CCDSoft

CCD Astronomy Software

User's Guide
Version 5

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Introduction

Welcome!

CCDSoft™ provides the tools needed to acquire and process your CCD images:

- **Acquire CCD images.** Fully automated imaging (as supported by the camera), including temperature control, autoguiding, multiple-exposure accumulation, dark frame acquisition, and color (LRGB) photography.
- **Automatically focus your CCD camera.** CCDSoft's @Focus technology, when combined with a compatible motorized focuser, allows you to achieve focus quickly and simply.
- **Process bitmap images.** A variety of image-processing techniques (LRGB combine, sharpening, blurring, convolving, masking, combining, and so on) can be applied to images, or folders of images.
- **View images from a variety of file formats.** CCDSoft can read and write to many popular bitmap file formats, including BMP, FITS, GIF, JPG, SBIG imager, TIF and more.
- **Create "slide shows" of your images.** Browse as many images as you like, either manually or automatically.
- **Print your images.** Print to any Windows-supported printer.
- **Access RealSky targets.** Display Digitized Sky Survey (DSS) images from the low- or high-compression DSS CD ROMs.
- **Perform professional-level research.** Search for comets, minor planets, or supernovas, generate reports for the Minor Planet Center, and even generate light curves of stars or minor planets.
- **Integration with TheSky Level IV version 5 astronomy software.** TheSky Level IV version 5 (sold separately by Software Bisque) and CCDSoft have numerous integrated features that are documented throughout this manual.

Minimum System Requirements

- Windows 95™, Windows 98™, Windows ME™, Windows NT™ (SP 6), Windows 2000™, Windows XP™, or later.
- Pentium-class (or faster) processor.
- 16 MB RAM (128 MB or more recommended for processing large-format CCD camera files).
- Mouse (or compatible pointing device).
- 10 MB minimum free hard disk space. Additional space is required for the Portable Document Format (PDF) version of this User's Guide (32 MB) and sample images (60 MB).
- TheSky Level IV version 5.00.014 or later for telescope/focuser/camera integration.

CCDSoft is licensed as a single-user product. Do not install CCDSoft on a network. If you need a site license, please contact Software Bisque.

Please read the contents of the file named `Readme.htm` in the CD ROM root directory. It might have information that was not available when we printed the manual.

Installing CCDSoft

CCDSoft is designed to run under Windows and take advantage of its features. It is not designed to operate under Windows 3.x.

1. Insert the CD ROM in the CD ROM drive.

2. Wait for the installation to begin.
3. Follow the on-screen instructions to complete the installation.

Uninstalling CCDSoft

Removal is easy — Windows does most of the work for you:

1. Click **Start | Settings | Control Panel** (**Start | Control Panel** under XP).
2. Double-click **Add/Remove Programs**.
3. Highlight CCDSoft in the list of installed applications.
4. Click **Add/Remove**.
5. From the InstallShield™ Wizard dialog box, select the **Remove** option and then click **Next**.

You may be asked to confirm the deletion of shared files during uninstallation of CCDSoft. These files can be safely removed from the computer, so click **Yes** when prompted.

Using Help

To display CCDSoft help, click **Help | Contents and Index**, or press `F1`.

To get help on a toolbar button, or any screen component, click the **What's This?** button in the Standard toolbar. Then click on the object you want information about.



Figure 1: What's This? help button.

Product Support

We have conscientiously tried to make this manual complete, accurate, and easy to understand. We ask that you spend a few minutes with the manual (or on-line help) before contacting us. Another valuable resource is the Software Bisque Technical Support Knowledge Base available on the Internet at:

`http://www.bisque.com/kb`

A bit of reading and experimenting should answer your question. If you think you've discovered a bug in CCDSoft, before submitting a technical support request, please check the Software Bisque Downloads page to obtain the most recent version of CCDSoft:

`http://www.bisque.com/download`

Each change and fix to the software is listed on the above web page.

If you're still stuck, or the problem you've encountered has not been resolved in the latest release, please submit a technical support request to:

`http://www.bisque.com/support`

Please have the following information available before submitting a technical support request.

- The exact software version number and serial number. They are displayed by clicking **Help | About CCDSoft**.
- The operating system.
- Your hardware configuration — make and model of computer, processor type and speed, video card manufacturer and model.
- The *exact wording* of any messages that appeared on your screen.
- What you were doing when the problem occurred.
- How you tried to solve the problem.

Despite our valiant efforts, there may be omissions or errors. If you find any, please let us know, and they'll be added to the "ReadMe.htm" file.

Chapter 1: Camera Control

Controlling a CCD Camera

CCDSoft provides a very high degree of control over your CCD camera. Fortunately, you don't need to exercise all of that control to start taking images. As you learn more about CCD imaging, you can use the advanced and specialized features in CCDSoft to gain more control over the imaging process.

To start taking images, you need to learn a few basic steps:

- How to link to the camera with CCDSoft.
- How to focus accurately.
- How to take images.
- How to adjust the appearance of your images so you can evaluate them.

Quick Start For Experienced Users

For this chapter, an experienced user is someone who has already used one or more camera control programs to set up and use a CCD camera. New users should skip ahead to the next section.

The Camera Control Panel is a major upgrade to CCDSoft. If you are already familiar with prior versions of CCDSoft, or if you are an experienced CCD imager, you can work your way through the following checklist to quickly get up and running with version 5 of CCDSoft.

The following steps assume that you have a bright star in the field of view, and that you are focused well enough to see the out-of-focus star's image.

1. Click **Camera | Setup** to display the Camera Control Panel.
2. Select your camera and, if present, filter wheel and/or focuser.
3. Click **Connect**.
4. Click **Temperature**, and set a target cooling temperature. Click the **On** option, and then click **OK.**
5. Click the **Focus Tools** tab and set the bin mode to the largest mode available (for example, **3x3**).
6. Set an appropriate exposure time and then click **Take Image/Series**. Refine focus as well as possible at the large bin mode.
7. Select a subframe by clicking and dragging around a suitable star. Set binning to **1x1**.
8. Check **Continuous**, and then click **Take Image/Series**.
9. Use the graph to refine focus so that you get the highest sharpness or brightness value. We recommend using sharpness as your primary tool for evaluating quality of focus position.
10. Click the **AutoSave** tab. Check the **AutoSave** option, and then select the target folder where images will be saved.
11. Click the **Take Image** tab.
12. Set appropriate values for exposure, frame (image) type, reduction method, number of images in series, filter, etc. Turn off subframe. Click **Take Image/Series**. CCDSoft will take an image, download it, save it to disk, and display it in a window (or take multiple images if the **Series** value is greater than 1).

CCDSoft's Camera Control Panel introduces features that go beyond the tools available in many other programs. Even if you have experience with camera control and image acquisition, we recommend you scan the rest of this chapter for information about the new features. Of most interest to experienced users:

- @Focus, an automated focusing algorithm.
- The **Color** tab of the Camera Control Panel, which provides extremely flexible color imaging capabilities.
- Extensive focusing tips in the manual focusing section.
- A compact, east-to-scan list of the features on all Camera Control Panel tabs in the section "Camera Control Panel Details."
- See "Chapter 7: Image Reduction" for information on the sophisticated image reduction tools in CCDSoft version 5. If you have used other camera control programs, "image reduction" is a more accurate term that corresponds to "image calibration."

Camera Setup and Linking

Before you attempt to link to the camera, run through this checklist to make sure you are ready to begin imaging:

- The camera should be securely attached to the telescope. If practical, attach a safety wire, cable, or strap to catch the camera if it works loose. The camera's power and other cables may tug on the camera as you move your mount, and if the camera isn't completely secure it can work loose.
- All electrical connections should be secure, and power to the camera should be turned on.
- The cable from the camera or control box to your computer should be securely attached, especially if you have a laptop that may get moved about during use.
- Double check the routing of all cables to make sure they will not catch on the mount, telescope, or other accessories. We suggest that you route your cables next to the mount, then along the telescope to the camera. This reduces the free-swinging weight of the cables and will provide a steadier imaging platform. If your mount provides internal routing for cables, make sure all cables attached to the mount are secure.



Some of the features in the Camera Control Panel are only active if you are also running TheSky astronomy software Level IV, version 5.00.014 or later. If you have TheSky Level IV version 5 installed but not running, CCDSoft will when appropriate start TheSky Level IV version 5 to take advantage of these features. The special features are described throughout the chapter. Other features require operator input, and in those cases you will see a message telling you to start TheSky Level IV version 5, as well as any settings you might need to adjust to take advantage of the feature.

Once the camera and the computer are powered up, start CCDSoft and then click **Camera | Setup**. This displays the Camera Control Panel shown in figure 1, with the **Setup** tab active. Select your camera from the **Camera** drop-down list (see figure 2). If you have a color filter wheel installed/attached, select it from the **Filter Wheel** list. If you have a motorized focuser connected to a serial port, or a focuser that TheSky Level IV version 5 can control, select the focuser from the **Focuser** list. See the "Using @Focus" section later in the chapter for detailed information about automated focusing.

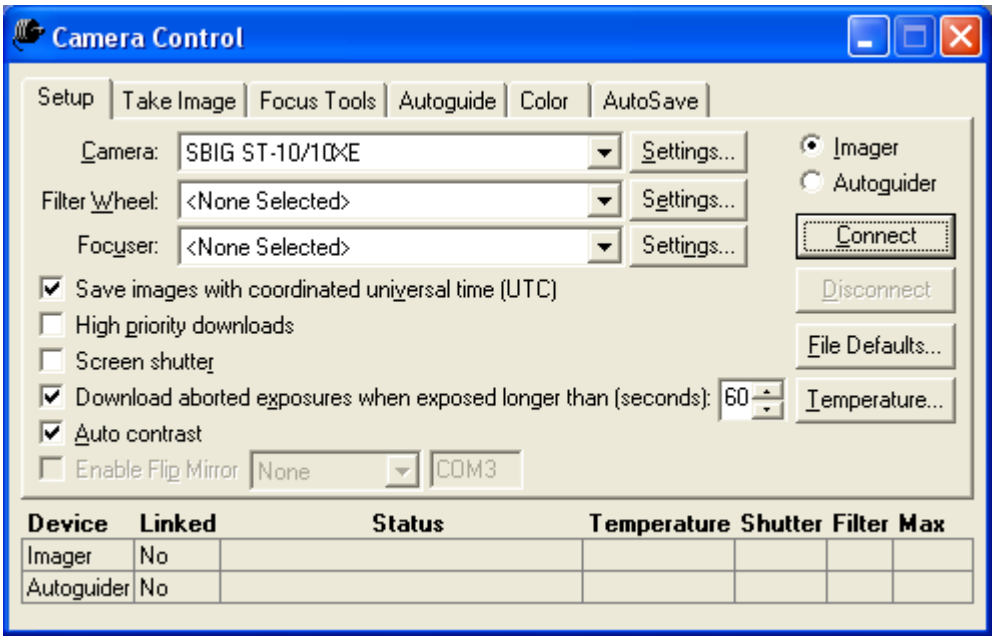


Figure 1: The Camera Control Panel.

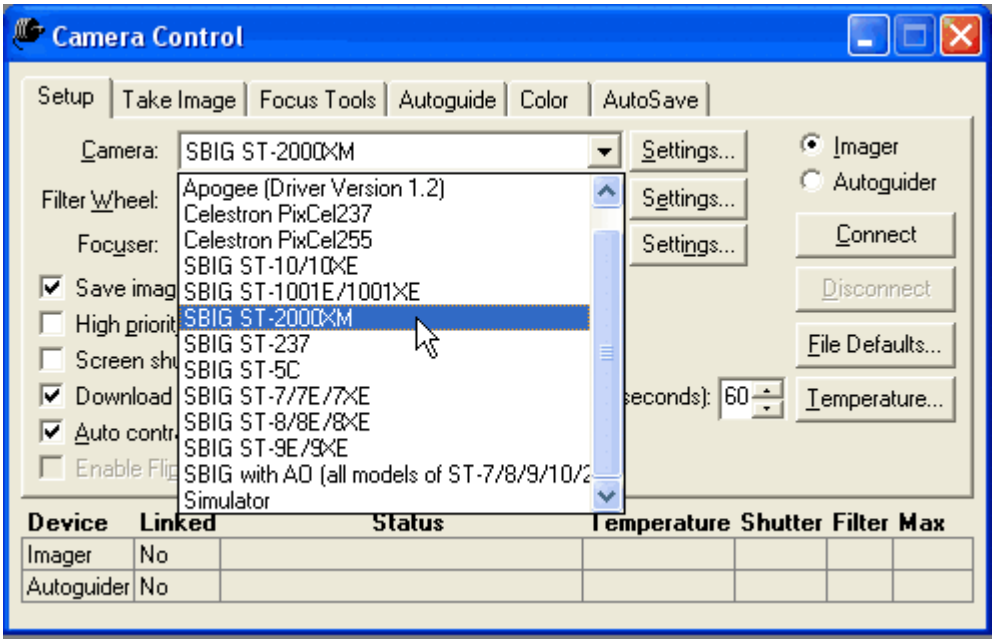


Figure 2: Selecting your camera type.



The Camera Control Panel stays active at all times while you are using the camera. You can still access other CCDSoft features, such as image processing tools, options, zoom, etc., while the Camera Control Panel is displayed. Or you can minimize or close the Camera Control Panel if necessary; it will still maintain the connection to the camera, or continue with autoguiding, focusing, or image acquisition that may be underway. You can re-open the Camera Control Panel to continue working with the camera.

To connect to the camera, click **Connect** on the Camera Control Panel. The Status area at the bottom of the panel will show connection progress, starting with "Attempting connection." If all is well, the appearance of the Camera Control Panel will change to show the current settings relating to the connection to the camera. Figure 3 shows a successful connection with an ST-237 camera. If your CCD camera has a built-in autoguider, you will see information about the autoguider as well. See the section "Camera Control Panel Details" later in this chapter for complete information about the many tools and features in the Camera Control Panel.

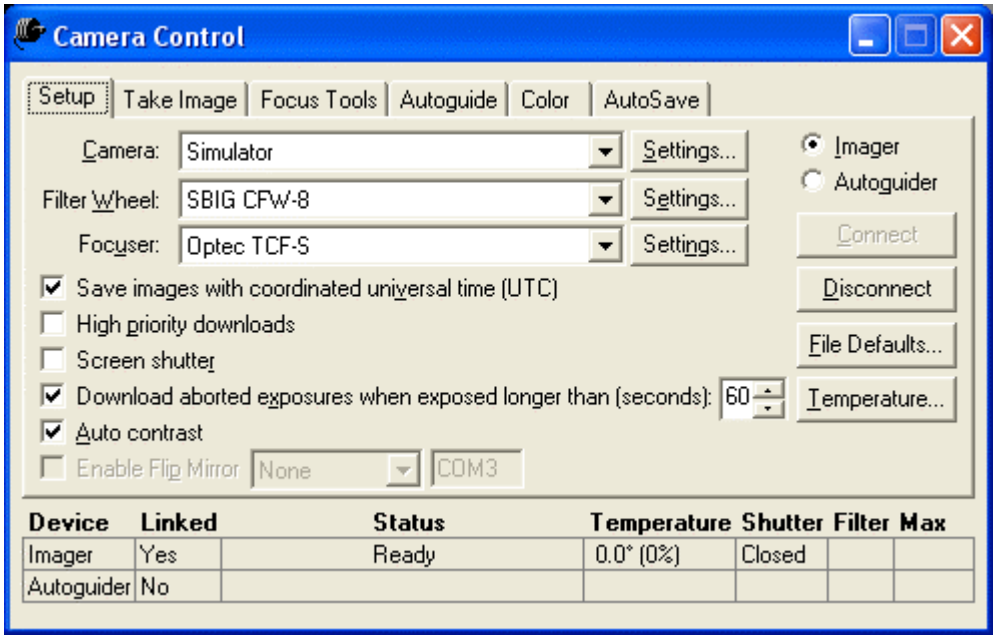


Figure 3: When your camera is connected, the status column shows "Ready."



The Temperature column in figure 3 shows the current ambient temperature (in degrees Celsius). If your camera has internal cooling, you'll need to set the cooling temperature before you take any images.

Temperature Control

CCD detectors have a small but significant amount of noise. Cooling the detector reduces this noise dramatically, so nearly all CCD cameras used in astronomy have some form of cooling. The **Temperature** button in the Camera Control Panel allows you to set the level of cooling for your camera.

Clicking on the **Temperature** button displays the Temperature dialog box (see figure 4). Click the **On** option to turn temperature regulation on. Then set an appropriate temperature for your camera, taking into account the ambient temperature and your camera's cooling capabilities. Figure 5 shows the settings for an ST-237; the setpoint is minus 2.5ºC. Your settings will vary depending on your camera's cooling capabilities and the ambient temperature.

Click **OK** to turn on cooling.

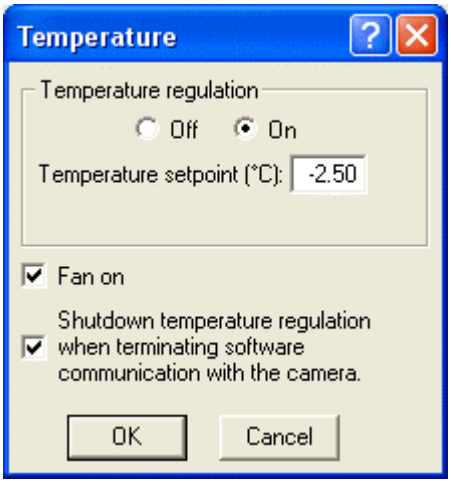


Figure 4: The setpoint you enter in the Temperature dialog box will vary with the ambient temperature.



The Temperature dialog box recommends a setpoint on cameras that provide ambient temperature data to CCDSoft, but you can also calculate it for yourself. Generally speaking, you want to set the cooling setpoint so that approximately 75-85% of the camera's cooling capacity is used to maintain that temperature. This leaves a sufficient reserve cooling capacity to quickly respond to changes in ambient temperature.

By keeping some cooling capacity in reserve, the camera can maintain the setpoint more accurately. Your camera documentation will contain information about the maximum cooling capacity of your camera, typically expressed in degrees below ambient temperature. For example, the ST-7E camera has a cooling capacity of 30 degrees below ambient. To calculate an optimal setpoint, take 75% of 30, and subtract it from the ambient temperature. For example, if the ambient temperature is 15 degree Celsius, and 75% of 30 is 22.5, then your target temperature is 15-22.5, or -7.5 degrees. If you were working with the ST-237 camera, cooling capacity is 25 degrees below ambient, so your target temperature is -2.5C. In the real world, cooling capacity will vary somewhat. As long as your values stay in the 75%-85% range, you are going to get good results.

Now that you have established a cooling setpoint, the Camera Control Panel will show you the current temperature of the detector. It will also display percentage of the camera's cooling capacity in use for cameras that provide this information. Figure 5 shows the results of applying the settings from figure 4 for an ST-237 camera. Note that the temperature of -2.7ºC results in using 79% of cooling capacity. This is within acceptable limits of ±5% of 80%.

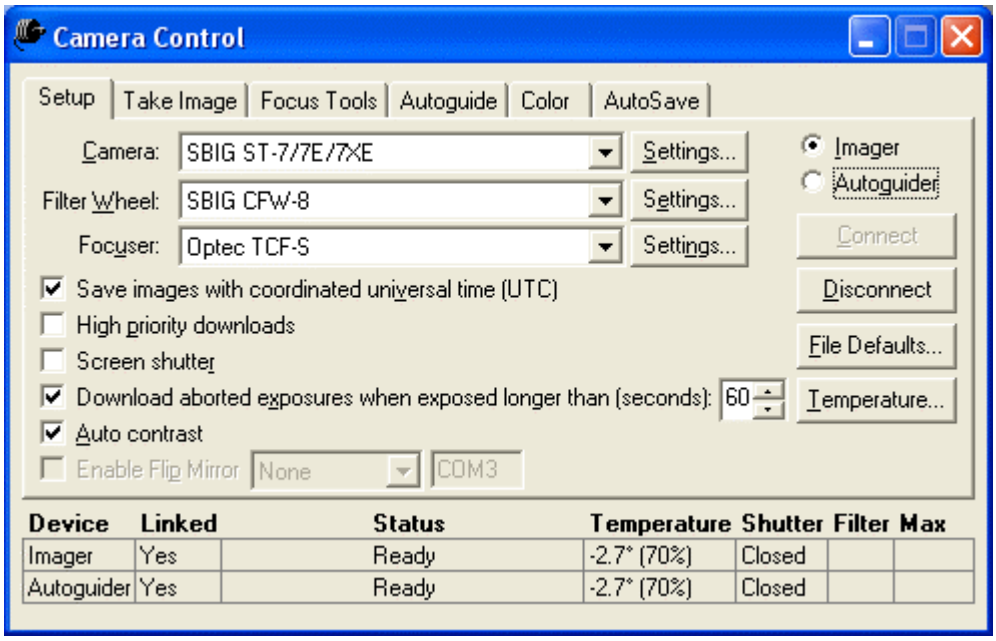


Figure 5: After a few minutes, the detector temperature has reached the setpoint: -2.7ºC for the imaging detector. 70% of cooling capacity is being used.

The camera's cooler requires several minutes to reach to the specified setpoint. We suggest that you let the camera adjust the temperature for 10-20 minutes before imaging whenever possible. This will help the camera achieve the most stable temperature.

Why is a stable temperature important? Dark frames are normally used to remove noise from images. This is explained later in this chapter, in the section "Image Reduction Fundamentals," and in more detail in "Chapter 7: Image Reduction." Maintaining constant temperature during both the imaging and dark frame exposures is important for proper image calibration. Otherwise, the noise subtraction process will not be as effective. Temperature is the largest factor in dark current, and dark current is the largest factor in image noise.

Note the following about the settings in the Temperature dialog box:

- Remember to select **Off** or **On**, as appropriate.
- If the setpoint you choose is too high, the camera will operate at 100% of its cooling capacity, and will not reach the setpoint temperature. This does not harm the camera or its cooler, but it does cause unreliable temperature regulation and your images will not be as well corrected when you apply image reduction. Remember that temperature is the largest factor in dark

current. If the temperature varies, the dark current will vary, and dark frames will not correct for the dark current effectively.

- The recommended setpoint is just that: a recommendation. The actual cooling performance of individual cameras varies. Observe your temperature and cooling capacity after about 5-10 minutes, and adjust accordingly. Aim for using approximately 75% of the camera's cooling capacity. If the camera uses 90% or more of its cooling capacity, the text displaying the temperature is displayed in red on the Camera Control Panel. This indicates that the camera's cooler is working too hard.
- Clear the **Fan On** option to turn of the camera's cooling fan. This may be desirable when controlling the AO-7 device to minimize vibrations.
- The checkbox for **Shutdown regulation upon disconnect** should normally be left checked. This setting causes the detector to be warmed up slowly during shutdown. Fast temperature changes stress the CCD detector. By using the cooler to slowly warm up the detector, you help maintain it in top operating condition.



If you are setting up the camera early in the evening, and expect to do the bulk of your imaging later when the air is cooler, you can start cooling at 85% of capacity, knowing that as the air cools you will gradually get to 75% of capacity, and perhaps even lower if you image late into the night. Keeping this single temperature allows you to make use of a single set of dark frames, and is a workable compromise unless you need a high degree of brightness accuracy (such as for photometry; see "Chapter 8: Research: Astrometry and Photometry." See the section on "Image Reduction Fundamentals" for more background on this concept.

The camera is now ready to operate. The next step is to use the built-in focusing features of CCDSoft to reach the point of critical focus.

Focusing Principles

The human eye is a marvelous instrument. Not only can it follow rapidly moving objects, but it can also adjust focus in real time, compensating for minor focus drift or out of focus conditions. The eye is a very forgiving focuser, in other words.

The CCD camera, on the other hand, is a very unforgiving measurer of focus. Cameras require very precise focus to get sharp, detailed images. Precise focus is also important for research (astrometry and photometry).

CCDSoft has features that will allow you to achieve the best possible focus. But there are also mechanical considerations about focus that play a role in how effectively you can achieve that "sweet spot" called *critical focus*.

"Critical focus" is a range of focal positions, not just a single point along the focuser's range of travel. Even at critical focus position, stars are not usually imaged as single points of light; atmospheric turbulence and other factors spread out the star's image on the CCD detector. Critical focus is the range of focus positions that provides the best possible focus and is dependent upon the focal ratio of your telescope.

The focal ratio alone determines the size of your critical focus zone. The zone of critical focus becomes shorter with lower, "faster" focal ratios. For the purposes of focusing, a fast focal ratio is f/6 or lower; a slow focal ratio is greater than f/6. The focal ratio is the ratio of the telescope focal length to the aperture.

For example, a telescope with an aperture of 100mm and a focal length of 500mm has a focal ratio of f/5. Lower-numbered focal ratios are said to be “fast” because they require shorter exposure times.

Figure 6 shows light cones for fast (f/5) and slow (f/10) telescopes. The front of a hypothetical telescope is at left. Light enters from the left, and is brought to a focus where the converging lines cross.

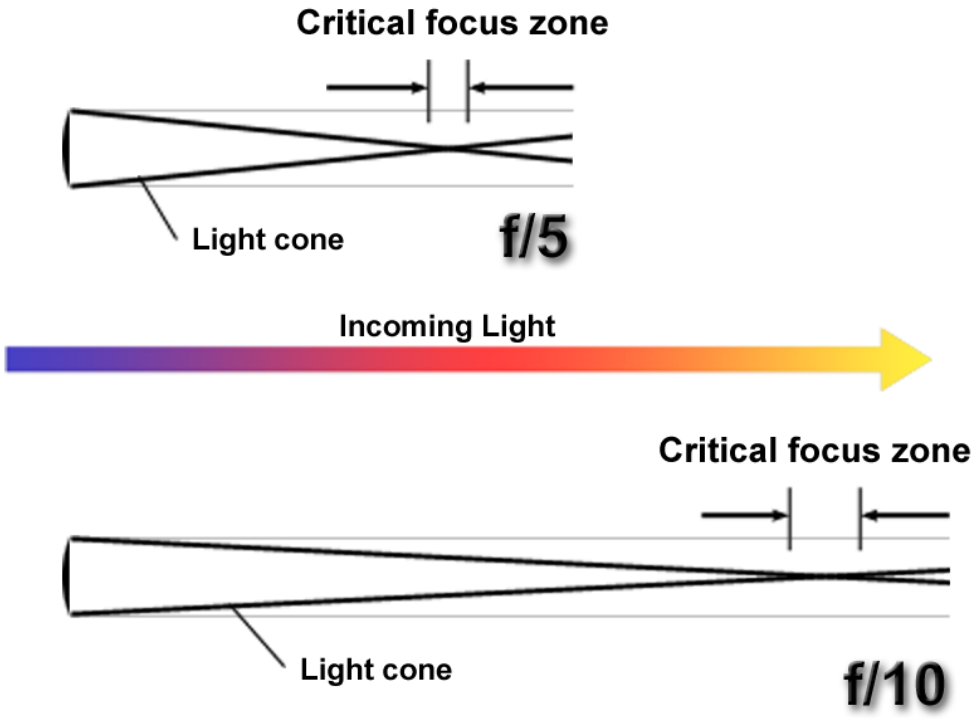


Figure 6: The focal ratio of your telescope determines the length of the critical focus zone.

The f/5 light cone is very steep; as you move away from the front of the telescope, the light converges to focus very quickly. The f/10 light cone is shallow, and does not converge as rapidly as you move away from the front of the telescope. For all telescopes, the light diverges again past the focal point. The telescope’s focuser, manual or motorized, moves the CCD camera back and forth. The CCD detector inside the camera must sit within the critical focus zone to get a sharp image. To bring the CCD camera to focus, the focuser moves the camera so that the CCD detector is within the critical focus zone, as shown in figure 6b.

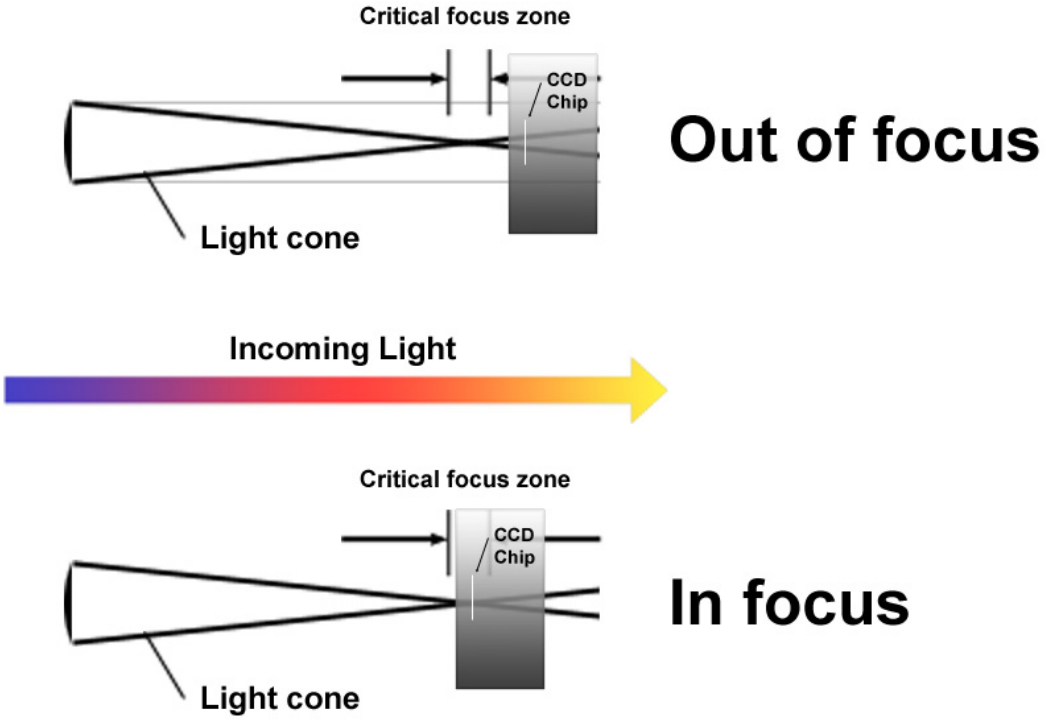


Figure 6b: Moving the camera into the critical focus zone.

This means that telescopes with fast focal ratios have a shorter critical focus zone, and thus they are more challenging to focus manually. You can improve your ability to focus a fast telescope by adding a motorized focuser. CCDSoft includes a focusing utility, @Focus, which is capable of making extremely small focuser movements limited only by the minimum step size of a motorized focuser. Fast telescopes are also more susceptible to anything that will cause focus drift, such as falling or rising temperatures. A motorized focuser can also help you adjust focus throughout a long imaging session.

The slower your focal ratio, the longer the critical focus zone and the easier it will be to find focus.

When the seeing is very good (i.e., the atmosphere is stable), star images hold steady and are very small and sharp. As the seeing deteriorates, star images begin to bloat and lose their hard edge. This makes measuring focus more difficult, and CCDSoft's automatic focusing tool, @Focus, may not converge on the best focus position under poor seeing conditions. Manual focusing is also harder to achieve under poor seeing conditions (turbulent atmosphere).



If the zone of critical focus is very short, you may find it difficult to achieve critical focus reliably or easily using a manual focuser. You can purchase various types of motorized focusers that can help with this problem, including some that have digital readout of focus position. A motorized focuser can provide smaller adjustments in many cases than you can do by hand, and is thus better at making the small adjustments that position the CCD detector inside the critical focus zone. To get useful results from a motorized focuser, it should enable you to make movements that are at least one-half the size of your zone of critical focus on nights of optimal seeing conditions. For optimal focusing, look for a focuser that will move in increments that are one-quarter or less the size of your critical focus zone.

