

AO-7 Adaptive Optics Accessory Operating Manual

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Introduction

SBIG's adaptive optics package is designed to enable users of SBIG Dual CCD cameras¹ (like the ST-7) to achieve the ultimate in resolution when imaging deep sky objects. The package consists of two components: a high speed tip-tilt mirror capable of correcting the telescope pointing at rates up to 50 times a second, and a software package that implements the Lucy-Richardson deconvolution technique for image sharpening. Both items were developed by SBIG in concert with Benoit Schillings and Brad Wallis, two advanced amateurs well known in the film and CCD imaging field. This package can produce a 2X improvement in resolution over normal self guided images, where corrections are applied only to the telescope drive. This package truly advances the capability of the amateur astronomer, considering that most professional observatories do not have comparable systems.

Theoretical Background

Under good seeing conditions, atmospheric turbulence causes the stellar image to wander about the mean position, in addition to blurring occasionally. Three levels of adaptive optic correction are possible. The simplest technique, which we have implemented, uses a high speed steering device to suppress the wander and hold the star image fixed on the sensing device. A second level of sophistication is to try to correct the lower level aberrations produced by the atmosphere, in addition to stabilizing the image, while viewing a star. The ultimate technique, developed by the military, uses a laser guide star to provide a point-like source high in the atmosphere that provides enough light to enable accurate sensing of the wavefront, and therefore correction. The laser guide star approach, however, can only correct the higher order aberrations; the image must still be stabilized by a tip-tilt mirror viewing the object, not the laser guide star.

The success of any adaptive optic technique is limited by three important considerations: First of all, the atmospheric aberration is not correlated spatially over a large extent. The isoplanatic patch commonly referred to in the literature is the angular extent over which the higher order aberrations are correlated, and is typically only a few arc seconds. The odds of having a suitably bright star so close to an object of interest is small, which is what has motivated the development of laser guide stars, which can be put where they are needed. The tip-tilt component of the aberration is correlated over a larger extent, minutes of arc, improving the odds of finding a suitable guide star.

The second consideration is that the atmosphere is constantly changing. With any system, you have to correct the telescope or adjust the mirror based on the last image acquired, which can be several milliseconds old by the time it is collected. For example, with a 10 millisecond exposure, the average position of the star is sensed as it was 5 milliseconds previously. This consideration forces one to work at very high rates to correct the higher order aberrations. The lower order effects, such as the tilt of the wavefront, change less rapidly and can be corrected with slower systems.

The last major consideration is field of view. Systems which correct the higher order aberrations typically can not improve the image over more than a 1 minute of arc field of view. This corresponds to an ST-7 used with a 934 inch focal length (24 meters).

The importance of these considerations is that a typical amateur CCD camera with a field of view of around 10 minutes of arc, using a guide star about 10 minutes off the center of the field, is not improved by correcting more than the tip-tilt component of the aberration, and does not need to run at excessively high rates to obtain all the possible improvement. The higher

¹ The AO-7 is not compatible with the Large Format ST-L line of cameras. At this time a new AO unit is being designed for those cameras.

order aberrations and fast image variation are simply not correlated between the two CCDs. This is the philosophy behind SBIG's AO-7 tip-tilt mirror design. Our correction rate allows correction of stellar wander up to about 5 hertz (50% wander reduction), assuming a bright enough guide star, and correlation between tracking and imaging CCDs. In general, deep sky objects do not have good guide stars imbedded in them, so our off axis location of the tracking CCD is essential for the user to acquire guide stars over a substantial area by rotating the camera. We do not feel better reduction of atmospheric effects than that provided by our unit is possible for amateur sized telescopes.

In general, adaptive optic techniques used for astronomy are always starved for light. We have optimized our noise performance to where one can typically guide on a 10th magnitude star at 10 frames per second with a 10 inch telescope. We call this rule the "10" rule of thumb! Finding a good bright guide star is aided by a good star atlas program, such as Software Bisque's The SkyTM, and focal reducers or Barlow lenses to put the best star at the right distance off axis. In general, even running at rates as low as 1 frame per second provides some improvement since the AO unit makes an accurate small move, much better than most telescope drives, since it has no backlash and a fast response.

