# SBIG

## ASTRONOMICAL INSTRUMENTS

Users Guide:
CCDOps Version 5

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# Introduction

Welcome to the exciting word of Digital Astronomical Imaging! Amateur Astronomers are taking CCD images today that rival the film images taken by the Professional Astronomers of the past. The power of today's Cameras is simply incredible.

This manual describes how to get the most out of your SBIG Camera using our CCDOps software. While it doesn't discuss every single feature of the software it does give you an in-depth understanding of what you'll need to take outstanding images.

Further detailed information can be found in the Help menu of CCDOps and Online at SBIG's Website:

**www.sbig.com**

Many users subscribe to the SBIG User Group (available from our Website). There you will find hundreds of other users doing exactly the same thing you are: Trying to Take the Best Astrophotos possible. Sign up and follow the discussions. If you have questions the community is usually happy to help. It's an invaluable resource.


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# 1 Setting Up Your Camera

There are several things you need to do in order to use your new camera:

1. Make the physical connections between the camera and computer, telescope, and power supply.
2. Set up CCDOps so it can find and talk to the camera.
3. Adjust the camera settings in CCDOps so the camera works the way you prefer.

The physical connections include the following:

- **A USB cable from the USB type camera to your computer.** Other USB devices on the same USB port could create interference with the camera, so we recommend that you run a single USB cable directly from the camera to your computer. USB cables are limited to 15 feet, but it is possible to use special equipment to create longer cable runs. See the SBIG web site for information on techniques for making longer USB connections.
  *or*
  **A parallel cable from the parallel type camera to your computer.** Conventional parallel cables are limited to about 15 feet. See the SBIG web site's Application Notes for details on how to build a longer parallel cable using special techniques.
  *or*
  A parallel cable from the camera to SBIG's E2P Ethernet to Parallel adapter box. Please see the SBIG web site for more information about the E2P.

- **The power cable from the power supply to the camera.** We do not recommend using an extension on the power supply because an extension can lower the voltage levels that the camera receives. The power supply can be mounted near the base of the mount to accommodate any camera position.

- **The guide cable from the camera to the mount.** A guide cable is included with all SBIG cameras. This cable has special wiring, and you cannot use just any similar cable for guiding. The connectors on the cable have to be aligned in the correct way. Please see the section "Cabling" for information about how guide cables must be wired.

Communication setup is very easy and is described below in the section "Set Up CCDOps." Other camera settings vary depending on the task at hand. You can learn more about the available camera settings in the section "Adjusting Camera Settings."

## *Physical Connections*

There are two ways you can attach most SBIG cameras to your telescope. The method you use depends on both your requirements and the telescope you are using. You can attach the camera like an eyepiece using standard adapters, or you can use threaded extension tubes.

Whichever method you use, it is very important that the camera be securely attached (no movement) and that the camera be square to the telescope's optical path. If the camera is tilted, the focus will vary across the CCD.

## Method A: Eyepiece-Style Connection

Every SBIG camera comes with a 1.25" and/or 2" adapter that allows you to insert the camera into almost any telescope's eyepiece holder. Be sure to check that the camera is well-secured and cannot slip out no matter where you point the telescope.

> **TIP:** Most SBIG cameras include a 1/4x20 threaded hole for mounting on a tripod. You can use this threaded hole and a shaft bolt to attach a safety line between the camera and the telescope. This will prevent the camera from falling to the ground. Make sure the cable isn't overly long—a fall into the pier can be just as damaging.
> *Caution:* If the bolt threads into the camera more than ¼ inch, it could damage the electronics inside the camera.

If you use an eyepiece-style connection to the telescope, check the connection for wobble and alignment. In most cases, you will get a secure and solid connection. However, an older telescope or one that is not designed to carry heavy weights may not be solid enough for CCD imaging without modification.

For example, some telescopes that provide a single thumbscrew for attaching eyepieces may not lock the camera down securely. The camera is heavier than the eyepieces the eyepiece holder was designed for. It may be possible to add a second or third threaded hole for additional thumbscrew(s) to get a more secure connection. This is not a trivial modification.

> **TIP:** If possible, attach the camera with the base of the 1.25" or 2" adapter flush against the focuser tube of the telescope. This helps to prevent tilt.

## Method B: All-Threaded Connection

Most SBIG cameras also include a threaded front end. The thread is built into some cameras and accessories, such as the STV and the CFW-8. On some cameras, a threaded attachment called a D-block can be secured to the front of the camera.

This thread is called a T-thread, and it is a standard thread used for photography. You can find accessories for T-threads, including extension tubes, from many SBIG dealers. By choosing the right size of T-thread extension tubes, you can create an all-threaded and very secure connection between the camera and the telescope.

> **TIP:** Some telescopes offer camera rotators that make it easy to rotate an all-threaded connection. Contact your telescope manufacturer to see if this accessory is available for your brand and model of telescope. If you are using the D-block, it has three easily-accessible set screws that can be loosened to rotate the camera. Make sure to firmly reseat the set screws before using the camera. Also make sure that the camera is still square to the optical path after all adjustments. If you take the T-Thread ring out of the D-block, make sure to put it back in the proper orientation. Figure 1 shows the correct orientation assuming the camera is at the bottom. The screws contact the angled portion from the sides and this forces the ring against the camera.
> *Caution:* If the ring is inserted upside down, the connection will not be secure.



*Figure 1 - The shape of the T-Thread ring in the D-block.*

If your telescope does not support T-threads directly, adapters are commonly available from the manufacturer or from dealers.

## Cabling

There are two possible connections you can make with your camera: a USB cable to connect the camera to the computer (required) and a guider cable to connect the guider output of the camera to the telescope mount (optional).

> **Note:** Some SBIG cameras use a serial or parallel cable for the computer connection. Please consult the documentation for your specific camera to determine what type of cable it requires.

### *Computer Connection—USB Cable*

Many SBIG cameras now come with a built-in connector for USB cables. The USB cable supplied with your camera is a high-quality cable, and if you replace it with another cable, make sure you get a high-quality cable for the replacement. A high-quality cable has better shielding from noise and will provide better overall performance. High-quality USB cables cost more, but are essential to getting the most out of your camera.

The maximum cable run for USB is 15'. If you need a longer USB cable run, please see the SBIG web site's technical notes section for suggestions.

### *Computer Connection—Parallel Cable*

Some SBIG cameras, such as the ST-237A and ST-1001E, use a parallel cable for the computer connection. Cable length is limited to about 15' for a standard parallel cable. For longer runs, an IEEE-1386 cable (which has improved shielding and other noise-reducing characteristics) should be used. See the SBIG web site's technical notes section for more suggestions on long cable runs for parallel cables.

### *Telescope Connection—Guider Cable*

The guider cable supplied with SBIG cameras looks like an ordinary phone cable, but it is not! It is wired specifically for guiding, and you should not try to replace this cable with a phone cable. The orientation of the 6-pin RJ-11 connectors on the end of the cable is the key issue. If you buy or make a guider cable for yourself, the cable must follow the orientation in the diagram in Figure 2.
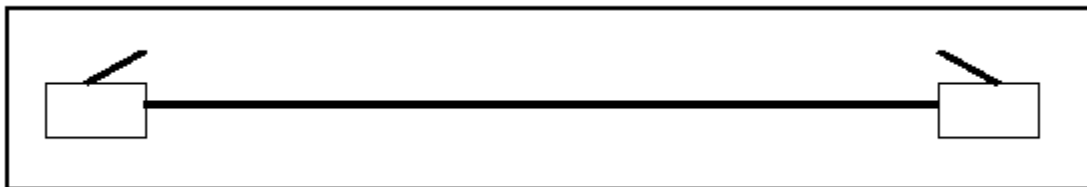


*Figure 2 - Orientation of the connectors on a guide cable.*

The connectors at each end of the cable are 6-conductor phone jacks. These phone jacks can be attached in two different ways: with the little retaining clips up or down. **A guiding cable must have the retaining clips on the same side of the cable at each end.** You can lay the cable flat on a table to make sure that the clips are facing the same direction as shown in the figure above.

Alternatively if you hold to two connectors side-by-side the wire colors inside the connectors should be mirror imaged in the two connectors as shown in the figure below:

Same wire color
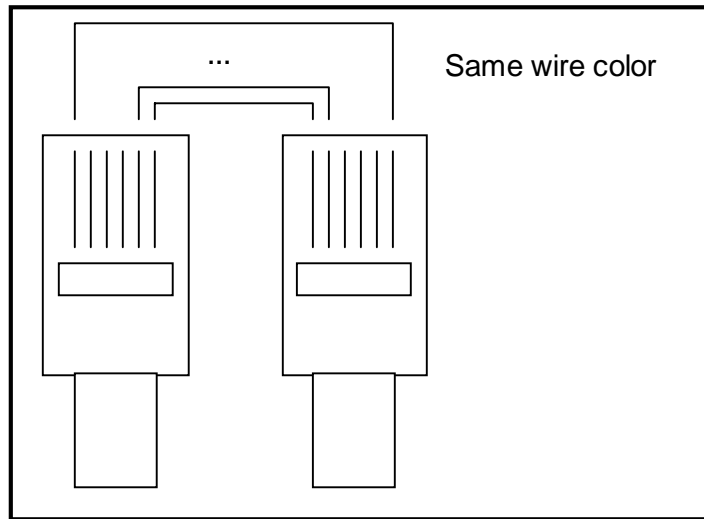
## Advanced Equipment Connections

Your CCD camera may have accessories that can be attached to it, such as the Adaptive Optics unit (AO-7), Relay Box, or a color filter wheel like the CFW-8. Please see the product documentation for the accessory to determine how to physically attach the accessory and any required cables.

## *Installing CCDOps and the Driver Checker*

The first thing you should do in all cases is to install CCDOps Version 5.XX and the Driver Checker utility. This is relatively simple:

1. ***VERY IMPORTANT:*** Make sure the camera is not connected to the computer. You will do this later.

2. Run the CCDOps Installer. It can be found in the CCDOps directory of the CD-ROM that came with your camera. Follow the onscreen instructions to complete the installation.

3. First make sure you are the Administrator or have Administrator privileges if you're running under Windows XP or Windows 2000. Next run the Driver Checker Installer. It can be found in the Driver Checker folder of the CD-ROM.
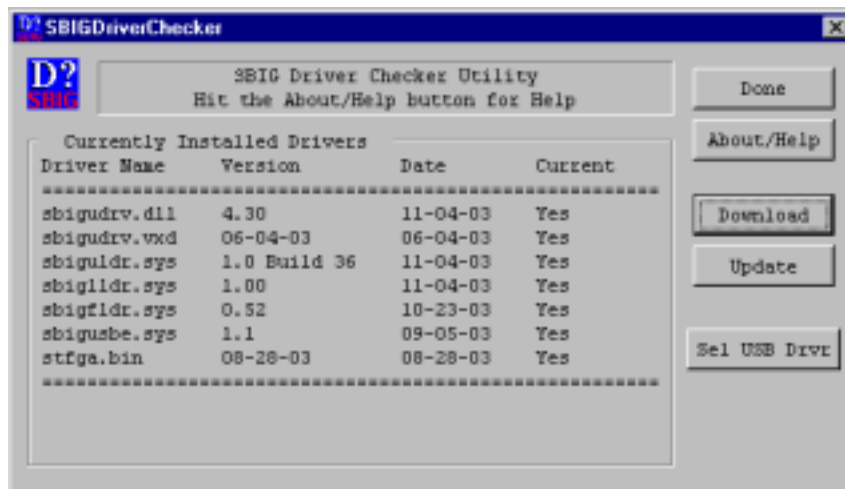
4. Towards the end of the Driver Checker installation the installer will run the Driver Checker Utility program. This utility checks to make sure you have the latest version of the SBIG camera drivers installed on your system. When the SBIGDriverChecker utility is run you'll see a dialog like:



If you have previously installed CCDOps you'll see some entries in the table. Most likely one or more drivers is not installed or is not up to date. Also if this is the first time you've run the Driver Checker you may get a warning something like "The sbigudrv service can not be found". Just ignore this error.

5. Using the Driver Checker to update your drivers is a two-step process:

A. If you have an Internet connection, Click on the Download button then follow the instructions to download the current drivers from SBIG's Servers. If you don't have an Internet connection on this machine then make sure you have downloaded the latest Driver Checker Installer from SBIG's web site, copied it to this machine and run it.

B. Whether you have an Internet connection or not then click the Update button. This will copy the current drivers to your system and make sure they are properly installed.

You may be asked to reboot your system as well. If so, click Done and do so. Otherwise simply click Done.

6. At this point skip ahead to the appropriate section below based on which version of Windows you have on your PC.

## Windows XP Users

1. Powered off, plug the camera into the computer with the supplied USB cable.

2. Plug in or turn on the power supply. The computer will then present you with the Found New Hardware Wizard. Click the "Install from a list…" radio button then click the Next button.



3. As shown below, click the "Search for the best driver…" radio button then check the "Include this location…" checkbox then click the Browse button.
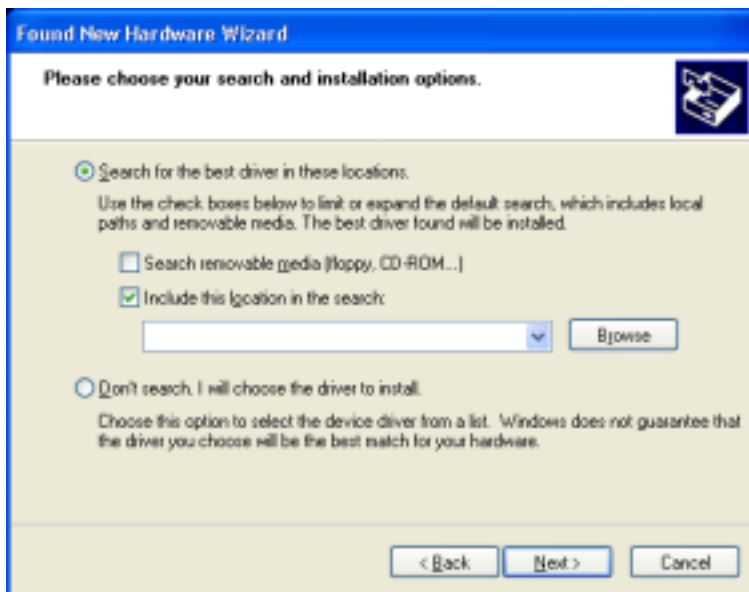
4. Navigate through the directory structure of you hard drive to the My Computer\C:\Program Files\SBIG\Driver Checker\SBIG Drivers directory. Expand each section by clicking on the "+" next to the name. For example scroll to the top and click the "+" next to My Computer, then click the "+" next to C:, etc. Finally click on the SBIG Drivers folder to select it then click OK. You'll then be back in the Found New Hardware Wizard as shown below. Click the Next button.
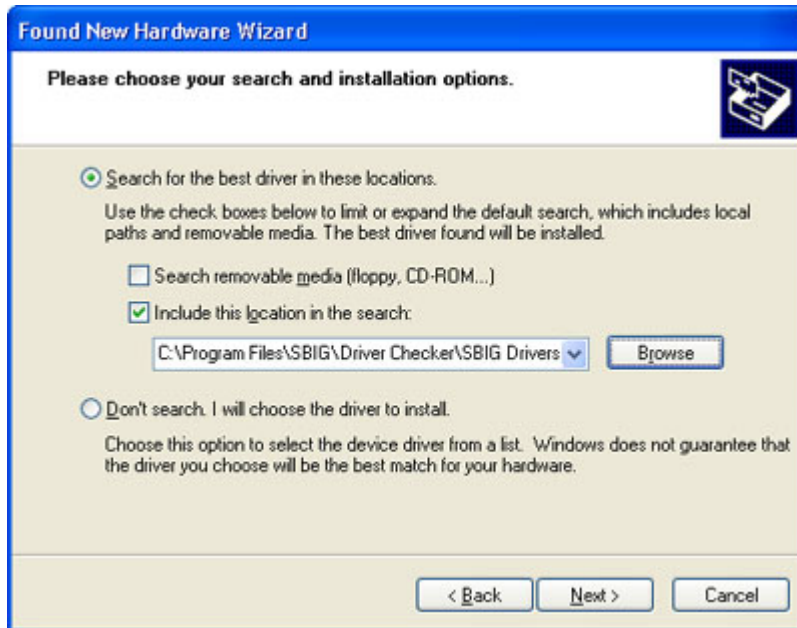


5. Windows will show the dialog below while it is copying the driver:
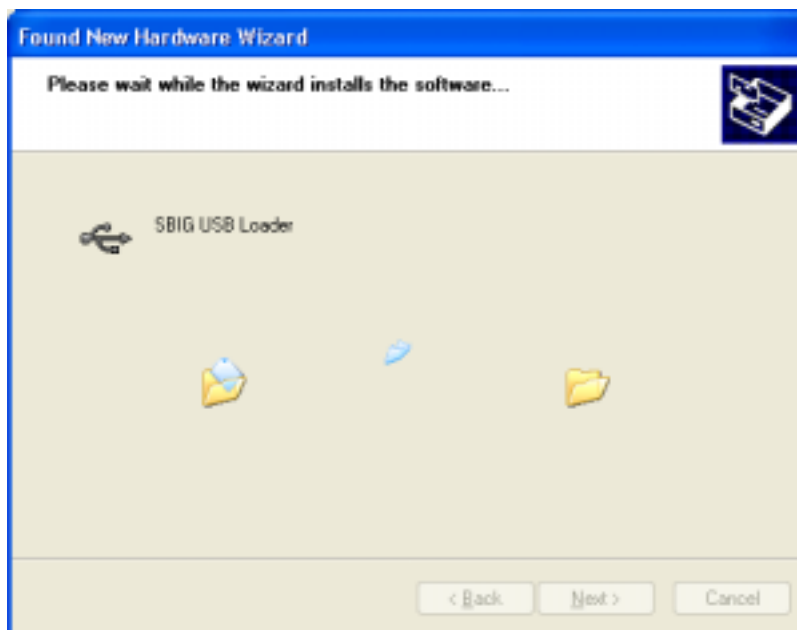
6. You may be presented with the dialog below warning you the SBIG USB Loader driver has not passed the Windows Logo testing procedure.  At this point click the Continue Anyway button.

**Hardware Installation**

⚠ The software you are installing for this hardware:

SBIG USB Loader

has not passed Windows Logo testing to verify its compatibility with Windows XP. [Tell me why this testing is important.]

**Continuing your installation of this software may impair or destabilize the correct operation of your system either immediately or in the future. Microsoft strongly recommends that you stop this installation now and contact the hardware vendor for software that has passed Windows Logo testing.**

[ Continue Anyway ]   [ STOP Installation ]

7. Windows will continue installing the driver as shown in the dialog below:

**Found New Hardware Wizard**

Please wait while the wizard installs the software...

SBIG USB Loader

sbigusbe.Inf
To C:\WINDOWS\INF

[ < Back ]   [ Next > ]   [ Cancel ]
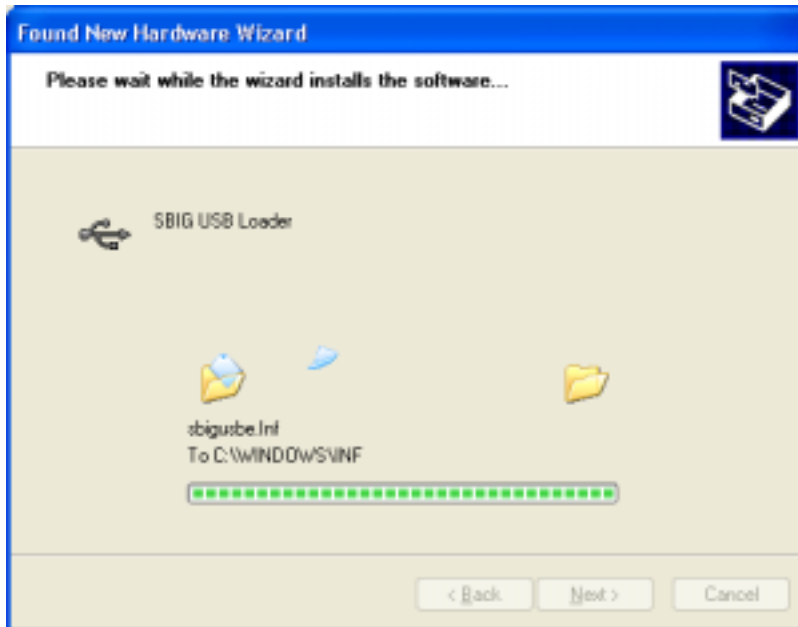
8. Windows will finish installing the SBIG USB Loader driver as shown in the dialog below



Hit the Finish button to move onto the SBIG USB Camera driver.

9. Again you will be presented with the Found New Hardware wizard for the SBIG USB Camera driver as shown in the dialog below. Repeat steps 3 through 8 for this driver just like you did for the SBIG USB Loader driver.

## Windows 2000 Users

1. Powered off, plug the camera into the computer with the supplied USB cable.

2. Plug in or turn on the power supply. The computer will then present you with the Found New Hardware Wizard shown below. Click the Next button.
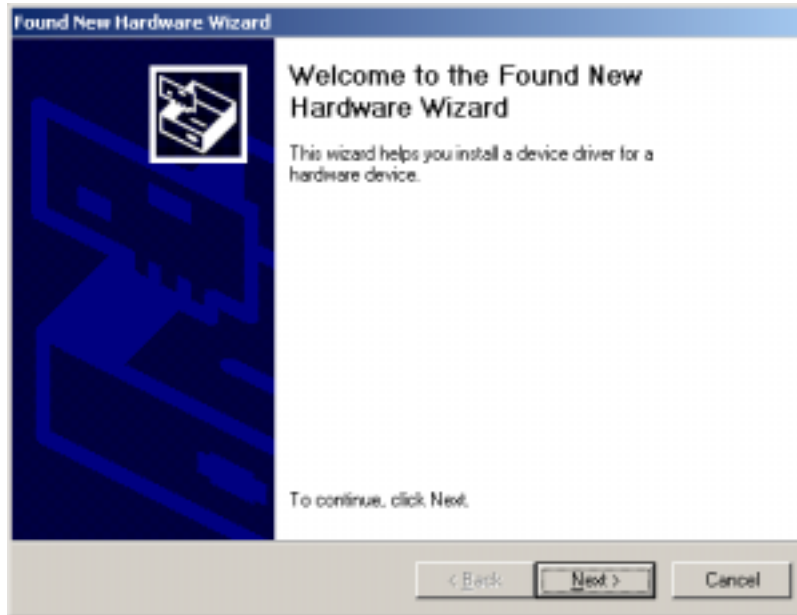


3. Click the "Search for suitable driver…" radio button as shown below:



then click the Next button.

4.  Uncheck all the options other than "Specify a location" as shown below:



then click the Next button.

5.  As shown below click the Browse button then navigate to the "My Computer\C:\Program Files\SBIG\Driver Checker\SBIG Drivers" directory. Expand each section by clicking on the "+" next to the name.  For example scroll to the top and click the "+" next to My Computer, then click the "+" next to C:, etc. Click on the SBIG Drivers folder to highlight it then Click OK in the Find File dialog then click OK back at the New Hardware Wizard.

6. Windows will find the driver and present you with the dialog below:
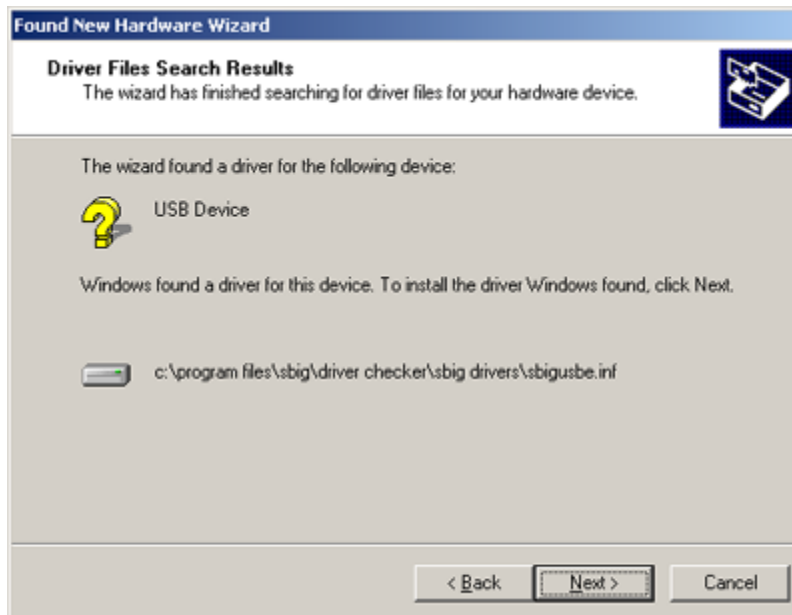


Click the Next button.

7. Windows will spin for a while, then present you with the dialog below. Click the Finish button and you're done. The SBIG cameras actually use two drivers and after you click Finish the system will automatically install the second driver.
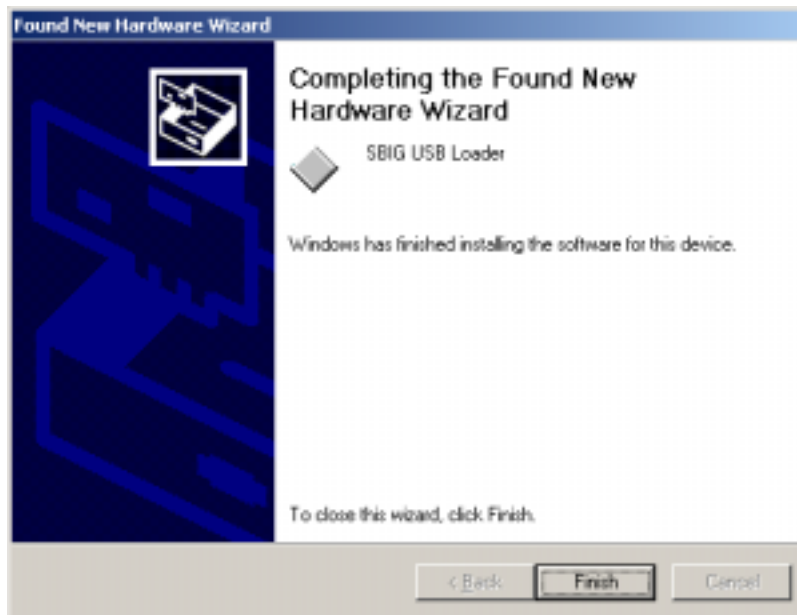
## Window 98/Me Users

1. With the power off, plug the camera into the computer with the supplied USB cable.

2. Plug in or turn on the power supply. The computer will then present you with the Add New Hardware Wizard shown below:
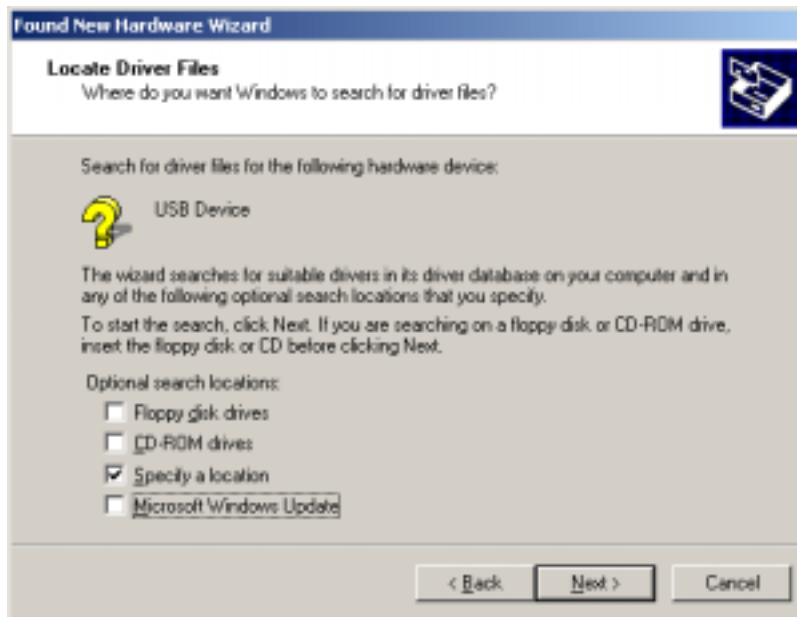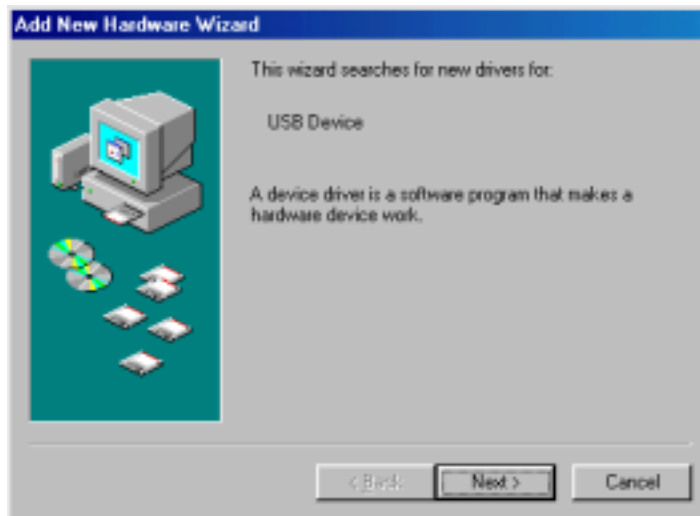
Click the Next button.

3. Click "Search for the best driver.." then click the Next button as shown below:
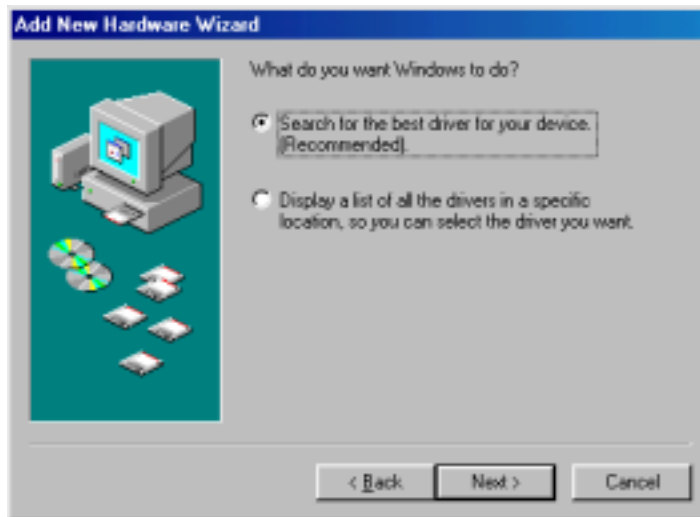
4. Uncheck all the options except "Specify a location" as shown below then click the Browse button



5. Navigate through the Browser window to the "My Computer\C:\Program Files\SBIG\Driver Checker\SBIG Drivers" directory as shown below. Expand each section by clicking on the "+" next to the name. For example scroll to the top and click the "+" next to My Computer, then click the "+" next to C:, etc.:
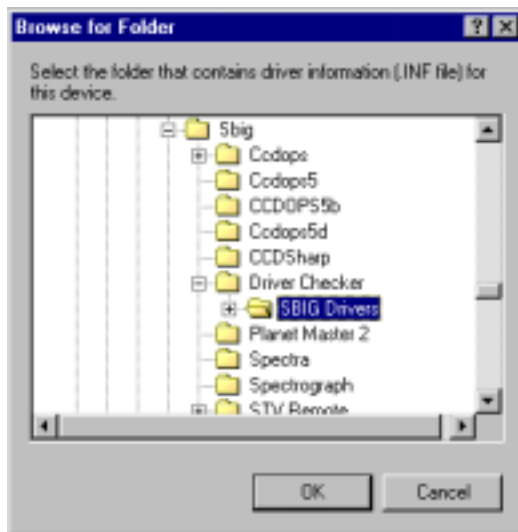


Click on the SBIG Drivers folder until it is highlighted as shown above then click the OK button. This will get you back to the dialog shown above in step 4 but with the location filled out. Click the Next button.

6.  You'll see the dialog below.  Click the Next button.
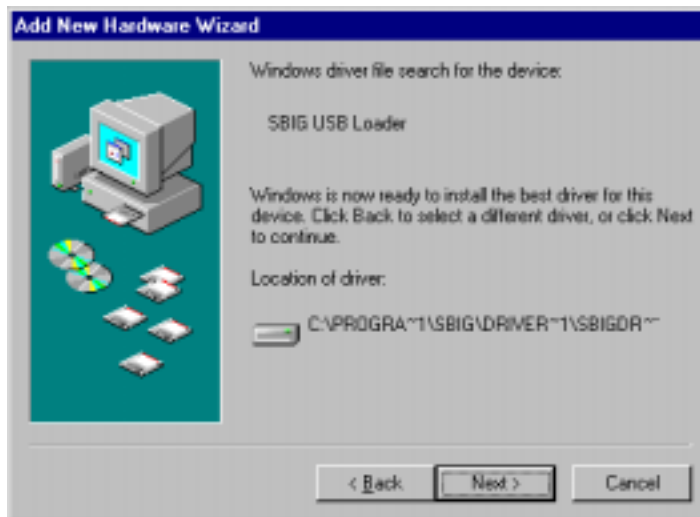


7.  Windows will spin for a while and then present you with the dialog below.  Click the Finish button and you're done.  The SBIG cameras actually use two drivers and after you click Finish the system will automatically install the second driver. **At this point the Fan and LED should come on in the camera**.
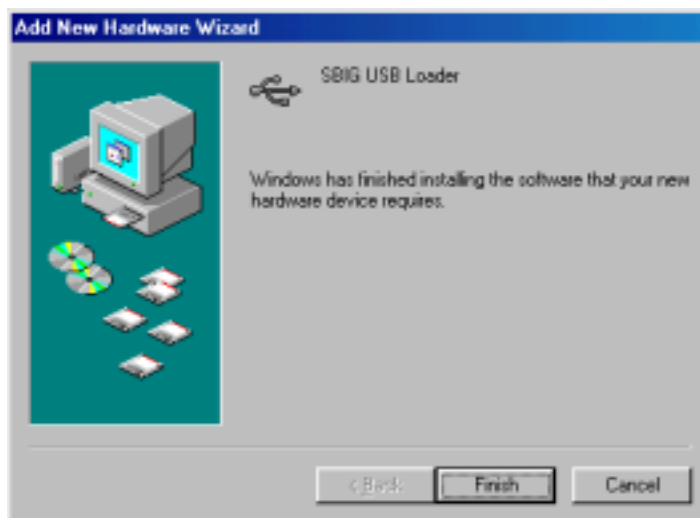
8. If you have any question about whether the drivers were installed correctly open the Device Manager tab of the System Control Panel. Click the "View devices by type" button and expand the "Universal Serial Bus controllers" section by clicking the "+" to the left. You should see something like the dialog below where we have highlighted the SBIG USB Camera in red outline:
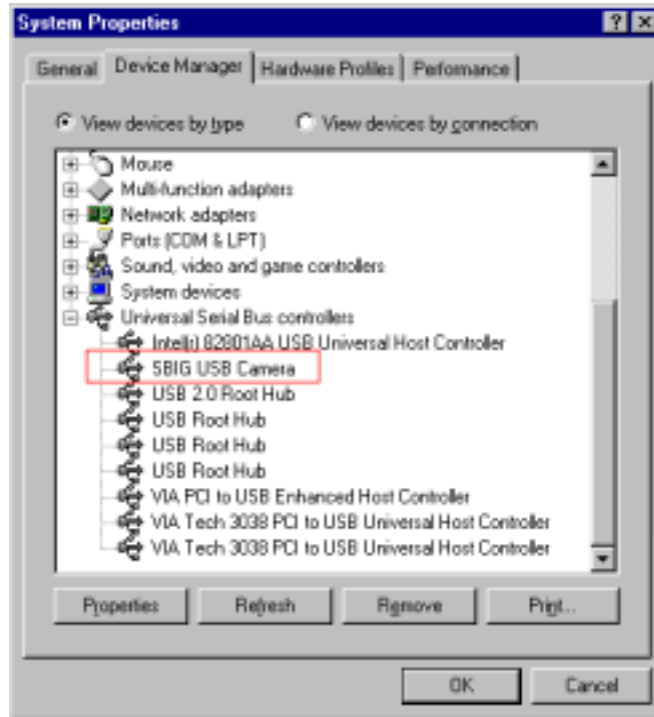
## *Set Up CCDOps*

### Communications Setup

Once you have made the physical connections to your camera, the next step is to set up communication between CCDOps and the camera. Use the Misc | Graphics/Comm Setup menu item to open the Graphics/Comm Setup dialog (see Figure 3)
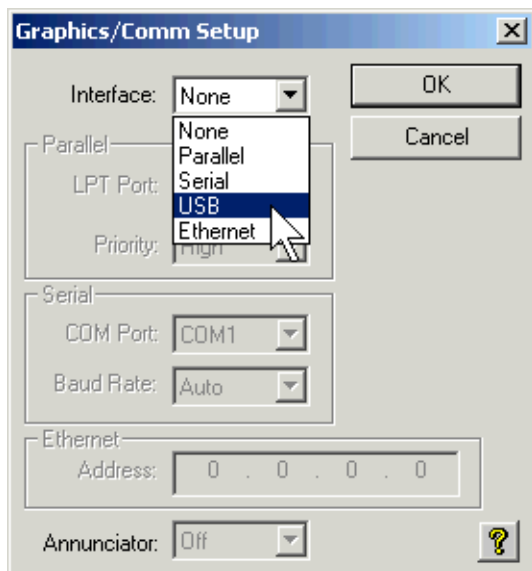


*Figure 3 - Selecting the Interface for your camera.*

For most cameras, select USB or Parallel as your Interface type. The majority of new SBIG cameras come with USB. The ST-237 and ST-1001E and some older cameras use the Parallel interface, and the ST-4X, ST-5 and ST-6 use a serial interface. If your camera uses parallel, set the LPT Port to LPT1, and the Priority to High. If you are using a different parallel port (e.g., LPT2), select that instead. High priority helps to preserve the integrity of your downloaded images, and should not normally need to be changed. If your camera uses a Serial or Ethernet interface, please see the CCDOps Help files for detailed information on communications setup.