The equation below computes the size of the critical focus zone (CFZ) in microns for a “perfect” optical system that is perfectly collimated:

$$CFZ = focal_ratio^2 * 2.2$$

So for a C-14 that is f/11:

$$CFZ = 11^2 * 2.2 = 266$$

266 microns is 0.266 millimeters or 0.01 inches. Here’s an example with an f/5 focal reducer on the C-14, making it effectively an f/5.5 system:

$$CFZ = 5.5^2 * 2.2 = 66.5$$

66.5 microns is 0.0665 millimeters or 0.0026 inches. Note that the critical focus zone is now one quarter that of the longer f-ratio system. This means that if you reduce the focal ratio by half, you reduce the close focus zone to one quarter. Note: real world values are approximately 10%-30% greater than the theoretical values above.

CCDSoft includes two methods of focusing: automatic using @Focus, and manual focusing. To use @Focus, you must have a computer-controlled focuser (for example, RoboFocus or Optec TCF-S), or a motorized focuser controlled by your mount (for example, JMI NGF-S or MotoFocus connected to a Paramount GT-1100, LX200, or Astro-Physics GTO). The smallest step size of your focuser must be smaller than the critical focus zone in order to use @Focus reliably. A good rule of thumb is to have a focuser step size that is no larger than one quarter of the critical focus zone.

To access CCDSoft’s focusing features, click the **Focus Tools** tab on the Camera Control Panel. Figure 7 shows the layout of the **Focus Tools** tab. See the section “Focus Tools Tab” at the end of this chapter for a complete description of all of the features of the **Focus Tools** tab.

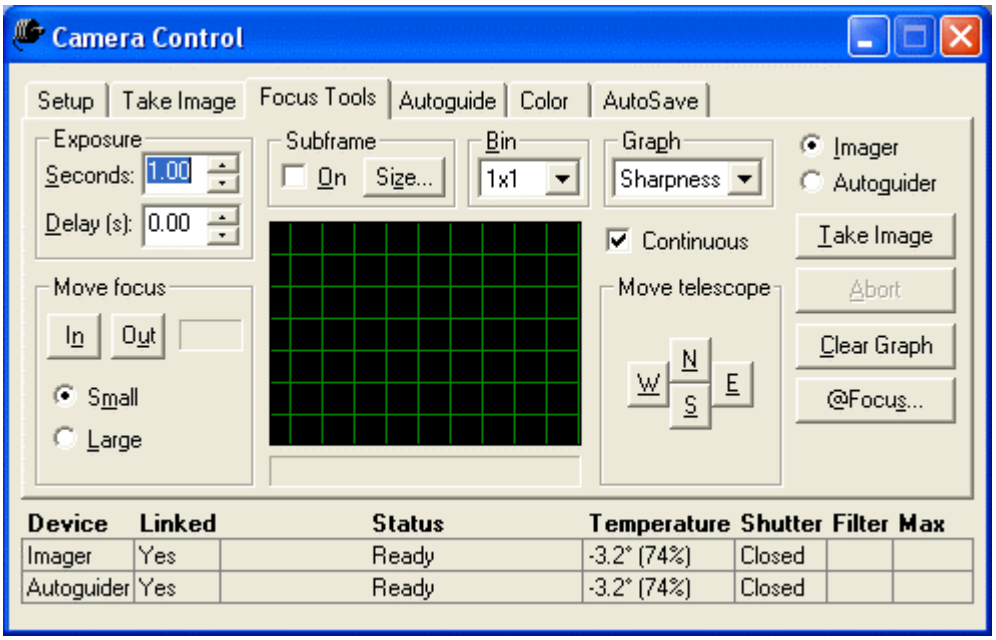


Figure 7: The Focus Tools tab of the Camera Control Panel.

Using @Focus

@Focus (pronounced “at focus”) is an automatic focusing algorithm. You first use manual focusing to get close to focus, and then @Focus does the hard part by optimizing the position of CCD detector in the critical focus zone. @Focus requires a focuser than can be controlled by TheSky Level IV version 5, or one that is directly to your computer and has a CCDSoft-compatible focus driver installed. The list of supported focusers can be seen in the **Setup** tab of the Camera Control Panel, in the **Focuser** list. The list of supported cameras at the time of writing includes:

Focuser	**Description**
FocusAPI	If you have developed your own focus hardware, you can write your own driver so that CCDSoft can control your focuser. Please contact Software Bisque for specifications on the FocusAPI.
Optec TCF-S	The TCF-S focuser connects to your computer’s serial port. It provides absolute focus position feedback to CCDSoft for optimal automated focusing.
RoboFocus	The RoboFocus connects to your computer’s serial port. It provides focus position feedback to CCDSoft and can be adapted to many different types of focusers.
JMI SmartFocus	The JMI SmartFocus is a stand-alone focuser that connects to your computer’s serial port.
TheSky’s Focuser	Several mounts, such as the Paramount ME, Astro-Physics GTO series, and Meade LX200 series, allow you to control focuser position through TheSky Level IV version 5. These focusers do not provide absolute position information back to CCDSoft. However, in the case of the Paramount ME, relays control the focus motor and give excellent focus positioning.

You can use the entire image or a sub-frame with @Focus. Sub-frame focusing is much faster and is almost as reliable as full-frame focusing. When you are far from focus, a full frame works better than a subframe. If you start close to focus, a subframe will give very good results.

The basic steps involved in using @Focus are:

Step 1: Get close to the critical focus zone.
Step 2: Click **@Focus** on the **Focus Tools** tab of the Camera Control Panel. Set the @Focus parameters to match your equipment's capabilities.
Step 3: Tell @Focus whether to start by moving in our out. If you are uncertain about direction, pick a direction at random and let @Focus figure it out. @Focus may take a few moments longer if the initial direction is not toward focus.
Step 4: Run @Focus, and verify that it finds the best focus position.



Before using CCDSoft to control a focuser (via TheSky Level IV version 5 or later), you must first launch TheSky, click **Telescope | Server Settings** and then mark the **Allow Remote Connections** and **Allow Remote Focus** options. This grants CCDSoft permission to access hardware that is controlled by TheSky.



If you are using TheSky to control the focuser, some options must be set in TheSky, such as large and small step sizes for moving the focuser.

@Focus automates the focusing process, but it needs an accurate focuser and appropriate settings to be successful. @Focus requires ample image data to reach accurate focus. The following table lists what conditions @Focus needs for the best possible results. It also describes what happens when conditions are less than ideal.

Condition	Description
Mechanical quality in the focuser	**Best case:** The focuser should have virtually no backlash, and be able to be positioned with an accuracy of one half or less the size of the critical focus zone. (Backlash is free play in the focuser mechanism.) **Potential issues:** Poor mechanical quality in the focuser results in an inability to position the point of focus accurately. Typical mechanical quality issues include: · Backlash (looseness) in the focuser, which results in varying movement when reversing direction. · Varying voltage levels in the mount or the focuser, which results in variable movement of the focuser. · Non-orthogonality (focuser does not hold camera square to the optical path), which results in image distortions that make it harder to define the best focus position.
Position feedback from the focuser	**Best case:** If the focuser reports its actual physical position to CCDSoft, this allows CCDSoft to position the focuser with a very high degree of accuracy. The TCF-S focuser, for example, matches numeric values to specific focuser positions. Zero always means that the focuser is fully in; 3,500 is exactly halfway; and 7,000 always means the focuser is fully out. **Potential issues:** Focusers that do not report their position do not allow

	CCDSoft to reliably position the focuser. These include the NGF-S, RoboFocus, etc. Some focusers, such as the NGF-S with DRO and RoboFocus, report a number but the number does not necessarily correspond to a physical focus position. For example, if the focuser reaches its end of travel, and the motor continues to turn, the numbers continue to change but focus position does not. See the section on "Focuser Types" below for additional information. There can also be delays within the device that communicates with the focuser. Some mounts, such as the LX200, introduce variable delays while processing focus commands. Because the length of the delay cannot be predicted, the effects on @Focus are variable and do not allow @Focus to reliably position the focuser.
No movement in the optical system	**Best case:** Nothing in the telescope/camera system moves, other than the motorized focuser controlled by CCDSoft. **Potential issues:** If you have a moving primary mirror, a movement of the mirror (even a very small one) will not only change focus, but will change the field of view as well. A mount that tracks poorly, or that is not well aligned to the celestial pole, can also change the field of view. Both effects confound the data collected by @Focus, and that may make it impossible for @Focus to get into the critical focus zone. Locking down the mirror in an SCT, and adding something like an NGF-S Crayford-style focuser, usually helps. Focusers that focus by moving the primary may or may not have sufficient accuracy to work well with @Focus. If any part of the focuser has backlash, it becomes very difficult for @Focus to move the focuser reliably. Experiment with different backlash settings in the Setup dialog box for your focuser to see which works best.
@Focus parameter settings	**Best case:** @Focus must be tuned to the focal length of your telescope, the focal ratio, the speed of your focuser, and other factors in order to perform effectively. These factors are described in detail in the section "Set @Focus Parameters" later in this chapter. **Potential issues:** If the large step size is too small, @Focus will not see much difference from one focus position to the next, and may judge focus prematurely. If the large step size is too large, @Focus may miss focus entirely by passing over it without generating enough data to know where best focus is. See the "Set @Focus Parameters" section for additional information.
Very good to excellent seeing	**Best case:** Steady seeing with minimal changes in apparent focus quality allows @Focus to converge upon focus quickly and easily. **Potential issues:** If the seeing is poor, the noise level in the focusing data makes it difficult to measure focus. A high noise level tends to make it more difficult for @Focus to determine focus. The averaging parameter allows @Focus to accommodate nights with poor seeing by averaging images and effectively averaging the noise. @Focus will take longer to find focus when averaging is high. @Focus will often work under surprisingly poor seeing, but we recommend that you monitor focus quality when the seeing is average or worse.
Dark skies	**Best case:** Dark skies without serious light pollution, moon glow, or sky glow.

	Potential issues: Any kind of sky illumination can decrease the signal to noise ratio in your images. The ultimate impact of a bright sky depends on whether you are using a light pollution filter, how bright the objects in the image are, and other factors. A bright sky by itself is usually not enough to confound focusing, but it can team up with other issues and make those problems harder to deal with.

Focuser Types

@Focus can either communicate directly with a motorized focuser, or use TheSky's focus control via mounts that support focusers (for example, the Paramount ME). There are two types of motorized focusers available:

- Focusers that have positional feedback. The Optec TCF-S is an example of this type of focuser. These focusers can be positioned with repeatable accuracy. They are the best type of focuser for critical focusing because when @Focus says, "go to a specific position for best focus," the focuser goes to ***exactly*** that position.
- Focusers that do not have positional feedback. Typically, the focuser is pulsed for a brief period of time by the mount. These focusers can be positioned with variable success, depending on how accurate the mount's pulse length is; how long it takes the mount to send the pulse (latency); how much backlash the focuser has, and other electrical and mechanical factors. When @Focus says, "go to a specific position for best focus," the focuser ***may or may not*** be able to go to that position.

@Focus is extremely reliable with focusers that provide positional feedback. Other types of focusers, and various combinations of focusers and mounts, provide varying degrees of success with @Focus. The current list of compatible focusers, in roughly the order of quality of focus provided, includes:

- **Best:** Optec TCF-S. This is the serial-port model; the TCF version cannot link to a computer. Contact Optec to have your TCF converted to a TCF-S.
- **Very Good:** JMI SmartFocus or RoboFocus attached to a Paramount ME mount.
- **Good:** JMI NGF-S attached to an Astro-Physics GTO series mount. Small delays may occur in making position changes; verify quality of final focus.
- **Fair:** JMI NGF-S attached to a Meade LX200. Key problems include delays in carrying out focus position changes, and variable voltage applied to the focuser motor. Both problems result in random errors in positioning. You should use the methods described later in this chapter to evaluate the quality of focus before imaging. If you cannot achieve focus with a non-positional focuser, bypass the LX200 and use a focuser than can be controlled by your computer's serial port.
- **Variable:** RoboFocus attached to your computer's serial port. Since the RoboFocus controls the existing focuser on your telescope, the results you get with a RoboFocus depend heavily on the quality of your telescope's focuser.

In addition to those listed above, other focusers from third parties will become available over time. @Focus has an open-ended architecture. Software Bisque provides a focusing API (Application Programming Interface) for companies to develop custom device drivers for their focusers. Please contact Software Bisque for specifications on the FocusAPI.

Keys to @Focus Success

There are some things you can do to get the best possible results with @Focus. Keep in mind that not all motorized focusers are accurate enough to work with @Focus. @Focus uses extremely small movements to adjust focus, and not all focusers are capable of making such small adjustments accurately.

Here are some suggestions for getting the most out of @Focus:

1. Use a focuser with an absolute minimum of backlash. The greater the backlash (free play or looseness), the less likely the focuser is to achieve accurate, repeatable focus. @Focus attempts to correct for backlash problems, but the less backlash, the better the results. If your focuser has too much backlash or other problems, @Focus should get you close, and you can manually refine focus following the @Focus run.
2. Use a focuser that provides accurate, absolute position feedback to @Focus (for example, Optec's TCF-S).
3. If your telescope uses a moving primary mirror for focus, lock down the primary mirror and use a motorized focuser such as the JMI NGF-S. Motorized focusers that move the primary mirror are among the least likely to be successful with @Focus.
4. Make sure that focus can be reached within the travel of the motorized focuser controlled by @Focus.
5. Set the correct small and large step sizes for focuser movement (see "Step 2: Set @Focus Parameters" for details on step sizes). The large step size must be large enough for @Focus to be able to detect changes in focus, and yet small enough so that @Focus does not completely move through focus in less than three steps. See the detailed information on step sizes in the section "Set @Focus Parameters" below.
6. Your mount must be well aligned to the celestial pole. Software Bisque's TPoint software, sold separately, can quantify polar alignment and is ideal for imaging. If objects drift in and out of the field of view during @Focusing, this will affects the sharpness values and could lead to spurious results. Minor drift will not have significant impact, but objects moving into and out of the field of view can cause problems.
7. There must be at least one (preferably more) object in the image. A single star usually leads to successful focus, but several stars are more effective. @Focus can also focus on extended objects, such as the moon, planets, galaxies, etc. The ability to focus on non-stellar objects may vary with the capabilities of your focuser and mount, however.

Step 1: Get Close to Focus

@Focus is designed to handle the hardest part of focusing: getting into the critical focus zone. Before you use @Focus, you need to get the focus position close to the critical focus zone. Here are some techniques you can use to get close:

- Move the focuser to a known good focus position. This technique works best with telescopes that allow you to physically see the position of the focuser tube, such as a refractor with rack and pinion focusing. Telescopes with internal focusers, such as many stock Schmidt-Cassegrains (SCTs), cannot use this method.
- Use an eyepiece that is parfocal with your CCD camera. (A parfocal eyepiece comes to focus at the same position as your CCD camera.) This can be an eyepiece manufactured specifically to match a certain camera, such as an IFocus eyepiece from Software Bisque, or an eyepiece that has been marked or modified to be parfocal.
- Adjust focus while using the Camera Control Panel's **Focus Tools** tab in continuous mode.



How close should you be to perfect focus before running @Focus? For the fastest @Focus run, start away from focus (about four times the large step size). This assumes that the large step size is set accurately; see the section "Step 2: Set @Focus Parameters" for details. Typically, the recommended starting position will show many stars in your image as hollow circles or doughnuts. See below for information about determining the large and small step sizes.

@Focus can find focus even if you do not start at the preferred focus point. It will just take a few moments longer while @Focus determines which direction improves focus.

Figure 8 shows an example of a good starting point for an @Focus run. The image was taken with an SBIG ST-8E camera, binned 3x3. Binning provides faster downloads, and it's an effective way to speed up the rough focusing process. However, for the hardcore astronomer going for the best focus, we recommend 1x1 binning for @Focus. The medium-bright stars are clearly small doughnuts with central holes. Brighter stars often don't display doughnut holes because the default image histogram settings (see "Chapter 9: Image Processing") tend to hide it.



Once you know your large step size (see "Step 2: Set @Focus Parameters" below), you can determine the starting point for an @Focus run quickly. The ideal starting point for a fast focus is about 4-5 large steps away from the critical focus zone.

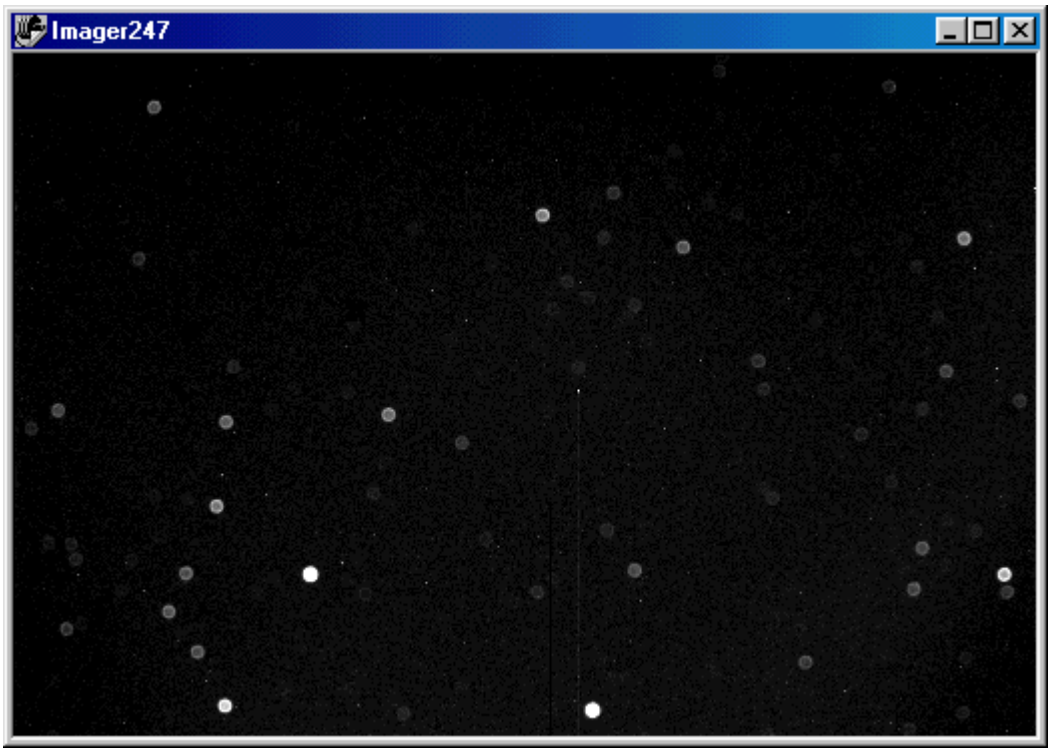


Figure 8: A good example of a starting point for @Focus.

@Focus works well with a small subframe (small white box in figure 9), even if there is only one star in the subframe. Generally speaking, @Focus is somewhat more “touchy” with less data (such as having only one star available). If you want to use a subframe, start the @Focus run closer to focus. If seeing conditions or the capabilities of your system won’t give you good focus with a single star, enlarge your sub-frame to include 3-5 stars, or more, as needed. To select a subframe, simply click and drag in the focus image to outline the area you want to use for a subframe (see figure 9) and continue with focusing. Only the data from the subframe will be downloaded. A subframe downloads much faster than a full frame, and can greatly speed up the focusing process.



Figure 9: Selecting a sub-frame.

If you include a bright star and a relatively dim one in the sub-frame, you can use the dim star to visually check the quality of focus. Dim stars often occupy little more than a few pixels when focus is accurate. Dim stars may not be obvious, as shown at left in figure 10. There are two very faint doughnuts to the left of the bright star. The right side of figure 10 shows the appearance of the same field of view at perfect focus. Not only are the two dim doughnuts now resolved into small, bright stars, but several other dim stars are visible as well. The left image in figure 10 is typical of a good starting point for @Focus. The right image is a good example of the kind of focus accuracy possible using @Focus.

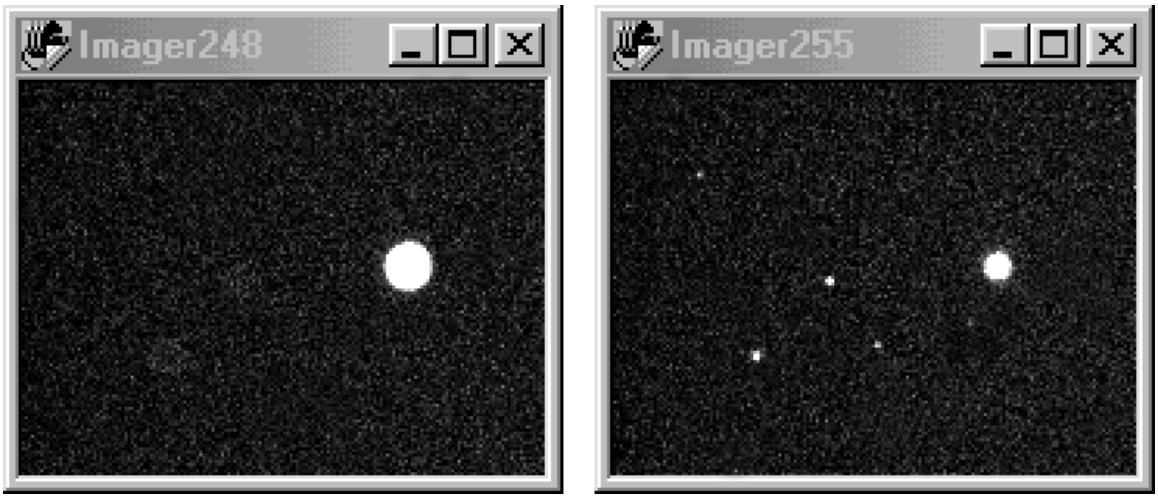


Figure 10: Using dim stars to evaluate the quality of focus.



Seeing conditions may have a significant impact on your ability to use faint stars for evaluating focus quality. This is especially true at longer focal lengths (greater than about 1500mm). The seeing may reach a point where fluctuations from turbulence scatter the light so much that it appears that you aren't at good focus. However, @Focus will still be able to find the best possible focus for the seeing conditions. Even on nights with very poor seeing there is a position of optimal focus. If the seeing is poor, and the best focus you can reach isn't good enough, switch to a shorter focal length if possible, or image when the seeing is better.

Step 2: Set @Focus Parameters

If you have followed the guidelines in the "Keys to @Focus Success" section, you are ready to configure @Focus for optimal focusing with your system. There are two places where you set @Focus parameters. Parameters that don't change often, or that are specific to your focuser type are found on the Setup tab of the Camera Control Panel (see figure 7). Click **Settings** to open the Settings dialog box for your focuser. Figure 11 shows samples for two serial-port focusers, the Optec TCF-S (left) and the RoboFocus (right). Different focusers support different parameters, so the appearance of the dialog box will be different for other focusers.

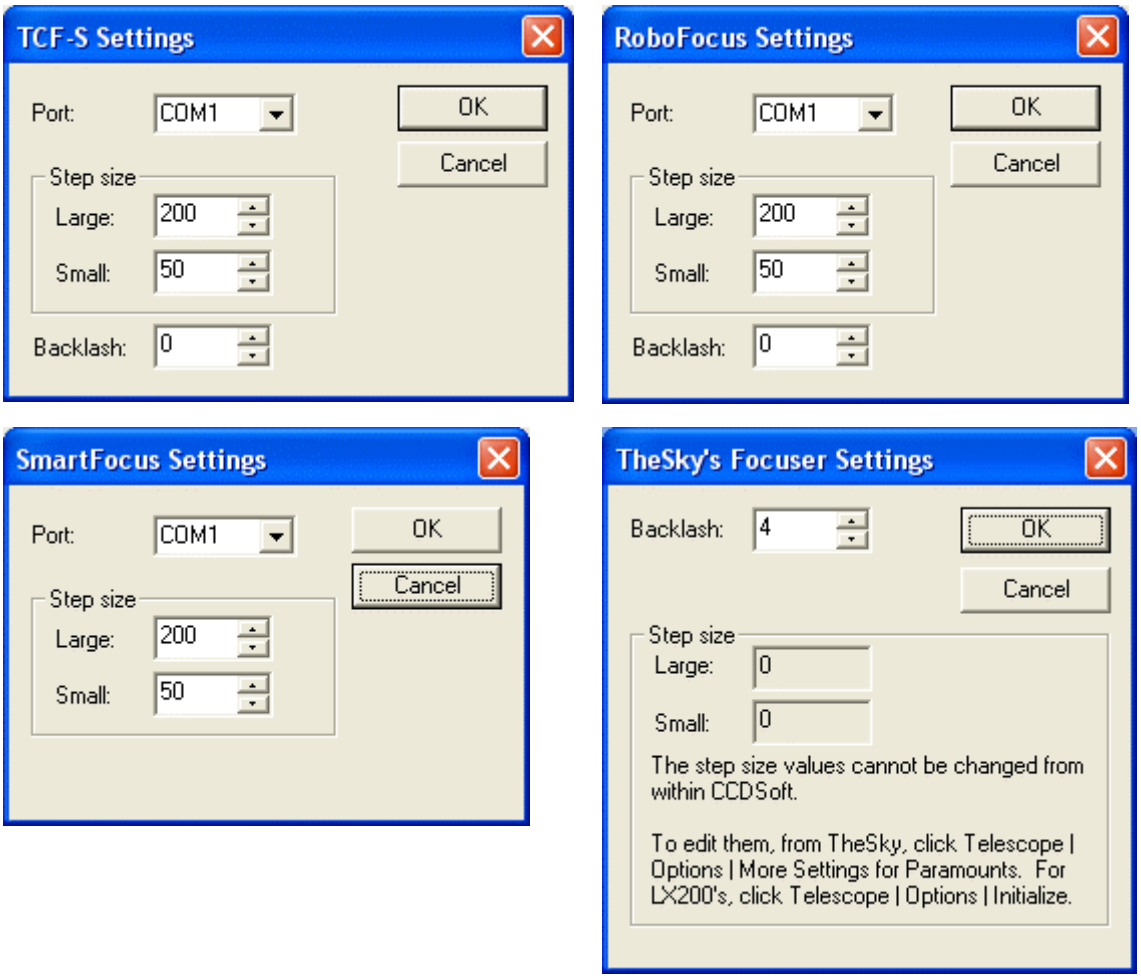


Figure 11: Setting @Focus parameters.

Parameter settings that change more frequently are included on the @Focus Setting dialog box, which opens each time you click on the **@Focus** button on the **Focus Tools** tab of the Camera Control Panel (see figure 12). When you click **OK**, @Focus starts a focusing run. We suggest you review the detailed information about the various parameters below before you try your first focusing run, as you may need to adjust some of these parameters to suit your system.

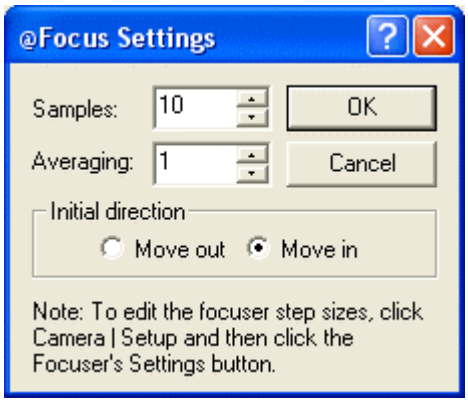


Figure 12: Setting @Focus parameters.

Focuser settings and @Focus settings are described in this section. The following list includes the parameters you may encounter using @Focus. Depending on the focuser you are controlling, however, some parameters may not be available.

Samples – This is the number of images @Focus will use to achieve best focus position. The available range is 10 to 50. For most applications, a value of 10 will give you good results. @Focus requires at least 3 samples on each side of the critical focus zone. For critical applications, you can increase the sample number, but you will need to reduce the large step size and the averaging parameter at the same time.

Averaging – This is the number of images per sample. Averaging can help when seeing is poor. For good to excellent seeing conditions with a high-quality focuser, a value of 1 is usually satisfactory. For poor to average seeing, a value of 2 or 3 is a good compromise between speed and quality. When the seeing is creating serious problems, averaging 5 or even 10 images will smooth out the Sharpness curve significantly, although it will take longer for @Focus to converge upon focus. You can also use averaging when the seeing is good to reduce the overall noise level in the focusing data. Experiment to determine the optimal setting for your system. Generally, the smallest setting that regularly achieves excellent focus is the right value to use. We recommend starting with the default values, then change settings one at a time to see what affect that has on focus quality.

Initial direction – This is the direction that @Focus moves the focuser when it begins the focusing run. If you know the direction to move for better focus, click the appropriate option. This works best when the starting position is about 4-5 large steps away from best focus. If you don't know the direction to move, let @Focus figure it out. @Focus initially attempts to determine which direction to move for better focus. If it is moving in the wrong direction, @Focus will recognize this and reverse. See the section Step 3: Choose Starting Direction later in this chapter for more details.

Large step size – This is the number of steps that @Focus will move the focuser when performing a focusing run. Setting the large step size requires some analysis of the behavior of your telescope/mount/focuser system, and is covered in detail below. If you set TheSky as your focuser type, you must change the large and small step sizes using TheSky. For the LX200 and compatible telescopes, click **Telescope | Options | Initialize**, and then click **Focus Settings** to set your large step size. For the Paramount GT-1100, click **Telescope | Options | More Settings**, and then change focus step sizes.

Small step size – This is a smaller step size that is used to position the focuser once @Focus has determined the best focus position. @Focus will use the Large step size to move the focuser as close as possible to the calculated best position, and then use the Small step size to get as close as possible. If you know the size of your critical focusing zone and the step size of your focuser, you should set a small step size that is about one half of the size of the critical focus zone. Otherwise, a good starting value for the small step size is about 1/10th to 1/25th of the large step size (assuming your large step size is well matched to the critical focusing zone). If you set TheSky as your focuser type, you must change the large and small step sizes using TheSky. See **Large step size** above for details.
Backlash – If your focuser has backlash, the last movement of the focuser during the @Focus run will typically fall short of best focus (see inset in figure 14). This is caused by backlash, which prevents @Focus from moving the focuser in a repeatable manner. To determine a value for backlash, note the position of the focuser at the end of the focusing run. Manually move the focuser to best focus using the large step size, and note the position. Subtract the smaller number from the larger, and then use the result as your backlash settings. Enter the value for backlash in the focuser setup, and run focus again. If you undershoot/overshoot best focus, adjust the backlash accordingly. Continue until you reach focus reliably. If you still cannot reach reliable focus, you may have multiple sources of backlash, variable backlash, too large of a small step size, etc.

The key parameter for success with @Focus is getting the large and small step sizes correct. On many nights, you can successfully use @Focus with a range of large step sizes. However, finding and setting the optimal step sizes will speed @Focus and give you better results.

Figure 13d shows an optimal @Focus graph of Sharpness during a focusing run. Note several features of this graph:

- There is a point where the Sharpness value increases rapidly (low shoulder).
- There is a very small zone where the Sharpness increase is smaller on both sides of perfect focus (high shoulder).

	The peak of the graph corresponds to the critical focus zone. For most telescopes, the critical focus zone is so small that it will not show up as a separate plateau on the curve.

