The Quest for Round Stars

Great deep-sky imaging begins with well-tracked exposures.

We all marvel at gorgeous pictures of galaxies, nebulae, and star clusters, and strive to make our own astrophotos just as inspiring. But many things can go amiss during the long exposures needed to make them. Some things we can't control — atmospheric seeing, variable sky transparency, or gusty winds, for example. But other factors that affect our images we can control. One is mechanical jerkiness in our mounts that can cause every star to look like streaks or even double stars. Another is poor collimation of our optics. This can produce weird star images in different parts of the field, indicating a problem that can sometimes be difficult to diagnose.

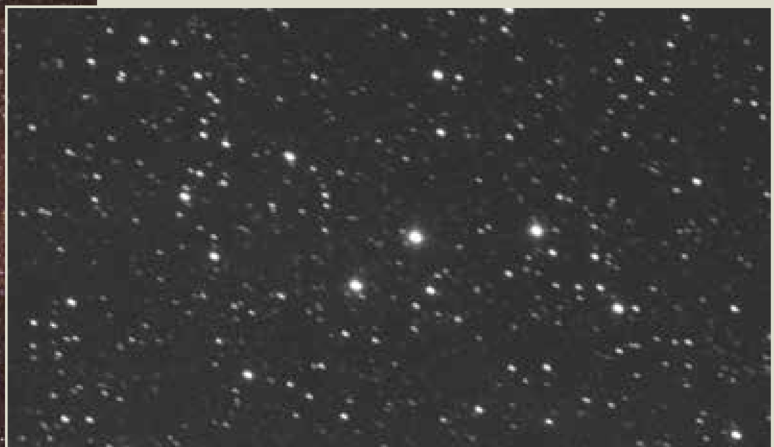
The stars in our images serve as excellent diagnostic tools to help us identify and correct problems in our imaging techniques. Capturing stars that are as round as our setups will permit makes post-processing easier and improves our overall results. Here are some common problems and how we can deal with them on an off night.

Collimation

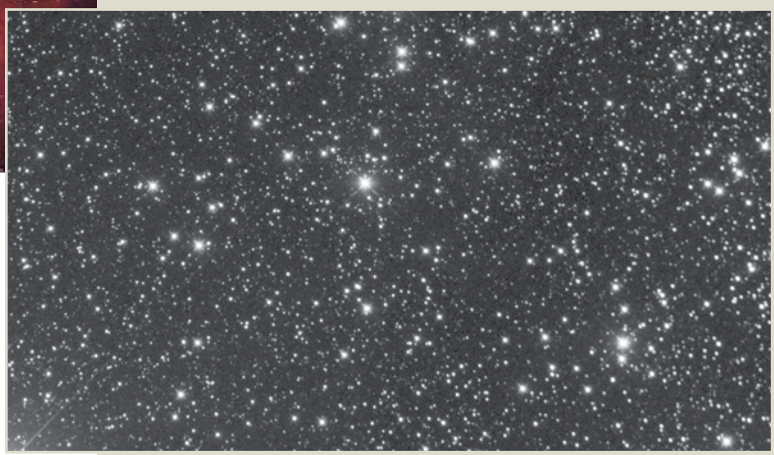
Perhaps the first thing to check with any imaging setup is its collimation. A system is collimated and performing at its best when everything is properly aligned and the light coming into the center of the telescope or lens reaches the center of

PERFECT GUIDING Perhaps the most critical step in deep-sky astrophotography is ensuring well-tracked images. This detailed image of NGC 7000 (left) and IC 5067 (right) includes more than 16 hours of perfectly tracked, unguided exposures using a Takahashi FSQ-106ED astrograph and a Moravin G3-16200 CCD camera. Unless otherwise noted, all photos are courtesy of the author.

▲ **POOR COLLIMATION** Ensuring your collimation is spot-on is an important step, particularly when shooting with fast Newtonian astrographs with coma correctors. This image of van den Bergh 15 displays comatic stars along the right side. These are particularly visible in the top right.



