703–1771) devised a lens design which used crown and flint glasses and which gave a relatively color-free image. The word for this type of lens is achromat (not color dependent). At this time, telescope making was a huge business so Hall worked in secret. He actually had the crown and flint lenses made by different optical shops. Hall’s achromatic lens was 2.5 inches in

diameter and had a 20 inch focal length. This was a monumental achievement, not least because 60 years prior, no less a personage than Isaac Newton had stated that the construction of an achromatic lens was impossible.

The nineteenth century saw a tremendous increase in the technical quality of glass and achromatic lenses. This was highlighted, in 1819, by the production of the lens for the Dorpat Refractor by Joseph Fraunhofer (1787–1826). This was a lens 240 mm in diameter with a focal ratio of f/17.7, which compares favorably with achromats produced today. This is the instrument used by F. G. W. Struve in his discovery and measurement of double stars. When you look at a double star catalog today and see the symbol Σ , it is one of the double stars discovered by Struve with this telescope.

In America, in the middle of the nineteenth century, Alvin Clark (1804–1887) and his sons began making quality telescopes. Their firm made numerous quality refractors, large and small. Their crowning achievement was the largest refractor ever built, which went into operation in 1897, for the Yerkes Observatory of the University of Chicago. Its lens is 1.016 m in diameter. For a detailed history of the Clark firm, I highly recommend the book *Alvin Clark & Sons: Artists in Optics* by Deborah J. Warner and Robert B. Ariail (Willmann-Bell, Inc., 1995).

In the twentieth century, achromatic refractors continued to improve. In the 1920s two problems were tackled: light loss caused by reflections off air-to-glass surfaces and internal reflections within the lens system. Both of these problems were solved by the Clarks and by Carl Zeiss, Inc. of Germany. These firms introduced oil-spaced objectives to solve these problems. The oil eliminated internal reflections and increased transmission by over 2% at each surface. It also smoothed out errors caused by irregularities in the lens’ surfaces. The cells which held these lenses had to be nearly perfect, however, or expansion and contraction due to temperature would cause the oil to leak out! Also, after a decade or so, early oils became cloudy and had to be replaced.

In the 1950s, coatings (most notably magnesium fluoride, MgF) were developed and these reduced light loss and internal reflections without the need for oil. A new type of glass, composed of calcium fluoride, CaF₂, was also invented. (The first fluorite objective in a telescope was offered in 1977, by Takahashi Ltd. of Japan.)

In 1951, United Trading Company began selling a high-quality line of refractors known as Unitron. These telescopes were heavily advertised from the 1950s through the 1970s (see any issue of *Sky & Telescope* during this time). All Unitron telescopes were supplied with well-corrected, air-spaced achromatic objectives.

The first refractor lens to be labeled “color-free” was a triple lens system offered by Roland Christen of Astro-Physics, Inc., in 1981. Only two apochromatic lenses were available at that time, both f/11 magnesium fluoride coated oil-spaced triplets. The smaller was a 150 mm and the larger a 200 mm. See Christen’s article in *Sky & Telescope*, October

1981, p.376, *An Apochromatic Triplet Objective*. This was the beginning of the new age of apochromatic refractors.

Note: Although apochromats are labeled “color-free,” different wavelengths of light do not come to exactly the same focus, although a much better focus than in achromats. Today’s apochromatic objectives have two to four lens elements. At least one is made with fluorite or ED (extra-low dispersion) glass, which provides even better color correction.

Thomas Back, designer of high-quality optical systems and owner of TMB Optical in Cleveland, Ohio, has given a wonderful definition of what it takes for a lens to be regarded as apochromatic:

Any telescope objective that has a Strehl ratio of 0.95 or better at the peak photopic null in the green–yellow part of the visual color spectrum, centered at 555 nm, coma corrected over its full aperture, diffraction limited from the C (red) to F (blue) wavelengths with no more than 1/4 wave spherical optical path difference (OPD) and the violet g wavelength with 1/2 wave or less OPD P–V spherical, satisfies the modern definition of “Apochromatism.” Lenses of this quality will be free from secondary color in focus and have extremely sharp and high contrast images.

Advantages of refractors

Good-quality achromatic or apochromatic refractors offer some advantages over reflectors. The first relates to the fact that refractors, by default, have a totally clear aperture. This means that there is no central obstruction causing light to be scattered from brighter to darker areas. Thus, the contrast is better in refractors. Refractors are often cited as the premier instruments for planetary or double star observing.