In general, the AO module cannot be used to image the moon, since there is no guide star. It cannot improve planet imaging unless a guide star is close by, such as might be provided by a moon of Jupiter.

How the AO-7 Unit Works

In SBIG's AO-7, a tip-tilt mirror is used to make fine corrections to the position of a star to hold the image fixed on the CCD during the exposure. The tip-tilt mirror has magnets on the back, which interact with the current flowing through a set of voice coils on the AO module housing to rapidly move the mirror. The technique is very similar to that employed in loudspeakers, except there the magnet is fixed and the wires are on the moving speaker cone. We put the wires on the fixed housing to better conduct heat away from the moving mirror, where it might distort the optical element.

The mirror and magnets are suspended using a flexible beryllium copper membrane. A needle pushes up against a jewel bearing mounted to the center of the mirror to hold the focus constant. SBIG has developed a proprietary technique to rapidly damp the motion of the mirror, so small moves are precise, with very little overshoot or ringing. The tilt of the mirror during operation is very slight, and does not lead to any measurable defocus at the edges of the frame, even on large format cameras like the ST-8. The correction range of the tip-tilt mirror is about ± 30 pixels with an ST-7

(± 250 microns); the software adjusts the telescope position to take care of drive errors greater than this if they exist. The telescope position is adjusted while the AO is running, but this does not cause problems since the AO corrects much faster than the telescope drive. The telescope drive is adjusted to keep the AO-7 voice coil drive levels between 25 and 75%.

The AO-7 accessory utilizes the tracking CCD integral to the Dual CCD cameras. The PC controlling the imaging process uses the tracking CCD to measure the position of the guide star, then sends a position correction to the tip-tilt mirror, waits for the mirror to move, and starts the next tracking CCD exposure. The imaging CCD continuously collects light throughout the cyclical process. In SBIG's tip-tilt mirror the mirror can complete the move in 10 milliseconds. Reading out the CCD and processing the information takes another 9 milliseconds, so with an exposure time of 1 millisecond the unit can achieve update rates of 50 frames per second. With an exposure of 10 milliseconds, the total time to go through the loop once is 29 milliseconds, corresponding to a rate of 34 frames per second. The maximum sinusoidal components of the

stellar motion that are well corrected are only about $1/10^{\text{th}}$ of the update rate. For example, a 40 frames per second update rate attenuates a four hertz stellar sinusoidal motion by about 50%.

Compatibility

The AO-7 can be used with SBIG's ST-7/8/9/10/2000 cameras (parallel or USB) with or without the CFW-8 filter wheel. The CFW-6 filter wheel is not supported.

Mounting the AO unit to the Camera and Telescope

1. Unpacking the AO module

The AO module's tip-tilt mirror is somewhat delicate due to the flex member and the needle bearing support. For shipping a piece of cardboard and a lens cloth is sandwiched between the two halves of the module to prevent the mirror from vibrating or hammering against the jewel bearing. Remove the long screws that hold the halves together, remove the cardboard, and reassemble the unit. Save the cardboard and lens cloth in case you need to return the unit to SBIG for service. If necessary gently clean the mirror with rubbing alcohol and cotton swabs. Never reuse the swabs – wipe the alcohol on with one swab, dry it with another, and repeat the process using new swabs until the mirror is clean. If fingerprints are present, reusing the swabs just moves the grease around, and does not remove it from the surface. This is why the swabs must be thrown away after one use. This is typically a good technique with optical elements.

It is a good idea to check the flexure when it is first unpacked. Gently depress the mirror around the edge with a swab or fingertip about 0.04 inch (1 mm). The mirror should have a firm, smooth spring action, with no gritty feel such as might result if the mirror was rubbing against the support structure. Check it in four places, 90 degrees apart. Contact SBIG if it doesn't feel right, or tends to hang when released.