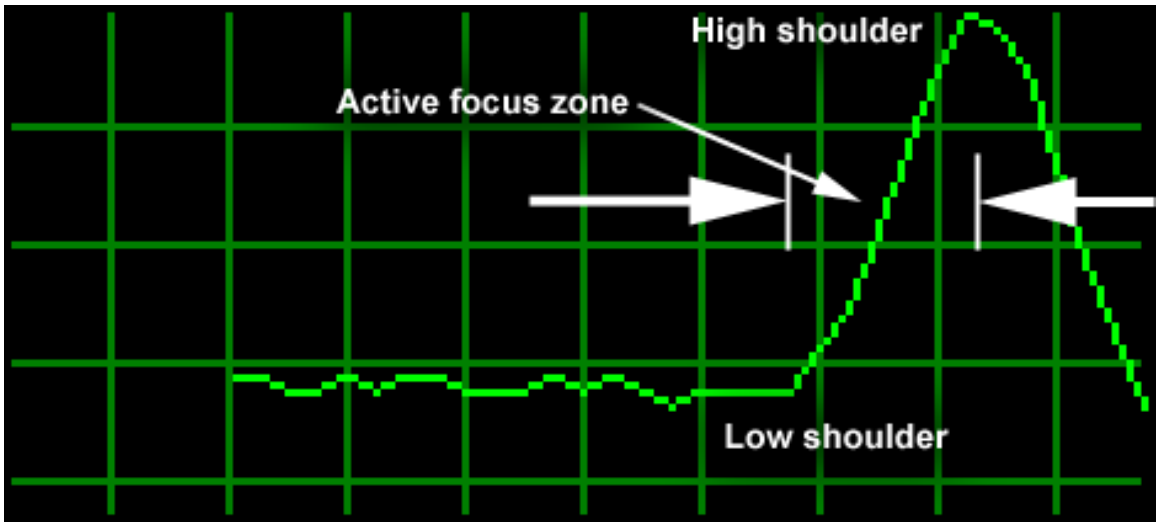


Figure 13: An ideal graph of the changes in Sharpness during an @Focus focusing run.

The area between the low shoulder and the high shoulder is the active focus zone. This is the only place where @Focus can be productive because this is where it is possible for @Focus to measure changes in focus quality (sharpness). Outside of the active focus zone, it is impossible for @Focus to converge upon focus because there is insufficient data. When the focus position is too far from best focus, the changes in the Sharpness value are too small to be reliable.

If you start out too far from focus, you can run out of samples before you get to the active zone, or you can have too few samples in the active zone. @Focus needs at least six samples in the active zone to determine best focus. The fastest possible focus run starts approximately in the middle of the active focus zone, and proceeds past focus. @Focus then calculates the focus position, and moves to it using a combination of large and small steps. The movement to the final focus position is not shown in figure 13.

The large step size is based on the length of the active focus zone. The large step size should be about one-fourth of the active zone. You can observe the values for current focus position in the **Move focus** section of the **Focus Tools** tab (see figure 14). Note the focuser position for each of the shoulders. If the large step size isn't about one-fourth of the difference between these two values, you may get better results if you change it to this value.

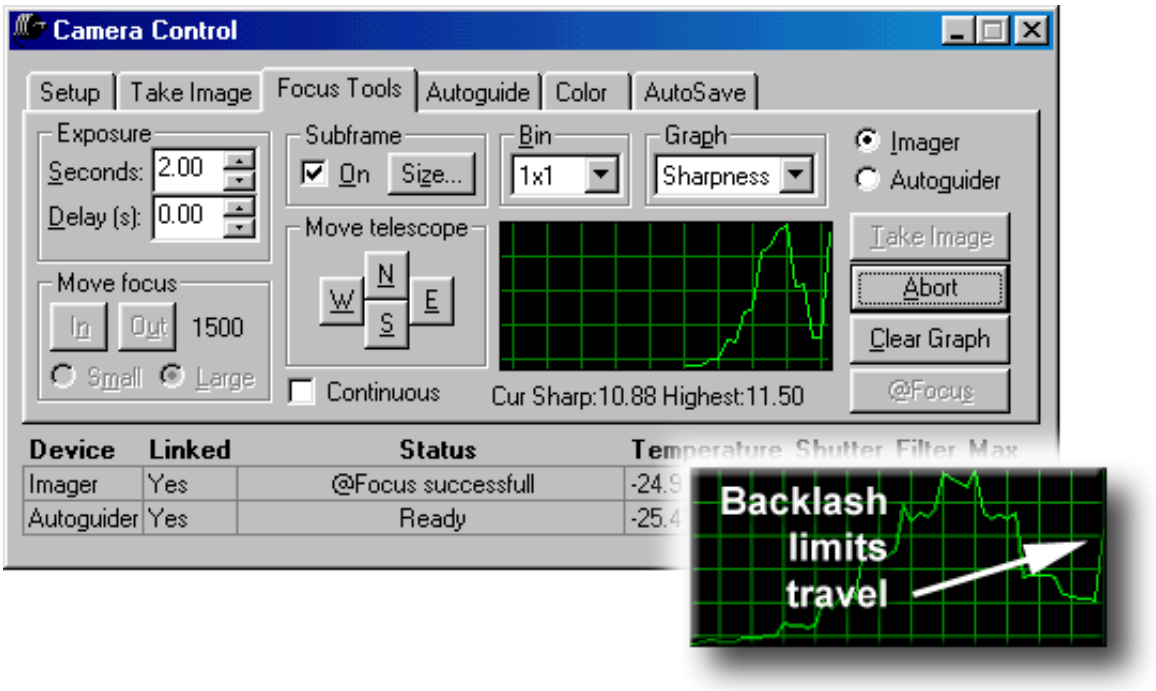


Figure 14: A typical @Focus focusing run. Inset: Backlash can prevent reaching focus.

Note that the main graph of Sharpness in figure 14 is very similar to the curve shown in figure 13, but it also includes the final move to the best focus position. The inset shows what happens if your focuser has too much backlash. Backlash will eat up some of the focuser travel, and @Focus will not reach focus. You can measure how much focuser movement you need to reach true focus. Watch the Sharpness graph to see when you reach focus, and observe the change in the value in the **Move focus** section. Enter the difference between the starting and ending values as your backlash setting (**Setup** tab, Focuser Setup dialog box). Some focusers can have so much backlash that you will not be able to reliably get to focus with @Focus. If that's the case, you can manually refine focus using Sharpness values to guide you.

The overall curve in figure 14 shows the noise and variations that are typical of real-world focusing sessions. Note that the focusing session was started very close the low shoulder, reached a peak, and then came back nearly to the low shoulder on the other side of focus. This was enough for @Focus to determine the best focus position, so it moved the focuser to that position and reported "@Focus successful" in the Status section at the bottom of the Camera Control Panel.

If you know the step size of your motorized focuser, you can use the equation for calculating the size of the close focus zone to calculate the initial large step size for your system. For example, if you are using the Optec TCF-S focuser on an f/5 telescope, you know that the critical focus zone is 55 microns. You also know that the step size of the TCF-S is 20 microns.



If you do not know the step size of your focuser, you can determine the large step size by trial and error. If you have access to a dial indicator, you can measure the step size of your motorized focuser directly. You will need an indicator that can measure movement as small as one thousandth of an inch. Measure movement when controlling the focuser with TheSky

using the smallest step size available.

A good starting point for your large step size is somewhere in the range of 40 times the size of your close focus zone. For example, an initial large step size for an f/5 scope with the TCF-S would be (40 * 55) = 2,200 microns. At 20 microns per step, a large step is about 110 TCF-S steps.

Figure 15 shows a very different example of a successful focusing run. In this example, the run started further away from focus, and the large step size was smaller. The net result is that @Focus did not get all the way down to the second low shoulder, but it still had enough data to accurately find the correct focus position. Note also that this run was accomplished with binning set to **3x3** (ST-8E camera), and the exposure time was ten seconds because no bright stars were in the field of view. Such a long exposure works, but you may find that focusing on a brighter star, and then moving to your object of interest, greatly speeds focusing.

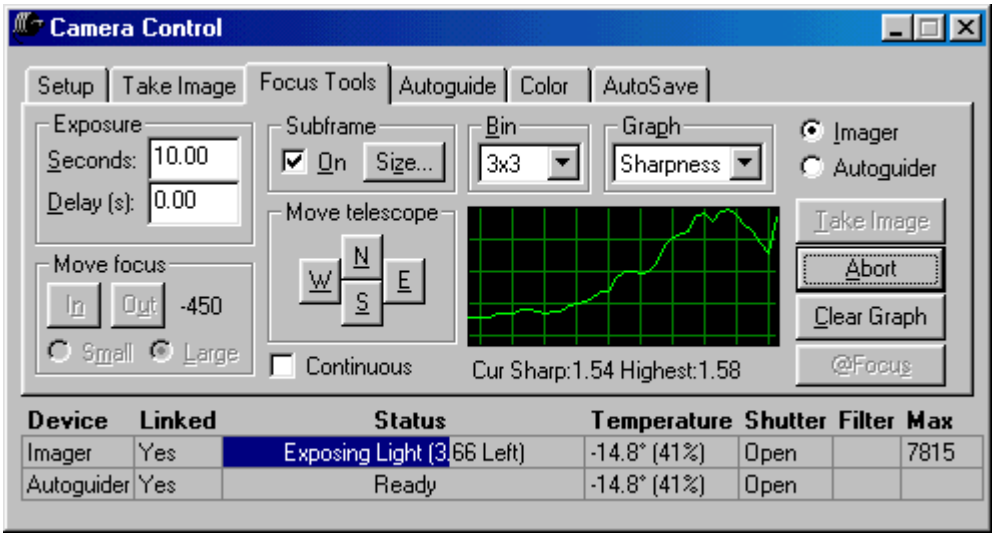


Figure 15: Another example of a successful @Focus run.

Step 3: Choose Starting Direction

@Focus should work well if you choose the wrong starting direction, but you are more likely to get good results if you give @Focus a "hint" by choosing the most productive direction. @Focus does its best work when the initial focus position is within an active focus zone (either inside our outside of focus). If the current focus is not within this zone, @Focus will most likely fail because there is insufficient data for @Focus make any decisions about focus. The Sharpness value changes most quickly in this zone. Starting with focus in the active focus zone, and then moving toward the critical focus zone, gives you the best chance and quickest way for @Focus to converge upon focus. With some experience, you should be able to look at your image and know that you are somewhere inside the active focus zone. The optimal starting point is the midpoint of the active focus zone, but you should be successful starting anywhere inside the active focus zone.

Experience with your camera and using the Sharpness graph will help you determine the best starting place. You can even get good results if you are away from the optimal starting locations. If possible,

determine where you are with respect to best focus: inside of focus, or outside of focus. Inside of focus means that the camera is closer to the front of the telescope than it would be at best focus. Outside of focus means that the camera is further from the front of the telescope than it would be at best focus.

If you aren't sure where you are with respect to the critical focus zone, choose either direction, and observe what happens to the Sharpness value and/or the size of the out-of-focus star images. If focus gets worse, abort the @Focus run (click **Abort** on the **Focus Tools** tab), choose the opposite direction, and perform a new focusing run. Click **@Focus**, verify settings, and then click **OK** to start the new run.

Step 4: Verify @Focus Results

The Sharpness graph clears automatically when you start a new @Focus run. You can clear the graph during a run by clicking the **Clear Graph** button at any time but this has no effect on the @Focus run. You must abort and start over if you want to get a fresh start. During the run, the Sharpness value appears below the graph, and each Sharpness value is plotted so that you can see the progress of the focusing run clearly. If the Sharpness line is moving up, and the out-of-focus doughnuts are getting smaller, focus is improving. Figure 16 shows a sequence of graphs from a focusing run, with the corresponding Sharpness values.

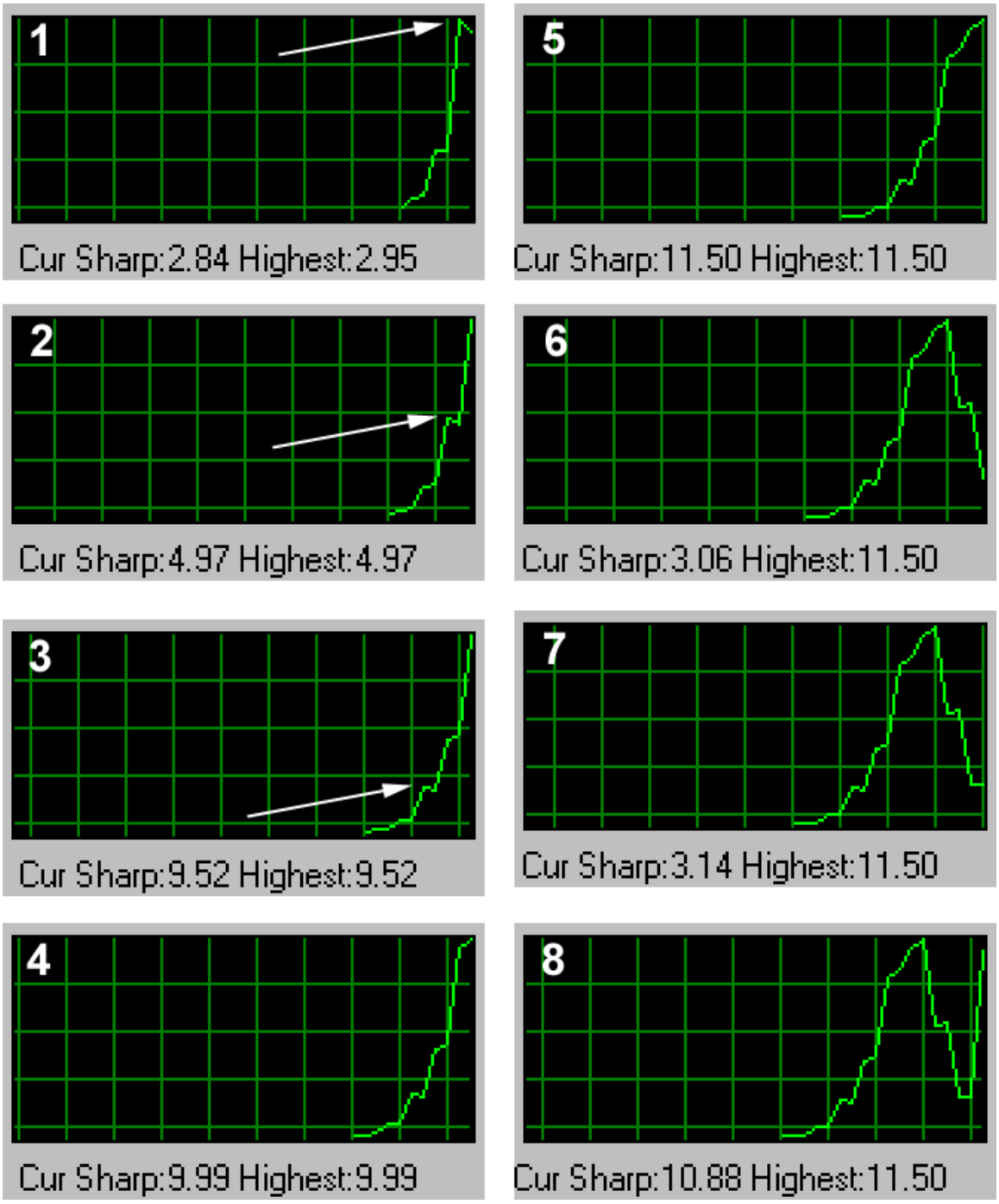


Figure 16: Eight steps in a typical @Focus run.

Note that the data below the graph tells you the current Sharpness value, as well as the highest Sharpness value so far.

The initial Sharpness value is always 1.00. The second Sharpness value is the ratio of the second reading divided by the first. If you are beyond the active focus zone, you might see very small changes in the Sharpness value – 0.98, 1.02, 1.01, etc. This is just natural fluctuation due to seeing conditions. When you reach the low shoulder, the Sharpness value starts to rise quickly. The top of the graph is always the highest Sharpness value so far – the graph is self-scaling so that it can adapt to whatever values occur during the run.

The three arrows in figure 16 show the same data point, a value of 2.95 for Sharpness. As increasingly larger values come in, the graph adapts itself.

Note in number 8 that the final focuser position does not result in a Sharpness value that is as high as the previous highest value. If you are using a focuser with absolute positioning, such as the Optec TCF-S, the difference is usually due to seeing fluctuations. If you are using a focuser through TheSky, absolute positioning is not guaranteed, and you can test focus by taking additional exposures and noting the resulting Sharpness values. You can also increase the Averaging setting to reduce the noise level in the data. Ideally, you should expect @Focus to set a focus position that gives you a Sharpness value that is close to the highest sharpness value recorded during the run. Changes in the environment – varying sky brightness; the presence of thin, high clouds; and other factors can interfere with this. When in doubt, try another @Focus run.

If your focuser has absolute positioning, you will almost always get a good result barring environmental issues such as those described above. Multiple @Focus runs should bring you very close to the same position each time. Serious imagers might run @Focus five times, noting the final position after each run. Then average the result of the five runs and manually move to the averaged position. If you have a focuser controlled through TheSky, or if your focuser has excessive backlash, positions are not as repeatable. You can either repeat the @Focus run looking for a better ending Sharpness value, or adjust the focus position by hand to get the highest Sharpness value.

You can also verify the results of an @Focus run by examining the final image visually. Figure 17 shows a final focus image. Note that the single star has a well-defined edge, and that there is a dim star at upper left that is well concentrated.

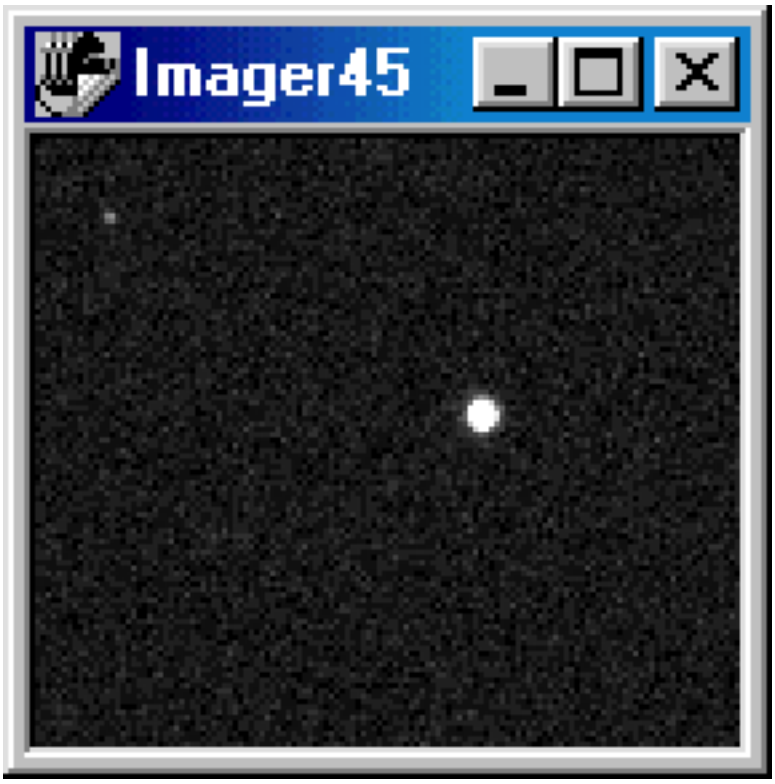


Figure 17: Image of a well-focused star.

Figure 18 shows a comparison of a slightly out of focus image (right), and a perfectly focused image (left). The perfectly focused image has a highly concentrated dim star visible at lower left. In the not-quite-focused image, the dim star is clearly enlarged and dimmer. Dim stars are very effective tools for evaluating quality of focus because the appearance of dim stars is strongly affected by slight errors in focus position. Bright stars, on the other hand, do not change appearance very much as you move through the critical focus zone.

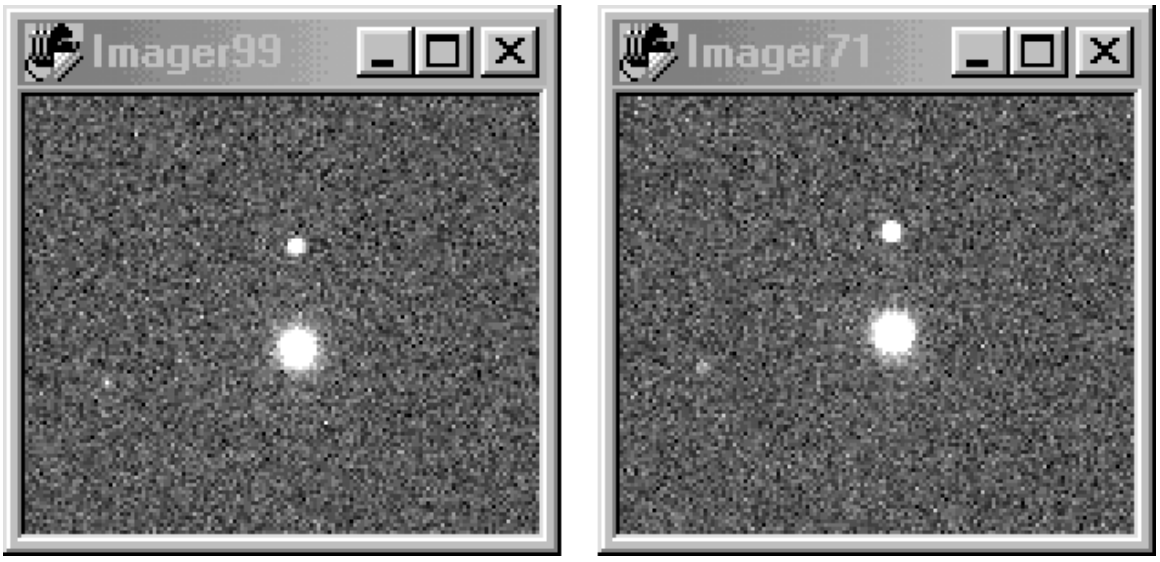


Figure 18: A comparison of a well-focused image (left) and a slightly out-of-focus image (right).

Manual Focusing

CCDSoft can assist you in reaching focus, but you need to be relatively close to focus to start. You can get close to focus in several ways:

- Use an eyepiece that is parfocal with your CCD camera, such as the IFocus from Software Bisque.
- If you found the correct focus position previously, mark the focuser position so you can move the focuser into position at the start of your imaging sessions. This will not work with scopes that have internal focusers, such as most Schmidt-Cassegrain telescopes.
- If you can get a very bright star in the field of view of the CCD camera, it will show a very large out of focus image of a star. The star should be magnitude 2 or brighter, or the out of focus image will be so dim that you might not recognize it. Center the star, and adjust focus until the star is close to focus.

Figure 20 shows four examples of images that are out of focus. Image A is just slightly out of focus. If you have a parfocal eyepiece or can position the focuser in the same place on subsequent nights, this is the type of focus quality you might see. Image B shows a star image very far out of focus, as it appears in a refractor. You can adjust focus to reduce the size of the star image, but you will likely have to make a large change in focus position to get close to focus. Image C shows a similar very far out of focus star image, but taken with an SCT. Note the shadow of the central obstruction. Image D shows an out of focus star image that is underexposed. The image is very grainy, and the default image settings had to be changed to show the star clearly.

The histogram or the background and range settings are used to make these changes; see “Chapter 9: Image Processing.” for details. You will generally need longer exposures to show out of focus stars, even very bright ones. You can reduce exposure time during focusing as the star’s image becomes smaller and brighter. If you are sure you have a star in the field of view, but think it might be very far out of focus, try a much longer exposure to see if the star’s out of focus image comes into view.

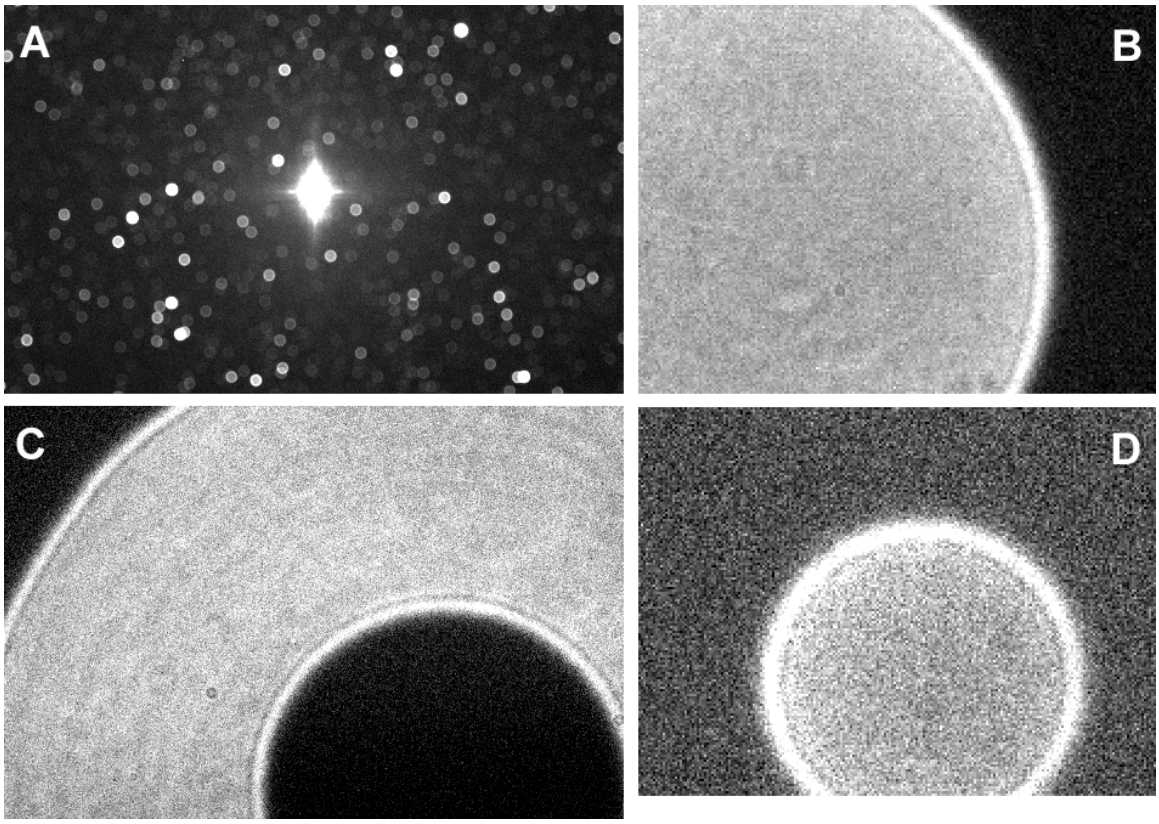


Figure 20: Various stages of focus. A: slightly out of focus with a wide-field refractor; B: far out of focus with a refractor; C: far out of focus with an SCT; D: moderately out of focus with a refractor and underexposed.

You may find it useful to center the out of focus star so that it will still be on the CCD detector when you get close to focus.

Step 1: Get your focusing tools ready

You can use the **Focus Tools** tab to focus manually (see figure 21). There are two options for adjusting focus: using the **Move Focus** section's **In** and **Out** buttons, or by adjusting the focus position outside of CCDSoft. To use the **Move Focus** buttons, you must have selected a focuser on the **Setup** tab. There are two types of focus adjustment outside of CCDSoft: manually changing the focus of your telescope, or controlling a motorized focuser with a hand paddle, such as a JMI MotoFocus.

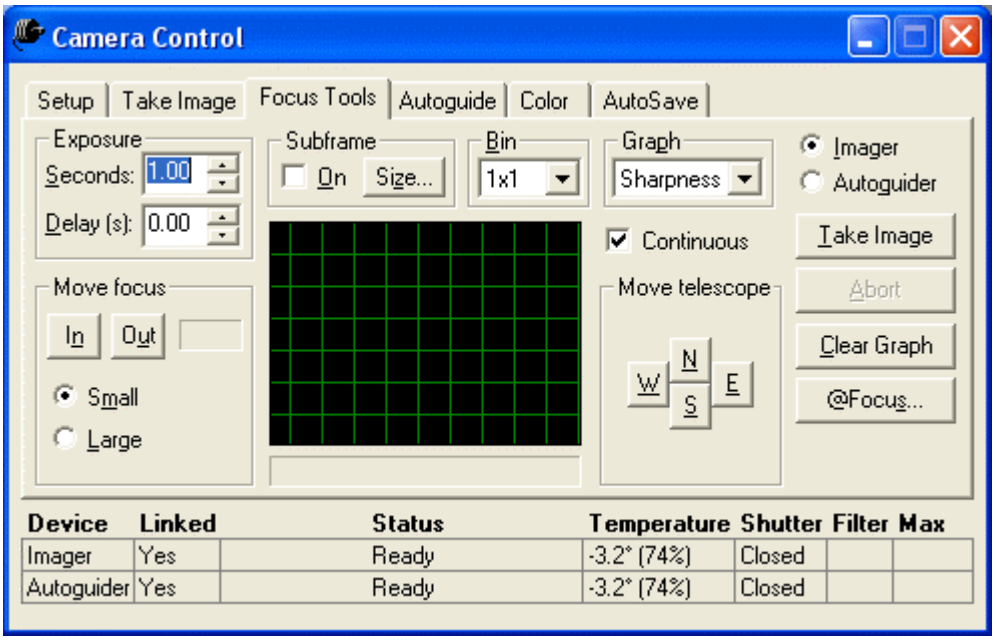


Figure 21: Most of the tools you'll need for focusing are found on the Focus Tools tab of the Camera Control Panel.



If the Camera Control Panel isn't visible, click **Camera | Focus Tools**.

Step 2: Verify Initial Settings

The initial focus exposure is often taken using the largest possible binning mode on your camera. Binning provides a faster download time, and lets you check your focus quality quickly. For example, with an ST-8E, the maximum binning mode is 3x3.

Several options on the **Take Image** tab (see figure 22) will affect the operation of the Focusing Tools panel. In particular, the Filter and Image (Frame and Reduction) settings are inherited from the **Take Image** tab. Typical initial settings should be: **Image Frame** set to **Light**, and **Image Reduction** set to **AutoDark**. CCDSoft will automatically take dark frames with the same exposure length as the light frames. This removes hot pixels from the focus images, and makes it easier to tell when dim stars are properly focused. If you have a filter wheel installed, set it to the Clear filter for focusing.

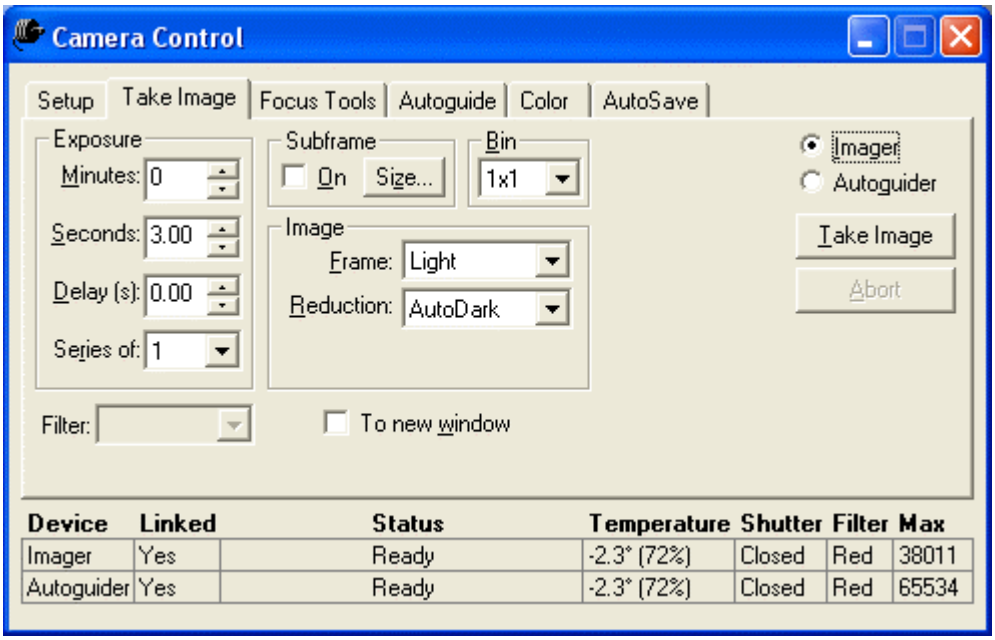


Figure 22: The Take Image tab has settings that affect your focus exposures.

If you switched to the **Take Image** tab to change settings, switch back to the **Focus Tools** tab. Verify that the **Imager** option is active, make sure **Subframe On** is not checked, and also make sure that **Continuous** is not checked (see figure 23). For a quick test of your current focus position, start with a **Bin** setting of **3x3**. Set the **Delay** to 0.00. Set the **Graph** type to **Sharpness** as this provides the most accurate assessment of focus quality.

