APPENDIX
A

Star Testing Your Telescope

Have you ever wondered whether your telescope is delivering the image quality it is supposed to? You can find out by conducting the star test, which can be done outside at night with no special equipment yet can reveal even subtle defects in a telescope's optics. It can also reveal problems that are not the fault of the telescope, so some care is required.

A word of caution—the star test is sensitive. So before dismissing any telescope, do other checks. How does it perform on the snap test? One of the quickest star tests is to watch the image as it passes through focus. Does the focus snap into place, or does it ooze through focus? Snap is good!

How does it do in comparison with other instruments of similar type, size and focal length? If your telescope always performs poorly in side-by-side comparisons, you have good reason to believe the instrument is at fault. Then consider the magnitude of the defect. Severe errors on any telescope include astigmatism that originates on the glass, bad zones or severe roughness. These warrant returning the telescope.

If the errors are minor, weigh the likelihood that you will get better optics at the same price. Also consider what you bought the telescope to do. If yours is a low-cost light bucket, be prepared to accept less-than-top-grade optics. On the other hand, if you have paid a premium price for a telescope advertised as diffraction limited, you have a right to expect high marks on the star test.

If your telescope seems to fail, do not immediately confront the dealer or manufacturer. You may be wrong. Like all observing, proficiency at star testing takes time. Try testing other scopes. Get a second opinion. If the telescope still fails, work with the manufacturer responsibly, and you will probably receive satisfaction.

Testing optics need not take an array of sophisticated test gear and lab equipment. A good assessment can be made with no more than a high-power eyepiece and some skill at judging images.

The Perfect Image
Here we compare two popular classes of telescopes:

Refractor
Assuming textbook-perfect optics, an unobstructed telescope such as a 4-inch refractor produces a bright Airy disk surrounded by a faint inner diffraction ring when in focus on a bright star. Out of focus, the images expand to filled-in diffraction disks that look identical both inside and outside of focus.

Schmidt-Cassegrain
With its larger aperture an 8-inch SCT produces an Airy disk half the size of the refractor's image but with a much brighter first diffraction ring, an effect of the obstructed aperture. The two extra-focal images look more like donuts, though still identical.

What You Should See

The star test is administered by examining star images at high power, both in focus and out of focus. Surprisingly, the out-of-focus images can demonstrate a great deal about a telescope's optical quality.

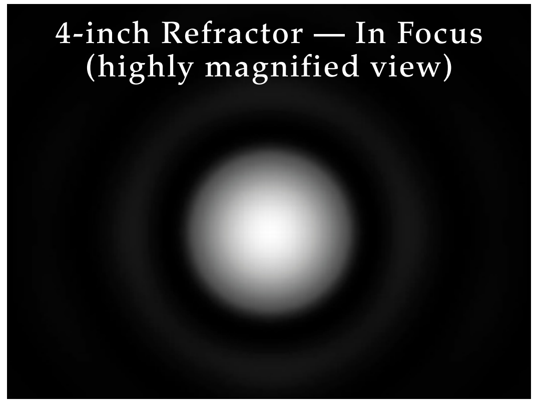
THE IN-FOCUS DIFFRACTION PATTERN

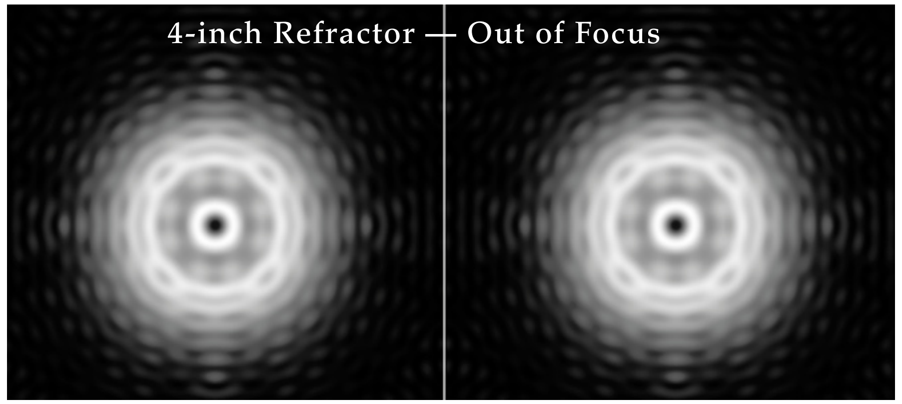
At high power, a star looks like a distinct spot surrounded by a series of concentric rings, with the innermost ring being the brightest and most obvious. This is called the diffraction pattern. The spot in the middle is known as the Airy disk. Any telescope that claims to be "diffraction limited" must create a good likeness of that pattern. Your telescope may not produce as perfect a bull's-eye as we've depicted. Few telescopes do. To see a perfect diffraction pattern mask your telescope down to a one-to-two-inch aperture. Then focus the telescope on a bright star well above the horizon, using a magnification of 100x to 150x. You should then see a classic diffraction pattern that can serve as a standard of comparison when testing telescopes.