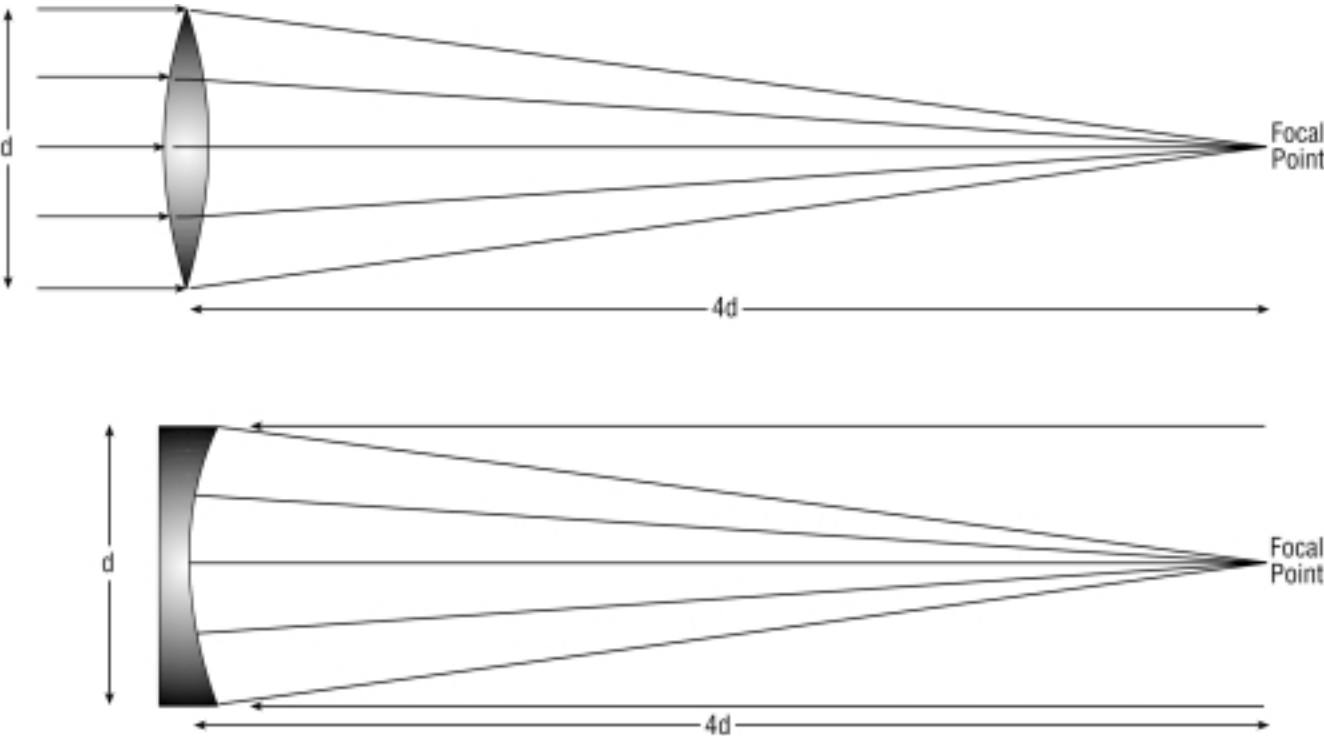
A second advantage of refractors is their low maintenance. Lenses do not require recoating. In addition, the optical tube assembly of a refractor does not generally require collimation. The lens is fixed into the tube and usually does not become misaligned, lacking some major trauma.

Disadvantages of refractors

Because the refractor is a closed-tube assembly, it can require a longer amount of time to cool to ambient temperature. Today’s thin-walled aluminum tubes have reduced this period significantly but it should still be taken into account.

A second disadvantage, related to achromatic refractors, is some chromatic aberration in bright images. This most commonly manifests itself as faint fringes of color around objects like the Moon or Jupiter.

The primary disadvantage of refractors is the expense that is involved in producing a large apo/achromatic lens. The reason is that an apochromatic triplet lens has six surfaces which must be figured. The cost ratio between a 150 mm apochromatic lens and a high-quality 150 mm mirror (only one surface to be figured) is at least 10-to-1.



Two similar systems. d is the aperture. $4d$ is the focal length. Because the focal length is four times the aperture, both are $f/4$ systems. (Illustration by Holley Y. Bakich)

Reflecting telescopes

The Scottish mathematician James Gregory (1638–1675) invented the first reflecting telescope. He published a description of the reflecting telescope in *Optica Promota*, which was published in 1663. He never actually made the telescope, which was to have used a parabolic and an ellipsoidal mirror.

The first working reflecting telescope was constructed by the great Isaac Newton in 1668. It had a spherical mirror with an aperture of 1 inch and a tube length of 6 inches. Not satisfied with his first effort, he completed an improved and somewhat larger reflector with an aperture of nearly 2 inches. The first “Newtonian” reflector was presented to the Royal Astronomical Society in 1671, and Newton was made a full member.

Early reflectors had mirrors made of speculum, an alloy comprising roughly 80% copper and 20% tin. Once figured and polished, this metal would begin to corrode after only a few months, whereupon it would need to be polished again. Care had to be taken to keep the same figure on the mirror with each polishing.

A Cassegrainian reflector is a type of reflecting telescope with a parabolic primary mirror and a hyperboloidal secondary mirror. Light is reflected through a center hole in the primary mirror, allowing the eyepiece or camera to be mounted at the back end of the tube. The Cassegrain reflecting telescope was developed in 1672 by the French



Kathy Machin, of Kansas City, Missouri, with her homemade 300 mm Dobsonian telescope at the Texas Star Party 2001. (Photo by the author)

sculptor Sieur Guillaume Cassegrain (1625–1712).

In the eighteenth century, Sir William Herschel constructed a number of reflecting telescopes with mirrors of various diameters and focal lengths. With his most famous, a “7-foot” (2.1 m focal length) reflector, he discovered the planet Uranus. This telescope had a mirror 165 mm in diameter. Speculum reflectors reached their height in the middle of the nineteenth century with the 1.8 m mirror in the telescope of William Parsons, Third Earl of Rosse, at Birr Castle, Parsonstown, Ireland.