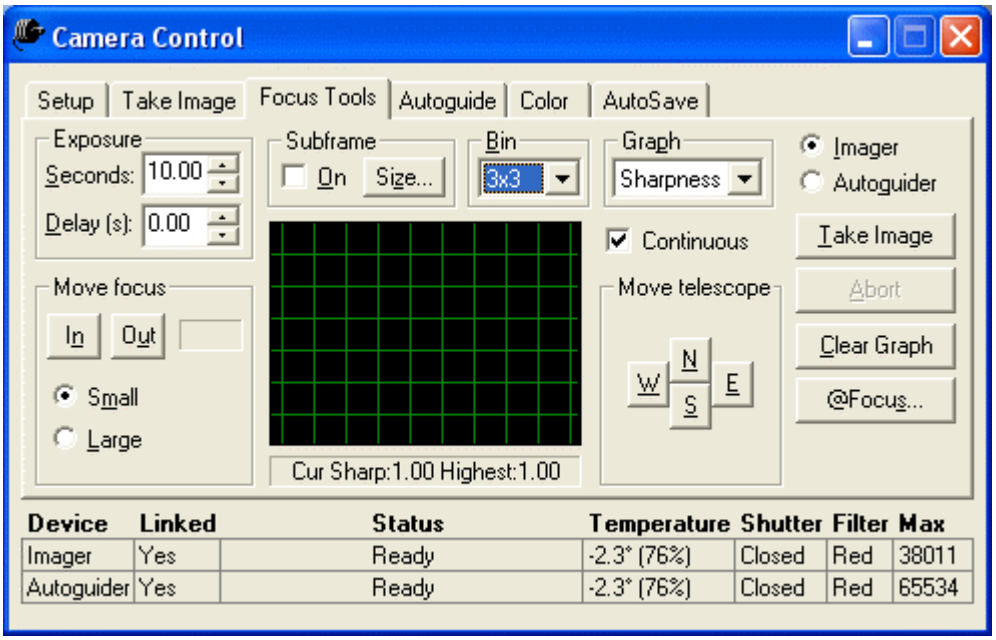


Figure 23:The Focus Tools panel is now set up for taking your first focus exposure.

Step 3: Enter an Exposure Time

Enter an exposure time in the **Exposure Seconds** box. This will typically be about 5 to 30 seconds, depending on how bright you expect the stars to be in your field of view, the aperture and focal ratio of your telescope, the quantum efficiency of your camera, the current state of focus, etc. Experience will show you what exposure lengths will work well for focusing with your setup. We suggest that you use 10 seconds as a starting point for your first attempt at focusing. You can increase or decrease this value based on the results you get from your system. If you have a non-antiblooming CCD detector, make sure your exposure is short enough that there are no blooming stars. Figure 23b shows an example of a blooming star. A bloom occurs when pixels have filled up with electrical charge and spill over (bloom) into their neighbors. Blooming only occurs in one axis, so a bloom is always a line extending from a star in two directions.



Figure 23b: An example of a star that is bright enough to bloom.

Step 4: Take an Image

Click **Take Image**. You will see various messages in the Status area at the bottom of the Camera Control Panel:

- Selecting filter (appears only if you have a color filter wheel).
- Exposing Light (appears during exposure, with a timer showing time remaining).
- Downloading Light (appears while the frame is being downloaded from the camera to your computer).
- Exposing AutoDark (appears during the dark frame exposure, taken with the shutter closed).
- Downloading AutoDark (appears while the dark frame is being downloaded from the camera to your computer.

The light frame will appear first. Do not be concerned if it has a large number of bright pixels; these will go away when the dark frame is downloaded and subtracted from the light frame. See the section “Image Reduction Fundamentals” for details about what dark frames are and why they are used.



The use of an AutoDark frame is optional for focusing. If you are using a very bright star for focusing, or if you are taking very long focus exposures, you can choose not to use AutoDarks. However, accurate focusing is critical to getting sharp images and useful photometry, and we recommend that you use AutoDark when focusing. The AutoDark is taken only when the exposure length or image size changes, so you only have to wait for the first one.

If the stars are not small, round, and numerous in the image, adjust focus in large steps until stars appear as small round dots. Aim for somewhere close to focus. Don't try to achieve optimal focus in 3x3-binned mode. You need to switch to 1x1 using sub-frames, covered below in step 5.



Make a mental note of the direction you are moving the focuser knob during step 4. Your goal is to approach focus from one side until it is optimum. In the next step, you'll be making very small changes, and it helps to know the direction you should be moving in to improve focus. Seeing conditions may interfere with clear evaluation of focus quality, and knowing the direction to move will help you keep track.

Step 5: Select a Star and Put It in a Sub-Frame

Another tool for speeding up your focusing is the sub-frame. This is a small portion of the image immediately around the star you will be using for focusing. To select a sub-frame, click and drag around a bright star in your 3x3 binned image, as shown in figure 24.

Which star should you select? The ideal star meets these criteria:

- It is one of the brighter stars in the frame, but it is not saturated. Move the cursor over the star and observe the brightness value in the status bar; make sure it's not saturated. That is, make sure it does not have a brightness level anywhere near the maximum value for your camera.
- There are other, dimmer stars close to the focus star. You can use these dim stars to assist you in accurately evaluating focus quality. When you are imaging in the Milky Way, this is easy to do. At other times, dim stars may not be available.



The better your polar alignment, the smaller your focusing sub-frame can be. With a good polar alignment, the stars will move very little between exposures, and you can use a small sub-frame without worrying about losing the star after a few exposures. The smaller your sub-frame, the faster it will download and the more efficiently you can focus. If the star gets close to the edge of the sub-frame, you can use the **N/S/W/E** buttons in the **Move telescope** section to make adjustments if you are have an autoguider connected to your telescope.

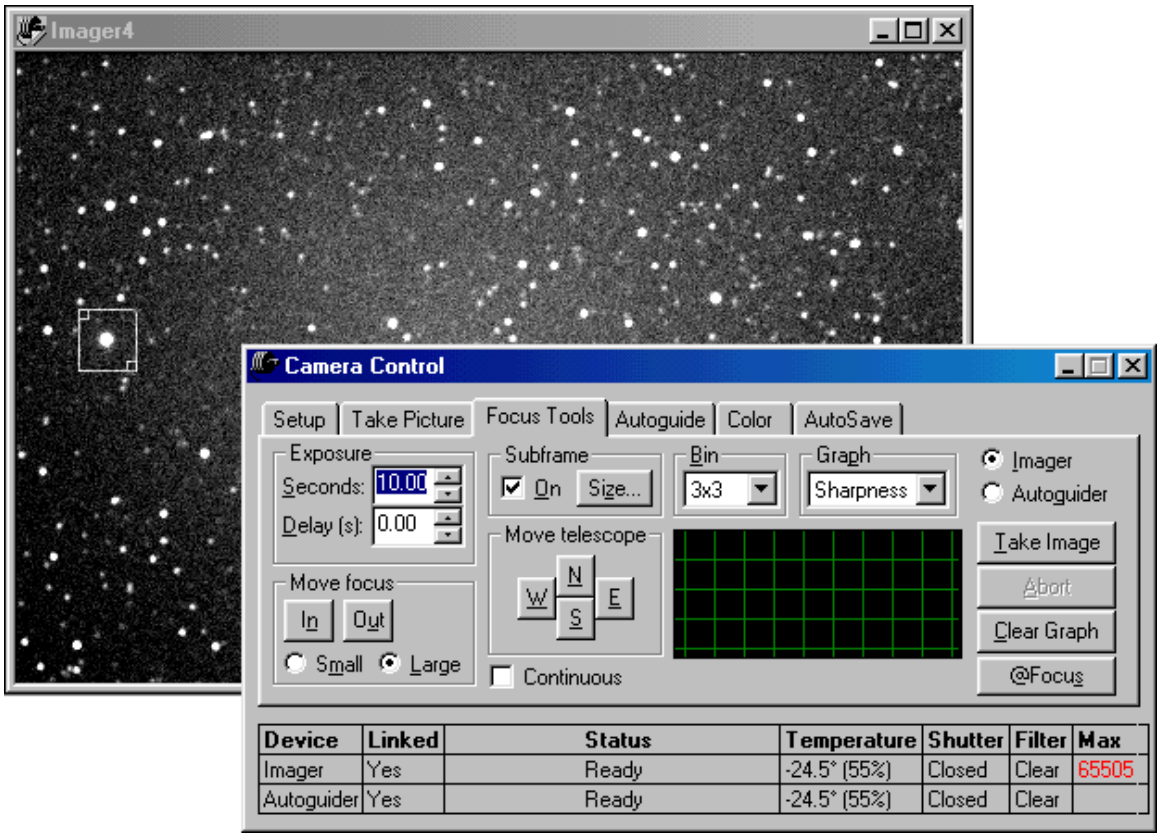


Figure 24: Select a focusing sub-frame by clicking and dragging in the image window.

Note that the Subframe checkbox in the Camera Control Panel gets checked automatically when you select a sub-frame using click and drag. You can also click **Size**, and enter the position of the subframe numerically, but for most focusing needs a click and drag will be your best bet. For best results, you want a small sub-frame so that you don't spend a lot of time waiting for focus images to download. Allow room around the star for any dim background stars to show up. These dim stars can be an effective asset when focusing.

Step 6: Adjust Focus Using Continuous Focus Mode

Click on the Continuous checkbox (refer to figure 24) on the **Focus Tools** tab. This activates continuous focus mode. CCDSoft will take focus exposures one after another while you adjust focus. If the star you

are using for focusing becomes too bright as you improve focus (that is, it becomes saturated and/or blooms), you can abort, adjust exposure time, and resume in continuous focus mode.

Use the **1x1** (unbinned) bin mode to get best focus. Use the **Bin** drop-down list at top center of the Focus Tools tab to select the **1x1** option.

You'll need some time between exposures to make manual (or motorized) adjustments to focus position. Enter an appropriate delay in the **Delay** box at upper left. We suggest 7-10 seconds when you are getting started. As you gain experience, you can use shorter delays to speed up your focusing process. Delays as short as 3 seconds can work once you are familiar with the process.



If you have an electric focuser that is controllable from TheSky software, but not accurate enough to work with @Focus, you can use the **In/Out** buttons in the “Move focus” section to make focus adjustments. Click the **Large** option to make large changes, and the **Small** button to make fine adjustments.

Figure 25 shows continuous focusing in progress. CCDSoft will expose a light frame, download it and display the image in a window. Adjust the focuser until you find the critical focus zone, defined as the highest value on the Sharpness graph (see details below). CCDSoft will continue to take focus exposures until you click **Abort**.

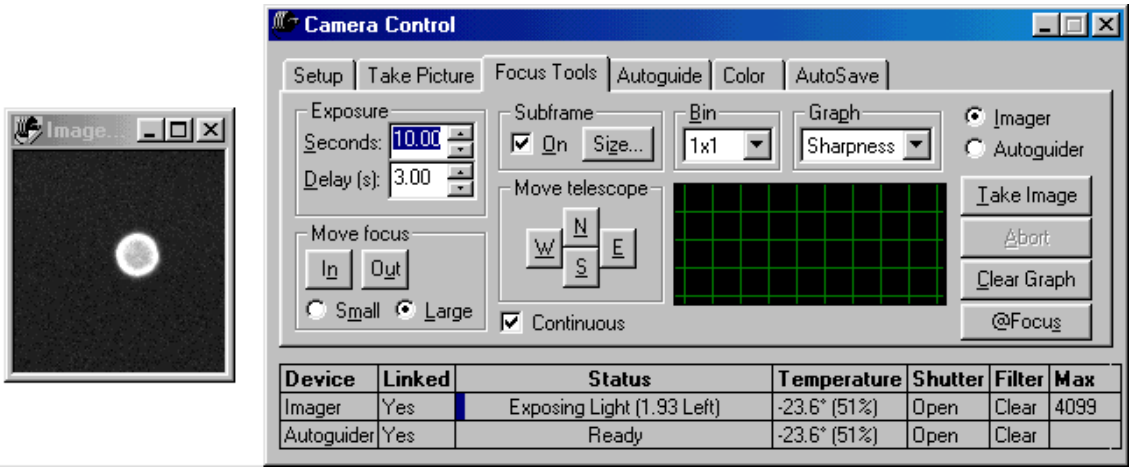


Figure 25: Working in continuous focus mode with a sub-frame window (left) active.

You can visually observe the sub-frame window to help you decide when you have reached optimal focus. The **Focus Tools** tab also provides several types of feedback that will help you identify when you are in the critical focus zone. These include a graph showing a history of sharpness or brightest-pixel values, and a numeric readout below the graph.

Figure 25 shows the start of a continuous focusing session. The star image is far enough out of focus to show diffraction rings blurred by atmospheric turbulence. To start fine focusing, continue focusing in the direction you established during your initial, very rough focusing procedure. The star image will get smaller, and the value of the brightest pixel in the image will increase. In the sample shown in figure 25, the brightest pixel value is 4,099.

The brightest pixel gets brighter because, as you get closer to optimal focus, you are concentrating more light energy from the star on the central pixels of the star image. This value rises steadily as you improve focus, but turbulence frequently causes it to become somewhat erratic as you get very close to focus.

The Sharpness value is the best tool for judging the quality of focus. Sharpness tracks the quality of focus more accurately than brightest-pixel values. You can always check the current brightest pixel value in the information lines at the bottom right of the Camera Control Panel, under the heading Max.

The initial Sharpness value is always 1.00. The second Sharpness value is the ratio of the second reading divided by the first. As you improve focus, you will see changes in the Sharpness value. If you are far from focus, the Sharpness value will increase slowly. If you are near the critical focus zone, the value changes more rapidly. This is a key advantage of the Sharpness value – it is highly sensitive to small changes near best focus. This makes it easier to judge focus quality.

Figure 26 shows a later stage in the continuous focusing session. The graph shows a record of several exposures, and the focus position is now closer to optimal. The brightest pixel value is now 9,094, more than double the initial value. This is typical when moving from an image as out of focus as the one shown in figure 25.

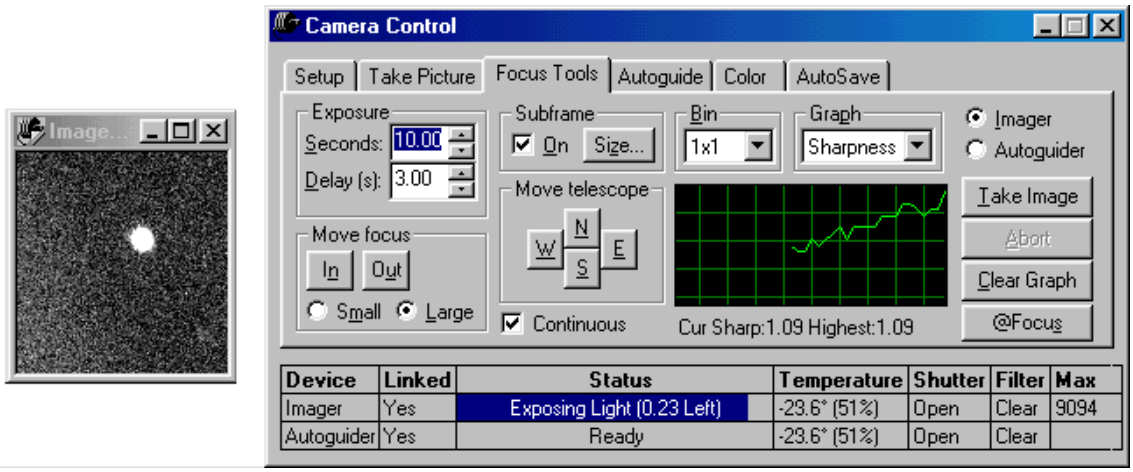


Figure 26: The middle of a continuous focusing session.

The trick when focusing is to know what to expect at the point of best focus. The simplest way to find this out is to go past best focus and observe what happens with the appearance of the image and the graph on the Focus Tools tab. As you move toward focus, the star's image gets smaller and brighter, and the graph trends upward. Past best focus, the star image will begin to get fuzzy again, and the graph will start to trend downward. Strong atmospheric turbulence makes the graph values especially erratic near optimal focus, but Sharpness is less susceptible to this compared to brightest pixel value.

Dim stars in your sub-frame are one of the best methods you can use to assist you in determining focus. The reason for this is simple: when you are out of focus, even by a little bit, dim stars will be invisible or extremely fuzzy. When you reach optimal focus, dim stars suddenly jump into view.

There is a very fuzzy, very dim star in figure 26, at the lower right. The main star looks reasonably well focused, but the dim star is still very fuzzy. This tells you that you are not at perfect focus yet.

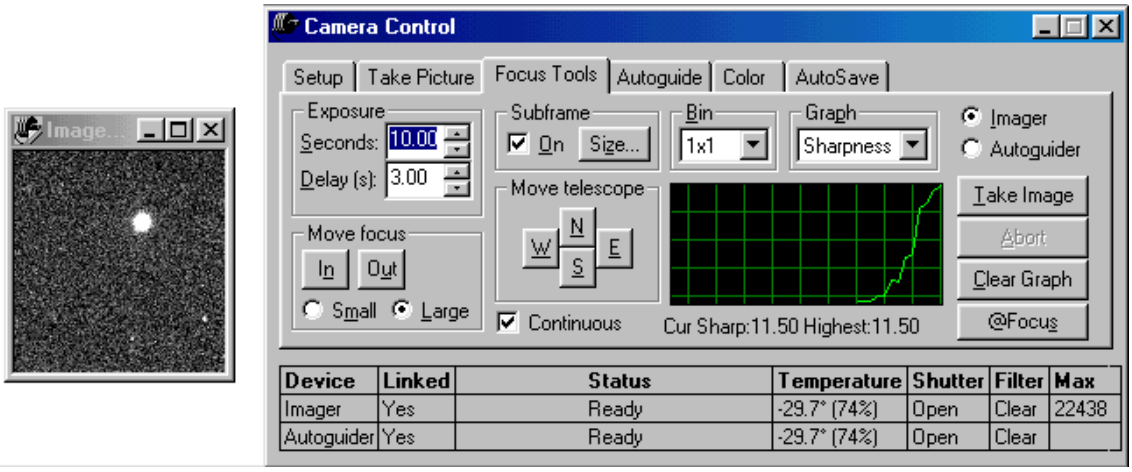


Figure 27: Using a dim star to assist you in evaluation focus quality.

Figure 27 shows the end of the focusing session. Several things indicate optimal focus. The brightest pixel value is now much higher than in the previous cases (22,438 units). The data point at the far right of the graph is also much higher, reflecting a Sharpness value of 11.5. Because the Sharpness value fluctuates, you should use secondary methods to validate the best possible focus position when a dim star isn't at hand. Some additional methods include:

- Observing sharpness of diffraction spikes, such as from a Newtonian's spider or masking tape across the front of the telescope. These will appear double when you are out of focus, and will get closer together as you approach the critical focus zone. When they merge and become a single, bright diffraction spike, you know you are at the optimal focus position.
- Various kinds of masks, such as a Hartmann mask, can be used to assist in determining best focus. Such masks cover the aperture of your telescope, and have two or more holes cut in them. The holes cause multiple star images, which merge when you reach the critical focus zone.
- You can also create diffraction spikes using artificial spiders. For example, you can make a cross of wooden dowels to put across the front of your telescope, or you can make a cross of masking tape quickly and easily across the front of your scope.

Figure 28 shows two examples of spikes from a Newtonian spider: slightly out of focus on the left, and in focus on the right. Masking tape will produce the same kind of diffraction pattern. Note the two dim stars in both images, and how they also come into sharp focus at the same time as the diffraction spikes.

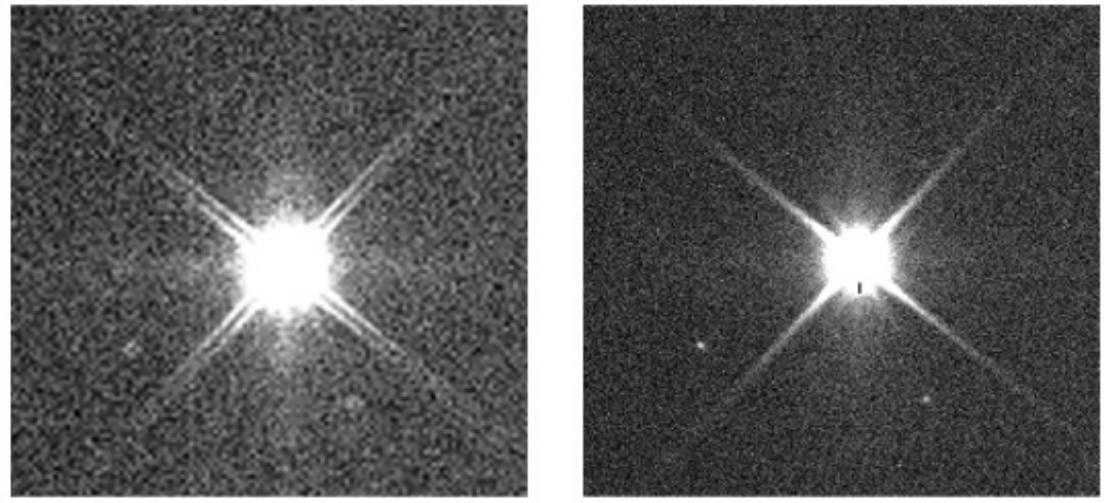


Figure 28: Diffraction spikes can be used to determine the point of best focus.

Figure 29 shows three examples of diffraction spikes created by three types of mask. From left to right, they are a three-hole mask, a two-hole mask, and a two-triangular hole mask. The advantage of the triangular-hole mask is that each triangle throws off diffraction spikes. When all the spikes have a common center, you are focused.

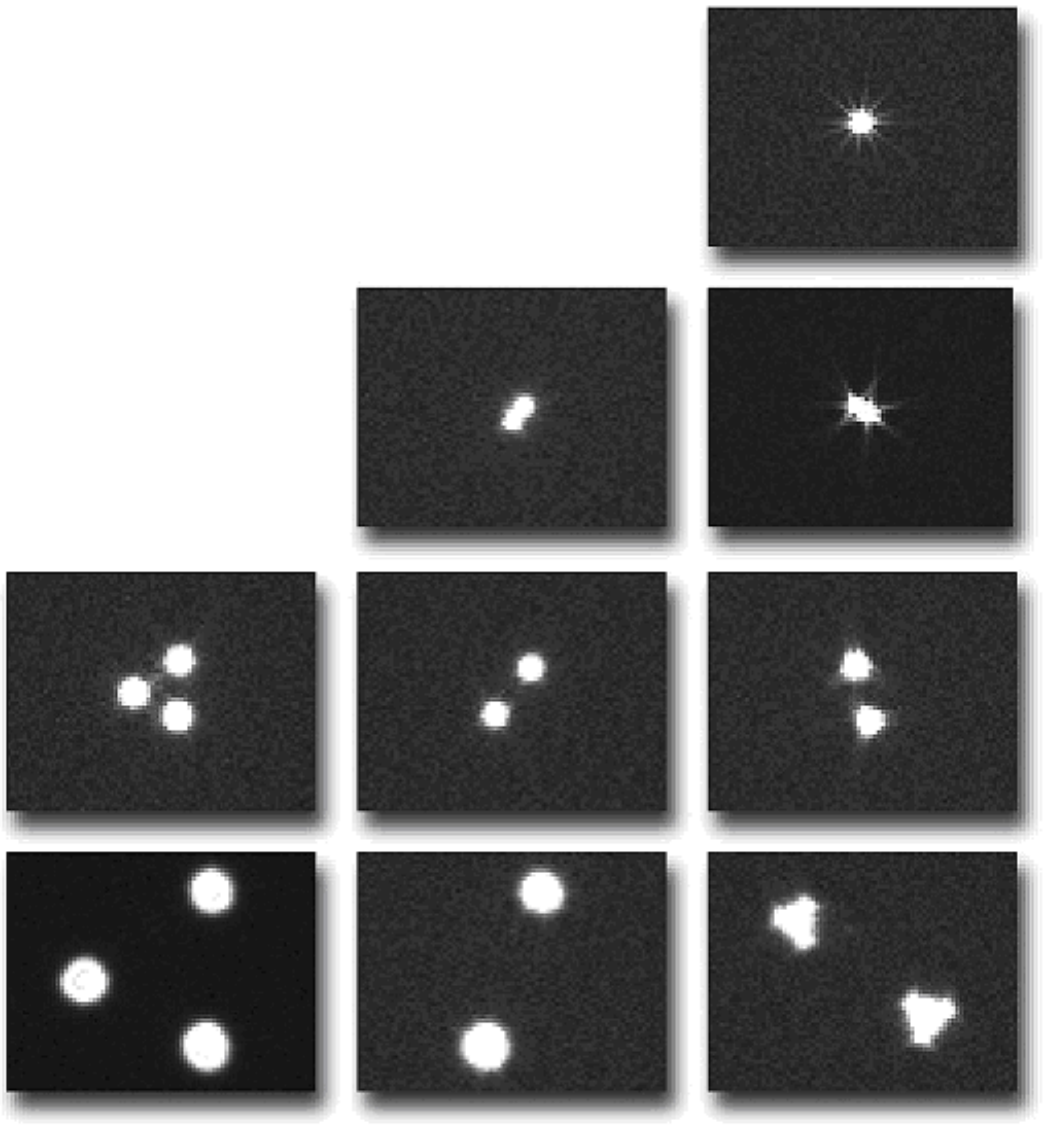


Figure 29: Focusing masks show bright spots with the same shapes as the holes in the mask. The holes converge as focus improves. The two-triangle mask (right) is easy to use because it has diffraction spikes; round holes do not have diffraction spikes.

When you have reached focus, you can proceed to capture images. CCDSoft offers several opportunities for productive imaging and guiding using the Camera Control Panel:

- Single images (see “Chapter 2: Working with Images and Files”)
- RGB color images (see “Chapter 6: Taking Color Exposures”)
- LRGB color images (see “Chapter 6: Taking Color Exposures”)

- Autoguiding (see “Chapter 4: Autoguiding”)

Exposure Control

One of the first questions often posed is: *How long should I expose?* The answer is that exposure times vary greatly. Jupiter or the moon might require an exposure of 0.05 second with one setup, and 0.1 second with another. A distant galaxy might need 10 or 20 minutes of exposure to reveal dim details. Deciding how long to expose for various objects is part of the learning process.



Because of the very large dynamic range typical of most CCD cameras, very long exposures are possible for many objects. Various factors, however, can stop you from taking long exposures, such as limitations of your mount or an object passing behind a tree during the exposure. The key to success is to take exposures that are long enough to suit your purposes. If you are hunting for minor planets, you want exposures that go deep enough to find the minor planets. If you want a beautiful image of a galaxy to put on your web page, you want exposures that give you the details in the dim areas of the galaxy. However you plan to use your images, you need a certain level of signal that overcomes the noise inherent in the process of collecting light from the distant reaches of space. Whether you find yourself taking long exposures or taking shorter exposures and combining them, the more photons you collect of a given astronomical subject, the better your results.

Exposure control for black and white images is controlled with the **Take Image** tab on the Camera Control Panel, which is shown in figure 30.

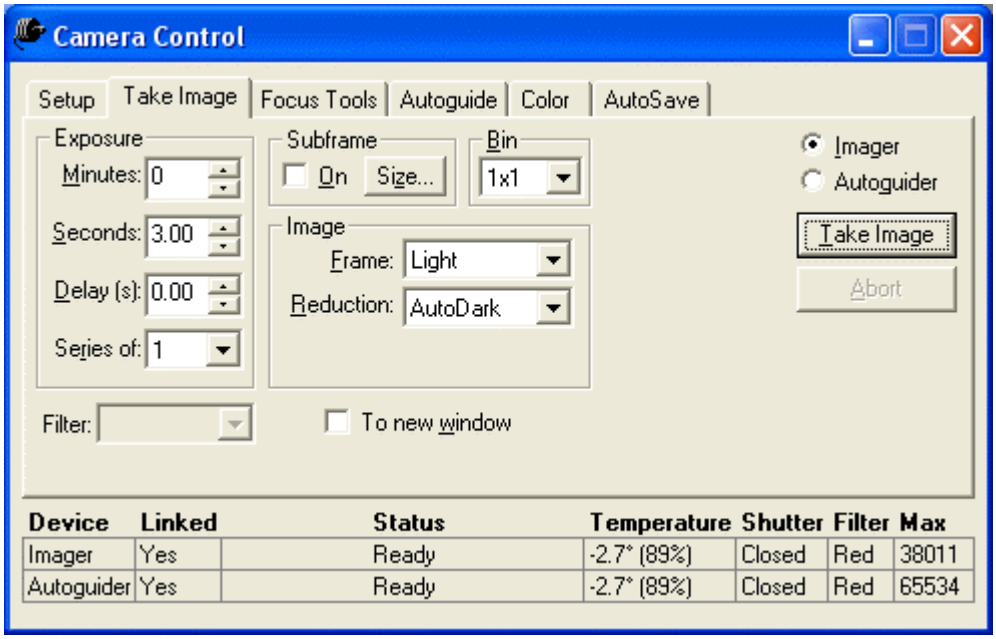


Figure 30: Exposure settings are set on the Take Image tab of the Camera Control Panel.

The settings in figure 30 are for a single, full-frame, three-minute exposure with an automatic dark frame. For information about dark frames, see the section on reduction near the end of this chapter, as well as

the more detailed treatment in “Chapter 7: Image Reduction.” The image is binned **1x1** (that is, it uses full resolution of the camera).

Once the telescope is focused, take a periodic test exposure to verify focus quality. We suggest taking an unbinned test exposure to see just how good your focus position is. Various factors can change the best focus position. For example, temperatures changes affect the geometry of your telescope. The focus position shifts slightly with changes in temperature.



A good method for checking exposure is to take a very short exposure with the Focus Tools tab, using the maximum binning mode available (that is, the lowest resolution), such as 3x3. Select a sub-frame that includes some dim and medium bright stars, and take an unbinned exposure (set bin mode to 1x1). Examine the resulting image for good focus. To get a sense of how much the focus is affected by seeing conditions, take a sequence of 3-10 such images and observe the change in the Sharpness graph. The greater the fluctuation in the Sharpness value, the more that seeing is affecting focus.

How long should you expose your image? The dominant factor in determining exposure for a given CCD camera and telescope combination is focal ratio. This is the ratio between the aperture and the focal length. The slower your focal ratio (for example, f/10), the longer your exposures must be. The faster your focal ratio (for example, f/2), the shorter your exposures must be. This is true no matter what the aperture of your telescope – all f/8 telescopes require the same exposure duration for the same camera.

For example, an f/1.95 system such as a Fastar-equipped Celestron Schmidt-Cassegrain telescope might saturate the sky background using an ST-237 camera in two minutes. An f/5.6 refractor, on the other hand, would require four times the exposure to saturate, and an f/10 SCT would require even longer exposures.

The brightness of your subject also affects exposure times. A bright star can cause blooming (see figure 23b) or saturation in a matter of seconds. On the other hand, if you are imaging an open cluster or a distant galaxy, exposure times of 10 to even 60 minutes might have little or no blooming. Blooming and saturation are merely cosmetic when taking an image. When you are focusing, blooming and saturation can create false readings and should always be avoided. Experiment with various exposure times for each subject you image to learn what works best for your camera and telescope.



There are two kinds of exposures: unguided and guided. In an unguided exposure, the mount tracks at a rate that is as close as possible to the rate at which the stars appear to move (the sidereal rate). There is no feedback to tell the mount how accurately it is following the stars (tracking). At some point in an unguided exposure, the small differences between the sidereal rate and the mount’s track rate cause stars to leave a linear trail on the image. In a guided exposure, some kind of feedback mechanism is used to adjust the tracking rate of the mount periodically. This could be your eye observing the tracking accuracy and your hand making corrections, or a second CCD detector taking images and measuring the deviation from a perfect tracking path. This is called guiding (separate telescope and detector) or autoguiding (integrated detector in the camera).