When reassembling the two halves of the unit, orient the halves so that the cable exits on either the + or – X side of the AO-7. The X axis is the same as the long direction of the CCD.

The CCDOPS software includes an Exercise command under the AO menu. This option allows one to drive the mirror to its limits in a rectangular pattern, or each axis individually. You can select the axis or combination, and the update rate between moves. This option is excellent for checking out the AO device after unpacking. Make sure it is connected to the camera, and the combination powered up. (only connect and disconnect the AO module to camera when both are unpowered!). Try an update time of 100 milliseconds initially, and look at a distant light reflected in the AO module mirror. You should see the mirror deflecting. Next increase the update rate to 20 milliseconds. The light should blur into a rectangular pattern of light, with no more than 20% overshoot at each corner. It will probably not be square, and may be slightly parallelogram shaped, with the axes not at exactly 90 degrees. This is satisfactory, since the resultant error of the move is small. Hit ESC to terminate the mirror motion.

2. Connecting the module to the Camera

There are three ways to attach the AO module to the camera, depending on your configuration. In all three you start by removing the T-Thread D-Block adapter from the front of the camera using a Philips head screwdriver as shown in Figure 1A below:

- Method 1: Without a CFW-8, directly connecting the AO-7 to the Camera.
- Method 2: With a CFW-8, directly connecting the CFW-8 to the Camera and then using the Male-to-Male T-Thread coupler to connect the AO-7 to the CFW-8.

- Method 3: With a CFW-8 and SBIG's new CFW/AO Adapter Plate, direct connecting the CFW-8 to the Camera then using the Adapter Plate to connect the AO-7 to the CFW-8.

Method 1 – Direct Connect AO-7 to Camera without a CFW-8

Using the supplied four 4-40 x 3/8 Pan-Head Cap-Screws attach the AO-7's Diagonal Piece to the camera as shown in Figure 1B below:

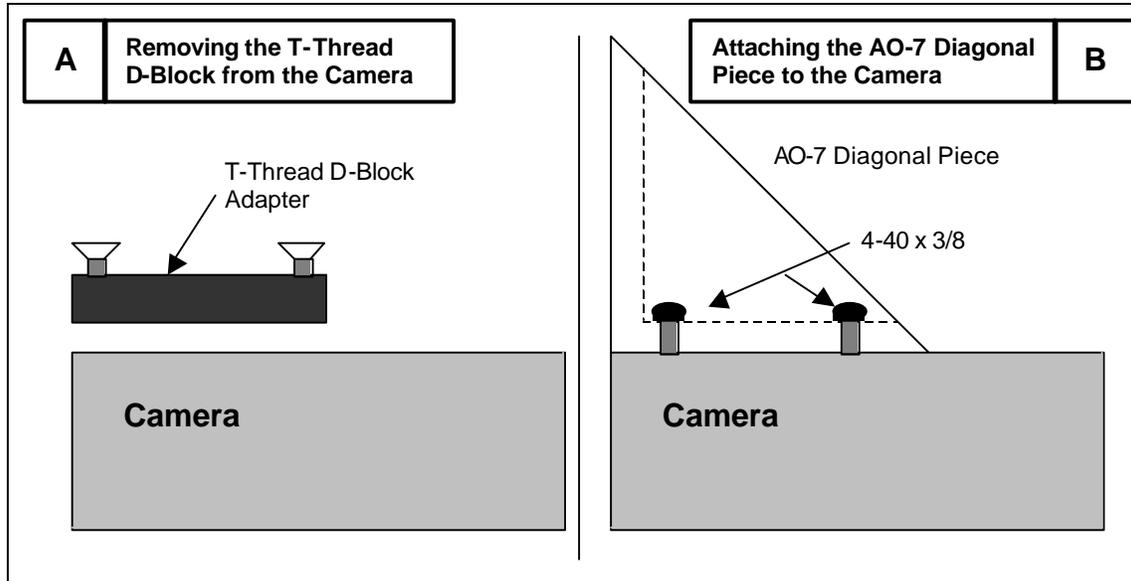


Figure 1

Method 2 – Direct Connect CFW-8 to Camera, T-Thread AO-7 to CFW-8

After unscrewing the CFW-8 front cover and removing the Filter Carousel, attach the CFW-8 body to the camera using four 4-40 x 3/16 Socket-Head Cap Screws as shown in Figure 2A below. Reassemble the CFW-8, making sure you install the Filter Carousel with the index pins pointing up (away from the camera). Then attach the T-Thread D-Block from the camera to the AO-7 Diagonal Piece with four 4-40 x 5/8 Flat Head Screws and four 4-40 Nut.

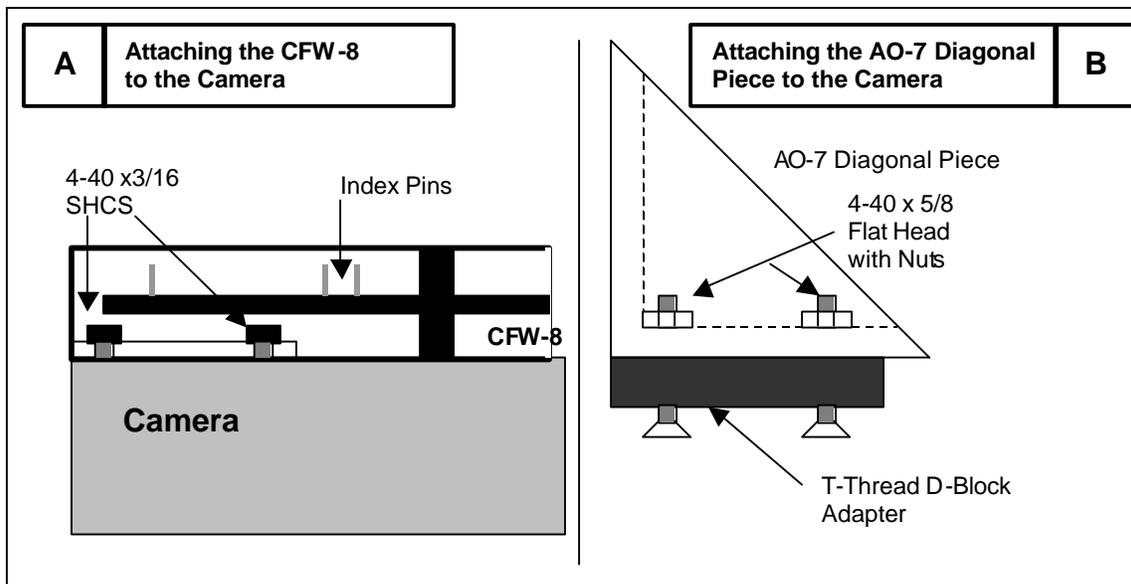


Figure 2

Finally attach the AO-7 Diagonal Piece to the Camera/CFW-8 using the Male-To-Male T-Thread Coupler as shown in Figure 3 below. Note that by loosening then retightening the three Cone-Point screws in the D-Block you can get the proper orientation of the AO-7 to the Camera/CFW-8.