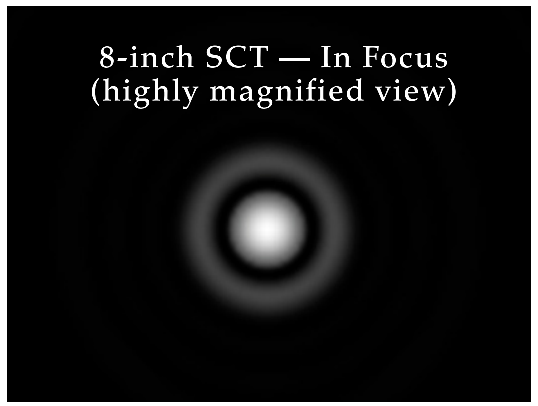
THE OUT-OF-FOCUS DIFFRACTION PATTERN

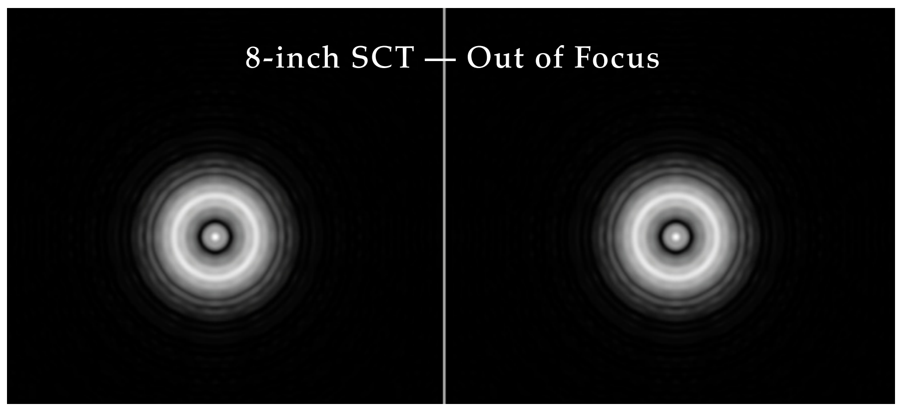
With the telescope stopped down, slowly rack the star out of focus. You'll see an expanding pattern of rings emerge. Defocus the instrument to the point where four to six rings show. Except for a fat outer ring, the light should be spread more or less uniformly among the rings. Now, rack through focus to the same place on the other side of focus. The pattern should look identical, with a uniform distribution of light within the diffraction rings.

In an unobstructed telescope, such as a refractor, the out-of-focus pattern will be filled in. In an obstructed telescope—any reflector with a secondary mirror—the out-of-focus pattern looks more like a doughnut. Examining the appearance of an out-of-focus star image (called the extra-focal image no matter which way it is defocused) is the essence of the star test. Doing so can help diagnose why in-focus images look soft.

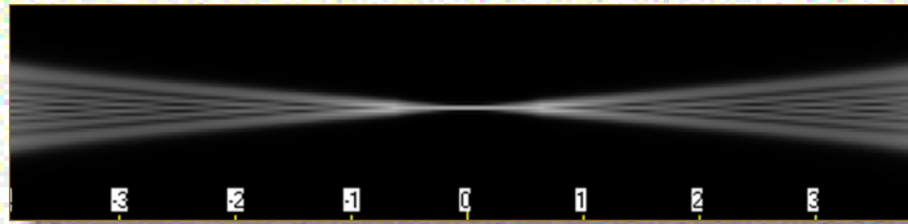

4-inch Refractor — In Focus (highly magnified view)