### Connect to the Camera

To establish a connection with the camera, use the Camera | Establish COM Link menu item, or Ctrl + K using the keyboard.

When you are connected, the CCDOps status bar reports information about the camera at the lower right of the CCDOps window (see Figure 4).

- Link status, including the camera name
- Connection type (LPT/USB)
- Image Resolution (high, medium, low; see note below)
- Temperature of the CCD chip in degrees Celsius
- Percentage of chip cooling capacity in use (0-100%)
- The name of the currently selected filter (if a filter wheel is present)
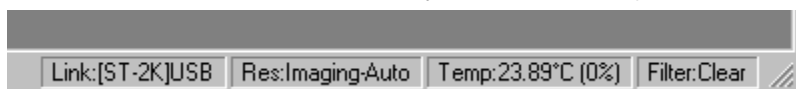
> **Note:** Image Resolution uses a camera feature called Binning. High resolution uses no binning. Each CCD pixel equals one pixel in the image. Medium resolution bins pixels 2x2 (into groups of four pixels). This increases the sensitivity of the camera and reduces download time. For low resolution, pixels are binned 3x3 (into groups of nine pixels). For more information about binning, please see the section "What Is Binning?"

## If You Have a Filter Wheel

If you have an SBIG color filter wheel installed, use the Filter | Filter Setup menu item to display the Filter Wheel Setup dialog (see Figure 5). The names shown are defaults and they will match factory-original filter wheels. If you change or add filters, you can edit the filter names in the Filter Wheel Setup dialog shown in figure 2. In the example, Filter 5 has been changed to indicate that this position contains a hydrogen-alpha filter.
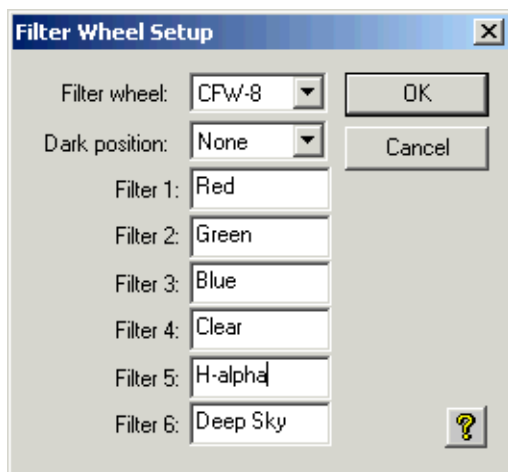


*Figure 5 - Setting up your filter wheel.*

> **Note:** Different filter wheels contain different numbers of filters. For example, filter position 6 is not present in the CFW-8. Names for unavailable filter positions can be ignored or left blank.
>
> **Note:** You must set up communication to the camera before you can set up the filter wheel. See the section "Communications Setup" above for details. If the camera isn't already connected when you use this menu item, CCDOps will attempt to connect to the camera.

There are three types of settings in the Filter Wheel Setup dialog:

**Filter wheel**—select the filter wheel model that you have installed.

**Dark position**—Select the filter to be used when taking dark frames. This is only required for cameras that use the filter as a shutter. For cameras that have a shutter, such as the ST-7/8/9/10, the shutter automatically closes when taking dark frames. For information about dark frames, please see the section "Cooling Explained."

**Filter names**—Enter the names of the filters installed in your filter wheel. You'll only need to do this if you installed different filters in the Color Filter Wheel as the default names cover the SBIG filters.

If the filter wheel links successfully, the selected filter position is shown at the far right of the status bar. In the future, when you connect to the camera, the filter wheel connection will be made automatically.

**TIP:** If you want to identify which filter is in which position in your filter wheel, you need to use a simple trick. When you look at a filter, you will usually see the color of light *reflected* by the filter. What you want to do is find out the color of light *transmitted* by the filter. The color transmitted is the color that the CCD chip sees when imaging. The reflected color is the opposite of the transmitted color. For example, the green filter looks magenta when you observe the reflected light.

To see the transmitted color, set the camera to take an exposure of several seconds (see later sections for information on taking exposures with your camera). This opens the shutter for cameras with a shutter. Situate yourself so that a fairly bright light is coming from behind you, and is shining into the camera. Observe the color of the CCD chip, not the color of the filter itself. The color of the CCD chip is the color that the filter transmits. This is the color that should be entered as the filter name in the Filter Wheel Setup dialog.

## *Adjusting Camera Settings*

The CDDOPS camera settings do two things:

- They tell CCDOps about your camera.
- They allow you to adapt the camera to different imaging tasks.

To access the camera settings, use the Camera | Setup menu item, or Ctrl + U on the keyboard. Figure 6 shows the Camera Setup dialog for the ST-7/8/9/10 cameras; the dialog is similar for other cameras.

Before we discuss camera settings, it is important to know several new concepts related to CCD cameras. Unlike video and digital cameras, CCD cameras have an internal cooler that helps to reduce noise in your images. This provides a significant performance advantage over other types of cameras.

## Cooling Explained

The CCD detectors used in SBIG cameras are electronic devices. Like all such devices, they have a low level of noise. For some types of electronic devices, such low levels of noise are insignificant. But when you are imaging the extremely dim objects of the night sky, even small amounts of residual noise must be dealt with. To overcome the residual noise levels SBIG cameras are cooled to 25-50°C below the ambient temperature. Cooling greatly reduces noise and allows you to take clean, professional-grade images.

The type of noise reduced by cooling is called dark current, or thermal noise. While the camera is taking an exposure, the laws of physics tell us that the occasional electron will creep into a pixel through the CCD detector's structure. Each pixel has its own characteristic susceptibility to this electron creep. Cooling slows this process down. However, once you cool the detector to -25 degrees Celsius, further cooling doesn't reduce noise significantly.  The dark current variation, pixel-to-pixel, produces pattern noise that is removed by a dark subtraction.

SBIG cameras are cooled using Peltier (pronounced "**pell**-tee-ay") technology. These are miniature heat pumps that move heat away from the CCD detector into the surrounding air. A fan makes heat transfer more efficient. Many SBIG cameras also have water cooling available (standard or optional, depending on the model). Water is a better conductor of heat than air, and improves cooling performance.

Whatever method is used to cool your camera, the goal is always the same: cool the CCD well below the ambient temperature so that noise will be minimized.

When cooling is active, CCDOps gives you information about cooling efficiency. You can use this information to control the amount of cooling. CCDOps provides two numbers related to cooling efficiency:

- Detector temperature, in degrees Celsius
- Percentage of total cooling capacity in use

Temp:-0.23°C (58%)
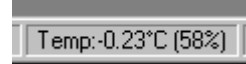
Total cooling capacity is the "delta-T" of cooling available. (The Greek letter delta—$\Delta$ or $\delta$—refers to "change," and the "T" stands for temperature. So "delta-T" means "change in temperature.") For example, the cooling system built into the ST-10XME camera provides about 30 degrees Celsius of cooling below ambient temperature. (This is a nominal value; actual cooling might be slightly above or below this number for a specific camera.)

For example, suppose that the ambient temperature is 10ºC. That means that the maximum cooling should bring the detector temperature down to approximately -20ºC. You might be tempted to pick -20ºC as your setpoint temperature, but that's not the best strategy. If the cooler is working at 100% of its capacity, there is no reserve capacity and it will not be able to maintain a steady temperature.

Why is a steady temperature important? Let's return for a moment to those creeping electrons. The rate at which electrons creep into the pixels varies with the temperature. When the temperature is warmer, more electrons creep in. When it is cooler, few electrons creep in. If the temperature is held steady, the rate of electron flow is also reasonably steady and predictable. (The rate will vary from one pixel to the next, but it will be predictable for each pixel.)

Here's the payoff: if temperature is steady, CCDOps can measure the electron flow (dark current) and subtract it from the image. Electron flow is measured by taking an exposure with the shutter closed (dark frame). The dark frame is subtracted from the light image to create a low-noise result. CCDOps includes tools to make dark subtraction simple and efficient. See the section "Dark Frames and Flat-Field Frames" for more information about dark frames and dark subtraction.

**TIP:** To keep the cooling temperature at a steady level, you should pick a setpoint (target temperature) that allows the cooler to work at no more than 75% to 85% of its maximum capacity. You can find the current percentage of capacity in use at the right side of the CCDOps status bar. If the temperature drops during the night, you can increase cooling but you will need to take new dark frames for the new temperature.

## Cooling and Other Camera Settings

**Note:** Not all settings described below are available for all cameras; these are the most common settings for the most popular cameras. Please refer to the CCDOps help file for information about specialized settings for specific cameras.

The cooling settings are found on the Camera Setup dialog (Ctrl + U). Figure 6 shows the Camera Setup dialog. If the camera isn't already connected (Ctrl + K), CCDOps will make the connection for you when you open the Camera Setup dialog.
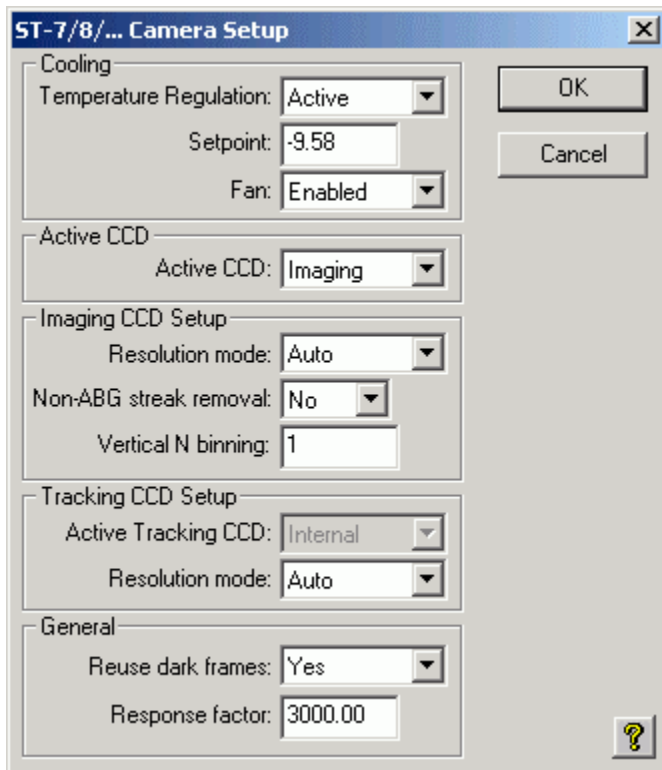
*Figure 6 - The camera setup dialog.*

**Cooling settings**

> **Temperature Regulation** (Off, Active)—When set to Active, the camera's built-in cooling is turned on.
>
> **Setpoint** (in degrees Celsius)—The target temperature for cooling. The setpoint should be a little higher than the ambient minus the camera's total cooling capacity (delta-T). See "Cooling Explained" for examples.  This is the actual CCD temperature, not the delta from the Ambient.
>
> **Fan** (enabled, disabled)—Turns the cooling fan on and off. Unless you have a specific reason to turn off the fan, you should always leave it on. The "delta-T" will be lower if the fan is off. **Some cameras can be damaged if the fan is off when secondary cooling is plugged in. Please check your camera documentation before using this feature.**

After connecting to the camera, always open up the Camera Setup dialog to make cooling active. Images longer than 10 seconds taken without cooling will have excessive noise. To turn on cooling, set Temperature Regulation to Active (see Figure 6). You can get the approximate ambient temperature by looking at the right side of the CCDOps status bar before you turn on cooling. This shows the detector temperature with no cooling. If the camera has been outside long enough to equalize with the air temperature, the temperature in the status bar will be reasonably close to the outside air temperature. You can use this information to establish the Setpoint temperature.

**TIP:** To estimate the correct Setpoint, subtract the maximum cooling capacity from the air temperature (both in degrees Celsius), and then add 3º to 5º. For example, if the uncooled camera temperature is 10.21º, and your camera provides a maximum of -35ºC cooling, a value of -20ºC would be a good initial setpoint.

Monitor camera temperature and cooling capacity to make sure you are using less than 75% of capacity. Allow 10-20 minutes for the camera temperature to stabilize before making this determination. For critical work such as photometry, working at no more than 65% of capacity for both light and dark frames will improve dark frame performance.

You can keep the same Setpoint throughout your imaging session, or you can lower the setpoint as the temperature changes. Changing camera temperature requires taking and applying dark frames more often. Please see the sections "Cooling Explained" and "Dark Frames and Flat-Field Frames" for additional information.

**Active CCD**

    **Active CCD** (Imaging, Tracking)—Determines which chip is used for taking images.

**Imaging CCD Setup**

    **Resolution Mode** (High, Medium, Low, Auto; other settings are for spectroscopy)—Determines if the camera's pixels are binned for greater sensitivity/faster downloads. See the section "What Is Binning?" for more information about binning. Note that the imaging and tracking CCDs have separate settings for resolution mode.[1]

    **Non-ABG streak removal** (Yes, No)—Setting this item to Yes utilizes a special readout mode of the non-ABG versions of the ST-7/8 that removes the horizontal streaking component of blooming from stars that bloom in the image. Users of ABG versions of the ST-7/8 should leave this set to No.

    **Vertical N binning** (used for spectroscopy)

**Tracking CCD Setup**

    **Active Tracking CCD** (Internal, External)—For the Large Format camera (ST-L) with it's external tracking head, setting this item to External allows imaging with the external tracking ccd.  Otherwise set this to Internal.

    **Resolution Mode** (High, Medium, Low, Auto)—Determines if the camera's pixels are binned for greater sensitivity/faster downloads.

A number of SBIG cameras come with two internal CCD chips. One chip is large, and the other is small. The large chip is used for imaging, and the smaller one for guiding (tracking). If you want to use the tracking chip for imaging, you can do so by setting the Active CCD to Tracking instead of Imaging. The Imaging chip will be the Active CCD in most situations. The ST-L series of cameras also have an optional external guide chip, and you can select the appropriate guide chip using the Active Tracking CCD item.

Resolution Mode refers to binning. There is a short introduction to binning in the "Connect to the Camera" section. A more detailed discussion appears below, including examples of binning and some discussion on binning strategies.

**General settings**

    **Reuse dark frames** (Yes, No)—When set to Yes, dark frames taken for one image will be reused for subsequent images. Reusing dark frames saves time, but may result in somewhat noisier images. In addition, if there are cosmic ray hits in a dark frame (common for exposures greater than 30 seconds), reusing dark frames will

---

[1] We highly recommend the Auto resolution mode as it will save you a lot of time.  Auto resolution uses High resolution everywhere except in Focus mode.  In Focus mode when you use Auto resolution mode and choose the Planet mode it takes the Full Frame image in Low resolution mode then switches to High resolution mode for the Planet sub-frame.

result in dark spots at the location of the cosmic ray hits. Using fresh dark frames reduces the risk of this particular problem.

**Response factor**—Used to determine star magnitudes. If star magnitudes are not reported correctly when using the Crosshairs window, you can adjust this up or down as required. For more information about the Crosshairs window, please see the CCDOps help file.

Dark frames record the camera's dark current, which is subtracted from images to reduce noise. When "Reuse dark frames" is set to yes, a single dark frame is taken at the start of a sequence of exposures. The same dark frame is applied to all light frames in the sequence. When "Reuse dark frames" is set to no, new dark frames are taken for each light frame. **Note:** dark frames are only taken when the exposure settings have dark frames turned on.

What effect does reusing dark frames have on image quality? A dark frame has its own noise—some of the pixels are a little brighter than average; some a little dimmer. If you reuse dark frames, every image will have exactly the same variations in brightness as a result of dark subtraction. If you take separate dark frames, the differences will average out and the final image will be somewhat cleaner. How much cleaner depends on the total number of images—averaging larger numbers of images results in better noise reduction.

Why reuse dark frames? Doing so reduces the time spent taking dark frames, and allows you to take more light frames. As you learn more about imaging and develop your skills, the additional noise reduction from separate dark frames may be of more use.

There are other ways to take and apply dark frames, however. Please see the section "Dark Frames and Flat-Field Frames" for an overall strategic approach to taking and using dark frames. For details on the relationship between noise and dark frames, please see the section "Cooling Explained."

## What Is Binning?

Binning is a technical term for grouping pixels when imaging. Binning increases the sensitivity of the camera for short exposures by combining the output of multiple pixels (reducing resolution). It is useful for finding objects and where high resolution can be sacrificed for speed of image acquisition.

There are three modes of binning that are typically used when imaging:

1x1 - Also called unbinned or High Res mode. Every pixel in the CCD sensor is represented in the image. No pixel combining of any kind occurs in this mode.

2x2 - Pixels are grouped in two by two squares, for a total of four CCD pixels making up one image pixel. This is also called Medium Res mode.  The signal from all four pixels is combined into one "super pixel" which improves sensitivity. Resolution, however, is cut in half. This type of trade-off is fundamental to binning. When you bin at 2x2 or greater, you get more photons per pixel but lower resolution.

3x3 - Pixels are grouped in three by three squares, for a total of nine CCD pixels making up one image pixel. This is also called Low Res mode.  This provides still more photons per pixel in the final image, but it also results in still lower resolution.

In addition, there are some specialized binning modes used for spectroscopy and other purposes. See the CCDOps Help system for information about these specialized modes.

Figures 7 through 9 show a comparison of 30-second exposures taken with an ST-10XE in various binning modes. These images give you some idea of the way binning affects an image's resolution *and* signal level. In Figure 4, the binning mode is 1x1 (that is,

unbinned). The image has the resolution to show good detail of M27, but the exposure is too short to reveal those details effectively.

*Figure 7 - High resolution: Unbinned (1x1) 30-second image of M27 taken with an ST-10XE.*
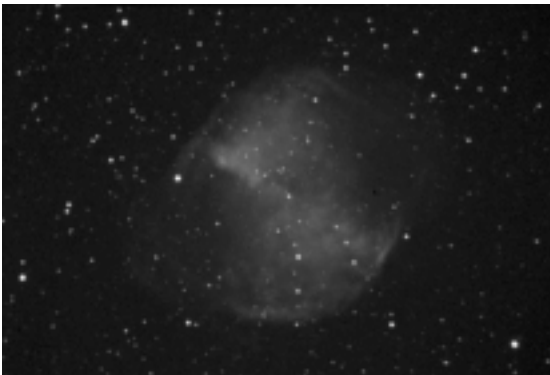


*Figure 8 - Medium resolution: 2x2 binned 30-second image of M27.*
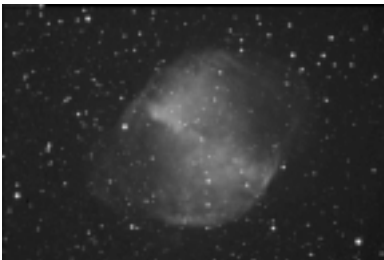


*Figure 9 - Low resolution: a 3x3 binned 30-second image of M27.*

Figure 8 shows the result of binning 2x2. The image is one-quarter the area of the first image because four pixels are combined into one virtual pixel. Resolution is reduced, but M27 itself shows up more clearly, and more stars can be seen as well. Binning helps reveal dim objects with shorter exposures.

Figure 9 shows what happens with 3x3 binning. The resolution is still lower, but the brightness of M27 is increased again.

The best use of binning is in relatively short exposures. Binning increases signal relative to noise, resulting in a cleaner image at the cost of resolution. Since noise is the main problem with short exposures, binning is most effective at cleaning up short exposures.

Long exposures do not get as much benefit from binning. The longer your exposures, the less likely you are to see significant benefits from binning since the limiting noise source is the sky background.

Figure 10 shows another way to look at binning. In figures 7-9, the images are different sizes. If we resize images so they are all the same physical size, the loss of resolution becomes clear. Figure 10 shows a small portion of three different images of M51. The left-most image shows the unbinned data. The middle example is binned 2x2, and has been doubled in size to match the resolution of the unbinned image. The right example is binned 3x3, and enlarged by a factor of 3. The difference in resolution is dramatic.
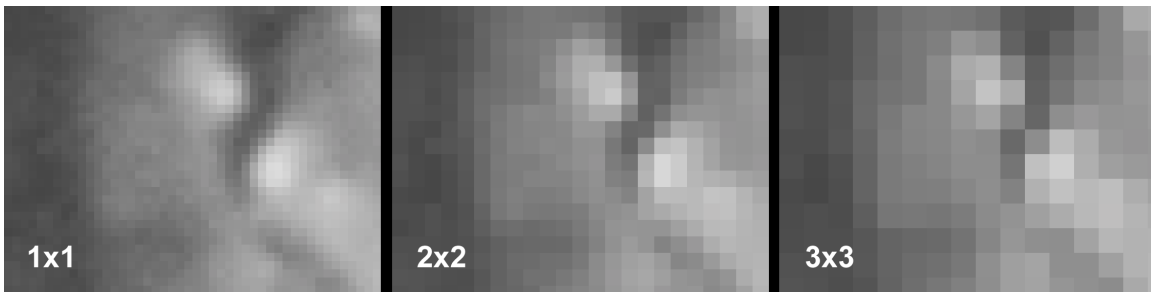


*Figure 10 - Portions of the M51 images showing effective resolution at different binning levels. The 2x2 and 3x3 images have been enlarged to show the difference in resolution that results from binning.*

One of the most common uses for binning is centering. You can take exposures as short as 5-10 seconds, depending on camera and telescope used, to center an object. Even dim objects will show up surprisingly well in 5-10 second exposures with 3x3 binning.

## Image Scale

Binning also changes the image scale of your system. The image scale is a measure of how much sky each pixel "sees." For example, an ST-9 on a 8" f/10 SCT has an image scale of approximately 2 arcseconds/pixel. This means that each pixel sees a portion of the sky that is 2 arcseconds on a side.

Since the ST-9 CCD chip has an array that is 512x512, the entire chip "sees" a portion of the sky that is (512*2) arcseconds on a side, or about 17.6x17.6 arcminutes.

You can calculate the image scale of any camera/scope combination using this formula:

$$\left(\frac{pixelSize}{focalLength}\right)*206$$

The pixel size must be measured in microns, and the focal length must be measured in millimeters. The image scale will always be in arcseconds/pixel.  CCDOps will also calculate this for you with the FOV Calculator discussed on page 90.

For example, we could calculate the image scale of an ST-10XME on a 6" f/7 refractor. (The focal length in mm is 150mm times 7, or 1050mm.)

$$\left(\frac{6.8}{1050}\right) * 206 = 1.33$$

Binning increases the pixel size to 13.6 microns, which changes the image scale by a factor of 2, to 2.66.

If you would like to enjoy the benefits of binning when focusing, but still use high resolution mode automatically for imaging, set the Auto resolution mode in the camera setup dialog (see Figure 3). The Auto setting uses the High resolution mode for every image acquisition command except for the Full size mode of the Focus command where the Low resolution mode is used.  When you go to Planet mode to focus on a star the binning reverts to 1x1 for the greatest focus precision.

# 2 Taking an Image

Before you can take an image, you must connect to the camera and turn on the cooling. See the previous sections for information on how to connect and adjust camera settings.

CCDOps has an icon toolbar that organizes imaging functions in a compact way. To turn the icon bar on and off, use Ctrl + I on the keyboard or the Edit | Show Icon Bar menu item. Figure 11 shows the functions that are available on the icon bar.
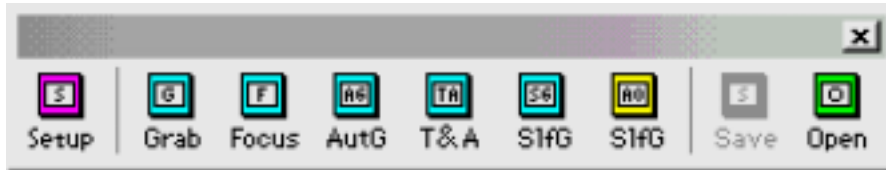


*Figure 11 - The Icon Bar.*

The buttons on the icon bar provide a quick and simple way to access the most common camera operations. The buttons have the following functions:

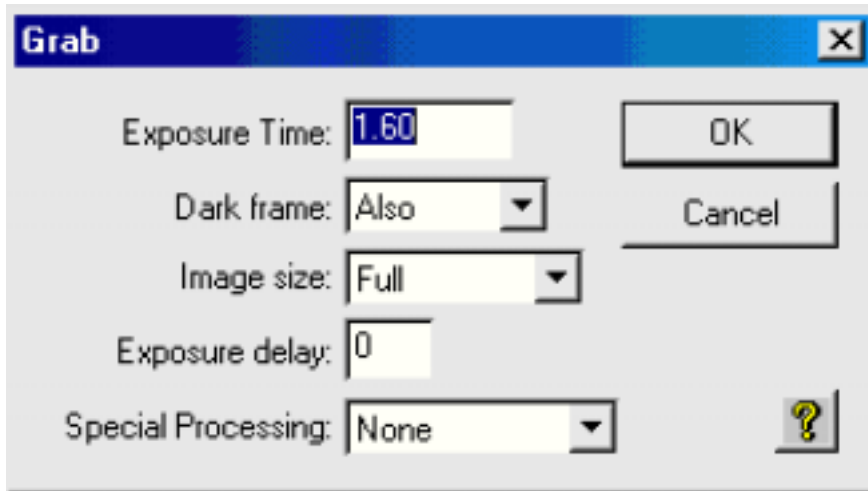| Button | Function |
| --- | --- |
| **Setup** | Change the camera settings in the Setup dialog. See section "Cooling and Other Camera Settings" for details. |
| **Grab** | Take an image. See section "Grab Dialog Settings" for details. |
| **Focus** | Start focus mode. See section "Precision Focusing" for details. |
| **AutG** | Autoguide (guiding only, such as when using a film camera or a second CCD camera to image). Use the Active CCD item on the Camera Setup dialog if you want to swap which chip is used for which function (imaging and guiding). See section "Guiding with CCDOps" for details. |
| **T&A** | Start the Track & Accumulate mode. See section "Using Track & Accumulate" for details. |
| **SlfG (SG)** | Selfguide using one CCD chip in a self-guiding camera (ST-7/8/9/10) while taking an image with the other chip. See section "Guiding with CCDOps" for details. |
| **SlfG (AO)** | Selfguide using the AO-7 (requires AO-7 adaptive optics unit). See the section below on AO Self Guiding. |
| **Save** | Save the current image to disk |
| **Open** | Open an image file |

*Figure 12 - The Grab Dialog.*

Figure 12 shows the Grab dialog. You can take your first image by setting an exposure time and clicking OK. The list below explains each of the settings in the Grab dialog.

**Grab Dialog Settings**

**Exposure Time**—Enter the duration of the exposure in seconds. This can vary from a fraction of a second for the moon or a planet to many minutes for an image of a very dim deep-sky object. The shortest possible exposure time is 0.01 second (frame transfer cameras like the ST-2000XE) or 0.12 seconds (full-frame cameras like the ST-7/8/9/10XE). If you enter a time that is too short for the physical limitations of a camera, CCDOps will use the shortest usable time available for that camera. The longest available time is 3600 seconds (60 minutes).

**Dark Frame** (None, Also, Only)—Determines if a dark frame is taken. A dark frame removes dark current from your images, a kind of system noise that is largely repeatable. If set to None, no dark frame is taken. If set to Also, a single dark frame is taken and subtracted from the image. If set to Only, only a dark frame is taken. You can use the Only setting if you plan to take and apply your own dark frames later. See the section "Dark Frames and Flat-Field Frames" for information about dark frames—what they are, why you use them, and how they work.

**Image Size** (Full, Half, Quarter)—Determines how much of the chip will be used for the image. Full uses all of the pixels on the chip. Half uses the central half of the chip. Quarter uses the central quarter of the chip. Half and quarter are useful when you have a small subject, or when you want fast download times.

**Exposure Delay**—The number of seconds to delay before each exposure. This is handy when you want to start manually guiding or turn off the lights for instance.

**Special Processing** (None, Color Grab, Auto Grab)—See the following sections for information about grabbing color images and sequences of images (Auto Grab): "Taking Color Images with CCDOps" and "Taking Multiple Exposures".

Click OK to take an image.

When the image appears, it will probably not be in focus. See the sections "Rough Focusing" and "Precision Focusing" for tips on focusing.

**TIP:** The best exposure time for an object depends on a variety of factors. If you are using an NABG (non-antiblooming) CCD chip, exposure duration will be limited by blooming. Good bloom-removal tools are available, including a bloom remover in CCDOps. Excessive blooming can be hard to remove, especially if it hides areas of nebulosity or portions of a galaxy that you are imaging. ABG chips do not bloom, and longer exposures are possible. Generally, longer exposures will have less noise. However, longer exposures are subject to problems such as satellite tracks, passing airplanes, bumped mount, guide errors, etc. As a general rule, exposures should be long enough to create a sky background value of 500-1000. (To measure background levels in an image, use the Display | Show Crosshair menu item. Click in the image to see pixel values and average values in the Show Crosshair dialog.) See Table 1 for a list of minimum suggested background brightness values for various SBIG cameras. The brightness values do not change if you use different filters.

*Table 1 - Suggested Sky Background Brightness Levels to be Sky Background Noise Limited*

| Camera Family | Approximate Brightness Level |
|---|---|
| ST-237A, ST-2000, ST-L-11000 | 1000 ADU, also known as counts |
| ST-7/8/9/1001 | 400 |
| ST-10 | 700 |

The suggested brightness level is for an individual exposure. Adjust your exposure time to achieve at least the suggested brightness level, if possible. **Blooming may limit your exposure time.** If your skies are very dark, or if you are using narrow-band filters such as hydrogen alpha or Oxygen III, you probably will not be able to achieve the suggested background levels in a reasonable amount of time. Since dark skies reduce the total noise level, this is an acceptable trade-off.

These brightness levels will reduce the noise contribution from the CCD chip to a very low level, typically a fraction of the total noise. This maximizes the signal to noise levels in your images. Generally speaking, you want more signal and less noise to get the best possible results in your images.

## Adjusting Image Contrast

The Contrast window will appear when you take an image. You can use the contrast window (see figure 10) to change the appearance of the image. This does not change the image data. The contrast window only changes the appearance of the image. The original data remains unchanged. For a quick adjustment, click the Auto checkbox. Figure 13 shows the Contrast dialog.
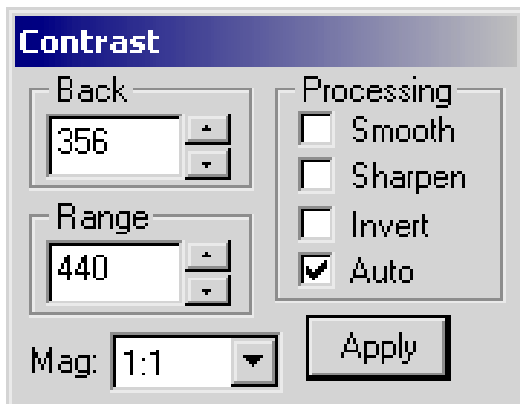
*Figure 13 - Automatic image contrast.*

Clicking the Auto checkbox sets two values in the Contrast window: Background and Range. The Background and Range settings are just two of the settings available in the Contrast window:

**Back**—Short for "background." This is the brightness value that determines the black point for the image. All pixels darker than the black point will be rendered as black. If the background of the image appears too bright, increase the background value. If the background is too dark, or if features of the imaged object are missing, try lowering the background value.

**Range**—The range of values to include in the visible image. Background plus range determines the white point of the image. All pixels brighter than the white point will be rendered as white.

For example, if the background is set to 500, all pixels with a brightness value less than 500 will be black. If the range is set to 1000, all pixels with a brightness value greater than 1500 (background + range) will be white. Pixels with values between 500 and 1500 will be rendered as shades of gray.

To apply manually entered background and range values to the image, click the Apply button.

Additional checkboxes in the Processing section

**Smooth**—Applies a non-destructive smoothing (blurring) to the image. If an image appears too noisy, you can smooth out some or all of the noise with this setting.

**Sharpen**—Applies a non-destructive sharpening adjustment to the image. If the image is low in noise, choosing this setting will bring out details in the image.

**Invert**—Inverts the brightness values displayed in the image. This creates a negative version of the image (see Figure 15). The inverted image is valuable for observing faint nebulosity or the faint outer portions of many galaxies. The human eye perceives faint features more effectively when they are gray against a white background.

**Auto**—When checked, CCDOps will set the Background and Range automatically. If desired, you can change the Background and Range settings manually.

**Mag**—Stands for magnification. Click on the drop-down list to choose one of the available magnification settings (see Figure 14). Like all settings in the contrast window, magnification does not make permanent changes to the image. It only affects how the image is viewed, not the image data.
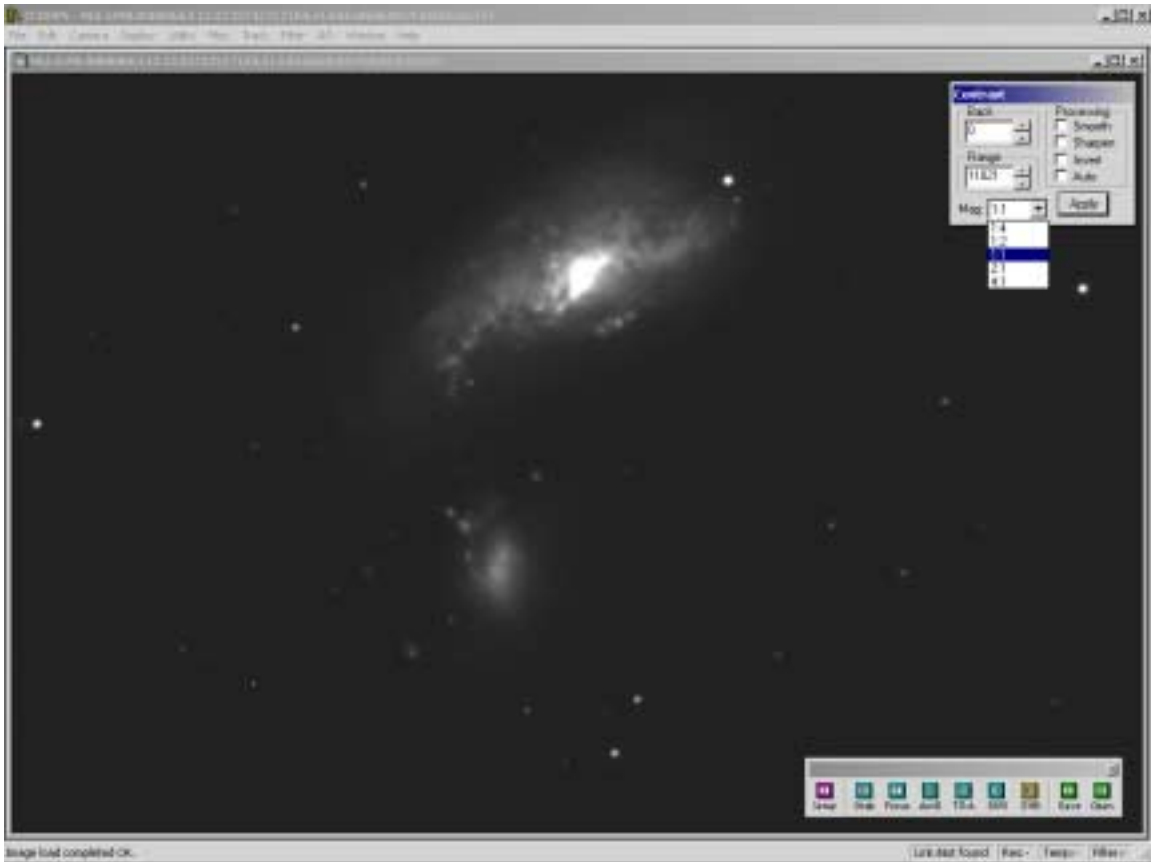
*Figure 14 - Setting Background and Range values manually. Note Mag dropdown, which can be used to change the image magnification. The physical size of the image does not change, just the size at which it is displayed.*

All changes made with the Contrast window are non-destructive. The Background and Range values are saved with the file, but no data is added or removed when you use any of the settings in the Contrast window.

**TIP:** On short exposures CCDOps will push the contrast. The range will be low, typically 64. This results in a grainy image because most of the available range is not included in the image. Increase the range to see a smoother rendition of the image. For planets and bright stars increase the range to a very high value, close to the peak value in the image. Without this adjustment, planets may show as all white. Increasing the range to the peak value will reveal details by raising the white point.
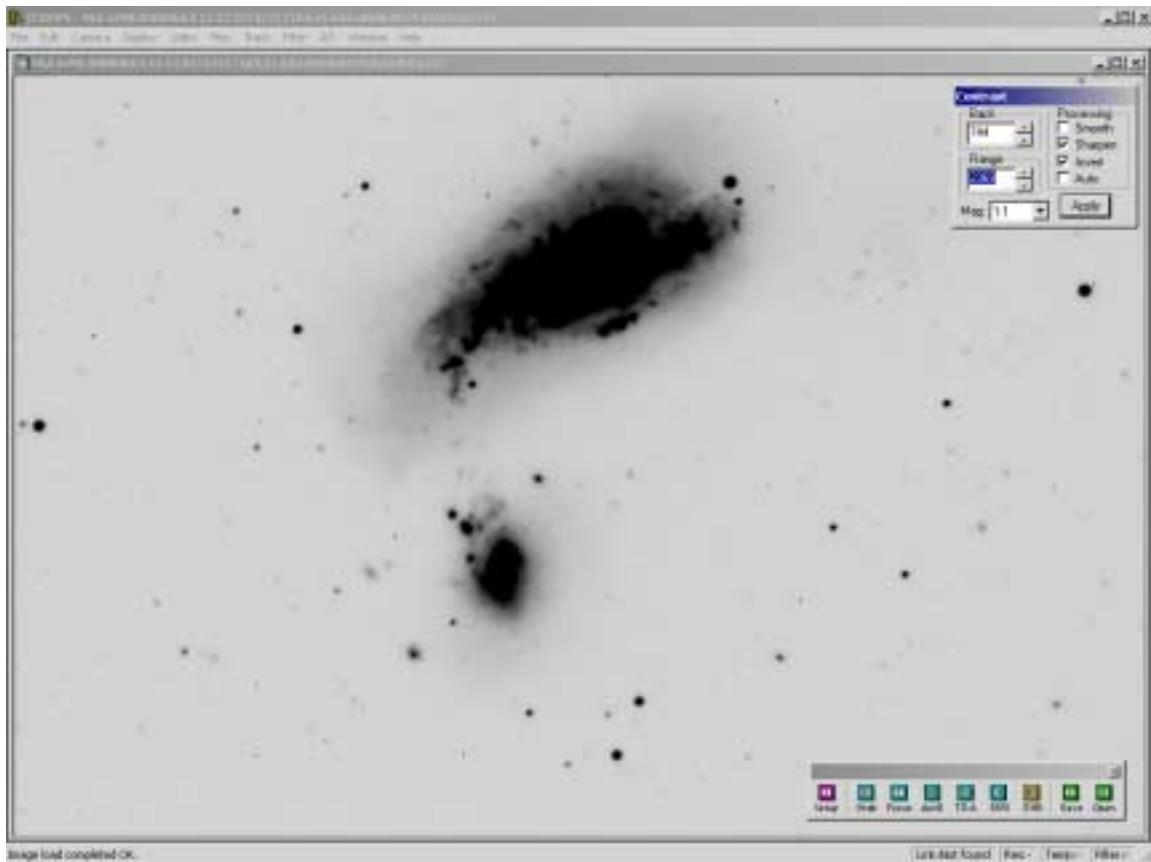
*Figure 15 - You can use the Invert checkbox to view images as a negative.*

**TIP:** If you want to make permanent changes to an image, such as smoothing or sharpening, use the image processing features of CCDOps in the Utility menu. See the section "Image Processing with CCDOps" for information about image processing. Image processing will make permanent changes to the image data. You may need your original data again at a later date, so we suggest saving your permanent changes using a new filename. For example, if your original filename is M51.sbig, and you sharpen the image using image processing, you might use "M51_sharp.sbig" as the new filename.

