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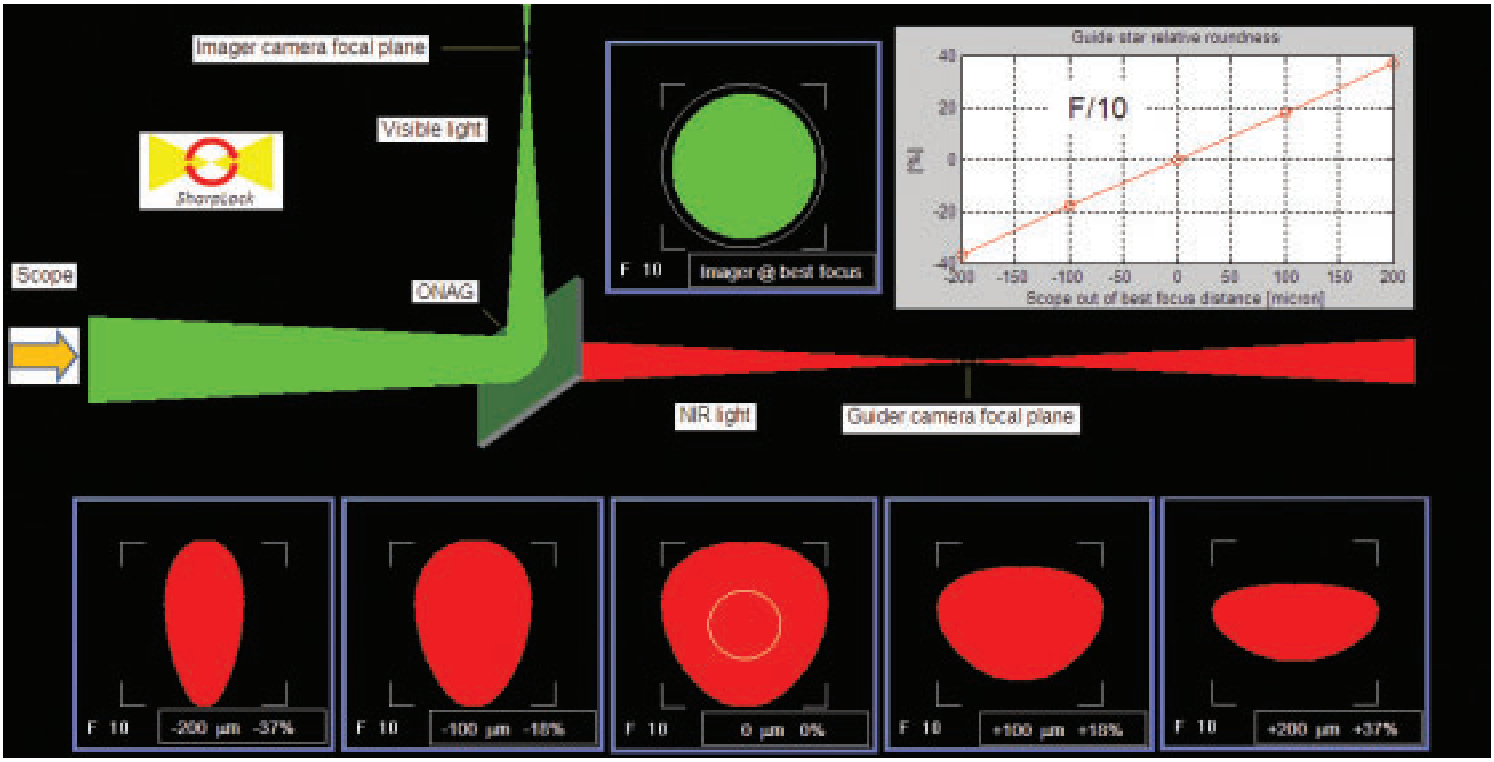

On Axis Guiding and Real Time Autofocus with ONAG and SharpLock

By Dr. Gaston Baudat

Focusing a telescope is a fundamental task for astro-photographic imaging. Maintaining best focus is crucial, but over time, load transfers due to the mount motion can cause significant changes in focus, as can changes in temperature.