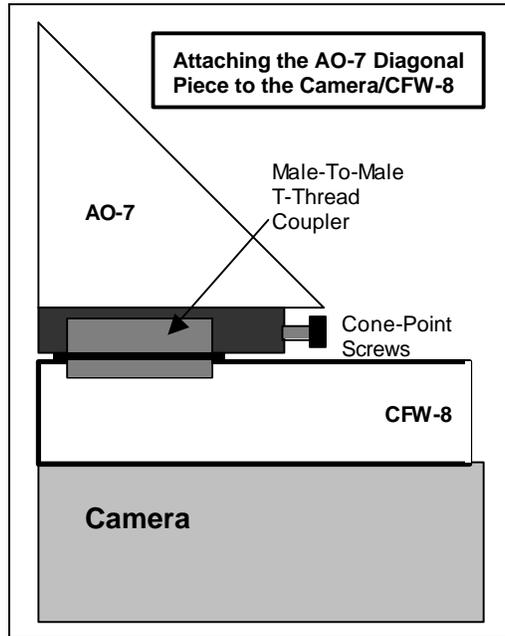


Figure 3

Method 3 – Direct Connect CFW-8 to Camera, AO-7 Mounts to CFW/AO Adapter Plate

Follow the first half of the instructions in Method 2 above to Direct Connect the CFW-8 to the Camera except when reattaching the CFW-8 Front Cover to the Main Body only use the two screws at the bottom of the Front Plate (the ones furthest from the aperture).

Now attach the CFW/AO Adapter Plate to the CFW-8/Camera using four 4-40 x 3/8 Pan Head screws and then attach the AO-7 Diagonal Piece to the CFW/AO Adapter Plate using an additional four 4-40 x 3/8 Pan Head screws as shown below in Figure 4.

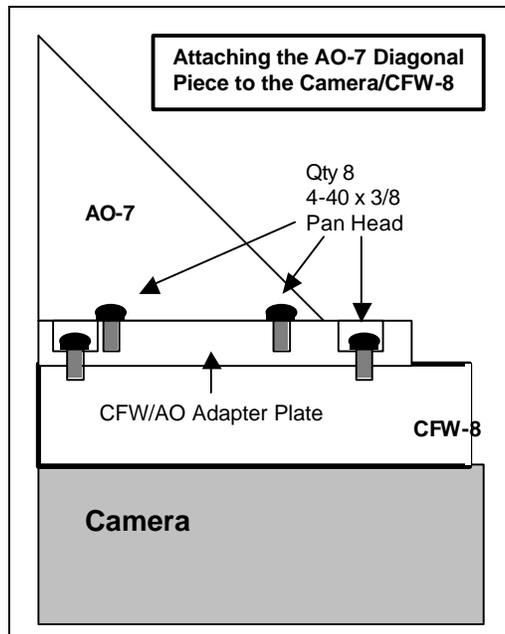


Figure 4

3. Attaching the Mirror Unit to the Diagonal Piece

Using the four long 4-40 Hex Head Cap Screws attach the AO-7's mirror unit to the Diagonal Piece. Use the White Stripe on the side of the unit to get the proper orientation of the two halves and make sure the small LED sticks through the hole in the back cover as shown in Figure 5 below.

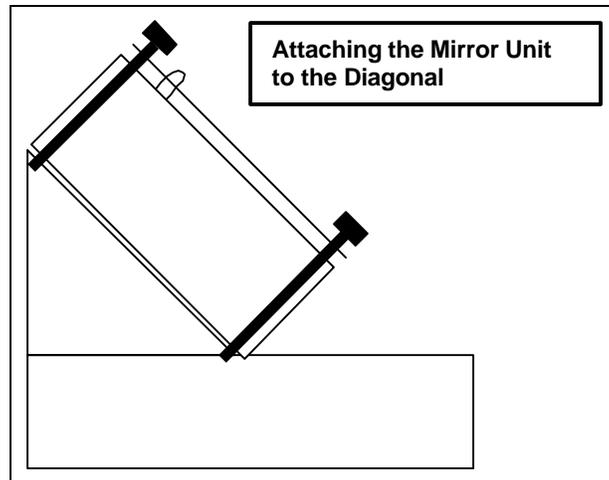


Figure 5

4. Attaching to the Telescope

It is important to be able to loosen and rotate the AO/Camera assembly without disturbing the telescope or changing the focus. For this reason, we have put four short posts on the telescope attachment so that it can be tightened with a minimum of effort. It is important to put grease on the threads of this coupling to prevent it from seizing. Try to avoid getting grease on the seat, since it is friction between this surface and the mating telescope surface that prevents the assembly from rotating relative to the telescope.