Gil Machin, of Kansas City, Missouri, christens his 32 cm, $f/13.5$ classical Cassegrain at the 2001 Texas Star Party. Did I mention that Gil built, not only the telescope, but also the mount? Mechanical excellence and a good performing telescope as well. (Photo by the author)

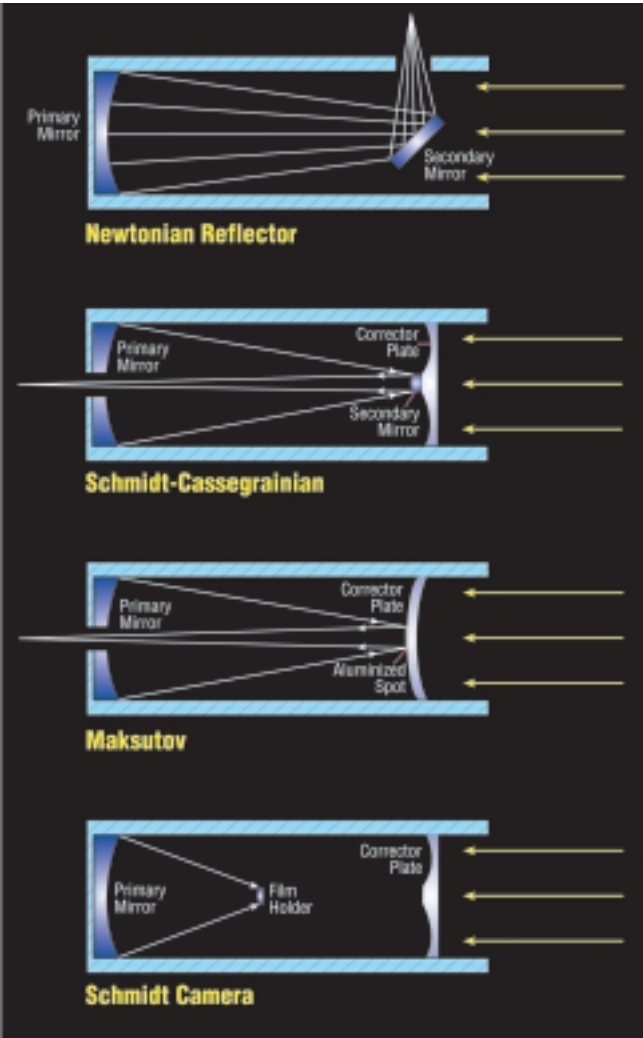
In 1835, a process for depositing a thick layer of silver on glass was developed by the German chemist Justus Leibig (1804–1873). This was a major step forward because when the silver tarnished it could be chemically removed and a new layer redeposited without altering the curvature of the mirror. Apart from tarnishing, silver is not the ideal reflective surface for a telescope mirror. Aluminum, for example, reflects 50% more light. John Donovan Strong, a young physicist at the California Institute of Technology, was one of the first to coat a mirror with aluminum. He did it by thermal vacuum evaporation. The first mirror he aluminized, in 1932, is the earliest known example of a telescope mirror coated by this technique.

Advantages of reflectors

Reflecting telescopes suffer no chromatic aberration. Mirrors have only one optical surface. An apochromatic lens has between four and eight. Mirrors are therefore much less expensive to produce. Telescopes over about 200 mm are all reflectors or catadioptrics (see later).

Disadvantages of reflectors

Because a secondary mirror is used, there is a central obstruction. This causes some scattering of light and loss of contrast. So-called planetary Newtonians have smaller central obstructions (some as small as 16% of the aperture).

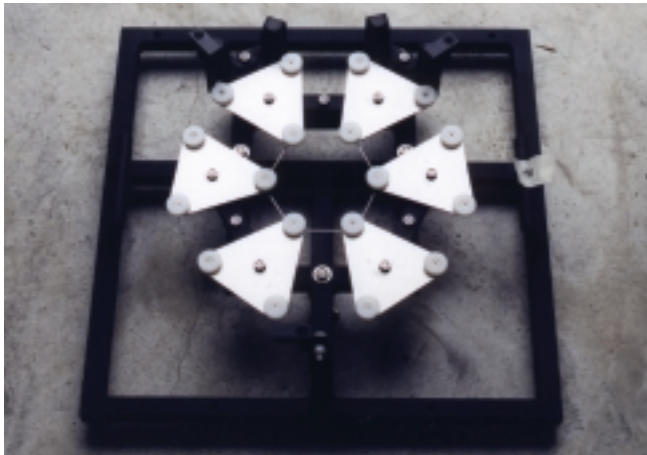


Telescopes using mirrors. Catadioptric telescopes also use a correcting lens. (Illustration by Holley Y. Bakich)

All Newtonian reflectors suffer from coma. The smaller the focal ratio, the greater the coma. Also, the uncorrected diffraction limited field becomes smaller. The use of a coma corrector such as the Paracorr at $f/5$ and below significantly increases the diffraction limited area. This makes it easier to keep the object in that part of the field of view, particularly if your telescope doesn’t have a drive.

Regarding maintenance, mirrors may require recoating after several years. And reflectors are quite sensitive to being bumped, jostled or transported. A reflector which is not set up as a permanent instrument should be collimated prior to each observing session. The shorter the focal length, the smaller the collimation tolerances for achieving diffraction limited performance, so accurate collimation becomes much more important.

Large reflectors with thick primary mirrors have a difficult time cooling to ambient temperature. Fans are sometimes employed to aid in the cooling process. Finally, very large Newtonian reflectors require a ladder for use when objects near the zenith are viewed.



The mirror mount for a 600 mm mirror in a StarMaster telescope. Note the excellent design of the support points which distribute the weight. The open construction also aids in cooling the mirror. (Photo by the author)

Ritchey–Chretien telescopes

This telescope design was developed jointly by the American optician George Willis Ritchey (1864–1945) and the French optical designer Henri Chretien (1876–1956) in the first decade of the twentieth century. Ritchey, who built the 60 inch and 100 inch mirrors for Mt. Wilson observatory, was so upset by the refusal to use this design for the 100 inch that he publicly criticized it, and was fired. George Ellery Hale, who engaged Ritchey in some heated debates and was the person who fired him, refused to consider this design for the Mt. Palomar 200 inch, choosing instead a Cassegrain design. Personalities notwithstanding, the Ritchey–Chretien design has been used for major telescopes at Kitt Peak, Mauna Kea, Cerro Tololo, the VLT, and even the Hubble Space Telescope.