How many of us have experienced this during clear but cold nights where we see fast temperature drops? Fall and winter seasons are typical candidates for this effect. To get sharp images, the scope must be refocused at 30-minute intervals, if not more frequently.

Although carbon-fiber optical-tube assemblies (OTAs) are great for minimizing temperature effects, they may not avoid focus shifts from other sources such as flexure, clamping and optical surface radii. Maintaining optimum focus is even more critical with more advanced scope designs, such as the Ritchey-Chrétien (R-C). R-Cs can deliver amazingly sharp images, but they can also exhibit significant astigmatism even inside the critical focus zone, so they must be at best focus all the time.

Less known and more subtle focus problems can be traced to temperature gradients inside mirrors, as well as different thermal inertias between secondary and primary mirrors. The former impacts the surface optical curvatures, the latter impacts the rate of such curvature changes, as well as optical distance between mirrors.

Since mirrors have significant optical powers, small changes in their shapes and registration are magnified many times. The R-C optical layout is very sensitive to this, and unless the mirrors are made of Zerodur-type material, you may very well face some touchy focus instabilities with changing temperature, even with a carbon-fiber OTA.

These types of issues are not easy to solve, leading eventually to recurrent refocus interruptions. Imaging-software packages typically allow for periodic refocusing. The classical procedure calls for slewing the scope towards a

Image 1 - Full-frame ONAG XT with its provided accessories.

bright enough reference star, then running an autofocus (AF) utility, such as a V-curve focusing algorithm, and finally reacquiring the target. This is, at best, a time-consuming procedure during which you are no longer imaging your target. It can also result in additional problems if the mount is unsuccessful at accurately reacquiring the target after the focus routine. As a general rule, every time you move away from your target, you not only lose precious imaging time, but you also open the door for other problems. It is quite common to find that the first frames after the target reacquisition have a poor full width at half maximum (FWHM) due to the mechanical settling time resulting from focus slewing. This effect can last for several minutes.

This article describes how we at Innovations Foresight decided to deal with focus changes. We developed patent-pending SharpLock technology to provide a true real-time autofocus (RTAF) solution. SharpLock continually checks and maintains critical focus without any interruptions in imaging operations. There is no longer any need to slew the scope to refocus stars.

On-Axis Guiding and Autofocus

At NEAF 2013, we launched a new full-frame ONAG XT for detectors with diagonals up to 50 mm (**Image 1**). It features a large laser-aligned dichroic mirror, a rigid 59-mm dovetail system for the scope and imager ports, and an adjustable astigmatism corrector inside the guider focuser. These features ensure an optimum optical alignment between the imager camera and the optical axis of the scope. This is extremely important with large chips to obtain a sharp image across the entire field of view (FOV). The new corrector provides diffraction-limited performance for the near-infrared (NIR) image going to the guider. This is very useful for special applications such as imaging NIR (up to 1800 nm) while using the visible light path for guiding.

Recognizing that high-performance astrographs and large CCD chips require an even more accurate focus, we developed a new solution for providing RTAF operation while guiding with an ONAG. We named this new technology SharpLock, and it provides RTAF using the guide star during normal imaging of the target object.

Any RTAF system needs information not only about the quality of the focus, such as FWHM or half-flux diameter (HFD), but also in which direction the focuser mechanism should move to achieve focus. Unlike conventional AF software, SharpLock's advanced algorithms analyze each guide-star image as it comes in, evaluates its focus quality, and determines the required focus correction without having to move the focuser. When a focus correction is required, the controller computes the necessary focuser motion (how many steps and in which direction) and provides RTAF capability. The SharpFocus solution keeps a system at best focus every time, all the time, efficiently integrating two crucial tasks for astrophotography: guiding and focusing.