Make sure when attaching the assembly to the telescope that the threads are properly aligned. A good way to ensure this alignment is to rotate the attachment backwards until the threads fall into place, which can be easily felt.

The adapter sold with the AO-7 will attach to most commercial Schmidt-Cassegrain telescopes. It can be removed by loosening the set screw that bears against the threads and unscrewing the adapter. The exposed threads in the AO-7 unit are M42 x 0.75 mm pitch and will mate with commercial T-Thread adapters.

Self Guiding with the AO Unit

It is recommended that when you first use this product, as well as any other product we sell, that you set up your telescope and computer in a location that has a view of the sky, but is also reasonably well lit and convenient. In other words, learn how to use the product under conditions such that an hour lost struggling with unfamiliar software is not an hour lost of good, dark sky. Full moon periods are great for initial experimentation!

At this point you should refer to the CCDOps Software Manual for operating the AO-7 and Camera combination.

**CCDSharp
Lucy-Richardson
Deconvolution Software**

Operating Manual

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Image Processing with SBIG's CCDSharp Software Package

SBIG's CCDSharp processing package will sharpen well exposed CCD images with little noise increase or objectionable artifacts, such as bright rings around stars. The software works with all SBIG images except those captured with an ST-4. The program implements the well known Lucy-Richardson algorithm used on Hubble Space Telescope images. It is designed to run on a PC compatible computer using the 32-Bit versions of Windows. It will not run under DOS or Windows 3.1. It also is very calculation intensive – a high speed Pentium class machine is strongly recommended. An ST-7 frame will process in about 20 minutes on a 133 Mhz Pentium.

Installing the Software

CCDSharp is installed by inserting the CCDSharp floppy into the A drive, and from the Windows START menu selecting RUN, and then entering A:\SETUP.EXE. The installation wizard will guide you through the process much like other Windows programs.

Using the Software

1. Displaying an Image.

Start the program as you would any other Windows program, and load up an image using the FILE menu item. The file operations are similar to other Windows programs. Once the image is on the screen a CONTRAST dialog box appears that allows you to adjust the brightness and contrast to best show the image, as well as invert the image, smooth it, or pick a contrast automatically. You can modify the image display using the little BACK and RANGE box by positioning the mouse over the center of the box, depressing the left mouse button, moving the mouse to select a contrast setting, and then releasing the button. The computer then redraws the image. BACK stands for the background pixel signal value in the image, and RANGE refers to the range of pixel signal counts that you wish to be mapped from black to white. The magnification of the image on the screen can also be adjusted within this dialog box.

Under the VIEW menu you can turn the toolbars on and off. The TOOLBAR is under the menu bar and contains the image processing tools that you can use. The STATUS BAR is the line at the bottom of the screen that reports deconvolution status during the process.

Under the DISPLAY menu you can select either PARAMETERS, which shows the information recorded with the image during acquisition, MODIFICATIONS, which shows the alterations that were performed on the image, such as dark subtraction, and CROSSHAIRS, which brings up a crosshairs dialog box.

Under the UTILITIES menu, you have a choice of flipping the image either vertically or horizontally to produce a view matching the object's orientation in the sky.

The WINDOWS menu gives you control over the display of multiple images on the screen. When multiple images are shown on the screen, the CONTRAST and CROSSHAIRS dialog boxes give information corresponding to the top, or highlighted image (the bar at the top of the image is colored).

The CROSSHAIR dialog box displays the pixel location in the image in pixels from the upper left corner, the value of the pixel, the average value of the square region centered on that pixel, the rms variation in the signal counts over the selected region, and a coarse measure of the stellar full width at the half maximum points. The last value is useful when evaluating seeing, or deconvolution improvement. One can also select the box size to define the region used in these calculations. One word of warning – do not use too small a box size when measuring halfwidths

or the reported value will be erroneous, smaller than they actually are. Use a box size that nicely encompasses a bright, but not saturated star. Too big a box will cause little harm!