During an unguided exposure, the mount is doing its best to track the motion of the stars relative to the earth. Some mounts are more capable in this regard than others. CCD imaging is very demanding of a mount, requiring tracking and corrections at extremely high levels of precision.

Polar alignment has a major impact on guiding. If you have a very good polar alignment, you will be able to take longer unguided exposures. If your polar alignment is only approximate, you will see star trails on relatively shorter exposures. At a focal length of 1000mm, you should be able to polar align well enough for one minute exposures without star trails on a regular basis. At 500mm, two minutes should be practical. At 2000mm, 20 to 30 seconds may be all you can get with a simple polar alignment. For precise polar alignment, consider using a drift alignment (see the section “Manual Drift Alignment” in Chapter 4: Autoguiding).

The quality of an unguided exposure depends on the accuracy of your mount. A mount that tracks poorly (for example, it has a large periodic error as described in Chapter 4: Autoguiding) will not be as effective for astrophotography as one that has a very steady tracking speed (small periodic error). Generally speaking, if the periodic error is small enough it will hide errors within the width of the smallest stars in your images. Some mounts have periodic error correction (PEC) that controls periodic error. The longer the focal length of your telescope, and the smaller the pixels in your CCD detector, the more accurately your mount must track for successful imaging.

To take an exposure, follow this checklist until you are familiar with the Take Image tab and are ready to experiment with additional options. Each of these items is covered in depth shortly:

1. Click **Camera | Take Image**.
2. Select an appropriate **Bin** mode.
3. Select the exposure duration.
4. Set Frame type to **Light.**
5. Set an appropriate reduction setting (we recommend **AutoDark** until you are comfortable with creating and using reduction groups; see “Chapter 9: Image Processing”).
6. If you have a color filter wheel, select the appropriate filter (Select the clear filter until you are comfortable using the **Color** tab).
7. If you want to take more than one image, select that number in the **Series of** drop-down list.
8. Click **Take Image/Series** and wait for the image to download; it will appear in the CCDSoft window after the download (see figure 31). If AutoSave is active and TheSky is available, the filename is built automatically and includes the name of the object at the center of the image, or the image coordinates if no object is present at the center. The coordinates are based on what the telescope reports, and will not be precisely accurate if your polar alignment is off.

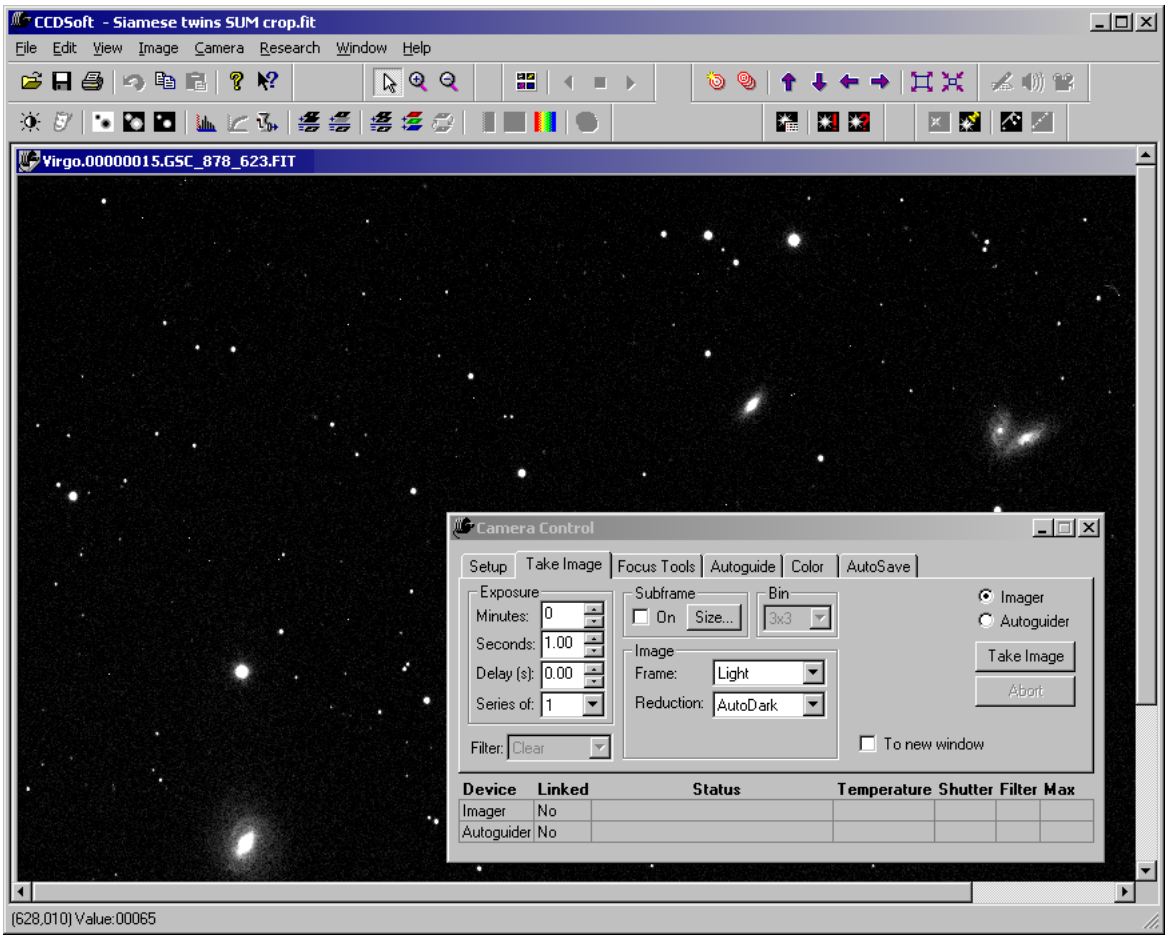


Figure 31: The downloaded exposure appears in a window in CCDSoft.

Select Bin Mode

Binning groups of pixels together allows you to match pixel size to telescope focal length. Pixels that are small require longer exposures and provide higher resolution. Large pixels allow shorter exposures but provide lower resolution. For any given combination of camera and telescope, one bin mode or another will provide the optimal compromise between exposure duration and resolution.

Figure 31b shows how binning works. Binning 2x2 groups four pixels together, giving you virtual pixels that are made up of 4 actual pixels. Binning 3x3 yields virtual pixels made up of nine actual pixels.

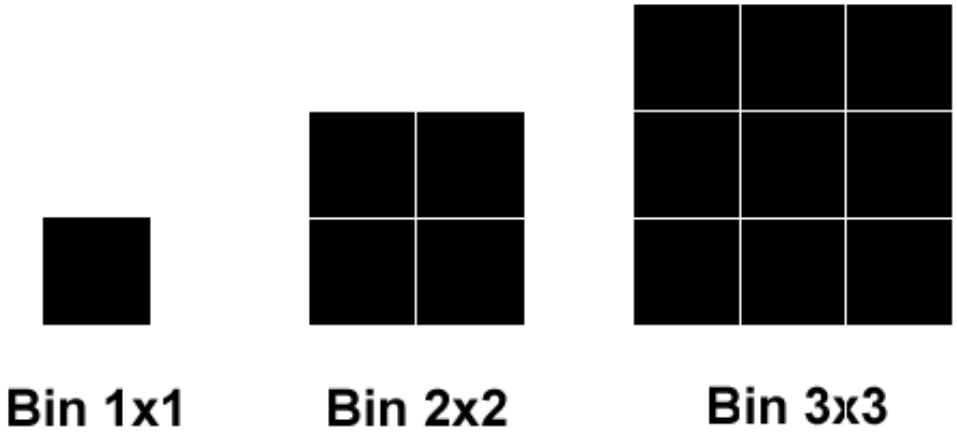


Figure 31b: Bin modes group pixels together for greater sensitivity, at a cost of lower resolution.

Figure 31c shows the relative sizes of image taken with 1x1 binning (large image) and 2x2 binning (small image). Both images cover exactly the same area of sky, about 1 by 1.5 degrees in this example. The 2x2-binned image shows that the binned detector is more sensitive because there is more detail visible in the dim areas of M42. It also shows that the binned pixels bloom less quickly – four pixels can hold more energy than one before they spill over into adjoining pixels.

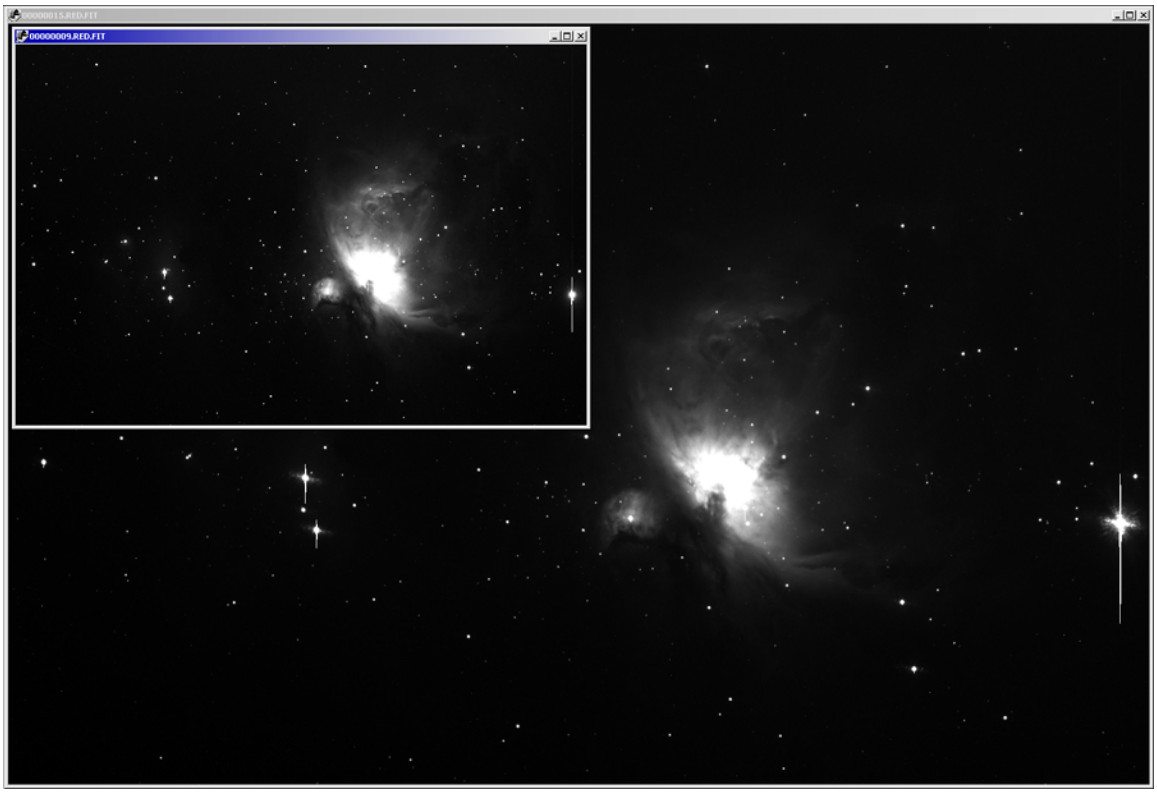


Figure 31c: Relative sizes of a 1x1- and 2x2-binned image.

Generally speaking, you will most often use a bin mode that will delivers between 2 and 4 arcseconds per pixel. This is the most common range for general-purpose CCD imaging. When working in this range, each pixel in the image “sees” or covers 2 to 4 arcseconds of the sky. The seeing conditions on most nights allow approximately 2 to 4 arcseconds of detail, and that is the reason for this range of values. If you have better or worse seeing conditions, select a bin mode based on your local conditions.

High-resolution imaging provides fewer than 2 arc-seconds per pixel, and can only be done on nights when the seeing is exceptionally good. This type of imaging is used most often for planets, but can also yield very fine detail on galaxies. The key is to wait for exceptional seeing conditions that will support higher resolution.

Low-resolution imaging (more than 4 arc-seconds per pixel) allows you to image wide fields of view, and can be done with camera lenses or telescopes with very short focal lengths. Seeing is unlikely to affect low-resolution wide-field images, so you can do this kind of imaging on almost any clear night.

You can use various tools and web pages to determine arcseconds per pixel for your camera and telescope combination, or use the following formula:

$$\frac{(205 * pixel_size_in_microns)}{telescope_focal_length_in_mm}$$

If you are binning 2x2, be sure to double the pixel size to get the correct value. For example, if you have an ST-7E camera (9-micron pixels) and are using it unbinned on a Meade LX200 8-inch at f/10, this is:

$$\frac{(205*9)}{2000}$$

Or 0.93 arcseconds per pixel. That's very high resolution. Since a typical night offers 2-4 arcsecond seeing conditions, you would rarely be able to use all that resolution. Binning 2x2 yields 18-micron pixels, which gives you 1.86 arc-seconds per pixel. This is just under two arcseconds per pixel, and offers a good compromise on nights of typical seeing.

You can also approach this from another direction: using a 50% focal reducer will bring the focal length of this scope down to 1000mm, which provides 1.86 arcseconds per pixel unbinned.



Binning also increases the sensitivity of your camera, as shown in figure 31c. Smaller pixel size means higher resolution, while larger pixel size means greater sensitivity. When you bin 2x2, you are making the pixel size four times larger in area, so the virtual pixel is four times more sensitive to light. You are making a tradeoff between resolution and sensitivity whenever you select a bin mode for your image. Try an experiment for yourself. Take a one-minute exposure of a galaxy using 1x1, 2x2, and (if available) 3x3. Note the differences in resolution and sensitivity.

Select exposure length

The maximum exposure length is determined by how good your polar alignment is, and by how accurately your mount tracks. If you see stars trailing into lines, shorten your exposure until this goes away (or take some time to improve your polar alignment or the accuracy of your mount's tracking). If you see wiggly lines on long exposures, then your mount's tracking error is too large for the current focal length. Use a focal reducer, or switch to a scope with a shorter focal length that better fits the capabilities of your mount.

The following table includes some recommended exposure times for various objects. The table assumes a focal ratio in the range of about f/7. Use longer exposures for longer focal ratios, and shorter exposures for shorter focal ratios. If you get blooming on a particular object, then go to a shorter exposure. If you don't get much detail in the image, or it seems washed out, go to a longer exposure. Generally speaking, unless you run into blooming, saturation, or other problems, longer exposures are generally better. Experiment to find the best exposures for your setup. You might want to keep a written record of successful exposures, which you can use as a guide for future imaging sessions.

Object	Suggested Exposure range
Sun	Use a visual solar filter, plus any additional filters needed to cut the light. Polarizing filters, moon filters, or other specialized filters such as h-alpha filters can reduce the light so that your camera's shortest exposure will be sufficient for solar images. Do not use so-called photographic solar filters. These are intended for film, which is much less sensitive than your CCD detector. Never attempt to image or view the sun without a proper solar filter!
Bright planets	Planets such as Venus, Jupiter, Saturn and Mars require surprisingly short exposures with most setups, as little as 5 to 10 thousandths of a second. However, if you use a Barlow or eyepiece projection to increase the focal ratio to

	f/20 or even f/30, longer exposures (up to a full second) may be required.
Moon	The moon is also very bright, especially around full moon, and may require some effort on your part to attenuate the light sufficiently for imaging. Polarizing filters and moon filters, or both, will get the job done. As with solar images, the shortest possible exposure of your camera should be tried first. Then add additional filtering if that isn't short enough, or increase the exposure if it's not long enough.
Open clusters, bright globular clusters	These require relatively short exposures, and exposure length is usually limited by blooming if you don't have an anti-blooming camera. If you do have an anti-blooming camera, you can even image open clusters long enough to image background galaxies. For clusters with very bright members, or globulars with very bright cores such as M13, exposures under a minute should be enough. Dimmer clusters may require exposures longer than a minute. Very bright clusters, such as the Pleiades, may only work well with anti-blooming cameras. For color imaging, be careful not to saturate bright stars so you can get truer star colors.
Galaxies	Galaxies come in a huge range of brightness levels. M31 will show up in an exposure of a few seconds; M101 may require 5 to 10 minutes or more. Generally speaking, edge-on spirals and elliptical galaxies are brighter and require shorter exposures. Face-on spirals are usually the dimmest galaxies and require longer exposures. When using a scope with a very long focal length, large pixels or binning may be required to get reasonable exposure times.
Nebulas	Nebulas come in an even wider range of brightness than galaxies do. Some, like M42, will yield excellent results in less than 20 seconds. Others, like the Rosette Nebula, may require 20-minute exposures to get good detail. A few trial exposures will help you determine the best exposure for any given nebula.

Generally speaking, longer exposures are better in most cases because they provide better-quality data. However, blooming, the risk of passing satellites or airplanes, and other factors usually limit the longest exposure time you can use. You can take multiple exposures and combine them in various ways to increase the quality of your images. See "Chapter 9: Image Processing" for details on aligning and combining images.

Set Frame Type to Light

The next step is to make sure that the Frame is set to **Light**. The Frame drop-down list also includes settings for taking image reduction frames, which is explained in detail in Chapter 7: Image Reduction. A CCD detector generates a certain amount of noise, and image reduction removes a great deal of that noise. When you are taking an image, always set the frame type to **Light**.

Briefly, the frame types are:

Light	A normal image, taken with the shutter open.
Bias	A frame of the shortest possible exposure, taken with the shutter closed. It represents the minimum noise in the CCD detector and camera circuitry. This is subtracted from Dark frames so that the dark frames can be scaled for time and temperature differences.
Dark	A frame taken with the shutter closed. It is in effect a picture of the electronic noise in the camera. This noise can be subtracted from a Light image to create a cleaner image.
Flat-Field	A flat-field is an image taken of an evenly illuminated field, with the shutter open. Think of the flat-field as an image of the optical noise in the system, such as dust motes on glass surfaces or reflections off of the inside of the telescope. The Flat Field is applied to the Light frame to remove this source of noise.

Set an Appropriate Reduction Setting

When you select Light as the frame type, you can also choose the type of reduction to apply to the image. Reduction is the process of applying bias, dark, and flat-field frames to your image to reduce system noise. See the section “Image Reduction Fundamentals” later in this chapter for more information about image reduction. Full coverage of image reduction is in Chapter 7: Image Reduction.

For your first images, choose the **AutoDark** reduction setting. After your exposure is finished, the software will automatically take a Dark frame with the same exposure settings, and subtract it from the image. This will give you a cleaner image with less thermal noise. When you gain more experience, you can explore the other reduction options:

None	The software performs no image reduction. Use this setting when you wish to manually apply your own bias, dark, and flat-field images; or when you simply want a quick image without any reduction.
AutoDark	This will follow the first exposure with a single dark frame. The dark frame is saved in memory and will be applied to all subsequent exposures with the same duration. If you change the exposure duration, a new AutoDark frame will be taken.
Bias, Dark, Flat	If you have previously taken bias, dark, and flat-field images and added them to a reduction group (see “Chapter 7: Image Reduction”), you can select which group to automatically apply to your images. The group names are hidden until you choose **Bias, Dark, Flat**.

If you have a filter wheel, select the appropriate filter

When you take an exposure, you can select which filter to use. If you do not have a filter wheel, this setting will be disabled. For your first exposures, start with the Clear filter setting. The Filter drop-down on the Take Image tab is designed for one-time images with a filter. If you plan to take color images, use the Color tab instead. See “Chapter 6: Taking Color Exposures” for details.



If you aren't sure if the filters in your filter wheel are set up in the default order, you can examine them visually without taking anything apart. Simply set the filter you want to test on the Take Image tab, and take a short exposure (one to three seconds). With a reasonably

	the Take Image tab, and take a short exposure (one to three seconds). With a reasonably strong light behind you, look into the front of the camera. As the shutter opens, you will see the CCD detector. The color of the detector is the color of the current filter. Ignore any reflections off of the filter; the color of the CCD detector will give you the true color of the active filter.

The filter setting, like the **Bin** and **Frame** settings, also affects focus and other camera operations.

Set the number of images

If you want to take more than one image, select that number in the “Series of” drop-down list. You can then combine images to improve the signal to noise ratio, which will make your images less grainy.

Click the Take Image/Series button and wait for the exposure and image download.

Once the **Take Image** tab options are set, click **Take Image/Series**. The software will signal the camera to begin the exposure. At the end of the exposure, the image will be downloaded and displayed. The software will automatically set the background and range settings (black point and white points). You can fine-tune these settings if you aren't satisfied with the automatic results. See “Chapter 9: Image Processing,” for more information about background and range settings.

Camera Control Panel Details

This section explains the options and features of the Camera Control Panel. The earlier part of this chapter provides step-by-step information about the most commonly used options. This section contains brief explanations of everything you'll find on the Camera Control Panel.

Setup Tab

The **Setup** tab in the Camera Control Panel is the first tab you interact with when you start up CCDSoft for taking images. You use it to tell CCDSoft which camera, filter wheel, and focuser you have connected to your computer. You can also use it to set various options related to the camera, and to set the cooling temperature for the CCD detector.

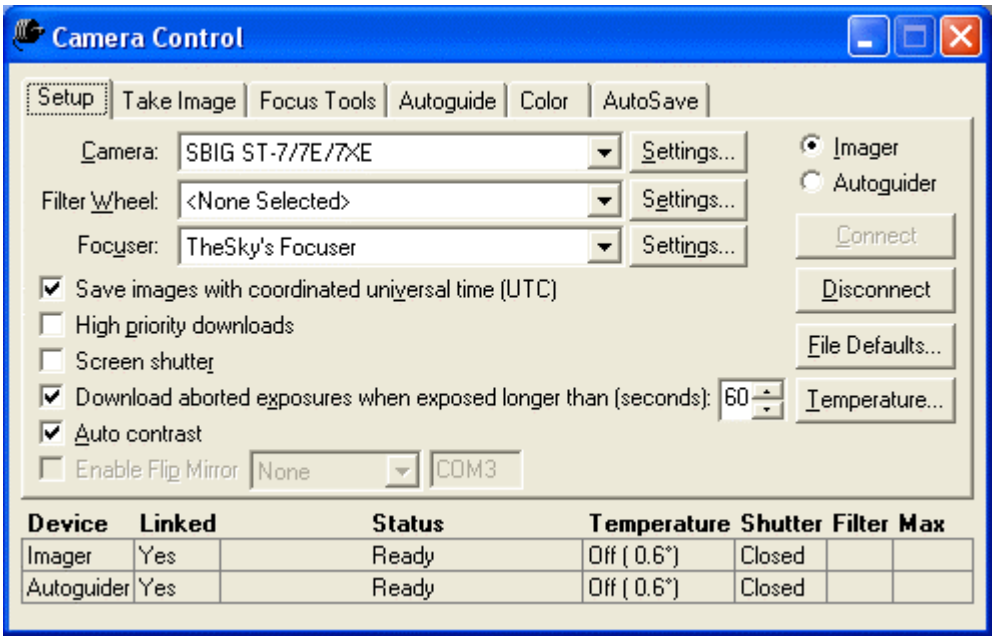


Figure 32: The Camera Control Panel, Setup tab.

Name of control	Description	Choices or options
Camera	Select the camera that is connected to your computer.	Changes as new cameras are introduced.
Camera Settings	Allows you to set values specific to your camera.	Varies with the camera.
Filter Wheel	Select the filter wheel that is connected to your computer, if present.	Changes as new filter wheels are introduced.
Filter Wheel Settings	Allows you to set values specific to filter wheel.	Varies with the filter wheel.
Focuser	Select the motorized focuser, if any, attached to your computer or mount.	Changes as new focusers are introduced.
Focuser Settings	Allows you to set values specific to your focuser.	Varies with the focuser.
Imager	Selects the Imaging detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Autoguider	Selects the Autoguider detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Save images with coordinated	When checked, the image	None.

universal time (UTC)	header includes the coordinated universal time (UTC).	
High priority downloads	When checked, image downloads have the highest priority. Other computer activities may slow down as resources are committed to the download process.	None.
Screen Shutter	When checked, the screen on your computer will go dark during exposures. This prevents light from the computer screen from reaching the camera or telescope.	None.
Download aborted exposures when exposed longer than (seconds)	When checked, if you abort an exposure, the data will be downloaded if the exposure duration exceeds the number of seconds specified.	None.
Auto contrast	When checked, the contrast of the image is adjusted automatically. Clear this option if you wish to use the same background and range settings for each new image.	None.
Connect	Click this button at the beginning of your image session to connect with the camera.	None.
Disconnect	End the connection to the camera.	None.
File Defaults	Set default values for image headers.	Observer, origin, telescope focal length, and aperture.
Temperature	Turn temperature control of the CCD detector on or off, or adjust the set point for detector temperature.	Temperature dialog box; see figure 4 earlier in this chapter.
Enable Flip Mirror	Control a custom flip mirror.	Select the correct COM port. This is a custom option and is used for the ISSAT telescope only.

Take Image Tab

The **Take Image** tab in the Camera Control Panel allows you to set exposure settings and take images.

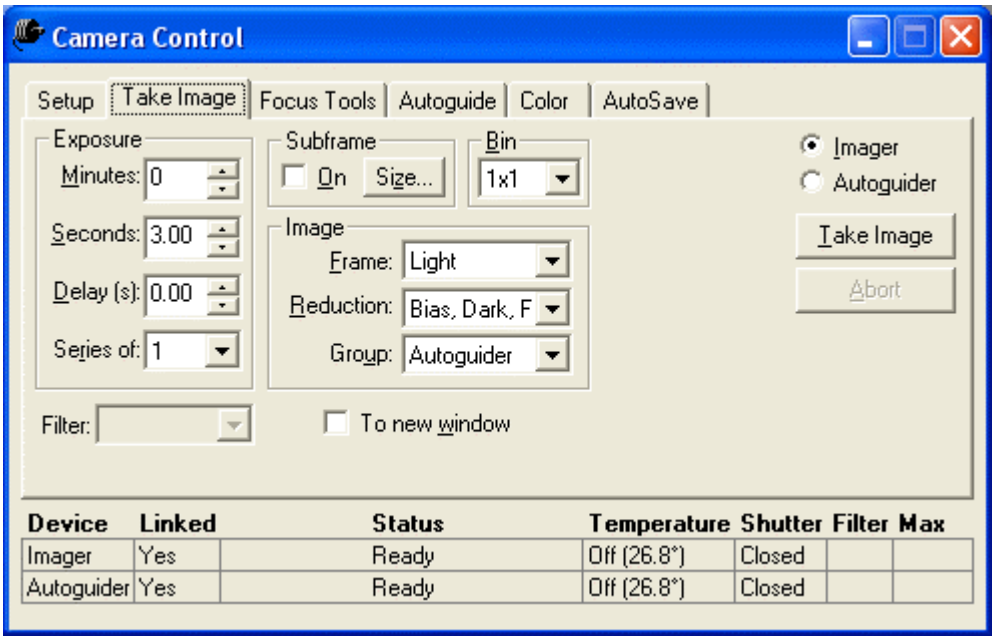


Figure 33: The Camera Control Panel, Take Image tab.

Control	Description	Choices or options
Minutes	Minutes portion of the exposure duration.	As short or as long as your camera permits.
Seconds	Seconds portion of the exposure duration. Use the shift and control keys to modify mouse left-click behavior: SHIFT+CLICK: tenths CONTROL+CLICK: tens SHIFT+CTRL+CLICK: hundredths.	As short or long as your camera permits.
Delay (s)	The delay before exposures. The delay will also occur before the first exposure. Use shift and control keys to modify mouse left click behavior: SHIFT+CLICK: tenths CONTROL+CLICK: tens SHIFT+CTRL+CLICK: hundredths.	You can use a short delay to allow autoguiding to re-center a star after an image download, or use a long delay to monitor changing weather conditions.
Series of	How many images to take in a series.	From 1 to 500.
Filter	The filter to set on the color filter wheel. If filter wheel is not	Depends on which color filter you have installed, if any.

	present, this will be disabled.	Typically, includes at least Clear, Red, Blue, and Green.
Subframe On	Indicates whether the image will be the full frame of the CCD detector, or a partial frame.	None.
Subframe Size	Click this button to manually enter the subframe coordinates and size. Most of the time, you will create a subframe by clicking and dragging in an image window.	Up to the full size of the CCD detector in pixels.
Bin	Sets the bin mode.	Will vary with CCD detector, commonly: 1x1 2x2 3x3.
Frame Type	Determines whether you are taking a light image, or creating a reduction image.	Light, Bias, Dark, or Flat-Field.
Reduction	This is active only if you chose **Light** as the frame type. It determines whether image reduction occurs automatically as you are taking images, and if so, what type of reduction.	**None** – no image reduction is performed. **AutoDark** – automatically take a dark frame after the light frame. **Bias, Flat, Dark** – use a reduction group created prior to taking the image.
Reduction Group	This is active only if you choose **Bias, Flat,** or **Dark** as the reduction setting. You use it to apply custom bias, flat, and/or dark frames to each image as it is downloaded.	You will see a list of reduction groups you have created. The default groups are Imager and Autoguider.
To new window	When checked, each image will be downloaded into a new window. When unchecked, a single window is used for all downloaded images, with the most current image replacing the previously downloaded image. If AutoSave is off, images are lost when they are replaced by new images if **To new window** is not checked.	None.
Imager	Selects the Imaging detector as the active detector for focusing and imaging, when a dual-detector camera is present	None.

Autoguider	Selects the Autoguider detector as the active detector for focusing and imaging, when a dual-detector camera is present	None.
Take Image/Series	Click this button to take one or more images using the current settings. **Take Image** appears if **Series of** is set to 1; **Take Series** appears if it is set to more than 1.	None.
Abort	Click to abort taking an image. Active only while an image is being exposed or downloaded.	None.

Focus Tools Tab

The **Focus Tools** tab in the Camera Control Panel helps you achieve optimal focus. You'll use it at the start of your imaging session to establish the initial focus, and periodically throughout your imaging session to adapt the focus to changing temperatures, or to change focus when you change filters or other equipment.

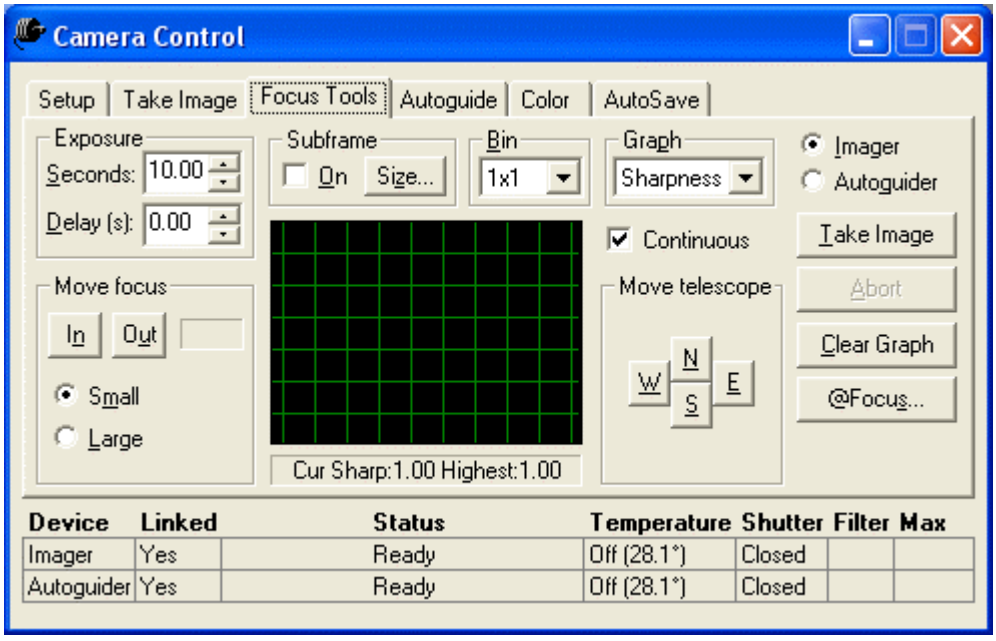


Figure 34: The Camera Control Panel, Focus Tools tab.