## Taking a Sample Image Indoors

Before attaching your camera to the telescope and taking pictures of the night sky, you can image with your camera indoors to familiarize yourself with operation of the camera. The CCD chip is extremely sensitive, however, so you need to take special steps to limit the incoming light when taking a test exposure. In addition, many telescopes do not focus at close distances, and imaging with your telescope in your living room may not provide enough distance to reach focus.

Those with recently purchased cameras may have received a test lens, which is much better than a pinhole (described below).  SBIG this as an inexpensive item individually, also.

You can use a simple pinhole camera to overcome these issues and take some indoor images. Your camera comes with one or more nosepieces (1.25" and/or 2"). Wrap a small sheet of aluminum foil over the nosepiece, and use a pin or paperclip to create a pinhole at the approximate center of the nosepiece. Be careful not to tear the aluminum.

The pinhole is in effect an extremely small aperture that creates a slow focal ratio imager. This simple arrangement will be in focus for both very close and very far subjects. It also limits the amount of light striking the CCD chip, allowing you to take indoor images. A brightly lit room may still provide too much illumination, so be prepared to dim the lights if your image over exposes.

See the previous section for tips on how to adjust the contrast of your images.

**Note:** When done imaging, use the Camera | Shutdown menu item. The Shutdown command ramps off the cooling, opens the shutter, and breaks the communications link. Give the camera 15 to 30 seconds after using the Shutdown command before turning off the power to the camera. This allows the CCD chip in the camera time to slowly warm up to ambient temperature, and reduces the risk of chip damage from fast temperature changes. It is unlikely that the chip will be damaged even if the camera is turned off suddenly, but the ramping process provides the safest possible method of warming up the chip.

## *Rough Focusing*

First-time focusing can be more challenging than routine focusing. Most CCD cameras do not come to  focus at the same position as your eyepieces—the difference can be surprisingly large with some eyepieces. Finding focus position the first time requires a few tricks.

The type of telescope you are using affects how you will reach focus, too. The following sections offer some tips for speeding up the first-time focusing process. Find the section that best matches your equipment, and follow the instructions for focusing.

For all types of telescopes, use the Focus tool to monitor focus. You can open the focus tool with the Ctrl-F key combination, or click the Focus button on the Icon Bar.

**TIP:** If your mount cannot reliably put a star onto the CCD chip when slewing, there are two ways to remedy that problem. Method one is to carefully align the finder scope with the main tube so that you can use the finder scope to put an object onto the CCD chip manually following a slew. Method two is to remove the camera and insert an eyepiece temporarily, which allows you to manually center an object. Both techniques can be used when imaging, not just when doing a rough focus.

Whatever method you use for rough focusing, use CCDOps to image while you adjust focus, using the following procedure:

1. Slew to a bright star. Depending on your camera and telescope, a star of magnitude 3-7 will work well. If the star is too bright, it will bloom when focused. The moon and planets are also very bright and do not make good targets for rough focusing. You can switch to a dimmer star, or reduce the exposure time if the focus target is too bright.
2. Open the Focus tool.
3. Set an exposure of 1-3 seconds, with Frame size set to "Full" (see Figure 16 for complete settings).

**TIP:** Your camera can take shorter exposures, and shorter exposures would update faster on the screen. But if the star is very far out of focus, you will need a long exposure to show the out-of-focus star against the background. You can restart the Focus tool with shorter exposures as you get closer to focus.

**TIP:** Go to camera settings (Ctrl-U) and set Resolution mode to Auto. This tells the Focus tool to use 3x3 binning (low resolution mode) for focusing. This provides the fastest possible update speed from one exposure to the next.
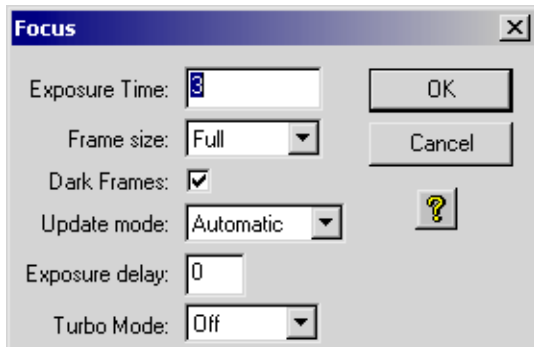


*Figure 16 - Try these settings for rough focus.*

4. Click OK.

5. CCDOps takes continuous exposures. Use the exposures to monitor the quality of focus as you adjust focus position.

6. Move the focuser in one direction or the other so that you can see what happens to the image. If the star gets smaller, you are moving closer to focus. If the star gets bigger, you are moving away from best focus. Adjust focus to make the star as small as you can, but you don't have to be fussy about the exact position. The next section describes procedures for achieving a precision focus.

Figure 17 shows a typical rough focus image. The star is far out of focus, and a major adjustment to the focus position is required to achieve focus. You may encounter stars even further out of focus, or you might get lucky and start very close to focus.
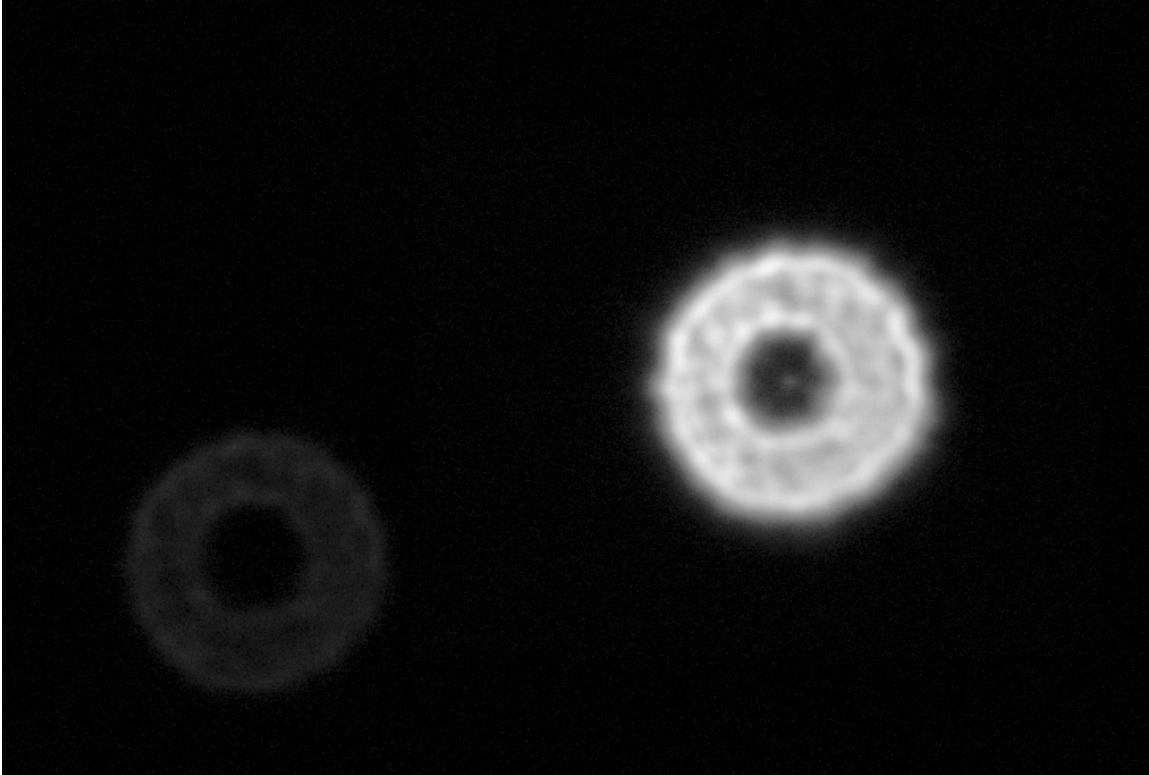
*Figure 17 - An example of out-of-focus star images. Image taken with 14" Schmidt-Cassegrain (SCT) and ST-10XME. Out-of-focus stars in a refractor image will not have the dark center, which is caused by the shadow of the secondary in an SCT.*

**TIP:** If you are very far from correct focus, the out-of-focus star may be very large. Before you assume that there isn't a star in the image, consider that the diameter of the out-of-focus image may be larger than the entire CCD chip. You can use even an extremely out-of-focus star image to start moving toward better focus.

## External Focusers (e.g., Refractors, Newtonians)

When the focusing knob and the focusing mechanism are visible outside the telescope, rough focus is easy to achieve after the first session. For example, you can use a piece of tape to mark the correct focus position on the focuser tube. To return to rough focus, simply move the focuser until the focus position lines up with the tape.

If you have an eyepiece that is approximately parfocal (that is, has the same focus position as the camera), you can mark the barrel of the eyepiece. After you achieve rough focus with the camera, insert the eyepiece, and adjust its position until the stars are in focus. Mark the barrel with permanent marker so that you can use the eyepiece to quickly achieve rough focus.

## Internal Focusers (e.g., SCTs and other Cassegrain-Family Scopes)

When the focuser is inside the telescope, as it is with most Schmidt-Cassegrain designs, you cannot visibly identify the optimal focus position. The simplest method for moving to the focus position is to count the number of full revolutions of the focus knob between best focus and either the full in or full out position. You can add a small mark or piece of tape to the focus knob to make it easier to see when a full revolution occurs.

The trick with an eyepiece from the "External focusers" section is even more handy with a scope that has an internal focuser.

## Motorized Focusers (e.g., JMI, Optec, Van Slyke, etc.)

If you have a motorized focuser, such as the JMI NGF-S or Optec TCF-S, you can use the hand controller for the focuser to make small, precise movements to achieve focus. Many of these focusers will work with long cable runs, so you can focus at a distance from the telescope.

Judging the Quality of Focus

So what does good focus look like? For rough focus, all you need to do is make sure that the star is approximately as small as you can make it. Rough focus is normally done in low resolution mode, and you will need to switch to high-resolution mode to achieve a precision focus. See the next section for details on how to find a very accurate focus position.

Judging when you are at the best focus position seems challenging, but there are some techniques you can use to help identify this position. The simplest technique is to take note of the peak value in the image. During focusing, CCDOps displays the peak value in large numbers (so you can see it easily while you adjust focus). Figure 18 shows the Focus dialog. The peak value in this example is 10319. The peak value will vary somewhat due to seeing conditions—just as stars twinkle to the eye, the peak value will vary somewhat because of movement in the atmosphere above the telescope.
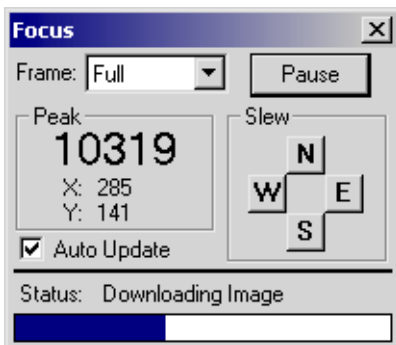


*Figure 18 - Judging the quality of focus using the peak value in the image.*

Observe the peak value for several exposures before moving the focus position. For increased accuracy, write down 3 to 5 peak exposure values and average them. Compare the average values to find best focus.

You can also use various diffraction aids to assist you in finding the best focus position. For example, if your telescope doesn't have a spider supporting a secondary mirror, you can create a temporary spider using tape or dowels at the front of the telescope. Figure 19 shows the appearance of a star when diffraction spikes are present, at a point slightly out of focus and at best focus.
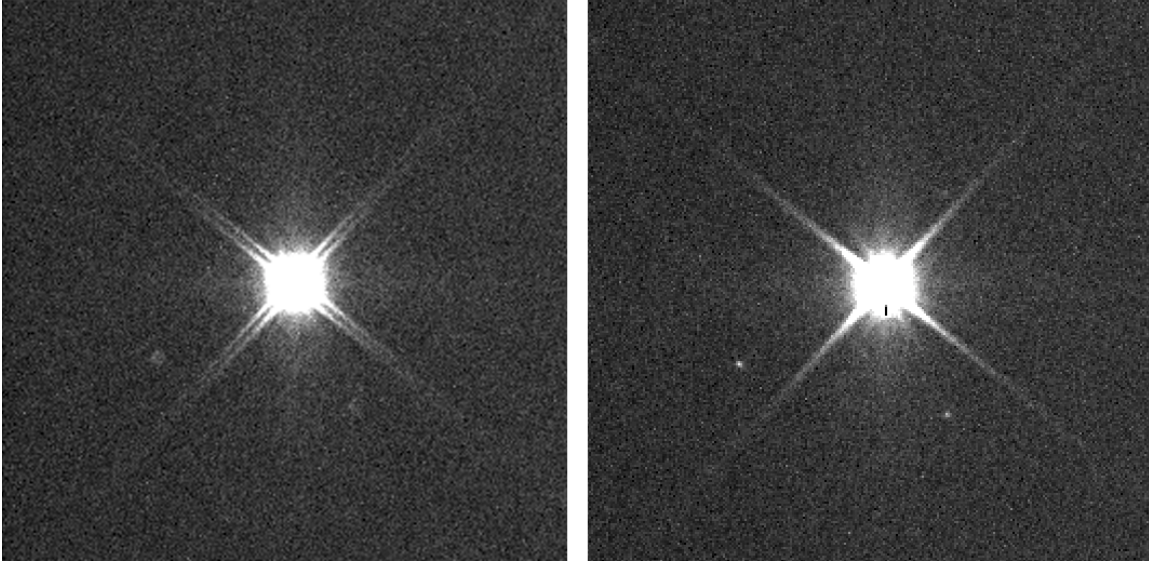
*Figure 19 - Using diffraction spikes to judge quality of focus. Left: just outside of focus. Right: right at focus.*

In addition to a real or fake spider at the front of the scope, you can use a mask with holes in it to assist in judging focus. The Hartmann mask is commonly used (see SBIG web site for more information), and various other masks will also work. The offset triangle mask (see Figure 20) is particularly easy to use because the diffraction spikes caused by the triangles do not overlap, and can be used to accurately determine when focus is reached.
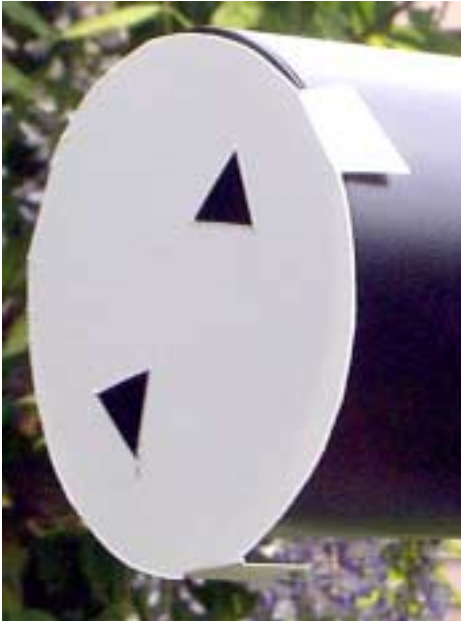


*Figure 20 - A two-triangle mask for evaluating focus quality.*

**TIP:** You can use the dimmest stars in the image to help evaluate focus. As shown in Figure 19, the dim stars seem to pop out sharply right at the critical focus position. This technique is especially effective when the field of view is wide. In a wide-field image, dim stars are very small and will disappear from view away from the best focus position.

## *Precision Focusing*

Precision focusing also uses the Focus tool, but with different settings than you used for rough focus. To open the Focus tool, click the Focus button on the icon toolbar, or use Ctrl + F.

**Focus Settings**

**Exposure Time**—in seconds. For focusing, an exposure of 1-5 seconds will help even out the effects of seeing. Faster exposures may make it harder to evaluate the brightest pixel value.

**Frame Size** (full, planet, full-high, full-low)—Full setting uses high resolution mode (unbinned). Planet mode is used for fast precision focusing as well as for planets (see details below). Full-low mode uses low resolution (3x3 binning) while showing the entire CCD field of view (FOV) where as Full-high uses high resolution, again at the full FOV.

**Dark Frames** (checkbox, on or off)—When checked, a dark frame is taken and applied to the focus image. Recommended setting: on.

**Update Mode** (automatic, manual)—When set to manual, you must click to take the next focus exposure. When set to automatic, focus exposures occur continuously.

**Exposure delay**—Delay between focus exposures. Typically used to delay the next exposure while you make an adjustment to focus position.

**Turbo mode** (off, enabled)—Keeps the shutter open during downloads for faster screen updates during focusing.

**Note:** If camera resolution mode is set to Auto in the Camera Setup dialog (Ctrl+U), the full frame mode will be binned 3x3 for focusing (same as Full-low mode). CCDOps automatically switches to High Res mode in the Planet mode.

Click Pause to stop taking exposures, or to allow time for adjusting focus. Click the Resume button to continue taking focus exposures. Uncheck the "Auto Update" checkbox to take one focus exposure at a time. To end the focus session, click the small "x" button at the upper right of the Focus window.

**Note:** if camera resolution mode is set to auto, Initial Planet frame will be binned 3x3. Otherwise, it will be unbinned full frame.

For precision focusing, set the Frame size to Planet, and the update mode to Automatic. Click OK to take a focus exposure. CCDOps takes a low-resolution image (see Figure 21), and displays the focus window. There is a thin white rectangle on the image. Drag the upper left and lower right corners of the rectangle to select the portion of the image you want to use for focusing. As shown in Figure 21, the best strategy is usually to drag the rectangle around a bright star. A small box will update frequently, providing near real time feedback for focusing. Click the Resume button to start taking exposures.

**TIP:** If your camera connects to your computer with a USB cable, it will have very fast downloads. You can use a larger rectangle with a USB camera. A larger rectangle is more likely to include dim stars that you can use to help evaluate the quality of focus.
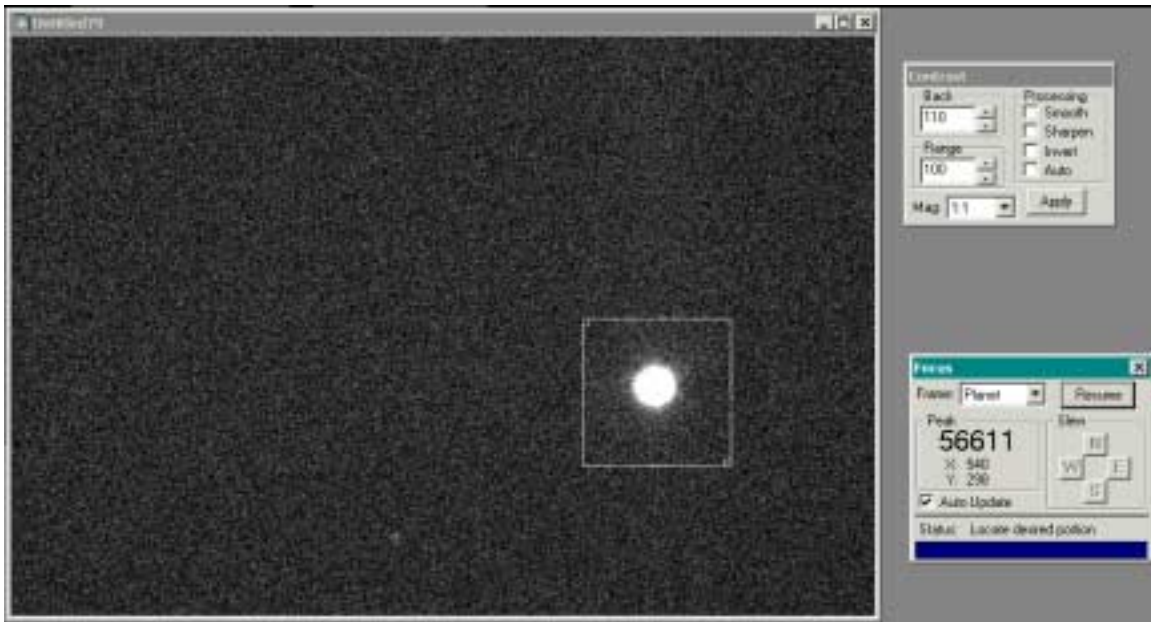
*Figure 21 - Focusing using Planet mode.*

CCDOps takes a series of exposures at high resolution, including only the area you specified with the rectangle. Adjust focus while CCDOps is taking images, and observe the image and the peak brightness value to determine when best focus is reached. The peak brightness value will be largest near best focus. If the brightest pixel reaches or exceeds the saturation level for your camera, you'll need to start over with a shorter exposure time or a dimmer star.

Table 2 shows the approximate saturation level for different families of cameras. The saturation for any camera can be determined using the formula:

$$saturation = \frac{full\ well\ in\ electrons}{A/D\ Gain}$$

A/D gain is the analog to digital gain. The full well and A/D gain of SBIG cameras is listed on the SBIG web site, but you can find the already-calculated saturation levels in Table 2.

**Note:** The saturation levels are similar for parallel and USB cameras. Saturation levels are approximate; there will be small differences between cameras.

*Table 2 - Camera Saturation Levels*

| Camera Family | Approximate Saturation Level |
| --- | --- |
| ST-7/8 NABG | 43,000 |
| ST-7/8 ABG, ST-237A | 25,000 |
| ST-9, ST-10 | 50,000 |
| ST-1001, ST-2000, ST-L-11000 | 62,000 |

You can use multiple methods to evaluating focus as described earlier. The more sources of information you have about focus, the more accurately you can focus.

**TIP:** Seeing will cause the value of the brightest pixel to vary somewhat, even if you do not change the focus position. It is useful to know how large these variations are so you can determine when a variation in brightest pixel value is significant. To determine how much the brightest pixel value changes randomly from seeing, take three to five exposures while you leave the focus position unchanged. The magnitude of these variations will be largest close to focus, giving you one more way to evaluate focus quality.

## Controls in the Focus Window

While focusing, you will see the following features in the Focus window (see Figure 22):
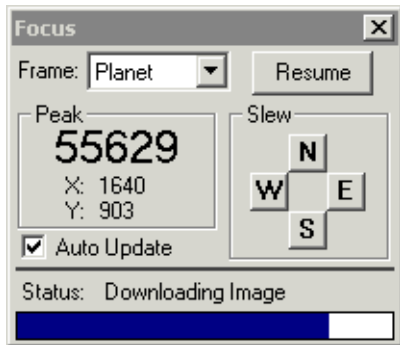


*Figure 22 - The Focus window.*

**Frame**—You can change the frame size during a focus run. The focus exposures are paused automatically if necessary, such as when you change from Full frame to Planet. The available choices are Full, Planet, and Full-High, Full-Low.

**Pause/Resume button**—You can pause focusing at any time. This button will also change to Resume automatically when using Planet mode when CCDOps pauses to allow you to resize the rectangle used for Planet mode. Sometimes response to this button is sluggish or intermittent during imaging

**Peak**—Value and location of the brightest pixel in the image. Brightest pixel value will be highest near best focus, but seeing will often make it jump up and down in value randomly.

**Slew buttons**—Move the telescope using the camera relays. Useful if you want to position an object on the chip before you continue focusing. For example, if a star is too close to the right edge, and the camera is oriented with North up, you can move the star closer to center by clicking on the E button. This moves the telescope to the east, toward the star. The rate of movement will be the currently set guide rate for your telescope.

**Auto Update**—When checked, exposures continue automatically. When unchecked, CCDOps stops between exposures. You can use this time to refocus before taking the next exposure. Click the Resume button to continue focusing. When this is checked, it is the same as starting in Manual mode. You can use this checkbox to switch between manual and automatic mode whenever you wish.

**Status**—Contains text describing the current activity.

## *Dark Frames and Flat-Field Frames*

The raw images downloaded from a CCD camera may contain noise. Noise shows up as variations in pixel brightness throughout the image, giving it a grainy appearance. Figure 23 shows an example of a raw image.

*Figure 23 - A raw image showing noise.*



*Figure 24 - An image with noise removed by dark subtraction (calibration).*

The graininess in Figure 23 comes from something called dark current. While an exposure is being taken, electric current flows at a very low level in the CCD chip. The amount of the current varies from one pixel to the next. The dark current causes individual pixels to vary in brightness. Fortunately, each pixel behaves in approximately the same way in every exposure. If a pixel is a little brighter because of dark current in one image, it will be a little brighter in other images, too.

In fact, an exposure taken with the shutter closed will result in nearly the same dark current in each pixel. This allows you to record the dark current. This record is called a dark frame. The dark frame can be subtracted from the light frame, resulting in a much cleaner looking image. Figure 24 shows the result of subtracting a dark frame from the image of M51 in Figure 23. The variations in brightness are gone, and the image is much cleaner.

CCDOps allows you to make and subtract dark frames to clean up your images. You can even tell CCDOps to automatically take a dark frame for each light frame, or to re-use a dark frame for subsequent exposures. Other operations, such as Track & Accumulate, allow you to specify how often a fresh dark frame will be taken. In all cases, the intent of the dark frame is to clean up the dark current as shown here.

Figure 25 shows a typical dark frame. It doesn't look like much, just a jumble of varying brightness levels in the pixels of the image that somewhat resembles "salt and pepper". But it enables you to obtain much cleaner images.



*Figure 25 - A dark frame records the dark current of the CCD chip.*

**Dark current varies with the temperature of the CCD chip and the length of the exposure. The cooler the chip , the lower the dark current. The longer the exposure, the greater the dark current. For this reason, the chip temperature and exposure duration of a dark frame must match the temperature and duration of the light frame to which the dark frame is applied.**

**TIP:** If you have a dark frame that doesn't exactly match the temperature of the light frame, or not exactly the exposure time, you can still use it. You may get slightly higher noise if you take this approach, however.  Use the Adaptive Dark under these circumstances.

In addition to dark current, other sources of noise occur in a CCD camera. The cooler built into the camera reduces noise from most sources. In general, you should operate your CCD camera as cool as is practical. You should not use more than 75% of the camera's cooling capacity, however. This allows enough spare cooling capacity to handle changes in ambient temperature. If you use too much of the cooling capacity, the cooler will not have enough capacity to adjust to temperature changes effectively. See the section "Cooling Settings" and Figure 3 for information about setting cooling temperature.

Camera cooling capacity allows for a maximum "delta" (change) in "T" (temperature). For most SBIG cameras, the delta T is 30 degrees Celsius without water assist. This means that you can cool the chip to a maximum of approximately 30 degrees below the ambient temperature. If the air temperature is 25°C, you will be able to cool the camera to approximately -5°C. If the air temperature is 5°C, you will be able to cool the camera to around -25°C. These figures assume that you will use approximately 75% to 85% of the camera's cooling capacity to maintain cooling. The CCDOps status bar shows the amount of cooling capacity in use. If you go above 75%, the chip temperature may vary too much, and you will see more noise in your images, even after you subtract a dark frame. Keep the capacity within limits to get good repeatability on dark current in your light and dark frames.

**TIP:** As the night progresses, ambient temperature typically gets colder. You can use the colder ambient temperature to reach a colder chip temperature. However, if you adopt this strategy, you will need to take new dark frames to match the new temperatures.

## Flat Fields

A telescope or camera lens does not illuminate the CCD evenly. The edges of your images may be slightly darker than the center, for example. There can also be dust on the various optical surfaces, which will cast slight shadows in your images. These changes in brightness limit your ability to process your images. Just as a dark frame records electronic noise so you can subtract it out, a flat field records optical variations so you can remove them as well.

Figure 26 shows an image of M51 taken with an ST-1001E and a C14. It is a 10-minute exposure. The center of the image is noticeably brighter than the edges, and there are shadows from dust motes on the optical surfaces.

**TIP:** You can use the size of shadows from dust to help determine where the dust is. Smaller shadows are cast by dust motes that are close to the CCD chip, such as on the outside window of the camera. Larger shadows are cast by dust motes that are further from the chip, such as on the filters in a filter wheel.

*Figure 26 - An image showing vignetting (darkening away from the center) and shadows from dust on optical surfaces.*

Figure 27 shows a flat-field image taken with the same camera. The telescope was pointed at an evenly illuminated surface (the inside of an observatory roof). A diffuser, consisting of white translucent plastic, was placed over the front of the telescope to make sure that the illumination was even. It may seem that there are too many dust mote shadows to allow this flat to work. But it works, and works well! This flat was chosen deliberately to show that dust shadows do not stop you from taking great images. You can clean your optical surfaces periodically to prevent excessive dust, but even moderate amounts of dust, as shown here, do not create serious problems for imaging.

**TIP:** If you are doing photometric measurements, you may want to invest more time in keeping optical surfaces clean. Flat fields can do an incredible job of cleaning up images affected by messy optics, but for precision measurements nothing beats a clean optical system.
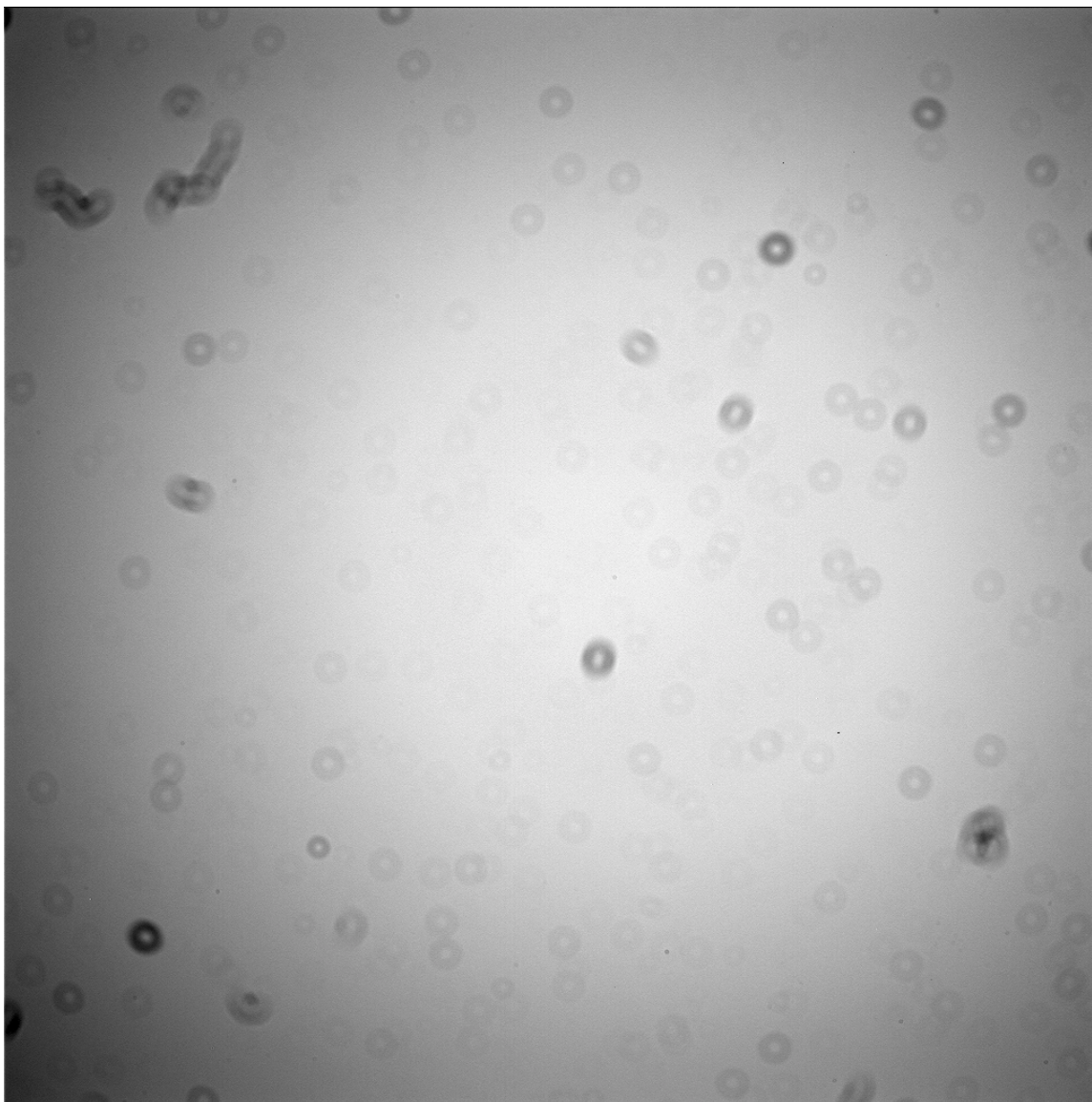
*Figure 27 - A flat field, showing the same vignetting and shadows as in Figure 26.*

Note that the shadows and vignetting are the same between the light frame and the flat-field frame. The camera should be at the same rotation angle and focus position when taking a flat field. If the camera is moved, the size and location of the dust shadows, and of any vignetting, may change, and the flat field won't do its job.

The flat field in Figure 27 looks ugly, but in fact the result of applying the flat to the image (see Figure 28) shows that even an awful-looking flat can work wonders on an image. The removal of the bright center and dust shadows allows the image of M51 to reveal subtle details that are otherwise hidden. The background is now even, providing a more satisfying appearance to the image.

**Note:** CCDOps Autocontrast can make dust shadows look worse than they are. Use the Crosshairs mode to determine how dark the shadows actually are. Measure the brightness of the surrounding area and the shadows. If the shadows are only 1 to 5% darker, a flat field will clean up the shadows effectively.

*Figure 28 - The result of applying the flat to the image.*

## Taking and Applying Dark and Flat-Field Frames

It is relatively easy to take a good dark frame, but it can be challenging to take a good flat-field frame. To be useful, a dark frame only requires two things: that the temperature and exposure time of the dark frame match the light frame. CCDOps has the ability to adjust for exposure time to a certain extent, but a dark that matches the light frame is your best strategy.

Flats, on the other hand, require some skill on the operator's part. You can't just aim your telescope at a blank wall and get a good flat-field frame. It takes some care and experience to take good flats. There are several different approaches you can use when taking flats:

**Sky flats**—Taken after sunset or before sunrise, these flats rely on a bright sky to provide an evenly illuminated subject. You can also take sky flats on a cloudy night, if the clouds are sufficiently illuminated (such as by the moon).

**Dome flats**—Taken with the observatory roof or dome closed. Can also be taken using any evenly-illuminated surface. Indirect illumination of the surface is best. For example, you can shine a flashlight on a piece of white cardboard, which then reflects the light onto the surface you will be imaging for your flat.

**Diffuser flats**—A translucent material, such as a T-shirt or white plastic, is used to diffuse the incoming light. There are many variations on this approach, including light boxes, that provide their own illumination instead of relying on ambient illumination.

However you take your flats, the proof of a flat is always in how well it works. As in the example above with M51, the result should be an even background and the removal of dust shadows from the image.

**Note:** It is sometimes convenient to take flats in the daytime, but if you do watch out for a common problem. Light can enter the telescope from the back end. This results in illuminated dust instead of dust shadows! If you see bright spots where dust shadows should be, you know you are dealing with this problem. Try covering the back of the telescope with a dark cloth to see if you can prevent the entry of unwanted light. Be careful to allow free flow of air around the camera so cooling will not be impeded.

### Take Dark Frames in CCDOps

You can grab a dark frame using the same steps you use to grab a light frame. Click the Grab button on the Icon toolbar, and set the Dark frame to "Only" as shown in Figure 29.
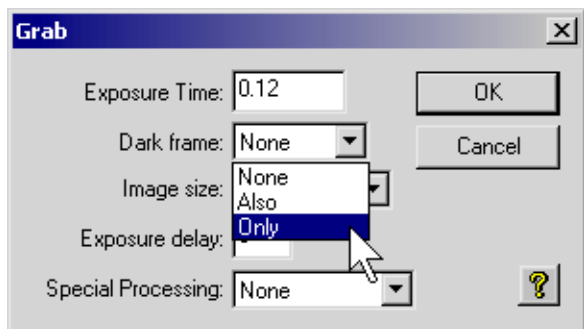


*Figure 29 - Taking a dark frame.*

**TIP:** You can use the "Also" setting for Dark frame. CCDOps will take a dark frame before the light frame, and automatically subtract it from the light frame for you. Automatic dark frames are not saved to disk.

To apply a dark frame to a light frame, open the light frame and then use the Utility | Dark Subtract menu item (keystroke: Ctrl-B). Navigate to the dark frame, highlight it, and then click the Open button. CCDOps will ask you if you want to use Standard or Adaptive for the dark subtraction. If the dark and the light frame have the same exposure time, choose Standard. If the dark frame has a different exposure time, choose Adaptive. Save the result to disk using a new name to indicate that the dark frame has been applied to the image. This retains the original data in case you wish to do anything different at a later date.