▲ **UNWANTED TRAILS** While some star elongation doesn't detract from wide-field nightscape images, the same can't be said for deep-sky astrophotography. If your results look like the image above, plan on spending some time identifying the cause of the tracking problem.



▲ **HALF IN FOCUS** Diagnosing the source of sensor tilt — seen in this image as the right half of the frame is out of focus, while the other side is not — can be tricky. Take an exposure pointed at the zenith then another pointed about halfway towards the horizon to make sure the problem isn't due to a sagging focuser drawtube.

COLLIMATION: SEAN WALKER / *S&T*

the sensor. Fast optics (those with a low f/ratio) are particularly sensitive to imperfect collimation.

In astrophotography, not only must the optics be aligned, but the camera's sensor must be properly positioned. Heavy cameras and filter wheels can cause some focuser drawtubes to sag, introducing misalignment. One clue that a focuser on a refractor or Cassegrain telescope is sagging is when stars appear round across a photo only when the telescope is pointed straight up towards the zenith and gravity is pulling the focuser holding a heavy camera squared to the optical axis. You can solve this sagging issue by tightening up any loose rails or bearings in the focuser, or by replacing it with an aftermarket model that can better support the camera's weight.

You can distinguish the effects of miscollimation from other problems by comparing the stars in short and long exposures. Its appearance in images is unaffected by exposure length, which can help to eliminate other issues such as poor tracking or field rotation.

An additional concern with deep-sky imaging is ensuring a camera's sensor isn't tipped within the focal plane of the imaging telescope. Large sensors are more sensitive to these tiny misalignments that mimic the effects of poor collimation but aren't corrected by adjusting the optics or the focuser. Images affected by sensor tilt appear the same regardless of where the telescope is pointed. Some astronomical cameras equipped with large detectors include a push-pull adjustment plate on the front of the camera that permits you to tweak the alignment of the sensor.

Most refractors and Maksutov-Cassegrains are collimated at the factory and don't require collimation by the user (although the camera and focuser may require adjustment as noted above). See articles on collimating a Schmidt-Cassegrain (*S&T:* Feb. 2018, p. 28) and Newtonian reflectors (*S&T:* April 2019, p. 68). Specialized collimating tools such as those offered by Hotech (**hotechusa.com**) permit collimation of Newtonian and Cassegrain optics during the day.

Polar Alignment

Even the finest equatorial mount won't produce images with round stars if it isn't properly aligned. Polar alignment is when the polar axis of the telescope is made parallel with the rotational axis of Earth. Our planet rotates around this axis, making stars appear to spin around the north or south celestial pole. As an object moves through the sky from east to west, a properly aligned mount will cancel out this movement, keeping the object centered in the telescope. Misaligned equatorial mounts (and alt-azimuth Go To mounts) can keep an object centered for visual observation but will slowly introduce field rotation, which makes such setups unsuitable for long-exposure astrophotography.

So how accurate does polar alignment need to be for tracked images to have round stars? The answer depends on several factors, such as the length of the exposure, the target's location in the sky, the telescope's focal length and pixel scale, and even the difference in pointing angle between the guide star and the imaging target. Richard Hook published equations concerning polar alignment in the February 1989 issue of *The Journal of the British Astronomical Association*. One of these equations tells us how well-aligned a mount needs to be for a given setup:

$$E = \frac{45{,}000 \times S \times \cos D}{T \times F \times A}.$$

In the equation, E is the maximum permitted polar alignment error in arcminutes, and S represents the tolerance for field rotation in microns. D is the declination of the target, while T is the exposure duration in minutes. Focal length (in millimeters) is represented by F, and A is the angle in degrees between the guide star and the opposite edge of the field.

This equation confirms that short exposures and short focal lengths combined with larger pixels are more tolerant of imperfections in polar alignment. In other words, the higher your pixel-per-arcsecond ratio is, the longer you can expose with less than perfect polar alignment.

If you know how accurately polar aligned your mount is, the equation can be rearranged to answer the question "Given my current polar misalignment and equipment, what's the longest exposure I can achieve before stars appear elongated?" like this:

$$T = \frac{45{,}000 \times S \times \cos D}{E \times F \times A}.$$

When shooting with an image scale of 1 to 4 arcseconds per pixel, polar misalignment by as much as 3 arcminutes is adequate for exposures up to about 15 minutes long.