Name of control	Description	Choices or options
Seconds	Seconds portion of the focus exposure duration. Use shift and control keys to modify	As short or long as your camera permits.

	mouse left-click behavior: SHIFT+CLICK: tenths CONTROL+CLICK: tens SHIFT+CTRL+CLICK: hundredths.	
Delay (s)	The delay before exposures. The delay will also occur before the first exposure. Use shift and control keys to modify mouse left click behavior: SHIFT+CLICK: tenths CONTROL+CLICK: tens SHIFT+CTRL+CLICK: hundredths.	Try 3-10 seconds to start with, depending on how long it takes you to make an adjustment. Use smaller number for electric focusers; longer numbers for manual focusers.
Move Focus In/Out buttons	If your focuser is connected and can be controlled by TheSky, you can use these buttons to move the focus position in and out.	Note: the current focus position is shown to the right of the buttons.
Move Focus Small/Large	Use the **Large** setting to make large changes in focus position, and use the **Small** setting to make fine changes as you get close to optimal focus position.	None.
Subframe On	Indicates whether the image will use the full frame of the CCD detector, or a partial frame.	None.
Subframe Size	Click this button to manually enter the subframe coordinates and size. Most of the time, you will create a subframe by clicking and dragging in an image window.	Up to the full size of the CCD detector in pixels.
Move telescope (N/S/E/W) buttons	Click and hold these buttons to move the telescope at the guide rate (typically 0.5x sidereal or slower).	None.
Continuous checkbox	When checked, focus exposures will repeat until you click the Abort button. If you have a delay set, it will occur between all exposures.	None.
Bin	Sets the bin mode.	Will vary with CCD detector, commonly: 1x1 2x2

		3x3
Graph	Choose which method to use for evaluating focus.	Maximum (pixel brightness) or Sharpness.
Graph with green lines on black background	The graph is self-scaling. It displays the current brightness or sharpness value during focusing. See the section on focusing earlier in this chapter for details on Maximum and Sharpness values.	The current values for maximum brightness or sharpness are displayed beneath the graph. Note: The maximum brightness value for both imager and autoguider appears at the bottom of the Camera Control Panel, in the column **Max**.
Imager	Selects the Imaging detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Autoguider	Selects the Autoguider detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Take Image	Click this button to take an image using the current settings.	None.
Abort	Click this button to abort taking an image.	None.
Clear Graph	Clears the graph.	None.
@Focus	Starts the autofocus algorithm. You must pick a valid motorized focuser on the Setup tab to use @Focus.	Varies with the focuser you are using, but often includes such things as large and small steps sizes, and backlash.

Autoguide Tab

The Autoguide tab in the Camera Control Panel controls the CCD detector in any autoguider you have connected to your computer. This can be a built-in autoguider, such as you find in the ST-7/8/9/10 series of cameras, or a separate guider (or camera being used as a guider) such as an ST-4 or ST-237. You can even select the imaging detector in an ST-7/8/9/10 as the guider if you so desire. This could be a practical solution when you are imaging with a film camera, and wish to use the larger imaging detector of an ST series camera for guiding purposes.

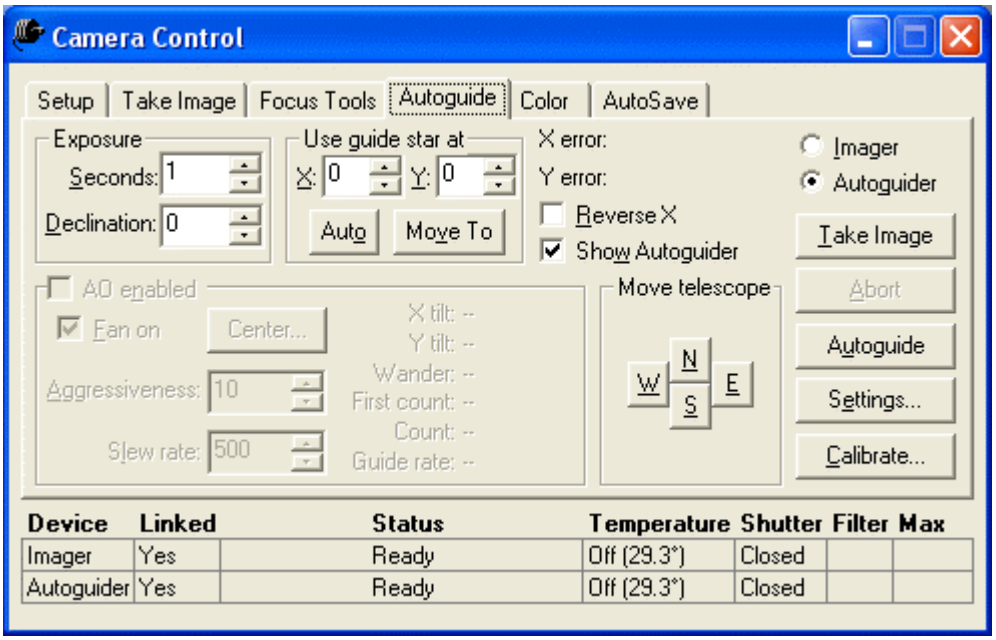


Figure 35: The Camera Control Panel, Autoguide tab.

Name of control	Description	Choices or options
Seconds	Length of the autoguide exposure. Use the shift and control keys to modify mouse left-click behavior: `SHIFT+CLICK`: tenths `CONTROL+CLICK`: tens `SHIFT+CTRL+CLICK`: hundredths	Exposures of 3 seconds or longer will help average out erratic seeing conditions. Typical values used are 2 to 10 seconds.
Dec	The current declination of the telescope. This is filled in automatically if you are using TheSky in conjunction with CCDSoft. Otherwise, enter it manually to allow CCDSoft to scale the guiding rate for subsequent images. Use the shift and control keys to modify mouse left-click behavior: `SHIFT+CLICK`: tenths `CONTROL+CLICK`: tens `SHIFT+CTRL+CLICK`: hundredths.	A number between 0 and 90 for the northern celestial hemisphere, or between 0 and -90 for the southern celestial hemisphere.
Use guide star at	The location of the guide star in the autoguider frame. You	Limited by the size of the guide detector.

	can enter it manually, but most often you will click in the autoguider frame and CCDSoft will enter the coordinates here.	
Auto	CCDSoft will scan the autoguider image and select the best guide star available.	None.
Move To	Click to move the current guide star to a new position on the guide detector. CCDSoft will move the mount so that the guide star moves to the new position. The current distance from the new position appears in the Error X/Y area.	The Move To dialog box appears, with starting and ending coordinates. Click on the autoguider image while this dialog box is displayed to set the ending coordinates.
Move telescope (N/S/W/E) buttons	Click and hold these buttons to move the telescope at the guide rate (typically 0.5x sidereal or slower).	None.
X Error	Displays the horizontal distance of the guide star from the starting position in hundredths of a pixel.	None; display only.
Y Error	Displays the vertical distance of the guide star from the starting position in hundredths of a pixel.	None; display only.
Reverse X	Reverses the direction of the X coordinate. Check this when you calibrated the guider on one side of the meridian, and you are imaging on the other side of the meridian without performing a new calibration.	None. With many mounts, you will get better results by re-calibrating the guider whenever you cross the meridian. Only mounts with truly orthogonal optics and minimal backlash reverse with sufficient precision to use this feature. It also works with telescopes with very short focal length.
Show Autoguider	Determines whether or not the subframe of the autoguider images with the guide star on it displays every time an image is downloaded during guiding. On by default, you can use the autoguider image to monitor guiding performance, and to spot changes in focus due to temperature changes.	None.
Imager	Selects the Imaging detector	None.

	as the active detector for focusing and imaging, when a dual-detector camera is present.	
Autoguider	Selects the Autoguider detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Take Image button	Takes an image using the guide detector. If there is more than one detector in your camera, this will be the detector you select using the Imager/Autoguider radio buttons.	None.
Calibrate	Click this button calibrate your mount for the autoguider.	None.
Autoguide	Starts autoguiding using the currently selected guide star and calibration settings.	None
Settings	Opens a dialog box that shows the autoguide settings.	Many options; see “Chapter 4: Autoguiding” for detailed information.
Abort	Ends the autoguiding session.	None.

Color Tab

The Color tab gives you control over the capture of color images using a color filter wheel. You can set individual options for up to four different filters in each set of images. You can use four filters for LRGB imaging; three filters for RGB imaging; or any combination of filters you wish for customized imaging. Individual filters can be made active or inactive easily, and you can take a single set or a series of exposures.

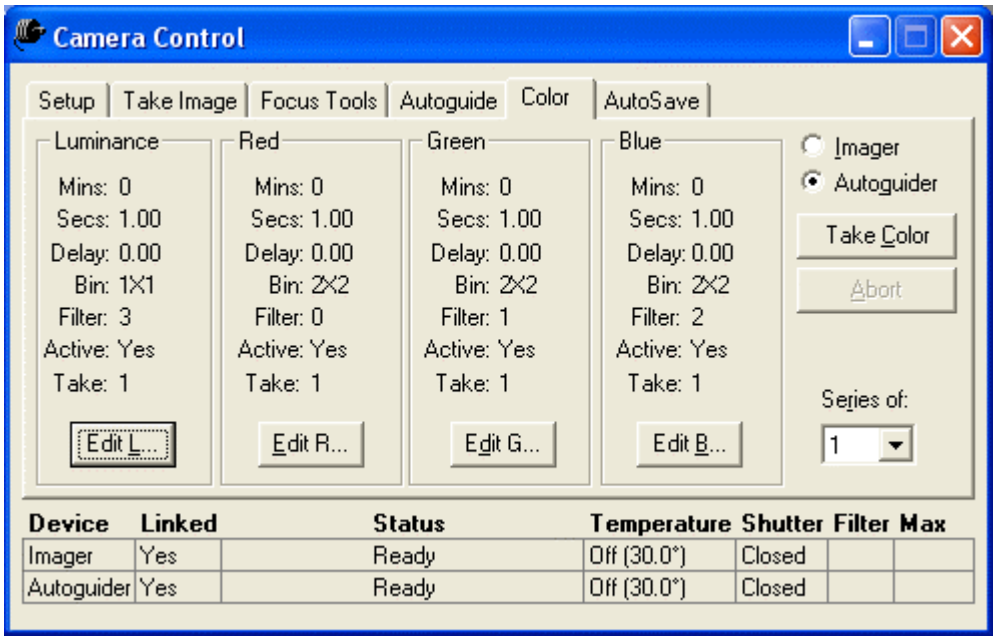


Figure 36: The Camera Control Panel, Color tab.

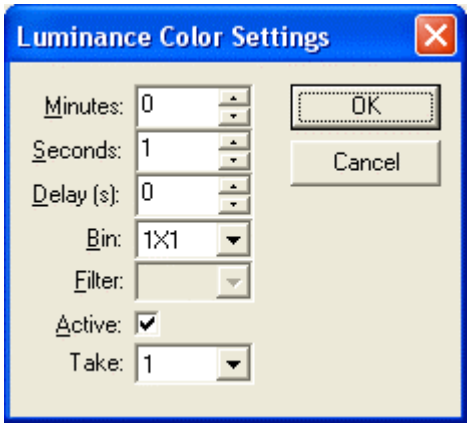


Figure 37: Settings for a single filter.

Name of control	Description	Choices or options
Edit L	Click to edit the settings for the luminance filter (or filter #1).	See Color Settings dialog box below.
Edit R	Click to edit the settings for the red filter (or filter #2).	See Color Settings dialog box below.
Edit G	Click to edit the settings for the green filter (or filter #3).	See Color Settings dialog box below.
Edit B	Click to edit the settings for the blue filter (or filter #4).	See Color Settings dialog box below.

Imager	Selects the Imaging detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Autoguider	Selects the Autoguider detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Take Color	Takes images for all filters currently active.	None.
Abort	Stops the current image on the current filter, and continues with the next image. Click a second time to completely stop the color series of exposures.	None.
Series of	How many images to take in a series.	From 1 to 500.

Color Settings Dialog Box

Name of control	Description	Choices or options
Minutes	Minutes portion of the exposure duration.	As short or long as your camera permits.
Seconds	Seconds portion of the exposure duration. If you enter a number larger than 60, the software will break it down into minutes and seconds. Use the shift and control keys to modify mouse left-click behavior: SHIFT+CLICK: tenths CONTROL+CLICK: tens SHIFT+CTRL+CLICK: hundredths	As short or long as your camera permits.
Delay (s)	Length of the delay before each image is exposed. Use the shift and control keys to modify mouse left-click behavior: SHIFT+CLICK: tenths CONTROL+CLICK: tens SHIFT+CTRL+CLICK: hundredths	The delay before exposures. The delay will also occur before the first exposure.
Bin	Sets bin mode.	Will vary with CCD detector,

		commonly: 1x1 2x2 3x3
Filter	Determines which of the available filters to use for this exposure.	Varies with the color filter wheel installed, but usually includes at least Clear, Red, Green, and Blue.
Active	If checked, exposures are taken with this filter.	None.
Take	Enter the number of images to take for this filter.	From 1 to 500.

AutoSave Tab

The **AutoSave** tab in the Camera Control Panel allows you to specify how your images will be saved. The most common choice is to automatically save all images. You can even save focusing images if you so desire. Images from both the imager and autoguider can be saved automatically.

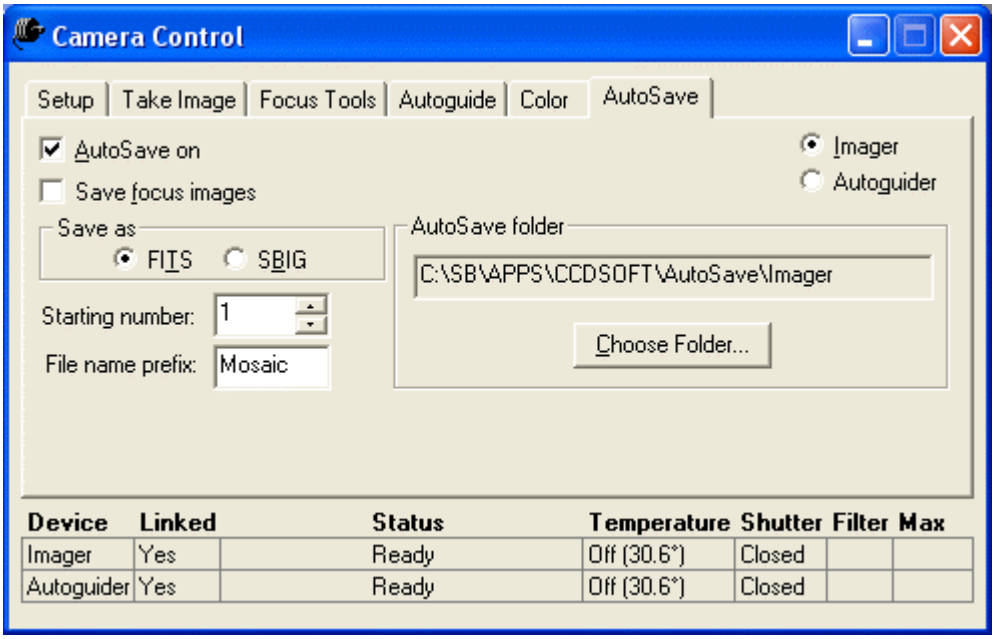


Figure 38: The Camera Control Panel, AutoSave tab.

Name of control	Description	Choices or options
AutoSave on	When checked, every image taken using the Take Image and Color tabs will be saved automatically. See below this table for information about file naming conventions.	None.

Save focus images	When checked, images taken with the Focus Tools tab are also saved to disk.	None.
Save as	Sets the file format to use for automatically saved images.	FITS or SBIG. If you are planning to use your images for astrometry and/or photometry, you must choose FITS so that the file header will contain the necessary information.
Starting number	The number to append to the filename of the next image to be saved. This number is incremented each time an image is taken.	A number from 1 to 99,999.999.
File name prefix	Optional. You may enter a text prefix to add at the start of each filename. See below this table for information about file naming conventions.	A text prefix.
Imager	Selects the Imaging detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
Autoguider	Selects the Autoguider detector as the active detector for focusing and imaging, when a dual-detector camera is present.	None.
AutoSave folder	This is the folder where autosaved images are stored.	None.
Choose Folder button	Click to open/create a folder for autosaving images.	None.

If you turn **AutoSave** on, downloaded images will be saved to your hard disk using simple naming conventions. Here are some examples of typical filenames that CCDSoft uses when TheSky is present and linked to your telescope. Note that the name of any object at the center of the image is incorporated into the filename: If no object is near the center, the right ascension and declination are added to the name instead.

Filename	**Comments**
`Flaming_Star.00000018.GSC_2398_586.FIT`	This name uses a prefix entered by the user in the **File name prefix** box (Flaming_Star). The star GSC 2398:586 is at the center of the image. This is image #18 in the current sequence.
`5min darks.00000002.GSC_1205_867.DARK.FIT`	This is the second image in a series, with the star GSC 1205:867 at the

	center of the frame. It is a dark frame, taken with the shutter closed and includes a user prefix.
00000005.23h55m45.3s_34d53m42sN.FLAT.FIT	This is the fifth image in a series. It is a flat field taken while the telescope was pointing at the right ascension and declination included in the name.
00000086.M37.BLUE.FIT	The 86th image of the night, this is an image with M37 at the center. It was taken through a blue filter.
00000052.GSC_1800_1749.LUMINANCE.FIT	The 52nd image, right in the middle of the Pleiades, taken through a clear filter as part of a color series.
00000053.GSC_1800_1749.RED.FIT	This is the very next image, taken through a red filter as part of the same color series (the same object is at the center of the image).

Note the following about the filenames:

- The prefix is optional.
- The object portion of the name can be one of many things – a star, a galaxy, or even the right ascension and declination coordinates of the center of the frame. If you are unsure of what the name refers, open TheSky and use the Find or Move To commands to quickly see what the telescope was pointing at.
- Special-purpose frames – reduction frames, color frames, etc. – have this fact recorded in the filename.

Image Control (Brightness & Contrast)

Once you have taken an image, CCDSoft will automatically balance the brightness and contrast of the image. You can also adjust these settings to suit your needs.



CCDSoft includes a full complement of image processing tools that allow you to do much more than adjust the brightness and contrast of your images. Please see “Chapter 9: Image Processing” for information about other image processing tools.

You will also find that adjusting brightness and contrast helps with such things as determining best focus, and finding out whether your exposure was long enough to bring out the fainter details in the image.

For example, when imaging the California Nebula, the default presentation of the image might look like figure 39. The nebula looks very dim, and you might question whether or not the exposure was long enough. If it was long enough, you can continue imaging. If not, then you should try a longer exposure. Figure 39 looks dim, but is it really dim? Adjusting the brightness and contrast will tell us.



Figure 39: The California Nebula, raw data with automatic adjustment of brightness and contrast.



The vertical streaks above and below the brightest stars are called “blooming.” An anti-blooming CCD detector would have made it possible to take even longer exposures without blooming.

There are two approaches you can use to adjust an image’s brightness and contrast:

Change the background and range settings – This method is based on the CCDOPS program. It uses numeric values, but it also offers an auto-adjust option. Click **Image | Brightness & Contrast | Background & Range** to open the Background & Range dialog box.

Modify the image histogram – A histogram graphs the brightness values in an image, and allows you to adjust the background and range interactively. You can see the results of your changes in real time, which helps you choose the best settings. Right click on an image and then click **Histogram**, or click **Image | Brightness & Contrast | Histogram**. See “Chapter 9: Image Processing” for a detailed discussion of how to use the Histogram tool.

Whichever method you use, the background value sets the black point – all pixels darker than the background setting will be appear black. The range establishes the white point – all pixels brighter than the background plus the range will appear white. The pixels darker and brighter than these values are still stored in the image, and you can use different background and range settings later if you wish to do so.

The automatic values calculated by the Background & Range dialog box for the image in figure 39 were:

Background:	1946
Range:	3907

These values are fine for the stars in the image, but the California nebula is very dim. It can be enhanced using a higher background setting, and a shorter range. Figure 40 shows the result of these new settings:

Background:	2380
Range:	650

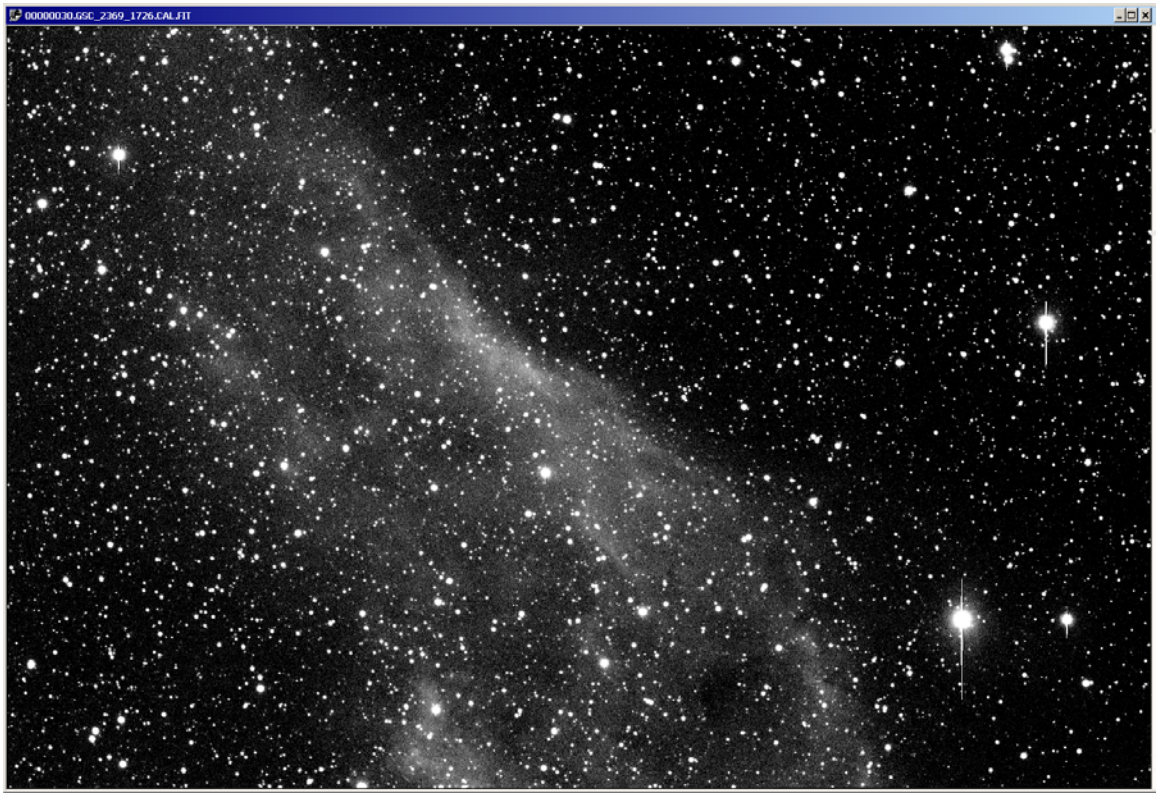


Figure 40: The California Nebula, with manual adjustment of brightness and contrast.



Stars are very bright, and show up best with a large range setting. Nebulae and the arms of galaxies are dim, and have a short brightness ranges. A short-range setting emphasizes these dim features, but at the cost of possibly "burning out" bright areas in the image by making them pure white.

Image Reduction Fundamentals

Image reduction is the process of modifying the raw data downloaded from the camera to remove known, repeatable sources of system noise. You can take bias, dark, and flat-field frames to record the noise, and then use those frames to remove the noise from your images.

There are two sources of noise when taking CCD images: electronic noise in the detector and camera, and optical “noise” that comes from dust, reflections, and/or vignetting in the optical system. See “Chapter 7: Image Reduction” for details on noise sources.

Electronic noise sources are inherent in the very nature of CCD detectors. Typical noise sources in a CCD camera include:

- Hot pixels that read with a higher value than is accurate.
- Cold pixels that read with a lower value than is accurate.
- Residual noise that is inherent in the electronics (bias).

- Thermal noise, which is usually minimized by cooling the CCD detector.

CCDSoft uses bias and dark frames to remove as much of this noise as possible. With careful attention to details, you can clean out a substantial percentage of the electronic noise found in a raw image.

Optical noise is caused by anything that add or subtracts light from the image. Typical optical problems include:

- Dust on the window immediately above the CCD detector, which casts small, sharp shadows on the detector.
- Dust on the external camera window, which will cause somewhat larger shadows.
- Dust on any filters that are in the optical path.
- Dust on the telescope optics.
- Vignetting from anything that physically blocks the path of light through the system, or from the optical design itself.
- Reflections of any kind from any surface in the optical system.

CCDSoft uses a flat-field frame to remove optical noise.

The bias, dark, and flat-field frames each enable CCDSoft to improve the appearance and accuracy of your images. For most cameras, dark frames are the most critical to use, and will show the greatest improvement. Flat-field images are most important when imaging at fast focal ratios, f/6 and slower. Flat fields are also useful if there is significant dust in the optical path, or if there is vignetting present. Bias images provide an additional level of accuracy, but are not as critical as flat fields and dark frames.

Bias frame – A bias frame is a record of the inherent minimum noise in the camera. Taken with the shutter closed, a bias frame is always the shortest possible exposure allowed by the camera. An ideal bias frame would have a zero exposure length, but most cameras are not equipped to provide this, so the shortest possible exposure is used instead. Figure 41 shows a bias frame from an ST-7E camera. Note that there are several types of noise present – brighter columns, hot and cold pixels, and lighter and darker areas. All of these are normal, and all are safely removed by applying the bias frame to a light image.

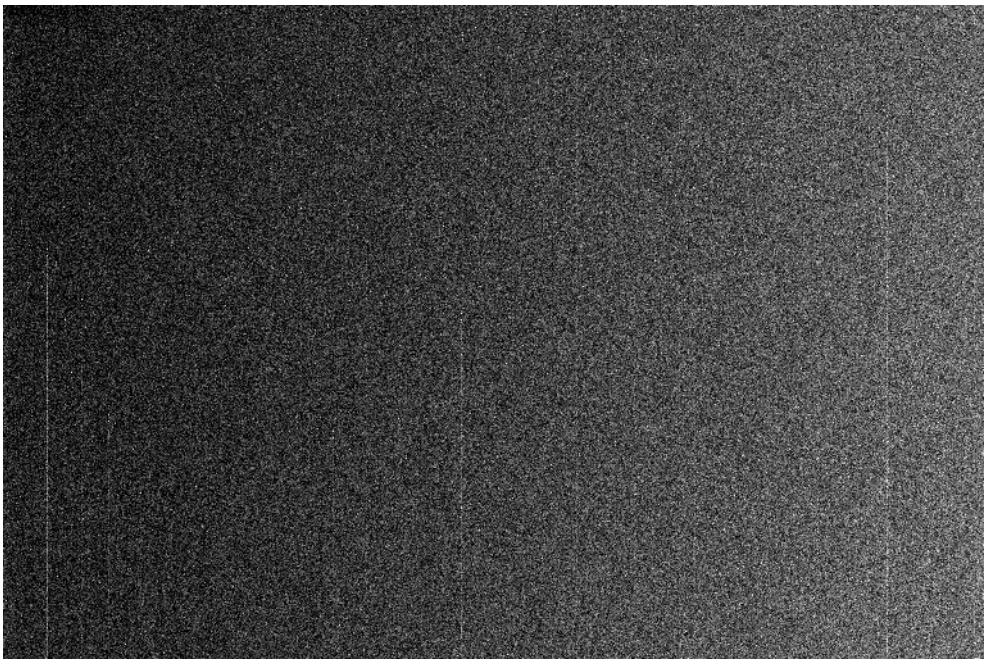


Figure 41: A bias frame from an ST-7E camera.

Dark frame – A dark frame is a record of the noise that builds up over time during a complete exposure. Dark frames are taken with the shutter closed. Dark exposures ideally should be identical in temperature and exposure duration to the light exposures to which they are applied, but they can be scaled (see below). Figure 42 shows a typical dark frame. Note that it has several cosmic-ray hits (larger white spots). Taking several dark frames and averaging them together will reduce problems from such random noise. The dark frame in figure 42 is relatively uniform, but many dark frames have a subtle gradient that is caused by additional dark noise building up during the length of time it takes to read from one edge of the image to the other. Such gradients are normal, and will be present in the light images, too. When the dark frame is applied to the light image, the gradient will disappear.

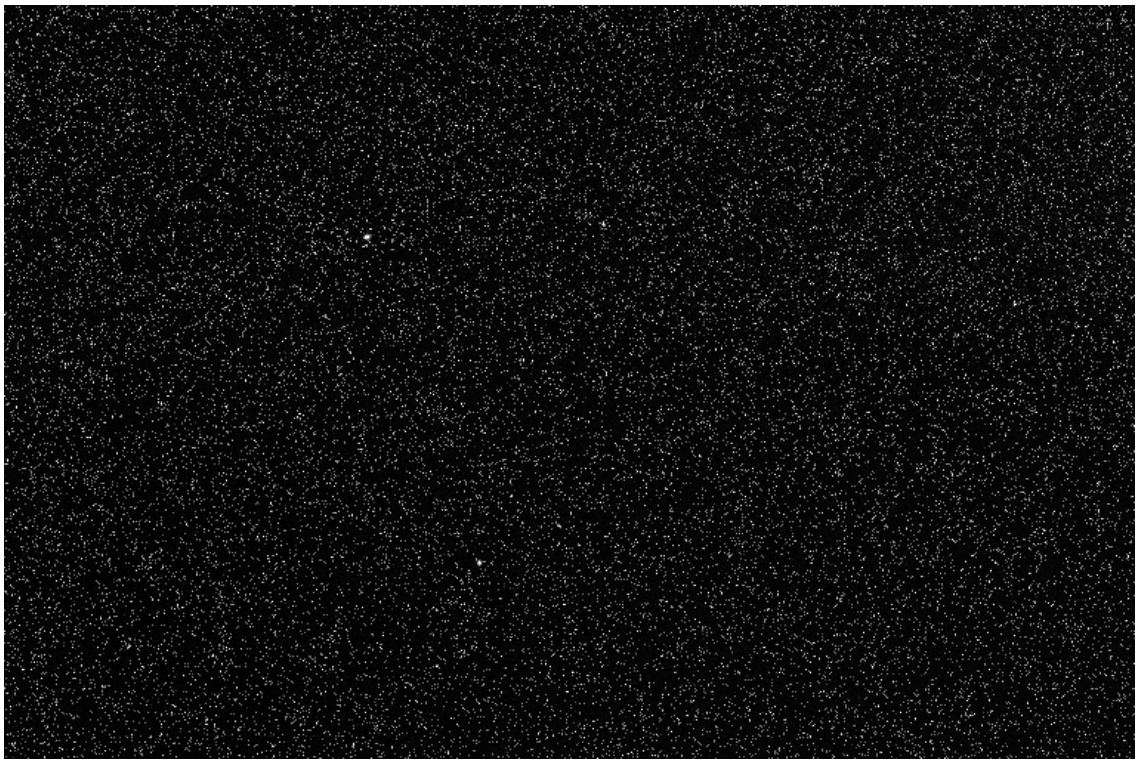


Figure 42: A typical ST-7E dark frame.

Flat-field frame – Every optical system has unique ways in which it adds or subtracts light to an image. Dust on any optical surfaces will cast shadows on the CCD detector. The closer the dust is to the detector, the sharper and smaller the shadow will be. The optical system may vignette (darken) away from the center, or some parts of the telescope may obstruct light (secondary mirrors, spiders, undersized focusers, dew shields that are too long, etc.).