### Taking Flat-Field Frames in CCDOps

There is no special step for taking a flat-field frame. The difference is all in the setup—finding a blank, evenly illuminated wall or observatory ceiling; stretching a T-shirt across the front of the telescope, etc. Take a normal light exposure, but add the word "FLAT" to the filename so you know it is a flat-field frame. Be sure to set the Dark frame to "Also"

so that your flat field has low noise. The peak brightness level of a flat should be about one half to two-thirds of the saturation level (see Table 2).

Apply the flat to a light frame after you apply a dark frame. To apply the flat, open the light frame, then use the Utility | Flat Field menu item. Navigate to the flat field frame, and click the Open button to apply it. Save the result to disk using a new name to indicate that the flat field has been applied to the image.

## *Taking Multiple Exposures*

In addition to taking single exposures, CCDOps can take a series of exposures. Multiple exposures give you the ability to stack (combine) exposures to reduce the overall noise in the final image. This provides a cleaner overall result, and is highly recommended. In particular, dim subjects will benefit the most from combining images.

Figure 30 shows averaging at work. The top images show the difference between a single image (left) and five averaged images (right) of NGC 3628. The subtle details just above center are hazy in the single image and crisp in the averaged image. The lower images show this area magnified. The single image is noisy, with so much graininess that faint details are hidden in the grain. The averaged image shows better contrast because of lower noise, allowing faint details to come through.

CCDOps performs averaging by simple mathematics. It takes the brightness value of a given pixel in each image, adds them together, and then divides by the number of images.

Noise causes the brightness values to fluctuate from one image to the next. Averaging the image together brings you closer to the true brightness level, and thus reduces the noise in the final image. Averaging is a very powerful tool for improving the quality of your images.

One further benefit of taking multiple shorter exposures is that tracking problems are less pronounced and if a satellite traverses one of your images you only waste a small amount of time redoing that image.

**TIP:** We recommend taking at least three images when combining multiple exposures. This is true for light frames, dark frames, and flat-field frames. Averaging does not eliminate cosmic rays, while median combining (which requires at least three images) does. At this writing, CCDOps does not support a median combine.
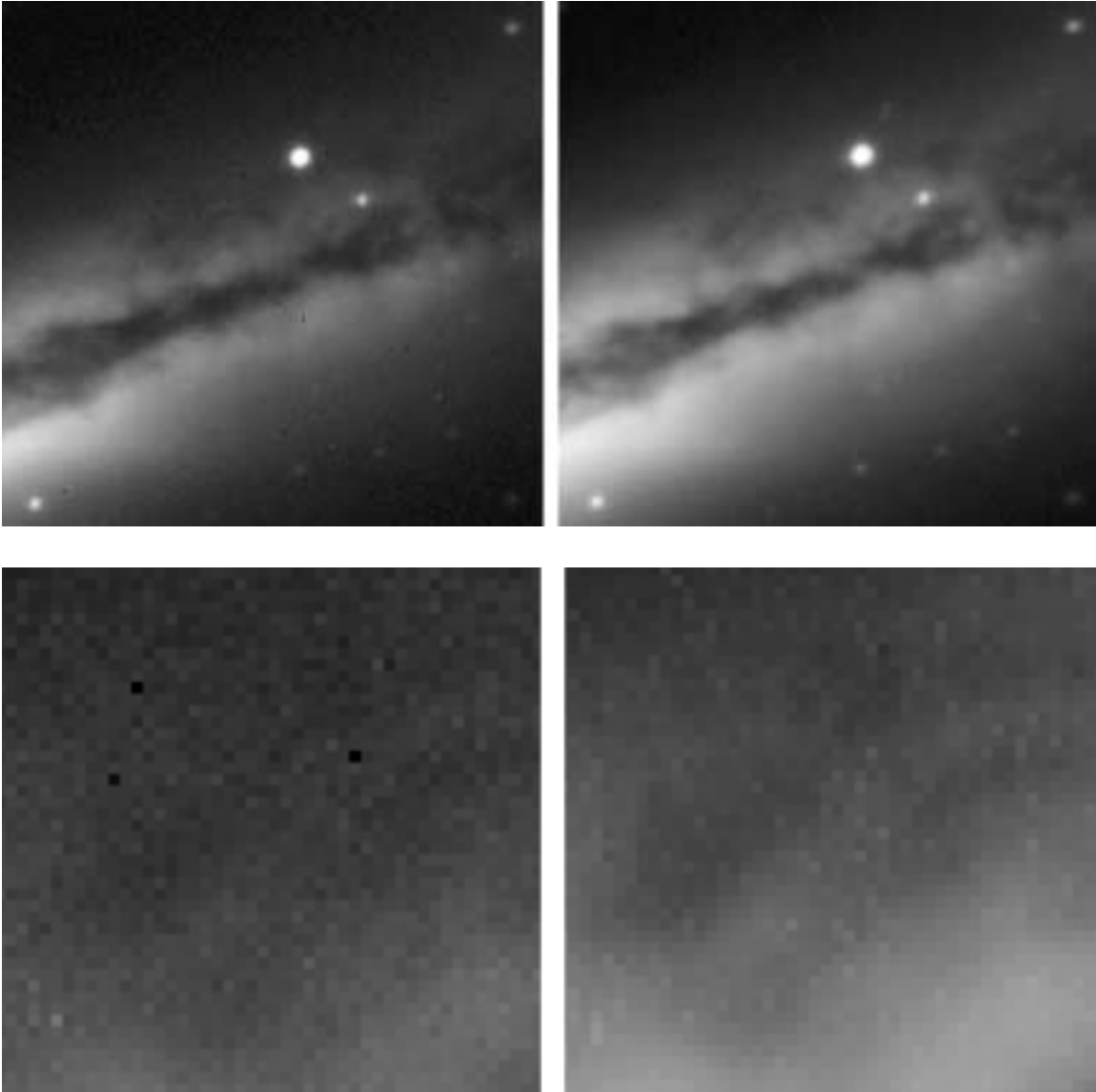
*Figure 30 - Averaging images together decreases noise. Single images are shown at left, and averages of five images are shown at right. See text for details.*

The fainter the objects you are imaging, the greater the benefit from averaging. See the following section for details on grabbing multiple images, and see the section "Combining Images" for details on doing an average combine. See Table 1 in section "Taking an Image" for advice on exposure times for single exposures.

But averaging does have a downside.  For example to get twice the signal-to-noise of a single image you have to take four images.  To get another factor of two requires sixteen!  The improvement in signal-to-noise increase as the square root of the number of images combined, not linearly.  This is also true for increasing the exposure length of long exposures.

## Auto Grab a Sequence of Images

Use the Auto Grab option to take a sequence of images. Start with the Grab on the Icon toolbar (Ctrl + I). Figure 31 shows where to find the "Auto Grab" selection on the Special

Processing drop-down list. Set the exposure time, dark frame, image size, etc. to meet your requirements. Click OK to continue.
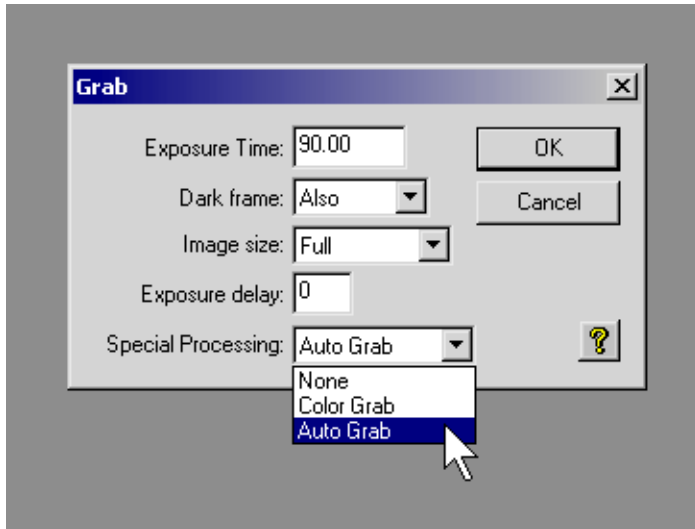


*Figure 31 - Setting up an Auto Grab sequence.*

This displays the Auto Grab Setup dialog (see Figure 32):
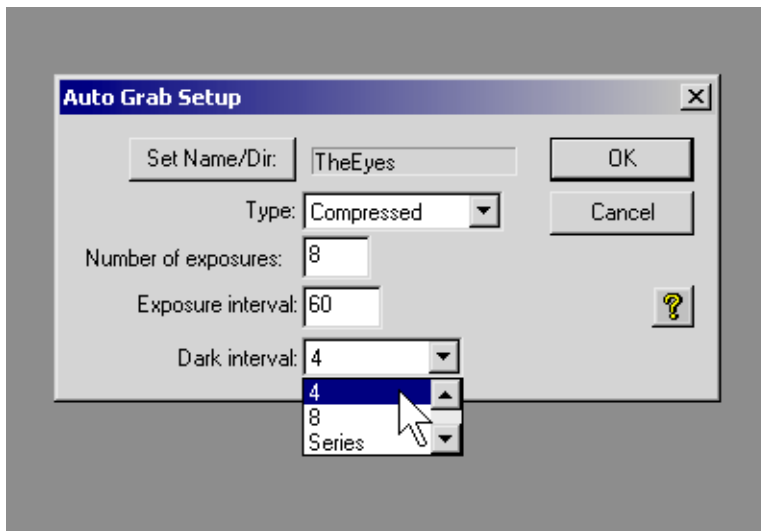


*Figure 32 - The Auto Grab Setup dialog.*

**Set Name/Dir button**—Click this button to set the base filename for your exposures, and to determine the folder where the images will be saved.

**Type** (Compressed, uncompressed, FITS, TIFF)—Sets the file type to be saved. Compressed and uncompressed are CCDOps file formats. Compressed will reduce the file space used without losing any of the image data. We highly recommend saving your images in the compressed format.  If you want to open the file in other CCD programs that don't support the SBIG formats, you can use the FITS format. Both SBIG and FITS formats are commonly supported by a wide variety of astronomical image programs. The TIFF format is a standard image format that can be read by image processing programs such as Photoshop, Picture Window Pro, etc. If you choose the TIFF file type, however, information such as exposure time and

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filters used will be lost—the TIFF file type does not support storage of this information.

**Number of exposures**—Determines how many exposures will be taken.

**Exposure interval**—Allows you to take exposures at a set interval. For example, if you were taking images of a transit of Mercury, and wanted to take a new image every three minutes, you would enter a value of 180 for exposure interval.

**Dark interval** (1, 2, 4, 8, Series)—Determines how often a dark frame is taken. If you do not specify "Also" in the Dark Frame setting of the Grab dialog (see Figure 31), this setting will not be available. If the Dark interval is set to 2, for example, a new dark frame will be taken for every second exposure. The Series settings causes a single dark frame to be taken at the start of the sequence, and it will be reused for every exposure. To help reduce noise, the dark interval should result in at least 3 dark frames being taken during the sequence.

Click the OK button to take the exposures. Files are saved in the folder you specify, using the base filename plus a numeric suffix. Using Figure 32 as an example, the filenames would be TheEyes001.STX, TheEyes002.STX, and so on up to TheEyes008.STX.

**Note:** The actual extension will be determined by the file type you select.

## Combining Images

Once you have taken a sequence of images, you can combine them in two ways:

- The Utility | Co-add menu item
- The Utility | Average images menu item

Co-adding adds a single image from disk to the currently open image, with a way to align the images with each other. Averaging combines multiple images in one step, without any way to perform alignment. Co-adding is useful for light images, and averaging is most useful for combining dark frames and flat fields into master frames.

To co-add images, open one of the images, and then use the Utility | Co-add menu item to select a second image. This opens the dialog shown in Figure 33. To shift the incoming image relative to the already open image, enter X and Y pixel offsets that will line up both images. The maximum pixel value is 65,535, and co-adding could result in pixel values larger than that. If the sky background is very bright (and is using up the available dynamic range), enter a value in Count offset. It will be subtracted from the sum to prevent values larger than 65,535 from occurring. Click OK when you are ready to co-add.
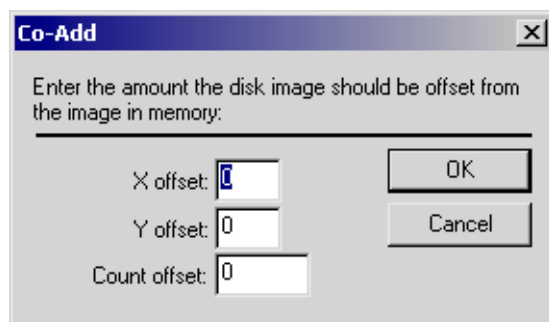


*Figure 33 - Co-adding images.*

To average images, use the Utility | Average images menu item. Select one image at a time, and click the Open button for each image. CCDOps will average the pixel values using data from all of the images, and create a new image. Save the image to disk using the File | Save As menu item.
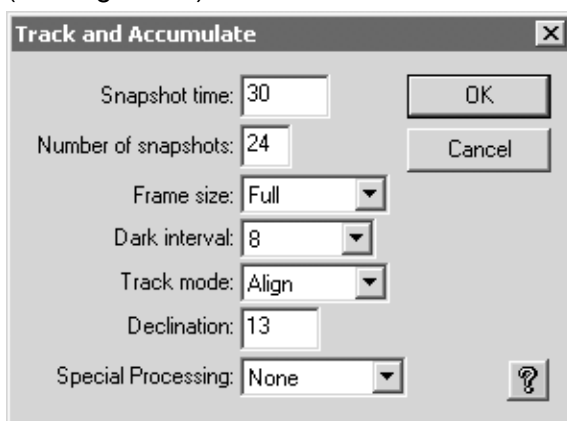
## Using Track & Accumulate

Track & Accumulate is an SBIG-patented method for taking and combining multiple images that automates the alignment and co-adding process for you. A typical Track & Accumulate session includes the following steps.

1. Set up the Track & Accumulate session
2. CCDOps takes the first exposure (including a dark if so specified)
3. You select a star on the image to use as a reference point
4. CCDOps takes the requested number of images, shifting and combining each image so that the reference star in each image lines up precisely.
5. During the Track & Accumulate session, statistics about the process are displayed in a dialog box. This allows you to evaluate the success of the process as it occurs.

The advantage of Track & Accumulate is that it simplifies the process of taking deep images. It is especially useful if your mount cannot take long single exposures. With Track & Accumulate, CCDOps will take multiple exposures and combine them on the fly. This leaves you with a single, deeper image.

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**TIP:** One of the most common reasons to use Track & Accumulate is to overcome limitations of your mount. If your mount cannot track accurately enough to take long exposures, you can experiment with different exposures times using the Grab command to determine the longest useful exposure. If the stars start to elongate, the exposure is too long. **If your camera has an internal guider, such as the ST-7XE, you can take longer exposures by using guiding to correct for mount errors.**

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To start a Track & Accumulate session, click the T&A button on the Icon bar or use the Track | Track & Accumulate menu item. This opens the Track and Accumulate dialog (see Figure 34)



*Figure 34 - Track and Accumulate dialog.*

Use the dialog to set up your Track & Accumulate session.

**Snapshot time** (exposure duration)—The individual exposure time in seconds. The exposure should be long enough to get a good signal level in your image, but not so

long as to allow stars to trail because of mount movements (e.g., periodic error, tracking errors, etc.).

**Number of snapshots**—The number of images to take in the series. The shorter your exposures, the larger this number should be.  But it's always better to take fewer long exposures than more short exposures.

**Frame size** (Full, Half, Quarter)—Determines what portion of the frame is used for the exposure.

**Dark interval** (1, 2, 4, 8, Series)—Determines how often a dark frame is taken. In the example in Figure 34, there are a total of 24 images, and a dark frame will be taken before each set of eight images. This results in 3 dark frames total. One will be taken at the start, another before image 9, and the last before image 17.

**Track mode** (Align, Relays, Both)—Determines the method used to align images. The Align method does not move the telescope and thus does note require the autoguiding cable to be connected to the telescope.  It simply aligns the images using the reference star you select. The Relays method bumps the telescope between exposures (calibration of the mount is required; see the section "Calibrating Your Mount" for details). When the Both setting is chosen, alignment and relays are used together to make sure that the images line up.

**Declination**—Required for Relays/Both (Track mode settings) to make accurate adjustments to telescope position. This scales the guide calibration if the declination of the image is different than the declination used for calibration.

**Special processing** (None, Color Grab)—If you have a color filter wheel, you can take a color series with Track & Accumulate by choosing "Color Grab." For a set of exposures with a single filter, choose "None."

Click OK to save the Track & Accumulate settings. CCDOps takes an image at the currently set resolution, and displays the image along with the dialog shown in Figure 35. For this example, M16 is being imaged with Track and Accumulate session.
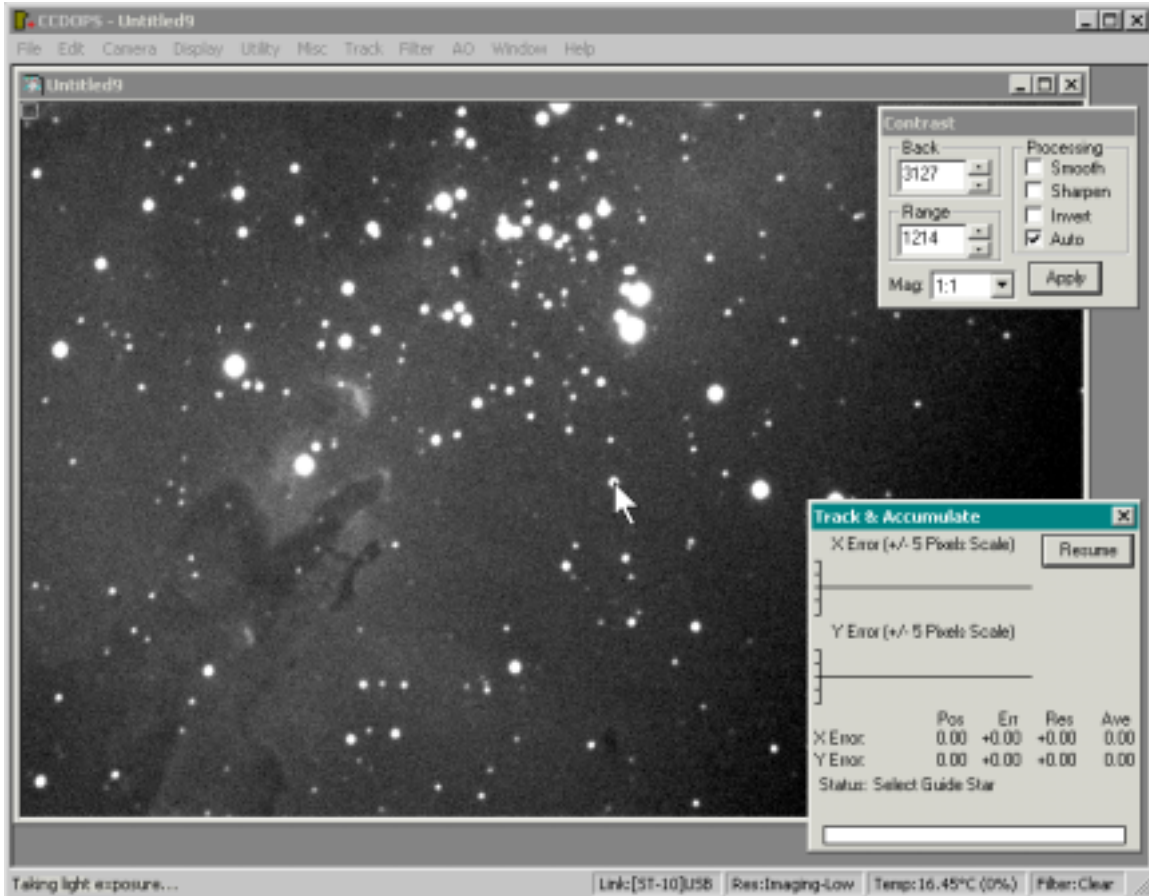
*Figure 35 - Selecting the reference star in the first image.*

There are two graphs in the dialog, one each for the X (horizontal) and Y (vertical) axes. These graphs will record the amount of drift in the series of exposures. Statistical information about the Track & Accumulate session will appear below the graphs, and the bottom part of the dialog includes status information and a progress bar.

At this stage, the status information is telling you to "Select Guide Star." Pick a bright but unsaturated star in the image to use as a reference star. CCDOps will identify this same star in each image, and use it to align the images. Simply click on the star to choose it (Figure 35 shows the arrow cursor pointing at a suitable star), then click the Resume button. CCDOps will take the remaining exposures, including any dark frames.

During the Track & Accumulate session, the image window is resized to a small rectangle, showing only the reference with cross-hairs superimposed. The progress bar indicates the progress of each individual image. As images are taken, the X and Y graphs are updated with the offset in each axis, and the statistical information is updated. See Figure 36 for an example of the appearance of the dialog during a Track & Accumulate session.

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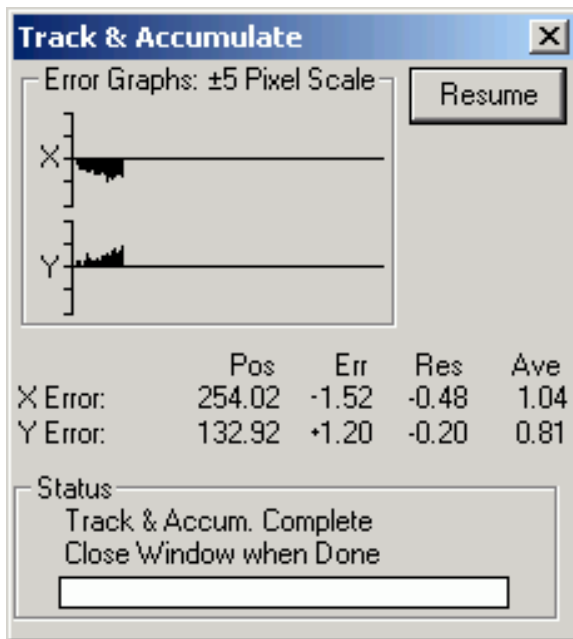
*Figure 36 - In-progress information about a Track and Accumulate session.*

The X error graph shows extremely accurate tracking, while the Y error graph shows a slight drift (a little over 2 pixels while taking 13 images so far).

The four columns of statistical information are:

**Position**—The X,Y coordinates of the reference star.

**Error**—The total amount of position errors due to drift of the reference star

**Residual**—The fractional pixel error after registration. Track & Accumulate aligns pixels, and if the centroid (center) of the reference star is offset by a fractional pixel, the amount of that residual error appears for each image.

**Note:** in Relays mode, this is the total error.

**Average**—The average error for images taken so far.

At the conclusion of the series of exposures, CCDOps displays the Track List dialog (see Figure 37). This dialog provides a summary of the session—number of snapshots, snapshot time, temperature, etc. The Pedestal is the value that is subtracted from the combined image to allow it to fit into a 16-bit range.
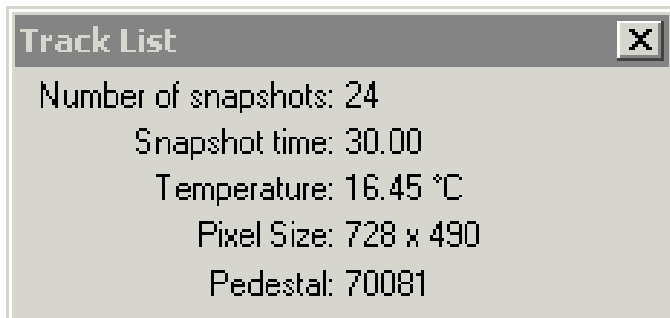


*Figure 37 - The Track List dialog.*

Click the small "x" at upper right to close the Track List dialog. CCDOps will ask you if you want to save the track list to a file. The track list includes information about every

image in the session, as well as some of the session parameters. The following listing shows the contents of a typical track list.  The Track List is used when Flat Fielding Track and Accumulate images so always remember to save it if you're going to apply flat fields to your Track and Accumulate images.

```
ST-10 Track List
Version = 1
Snapshots = 24
Snapshot_time = 30.00
Temperature = 16.45
Height = 490
Width = 728
Offset = 0
0,0
0,0
0,1
-1,2
0,3
-1,3
-1,3
-2,4
End
```

When you are done, save the Track and Accumulate image to your hard disk with an appropriate filename. Figure 38 shows two examples of images taken with Track and Accumulate. Both sessions used a large number of images (more than 20) and sufficiently long exposures (90 seconds) to capture faint details.
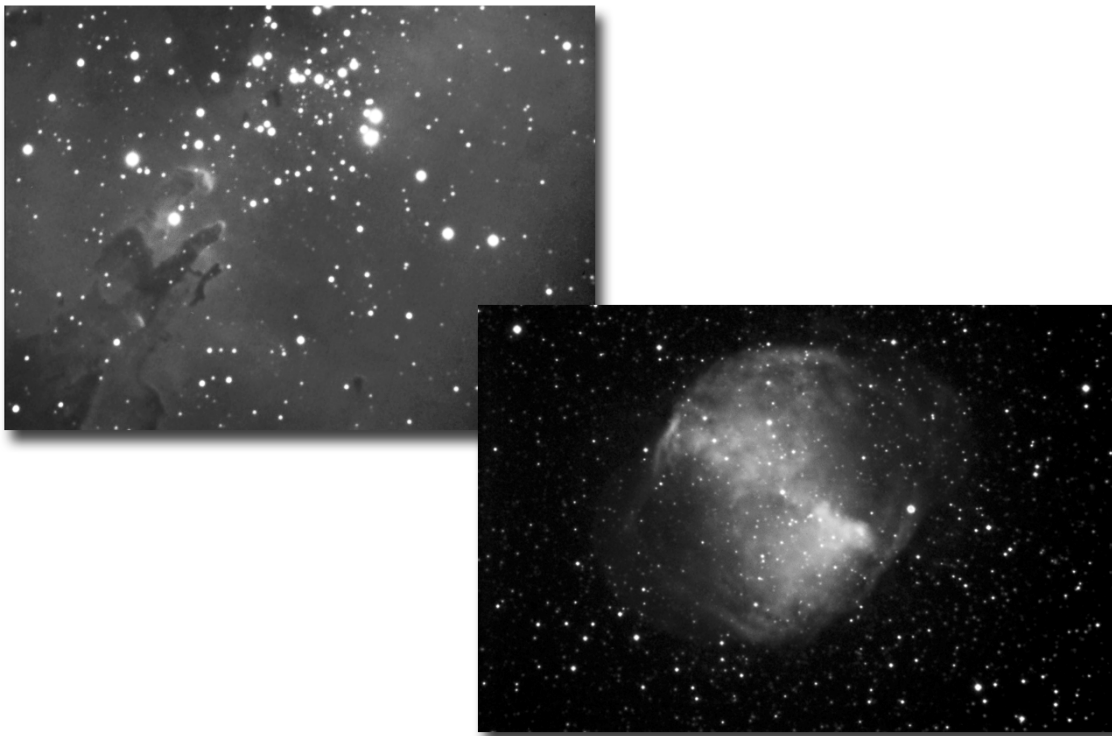


*Figure 38 - Two examples of images taken with Track and Accumulate (M16 and M27).*

> **TIP:** Short exposures may result in what is called *correlated noise* in the final image (see Figure 39). The small error from one exposure to the next causes the image to drift a bit from one exposure to the next. When Track & Accumulate combines the image, those hot and cold pixels can form lines and squiggles in the combined image. Longer exposures limit correlated noise; short exposures make it more likely. Typical exposure times for Track & Accumulate are in the range of 60-120 seconds.  Individual exposures less than 30 seconds show increased noise and correlated noise.



*Figure 39 - A Track and Accumulate image showing correlated noise from too short of an exposure time for the individual images.*

The image in Figure 39 shows the black margins that result from drift during image acquisition. This is normal. The faster your mount drifts, the larger the borders will be. A good polar alignment will assist you in getting better results with Track and Accumulate. If the polar alignment is accurate, drift will be smaller. Polar alignment and the ability of your mount to track accurately are the two key ingredients in a successful Track & Accumulate session.

## Taking Color Images with CCDOps

Color images are made up of at least three images, one for each color channel. The human eye sees millions of colors, but all those colors can be created using just three primary colors: red, green, and blue. Even film color photos use this same basic idea, with layers of chemicals that are sensitive to different wavelengths (colors) of light.

The CCDs used in SBIG cameras are sensitive to all of the colors that the human eye can see, as well as to more extreme wavelengths of light (infrared and ultra-violet). By placing filters in front of the CCD chip, you can select the color of light that reaches the chip. The CFW-8 filter wheel, for example, comes with clear, red, green, and blue filters. The simplest approach to color imaging is to take three images, one each through the red, green, and blue filters, and then combine the images into a color image in CCDOps.

The individual images do not show color—taking an image through a red filter does not yield a red-colored image. **The red-filtered image shows in up shades of gray just like any other individual image**. It is the act of combining all three images with CCDOps that yields a color image. Figure 40 shows the three images that make up a color image of M101, and the result of the combining the individual red, green, and blue

images into a color image. The color image is often referred to as an RGB image because it is made up of red, green, and blue components.
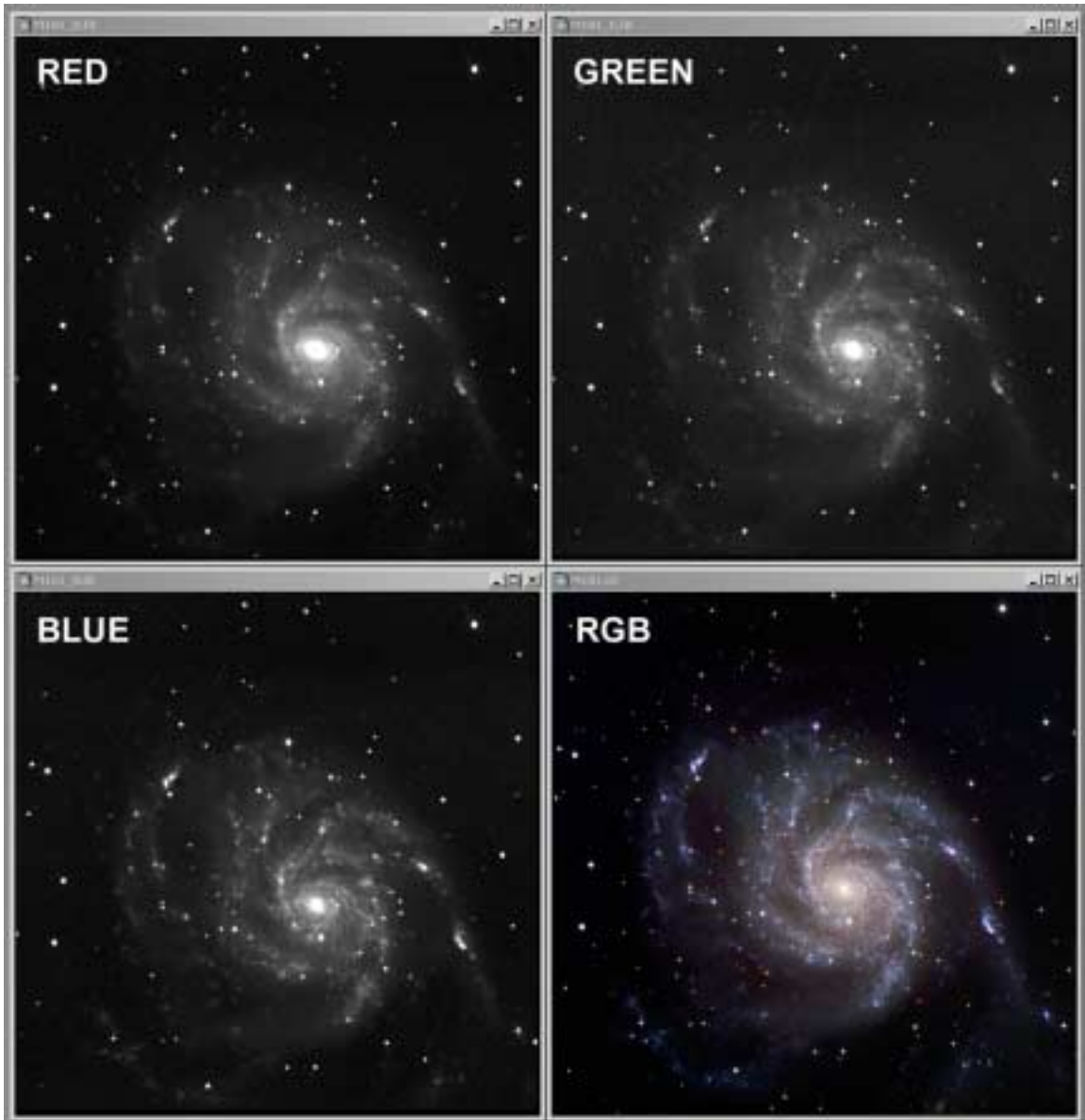


*Figure 40 - The red, green, and blue images that make up a color image appear gray prior to combining.*

CCDOps automates the taking of images through SBIG color filter wheels, such as the CFW-8. A color exposure sequence starts the same way as a normal exposure: with the Grab tool (see Figure 41). You can start a Grab using the Grab icon on the Icon toolbar, or the keystroke combination, Ctrl + G, or using the Camera | Grab menu item. The only difference is that you select "Color Grab" in the Special Processing drop-down list. Click OK to continue.
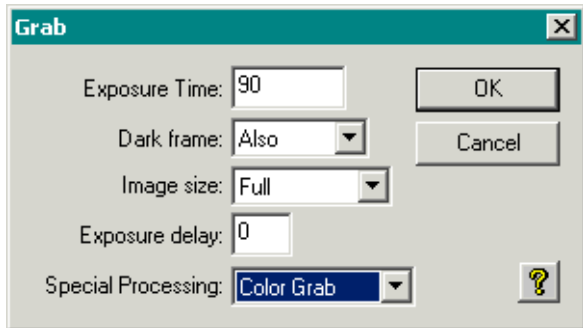
*Figure 41 - Setting up for a color grab.*

This displays the Color Grab dialog (see Figure 42). Use the settings in this dialog to control the color grab. Note that the red exposure is entered in seconds, and that the green and blue exposures are multipliers of the red exposure time. For example, if you enter 90 seconds for the red exposure time, and a green multiplier of 1.8, then the green exposure time will be 90 * 1.8 = 162 seconds.

**TIP:** The default multipliers you should use with the CFW-8 filter wheel are 1.0 for green and 1.6 for blue for the ST-7/8/9/10 and ST-1K.  For the ST-2K and the ST-L-1001 they are 0.5 for green and blue. The default multipliers for the filter wheel used in the ST-5C, STV, and ST-237 are 1.0 for green and 1.0 for blue (same exposure for all three filters). When imaging at low elevations in the sky, blue and green light are scattered more than red, and longer exposures will be required under those conditions. See **Error! Reference source not found.** for more information about his effect.
Using the same exposure for each image and adjusting the color balance later is fine. An advantage of this is you can use the same dark for each color.
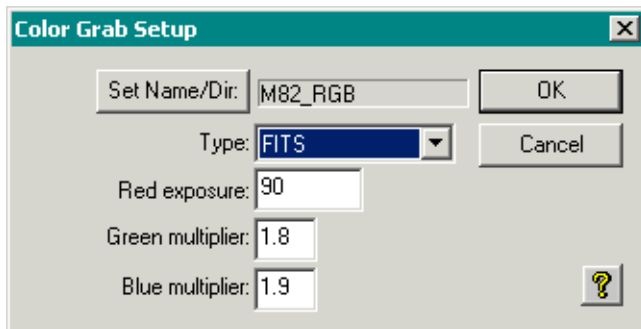


*Figure 42 - Color Grab  Setup dialog.*

**Set Name/Dir button**—Click this button and navigate to the folder where you want to save your color images (see Figure 43). Enter a filename that describes your image. In this example, the filename is M82_RGB. Click the Save button to save the filename and folder you selected.

**Type** (Compressed, uncompressed, FITS, TIFF)—Choose the file type. See the text description below Figure 32 for details on file types.

**Red Exposure**—The time, in seconds, of the red exposure.

**Green multiplier**—The amount by which the red exposure time should be multiplied to obtain the correct green exposure time.