The lower the amplification factor of the secondary mirror, the flatter the field. The Ritchey–Chretien system has a secondary mirror which magnifies $2.7\times$, whereas the Schmidt–Cassegrain has a $5\times$ secondary. The Ritchey–Chretien design is coma-free, whereas the Schmidt–Cassegrain is not. Production-type Schmidt–Cassegrains use a spherical primary and secondary which do not correct for coma. Ritchey–Chretien telescopes have hyperbolic primaries and secondaries which correct for coma. Finally, the Ritchey–Chretien design has two optical surfaces. All Schmidt–Cassegrains have four. On the down side, some astigmatism and field curvature have to be compensated for.

Catadioptric telescopes

Catadioptric means pertaining or due to both reflection and refraction of light. They are also known as compound telescopes and are hybrids that have a mix of refractor and reflector elements in their design.

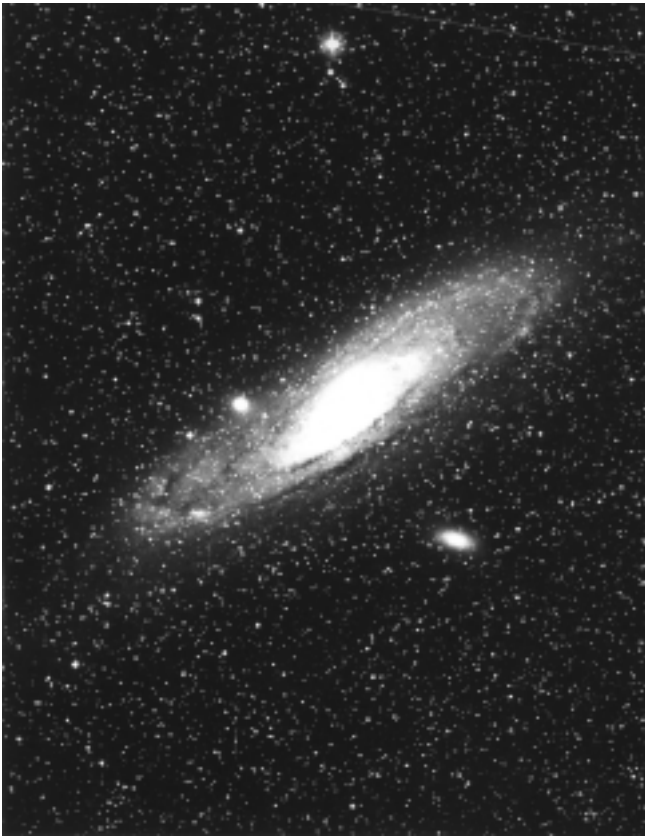
The first compound telescope was made by the German astronomer Bernhard Schmidt (1879–1935) in 1930. The Schmidt telescope had a spherical primary mirror at the back



The Schmidt–Cassegrain telescope (SCT) at Everstar Observatory in Olathe, Kansas, is a Meade 250 mm LX200. (Photo by Mark Abraham)

of the telescope, and a glass corrector plate in the front of the telescope to remove spherical aberration. The telescope (or Schmidt camera, as it is often called) is used for photography by placing photographic film at the prime focus.

The Schmidt design is the precursor of today’s most popular telescope design, the Schmidt–Cassegrain. This combination of the Cassegrainian telescope with the Schmidt corrector plate was invented in the 1960s. Like the



M31. (8" Celestron Schmidt camera, f/1.5, 30 minutes on TP 2415 film, 13 Nov 1979, Naco, Arizona. Image by David Healy, Sierra Vista, Arizona)



Meade 300 mm SCT, showing the main panel. (Photo by the author)

Cassegrain reflector, a secondary mirror bounces light through a hole in the primary mirror to the eyepiece.

The second type of compound telescope was invented by a Russian astronomer, Dmitri Maksutov (1896–1964) in 1944. Details of a similar design were published by a Dutch astronomer, A. Bouwers, in 1940, who was experimenting with corrector plates in front of mirrors. The Maksutov telescope is

similar to the Schmidt design, but uses a more spherical corrector lens. This new lens was used to produce a compact and rugged catadioptric telescope. The meniscus corrector used with a center-hole primary mirror Cassegrain configuration was to become known as the Maksutov–Cassegrain.

The Maksutov–Cassegrain was first popularized in the 1950s by Questar Telescopes. Questars provided views



The Meade 300 mm LX200 GPS Schmidt–Cassegrain telescope (SCT) set up in the backyard to cool. (Photo by the author)



The Meade 300 mm LX200 GPS Schmidt–Cassegrain telescope (SCT) getting ready for a night’s observing. (Photo by the author)

similar to the finest apochromatic refractors of the same aperture, but were only one third of the physical length of the typical refractor.

In the early 1990s, the Maksutov corrector was coupled to a Newtonian reflector to create the Maksutov–Newtonian. The first popular Mak–Newt was introduced by Ceravolo Optical of Ottawa, Canada. This design is different in that the secondary mirror is a flat and imparts no power as do those of the Mak–Cass or Schmidt–Cass telescopes. Also, the optics path is not folded. The effective focal length of the telescope, and the overall physical length of Mak–Newt telescopes are about equal to the focal length. Finally, the primary mirror has no hole, so the focuser of a Mak–Newt is positioned as is the traditional Newtonian.