Thus a flat-field frame is a record of the dirt, obstructions, and reflective surfaces in the optical system. Flat-field frames are taken with the shutter open, and at the same focus position used for light images. Flats, as they are often called, should be about 33-50% of saturation for your CCD detector. Figure 43 shows a flat-field frame taken with an ST-8E camera and a Takahashi FSQ-106 refractor.

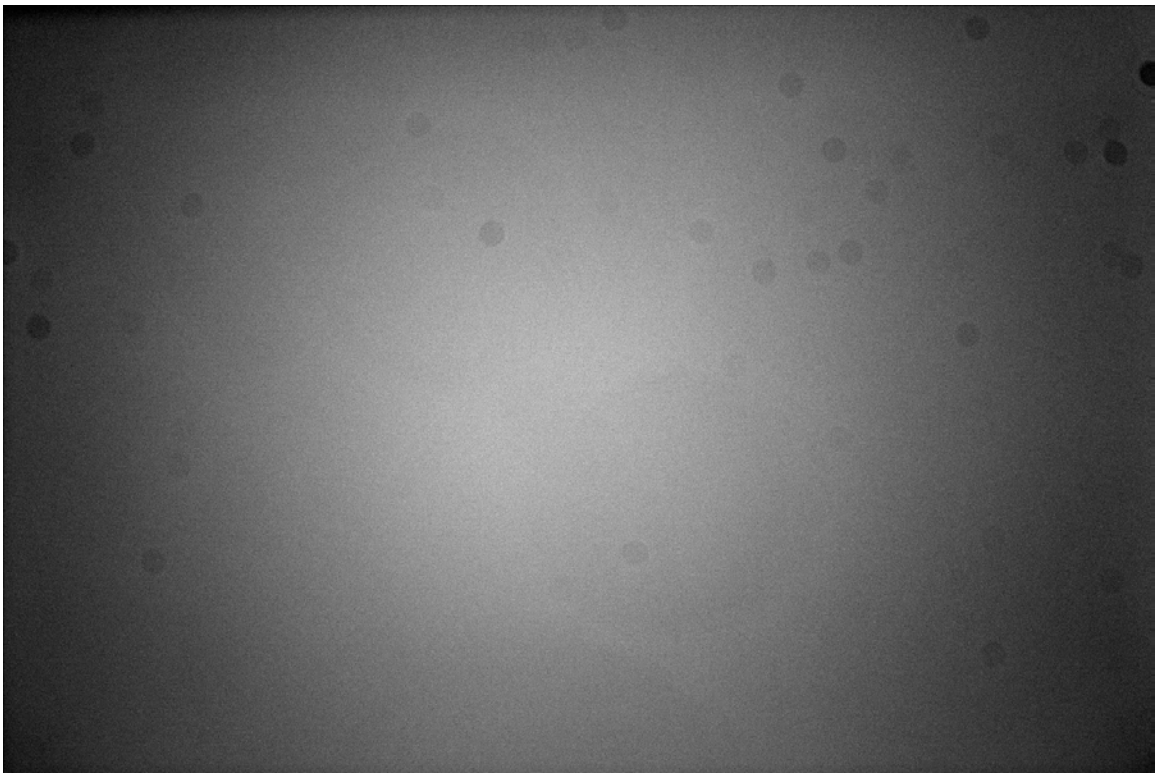


Figure 43: An example of a flat-field frame.

See “Chapter 7: Image Reduction” for more information about bias, dark, and flat frames. You will learn how to take bias, dark, and flat-field frames, reduce individual images, reduce folders of images, and manage groups of reduction frames.

Reduction During and After Image Acquisition

You can reduce your images as you take them, or afterwards. CCDSoft supports both approaches. When you take an exposure with the Camera Control Panel's Take Image tab, if you set the Frame type to **Light**, you can choose two methods of image reduction that will be applied as you take images: **AutoDark** and **Bias, Dark, Flat**.

If you choose **AutoDark**, a dark frame of the same duration as your light exposure is taken after the first light image and applied to that first image and each subsequent image. If you change the exposure length, a new dark is taken and applied to images with that exposure duration. The **AutoDark** option does not apply bias or flat-field frames to your images. If **AutoSave** is turned on, the original unreduced image is saved to disk, as well as the reduced one. If **AutoSave** is off, then the image is downloaded, reduced, and is left open in CCDSoft. In other words, the raw data is lost if **AutoSave** is off. If you want to retain your raw data when reducing images automatically, make sure you turn **AutoSave** on.

If you choose **Bias, Dark, Flat**, you will see a drop-down list of the available reduction groups below the **Reduction** list on the **Take Image** tab. The default groups are Imager and Autoguider. These groups must be setup in advance before applying them to your images.

If you want to reduce images automatically as they are taken, you can build a library of bias, dark, and flat-field images. You can also take new ones every night before you start imaging. Or, you can simply take your images and reduce them later. If you are taking a high volume of images and do not need perfect reduction, such as when hunting for minor planets, automatic reduction can streamline your data acquisition process. If you want the best possible reduction for each image, then reducing images one at a time, and visually confirming each step in the process, may be your best option.

“Chapter 7: Image Reduction” contains detailed information about taking bias, dark, and flat-field images. It also covers the creation, management, and use of reduction groups. If you plan to automatically apply reduction groups to your images, please read “Chapter 7: Image Reduction.”

Controlling Multiple Detectors in a Single Camera

CCDSoft offers the greatest possible flexibility in controlling cameras like the ST-7/8/9/10 series. These cameras have multiple detectors, one for imaging and one for autoguiding. You can use either detector for imaging or autoguiding. Every tab in the Camera Control Panel allows you to select either the imaging or autoguiding detector as the active detector for the purposes of that panel. You can even take a series of full-color RGB or LRGB images using the autoguider detector should you need to do so.

This also means you can use the much larger imaging detector for guiding. This is useful when taking images with a camera through a second telescope on the same mount.

Chapter 2: Working with Images and Files

CCDSoft offers a great deal of flexibility in how you create, save, and manipulate image files. You can use various features in CCDSoft to create slide shows, link text or multimedia information to images, and change file formats to allow you to use other software to manipulate images.

This chapter discusses most of the basic file and image processing tasks. The following functions are covered in detail:

- Saving images to disk.
- Converting to other file formats.
- Copying, pasting, cropping, and duplicating images.
- Printing images.
- Zooming and fitting images to the CCDSoft window.
- Creating slide shows.
- Viewing and editing file information.
- Selecting and arranging toolbars.
- Setting status bar options.
- Changing display modes.

Quick Start For Experienced Users

For this chapter, an experienced user is someone who has used a previous version of CCDSoft or other camera control software.

If you have experience with camera control and image processing software, the following features are most likely to be of interest to you:

1. If your screen size is smaller than your camera's detector size, click **View | Fit to Window | Maintain Aspect** to display images at a smaller size.
2. For fast zooming in and out, use keyboard shortcuts. The `Ctrl` key is for zooming in, and the `Alt` key is for zooming out. `Ctrl+2`, for example, zooms in to 2:1, while `Alt+2` zooms out to 1:2.
3. For operation near your telescope, use the Night Vision mode (click **View | Night Vision Mode**). It displays all screen elements in shades of red. This command toggles the red effect on and off.
4. You can quickly get information about the exposure, right ascension and declination, and other aspects of a FITS image using the FITS information window (click **View | File Information**). You can also use this feature to edit the FITS header information.
5. Toolbars can be moved, hidden, and displayed as needed. Click **View | Toolbars** to make changes. Toolbars can be moved to any side of the window (top, bottom, left, or right) and docked there, or you can leave them floating freely if desired.
6. The status bar displays much information about an image. Watch the status bar as you pass the cursor over an image. If you add WCS coordinates to an image (see "Chapter 8: Research: Astrometry and Photometry"), even more information is available.

Saving Images to Disk Automatically

You can save your image files to disk in two ways:

- By turning marking the **AutoSave on** option in the Camera Control Panel (AutoSave tab).

- By manually saving the files yourself.

The AutoSave option automatically names and saves files as you take images. This is the recommended method. If AutoSave is on at the start of an imaging session, you will have a clear record of your work for that session. The recommended initial settings are:

- Check **AutoSave on** to turn on the AutoSave feature.
- Set the **Starting number** to 1.
- Create a new folder for each session, unless you want to save files in the same folder as a prior session.
- Make sure that **Imager** is selected as the active CCD detector for AutoSave.

Figure 1 shows the **AutoSave** tab of the Camera Control Panel, with the recommended default settings. For more information about AutoSave, including examples of the detailed filenames used during AutoSave, please see the section “AutoSave Tab” in Chapter 1: Camera Control.

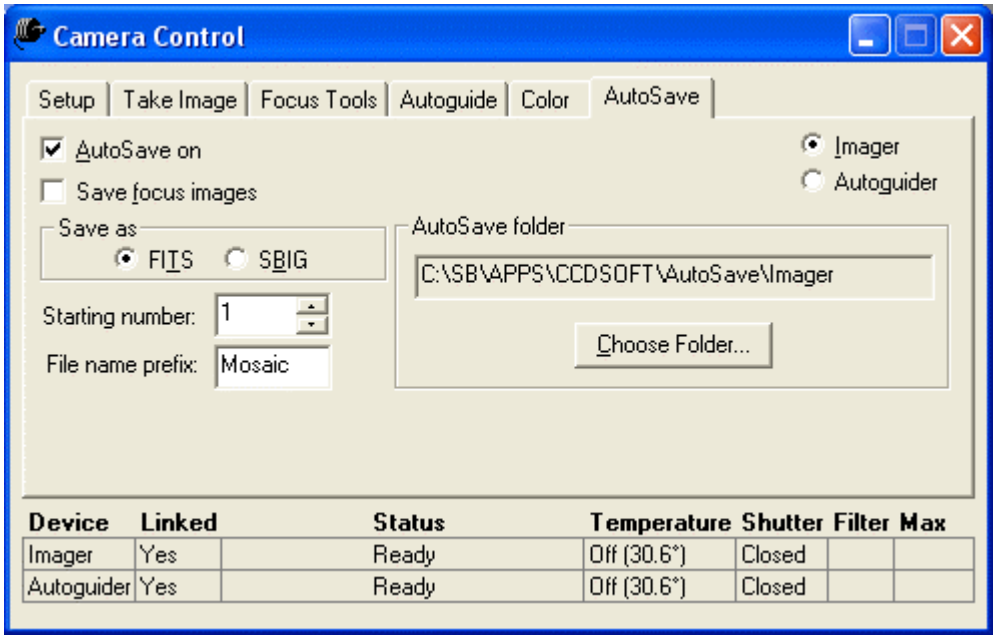


Figure 1: The Camera Control Panel, AutoSave tab.

There are a number of occasions where you will need to save files manually. These include:

- Any time you change the histogram settings (see “Chapter 9: Image Processing” for information about histograms).
- When you perform a manual reduction (see “Chapter 7: Image Reduction” for information about image reduction).
- When you edit the image. It’s a good idea to keep your original images; save your edited versions under a different name by clicking **File | Save As**.
- When you save a file to change the file format or data type.

To save a file manually without changing the name, press `Ctrl+S`, or click **File | Save**.

To save a file under a new name:

1. Click **File | Save As**. This opens the Save As dialog box. If you want to save the file in a different folder than the original, use the Save window to navigate to the folder where you want to save the file.
2. Type in the new filename.
3. Click **Save** to save the file with the new name.

You can also use the Save As dialog box to save the file with a different file format. See the next section for details.

Converting to Other File Formats

The default format for CCDSoft is the Flexible Image Transport System (FITS) format, which uses the ".fit" extension. FITS is the standard data exchange format used in the astronomy community. Many CCDSoft features *require* that you save images in the FITS format, including all of the astrometry- and photometry-related commands (see "Chapter 8: Research: Astrometry and Photometry").

Many CCD imagers do their initial image processing in CCDSoft, and then use other image processing programs, such as Photoshop™ or Picture Window™, to perform specialized operations. Many image editing programs do not support the FITS format, however, CCDSoft can save files to a variety of standard formats that will allow you to use just about any image processing program.

CCDSoft also supports several specific formats. The list of supported formats is shown below.

File Format Name	Extension	Description
Bitmap	.bmp	Commonly used file format found on Windows computers.
Postscript	.eps	Often used for sharing images that will be printed out on a Postscript printer.
Graphics Interchange Format (GIF)	.gif	A lossless compression format. It compresses by storing repeating sequences in compressed form. The original image is recreated exactly. Compare to JPEG.
JPEG	.jpg	A lossy compression format. It compresses by using mathematical expressions to describe the image. It loses information in blue and in details, which is not recoverable. Save to the JPEG format only *after* all changes have been made, and keep your original file in case you want to make more changes later. You can't open a JPEG file and edit it again, as it will lose even more details the second time around. Compare to GIF.
PCX	.pcx	An older file format used by some image processing programs.
Mac Picture Files	.pct	Macintosh picture format.
PDS	.pds	
SBIG Format	.stx, .st5, .st6, .st7, .st8, .255	Format used for most SBIG cameras.
SBIG ST-4 Files	.st4	File format used for the SBIG ST-4 camera.
TARGA	.tga	A file format often used in the past, but less common today.

		Capable of storing 16-bit and 32-bit image data.
Tagged Image Format File (TIFF)	.tif	A common format supported by almost all image-processing programs. When you need to move your CCDSoft images to another program, this format is the most likely to do the job successfully.
Phillips Lab Tagged Image Format File	.tif	A specialized variant of the TIFF file format. Don't use this format for TIFF files unless you need to. Use the standard TIFF format whenever possible.
DrawPerfect	.wpg	Supported by Word Perfect's DrawPerfect imaging program.
Flexible Image Transport System (default)	.fit	The standard format for exchanging astronomical data (such as a CCD image) in the astronomical community.
Intensity Data Files	.int	“Intensity-data format” files for plotting a graph of a mirrors wave front data.

You can also use CCDSoft to convert files from grayscale to color, and color to grayscale. The complete list of options is shown in the following table. Use the **Image | Convert To...** commands to convert between formats. Not all conversions are available for all image types. The conversions available will depend on the bit-depth and image type of the current image.

Generally speaking, CCDSoft will convert CCD camera-specific file formats (for example SBIG ST-X files) to FITS or to other general-purpose file formats (gif, tif, bmp, jpg). However, CCDSoft does not convert all file formats to all other file formats. For example, CCDSoft does not convert a 256-color Windows bitmap (BMP) file to a 16-bit grayscale FITS file.

Convert to	Bit-depth	Description
Black and White	1	The output contains only black and white pixels. You can choose the type of dithering to apply to simulate gray in the image. Possible choices are Error Diffusion, Ordered Dither, or Bayer Dither. Experiment to see which provides the best result for a specific image. This command only operates on grayscale and 256-color images.
Grayscale	8	Converts RGB and 256-color images to 8-bit gray scale (256 levels of gray).
256 Colors	8	Converts RGB color images to 256-color images.
RGB Color	24	Converts grayscale images to color format. The actual image remains black and white, but the internal storage format now allows for color processing of the image.

Copying, Pasting, Cropping, and Duplicating Images

You can use the Windows Clipboard to copy and paste images. You can copy the currently selected image to the clipboard using any one of these methods:

- Click **Edit | Copy**.
- Press `Ctrl+C`.

Once an image is on the clipboard, you can paste it into many other windows applications, including word processing programs, image editors, or email programs. You can then use or edit the image in the new context in whatever ways that context supports images. For example, you could paste an image into your word processor and then resize it. Or you could paste the image into another image editing program and use tools specific to that program to operate on the pasted version of the image. These changes will not affect the image in CCDSoft.

You can also copy images from other programs to the clipboard, and then paste them into CCDSoft, where you can manipulate them using CCDSoft's tools. You can paste an image into CCDSoft using any one of these methods:

- Click **Edit | Paste**.
- Press `Ctrl+V`.
- Press `Shift+Insert`.
- If you want to make a duplicate of an image already open in CCDSoft, click to select it (that is, make it the active image), and then click **Edit | Duplicate** (or `Ctrl+Shift+D`).

You can experiment on the duplicate image to work out the best method for processing the image, or you can make multiple duplicates, apply different processing to each, and then compare the results so you can choose the best option.

To crop an image, click and drag to outline the area you want to keep (see figure 2). Then click **Edit | Crop** (or `Ctrl+Shift+C`) to crop the image. The cropped image (see figure 3) includes the same header information as the original. For FITS images, this includes the right ascension and declination of the image center. If you crop away from the center, you may need to adjust the right ascension and declination if you later perform astrometry. See “Chapter 8: Research: Astrometry and Photometry” for information about astrometry and making changes to the header of a FITS image.

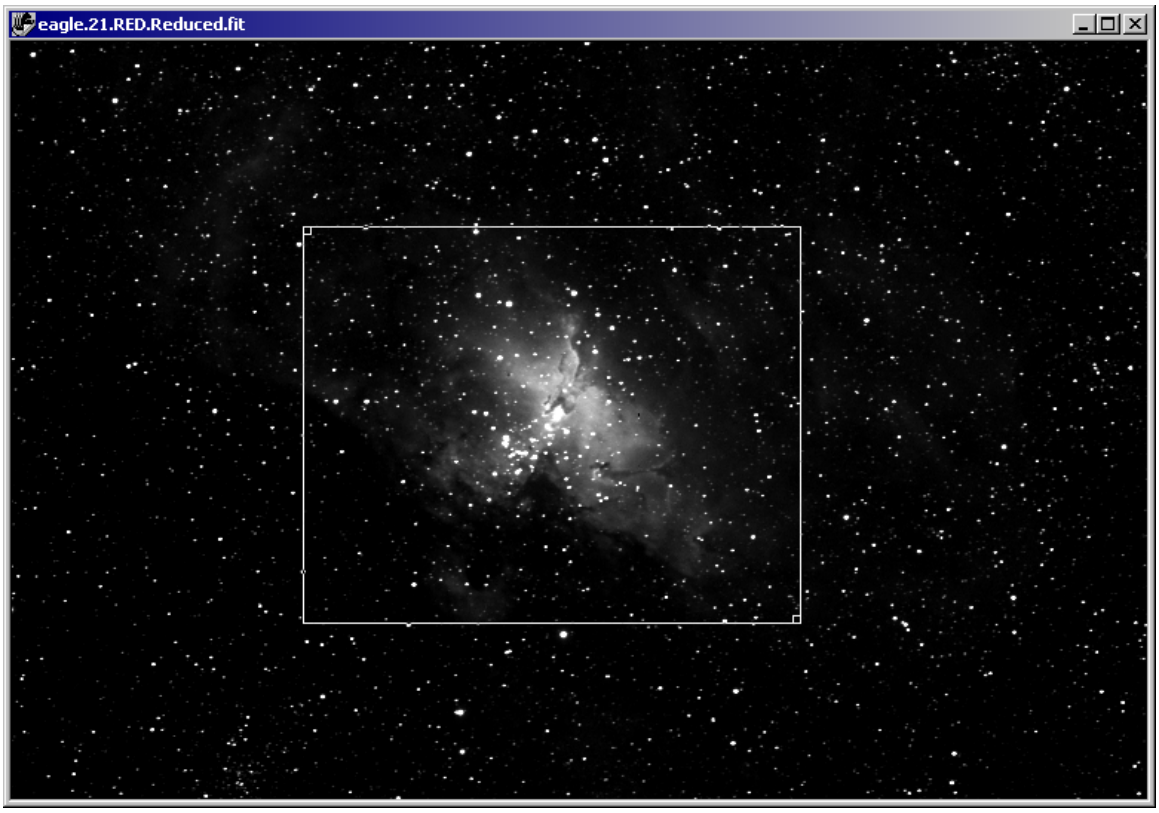


Figure 2: Click and drag to outline the area you want to crop.

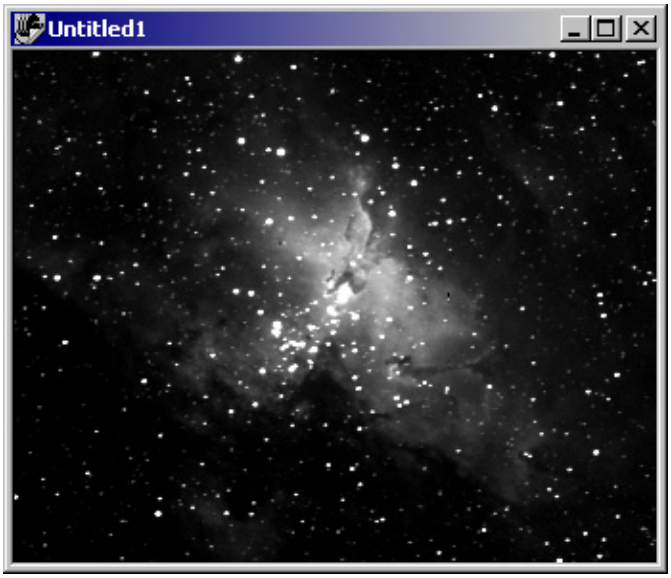


Figure 3: A cropped image of the Eagle Nebula.

Printing Images

CCDSoft supports any Windows printer. Click **File | Print** to open the Print dialog box. This dialog box allows you to select the number of copies you want to print, and several other options. Figure 4 shows a typical Print dialog box.

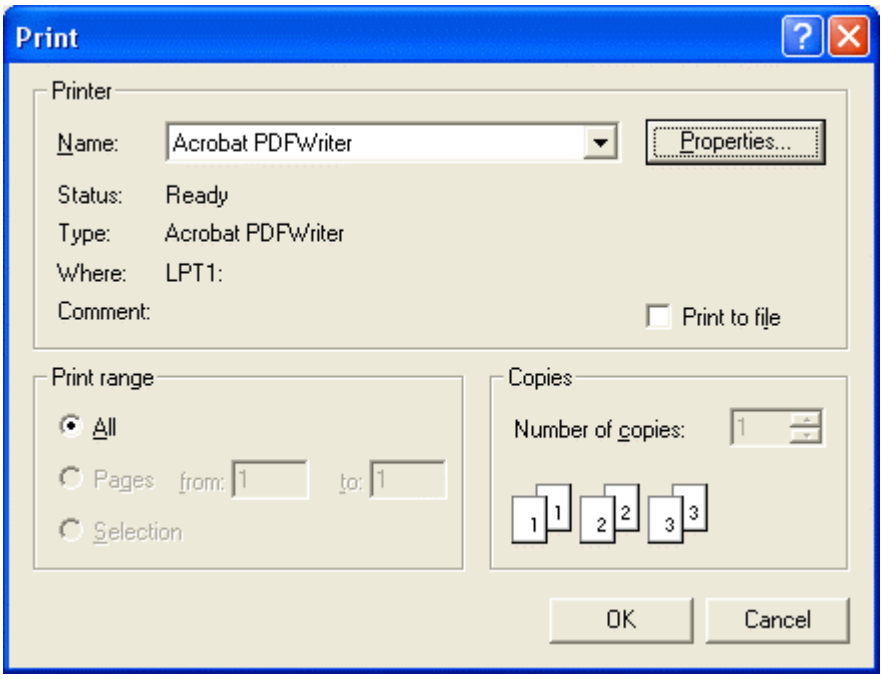


Figure 4: The Print dialog box.

If you have a printer that supports color or photographic quality printing, click on the Properties button of the Print dialog box (see figure 4) to set the printer-specific settings you need for high-quality printing. Figure 5 shows the settings available for a Hewlett-Packard 1220C, including print quality, paper size, type of paper (plain, photo-quality, matte finish, etc.) as well as paper orientation (portrait or landscape). The features available may vary for your printer. Be sure to check out the various tabs at the top of the dialog box, which may give you access to printer features that would be useful for printing your astrophotographs.

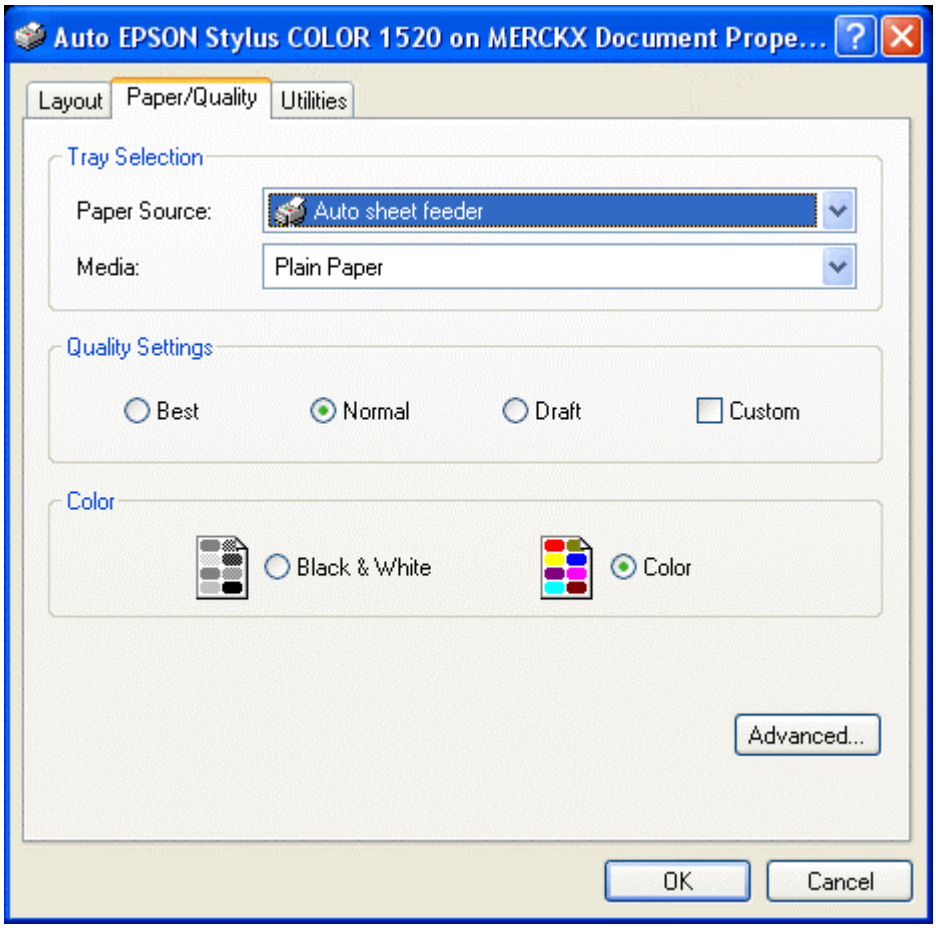
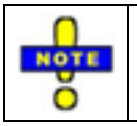


Figure 5: Setting printer options. Options will vary from printer to printer.

Fit to Window

If your screen size is smaller than the images produced by your CCD camera, you can click **View | Fit to Window** commands to display images at a smaller size. There are two options for this command:
Maintain Aspect – The image will keep its aspect ratio when you change the size of the window. For example, the ST-237 camera has an image size of 640x480, which is an aspect ratio of 4:3. If you change the window size so that the width is 100 pixels, then the height will be 75 pixels.
Stretch to Fit – The image will stretch to fit the dimensions of the window. If the aspect ratio of the window is different from the aspect ratio of the image, the image will be distorted to fit.

Figure 6 shows two window with the same image displayed. The long narrow window has been set to **Stretch to Fit**, while the normal-looking window has been set to **Maintain Aspect**.



The image data remains unchanged; you are only changing how the data is displayed on your screen.

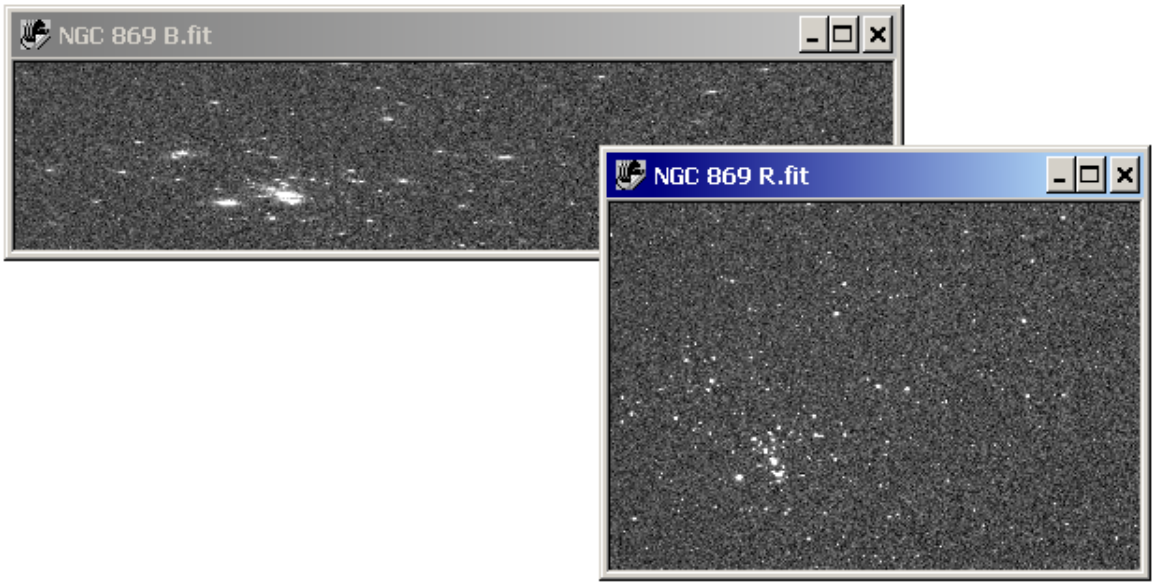


Figure 6: Fitting the image to the window size. Upper left: Stretch to Fit. Lower right: Maintain Aspect.

Zoom

You can change the apparent size of an image by zooming in and out. Zooming does not change the image data. It affects how the image is displayed on your screen. Zoom either by clicking **View | Zoom In** and **View | Zoom Out**, or by using the following key combinations:

- `Ctrl + number key` (for example, `Ctrl + 2`) to zoom in.
- `Alt + number key` to zoom out.

You can also zoom in and out using the Zoom In and Zoom Out tools on the toolbar. Figure 7 shows the Tools toolbar, which includes the Selection tool, the Zoom In tool, and Zoom Out tool. To use the Zoom tools, click on the tool to activate it, and then click in the image to perform the operation.



Figure 7: The undocked Tools toolbar.

If you need to zoom in or out by more than a factor of nine (such as 1:10 or 10:1), you must use the appropriate command. This allows zooming up to a maximum of 16:1 and a minimum of 1:16.

You can also open the Live Zoom window, which shows a magnified portion of the current image. Click **View | Live Zoom** to choose between Normal Zoom and Linear Zoom.

Normal Zoom – captures a square region of the screen and stretches this region to fit within the zoom window.
Linear Zoom – creates and displays a new image that is an average of the captured region of the screen. This process helps preserve the look of the original image even at large magnification. (Note: a 256-color video display setting is required for this option.)

To use the Normal and Linear Zoom:

1. Place the mouse pointer in the Normal Zoom window. The mouse cursor turns into magnifying glass.
2. Drag the mouse to zoom in on any portion of the window. When you release the mouse button, the current zoom window is copied to the clipboard.

To change the magnification of the zoom window, drag the scroll bar control on the Normal Zoom window. Scrolling up decreases the magnification, while scrolling down increases magnification.



The image data remains unchanged when you zoom. You are only changing how the data is displayed on your screen.

Creating Slide Shows

You can create slide shows with CCDSoft to display your images. You can play the slide show automatically, or manually move through the images in the show. To select the images that will be included in the slide show, click **Research | Slide Show | Create List** to display the Create Slide Show List dialog box (see figure 8).