Clicking on a star with the left mouse button while the Gaussian profile box is selected (in the toolbar) will bring up a stellar profile graph, which shows the radial energy distribution of the light in a star.

 - **Gaussian Profile Icon**

The computer first calculates the centroid of the image, and then displays each pixel in the box (box size selected in the CROSSHAIRS dialog) according to its brightness and distance from the centroid. The horizontal axis is in units of arcseconds, based on the focal length shown under PARAMETERS. The telescope parameters cannot be modified within this program, so take care to set them correctly when running CCDOPS. The stellar profile is useful for viewing the quality of the stellar images, and selecting unsaturated stars for use by the deconvolution algorithm. Saturated stars are obvious since the stellar profile is clearly flat-topped.

2. Deconvolving the image:

When a celestial field is imaged the CCD records the field blurred by the telescope optics, atmospheric turbulence, and tracking errors. Usually the blur is constant across the field. Mathematically the final image is described as the scene convolved with the system point spread function. Deconvolution is the process of removing the blur and recovering the original scene. In practice the blur can only be partially removed due to the finite signal to noise of the recorded image, and the fact that the recorded image is sampled. However, even a modest improvement can produce striking results!

To deconvolve an image, first load up the image, and verify that all preprocessing is complete. Preprocessing usually includes dark subtraction, flat fielding, and perhaps warm and cold pixel removal. Select the cross icon from the toolbar, and mark one to eight isolated, not saturated, stars with the crosses by positioning the cursor over them and clicking the left mouse button.

 - **Cross Icon**

These stars will be used by the routine to determine the point spread function of the system, which is essential in optimizing the deconvolution. If a star is selected inadvertently, click it again to remove the cross mark. Next, select the rectangle icon from the toolbar, and select the region to be processed.

 - **Rectangle Icon**

If the placement of the box is not as desired, simply do it again. If no box is marked the software will process the whole image. When both isolated stars and the selected region have been chosen, click the GO icon button in the toolbar. Select the number of iterations from the dialog box that pops up, and the deconvolution process will begin. The number of iterations that is optimal can best be determined by processing a small portion of the image initially before doing the whole image. The denser the image, the better the signal to noise, the greater the number of iterations that can be used. Too few iterations doesn't provide much improvement, and too many gives the background and unfeatured portions of the image a "bubbly" look. Five iterations is a

good starting point for a well exposed deep sky object. Deconvolution can be overdone, so we recommend selecting this parameter conservatively.

When the software deconvolves the image it applies a background limit to the process to minimize the rings around bright stars that plagued early image processing programs. While this limit produces a much more pleasing visual image, it can alter the total counts associated with the star slightly. In mathematical terms, the total counts in the star are not conserved. This means that precision photometric analysis should not be performed on deconvolved images, but rather be restricted to the original images.

After deconvolution, save your images. The improvement wrought by the deconvolution process is best seen by displaying the original image next to the processed image with an identical contrast setting. Viewing some stellar profiles in each image further illustrates the improvement. The red crosses and selection rectangle can be removed from the final displayed image by using the BROOM button in the toolbar.



Broom Icon

SBIG AO-7 PRODUCT NOTE:

11/21/97

During initial production of the AO-7 device it has become apparent that the adjustment of the needle bearing pivot at the center of the mirror is critical. This adjustment is made here at SBIG and the adjustment screw head staked with a dab of epoxy. We have limited experience with the robustness of this adjustment when subjected to the vibrations and shocks encountered during shipping. When you first assemble the unit to the camera and power it up, hold the AO-7 unit so the mirror faces down. If the bearing has loosened the mirror will go into oscillation, and the vibration will be easily felt. It is also audible. All units we ship pass this test before they leave here.

If your unit exhibits a vibration please contact SBIG. If the unit does not vibrate, then you may use the unit with confidence. We thank you for your patience as we gain experience with the stability of this design.