Unusual telescopes

Of course, the telescope designs described above are not the only ones ever constructed. For a look at some unusual designs, see David Stevick’s “Weird Telescopes” page on the internet at <http://bh.sbroo.k12.wv.us/homepage/alumni/dstevick/weird.htm>

Active cooling

Some observers use one or more small fans to help bring large telescope mirrors more rapidly to ambient temperature. This can definitely help, especially during the early evening hours. The consensus seems to be that you should leave the fan on until the mirror reaches ambient temperature. Then, as the air temperature continues to fall, allow the mirror to radiate its heat away naturally.

Technical stuff: RMS, Strehl ratio and P–V

RMS refers to the root-mean-square of the wavefront deviation measured at best focus with light of wavelength 550 nm. Some regard this as a better measure of deviation than the P–V deviation (see later).

The Strehl ratio of a mirror is the light falling in the Airy disk as a percent of what a perfect mirror of the same dimensions would give. Disregarding complications by the secondary obstruction, a perfect aperture would have 83.7% of the light in the Airy disk and 16.3% in the rings surrounding the Airy disk. So if the Strehl ratio were 0.994, the light inside the Airy disk would be $83.7\% \times 0.994 = 83.2\%$, with 16.8% in the rings.

The P–V (Peak–Valley) deviation of the surface of a mirror is the maximum deviation minus the minimum deviation from the best-fit parabola. A convenient unit for the surface P–V is nanometers. It is also popularly given in terms of waves, in which case it is twice the surface P–V divided by the reference wavelength of light. The Rayleigh Criterion says that the P–V should be less than one-quarter wave, or surface P–V less than 68.8 nm.



A 250 mm, f/20 Maksutov–Cassegrain made by Yuri Petrunin of Telescope Engineering Company (TEC) of Golden Colorado. The central obstruction is less than 22%. (Photo by Robert Kuberek of Valencia, California)

Jeff Medkeff of Sierra Vista, Arizona, has originated an interesting thought problem related to all of the above indicators of mirror quality. He says . . .

The reason that P–V is not a very useful indicator of optical quality can be illustrated by a thought exercise. Imagine that you have one eight-inch objective mirror or lens that is optically perfect, except for a one-millimeter square patch that has a 300 wave error (a tower, or a pit, on the surface that is 300 wavelengths off optimal). This objective would have a very poor P–V rating; if a mirror, it would have a hugely bad 600 waves P–V wavefront.

Now imagine a second eight-inch objective. This one has a very slight linear trough running from opposite points on the edges, through the center of the mirror, but the bottom of the trough is only 1/8 wave

lower than the optimal surface. If a mirror, this would result in a 1/4 wave P–V wavefront. Obviously, the second objective has better looking numbers. What will actually be seen if one looks through such telescopes?

The first telescope will render essentially perfect images. The one-millimeter square defective area will not be noticed by even the most critical observer, and the effect will be hard if not impossible to measure without dedicated optical testing. The second telescope will show noticeable astigmatism, where stars focus (or don’t focus, rather) into lines rather than points, and planets will lose almost all their detail. Given the choice, everyone here would flock to the 600-wave P–V wavefront scope and abandon the 1/4 wave P–V wavefront scope to the trash heap, because the former would have a Strehl ratio hanging around 0.99 or so. As can be seen, Strehl ratio takes into account the amount of the surface that is affected by the error, and weights things accordingly.

This is of course exactly what optical quality measurements should do. They “should” empower the user to make rational decisions about what kind of telescope to use or what kind of optics they should be looking for. And they can and do succeed at that for some of us. But it can only happen if the user understands what the numbers mean, and to this extent knowing something about those measurements and how they are taken is essential.

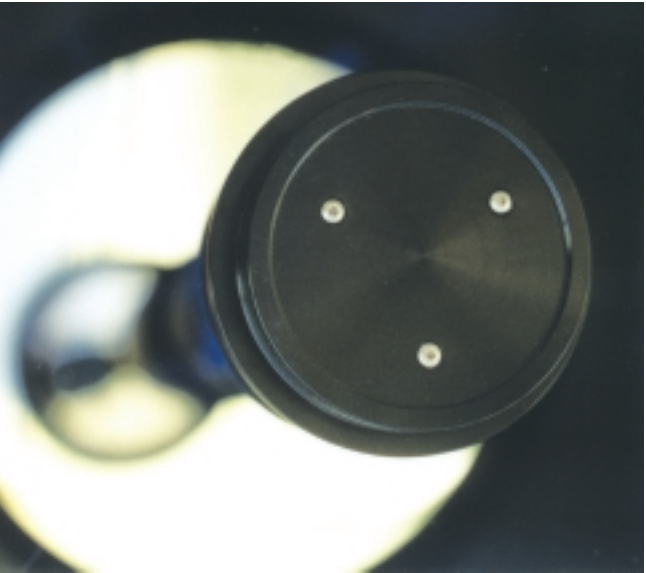
The two sides to this coin are the ignorant masses who don’t think anything worse than <insert number here> is any good on the one hand, and the optical cognoscenti who think that no optical quality measurements are ever useful to the end user on the other. Each position is clearly flawed, and the latter feeds off the discontent promulgated by the former. Education is the solution to bringing the former to an appreciation of where they err, and will reduce pressure and discontentedness in the latter. To that extent it’s discouraging to see people hand waving and saying “good enough is good enough” and “just observe” and “who cares about optical quality.” Obviously, a lot of folks already care about it if they are obsessed about their wavefront errors. Rather than harangue them, let’s give them what they need to move on, and if they ultimately want to be amateur opticians rather than amateur astronomers, let them.

Telescope maintenance

The reason a telescope must be cleaned and aligned is to bring out its best performance. I equate it to tuning a musical instrument prior to playing it. Properly cleaning and aligning the telescope’s components can make the difference between a good observing session and one where “firsts” or “bests” are recorded.