4-inch Refractor — Out of Focus

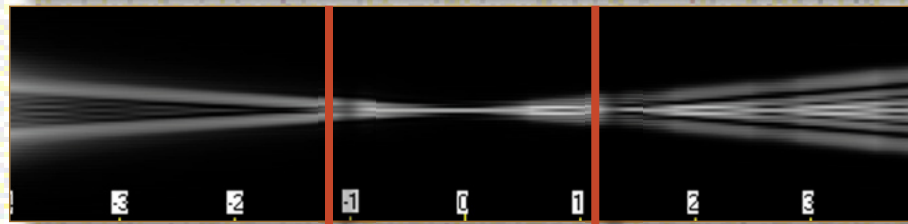

8-inch SCT — In Focus (highly magnified view)


8-inch SCT — Out of Focus

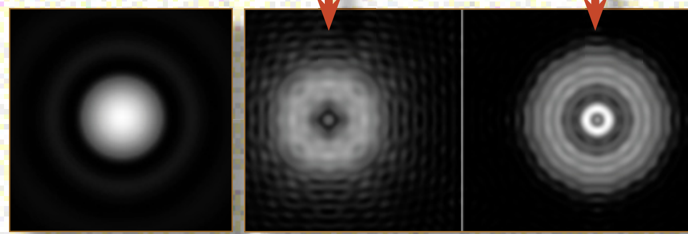
Atlas of Aberrations



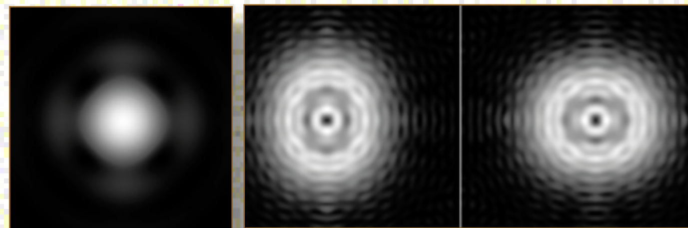
Perfect Focus
In perfect optics, the converging and diverging light cones (seen here in profile) contain identical bundles of light rays. Light comes to a sharp and certain focus (it snaps to focus).



Imperfect Focus
With spherical aberration, light from the perimeter of a lens or mirror does not focus at the same point as the light from the optic's center. The result is unsymmetrical light cones and a smeared focal point.

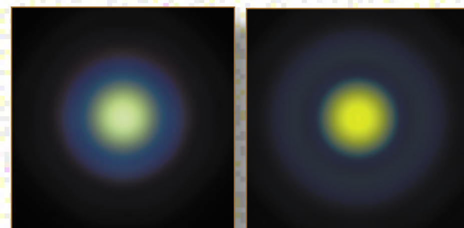


1. Spherical Aberration
The basis of the star test is to look at the pattern of a defocused star, effectively slicing through the light cones on either side of focus. In the case of spherical aberration, this pattern can look fuzzy on one side of focus yet look tightly defined on the other. In focus (at far left) the diffraction rings look brighter than in perfect optics.

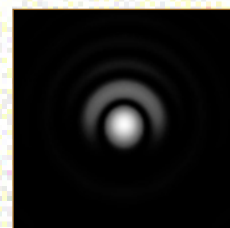


2. On-Axis Astigmatism
If the lens or mirror is ground so that it is not rotationally symmetrical, the result is an extra-focal diffraction disk that might appear elliptical. Its axis flips 90° from one side of focus to the other. In focus, stars always appear vaguely cross-like (far left). Optics that are physically pinched can produce a similar effect.

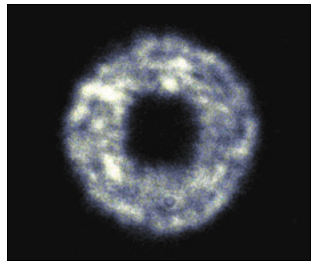
3. Chromatic Aberration (Longitudinal)
This aberration, found only in refractors, arises when all colors are not brought to the same focal point. The illustrations depict a focused star as seen through a 4-inch f/8 refractor with 0.6-wave (near right) and 1-wave (far right) of chromatic aberration. The latter is typical of standard f/6 to f/8 achromatic refractors. While the blue haloes are distracting, this aberration does not degrade the image nearly as badly as do other aberrations.