The autoguiding and therefore RTAF rate is typically between 1.0 to 30 seconds depending on the guide exposure settings. AF corrections at such rates are very small (a few microns), and the required focus correction does not impact image quality. In fact, any movement caused by the focus correction should be corrected by the autoguiding function before it becomes visible. If continuous focusing is not desired for some reason, there is a user setting that allows SharpLock to defer focus corrections until the exposure is completed and is being downloaded.

How Does SharpLock Work?

SharpLock is based on our ONAG technology. NIR light (>750 nm) used by the guider camera is transmitted through the ONAG dichroic mirror (**Image 2a**). The mirror is set at an angle of 45 degrees for reflect-

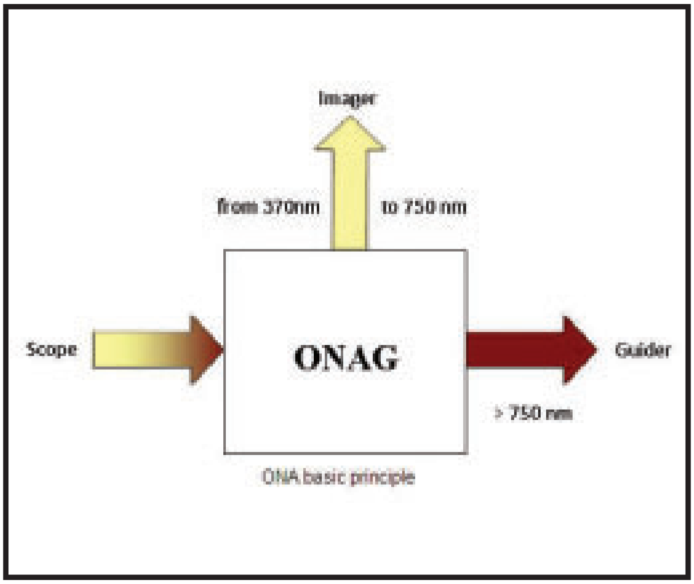

Image 2a - ONAG principle sketch.

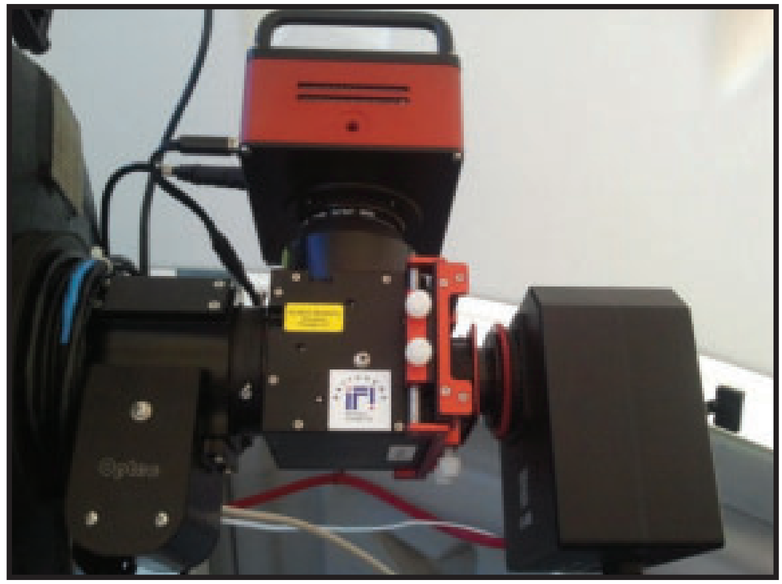

Image 2b - ONAG XT on a 10-inch R-C.

ing visible light (<750 nm) toward the imager camera.

With this optical design, the guider camera is looking through a "tilted window," and this causes a slight but useful distortion of the guide-star image. **Image 3a** shows a typical guide star as seen by the imager camera (in visible light). Here there is no distortion since the light has been perfectly reflected. **Image 3b** (right image) shows the same star as seen by the guider (in NIR). Although both have almost the same HFD, which is all that matters from an autoguiding point of view, the NIR guider image exhibits some degree of astigmatism.