Collimation

Collimation is the alignment of the optical components of a telescope. Slight misalignments can cause or increase star image flaring, rob images of contrast, or prevent images from being uniformly in focus. Severe misalignments can reduce the light gathering capability of the telescope or make it impossible to bring objects into focus at all.



Meade 300 mm SCT collimation screws. Collimation is the bane of many an amateur astronomer. (Photo by the author)

A quick method of collimating a refractor

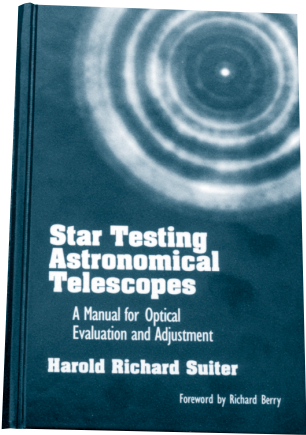
Most refractors hold their collimation very well. So, it isn’t unusual to find them still correctly collimated after they have shipped to the customer. Unfortunately, many refractors are designed so that they are not easily adjusted for collimation by the owner. Those that can be adjusted usually have a three-pair, “push–pull” screw system built into the lens cell. Here’s how to do it.

- (1) Point the scope at a relatively dark wall or put the lens cap on.
- (2) Slip a Cheshire tool in the focuser. (Note: The Cheshire is a development of the simple peephole tube, with an illuminated face (white or shiny) set at 45°. A hole in the side of the tube lets in light to make the reflection of the center spot visible against the bright face. There may be a “field stop” to better define the edge of the bright area. A Cheshire eyepiece or “tool” may be purchased from a variety of vendors.)
- (3) Shine a bright light at the mirror in the Cheshire tool.
- (4) Look through the Cheshire tool. You should see a bright round disc with a dark spot in the center, if the refractor is collimated. If it is out of collimation, you will see overlapping bright discs and black spots.
- (5) Some refractors have three pairs of “push–pull” screws

in the front of the lens cell. You need to loosen and tighten them as needed to shift the image so that you see one round bright disc with a black spot in the center. **Tip:** When doing any type of collimation, only turn the screws a tiny bit. Large motions are NOT required.

Collimating reflectors and catadioptrics

So much has been written about the processes and minutiae of collimating reflecting and catadioptric telescopes that to even summarize them here would be impossible. If you purchased your telescope new, follow the collimating instructions that came with it. One of the finest books ever written about evaluating and adjusting telescopes of all types is *Star Testing Astronomical Telescopes* by Harold Richard Suiter (Willmann-Bell, Inc., 1994, plus additional printings).



Star Testing Astronomical Telscopes
by H.R. Suiter. (Photo by the author)

I do have a few quick tips for you to think about regarding collimation, based upon my own experiences:

- Collimation is much more critical as the focal ratio decreases (especially below about f/6). This is due to the increased curvature of the focal plane in these telescopes, resulting from a deeper mirror parabola.
- Be certain the primary mirror is centered in the rear of the telescope (aligned with the centerline of the telescope tube). If it isn't, there is an increased chance that the front edge of the telescope will vignette some of the incoming light.
- Although it is not critical for the light path to be reflected by exactly 90° from the primary off the secondary (two 45° angles), the most efficient design employs a 90° bend as this angle minimizes both the height of the focuser/eyepiece and the size of the diagonal.
- To aid in collimating an SCT, I highly recommend a set of Bob's Knobs, available via the internet at <http://hometown.aol.com/rkmorrow/myhomepage/index.html> This is such a great idea. I never liked using Allen wrenches in the dark.

- Laser collimators are wonderful tools once rough collimation has been done. There is, however, one danger in using collimation tools: they will indicate collimation based solely on the point that you've chosen as the center of the primary mirror. Choose this point carefully!
- Finally, after all your mechanical collimation is done, perform a star collimation. A star collimation uses light reflected from all of the mirror surfaces plus the eyepiece and so is the ultimate guide.

Star test

When a star is slightly de-focused on the inside or outside of focus, it will display a bright disk surrounded by a series of rings. If the optics are collimated, the disk and rings will be concentric. Practice making star collimations. They can be difficult to perform, as they require good seeing and high magnification (at least 2 × per millimeter). Keep the star centered in the field of view to reduce other effects such as field curvature.

When the image is a little inside or outside of focus, you should see rings of light and a darker center, and all should be round and well-centered. If not, note if the image improves if you move it a little off-center in any direction. If so, adjust the collimation screws to move the image toward the center of the field until it looks symmetric. And remember, very small motions of the screws (or knobs) are all that are required.

Cleaning optics

From time to time, optical surfaces get dirty. There's really only one way to avoid this and that's to keep them sealed in their original boxes unused. Certainly that is not what this book intends you to do!

Some tips from Meade Instruments will get us started on the road to proper telescope care. Meade points out, and I agree, that prevention is the best recommendation that a telescope owner can follow in keeping a telescope in top working order.

Dust and moisture are the two main enemies to your instrument. When observing, always use a dew shield. The dew shield not only helps prevent dew from forming and dust from settling on the lens, it also prevents stray light from reducing image contrast during observing.

Although dew shields go a long way to prevent moisture build-up, there can be times when the telescope optics will have a uniform coating of moist dew. This is not particularly harmful, as long as the dew is allowed to evaporate from the instrument, accomplished by setting up the telescope indoors with the dust covers removed. Never attempt to wipe down optics that are covered with dew. Dust and dirt may be trapped with the collected dew, and upon wiping the optics you may scratch them. After the dew has evaporated you will most likely find the optics in fine condition for the next observing session.