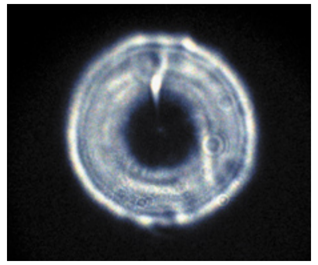


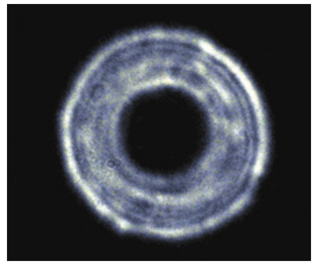
4. Off-Axis Coma
Coma, an inherent aberration of many reflectors, makes stars that are off-center in the field look flared to one side. The farther the image is from the center of the field of view, the worse the aberration gets. Coma also becomes more severe in faster optics, with fast f/4 or f/5 Newtonians having a much smaller coma-free field than an f/8 instrument. For this reason, precise collimation of fast Newtonians is critical, or else all images will look fuzzy.



This is the "big four" of aberrations, representing the main optical flaws backyard astronomers are likely to encounter, usually in some combination. These and the other star test simulations shown in this Appendix were produced with a free astronomy software program called Aberrator, produced by Cor Berrevoets and available for Windows computers at http://aberrator.astronomy.net







Settling Down
A valid star test requires a night of good seeing. If the air is turbulent (as at top) the out-of-focus diffraction disk will distort and blur. If warm air remains in the telescope tube, rising currents can produce plumes (middle) which can also distort star images. But once the telescope has settled down and if the seeing is good, you'll see a smooth and uniform diffraction disk when a star is thrown out of focus (as at bottom). These images are actual photos of defocused stars.

Needing Collimation
A telescope (in this case a Newtonian reflector) that is out of collimation will produce a skewed diffraction disk when a star is defocused for testing.

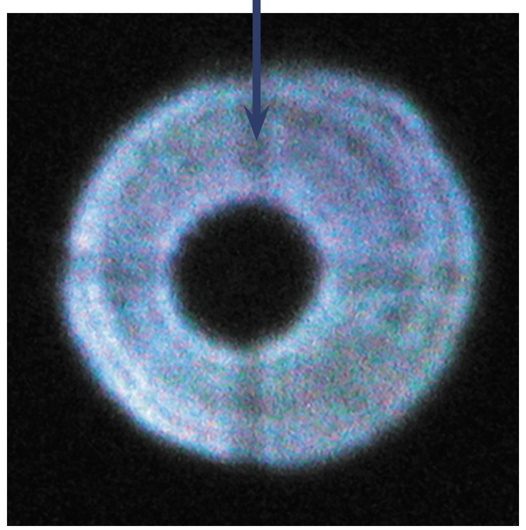
What You Might See

It is important to understand that factors besides the quality of the optics can ruin star images. Otherwise, you may blame your telescope for a defect it does not have. To conduct a star test, use the full aperture of the telescope and a good-quality eyepiece such as a Plössl or Orthoscopic. Be sure to do the star test with the image centered in the field of view. If you can, remove any star diagonal so you are looking straight through the optics (cheap diagonals can mimic the effect of poor collimation).

NOTE: In the diagrams at right, and on the previous and following pages, the "in-focus" Airy disk pattern is shown at much higher magnification than the "out-of-focus" diffraction disks. The two types of images are not drawn to the same scale.

TELESCOPE COLLIMATION

A telescope that is out of collimation will likely fail the star test. The out-of-focus diffraction pattern in such a telescope looks like a striped, tilted cone as viewed from the pointy end. If your telescope gives poor images, it is probably because of poor collimation. Follow the directions in Appendix B (available at www.backyardastronomy.com) before conducting a star test.



ATMOSPHERIC TURBULENCE

On nights of poor seeing, turbulent air churning above the telescope can turn the view into a boiling confusion. When this happens, don't bother testing or collimating. Because they look through a larger volume of air, large telescopes are affected more by this problem than small ones, making it difficult to find a good night to test big instruments. Even so, on nights of bad seeing small scopes may look sharper but big scopes will always show as much, if not more detail, given good optics in both.