The guide-star distortion does not impact autoguiding algorithms, which typically use a centroid strategy, but this effect does provide a

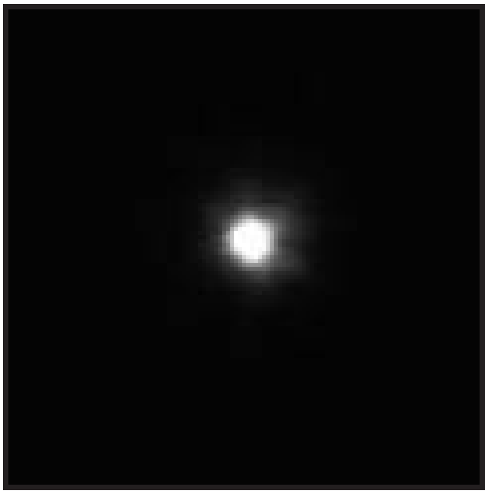

Image 3a - Guide star seen by imager camera (HFD = 6 px).

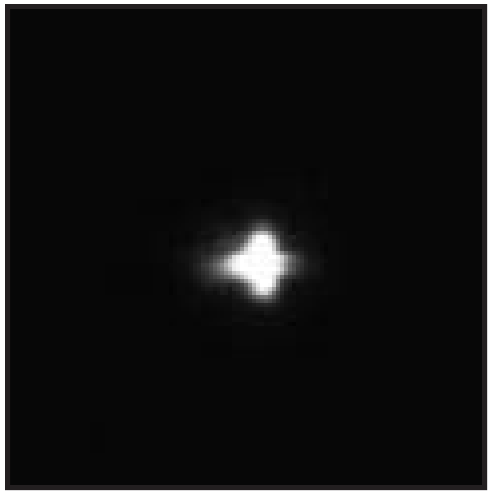

Image 3b - Guide star seen by guider camera (HFD = 5.2 px).

unique RTAF opportunity. When the scope focus changes even a small amount, the guide star shape seen by the guider camera evolves in different ways depending of the direction of the focus motion (in or out). The ONAG XT guider-port optical corrector can be rotated to select a suitable level of astigmatism for this purpose.

The two images in **Images 4a and 4b** clearly show this. Moving the focuser by as much as +/- 400 microns (0.4 mm) leads to two very different star shapes. Of course, the RTAF controller would not, and should not, wait until the guide star reaches such an extreme level of distortion before acting. Just a few microns of focus motion are already enough to detect a guide-star profile change accurately and therefore allows processing it for AF correction. Such a change is too small to be seen by the naked eye in the guider image, or to impact the target image in any visible way. However, after image processing and filtering of a sequence of guide-star images, these small shape changes provide very sensitive and reliable information for the RTAF controller.

Astronomical image-processing and telescope-control software packages can use a SharpLock calibration procedure to automatically learn the system dynamic-focus parameters. From this data, the RTAF algorithms retrieve the necessary information to process the guide-star images and to control the focuser according to the user settings.

The SharpLock-ONAG table in **Image 5** shows various parameters extracted from the calibration process. In this example using a 7-inch f/10 telescope, the guide-star FWHM major and minor axes' relative ratio rate of change is about 0.6 percent per micron of focuser travel.

At f/10, +/-10 microns of focuser motion will increase the circle of confusion by one micron. This blur is tiny in comparison of the actual star profile, yet it already represents about 6.0 percent of variation of the guide-star FWHM minor-to-major axes relative ratio. It would still be about 4.0 percent at f/6. For a telescope with a 3000-mm focal length, one micron on the CCD is only about 0.07 arc-second. If we assume good seeing of 1.5 arc-second (FWHM) and that we want to aggressively keep the out-of-focus blur at, or less than, 10 percent of the seeing, then under these assumptions, this leads to 0.15/0.07 = 2.0 microns on the sensor plane, almost 12 percent of our relative ratio at f/10 and about 7 percent at f/6. The SharpLock technology can easily hold this ratio below 3.0 percent to provide perfectly sharp, focused images all night long.