If you live in a very moist climate, you may find it necessary to use silica desiccant stored in the telescope's case to ward off moisture and the possibility of fungus growing on and within the coatings of the optics. Replace the silica desiccant as often as necessary. Packets of silica desiccant can be "restored" by baking in a kitchen oven set on the lowest setting for 15 minutes.

Those living in coastal areas or tropic zones should also cover the electronic ports on the optional power panel and the keypad with gaffer tape to reduce corrosion on the metal contacts. Apply a dab of a water displacement solution (such as WD-40) with a small brush on all interior metal contacts and the input cord metal contacts. The keypad and all separate accessories should be kept in sealable plastic bags with silica desiccant.

A thick layer of dust will attract and absorb moisture on all exposed surfaces. Left unattended, it can cause damaging corrosion. To keep dust at bay when observing, the telescope can be set up on a small section of indoor/outdoor carpet. If you are observing for more than one night in a row, the telescope can be left set up but covered with a Cosmic Storm Shield (see "Telescope accessories" chapter) or even a large plastic bag (such as the one supplied with the telescope).

Eyepieces, diagonals, and other accessories are best kept in plastic bags and stored in cases. All of the non-optical surfaces of the telescope should be cleaned routinely with a soft rag and alcohol to prevent corrosion. The cast metal surfaces and the individual exposed screws can also be kept looking new and corrosion-free by wiping them down with a water displacement solution (such as WD-40). Take care not to smear the solution onto any optical surface, and to wipe up any excess solution with a clean dry cloth. The painted tube can be polished with a liquid car polish and a soft rag.

In my long "career" as an amateur astronomer, I have cleaned few mirrors and fewer lenses. I have, therefore, called upon Leonard B. Abbey, an expert in the cleaning of optics. He has graciously allowed an article he wrote about this subject to appear here. For more articles about all aspects of amateur astronomy, I recommend his "Compleat Astronomer" website, on the internet at <http://LAbbey.com>

How to clean mirrors and lenses

Leonard B. Abbey, FRAS

The cleaning of optical surfaces, especially those of first-surface mirrors, is the most delicate and exacting task which the astronomer is called upon to perform. At the time of cleaning, a lens is most vulnerable to damage; damage which cannot be repaired. Yet if a telescope is to perform at its greatest potential, cleaning must be done time to time.

I have used the following method for over thirty years without adding a single scratch to the surface of a mirror or lens. It has the advantage of requiring only materials which are readily available at the

neighborhood pharmacy or grocery store. The cost is less than twenty-five cents per cleaning.

First you must realize that usually the best advice on cleaning mirrors and lenses is...DON'T DO IT. Dirt and grease which are adhering to the surface of mirrors and lenses may degrade image quality slightly, but they will not damage the delicate optical surface until they are moved against it. The need to remove dirt without allowing it to move against the underlying optical surface is what makes cleaning such a tricky task. However, if your mirror or lens is so dirty that it must be cleaned, then this is the way to do it.

For mirrors

1. Blow all loose dirt off with "Dust Off" or another canned, filtered, clean air product. (Available in camera stores.) Take care not to shake the can while you are using it, and be sure to release a little air before using it on the optical surface. This will assure that no liquid is dispensed to make things worse! You can use a rubber bulb for this purpose, but it is not nearly as effective.
2. Prepare a VERY dilute solution of mild liquid detergent (e.g., Dawn). It is very important that the detergent does not contain any form of hand lotion or lanolin. This product usually comes in a plastic bottle with a dispenser spout. Dispense the tiniest amount possible into a clean cup. (One drop, if possible.) Fill the cup with water. Stir. Throw almost all of this water away, and refill the cup. Now you have a VERY dilute solution.
3. Rinse the mirror off under a moderate stream of lukewarm water for two or three minutes. Test the temperature of the water with your wrist, just as you would when warming a baby's bottle. Leave the water running.
4. Make a number of cotton balls from a newly opened package of Johnson & Johnson sterile surgical cotton, U.S.P. (The "U.S.P." is important. It means that you have REAL cotton instead of a polyester substitute.) Soak 2 or 3 balls in the detergent solution. The cotton balls should be fully saturated with the detergent solution. Do not squeeze any of the liquid out. Wipe the surface of the wet mirror with a circular motion, going first around the circumference, and then working your way towards the center. The only pressure on the cotton should be its own weight. For this first "wipe" you should use several fresh sets of cotton balls. As you move the cotton balls around the mirror's surface, rotate them slightly so that the dirt they pick up is moved away from the mirror's surface, and toward the top of the balls.
5. Throw the cotton balls away.
6. Repeat the process with new cotton balls, using a LITTLE more pressure.

7. Rinse mirror thoroughly under tap, which has been kept running for this step.
8. Rinse mirror with copious amounts of distilled water (do this no matter how clean or “hard” your tap water is).
9. Set mirror on edge to dry, using paper towels to absorb the water which will all run to bottom of mirror. Keep replacing the paper towels as the mirror dries.
10. If any beads of water do not run to bottom, blow them off with Dust Off, or the rubber bulb. Any stubborn drops which remain on the aluminum surface can be picked up with the corner of a paper towel. The paper towel doesn’t even need to touch the mirror’s surface.
11. Replace the mirror in its cell, being careful to keep all clips and supports so loose that the mirror can rattle in the cell if it is shook. (Perhaps 0.5 to 1mm clearance.)
12. Spend some time realigning your scope.
13. If you do anything more than this, you will risk damaging the coating. But remember, if you follow these instructions any damage will almost certainly be to the coating, not the glass. When the mirror is re-aluminized it will look new in all respects.
14. You should not have to clean an aluminized mirror more often than once per year. Do NOT over clean your optics.