**Blue multiplier**—The amount by which the red exposure time should be multiplied to obtain the correct blue exposure time.
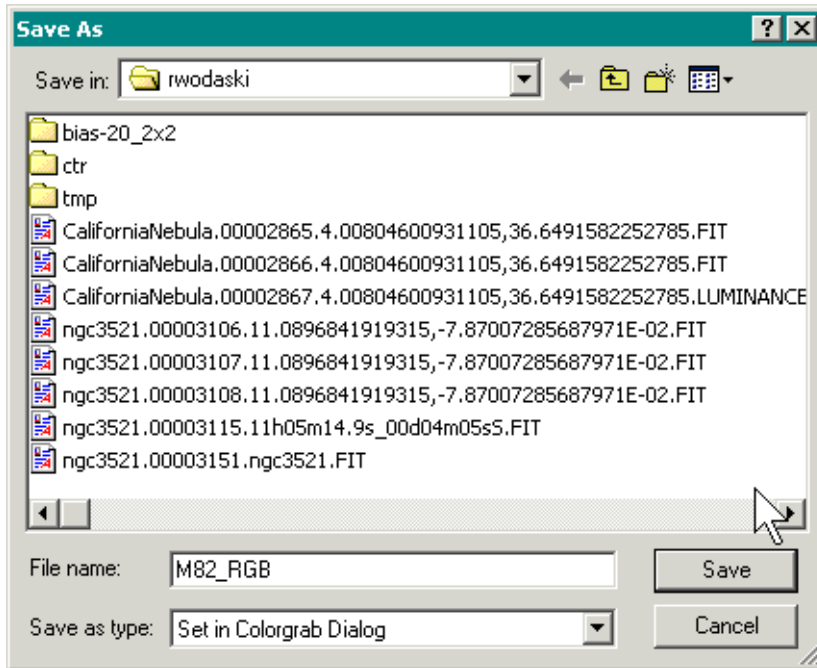
*Figure 43 - Setting the filename and save location for the color grab.*

When you have the color grab parameters set up, click OK to start the color grab. CCDOps will report the progress of the grab with a progress bar (see Figure 44, which shows a dark exposure being taken for the red-filtered image). The time of each exposure, the time remaining in the exposure, the time of dark frames, etc. will appear on the progress bar so that you can follow the color grab. The individual red, green, and blue images will be saved to the folder you chose, with the extension indicating which file belongs to which filter. For example, the blue-filtered image would have a filename of M82_RGB.B for this example.
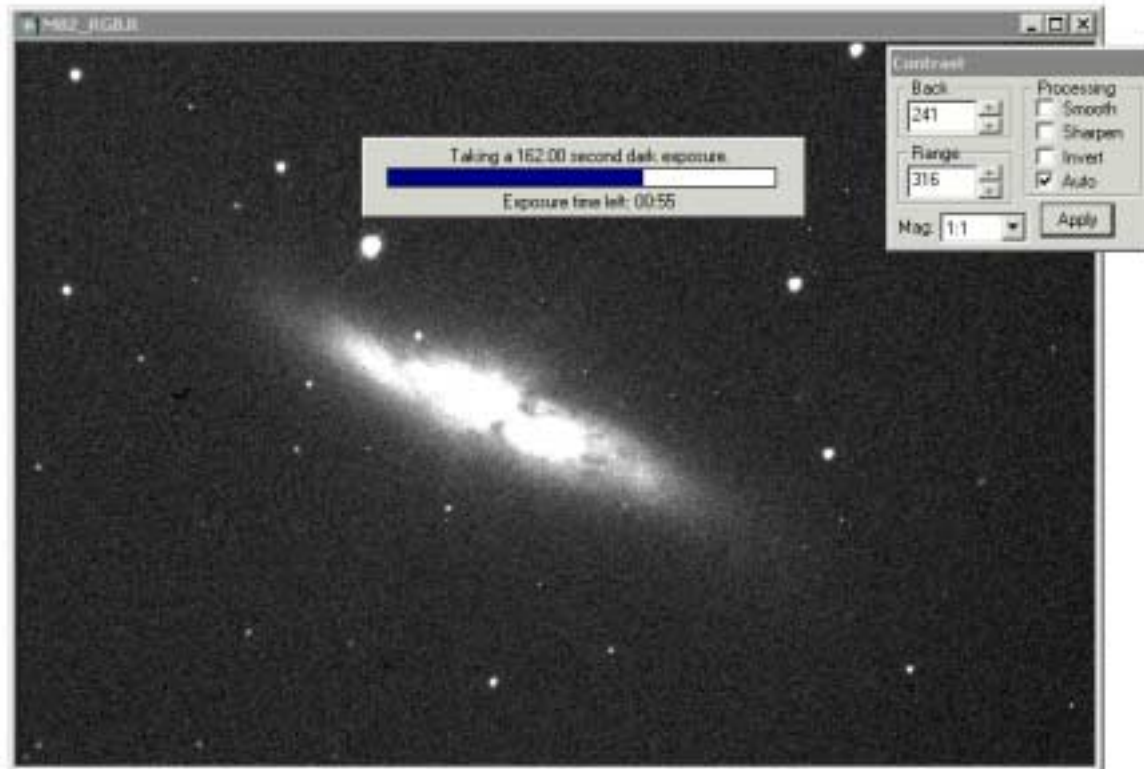
*Figure 44 - A color grab in progress. CCDOps is taking the dark frame for the green-filtered exposure.*

You will not see any color at the conclusion of the color grab. The images, taken through colored filters, are still monochrome individual images. They contain the data needed to make a color image, but do not show up in color. To see the color image, you must combine the red-, green-, and blue-filtered images using the CCDOps RGB Combine tool. See the section "Combining Color Exposures" below for details. CCDOps does not support tracking during an autograb or color grab.

## Atmospheric Extinction and Exposure Times

When you image at different elevations, you are imaging through different thicknesses of air. For example, the column of air is thinnest when imaging straight up (the zenith), and thickest when imaging near the horizon. Thicker air presents a variety of problems, including poorer seeing and some absorption of the incoming light. You can largely avoid these problems by imaging at a sky elevation of 45 degrees or higher.

If you do image at low sky elevations, the earth's atmosphere presents additional problems for color imaging. The column of air you are imaging through affects different colors of light differently. Red light, for example, has a longer wavelength and is scattered less by the air. Blue light, on the other hand, has a shorter wavelength and is therefore subject to greater scattering. This is why the sky looks blue—the blue light is scattered throughout the atmosphere.

Red, green, and blue light are scattered, but blue light is scattered the most, and red light the least. This means that as you image further away from the zenith, more total light is scattered, and more blue light is scattered than red—with green somewhere in the middle.

## Changing Filters Manually (No Filter Wheel Present)

You can also change filters manually and then use the Grab tool to take one or more images with that filter. To change a filter, use the Filter menu in CCDOps. If you have the CFW-8 or some other SBIG filter wheel installed, simply select the filter you want by name from the menu, and the filter wheel will automatically rotate to place the desired filter in the optical path. If you have a manual filter setup, a dialog box will ask you to "Please select the <color> Filter". Put the desired filter into position, and click OK.

If the names on the Filter menu do not match your setup, use the Filter | Filter Setup menu item to enter the correct filter names.

## Combining Color Exposures

Once you have taken a set of red-, green-, and blue-filtered images, use the Utility | RGB Combine menu item to create a color image (see Figure 45). Click the "Set Name" button for the red channel to load the red-filtered image (M82_RGB.R in this example). If you used CCDOps to take the images, the filenames will be the same with different extensions for each color, and the set of three images will be loaded automatically.
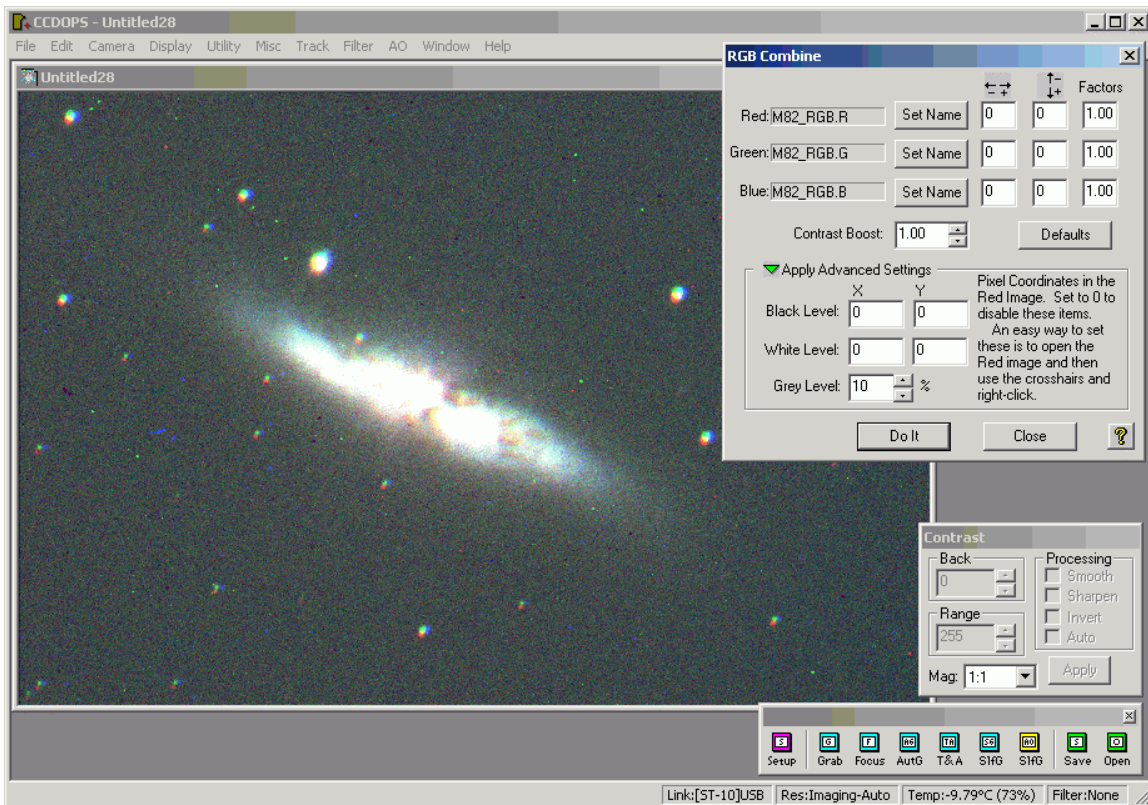


*Figure 45 - Loading RGB images using the RGB Combine dialog.*

**TIP:** If you used CCDOps to capture the color images, loading the R image will automatically load the G and B images as well.

In Figure 45, all three images have already been loaded. Note that the color images do not line up exactly. The star right of center shows this most clearly (see Figure 46 for an enlarged view). You will use the two columns of boxes to the right of the Set Name buttons to shift the color images relative to each other to line up the images.

If you don't see the advanced settings shown in Figure 45, click the little green arrow to open the advanced settings area.
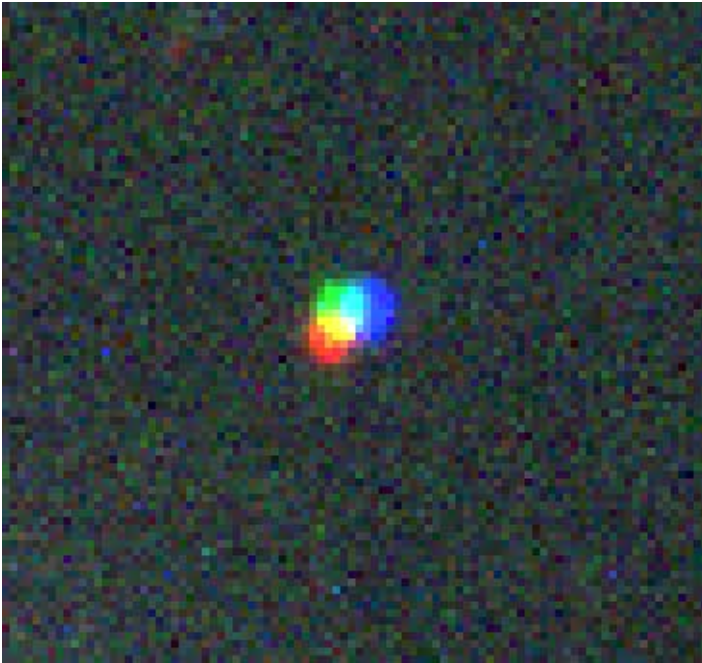


*Figure 46 - The color channels are not aligned.*

In this example, the green image is between the red and blue images, so we will shift the red and blue images to line them up with the green image.

**TIP:** Click the Do It button to apply your settings. If you don't like what you see, adjust the settings and click the Do It button again to see the results of the changes.

There is another issue with the image in Figure 45: the center of the galaxy is washed out. You will use the Contrast Boost setting to adjust the overall brightness of the image to show details in the core of the galaxy.

Increasing the Contrast Boost makes the image brighter. Decreasing it makes the image darker. Figure 47 shows the effect of setting Contrast Boost to 0.50. The overall image is now darker, and the core of the galaxy is better. Small portions of the core are still washed out, however. Lowering the Contrast Boost to 0.35 yields a good result (see Figure 48).

**NOTE**: When CCDOps first does a color combine it uses the background and range values saved with each image to scale each color to 256 shades of "gray".  You should save each file with an attractive looking contrast setting to simplify the color balance process.
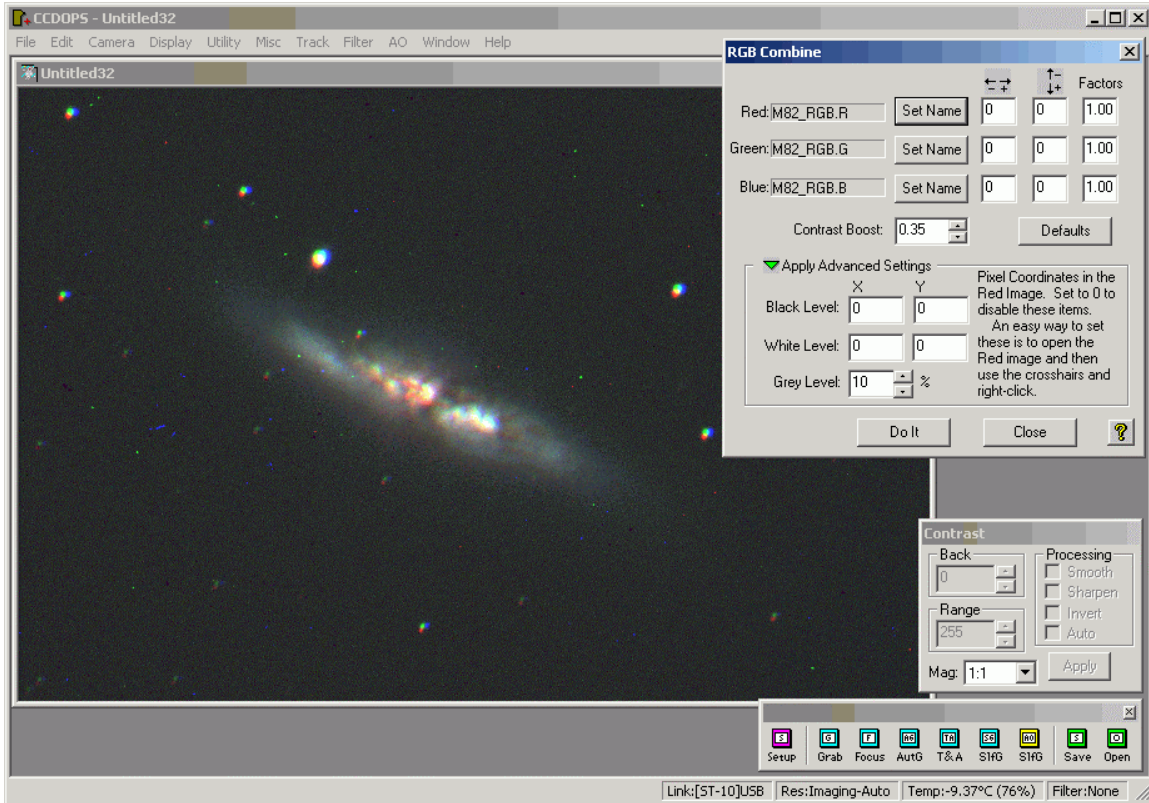
*Figure 47 - Adjusting the Contrast Boost to darken the image and show more of the core.*

Now let's use the alignment columns to line up the images. The same star at right of center is a good one to watch while performing an alignment. The column immediately right of the Set Name buttons adjusts the horizontal alignment, and the next column adjusts the vertical alignment. We'll need some of both for this example. The numbers in the boxes indicate the number of pixels to shift each color image.

Figure 48 shows the adjustments required for the image of M82. The red channel is moved 1 pixel right, and four pixels up. The blue channel is shifted three pixels left. The Contrast Boost has been lowered a bit more, to 0.30. Click the Do It button to apply your changes. If the changes are not quite right, adjust them, and click the Do It button again.

**TIP:** The arrows above each column tell you which direction positive and negative numbers will shift the alignment.
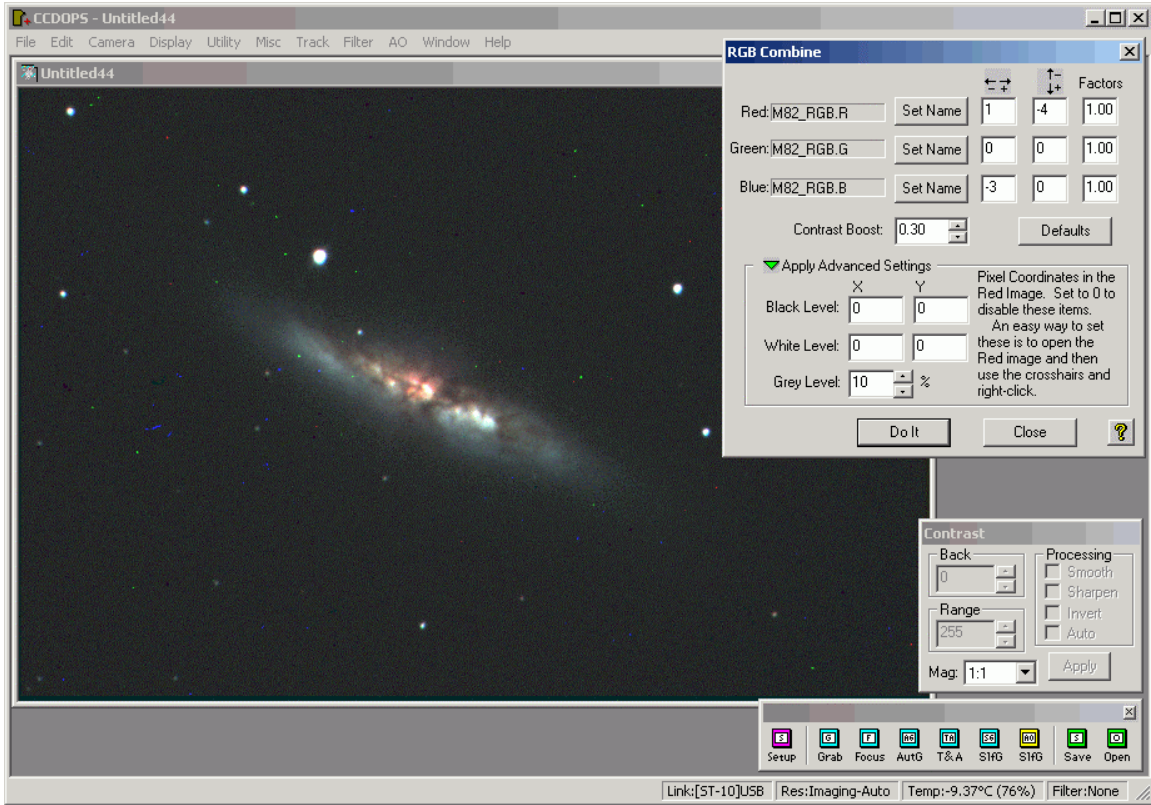
*Figure 48 - Aligning the color images.*
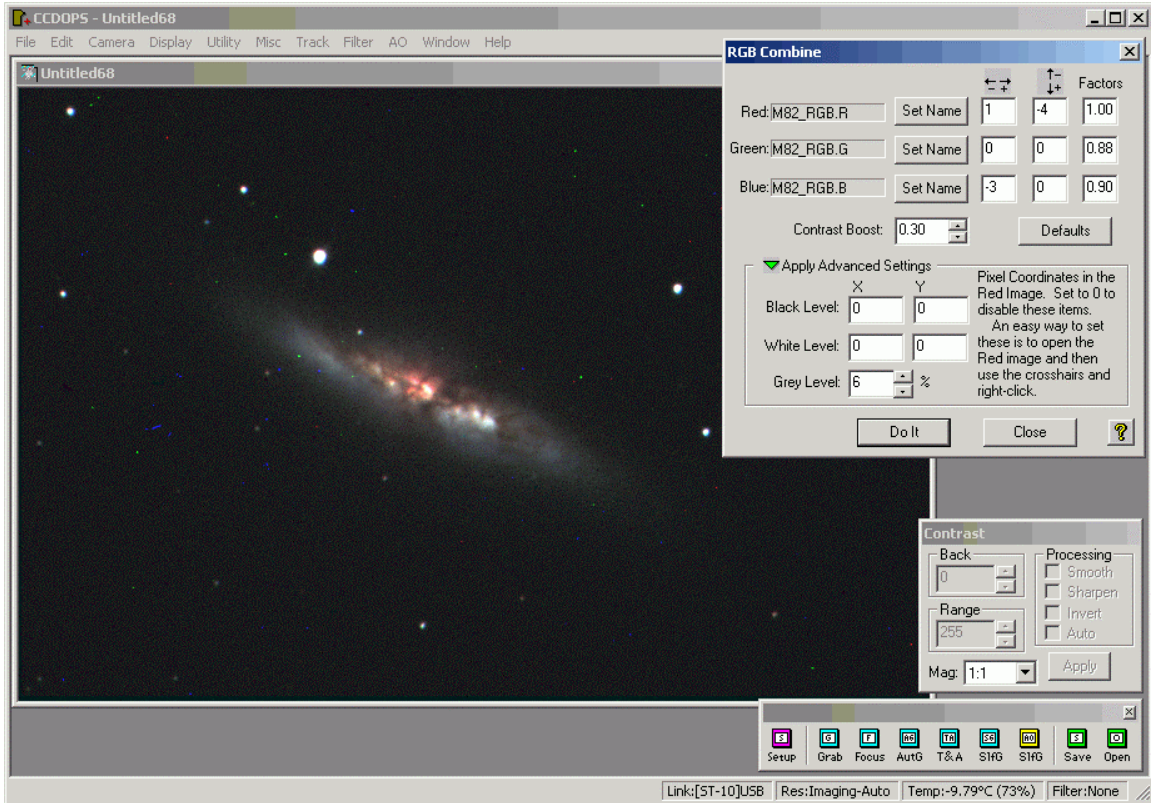


*Figure 49 - Fine-tuning color balance.*

The images are aligned, the core details can now be seen, but the color balance is slightly off. The image has a little too much green and blue relative to red. You can balance color by changing the Factors for the individual colors. For this example, red remains at 1.00, green is reduced to 0.88, and blue is reduced to 0.90. These values are determined by trial and error until correct color balance is achieved.

If desired, you can make additional changes to the image in an image editing program such as Photoshop, Picture Window Pro, etc.

**Note:** When saving color images, you can only save as a TIFF image. The compressed, uncompressed, and FITS images do not support combined RGB images.

### Using Advanced Settings

The advanced settings allow you to set black and white levels for the final color image. Before you do the color combine, open the Red image using the File | Open menu item. Right click on the image and choose the Show Crosshairs menu item. This opens the crosshairs dialog (see Figure 50).

To set the black level, right-click in the background of the image and choose the Set RGB Black Level menu item. CCDOps will remember this value in the color combine.

To set the white point, right-click a bright area or star (but not saturated) and choose Set RGB White Level.

When you start the color combine, the red image and the crosshairs will automatically be closed for you.
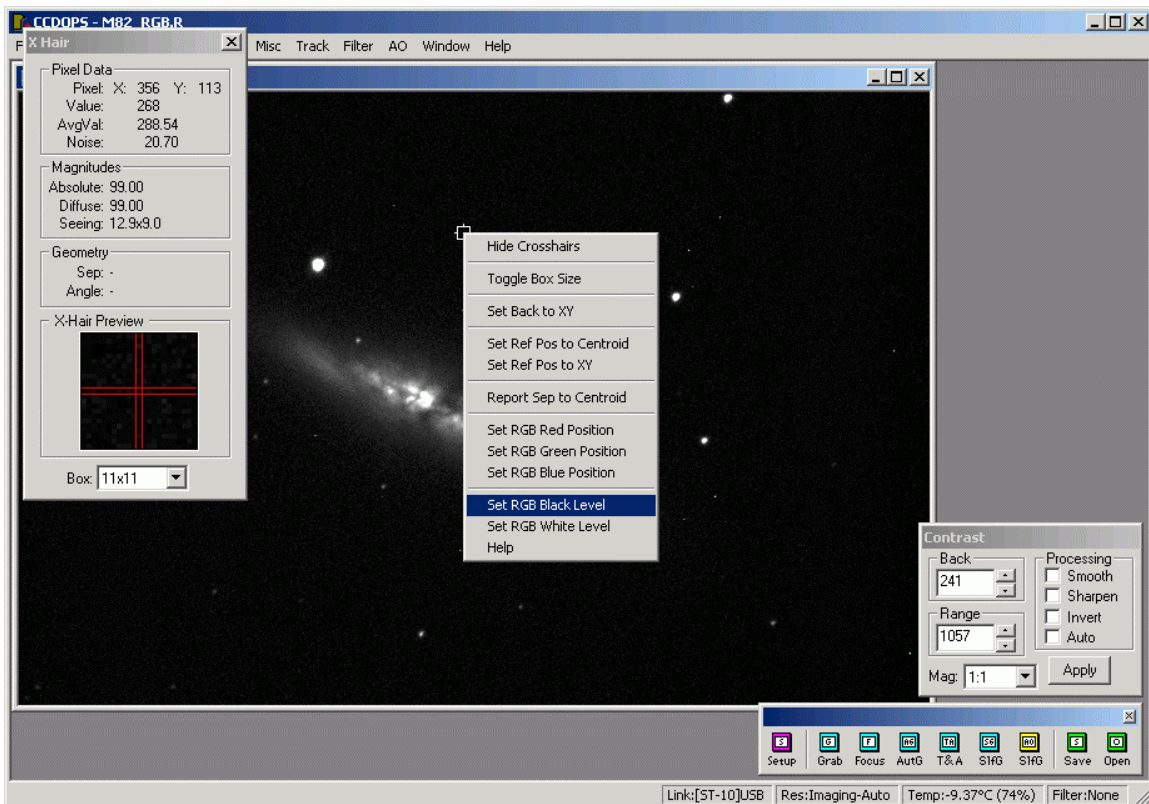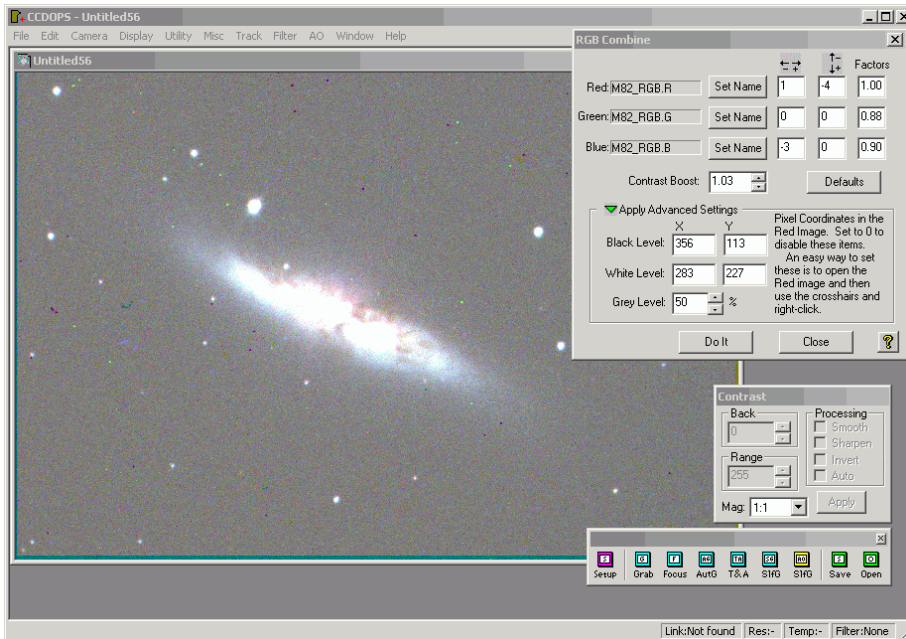


*Figure 50 - Setting the black level prior to a color combine.*
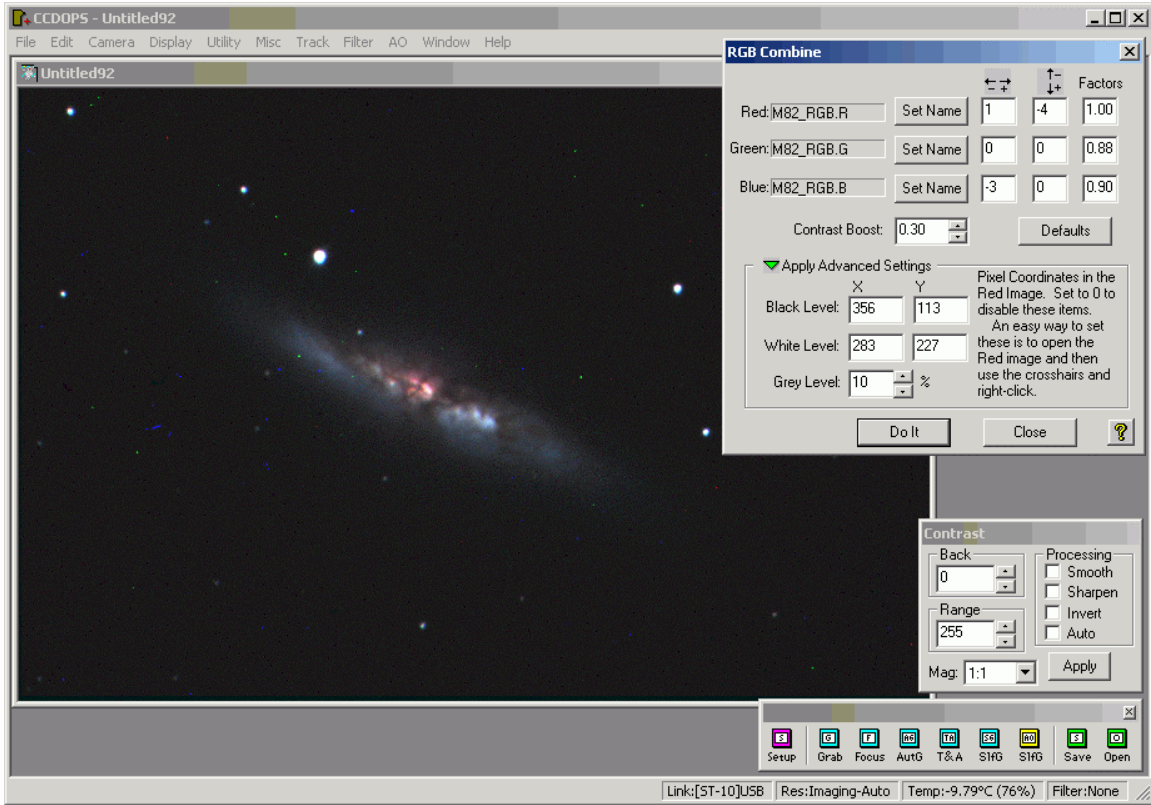
*Figure 51 - The result of setting black and white levels.*

If the image is too bright or too dark, you can adjust the black level and the white level interactively using the RGB Combine dialog. The Gray Level setting adjusts the black level, and the Contrast Boost setting adjusts the white level.



*Figure 52 - An image with a high black level and a low white level.*

For example, the image in Figure 52 has a black level that is too high. With a Gray Level of 50%, the background is gray, instead of dark. A Contrast Boost setting of 1.03 results in a white level that is too low (bright details are washed out).

In figure 53, the black level has been adjusted by setting the Gray Level to 20%. In figure 54, the white level has been adjusted by setting the Contrast Boost to 40%.
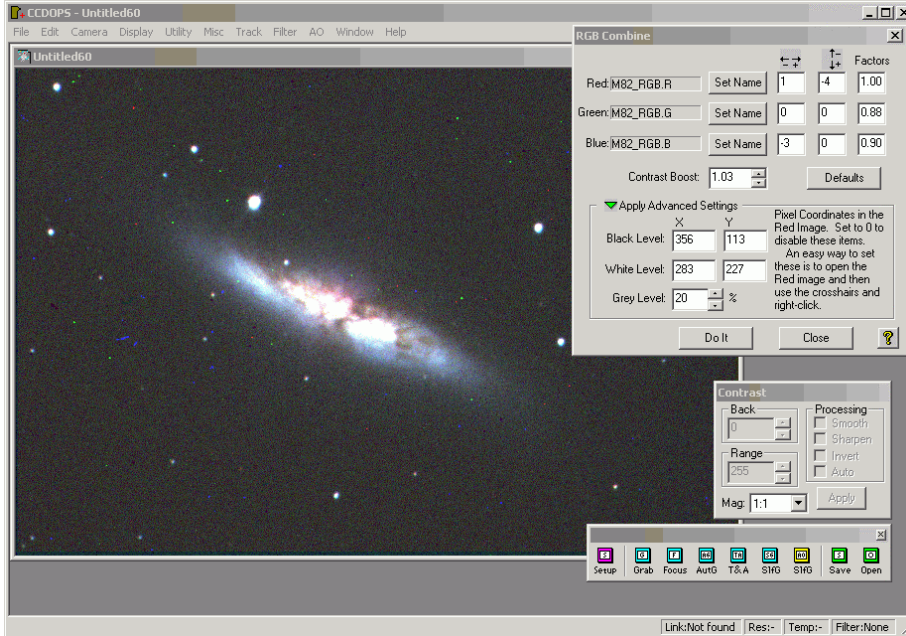


*Figure 53 - Lowering the Gray Level also lowers the black level.*
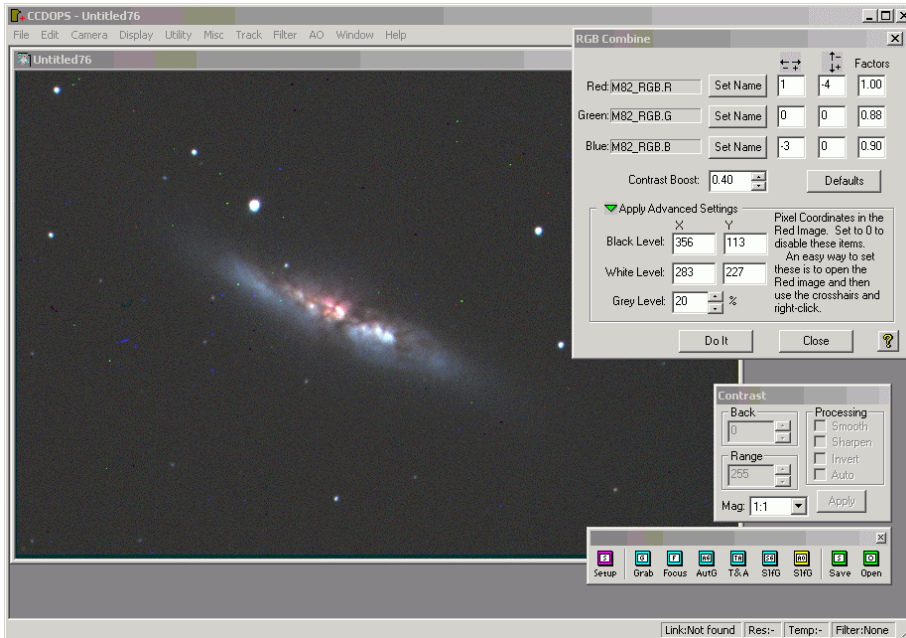


*Figure 54 - Lowering the Contrast Boost raises the white level, and improves the appearance of the image.*

**TIP:** The Contrast Boost raises and lowers the white level for all three colors at the same time. Use the Factors to change the white level of one color at a time for color balance.

## *Shutting Down the Camera*

When you are done working with the camera, there isn't a switch on the camera to turn it off. The shutdown procedure, however, is still fairly simple:

- Use the Camera | Shutdown menu item to disconnect the camera from CCDOps. As a side benefit, CCDOps triggers an internal warm-up procedure in the camera. This prevents overly rapid warming of the CCD chip. The chip is not likely to be harmed if it warms up suddenly, for example in a power failure. Slow warm-up, however, places less stress on the chip.

- Disconnect the power cable from the camera. If the camera is plugged into a power strip that has a switch, you can also cut power using the switch on the power strip.

**TIP:** If you are disconnecting the power cable, pay attention to the order in which you connect cables the next time you use the camera. If the computer is already running, connect the USB cable first and the power cable second. This allows the camera's USB boot-up procedure to execute correctly.

## *Using Planet Master*

Planet Master allows you to take continuous images and evaluate them for sharpness and quality. Only the best image is retained for saving to the hard disk. While designed for planetary imaging, where sharpness is at a premium, you can also use Planet Master to take images of other bright objects, such as the moon and even globular clusters.

Use Planet Master for interactively taking planetary images. If you already have images and want to evaluate them for sharpness, use the Utility | Grade Images by Sharpness menu item. See section "Evaluating Existing Images for Sharpness" for information about this feature.

### Taking Images with Planet Master

Some imaging targets place a higher premium on sharpness. Planets are in this group. While a large target like M8 or M42 can provide pleasing results on a night of average seeing, images of the sun, moon, and planets benefit greatly from excellent seeing conditions.

Long periods of exceptional seeing are rare, so Planet Master was devised to take advantage of the fact that seeing can improve over very short time scales. Even on nights when the seeing is only average, there will sometimes be brief moments when the seeing is better than average. By taking short exposures, you can take advantage of these brief windows of improved seeing. They do not occur on every night, but when they exist Planet Master gives you the ability to take advantage of these brief improvements.

Planet Master takes a series of images. During the sequence, Planet Master displays the current image and the best image side by side so you can see the results (see Figure 55).
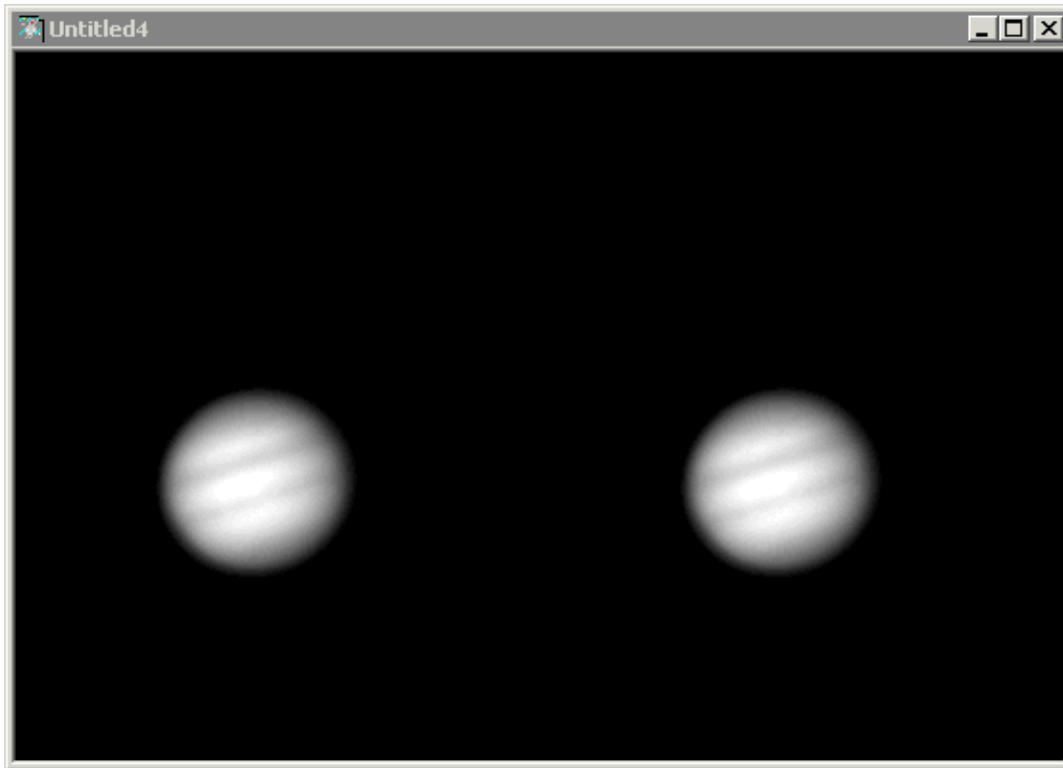
*Figure 55 - Planet Master displays the current and best images side by side.*

As each image is taken, Planet Master evaluates the image quality using a variety of criteria. This establishes a figure of merit (FOM) for each image. The FOM is a single number that describes the overall quality of the image. The larger the FOM, the better the image quality. At the end of the sequence, Planet Master keeps the image with the highest FOM value for you to save to the hard disk.