TUBE CURRENTS

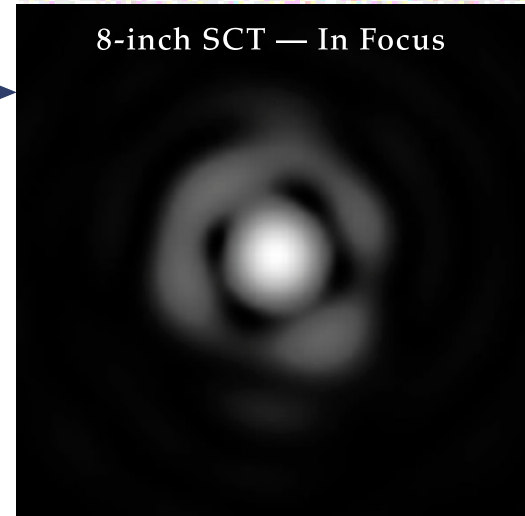
Slow-moving currents of warm air inside a telescope can introduce defects that mimic permanent errors on the glass. Diffraction patterns look flattened or flared. These image-distorting currents occur when a telescope is taken from a warm house into the cooler night air. When star testing, always allow the telescope, eyepiece, and even the star diagonal to cool down. Even a warm eyepiece inserted into cold telescope can introduce heat plumes. Expect to wait an hour or more, especially on cold nights.

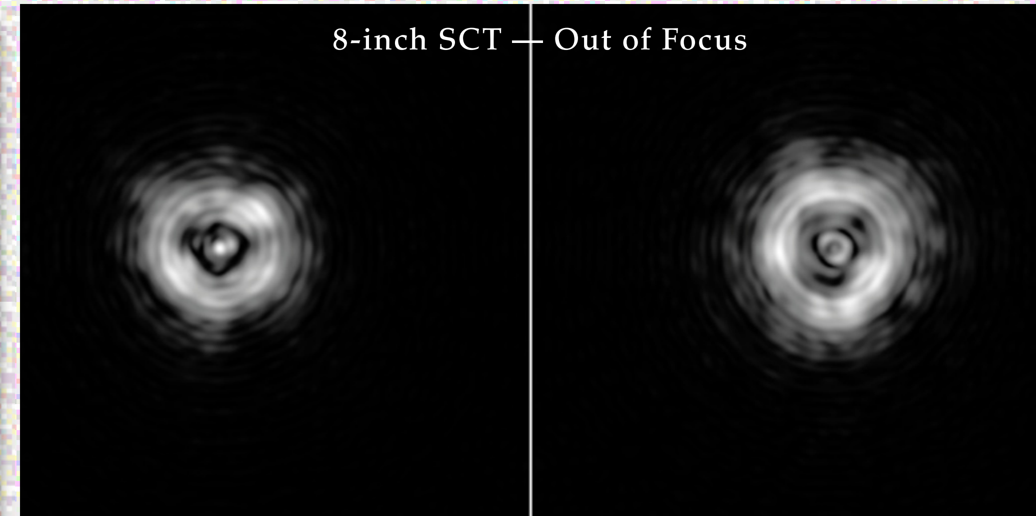
PINCHED OPTICS

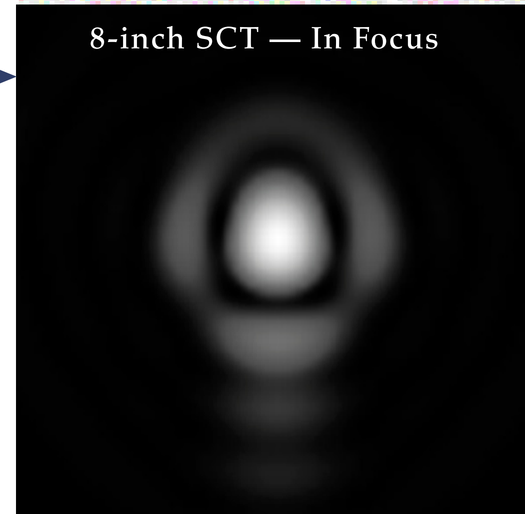
Badly mounted optics create very unusual diffraction patterns. Most common for Newtonians is a triangular or six-sided spiking or flattening (depending on which side of focus you are on). This occurs if the clips holding a mirror in its cell are too tight. The solution is to loosen them though doing so requires removing the mirror and cell from the tube. Secondary mirrors and star diagonals glued onto holders can also suffer from pinching. Back off the bolts holding the secondary mirror.