Some telescope-control software and autoguiding software programs include tools that make precise polar alignment relatively simple. Hardware tools such as the QHYCCD PoleMaster are also available (*S&T:* July 2018, p. 62). The tried-and-true manual method of drift alignment takes longer but works well even if you don't have a clear view of the celestial pole. Numerous drift alignment tutorials are available online.

▶ **AUTOGUIDING** Most astrophotography rigs require autoguiding to keep the telescope pointing exactly at the target throughout the entire exposure. This setup includes a 10-inch ASA f/3.8 Newtonian astrograph that has a piggybacked 80-mm refractor for autoguiding.

Autoguiding

While good polar alignment, tracking, and collimation can improve the roundness of the stars in our images, many telescope mounts require a little help staying on target. This is because most mounts use gears that produce a repeating error known as *periodic error* (PE), which causes a slight oscillation of the field. This often is represented in the technical specifications of your mount as, for example, a PE of +/- 3 arcseconds. Some high-end mounts reduce this error to near-imperceptible levels below one arcsecond, which permits long, unguided exposures at moderately long focal lengths. For most of us, though, long-exposure imaging requires guiding on a field star near your target and correcting these small periodic errors.

Guiding used to be performed manually using a reticle eyepiece, your own eye, and copious amounts of both time and patience. Thankfully, technology eliminated the need for manual guiding almost three decades ago. Autoguiders are small, inexpensive CCD or CMOS cameras that you use to monitor a star and make the corrections necessary during a long exposure.

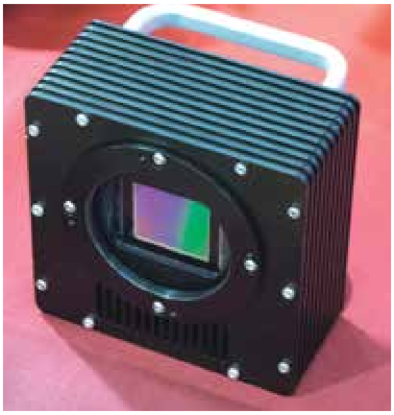
You can use an autoguider in either of two configurations: through the imaging telescope equipped with an off-axis guider, or attached to a separate telescope mounted on the side of your imaging scope. The autoguider checks the position of a single star (the guide star) every few seconds and sends pointing corrections to the mount as needed to keep the guide star centered.

Most camera-control software has autoguiding capabilities, including *TheSkyX* with camera control (**bisque.com**), *MaxIm DL* (**diffractionlimited.com**), and *PHD2* (**stark-labs.com**, reviewed in *S&T:* Dec. 2017, p. 64). Lots of good documentation can be found online explaining how to use autoguiding software and how to troubleshoot any issues.

One common problem encountered when autoguiding through a guidescope is known as *differential flexure*. This generally occurs when the guidescope isn't attached securely enough to prevent slight differences in movement between the guidescope and imaging scope. A device called an off-axis guider, or OAG, can mitigate this problem by eliminating the guidescope entirely. Placed between the telescope and main camera, an OAG contains a small pick-off prism that directs light from the telescope to the guide camera's sensor. When correctly positioned, this prism protrudes only far enough into the light path to capture star images for guiding and should not cast a shadow on the main camera's sensor. The small field provided by the prism should contain an adequately bright guide star. If not, the position of the telescope can be adjusted slightly to bring a suitable star into the autoguider's field of view.

An OAG takes up some of the physical space between your camera and any field flattener or coma corrector in your optical path, so check that you have adequate room between the two before using one.

While autoguiding can help immensely, it isn't always sufficient to produce round stars. I recommend that you consider autoguiding only after optimizing the mechanical and optical aspects of your setup. If you have an excellent mount, or if you're shooting at short focal lengths or limiting your exposures to only how long your mount can go before PE becomes noticeable, you may not need to autoguide at all.