To run Planet Master, use the Camera | Planet Master menu item. This displays the dialog shown in Figure 56.
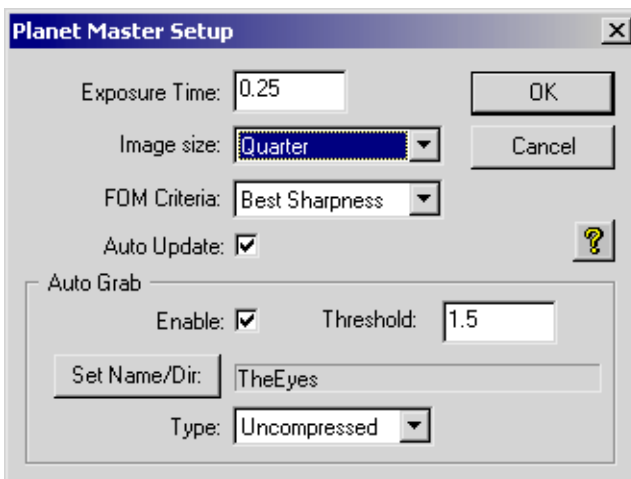


*Figure 56 - The Planet Master Setup dialog.*

The Planet Master Setup dialog has two sections. Basic setup options are located at the top, and a separate Auto Grab section allows you to capture a sequence of images to disk based on the FOM (figure of merit) of each image.

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**Exposure Time**—The length of the exposure, in seconds. Shorter exposures are best, and the exposure time should always be short enough to prevent saturation. If the shortest possible exposure is not short enough, you can use a Barlow lens to magnify the image. This effectively increases the focal length of your telescope, which raises the focal ratio and changes the exposure requirements. For example, an f/10 telescope with a 2X Barlow becomes an f/20 telescope. The image at f/20 will be less bright. Soemtimes a filter is necessary to reduce the brightness further.

**Image Size** (Full, Half, Quarter)—If you are imaging a planet, you can use the Quarter option to capture just the central quarter of the CCD chip. This allows faster downloads and more frequent updates. If your telescope does not track well enough to use the Quarter setting, or if the planet's moons are widely separated, you can use the Half or Full settings as required.

**FOM Criteria** (Best Sharpness, Peak Brightness)—The Best Sharpness option evaluates the image based on image contrast and other factors. This option is ideal for planets, the moon, and the sun. These are not point sources, and the sharpness of the image is the best method for evaluating image quality. If you are imaging point sources (such as a star cluster or double star), the Peak Brightness setting is more appropriate.

**Auto Update checkbox**—When checked, does not pause between images. When unchecked, you will have to click the Resume button to take the next image.

The Auto Grab section controls whether and how Planet Master captures images to the hard disk. If Auto Grab is not enabled, you will need to use the File | Save As menu item to save the single image at the end of the Planet Master session.

**Enable**—When checked, images that meet the Threshold requirement are automatically saved to disk. Even if no images meet the Threshold requirement, Planet Master will operate normally—the best image will still be available for saving at the end of the session.

**Threshold**—Minimum FOM (figure of merit) for saving to disk. You should run Planet Master without Auto Grab first to determine the Threshold setting to use for best results.

**Set Name/Dir button**—Click to set the base filename and the folder for saving images.

**Type** (Compressed, uncompressed, FITS, TIFF)—The type of file that is saved. See the text near Figure 32 for information about the file types.

As Planet Master takes images, you will see the dialog shown in Figure 57.
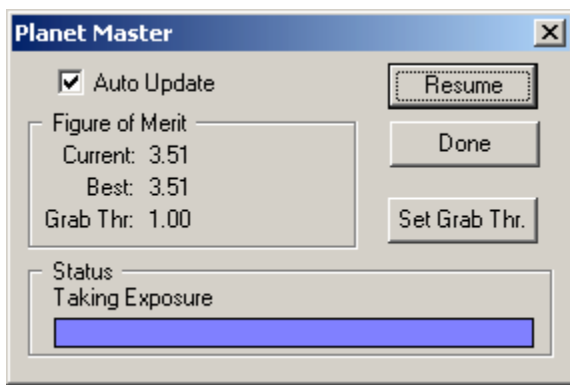


*Figure 57 - The Planet Master progress dialog.*

**Auto Update checkbox**—To start or stop automatic update, check this box and then click the Resume button.

**Pause/Resume button**—If Auto Update is on and active, or if an image is currently being acquired/evaluated, this will be the Pause button. Click it to pause acquisition. If Auto Update is off, and no image is being acquired, this will be the Resume button. Click it to take the next image.

**Set Grab Thr. button**—When the auto-grab feature is enabled clicking this button sets the Grab Threshold to the current FOM.

**Done button**—Click this button when you have acquired the desired number of images or the final image is of sufficient FOM.

**Figure of Merit** (current and best)—This area will display the FOM of the current image and of the best image so far and if Auto Grab is enabled it shows the current threshold for saving images.

**Status**—Displays text and a progress bar indicating the current state of the session.

When done, the image with best FOM is displayed. If Auto Grab was enabled, all images with a FOM greater than or equal to the Threshold setting will be saved to the folder you selected using the base name you supplied.

## Evaluating Existing Images for Sharpness

Planet Master evaluates images in real time as they are taken. You can also evaluate images that you have already taken and saved to disk. Use the Utility | Grade Images for Sharpness menu item to start the process. This opens a dialog that asks you to select the images you want to grade for sharpness (see Figure 58). You can use Shift + left click to select a range of images, or Ctrl + left click to add images one at a time. The simplest approach to use is to copy the images you want to grade into a folder, and then use Ctrl + A to select all of the images in the folder. Click the Open button to open the files and start the evaluation.
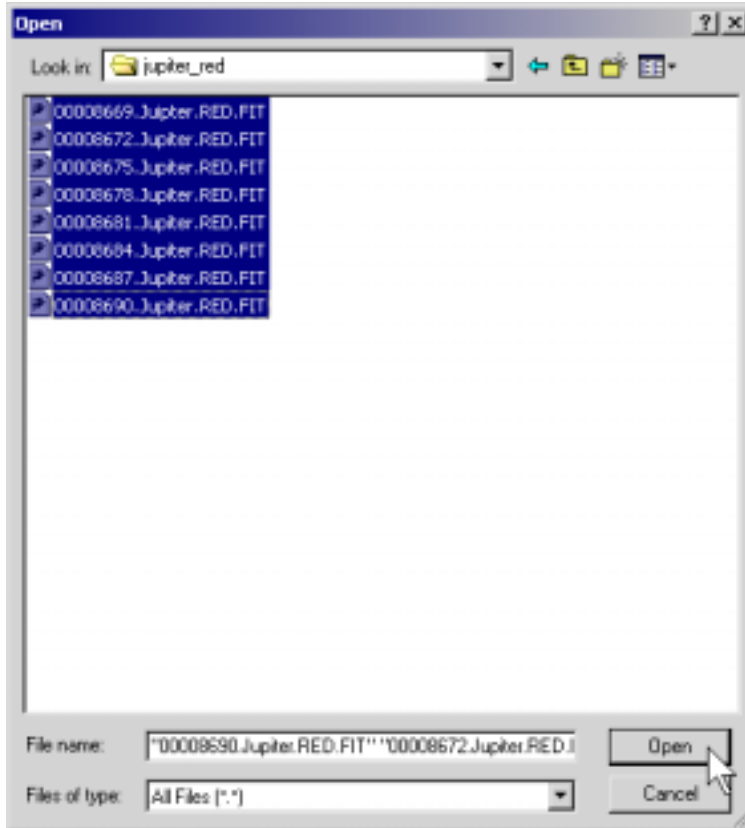
*Figure 58 - Grading images for sharpness.*

You will see various progress messages as the files are opened and graded with a figure of merit (FOM). When the process is complete, CCDOps displays a dialog with the results (see Figure 59). Click the Save button to save the results to disk as a text file. The text file will contain the exact same information as the dialog. The very best image is listed at the top of the file, and all images are listed with their FOM in the remainder of the file.
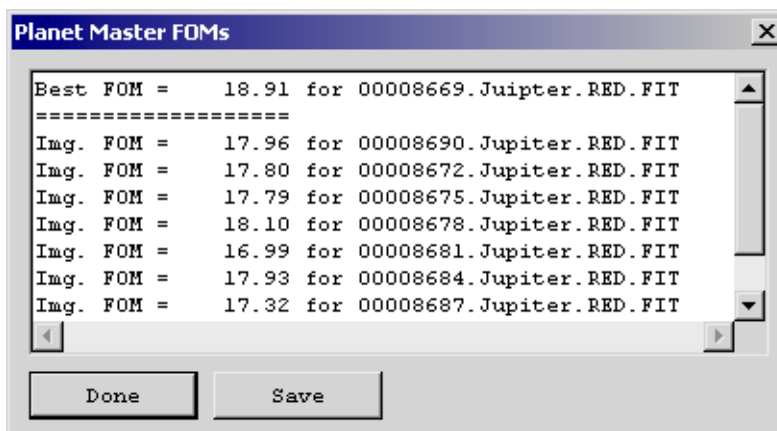


*Figure 59 - Grading images for sharpness.*

# 3 Guiding with CCDOps

Guiding is the process of taking CCD images, measuring the movement of a guide star, and then adjusting the position of the mount based on the movement of the guide star. CCDOps offers two ways to guide exposures:

**Selfguiding**—Many SBIG cameras include two CCD chips. One is for imaging, and the other is for guiding. In Selfguiding mode, the two chips are imaging at the same time. The imaging chip is taking the main image, and the guiding chip is taking a series of guide exposures. The guide exposures are used to maintain accurate pointing.

**Autoguiding**—All SBIG cameras can also be used as autoguiders. An autoguider is a CCD camera that performs automated guiding while a film or second CCD camera takes an image.

**Note:** You must calibrate your mount before you can guide. See the section "Calibrating your mount" to learn more.

## Guiding Performance

Guiding is not just a simple process of turning on one of the guiding modes and getting great results. The accuracy of your guiding will be determined by the physical characteristics of your mount, the focal length of your telescope, the pixel size of your guiding and imaging CCD chips, and other factors. Please read this section on guide performance before you try your first guiding session.

The process of guiding a telescope mount requires a great deal of precision. Consider what has to happen when you are guiding a typical 8" SCT with an ST-7XE camera. Each pixel on the imaging CCD chip "sees" a small area of sky. In the case of an ST-7XE and an 8" SCT, this is a square about 0.9 arcseconds on a side. An arcsecond is an exceptionally small unit - the size of a penny 2.4 miles away.

When guiding, the goal is to avoid errors above the size of what a single pixel sees. This means that guiding corrections must be very small, and very accurate.

A guiding correction occurs when the image of a guide star wanders from its original position. CCDOps takes a series of guide exposures during the imaging exposure. Typical imaging exposures range from about 15 seconds to many minutes. Guide exposures are usually much shorter, from a fraction of a second up to about 15 seconds, though shorter and longer guide exposures are possible with some types of equipment.

The following general rules apply to the process of guiding:

- **Not all mounts will be up to the task of accurate guiding.** To guide accurately, a mount must be designed and manufactured to a certain degree of accuracy. If you are not getting the accuracy you believe the mount is capable of, the mount may require adjustments and tuning so that it can reach the level of accuracy that it was designed for.

- **Each mount has a maximum level of accuracy that it can reach.** Attempts to guide beyond this level of accuracy will not be successful. If you are beyond the accuracy limits of a mount, using a lighter/shorter telescope may help. The best solution is often simply to work at a shorter focal length. Focal reducers, or a different telescope, can accomplish this goal.

- **Small things can make a big difference when guiding.** For example, if the load on your mount isn't correctly balanced, guiding may be less effective. The best balance is to have a slight excess of weight on the east side of the mount. This will keep the gears engaged and smooth out guiding corrections.

- **Rapid errors are a much more serious problem than slow errors.** Every mount has at least a small amount of tracking error. There are two types of tracking error: periodic error, and random error. Periodic error results from slightly (or not so slightly) out-of-round gears. All gears have at least an arcsecond or two of error. Some gears have 10, 20, 30 or more arcseconds of error. (Some mounts have periodic error correction which, if effective, will reduce the size of total error.) A problem occurs if the periodic or random errors occur quickly. For example, if an error of 5 arcseconds occurs in one second, and your guiding exposures are three seconds long, then the mount can move a long distance before the guiding correction occurs. This will create trailed stars in your images. The solution is to look for grit or filings in the gears, to use periodic error correction if available, or to have the gears repaired or replaced if they are faulty.

If you experience problems while guiding, keep in mind that you will probably need to troubleshoot your hardware first and your technique second. If possible, assess the guide performance of your mount with respect to adjustments and tuning before you do your first guiding sessions. Some things to check:

- **How much backlash is there in each axis?** You can roughly determine backlash by grasping the telescope and gently rocking it back and forth around a given axis. If you can feel movement, or hear clicking, then backlash exists. The larger the backlash, the more limiting it is going to be with respect to guiding. Backlash is mostly an issue in Declination. The RA axis is moving at the sidereal rate, so guide corrections result in speeding up or slowing down, not a complete stop. Backlash only occurs when reversing directions. If Dec backlash is excessive and cannot be reduced, you can determine the direction in which Dec guide corrections are required, and switch off corrections in the other direction. Consult your mount's manual to find out if this feature is available.

- **Looseness may be end play, not backlash.** Most mounts use a worm and gear to track across the sky. The worm rotates between two end blocks. If one or both end blocks are loose or out of adjustment, the worm can shift back and forth. This can cause a variety of guiding problems, and must be fixed before you can guide successfully. It's not simple to tell the difference between end play and backlash unless you can actually see the worm. Contact your dealer or manufacturer if you suspect end play problems.

- **The tracking accuracy of your mount affects guiding.** If your mount has large or rapid errors when tracking, guiding has to compensate for these errors. If the errors are too large or too fast, guiding will not be able to compensate effectively. The longer the focal length of your telescope, the more likely you are to run into these kinds of problems. The solution is to image at a shorter focal length.

- **Accurate polar alignment of your mount makes guiding easier.** If your mount is not accurately polar aligned, drift will occur more quickly, and guiding will have to make larger adjustments to keep up. Generally speaking, anything you can do to reduce the size of the required guide corrections will improve the accuracy of guiding. A polar alignment error of less than 2 arcminutes is ideal, but alignment errors of 5-10 arcminutes *may* be tolerated if your mount's physical adjustments, tuning, and periodic error are all set optimally.

The above suggestions may sound like a lot, but in practice you only need to adjust and tune your mount once per year, perhaps less if you have a permanent setup. A little time spent in optimizing the physical performance of your mount will reward you with increased guiding accuracy and beautiful images.

## *Calibrating Your Mount*

Mount calibration is a necessary step before you can use either the autoguiding or selfguiding features of CDDOPS. During calibration, CCDOps moves the mount in different directions and takes images to measure how far the mount moves in a fixed amount of time. This tells CCDOps the speed of the mount in pixels per second, and allows it to make accurate guide corrections.

**Note:** If your mount has a large amount of backlash (see the section "Calibrating Your Mount" for details), accurate calibration difficult. You'll need to adjust the mount's gears properly before you can calibrate. Calibration measures mount movement, and the mount does not move until backlash is taken up. This creates a false value for movement in at least one direction. Minimizing backlash is an important part of routine mount maintenance.

Prior to starting calibration, please do the following:

- **Install the guide cable between the camera and the mount.** The cable you use, and how you connect it, will vary with the mount and the camera accessories you have installed.

- **Set your guiding speed.** This is normally some fraction of the sidereal rate. For most mounts, a speed of 0.5X sidereal is a good place to start. You can adjust the speed up or down as you learn more about how your mount behaves while guiding. The method you use for setting guide speed depends on your mount or the software you use to control it. Check you mount/software documentation for speed-setting procedures.

- **Activate the guide rate.** Some mounts automatically move at guide rate, and some mounts require you to activate a guide mode (using software or the mount's hand paddle). The method you use for this varies from mount to mount.

- **Center a bright but unsaturated star in the field of view.** The star should be significantly brighter than any surrounding stars, so that CCDOps can tell clearly which star is the calibration star. Avoid double stars. Use Table 2 to determine the saturation level for your camera if you are calibrating the image chip. Use Table 3 to determine saturation level if you are calibrating using the guide chip. Adjust the exposure time to make sure the calibration star is bright enough but still unsaturated. A exposure time that results in a brightness level between 10% and 75% of saturation is ideal for calibration.

**Tip:** It is usually easier to calibrate with a star on the imaging CCD so you can take longer moves and reduce the errors caused by mount backlash.

To begin a calibration session, use the Track | Calibrate menu item. This opens the dialog shown in Figure 60.
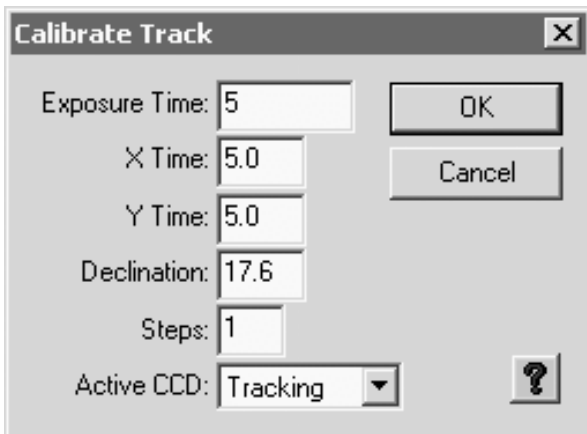


*Figure 60 - Starting mount calibration.*

**Note:** Make sure that you set your mount to guiding speed before calibration. Consult the manual for your mount to find out how to set this speed. If you have the option of setting different guide speeds, start with a speed of 0.5X sidereal. You can increase or decrease guide speed if the default does not give satisfactory results.

**Exposure time**—The length of the calibration exposure, in seconds. Adjust the exposure time so that the star brightness is in the range of 10-75% of the saturation level of the guide chip. See Table 3 for saturation levels for the two guide chips that have been used in SBIG CCD cameras.

**X Time**—How long to move the mount in the X axis (Right Ascension) for calibration. This time varies with the focal length of your telescope. Use a longer X time for a short focal length, and shorter X time for longer focal lengths. See the section "Calculating calibration time" for suggestions.

**Y Time**—How long to move the mount in the Y axis (Declination) for calibration. For both X and Y times, you should use a time that results in a move of at least 10 pixels, but a larger move will be more accurate. 100 pixels is definitely better!

**Declination**—The approximate declination of the telescope during the calibration. This allows CCDOps to scale the results of calibration when you move the telescope to other parts of the sky. If you plan to calibrate for every position you slew to, set declination to zero.

**Steps**—For most users, leave this set to 1. If your mount moves at different speeds for long and short corrections, increase the number of steps so that calibration occurs in small steps. Guide corrections occur in small steps, and you can use a larger step number to force small steps during calibration. Most mounts do not have this problem, and you should only change the steps if you have problems related to varying speeds in long and short moves.

**Active CCD** (Imaging, Tracking)—Choose the CCD chip you want to use for autoguiding or selfguiding. If you are selfguiding (taking an image while guiding), you will almost always use the Tracking chip for guiding and the imaging chip for taking the image. However, it is often easier to calibrate using the image CCD. CCDOps will automatically correct for any pixel size difference between the image chip and the tracking chip.

### Table 3 - Guide Chip Saturation Levels

| Guide Chip | Approximate Saturation Level |
|---|---|
| TC-2ll | 65,000 |
| TC-237 | 65,000 |

Click OK to start calibration. During calibration, CCDOps moves the mount at guiding speed in four directions—up/down (Y) and left/right (X). After each move, CCDOps takes an exposure and measures the shift in the position of the calibration star. The calibration star is always assumed to be the brightest star in the image. That is why it is important to use a calibration star that is brighter than any of the surrounding stars—you do not want CCDOps to get confused about which star is the calibration star. CCDOps displays the results of the calibration in the format shown in Figure 61.



**Calibration Results**

┌─ Star Positions ────────────────────────────────────────
Initially:Star at pixel    344.27,   207.28 with brightness 1701
+X Relay :Star at pixel    426.00,   209.29 with brightness 1492
-X Relay :Star at pixel    340.85,   206.58 with brightness 1687
+Y Relay :Star at pixel    335.16,   299.18 with brightness 1759
-Y Relay :Star at pixel    336.59,   208.44 with brightness 1537

┌─ Calibration Results ─────────────────
+X Relay : Speed = 16.35 at  89 degrees
-X Relay : Speed = 17.04 at 268 degrees
+Y Relay : Speed = 18.55 at 356 degrees
-Y Relay : Speed = 18.15 at 179 degrees

Copy to Clipboard          OK

*Figure 61 - Calibration results.*

If the star brightness changes dramatically from one move to the next, CCDOps may have locked onto a different star instead of the desired calibration star. It's also possible that clouds or seeing could cause large variations in brightness.

In Figure 61, note that after each move the coordinates of the calibration star change in a methodical way. The calibration star is at 344,207 initially. After the first move, it is at 426, 209. There is a large change in X, and a very small change in Y. This indicates that the camera is almost exactly square to the RA/Dec axes, and this is validated by the vectors in the small box at bottom right. This box shows the actual X and Y move directions for the current camera rotation. After the second move, the calibration star is close to the initial position in both X and Y (340,206).

**Note:** If your mount has significant backlash, the star may not move back to the original position. If the difference is less than 25% of the total distance moved, you may still get adequate guiding. If backlash is excessive, you may not be able to calibrate or guide. Consult your mount's documentation or contact the manufacturer for information on how to reduce or compensate for backlash. Be very careful never to overcompensate for backlash; this will create a sudden jump when the corrections reverse direction, which will ruin your images.  If your mount has backlash correction, start out with this feature disabled.

## *Autoguiding and Self Guiding*

**Note:** Before you can autoguide or self guide, you must calibrate your mount so CCDOps knows how fast the mount moves. Please see the earlier section, "Calibrate Your Mount." Also make sure that your have set your mount to move at guide speed before autoguiding.

Autoguiding and Selfguiding are similar in function, but have very different purposes. When you guide using either method, the camera takes images and tracks a guide star, making corrections to the pointing of the mount. Autoguiding involves using the camera to guide automatically while you image with another camera (film or CCD). Selfguiding involves using a secondary (tracking) chip found in most SBIG camera to guide while you image with the primary (imaging) chip. Selfguiding also applies to the external guider available as an option with the ST-L series of cameras.

Prior to starting an autoguiding or selfguiding session, move the telescope mount so that a star falls on the chip you are using for guiding. For Autoguiding, you can use the larger Imaging chip because it is not needed for imaging[2].

You can change the default parameters for all types of guiding using the Track | Autoguide Parameters menu item (see Figure 62). For most applications, no changes will be required to these settings. If you experience over-correction, try a lower aggressiveness setting.
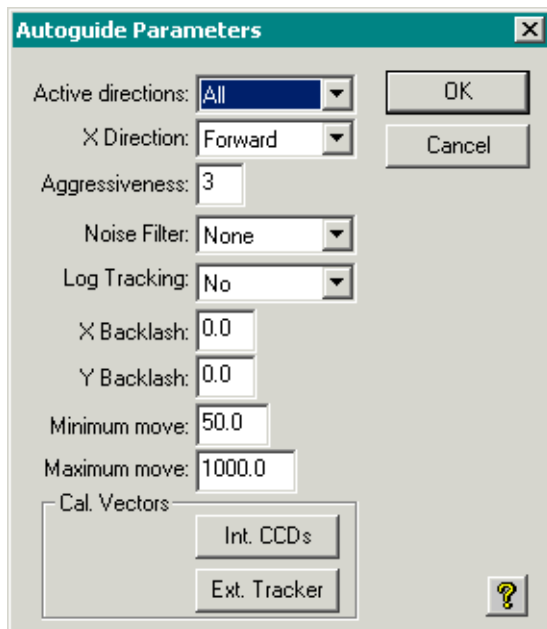


*Figure 62 - Setting Autoguide parameters.*

> **Active directions** (All, None, X only, Y only)—Determines which directions are enabled for guide corrections. Normally set this to All. If your mount does not have Dec corrections, use X only. If you want to use the Log Tracking feature without making corrections to observe guiding performance, set this to None.

---

[2] Note that you will get faster guide update rates when using the Tracking CCD as it is smaller and has less overhead.

**X Direction** (Forward, Reverse)—If you have a German Equatorial mount, change this to Reverse when you flip the mount to the other side of the meridian from where you calibrated. For fork mounts, leave this set to Forward at all times.

**Aggressiveness**—Determines what portion of the guide correction gets applied with 10 corresponding to a full correction. When set to 5, for example, one half of the guide correction is applied. Seeing and small random movements of the mount can lead to over-correction. Setting a lower aggressiveness smoothes out corrections and avoids over-correction. A low aggressiveness effectively averages multiple looks.

**Noise Filter** (None, Low-Pass, Median)—Determines the type of noise filtering, if any, that is applied to the guide images. Filtering is most helpful when the guide star is dim. Both filters are smoothing filters; try each one to see which is best for the current conditions.

**Log Tracking** (Yes, No)—Determines whether the images used for guiding corrections are saved to the hard disk. When guiding is complete, use the Track | Convert Track Log File menu item to create a mosaic of the guide images as well as a spreadsheet showing the results of a guide session.

**X Backlash, Y Backlash**—The number of seconds for taking up backlash. Use *only* if you are unable to compensate for backlash using controls built into your mount. The value entered is the number of seconds of backlash. Does not apply to calibration, only to guiding. For most situations, zero is a good value.

**Minimum move**—The shortest guide correction that CCDOps will make, in thousandths of a second. Few mounts can respond to values shorter than 50 milliseconds.

**Maximum move**—The largest guide correction that CCDOps will make, in thousandths of a second. A value of 1000 is the default, but you will seldom make corrections that large, so smaller values can be used to keep corrections short.

**Cal Vectors** – Click on these buttons to edit the calibration vectors. Figure 63 shows the dialog for the internal calibration vectors. The external vector dialog is very similar, and is used when the optional external guider is used with the ST-L series of cameras. The left column shows the speed that CCDOps has calculated for each direction (+X = right, -X = left, +Y = down, -Y = up). The right column shows the angle for each direction. The plot at right shows a graph of the angles and speeds. These values are set when you Calibrate your mount.
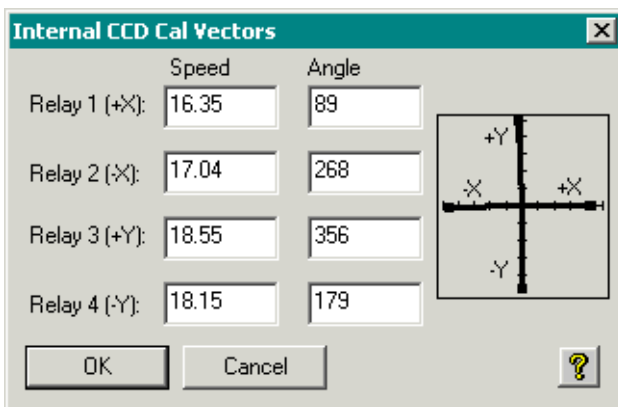


*Figure 63 - Viewing internal calibration vectors. External guider is similar.*

**Note:** +X refers to the RA relay, not the direction on the CCD. CCDOps will track at any angle – the vectors don't need to line up with the CCD rows and columns.

To start a autoguiding session, use the Track | Autoguide menu item, or click the AutG button on the Icon bar. This displays the Autoguide dialog (see Figure 64).
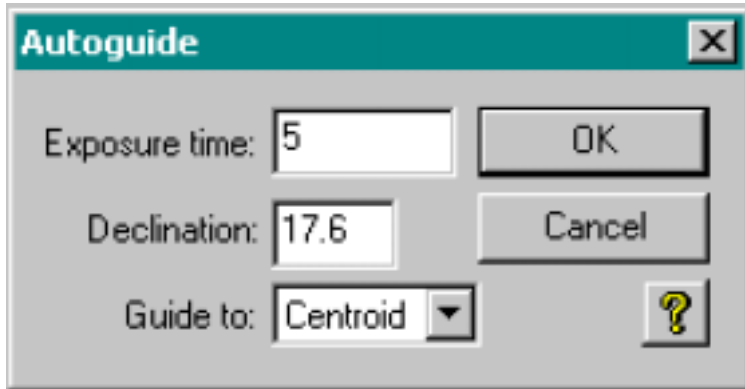


*Figure 64 - Setting up Autoguiding.*

There are three parameters required for autoguiding:

**Exposure Time**—the length of the guide exposure, in seconds. This must be long enough to clearly image the guide star, but short enough to match the capabilities of your mount. If your mount tracks very accurately, you can use longer guide exposures as long as the guide star is not saturated or bloomed. If the guide star saturates or blooms, CCDOps cannot find the center of the star accurately. If you mount tracks less accurately, more frequent guide corrections will be required and shorter guide exposures are more likely to work well. One to three seconds generally works well.

**Declination**—Enter the declination of the portion of the sky where you are imaging. This allows CCDOps to scale the guiding corrections for the current declination. If you do not wish to use scaling, enter zero. Note that you must have entered the correct declination during calibration in order to use scaling.

**Guide to** (Centroid, Cursor)—Determines the target for guiding. When set to Centroid, CCDOps guides to where the guide star is. When set to Cursor, CCDOps guides to the pixel where you click as shown in the Lower-Left corner of the CCDOps window.

To start an selfguiding session, use the Track | Self Guide menu item or click the **SlfG** button on the Icon bar. Figure 65 shows the Selfguiding dialog.
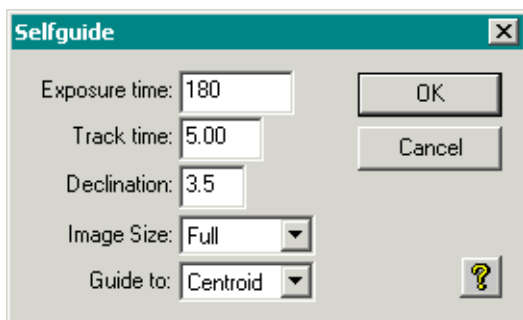


*Figure 65 - Setting up Selfguiding.*

**Exposure time** (for imaging CCD)—Because selfguiding is for imaging and tracking with the same camera, you must enter two times: the time for the imaging exposure, and the time for the guiding exposures. Enter the imaging exposure here.

**Track time** (for tracking CCD)—Enter the duration of the guide exposures. See the "Autoguiding" section for details on how to set a guide exposure time.

**Declination**—Enter the declination of the portion of the sky where you are imaging. This allows CCDOps to scale the guiding corrections for the current declination. If you do not wish to use scaling, enter zero. Note that you must have entered the correct declination during calibration in order to use scaling.

**Image size** (Full, Half, Quarter)—Applies to the imaging CCD, not tracking CCD.

**Guide to** (Centroid, Cursor)—Determines the target for guiding. When set to Centroid, CCDOps guides to where the guide star is. When set to Cursor, CCDOps guides to the pixel where you click.

Click OK to begin the autoguiding or selfguiding session. CCDOps takes an image and displays it along with the Autoguide or Self Guide dialog (see Figure 66). Click on the star you want to use as the guide star. Unlike calibration, it does not have to be the brightest star in the image. It must not be saturated or bloomed, and be bright enough to provide accurate guiding. When you are satisfied with the guide star selection, click the Resume button at top right.
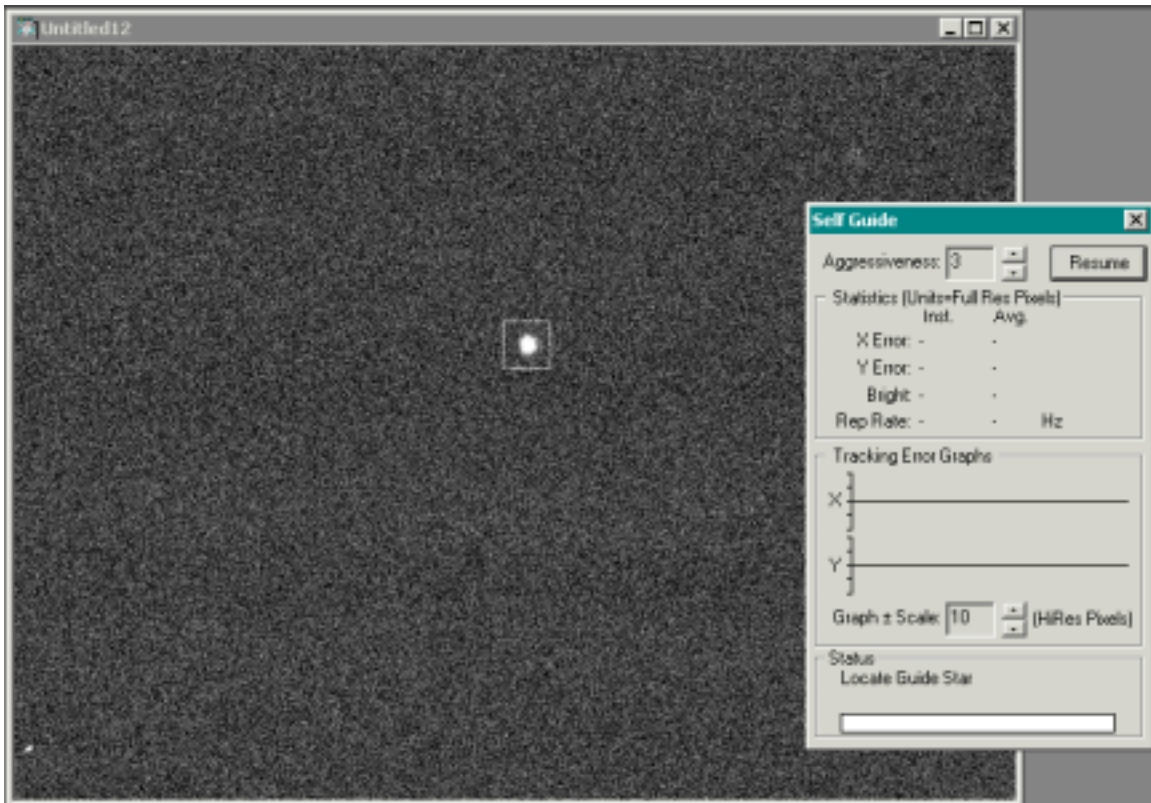


*Figure 66 - Selecting the guide star by clicking in the guide image.*

During autoguiding, the Tracking or Self Guide dialog shows lots of information about the guiding process (see Figure 67). This includes:

**Aggressiveness**—Use values from 1 to 10. A setting of 10 makes 100% of the calculated correction; a setting of 5 makes 50% of the correction.

**Statistics**—Information about the guiding session. The left column provides the X and Y image-to-image errors in pixels. The right column provides the average for the last 16 images. The integrated brightness (summed over the track box) of the guide star relative to the original exposure is also shown. The Rep Rate indicates how rapidly the guide exposures occur. One Hz equals 1 exposure per second.

**Tracking Error Graphs**—The graphs show the error in X and Y graphically. Use the Graph Scale to increase or decrease the scale of the graph to match the current seeing conditions. The coarser the seeing, the larger this value should be. The smaller the corrections, the smaller the scale can be.

**Status**—Indicates what operation is currently in progress.

After each guide exposure, CCDOps makes brief corrections to the mount at guide speed to correct for these errors. CCDOps provides an enlarged view of the current guide exposure so that you can evaluate the guide star exposure (see Figure 67).
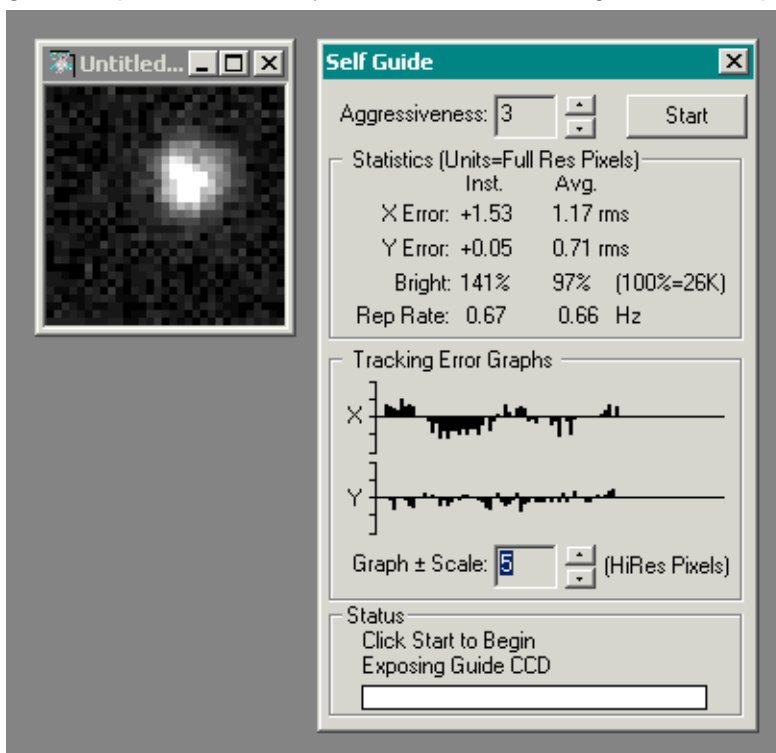


*Figure 67 - The Tracking dialog shows the current X and Y guide error as well as other information about the guiding session.*

If you are autoguiding, you can pause the guiding session at any time by clicking the Pause button. If you are selfguiding, click the Start button and CCDOps will begin the imaging exposure. The Self Guide dialog allows you to monitor guiding during the main exposure.