For objective lenses

DO NOT UNDER ANY CIRCUMSTANCES REMOVE A LENS FROM ITS CELL, OR THE CELL FROM THE TELESCOPE.

This restriction means that the above procedure must be modified. Only the front surface of the objective can be cleaned. If you remove the cell from the telescope, you will be in big trouble. There are very few people who can collimate a refractor. If you are reading these instructions, you are not one of them!

1. Blow loose dirt off with “Dust Off” or a rubber bulb, using the above precautions.
2. Soak the cotton balls in a 50:50 solution of Windex (commercial glass cleaner containing ammonia) and distilled water. Squeeze slightly so that the balls are not dripping wet.
3. Wipe front lens surfaces with the wet cotton, using only the pressure of the weight of the cotton balls. Follow immediately with dry cotton, using little or no pressure.
4. Repeat procedure, using slightly more pressure.
5. If some cotton lint remains on surface, blow off with Dust Off or rubber bulb.
6. Repeat this procedure if the lens is not clean, but if one “repeat” does not do it give up and leave it as is.
7. Inspect the lens to make sure that no cleaning

solution has found its way into the lens cell, or between the elements. If this has happened, leave the telescope with the lens uncovered in a warm room until it is dry.

For Schmidt–Cassegrain and Maksutov telescopes

The only optical surface you should attempt to clean is the front of the corrector plate. Use the instructions for cleaning refractor lenses. If your SCT needs more cleaning than this, send it back to the factory for cleaning.

For eyepieces and Barlows

Follow the procedure given for objective lenses, but use Q-Tips (U.S.P. cotton on plastic sticks) instead of cotton balls. You may, of course, clean both surfaces. The eyebrow juice on the eye lens of eyepieces may require repeated applications. I think that this is OK in this case.

SOME DONT’S

1. Do not use any aerosol spray product, no matter who sells it, or what their claims are.
2. Do not use lens tissue or paper. It DOES scratch.
3. Do not use pre-packaged cotton balls, they frequently are not cotton.
4. Do not use any kind of alcohol, especially on aluminized surfaces.
5. Do not use plain water for the final rinse.
6. Do not use any lens cleaning solution marketed by funny companies, like Focal, Jason, or Swift. Dawn and Windex (or their equivalents in other countries) are inexpensive and commonly available.

Re-aluminizing a mirror

Eventually, if you own a reflecting or catadioptric telescope for a long enough period of time, you will need to have the mirror re-aluminized. Owners of Newtonian reflectors will have to re-aluminize their mirrors more often than owners of Schmidt–Cassegrain telescopes, due to the closed tube design of the latter.

The number one factor which contributes to the need to re-aluminize a mirror is improper cleaning and/or handling. Other factors are excessive dust, which is abrasive, and condensation which may contain acidic atmospheric aerosols.

How can you tell if it is time to have your mirror re-aluminized? The deterioration of the coating is a gradual process and the recognition that it has degraded can be difficult. Obvious signs, such as numerous scratches, blotches or hazy spots, are rare. Look instead for halos around the brighter celestial objects when your mirror is dust-free. Also, if you suspect deterioration in the coating, try to compare the view through your telescope side-by-side with a telescope of equal aperture. Finally, if you feel that the coatings could be better, check the calendar. If it has been more than five years since your mirror has been re-aluminized, it is probably time.

Tip: If you are sending your primary mirror for re-aluminizing, send your secondary mirror as well.

Enhanced coatings

The same company which re-aluminizes your mirror can also add a coating to it. Some coatings are for the protection of the aluminum surface. Most overcoatings are silicon monoxide (SiO). Magnesium fluoride (MgF₂) is sometimes used, but it isn’t as resistant to scratches as SiO.

Other mirror coatings, called enhanced coatings, raise the reflectivity of the surface of the mirror by 5–10%. Since an enhanced coating is considerably more expensive than a regular coating, sometimes costing double, we may well ask the question, “Is it worth it?” The general consensus is, “No, it is not worth it.” Enhanced coatings are more susceptible to atmospheric conditions such as high humidity, airborne particles and acidic content than are regular coatings. Most amateur astronomers subscribe to the rule that enhanced coatings deteriorate much more rapidly than regular ones.

Rick Singmaster, owner of StarMaster Telescopes, has extensive experience with mirror coatings of all types. He provides some perspective on the “value” of enhanced coatings . . .

Regarding enhanced coatings, we here at Starmaster do not recommend them on our primary mirrors, and we are not alone. Other major optical companies who do not advocate enhanced coatings include: Pegasus

Optics of Brackettville, Texas, Spectrum Coatings of Deltona, Florida, Astro Systems, Inc., of LaSalle, Colorado, and Zambuto Optical Co., of Rainier, Washington. Swayze Optical, Inc., of Portland, Oregon, has only used them on approximately 5% of the primary mirrors they have produced.

The failure/recoat rate on early Starmaster primary mirrors which were enhanced was more than double that of standard coated optics. Many primary mirrors wouldn’t even come to focus because the enhanced coatings severely degraded the wave front.

Another problem we encountered was that the contrast was lower with many of the enhanced coated primary mirrors. This was noticed when they were compared side-by-side with “standard” coated mirrors from the same coating company. Furthermore, this difference was also noted when comparing various coating companies’ products so it wasn’t limited to just one company.

I personally made these comparisons when testing scopes side-by-side prior to shipping. Since I have done this for every scope we have made, this opinion is based on my own observation of a large sample.

At Starmaster, our only concern is that our customers receive a fine performing scope. I don’t have anything against trying to obtain more performance from a scope by whatever means, but when I see something which degrades performance time after time, I simply can’t in good faith recommend it to my customers. Especially if it adds cost.