Focus Versus Time Analysis Using SharpLock

With SharpLock and ONAG technologies, it is possible to analyze in detail the focus change over time of a system. This provides some insight into the value of real-time focus management.

SharpLock is enabled, and the external temperature and the actual absolute focuser position are logged during an actual imaging run. The following experiment used a Ritchey-Chrétien carbon-fiber OTA telescope with a 10-inch aperture at f/8 mounted on a Paramount MX. The scope was equipped with a field flattener, an absolute focuser, and an ONAG XT. The guider camera was a monochrome Moravian G2-4000 with 7.4 micron square pixels. The scope was equilibrated with three cooling fans running for one hour after sunset. NGC6823 was selected as the target (altitude 73 degrees). The seeing was around 2.0 arc-seconds. Both the temperature and focuser absolute position (controlled by SharpLock) were recorded for 70 minutes after the initial one-hour cooling time, half before and half after the meridian (with no mount flip).

In **Image 6** we can clearly see that temperature decreases (top plot in degree C) almost linearly over time (in minutes), while the absolute position of the focuser (bottom plot in mm) needed to hold the best focus does not.

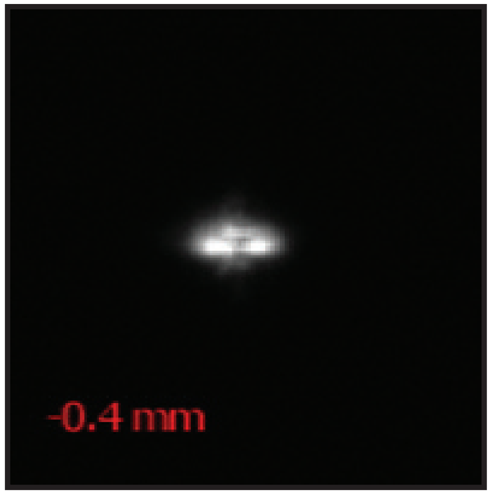

Image 4a - Guide star: Focuser moved in 400 μm.

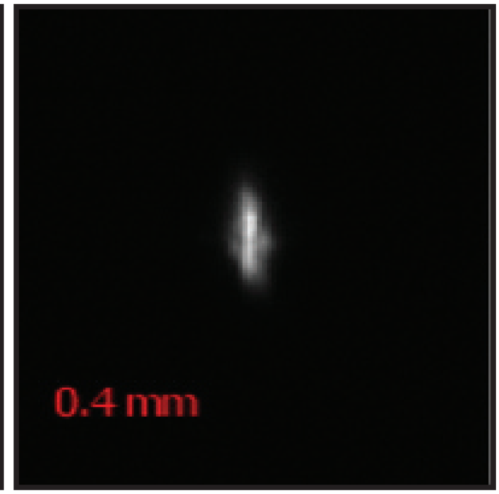

Image 4b - Guide star: Focuser moved out 400 μm.

At first, the focuser moved inward by about 170 microns in 12 minutes, then outward by 200 microns or so in 10 minutes, before eventually traveling inward again. The temperature dropped at a rate close to 3.0 degrees C per hour, which is fast enough to create such behavior. Modeling of this effect is very difficult, and that prevents a correction strategy based on predictive open-loop techniques.

The classical critical-focus zone at f/8 is around 160 microns (+/-80) for an Airy disk of 10 microns, or 1.0 arc-second. In this ex-

SharpLock – ONAG® table					
Foc offset (mm)	FHWM major axis (pixels)	FHWM minor axis (pixels)	Ratio maj/min	Angle (°)	HDF camera principale (pixels)
-0.5	11	4.4	2.5	57	8
-0.4	11.8	5.9	2.0	53	7.7
-0.3	9.5	3.5	2.7	55	6
-0.2	9.5	3.5	2.7	55	5.1
-0.1	7.9	4.6	1.7	53	5
0	5.5	5	1.1	49	3.4
0.1	6.4	4.3	1.5	-33	3.6
0.2	7.5	3.8	2.0	-32	3.7
0.3	8.7	3.1	2.8	-33	4.2
0.4	10	2.5	4.0	-36	5.2
0.5	11.2	3.2	3.5	-35	6.4
0.6	failed	failed	failed	failed	8.5
F/10					
F=1800mm					

Image 5 - 7-inch f/10 telescope calibration table.