## *Self Guiding with the AO-7*

To capture images using the AO-7, first point the telescope at a bright star (1st magnitude or so), center the star in the eyepiece, and then attach the AO/Camera assembly.  Power up the camera, establish communication, turn on the cooling, and focus the star carefully.  When the focus is close, move to a dimmer star (5th or 6th magnitude) and complete the focus.  Next, move the star up to the tracking CCD with your telescope hand control and switch to viewing the tracking CCD.

**Tip:** Relative to the images displayed on the computer screen, the tracking CCD is above the imaging CCD.

## Setup

Use the Setup command in the AO menu as described below:
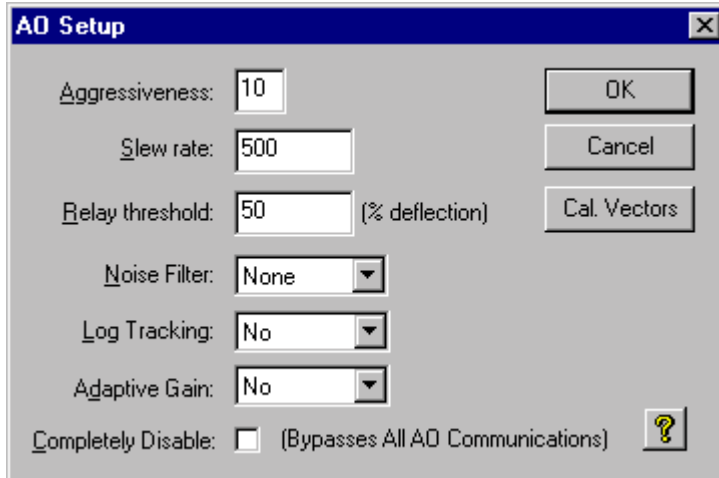


*Figure 68 - The AO Setup dialog.*

**Aggressiveness** Like that in the Tracking dialog above, this controls how "aggressive" the tracking is.  Use values from 1 to 10. A setting of 10 makes 100% of the calculated correction; a setting of 5 makes 50% of the correction.

**Slew rate** This is another way to change the aggressiveness of the tracking and controls how fast corrections will be made at the AO-7.  The default value of 500 should work in most cases but if you feel the AO-7 is still correcting too much you can lower this value.  You must set the telescope focal length accurately in the Telescope Setup command or this limit may be incorrectly applied.

**Relay Threshold** This controls when the relays kick in and start correcting.  As the telescope drifts and the AO-7 moves from the center towards the limits of it's motion the relays will kick in to move the telescope back.  This controls when that occurs and ranges from 10 to 90 percent of the way from center to edge.

**Noise filter** Typically the None setting will work best here.  If however you are guiding on an extremely dim guide star or your CCD seems to show a lot of hot pixels in the guiding image using the Low-Pass or Median settings will filter the Tracking image before using it for guiding.

**Log Tracking** Typically you will leave this turned off but you may turn this option on to make a Track Log file for troubleshooting guiding.

**Adaptive Gain** Start guiding with this option off.  Once you have a feel for how the AO-7 performs you may want to turn this option on to have the AO guiding automatically adjust the "aggressiveness" while guiding.

**Completely Disable** Leave this option unchecked.  If you are having troubles with your AO-7 and are worried that CCDOps may be making it move unintentionally you may check this item but remember to uncheck it when you want to use the AO-7.

**Cal Vectors Button** Click this button to inspect the AO-7 calibration vectors.

# Calibration

In order to track the star the AO-7 must first be calibrated.  The nice thing about calibrating the AO-7 is that the tip-tilt mirror calibration is not a function of declination, nor does it change when you rotate the Camera/AO-7 assembly.  You only need to calibrate the AO-7 once a night if you don't interface to the telescope!  For calibration, the PC commands the AO unit to make a maximum move in both X and Y directions to establish the correction rate.  Use the Calibrate command in the AO menu as described below.
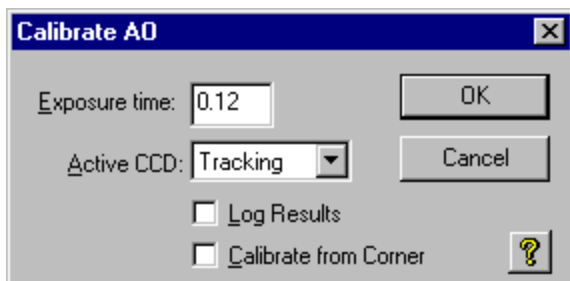


*Figure 69 - The Calibrate AO dialog.*

> **Exposure time** Set this based on the brightness of the calibration star.
>
> **Active CCD** You can calibrate with either CCD and CCDOps will sort it out.
>
> **Log Results** If this item is checked CCDOps will save the five calibration images with the names TrackCal0 - TrackCal4.  This can be handy for diagnosing problems.
>
> **Calibrate from Corner** We recommend you check this option.  Your two choices are to calibrate from the corner or from the center.  We find you'll get better calibration results from the corner.

In response to the AO Calibrate command CCDOps will take 5 exposures interspersed with full excursion mirror tilts to establish the correction rate.  When it is done, it will show the correction speeds.  The values for a +X and –X move should be similar, as well as those for a +Y and –Y move.  X and Y values should be within 2X of each other.  If this is true, you have achieved a successful calibration!

The AO-7 CCDOPS software does allow the telescope to be controlled at the same time as the tip-tilt mirror.  The telescope position is bumped in the appropriate direction to maintain the tip-tilt mirror drive levels between 10 and 90% of full scale.  The calibration of the telescope drive controls works identically to an camera used alone.  Use the Calibrate option under the Track menu to calibrate the drive, as described above.  The only difference between the guiding with the AO-7 software and the guiding with the camera standalone, as far as the telescope is concerned, is that the drive is "bumped" in 0.1 second increments in the proper direction.  The standalone software made variable, calculated moves to reduce the error to zero.  We use the bump technique here in case the AO-7 is being used at slow rate, such as 1 frame a second.  For example, if the AO-7 is running at 40 frames per second, it will operate right through a telescope move without interruption.  If it is running at one frame per second, the telescope will only be "bumped" once per AO-7 frame.  The AO-7 does make a calculated move, so it should always dominate the tracking performance.

The telescope "bump" correction is always there.  If the AO-7:ST-7 combination is connected to the telescope, it should be calibrated, because it will be "bumping" the telescope.  If you have not calibrated the mount you should disconnect from the

telescope so it won't be moved in the wrong direction.  Your computer speaker will make a short beep every time the telescope position is bumped.

## AO Self Guide

Once calibrated, select Self Guide command under the AO menu.  You'll get the following dialog:
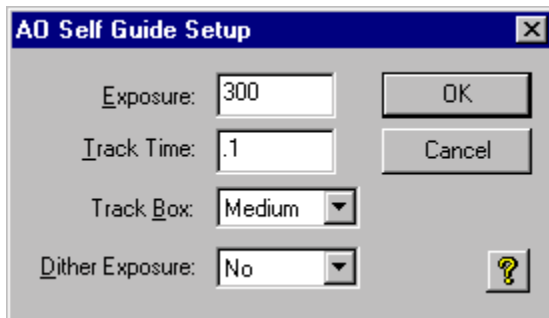
*Figure 70 - The AO Self Guide Setup dialog.*

> **Exposure** This is the exposure for the imaging CCD and will typically be several minutes long.

> **Track Time** This is the exposure for the Tracking CCD and will typically be short.  Use a long enough exposure so that you get good image of the guide star with at least a thousands counts of integrated brightness.  This can be as short as 1 millisecond (0.001).

> **Track Box** You have three choices: Small, Medium and Large.  Small will be the fastest whereas Large will allow larger atmospheric motion of the guide start without losing the guide star.

> **Dither Exposure** Typically you will leave this off.  Turning it on allows you to compare the Guided and Unguided performance by guiding for 5 seconds, displacing the AO and running unguided for 5 seconds, etc.  In this way you get a double image showing guided and unguided performance.

To take an exposure, input an imaging exposure and tracking time, select a tracking box size, enter No for dithering, and hit Enter.  We recommend that for initial experimentation you try a 60 second exposure with a tracking time of 0.1 second, and a medium sized track box.  The camera will take a short tracking CCD exposure, and display it on the screen.  Select the desired guide star by moving the box onto it (it doesn't need to be exactly centered) and then click the Resume button in the AO Self Guide dialog described below.   The PC will then capture a series of 8 dark exposures of the track box to create an averaged, low noise dark for the tracking CCD, and then begin tracking at the selected speed.  The track box containing the star is shown.  The mirror is slightly adjusted to place the star on the corner between four pixels initially, so a very stable stellar image produces a box of four equally bright pixels.
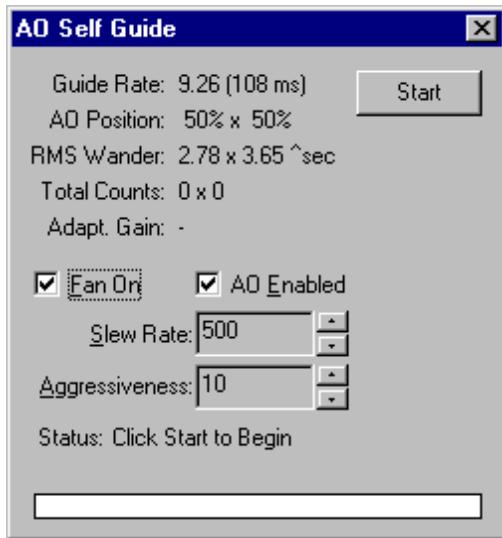
*Figure 71 - The AO Self Guide dialog.*

**Guide Rate** This shows the average guide rate and period achieved. Faster is usually better and you get faster by using bright guide stars with short exposures and the small track box.

**AO Position** This shows the X and Y position of the AO. The center is at 50% and one edge is 0% and the other is 100%. Watch this throughout the exposure to make sure it stays within range. If you telescope drift is high or your polar alignment is not too good you may have to use the "Bump" feature and connect the Guiding cable to the telescope.

**RMS Wander** This is an indication of the guiding performance and is shown in arcseconds. For this to be accurate make sure you have set your telescope focal length in the Telescope Setup command in the Misc menu.

**Total Counts** This shows the total counts in the star in real time and the value it started at. Clouds passing overhead can bring down the total counts.

**Adaptive Gain** If you have this feature enabled in the AO Setup command this shows you the X and Y gain factors being applied.

**Fan On** If you are worried that you fan is vibrating the telescope you can turn it off temporarily and see if the guiding improves.

**AO Enable** With this item you can momentarily disable the AO and see what happens to the guiding performance. Make sure you re-enable it before starting the exposure.

**Slew Rate and Aggressiveness** Raise or lower these to try to improve the RMS Wander. On nights with a lot of atmospheric disturbance you may actually improve the performance by reducing the Slew Rate as this stops the AO from chasing the seeing.

**Start Button** When you are convinced the AO is adequately tuned click this button to start the Imaging exposure.

## Optimizing the High-Speed Guiding

A number of parameters can be adjusted to optimize the guiding. The first is the size of the track box. A small track box uses 4 by 4 tracking CCD pixels, a medium 8 by 8, and a large 16x16. A small track box should be used on a really good night when the stellar

wander is small.  The small track box, since less pixels are viewed, can be read out slightly faster, resulting in a higher frame rate.

If the night is not that good the star may jump out of the track box, causing loss of the guide star.  Under these conditions use the medium track box.  The large track box is intended for use by professional observatories with telescopes having focal lengths exceeding 10 meters.

The aggressiveness is a number from 1 to 30 that is a scaled multiplier to apply to the calculated correction.  For example, assume that the calibration of the AO finds that a 50 unit change in the tip-tilt mirror position will move the star 1 pixel.  If the star is found 1.5 pixels off from the center of the track box the software would normally send a 75 unit move to the AO module to move the star back.  This calculated move is multiplied by the aggressiveness divided by 10.   If the aggressivess is set to 10, the commanded move is therefore multiplied by 1.  If you find that the stellar motion is too jumpy, reduce the aggressiveness.  If it seems sluggish, increase it.  What we recommend is that you observe the RMS Wander in arcseconds displayed on the screen, and try changing the aggressiveness to minimize the wander.  If the aggressiveness is too high, up around 20, you may observe the star starting to oscillate.  This is undesirable, and the aggressiveness should be reduced slightly.  In practice you will probably use values between 5 and 15**.**

After optimizing the aggressiveness, look at the slew rate.  The slew rate is a limit in arcseconds per second that can be applied to the movement of the tip-tilt mirror, and it mainly reduces its response at higher frequencies.  If the star is jumpy, lowering the slew rate limit may suppress some of the erratic behavior.  Since the unit can theoretically only suppress sinusoidal frequencies corresponding to a tenth of the frame rate, a lot of the high speed motion of the star should be ignored since it doesn't correlate from frame to frame.  Once again, vary this parameter to find the optimum value.  Increase the slew rate to the point where the rms wander starts to go up, and then back off slightly**.**

The wander and the slew rate are both in terms of arcseconds.  In order for the value in arcseconds to be correct the telescope focal length must be correctly entered into the program.  This parameter is input using the Telescope Setup command under the Misc menu.

The total brightness of the star is shown in counts when the track box is shown.  The tracking time exposure time should be set to yield several hundred counts in the stellar image for reliable tracking.  If the guide star is lost during a long exposure the software will terminate the exposure and read out the imaging CCD.  You can then take a comparable length dark frame if you wish to keep the data, or restart the exposure.

The software also allows one to turn the mirror correction on and off during the guiding, and also turn the ST-7/8 fan on and off.  This is useful for troubleshooting.  We have had an occasional user mention that they believed the fan was shaking the telescope, but no one consistently sees this effect.  The only way we believe that this can occur is if the fan frequency coincides with a resonance in the telescope system.  Changing the mass distribution on the telescope should fix this problem, if it occurs**.**

## Tips for Optimizing the Improvement seen with the AO-7

The AO-7 allows the guide star image to be viewed during the imaging camera exposure.  On many occasions you may find that the guide star motion is clearly suppressed when the AO-7 is on, but yet the imaging CCD image quality is not improved much.  This can occur for a variety of reasons.  Typically the RMS Wander is only about half of the stellar halfwidth, so the potential AO-7 improvement is modest at best .  If the

star image is further blurred out by optical aberration or defocus the improvement is reduced, since the wander was a smaller portion of the blur to begin with. Make sure your focus is good. To determine the limit of your optical quality, take short images (0.1 second) of a bright star, and measure the half width of the star on the best image you collect. The AO-7 will never improve the quality of what you can get on an above average 0.1 second exposure! If you find that the star image is not too good on the best short exposure, suspect optical aberration. If you are using a commercial Schmidt-Cassegrain, collimation is very important!

If you find that the star is less than 2 to 3 pixels halfwidth on the average image, then you will need a longer focal length to see a visible improvement.

The best nights will be those with little wind. If the wind is blowing hard, there will be little temporal correlation between successive guide star frames. The predictive value of each image on correcting the error in the next image diminishes to zero. If one has an 8 inch aperture (20 cm), and the wind is blowing at 10 mph (1.6 kph), the CCD will be looking through a completely new cylinder of air every 50 milliseconds. Once again, large telescopes have an advantage in that the wind takes longer to refresh the air in front of the aperture.

In the final analysis, how much improvement can you expect? Our experience is that on most good nights with a C11 (28 cm), F/10 telescope we found a stellar peak brightness improvement of 50%. Our AO-7 guided images had 2.0 arcsecond halfwidth stars, while the normally guided images yielded 2.5 arcsecond stars. Beta testers of our product found similar improvements. The better the seeing, the greater the improvement. We eagerly await results from other regions of the USA and the world. We suspect that under arc-second quality seeing the peak brightness would double. In our experience, the image is never degraded by the AO when the seeing is better than 3 arcseconds. While this improvement may seem modest, it is important to remember that there is no other way to achieve this improvement short of moving to a better site, such as a mountaintop. Even on the mountaintop, the AO-7 unit will produce a sharper image! We have also found that there is no commercial mount so good that an AO-7 does not help it.

## Troubleshooting the AO-7

This section describes the common problems found with AO-7s and shows you how you can test your AO-7 for proper operation. AO-7s are somewhat delicate mechanisms and can require adjustment by the user.

A common complaint about AO-7s in the field is that they "won't Calibrate", meaning when you run them through the Calibrate routine, they fail with a message like "Invalid motion in X Axis". We've added diagnostic functionality to CCDOPS to help you and us troubleshoot these problems.

### *The Exercise Command*

The first test you should perform on your AO-7 is to have CCDOPS Exercise the unit while looking at the mirror or reflecting a laser (or other collimated point source) off the mirror onto a wall. Remove the AO-7 from the front of the camera so it's easier to see the mirror motion, plug the AO-7 cable into the camera, Establish a Link to the camera then use the Exercise command in the AO menu where you'll be presented with the following dialog:
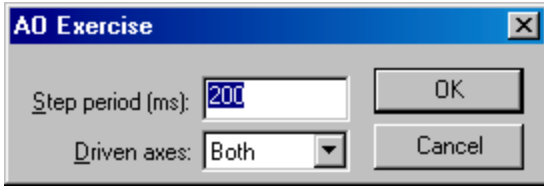
*Figure 72 - The AO Exercise dialog.*

Select a Step Period of 200ms and a Driven axes of "Both" as shown. This will move the AO through the four corners of its motion, pausing 200ms at each corner. If you're looking with your eye you should see the AO move through the four positions as seen by looking at some object reflected in the mirror. While it's hard to detect the exact pattern, you should be able to see that the AO moves in both axes. When using you eye you may find it easier to see the motion with a longer Step Period.

If you were able to project a laser off the AO-7 and on to a wall you would see a pattern something like the following:
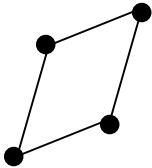


*Figure 73 – Typical AO-7 Exercise Pattern.*

While you might expect the pattern to be a perfect square, the AO-7 often produces a "flattened parallelogram". The two axes may not be perpendicular but can be at angles of up to 60 degrees or so. All this is normal and the AO-7 Calibration routine measures the actual motion of your AO-7 and then uses the size and shape to make the proper corrections in response to guiding errors.

If you don't get a square or parallelogram type pattern out of the Exercise command, or one of the four corners seems to be way out of place then you might try making a mechanical adjustment to the AO-7. The flexure membrane tension has to be balanced (a lot like tuning a piano) to get uniform patterns. Take the triangular piece off the AO-7 so you can get to the mirror, and (with the AO-7 and camera off the telescope), start the mirror exercising with a 20ms step period. While exercising the AO-7, loosen the four tiny Philips Head screws ½ a turn then retighten them evenly. This balances the flexure tension
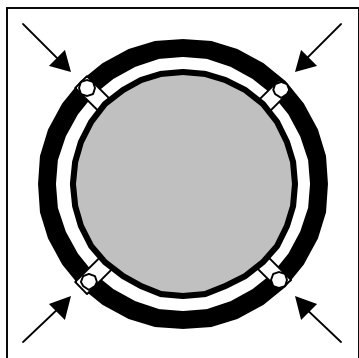
*Figure 74 – AO-7 Mirror Flexure Retention Screws.*

## The Image While Exercising Command

Another test you can perform on your AO-7 is to have CCDOPS take an image while exercising the unit.  Like using a laser reflected off the mirror, this uses a star to show the motion of the AO-7.

To do this test you need to mount the AO-7 onto the camera and then point and focus the telescope at a star field containing one or more bright stars on the Tracking CCD that aren't too close together.  It's important to have a well-focused image on the Tracking CCD as that's the CCD that's used to take the images.  Once you have the AO-7, camera and telescope set up, use the Image while Exercising command in the AO menu where you'll be presented with the following dialog:
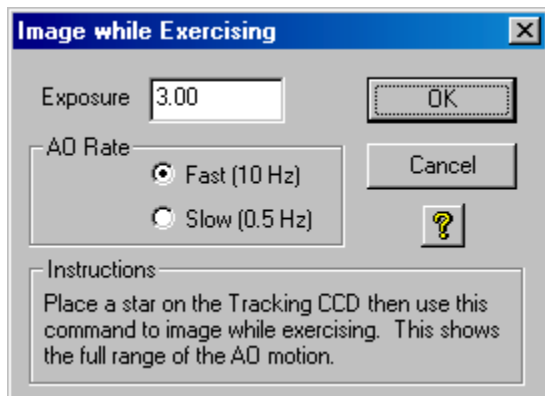


*Figure 75 – Image while Exercising Dialog.*

There are just a few options you need to select.  First off you can choose to image the "Fast" response of the AO-7, whereby the AO-7 moves from corner to corner every 100ms, something typical of what you might expect while actually guiding.  Alternatively you may choose to image the "Slow" response whereby the AO-7 moves from corner to corner every 2 seconds, something typical of what the AO-7 would see while calibrating.  It's advised to take and inspect both images.

The final option you need to select is the Exposure time.  Here the key is taking an exposure that is long enough to let the AO-7 hit all four corners (at least 0.4 seconds for the Fast option and 8 seconds for the Slow option), an exposure long

enough to show get a decent exposure on the stars, but short enough such that drift in the mount doesn't smear the pattern or cause multiple patterns. We advise trying 1 to 3 second exposures in Fast mode and 20 to 60 second exposures in slow mode.

The Image while Exercising command takes a dark subtracted image, which should show star patterns like that shown in Figure 1 above or like Figure 2 below.
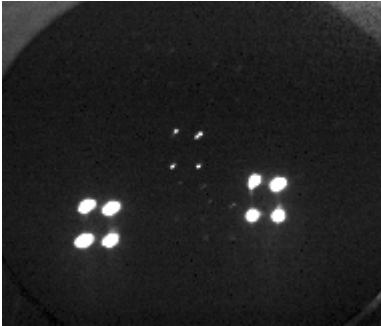


*Figure 76 – Typical Image from Image while Exercising*

### *Calibration Problems*

Many of the problems associated with the AO-7 come down to the Calibration. The figures below show what "near-perfect" nd "typical" calibration results look.
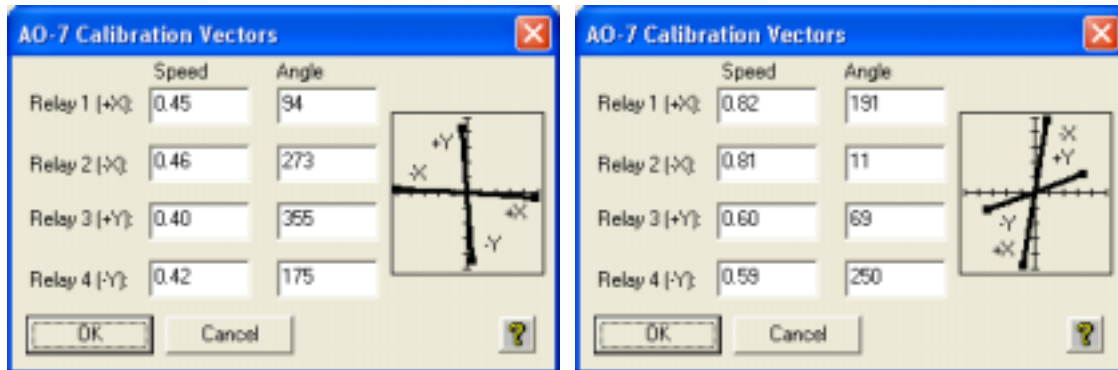


*Figure 77 – "Near-Perfect" and "Typical" AO Calibration Results.*

In the "Near-Perfect" results the axes are all perpendicular and the speeds are the same. Basically this is what you would expect from the AO-7. In the typical AO-7 Calibration Result the axes are not orthogonal but are a little skewed. The speeds in one axis are less that the speeds in the other. Even with Calibration Results like this the AO-7 will guide effectively.

When the AO-7 fails calibration you must look a little further. The things that can cause the AO-7 calibration to fail are:

- The calibration star can move off the CCD or another brighter one can move on. Alternatively poor seeing could cause the brightness of the star to vary. You can tell this by looking at the brightness numbers in the positions. If they change by more than a factor of 2 suspect something like this is happening.

- The motion of the star is not great enough to get a valid calibration. You can tell this by looking at the star positions. The star needs to move at least 5 pixels. If not, try the "Calibrate from Corner" option.

- The two axes are too far from being perpendicular. CCDOPS expects the axes to be somewhat perpendicular and if they aren't it will fail. Click on the Show Vectors button to inspect the calibration results graphically.

### *What to Do when All Else Fails*

If you simply can't get the AO-7 to calibrate then do the following and email the data to our Tech Support Staff. We'll help you figure it out or in the worst-case ask you to return the AO-7 for repair.

1. Take Fast and Slow images using the Image while Exercising command. Save the images in SBIG format.

2. Try the Calibration with the "Log Results" option selected. Gather the five images that are created.

3. In the Calibration Results dialog after the calibration is complete and has failed click the Copy to Clipboard button then paste the results into your email.

4. Email the two "Image while Exercising" images, the five TrackCal images and the Calibration results to sbig@sbig.com.

# 4 Image Processing with CCDOps

> **TIP:** Most image processing tools alter the image data. It's a very good idea to keep your original image in case you'd like to try something different with it. Always save your files with a new name after making permanent changes. For example, if you open the file M15.STX and sharpen it, you could save it with the filename M15_sharp.STX.

CCDOps image processing tools are located on the Display and Utility menus. These tools allow you to enhance images to show more detail or to show information in different ways. Most tools have a range of settings, and you will need to experiment to find the right settings for a given image. Where possible, we have included general guidelines to help you find the optimal settings. But every image is unique, and the exact settings can be determined by observing how they affect the image.

One other item that will save you much time in image processing is the Revert To Saved command in the File menu. This command discards any changes you've made to the image since the last save. It's like a global Undo function.

## *Display Menu Tools*

> **Note:** None of the commands in the Display menu actually modify the image data. These commands change the way that the data is displayed only.

**Crosshairs**—When active, the Crosshairs window displays information about the pixel or region under the cursor. Available information includes pixel brightness, average brightness, noise level, magnitude, separation, and angle.

**Histogram**—Shows the distribution of brightness values in the image. Figure 78 shows a histogram for an image. The peak shows that most of the pixels in the image have a brightness value of about 410.
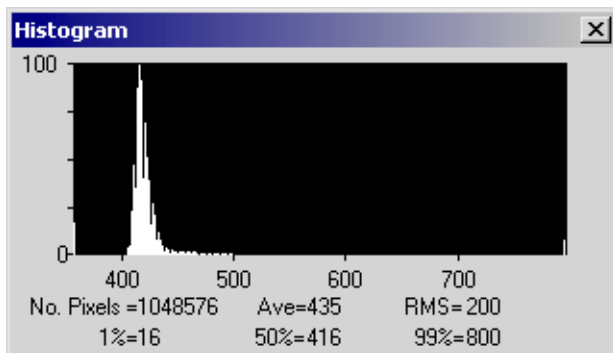


*Figure 78 - An image histogram.*

The vertical axis is scaled so that the peak is 100. The horizontal axis shows the ADU values.

**Parameters**—Information about an image. Includes information about the filename, date of observation, camera used, exposure time, telescope data, etc. Click on the parameters window to close it.

**Modifications**—Displays a list of changes made to the image, such as AutoDark, smoothing, resizing, etc. Actions read left to right, then top to bottom. Does not apply to images saved in FITS format.

**Color Table**—Set the palette to use for image display. Includes the ability to use a false color palette for black and white images.

**Photo mode**—Displays an image in full-screen mode

## *General-Purpose Utilities*

The following Utilities menu items are covered in detail elsewhere in this document:

**Dark Subtract**—see "Dark Frames and Flat-Field Frames"

**Co-Add**—see "Combining Images"

**Flat Field**—see "Dark Frames and Flat-Field Frames"

## *Utilities that Filter Images*

### Smooth

*Description*

    Reduces grain in an image by blurring.

*Example*
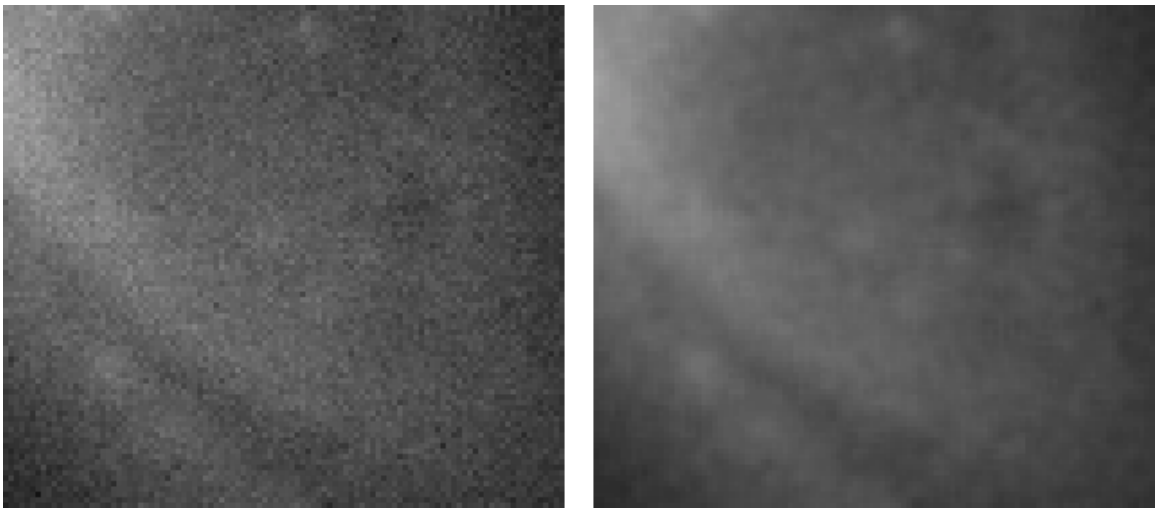


*Smoothing an image reduces grain by blurring adjacent pixels together. Left: before smoothing. Right: after smoothing medium.*

*When to use*

    When your exposure is short, or if the object you are imaging is dim, you may wind up with some graininess in your image. The Smooth filter will reduce the grain, at the cost of blurring some details.

*How to use/settings*

    CCDOps provides three settings for smoothing: Soft, Medium, and Hard. These are increasing amounts of blurring. Use the lowest setting that provides an acceptable result.

*Mistakes to avoid*

    If you smooth too much, you'll lose valuable details. Smooth only enough to reduce blurring; don't over-apply this filter or you will blur away details you could be saving.

# Sharpen

*Description*

Increases contrast between adjoining areas to make the image look sharper. The sharpening method is Unsharp Masking.

*Example*
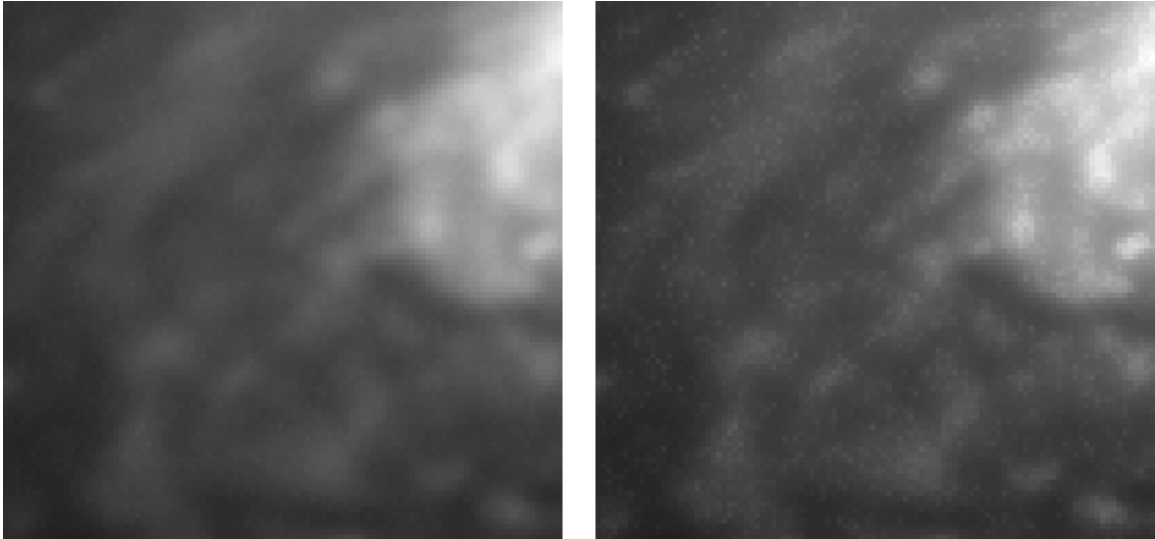


*Sharpening an image makes details more visible. Left: before sharpening. Right; After sharpening hard.*

*When to use*

Sharpening can be used on images that are not grainy. If the image is grainy, use Smoothing. If you try to sharpen a grainy image, it will create artifacts that are false details.

*How to use/settings*

There are two settings for the sharpening tool:

**Mode** (Nebulae, Lunar-Planetary)—The type of sharpening to use. Nebulae also works for galaxies and other extended objects. Chose the mode that best matches your subject. Nebulae applies less sharpening, and Lunar-Planetary applies more. The main purpose of the Nebulae mode is to avoid dark rings around stars when sharpening.

**Strength** (Soft, Medium, Hard)—How much sharpening to apply.

*Mistakes to avoid*

Over sharpening is the most common mistake. Use only as much sharpening as the image will allow. The less grain there is, the more you can sharpen.

## DDP

*Description*

Applies Digital Development Processing (DDP) to the image. DDP is a process created by K. Okano of Japan. It is designed to make CCD images look more like film images. DDP combines two operations: compression of the image's dynamic range (it shows more details in bright and shadow areas) and sharpening.

*Example*
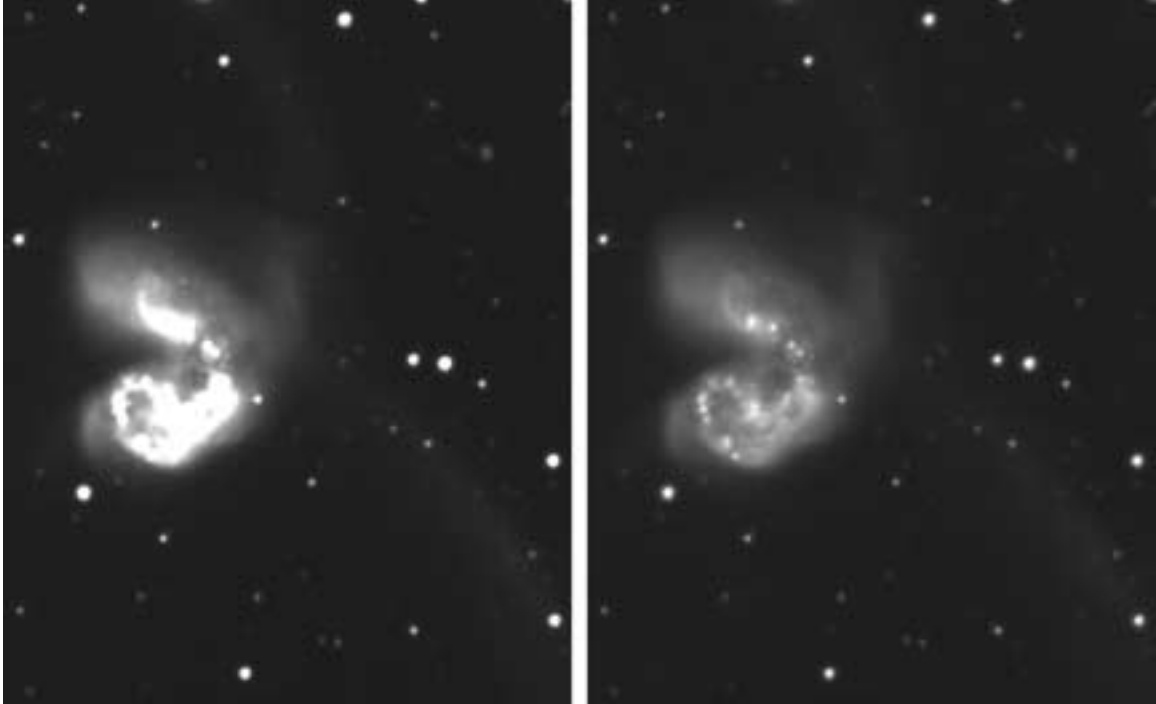


*DDP preserves details in both the bright and dark areas of the image. Left: before DDP. Right: after DDP.*

*When to use*

You can use it whenever you see burned out white areas or dim details that are nearly black.

*How to use/settings*

It's best to use Auto-Contrast before applying this filter.  There are no settings for DDP.

*Mistakes to avoid*

Very few images will look worse with DDP, so feel free to use it often.

## Median Filter

*Description*

Removes hot and cold pixels by performing a median operation with surrounding pixels.