◀ **SENSOR COLLIMATION** Cameras with large CCD and CMOS detectors are highly sensitive to having the sensor square to the telescope's optical axis. Some (such as the Starlight Xpress camera at left) include a push/pull adjustment plate at the front of the camera that allows users to fine-tune the squareness of the detector.

COLLIMATION: SEAN WALKER / S&T

Balance

Another consideration for improving tracking is making sure the weight on your mount is evenly distributed. This minimizes the load that the motors need to bear, reducing wear and tear on one of the most crucial parts of an imaging rig. Having the payload and counterweights balanced well can go a long way toward reducing tracking errors.

To balance equipment on a German equatorial mount, start by balancing the declination axis first. Throughout this process, be sure to hold the equipment steady to prevent sudden rotation due to extreme imbalance. Orient the mount so that the counterweight shaft is horizontal, and the scope with all the gear you intend to use (include any anti-dew straps, and remember to remove any lens caps) is also pointed horizontally. Loosen the clutch on the declination axis and gently nudge the scope up and down. If it moves easily in

▼ **FIELD ROTATION** This photo of the Double Cluster (NGC 869 and NGC 884) suffers from field rotation, where all the stars appear to arc around a point outside the top-left side of the image frame. The cause may be either inacurate polar alignment or differential flexure between the imaging telescope and guidescope.

◀◀ **A MATTER OF BALANCE** Ensuring your equipment is balanced properly on your mount will go a long way toward reducing tracking errors. Adjust the weight of the telescope tube first on the declination axis, then check the right ascension by sliding a counterweight on the shaft.

◀ **CABLE MANAGEMENT** Secure any dangling cables close to the telescope and mount so that they don't snag during an exposure or while slewing to another target.

both directions, your scope is in balance in that axis. If not, then adjust the position of the scope forward or backward in its tube rings or along the dovetail plate to balance it. Tighten everything up and then move to the right ascension (RA) axis. Loosen the RA clutch and simply slide the counterweights on the shaft to balance the scope in RA.

Balancing on a fork mount is similar, though you may need to add counterweights to a rail attached to your telescope tube if there aren't accommodations to shift the position of the tube.

Once you have your payload properly balanced, be sure everything is locked down and then test the mount's performance in a guided image. You should also repeat the test with a target on the opposite side of the meridian.

Some mount manufacturers recommend that you keep the RA axis very slightly unbalanced towards the east side for long exposures. This ensures that the RA worm gear is always engaged as the mount tracks the motion of your target. If you find unbalancing the mount helps, first find perfect balance as described above. Then use a very small weight (just an ounce or two will usually do) that can be attached to the telescope or the counterweight shaft as needed, depending on where your target lies.

Ensure any cables connecting your equipment to the control computer are bundled neatly and secure them to the telescope in a manner that minimizes any stresses that could change as the telescope tracks the sky.

▼ **PERFECT EVERY TIME** Once you've solved all your guiding issues, you're more likely to produce a steady stream of excellent data ready for processing. The author recorded this colorful image of IC 410 (left) and IC 405 through the same equipment as the photo on pages 64-65.

If You Don't Succeed

The best-laid plans don't always work as expected, so if you still end up with slightly trailed stars in your exposures, you can turn to tools that can repair misshapen stars after the fact.

For example, *PixInsight*'s Deconvolution tool has a Motion Blur PSF mode that can significantly reduce star elongation when you input the length and angle of the trailing in your image. There's also a powerful plug-in script for *Maxim DL* that can repair elongated stars (**https://is.gd/trailfix**). Just be aware that no after-the-fact fix will produce as high a resolution in your image as does preventing the problem from happening in the first place. Remember that if stars are elongated, any non-stellar objects in the image are also smeared, and they can't be repaired as easily as the stars.

You may have heard it said that "Good data never go bad." You can always reprocess good images as your processing skills improve and your artistic tastes change over time. Unfortunately, the reverse is also true: Bad data never get better. That's why it's worth spending the time to get your imaging system performing at its best before your next clear, moonless night. There's nothing quite as satisfying as sitting at the computer on a perfect night watching while each subexposure downloads and displays tight, round stars.

■ **RON BRECHER** images the night sky from his backyard observatory in Guelph, Ontario.