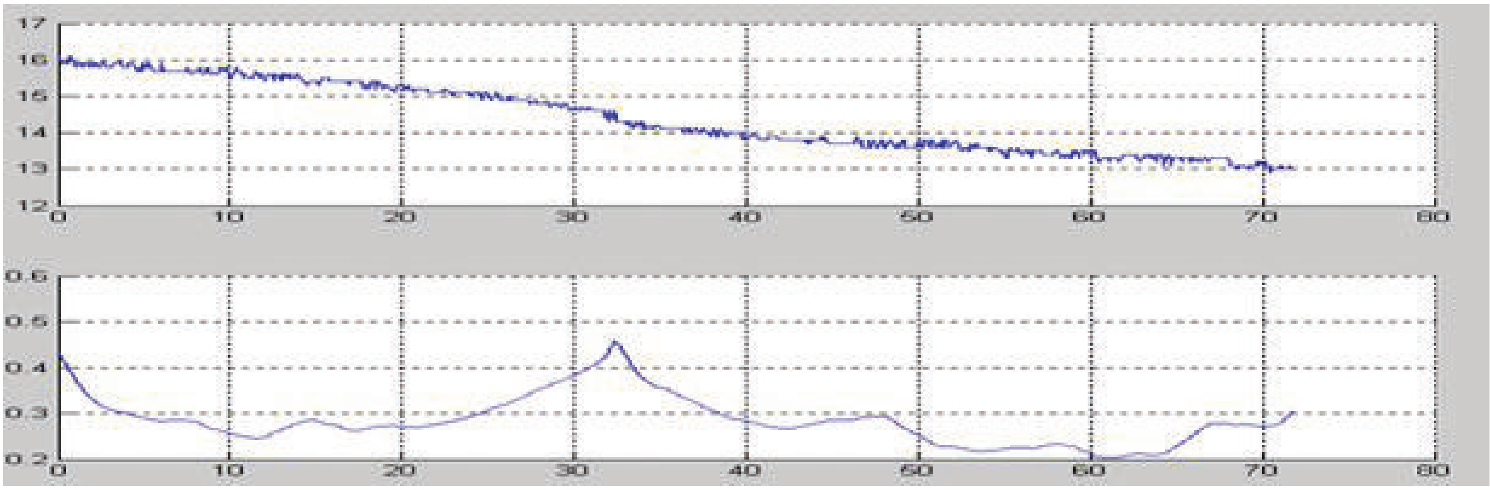

Image 6 - Temperature (degree C) and absolute focuser position (mm) versus time (minute).

periment, the focuser moved by 260 microns peak-to-peak. Without refocusing, this would have led to blurred images and, with an R-C, to significant astigmatism even inside the +/- 80-microns band. The classical critical-focus zone calculation is geometric in nature and somewhat optimistic. A tighter tolerance should be sought since the circle of confusion theory is only valid when the sensor plane moves while everything else remains the same. This assumption is not met when there are temperature-induced optical-system alterations, such as registration, spacing, and curvature changes.

So many carbon-fiber OTAs are not immune to focus shifts, especially in the context of a fast temperature drop. Only expensive, very low-expansion optical glasses, such as Zerodur (Schott) or Astrosital, in addition to careful temperature-compensated telescope mechanical designs may achieve stable focus without focus adjustment. Without the need of extreme materials and design efforts, SharpLock technology is able to evaluate actual images in real time and hold optimum focus by continuously compensating for changes. Your images will remain sharp frame after frame. ATT