*Example*
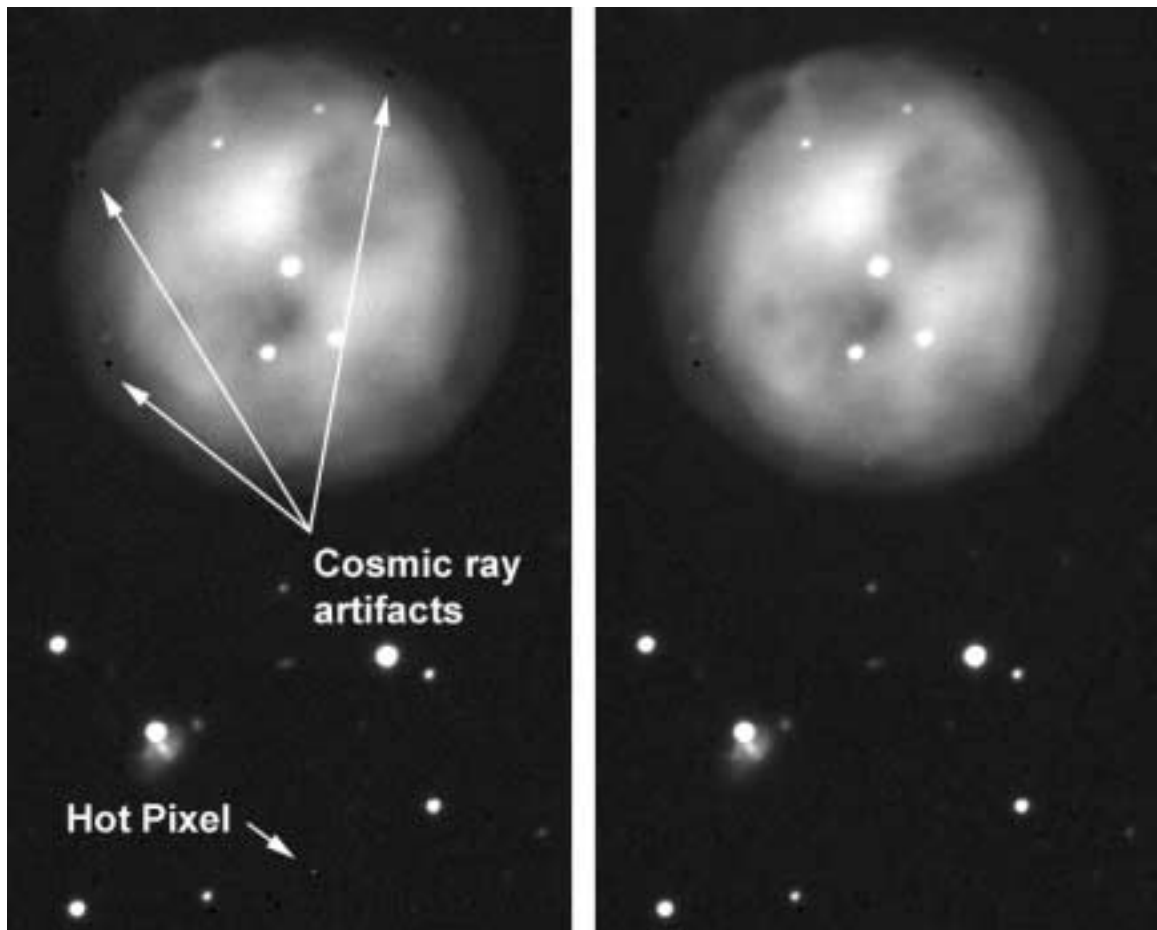


*There are two types of problems with the image on the left: a hot pixel, and several dark spots that are remnants of cosmic rays striking the dark frame. The median filter cleans up the hot pixel, but has less impact on the cosmic ray artifacts.*

### When to use

Applies a general softening to the entire image, so use with discretion.

### How to use/settings

There are no settings for the Median filter.

### Mistakes to avoid

You may lose fine detail in an image if you use the median filter when it's not needed.

# Remove Cool Pixels

*Description*

Removes cool (dark) pixels from an image. It is less aggressive than the Median filter, and has little to no impact on other parts of the image. It operates only on isolated dark pixels.

*When to use*

Use this filter to clean up individual dark pixels in an image.

*How to use/settings*

There are three settings, from least to most aggressive: Soft, Medium, Hard.

*Mistakes to avoid*

Overly aggressive removal of cool pixels may affect small dark details in the image.

# Kill Warm Pixels

*Description*

Removes warm (bright) pixels from an image. It is less aggressive than the Median filter because it only operates on isolated bright pixels. The bright pixel is replaced with a weighted sum of the surrounding pixels.

*When to use*

Use this filter to clean up individual bright pixels in an image.

*How to use/settings*

There are three standard settings, from least to most aggressive: Soft, Medium, Hard. There is also a "Saturated only" setting, which will remove only pixels that are fully saturated. See Table 2 for saturation levels for various cameras.

*Mistakes to avoid*

If you are imaging with a very wide field optic, such as a camera lens or short focal length refractor, the warm pixel filter may also remove the dimmest stars. Use with caution in this configuration—the Saturated Only option is usually best in this situation.

## Column/Row Repair

### *Description*

Replaces a bright or dark column with an average of the neighboring columns. Column defects are rare, and if they exist they are usually located away from the center of the image. In most cases, bright partial columns are actually the result of individual hot pixels, not a defective column. The bright pixels cause the rest of the column to read hot as well. This can be repaired using the Column/Row Repair tool.

### *Example*
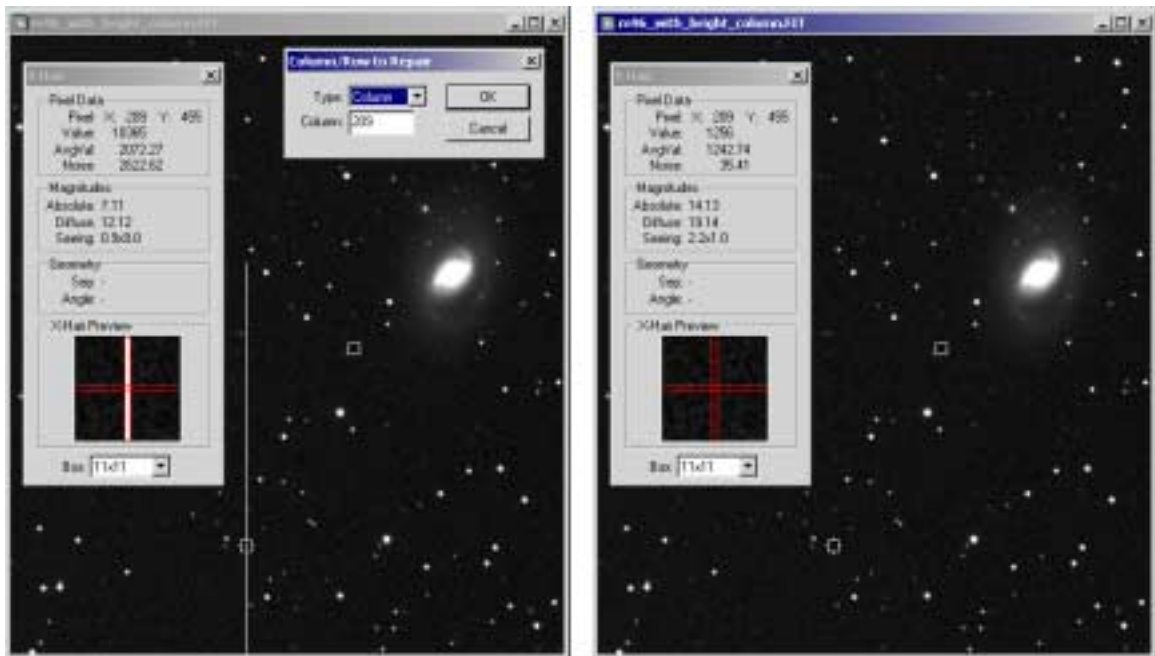


*The partial bad column on the left can be repaired with the Column/Row Repair tool. Left: Use the Display | Show Crosshairs menu item to display the Crosshairs dialog, and use the cursor to identify the column or row number. Then use the Utility | Column/Row Repair menu item to open the repair dialog.*

### When to use

Whenever you have a full or partial column that is noticeably brighter or darker than the surrounding columns.

### How to use/settings

There are two settings: the Type (column, row) and the column number. Note that the column repair dialog will get the column/row from the crosshairs window if is open.

### Mistakes to avoid

Make sure to keep the crosshairs window open when making the repair. The most common mistake is to close the crosshairs window.

## Pseudo 3D

### Description

Applies a filter that makes bright pixels look high and dim pixels look low.

**Example**
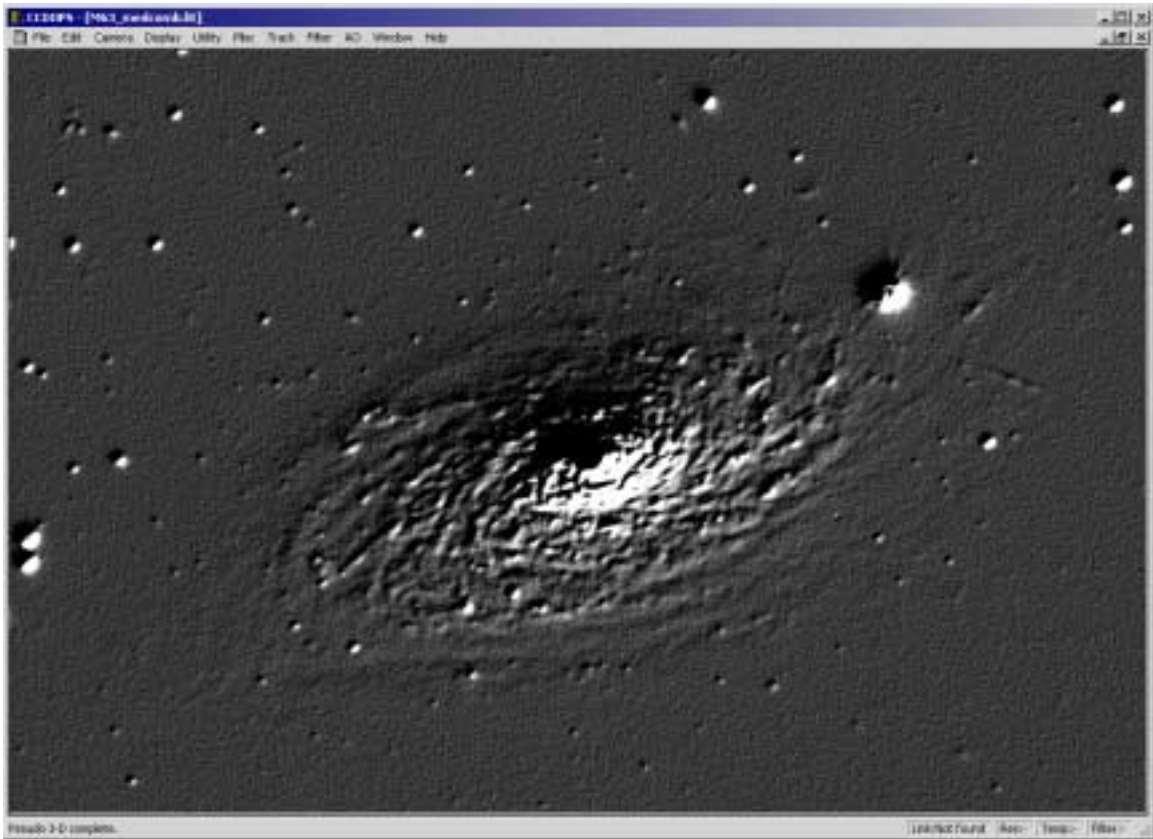


*The Pseudo 3D Filter can reveal subtle changes in brightness in an image.*

*When to use*

This filter can reveal subtle brightness values as 3D effects. It is useful for analyzing the structure of celestial objects.

*How to use/settings*

There are three options, from least to most aggressive: Low, Medium, and High.

*Mistakes to avoid*

If the image is very noisy, the grain will interfere with the 3D effect.

## Fix Uncooled TDI Image

*Description*

Detects and offsets hot columns in uncooled Time Delay Integration (TDI) images.

*When to use*

TDI is a method for scanning the camera's field of view while the camera is moving relative to the field. For example, TDI can be used to image with a telescope that is not tracking. For more information about TDI, please see the SBIG web site.

## Fix ME Spikes

*Description*

Some CCD chips (such as the chip in the ST-10XME) use cylindrical micro lenses to improve their quantum efficiency (QE). At fast focal ratios such as f5 or f/7, a very slight vertical spike may appear when using these cameras. This filter removes the spike and restores the star's normal profile.

*Example*
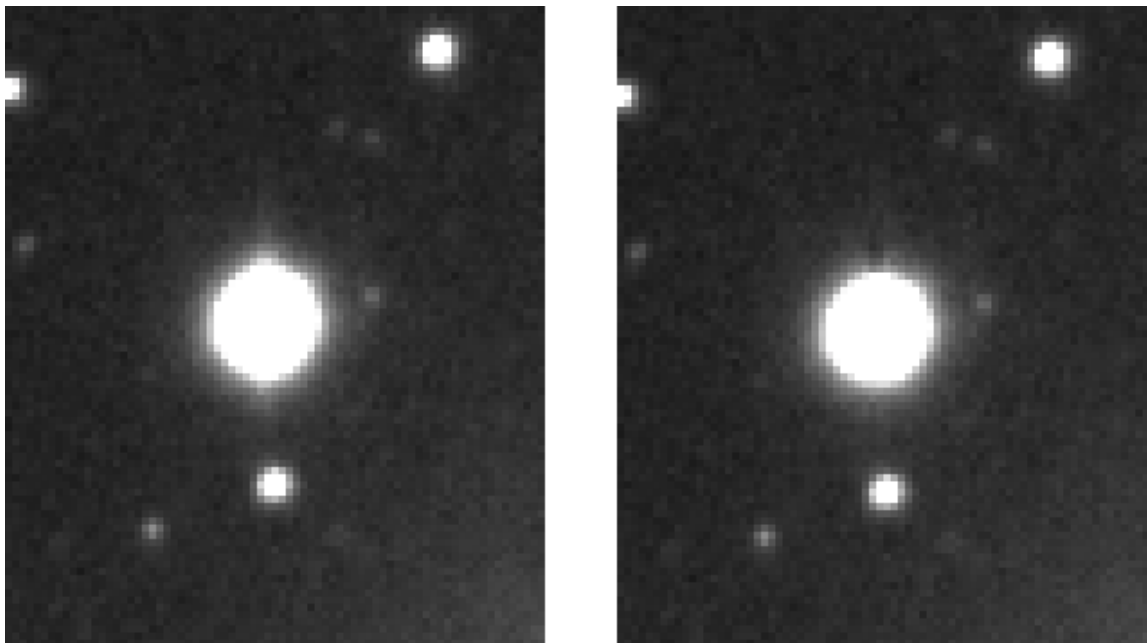


*Removing spikes from cameras that use microlens (ME) chips. Left: the slight vertical spikes found on bright stars in images taken with microlens CCD chips. Right: The result of removing the spike. If the dark area is too pronounced, as shown here, use a lower value for strength. If the removal is incomplete, use a higher value.*

*When to use*

This filter is only useful if you have a camera with cylindrical micro lenses. Cameras with hemispherical micro lenses, such as the ST-2000XE, do not create the subtle spikes.

*How to use/settings*

The ME spike filter takes a single parameter—the strength of the filter. Start with a value of 1, and change this up or down to see what the best value is. Lower values weaken the strength, and higher values increase it. If the spike is not completely removed, use a higher value. If the spike area turns dark, use a lower value. You can crop the image (see the Crop tool later in this section) to include just a single spiked star, and use the ME spike tool to find the correct strength. Follow this procedure:

1. Crop the image so that it includes at least one spiked star.

2. Adjust the background and range to show the spike. Typically, this involves lowering the range quite a bit, and perhaps raising the background a little.

3. Save the image.

4. Apply the filter with a strength of 1.00 to start with.

5. Examine the result. If it's not right, use the File | Revert to Saved menu item to open the saved version of the image. Try a larger or smaller strength settings, as appropriate.

6. Continue until you get a smooth result.

***Mistakes to avoid***

Only use the ME spike filter on cameras with "ME" in the camera name. Those cameras have cylindrical micro lenses. Be patient finding the correct strength, and you will be rewarded with nice round spike-free stars.

If the spikes are too faint to see, then you don't have to worry about them.

## Fix Blooming Streaks

***Description***

Non-antiblooming (NABG) CCD chips "bloom" when too much light strikes a pixel. This does no harm, but it affects the appearance of the image. Longer exposures reveal more details, but longer exposures are also more likely to create blooms. The additional details are valuable, so bloom removal is a common task for many imagers.

***Example***
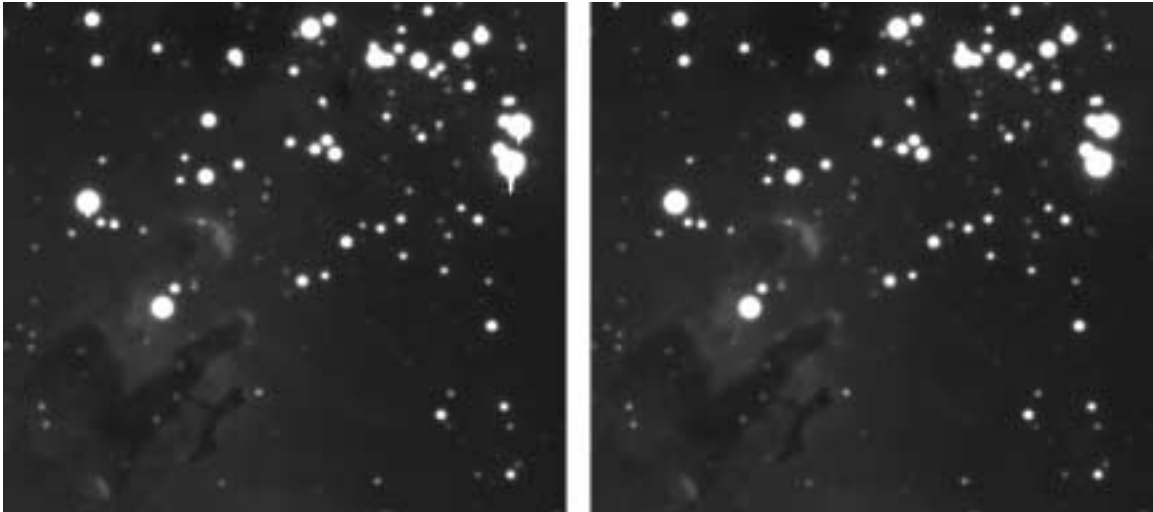


*Left: several stars have blooms, the white extensions below the stars. Right: bloom removal cleans up the mess.*

***When to use***

Whenever blooming occurs on the stars in an image.

***How to use/settings***

There are no settings—just choose the Utility | Fix Blooming Streaks menu item, and CCDOps does the work.

***Mistakes to avoid***

None.

## *Utilities that Flip or Rotate*

### Flip Horizontal/Vertical

***Description***

Flips an image from side to side/top to bottom.

***Example***



***Two flips have been used to present the image of M104 (the Sombrero Galaxy) to best advantage. The original is at left. The center image show the result of a vertical flip, followed by a horizontal flip for the rightmost image.***

***When to use***

You can flip images to match a chart or planetarium program, or for aesthetic reasons (because you like it better).

### Rotate CW/CCW

**Description**

Rotates the image 90 degrees clockwise/counterclockwise.

***When to use***

This tool provides 90-degree rotations that are very useful for aesthetic composition of images.

## *Utilities that Resize Images*

## Resample Pixels

### *Description*

Converts non-square pixels to square, which corrects the aspect ratio of an image taken with a camera that has non-square pixels (e.g., ST-6)

### *Example*
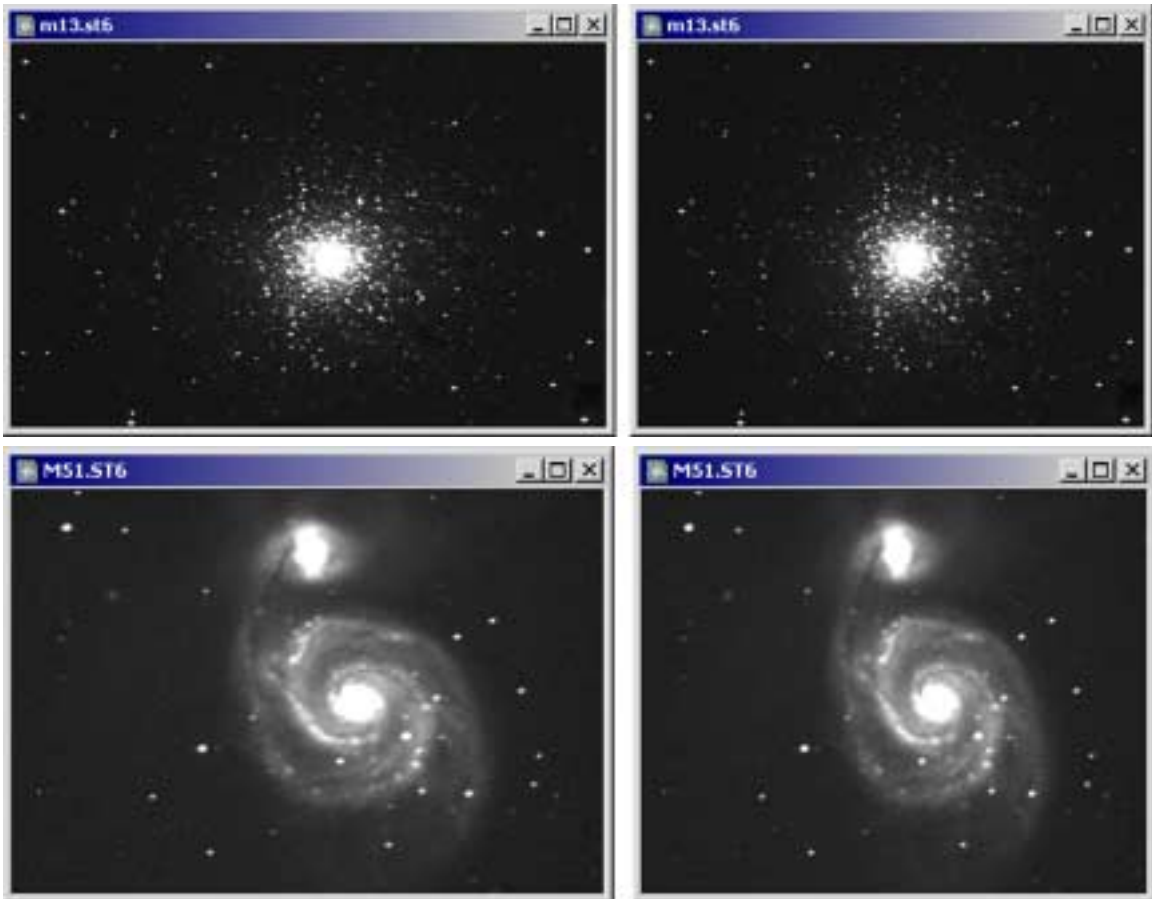


*The images on the left show original ST-6 images. The images on the right have been resampled to square up the pixels. Note how the oval shape of the original images is automatically corrected during resampling. M13 courtesy Dave Toth. M51 courtesy of Chuck Faranda.*

### *When to use*

This utility should only be used with images that were taken with a camera that does not have square pixels.

### *How to use/settings*

This utility examines the image to find out what the pixel dimensions are so there is nothing to enter. CCDOps will look up the pixel dimensions and make the change automatically.

***Mistakes to avoid***

If you try to resample an image that already has square pixels, you will see a warning dialog telling you that the pixels are already square, and nothing will be done to the image.

## Enlarge Image 2x

***Description***

Doubles the size of the image.

***When to use***

If you have taken an image at Medium or Low resolution, it may have blocky stars. This is more common when taking wide-field images. In addition to enlarging the image, this utility interpolates between pixels to provide some smoothing and reduces blockiness in stars.

***Mistakes to avoid***

The maximum image size you can create with this utility is the full size (unbinned) for a given camera. If you try to create a larger image than this size, you will get a warning message.

## Reduce Image 2x

***Description***

Reduces the size of the image by half.

***When to use***

If nebulosity is too faint in an image because of noise, reducing the image by 2x2 (also called software binning) may help reveal the dim details by smoothing out the noise.

## *Other Utilities*

## Scale

***Description***

Re-scales the pixel brightness values, either linearly or logarithmically.

***Example***
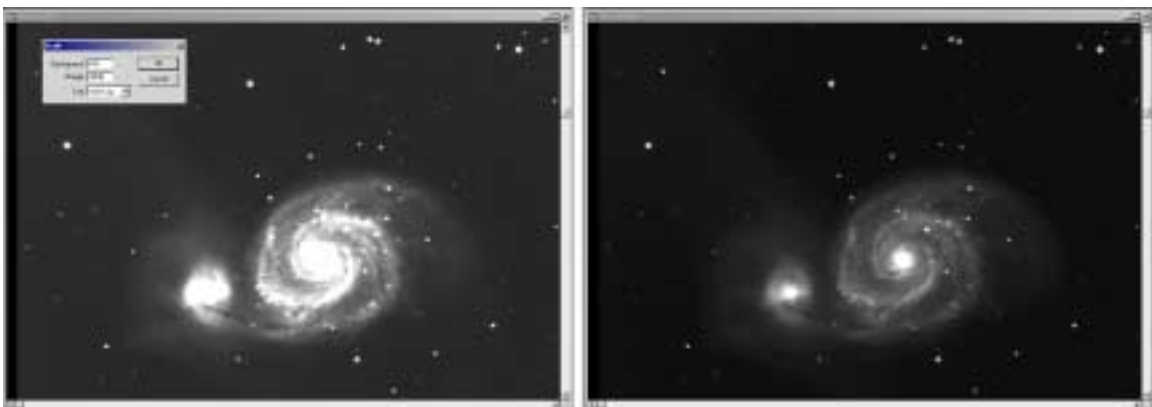


***Scaling using Auto-Log allows you to display more of the bright and dim details in an image.***

### When to use

This is an alternative image processing method to DDP. In most cases, DDP will provide the best result. If DDP does not provide the results you want, try scaling. You can also use scaling to remove pixel values from the image that are not needed. Scaling removes the darkest and brightest values from the image (using the Background and Range settings you provide), and then scales the remaining pixels to fill the 65,535 available brightness levels.

### How to use/settings

There are three parameters for scaling:

Background—All pixels darker than this brightness level will be set to a value of 100 (effectively, black).

Range—All pixels brighter than this value will be set to a value of 65,535 (white).

Log (Yes, No, Auto-Log)—Determines the method used for scaling. For linear scaling, set to No. For manual logarithmic scaling, set to Yes. To have CCDOps determine the best settings for a logarithmic scaling, choose Auto-Log.

### Mistakes to avoid

Manual log processing requires some trial and error to determine the best background and range values. Use the File | Revert to Saved menu item to quickly get back to your starting situation. You can use the Crosshairs tool (Display | Show Crosshairs) to measure the brightness values in the background and in the brightest portion of the image to help you set the Background and Range correctly.

## Invert Pixels

### Description

Converts to a negative image.

### Example
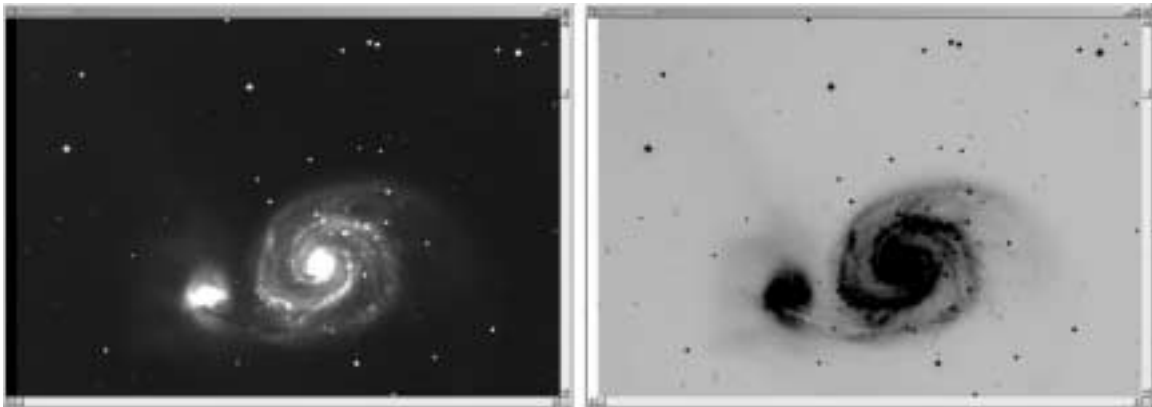


*A normal image (left) and an inverted image (right).*

### When to use

Negative images often make it easier to observe very dim details. The eye sees dark on a white background with greater clarity than dim gray on a black background. Images that show very dim portions of a nebula or galaxy make a good candidate for the Invert Pixels utility.

## Pixel Math

*Description*

Performs simple arithmetic on images.

*Example*
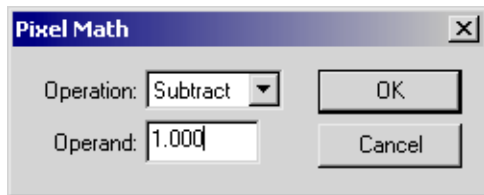


*Pixel math makes arithmetical changes to images.*

*When to use*

When you want to make two or more images match each other in background and/or brightness. For example, if you took a series of images over a period of time, the background brightness might vary. You might have moved into/out of a light dome, or the light pollution levels might be lower as your neighbors turn off their lights as the night progresses.

For example, suppose that you took two images of M51—one while it was high in the sky and well out of the light pollution, and another when it was lower, with a slightly brighter background due to light pollution. Before averaging the two images together to reduce noise, you should use pixel math to subtract a constant from the image with a brighter background.

*How to use/settings*

You can perform the four arithmetic operations on an image. You can add or subtract a constant from an image, or you can multiple/divide an image by a constant.

**Note:** CCDOps adds a constant of 100 to dark subtracted images so the signal at low levels is never clipped at zero. Pixel math functions assume this baseline of 100 is thee and do the math accordingly.

## Set Pixel Saturation

*Description*

Sets all pixels brighter than the value you specify to that value.

*How to use/settings*

The Utility | Set Pixel Saturation menu item displays a dialog that asks for the saturation value. For example, if you enter a value of 5000, all pixels brighter than 5000 will be set to 5000.

*Mistakes to avoid*

Be careful not to erase image details by setting this value too low. Use the Show Crosshairs feature to examine the brightness levels in an image. Use File | Revert to Saved if you make a mistake.

## Average Images

### Description

Combines images by calculating the average values for each pixel in each image. Each pixel in the resulting image has a brightness value that is the average of that pixel in all images.

### When to use

Whenever you want to reduce noise in your images, you can do so by averaging images together.

### How to use/settings

For information on using the Averaging features of CCDOps, please see the section "Combining Images."

### Mistakes to avoid

The most common mistake made when averaging is combining images that have different brightness levels. For best results when averaging, combine images of equal exposure and taken under similar conditions. If necessary, use the Pixel Math tool to equalize images before averaging. Add/Subtract to equalize background, and use Multiply/Divide to equalize exposure times.

## Edit Parameters

### Description

Certain information about each image is saved with the image, in an area of the file called the header. You can use the Utility | Edit Parameters menu item to view or edit this information.

### Example
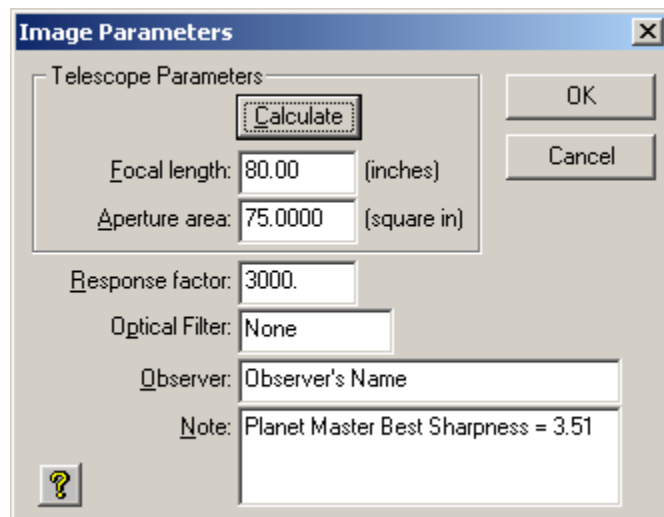


*Setting image parameters.*

### When to use

If you need to know when you took an image, what the exposure time was, and so on, you can get that information here. If you just want to see information about the image and do not need to edit it, use the Display | Parameters menu item.

### How to use/settings

You can use the Calculate button to have CCDOps do the math for you. The figure below shows the FOV calculator that this button displays. Choose your camera and enter the requested information, then click the Calculate button. Then click Done, and the results of the calculation will be added to the parameters dialog.



*Calculating the field of view (FOV)*

### Mistakes to avoid

Some of the information in the Image Parameters dialog comes from default information that you enter. If you want to change the default values, use the Misc | Default Note menu item to change the Note, and the Misc | Telescope Setup menu item to change the default values for Focal length, Aperture, and Observer.

# Crop

### Description

Crop an image to include only the details you want to keep.

### Example
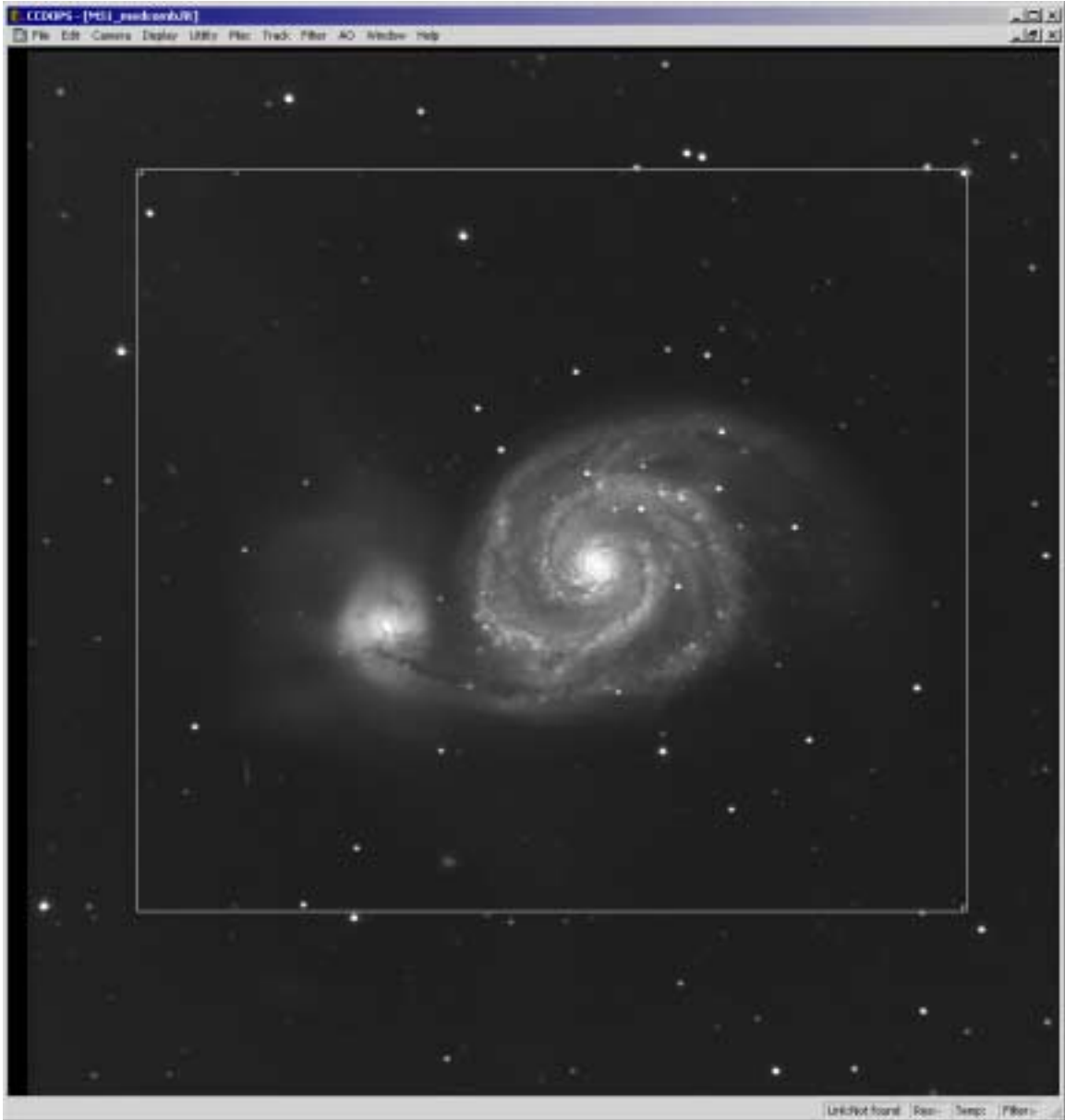


*Cropping an image.*

### When to use

Use Cropping whenever you have portions of the image that you do not want to keep, or to emphasize an object that is smaller than the full image size.

### How to use/settings

There are four types of crop built into CCDOps:

**General**—A custom crop size that CCDOps remembers from session to session.

**Spectroscopy**—A long, narrow crop designed to extract spectrographic data from images made with the SBIG Self-Guided Spectrograph.

**640x480**—A crop that matches a common screen size.

**Half**—A crop that has sides half that of the image. For example, if you are imaging with the ST-8XE, which has an image size of 1530x1020, the Half crop setting will give you a crop box that is 765x510.

**Quarter**—A crop that has sides one-quarter that of the image. For example, if you are imaging with the ST-1001E, which has an image size of 1024x1024, the Quarter crop setting will give you a crop box that is 256x256.

A crop requires two steps:

1. Use the Utility | Crop | <size of crop from above list> menu item to put a crop box on the image. Adjust the size of the box, if necessary, by clicking and dragging the small boxes at the upper left and lower right of the box. Or you can click anywhere in the image and the center of the crop box will jump to that location.

2. Use the Utility | Crop | Crop Image menu item to perform the crop. The area outside the crop box is discarded, leaving just the portion of the image in the box.

If you decide not to make the crop, use the Utility | Crop | Forget the Crop menu item to get rid of the crop box.

**Mistakes to avoid**

The Crop tool permanently changes the image. After cropping, be sure to save with a new filename so you still have your original data.

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**Tip:** A crop window can be display from the Edit menu that shows the precise size of the crop box for greater control.

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