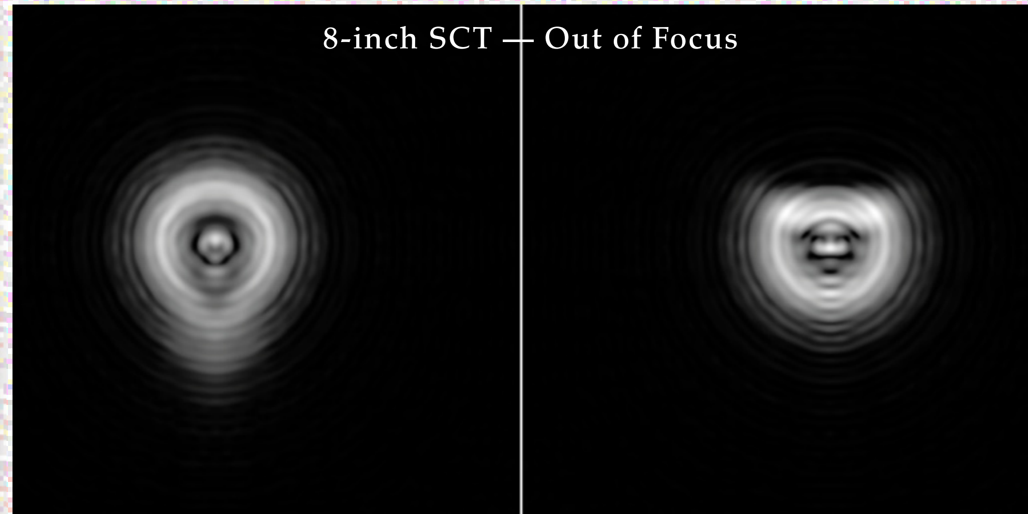
Non-Optical Problems

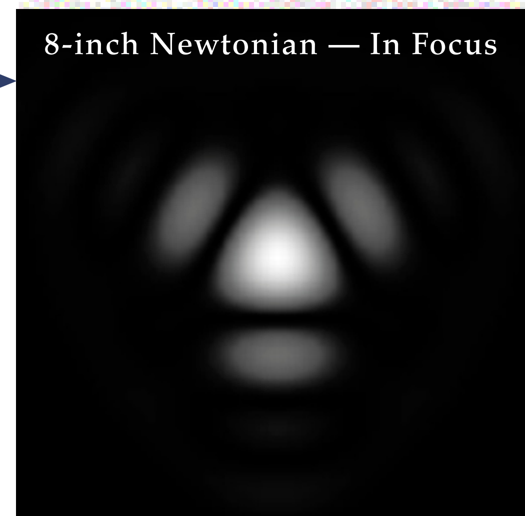
This series of simulations shows the effect of various problems that can blur images but that are not the fault of the optics. On the left is the magnified view of a star seen in focus. At right is the simulated appearance of the "extra-focal" disks seen on either side of focus.

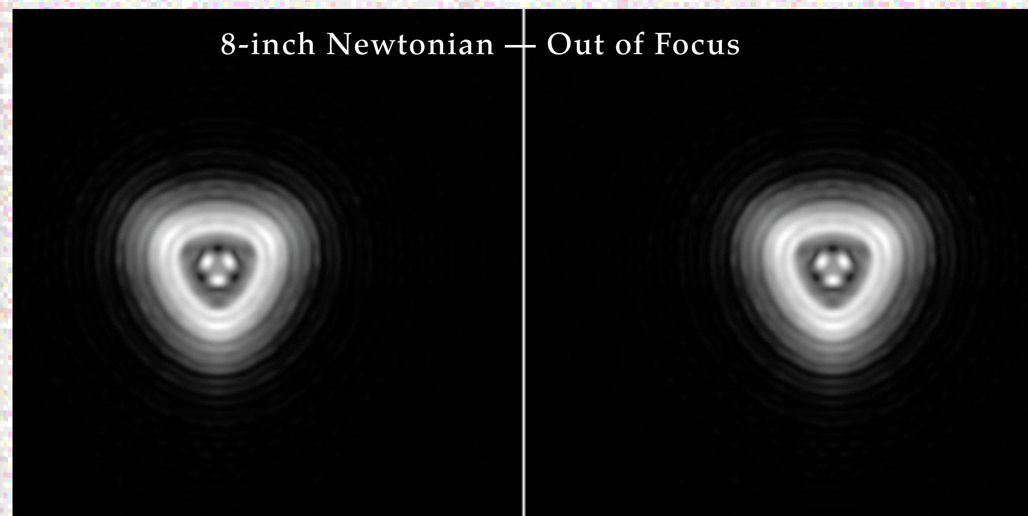


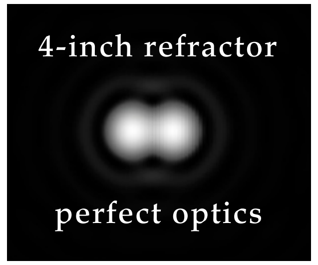


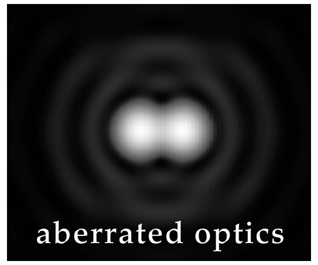




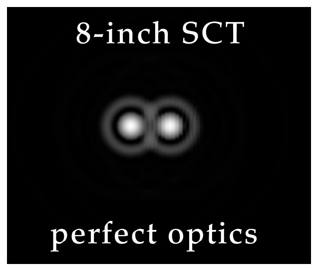


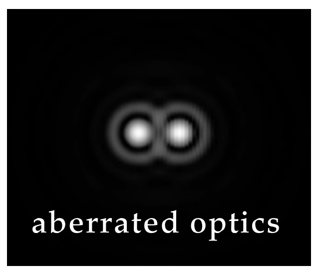






The Double Star Myth
A persistent myth is that splitting close double stars is good test of optics. Above is a 4-inch refractor, below is an 8-inch SCT. The top image in each pair represents perfect optics, the bottom image of each pair is the same telescope with bad spherical aberration. Notice that the double star is still well resolved. However, the poor optics surround the stars with a glow and haze from overly bright diffraction rings. The Airy disk pattern is not cleanly separated from the surrounding dark sky.





What You Don't Want to See

Now, on to determining whether there is a defect in the optics themselves. Errors on the optical surface are divided into categories. What you might see will likely be a combination of two or more of these defects. However, the most common flaw, present to some degree in all but the finest optics, is spherical aberration. Purchasing slower f/8 Newtonians or f/11 to f/15 refractors is one way to avoid this aberration, as fast lenses and mirrors are notoriously difficult to make well. This advice is a prime source of the adage, even myth, that slow f-ratio scopes are best for the planets. This used to be a good rule-of-thumb but today superb optics can be found at all f-ratios, though at a price. It is optical quality, not f-ratio per se, that determines a telescope's suitability for the most demanding task of a telescope—revealing subtle planetary detail.

ZONES

Zones are small figuring errors that often result from harsh machine-polishing. Most commercial optics suffer from zones to some extent. Severe cases degrade image quality noticeably. To check for zones, defocus the image more than is usual in the star test. On one side of focus or the other, you may notice that one or more of the rings looks weak.

With reflectors, in any star testing be careful not to be confused by the secondary mirror's central shadow. The important point is that the pattern should be the same on both sides of focus.

ROUGH SURFACES

This defect, also often present in mass-produced optics, appears as a lessening of contrast between the rings plus the appearance of spiky appendages to the rings. Do not confuse diffraction from spider vanes with these spikes—spider diffraction is spaced regularly. A velvety smooth ring system means you do not have trouble with surface roughness.

SPHERICAL ABERRATION

Spherical aberration can happen when a mirror or lens is undercorrected, making light rays from the perimeter focus closer in than rays from the center. Inside of focus, the diffraction pattern has an overly bright outer ring; outside of focus, the outer rings are faint and ill defined. The opposite pattern, with a fuzzball inside focus and a doughnut outside focus, results from overcorrection. Either error leads to fuzzy images—stars and planets never snap into focus and planetary disks look gauzy.

ASTIGMATISM

A lens or mirror ground asymmetrically makes a star image look like a stubby line or an ellipse that flips over at right angles as you rack from one side of focus to the other. At best focus stars look more like crosses. The easiest way to detect astigmatism is to rock the focuser back and forth quickly. Mild astigmatism may show up with only three rings visible, when the star is just out of focus. Mild astigmatism will soften planetary images and blur the Airy disk of stars. Again, there is no crisp, snappy focus point.

MIXED ABERRATIONS

A more common situation is a scope suffering from a blend of maladies. These views simulate a mix of tube currents, coma, spherical aberration and astigmatism.

Adapted with permission from *Test Drive Your Telescope*, May 1990 issue of Astronomy magazine. For more details, the star-testing bible is the recommended book *Star Testing Astronomical Telescopes* by Harold Richard Suiter (Willmann-Bell, Inc., 1994).

Flaws in the Optics

This series of simulations shows the effect of various aberrations that originate in the optics themselves. On the left is the magnified view of a star seen in focus. At right is the simulated appearance of the "extra-focal" disks seen on either side of focus.