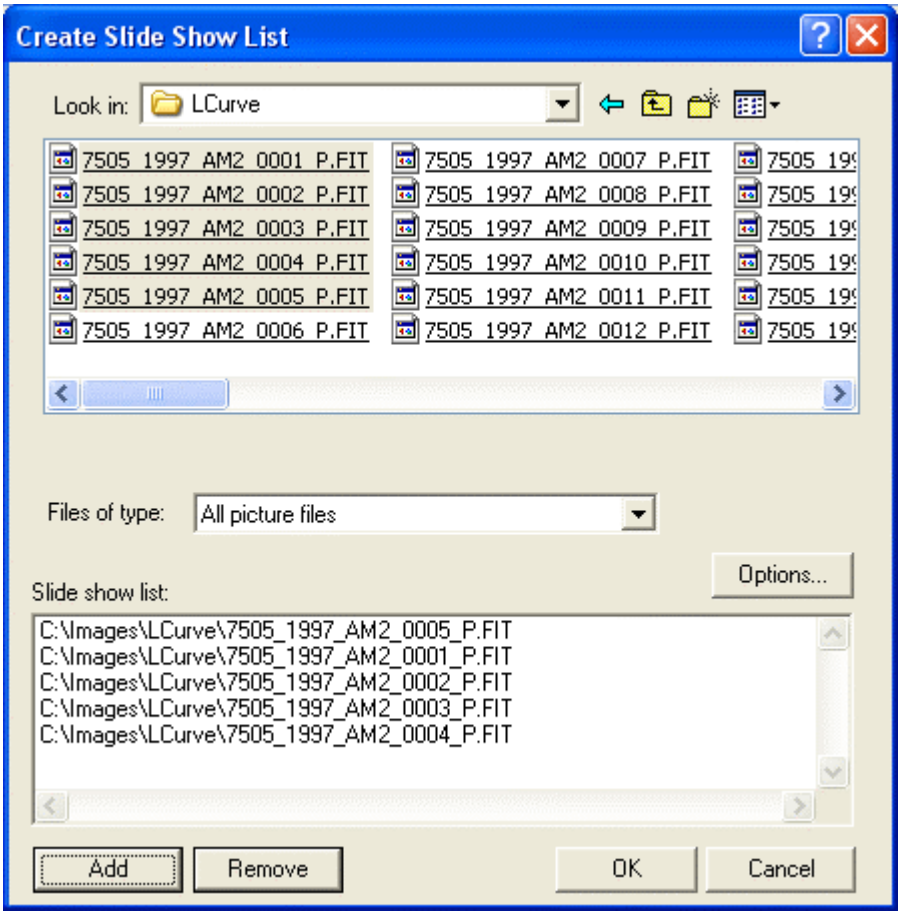


Figure 8: Selecting images for a slide show.

Use the top portion of the dialog box to navigate to folders where the files you want are stored. Click **Add** to add selected files to the slide show list at the bottom. To show files of only a certain type, use the **Files of type** drop-down list. Click the **Options** to turn automatic advance from one slide to the next on or off.

When you have selected all of the desired files, click **OK**. To open the slide show, click **Tools | Slide Show | Forward**. To move backward through the show, one slide at a time, click **Tools | Slide Show | Backward**.

TIP	To have the slide show play automatically, click **Options**, and check **Automatic Advance**. Or, you can simply use the **Tools	Slide Show	Play as Movie** command.

To stop a slide show in progress, click **Tools | Slide Show | Stop**.

Viewing File Information

FITS files have special information saved in the image file. It is stored separate from the actual image data, in a section of the file called the *header.*

Click **View | File Information** to look at this data. Figure 9 shows the appearance of the information for FITS files. There are two tabs, **Standard** (figure 9) and **Edit Header** (figure 10). The Standard tab shows the most commonly referenced information about the image. The Edit Header tab shows every piece of information in the file header, and you can add, edit, or delete information.

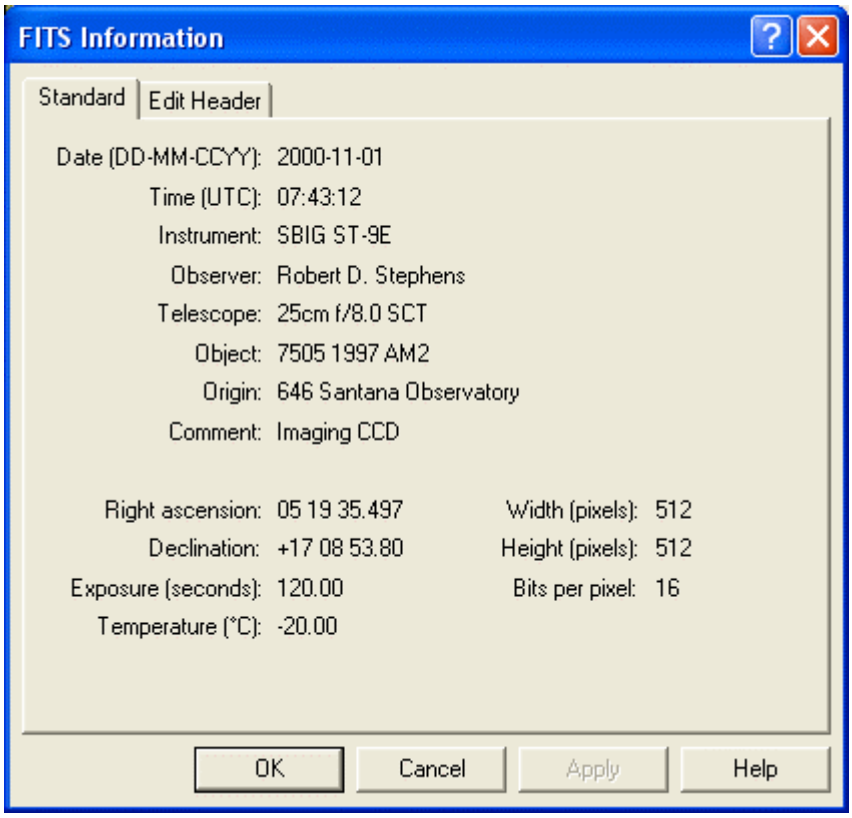


Figure 9: Standard file information in the FITS Information dialog box.

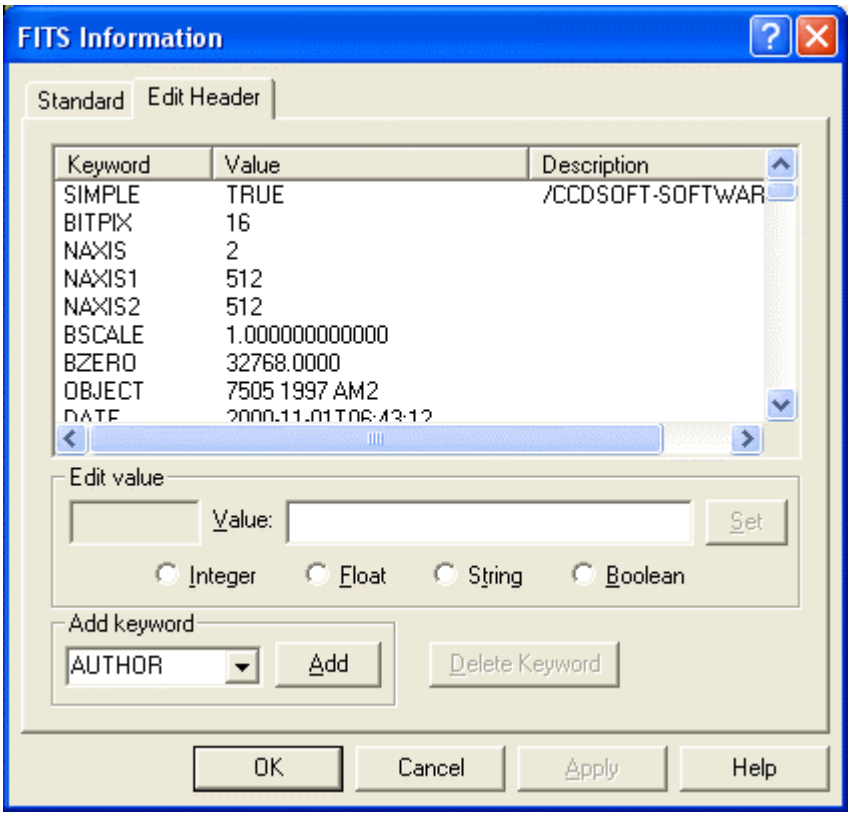


Figure 10: Editing the FITS header in the Edit Header dialog box.

For example, if you want to change a value in the file header, you can do so as follows:

1. Click on the keyword in the top portion of the panel. The keyword appears in the **Edit Value** box, and the value of the keyword appears in the **Value** box.
2. Make any changes to the text in the **Value** box. Verify that the data type selected below the Value box is correct (Integer, Float, String, Boolean).
3. Click **Set**.

You can also select a keyword from the **Add keyword** drop-down list, and then click **Add** to add the keyword to the file header. You can then edit the **Value**, and click **Set** to add the keyword and its value to the file header.

TIP	Changes to the header are not saved until you save the file to disk. For more options for editing a FITS header and for information about the **View | Cursor Information**, please see “Chapter 8: Research: Astrometry and Photometry”

Selecting and Arranging Toolbars

CCDSoft organizes the various tools available to you using toolbars. Click **View | Toolbars** to see a list of the available toolbars, and to show or hide each toolbar as needed. Figure 11 shows the Toolbars

dialog box. Toolbars that are checked will be visible. Unchecked toolbars will not be visible. The commands for both visible and hidden toolbars remain functional at all times.

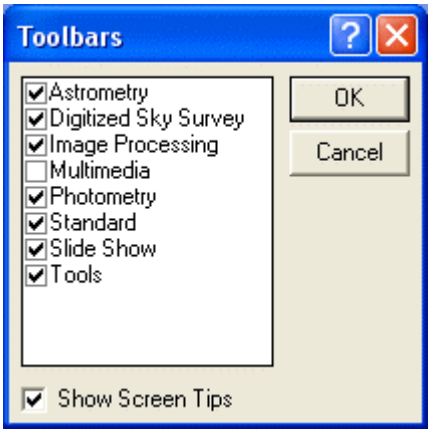


Figure 11: Selecting which toolbars to display.

Toolbars can be docked or undocked. Docked toolbars snap to the edge of the CCDSoft window. Figure 12 shows some toolbars docked at the top of the window, and others docked at the left edge. Undocked toolbars are small, separate floating windows that can be dragged anywhere on your desktop, even outside the boundaries of the CCDSoft main window. Figure 13 shows an undocked toolbar window.

Screen Tips are the small messages that temporarily appear when the mouse cursor is placed over a toolbar button. Clear the **Show Screen Tips** option to hide these messages.

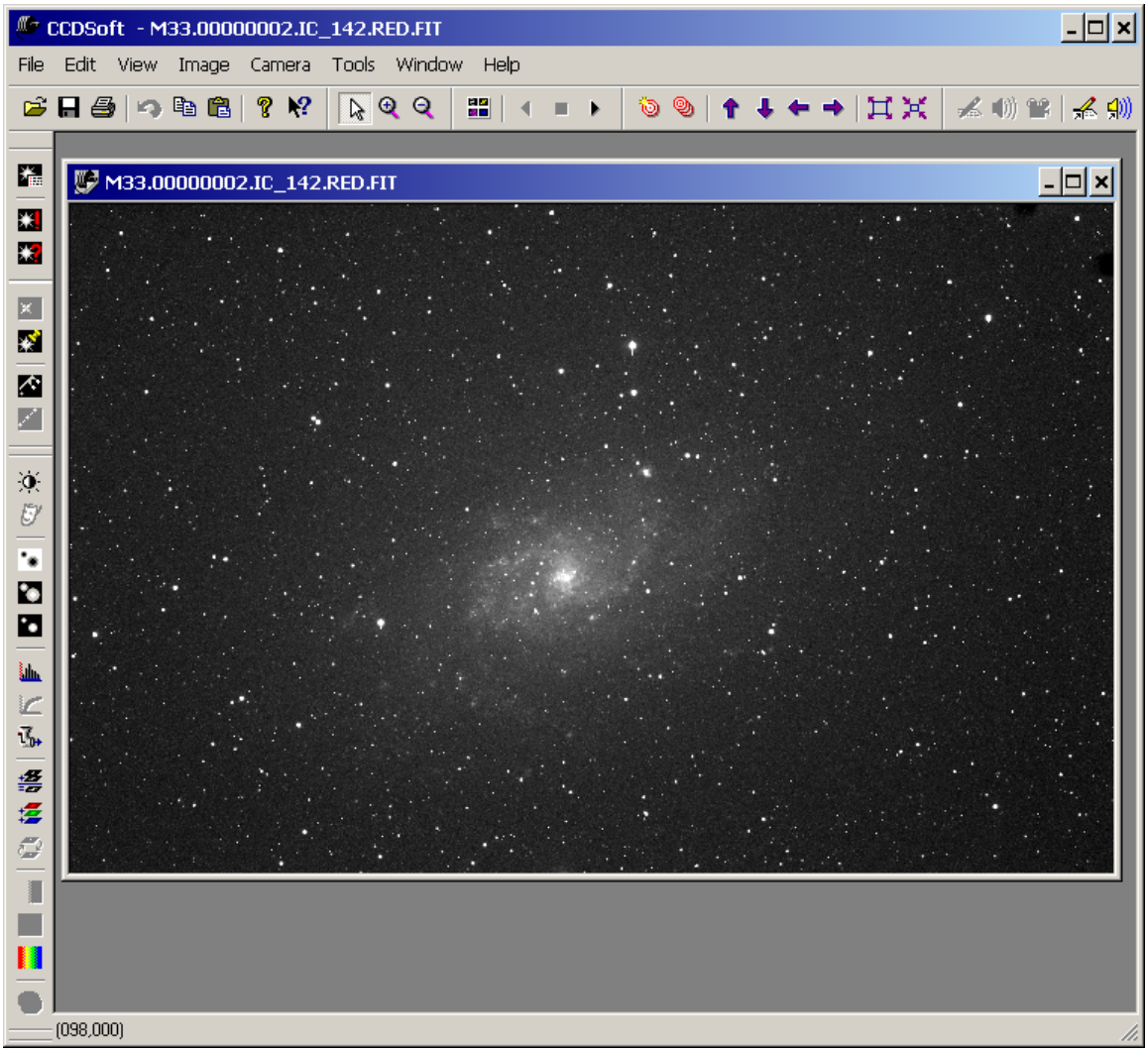


Figure 12: Toolbars docked at top and left of the CCDSoft window.



Figure 13: The undocked Astrometry toolbar.

Status Bar Options

If you need more space for viewing image files, you can hide the status bar. The status bar displays data about various aspects of CCDSoft. To turn the status bar on or off, click **View | Status Bar**. When this item is checked, the status bar is visible. When it is unchecked, the status bar is hidden.

Display Features

CCDSoft includes two display features that allow you to change the appearance of the program:

- Night Vision Mode
- Full Screen Mode

Night Vision Mode

Night Vision mode changes the screen colors to shades of red (see figure 14). This helps preserve night vision because red does not appreciably affect your ability to see fainter objects at night. To toggle Night Vision mode on or off, click **View | Night Vision Mode**.

This command changes the Windows system colors to red. This means that all running applications will also have red screens.

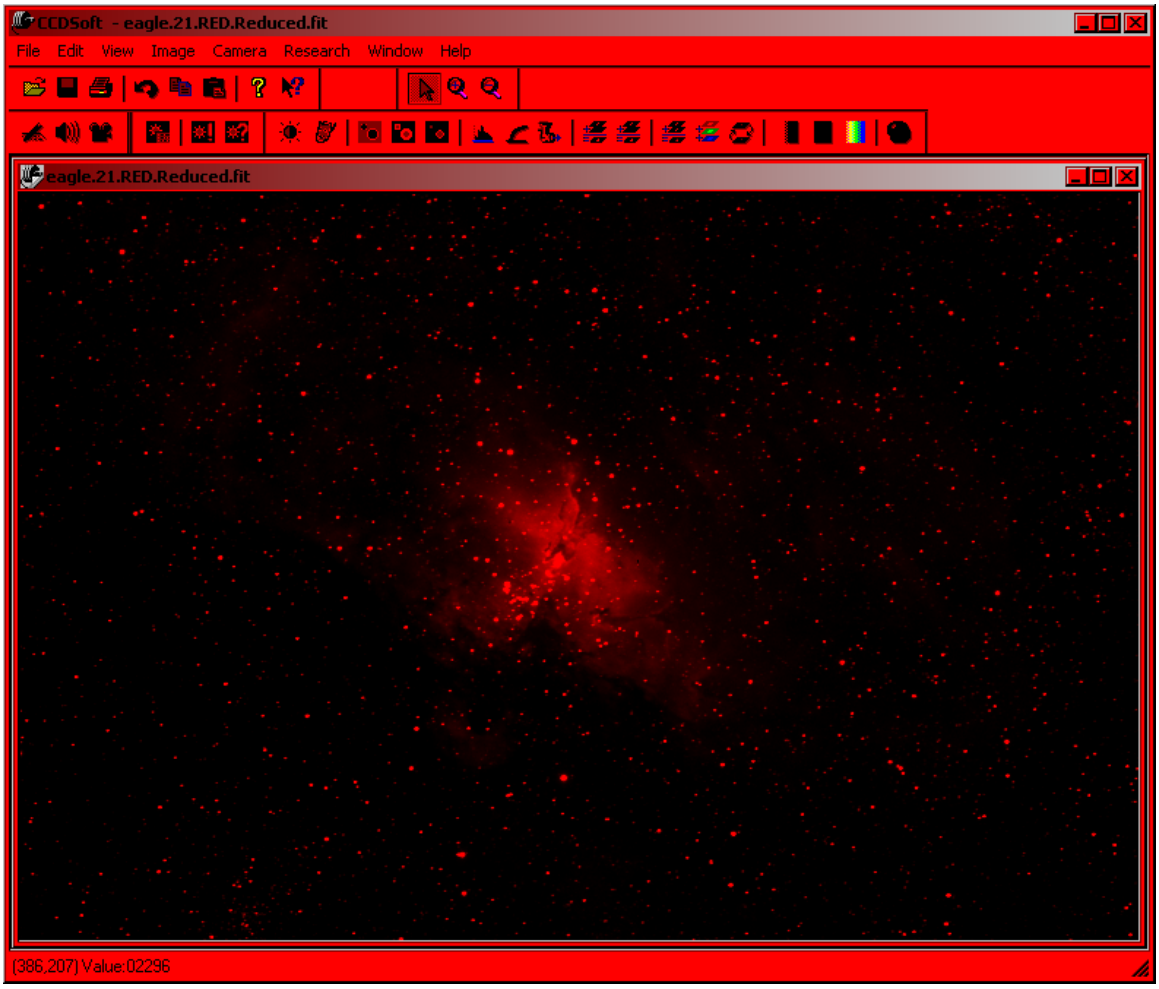


Figure 14: Night Vision Mode screen.

NOTE	In order for CCDSoft to replace the existing system colors when Night Vision Mode is turned off, a color scheme must be saved. Consult the operating system's help file (click **Start | Help** and then search the keywords "color scheme" for details about saving a color scheme.

Full Screen Mode

The Full Screen mode displays the active image using the entire screen (see figure 15). No toolbars, menus, or other program elements are visible. You can use the **View | Full Screen** command or press the `Spacebar` to turn **Full Screen** mode on. Press the `Escape` key (or any non-function key) to exit the **Full Screen** mode.

If the image is smaller than the screen size, the image is centered and the area around the image is filled with black. If the image is larger than the screen size, the portions of the image outside the screen size are not visible.

The current zoom level is preserved in **Full Screen** mode.



Figure 15: Full Screen mode.

Chapter 3: Aligning and Combining Images

The best CCD images have a good signal-to-noise ratio. This means that there is a lot of signal (the image) and very little noise (unwanted, random signal). There are several things you can do to get the highest possible signal-to-noise ratio:

- Image under dark skies.
- Take long exposures.
- Combine multiple images.

You don't have to do all three to get a good image. For example, if you are imaging from your back yard, bright skies may be the norm. If that's the case, then you can lean more heavily on the other two techniques: take long exposures and combine images. Similarly, if you are unable to take long exposures, you can use dark skies and combining images to get a better signal-to-noise ratio.

The signal-to-noise ratio is simply the ratio of the signal in your image to the noise in your image. If the signal is 1000, and the noise is 50, then the signal-to-noise ratio is 20. The signal-to-noise ratio is often referred to as S/N.

The noise in an image is the uncertainty in the brightness level. Various noise sources interfere with accurately recording the brightness at each pixel. To measure noise, you must repeat a measurement many times and analyze it statistically. However, you don't need to measure noise to take steps to reduce it. Dark skies, long exposures, and combining images each can work to improve the quality of your images.

Combining improves the signal-to-noise ratio of the final image because signal increases faster than noise when you combine images. This allows you to take shorter images and still get excellent results. Although you will always get the best possible signal-to-noise ratio by taking one very long exposure, a number of factors can limit the maximum exposure time:

- Non-antiblooming cameras allows stars to bloom. The longer the exposure, the greater the blooming that can occur.
- Environmental conditions can limit exposures times. Sky glow, for example, can create excessive background levels in long exposures, resulting in a poor signal-to-noise ratio.
- The risk of various hazards increases with the length of the exposure. These hazards include tracks on the image from satellites, meteors, cosmic rays, etc. The longer your exposure, the greater the likelihood of a problem.

For example, you might find that a 30-minute exposure of the Cone Nebula results in excessive background levels due to light pollution. You could take three 10-minute exposures, or six 5-minute exposures, or any combination of exposures that suits your conditions. Combining these exposures would get you very close to the signal-to-noise ratio of a single 30-minute image.



You cannot make copies of an image and then combine them to reduce noise. The images must be taken separately and then combined in order to reduce noise.

In fact, combining usually results in a better signal-to-noise ratio. Because of the reduced risk of hazards, you can take large numbers of shorter images. You can discard any that are ruined by hazards. For example, you could take a series of images adding up to 45 minutes, and combine them to get a better signal-to-noise ratio than a single 30-minute exposure.

Figure 1 shows a single image of the Cone Nebula. The exposure length was 3 minutes, which was as long as it was possible to go without blooming. The histogram was adjusted and tuned to display as much nebulosity as possible. Note that the dim areas of the nebula are grainy.

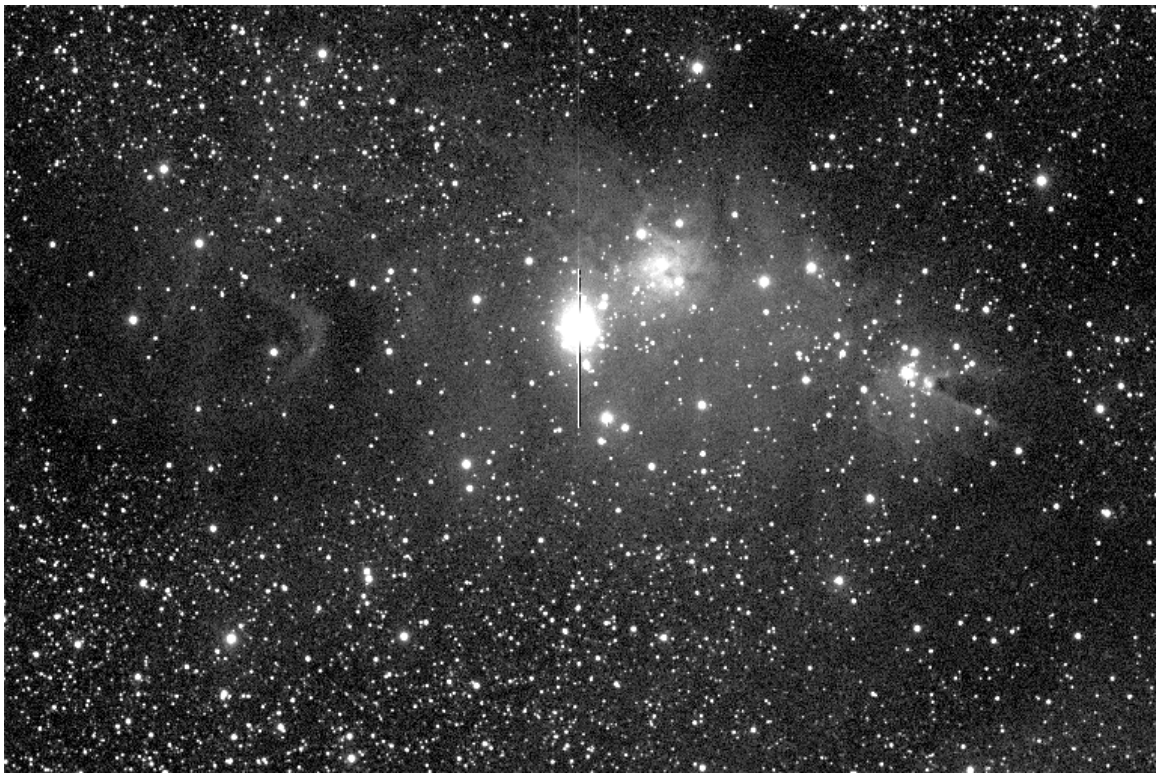


Figure 1: A single image of the Cone Nebula.

Figure 2 is also an image of the Cone Nebula, but this time three exposures of three minutes each have been summed together. The minor blooming has been cleaned up in this image. Note that the dim areas are much smoother than in the single image. This lack of graininess is characteristic of good signal-to-noise ratio. Summing the images improves the overall signal-to-noise ratio, since signal increases faster than the noise. The lack of graininess increases the overall contrast of the image, and reveals the structural details of the nebula more clearly.



Figure 2: A sum of three separate images provides a better signal-to-noise ratio.

Figure 3 shows a small detail area from four images of the Cone Nebula. The two images on the left are single images, and clearly show noise (graininess). The two images on the right are the result of combining images, and both show less noise. The image at upper left is a single image, which has had no image processing other than a histogram adjustment. The image has pronounced graininess, which is the visual indication of noise. Tuning the image, bottom left, tends to slightly increase the grainy appearance. Combining three different images using averaging significantly improves the signal-to-noise ratio, as shown at upper right. The grainy appearance is reduced. Summing (adding) three images does a slightly better job of reducing noise, as shown at lower right. The advantages and disadvantages of averaging and summing are discussed in detail in the “Combining Images” section later in this chapter.

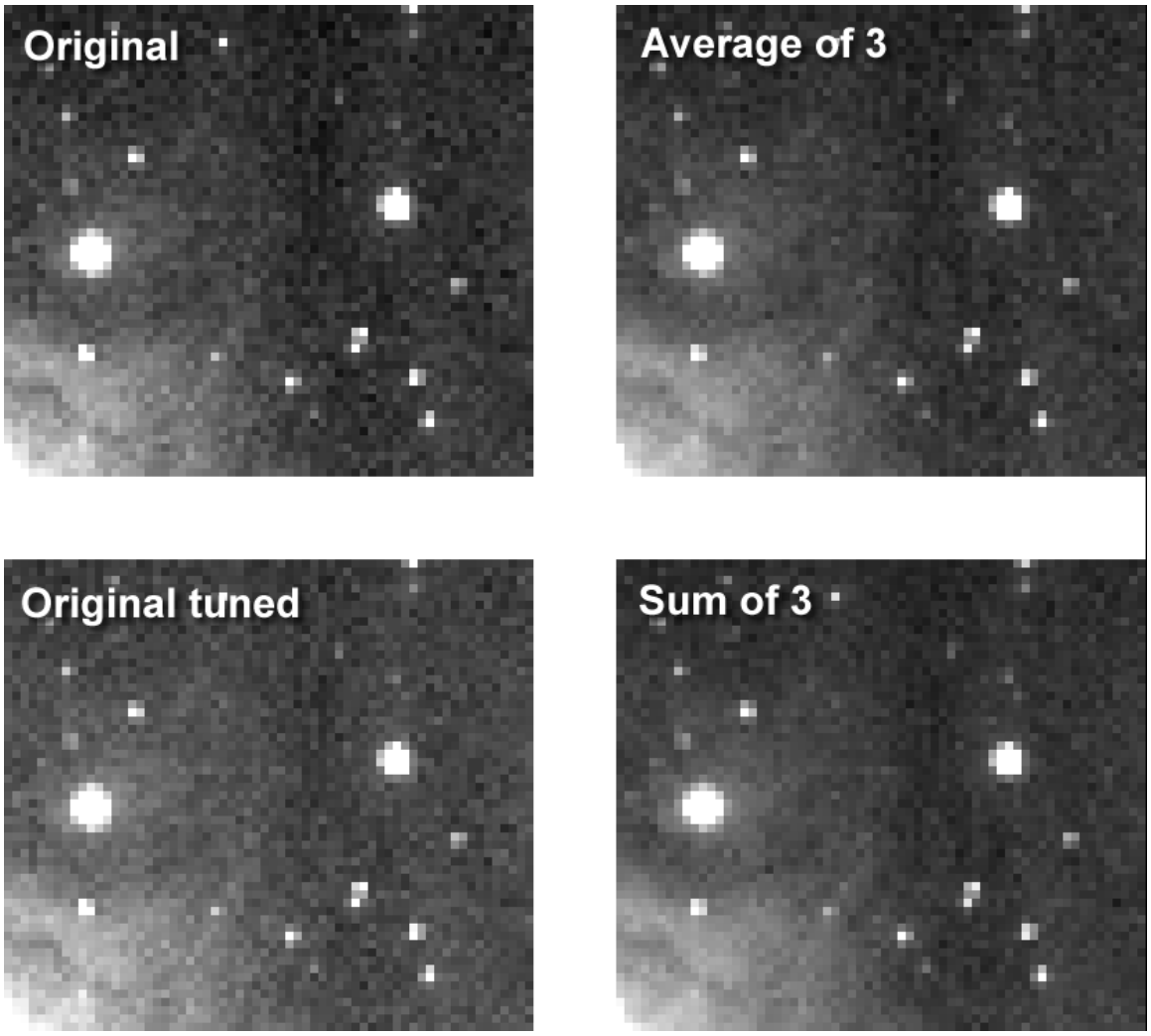


Figure 3: Comparing the noise level (graininess) of different images. See text for details.

Before you can combine images, they images must be aligned. CCDSoft provides sub-pixel alignment of images, as well as centroid alignment (aligning using the centroid of a star). In this chapter, you'll learn how to align images, and then how to combine them in various ways.

Quick Start for Experienced Users

For this chapter, an experienced user is someone who has experience taking multiple images of the same area of the sky and then aligning and combining them. It also refers to someone who has used the Track & Accumulate function in previous versions of CCDSoft.

CCDSoft is optimized for aligning and combining images in batches. To get the most out of CCDSoft, put all of the images you want aligned and/or combined in a single folder, with no other images present. If

you align a folder of images, CCDSoft provides sub-pixel accuracy including shifting and rotation. (You can also align two images at a time using a single centroid in each image; see the “Align Centroids” section later in this chapter for details.)

To align a folder of images:

1. Copy the images you want to align into a folder. Only the images you want to align should be in the folder.
2. Images to be aligned can have different bin modes. Images will not be resized, only aligned.
3. Click **Image | Align | Align Folder of Images** to display the Align Folder dialog box.
4. Use the upper **Choose Folder** button to select the folder with the images you want to align.
5. Use the lower **Choose Folder** button to select the folder to which you want the aligned images saved.
6. Click the **Align**.

To combine a folder of previously-aligned images:

1. Copy the images you want to combine into a folder. Only the images you want to combine should be in the folder.
2. Images to be combined should have the same dimensions. Click **Image | Resize | Resize Folder of Images** to ensure that your images have the same size.
3. Click **Image | Combine | Combine Folder of Images** to open the Combine Folder dialog box.
4. Use the **Choose Folder** button to select the folder with the images you want to combine.
5. Select the combine method from the **How to combine** drop-down list. **Add** will sum the images and provide the best signal-to-noise ratio. **Average** and **Median** will reduce the effects of cosmic rays, satellite tracks, etc. at a slight cost in increase overall noise.
6. Click **Combine**. A progress window appears. When the combine is complete, a new window opens with the results of the combine.

If you used Track & Accumulate in previous versions of CCDSoft, you can use CCDSoft’s ability to take a sequence of images in conjunction with Combine Folder to simulate Track & Accumulate functionality:

1. To take a sequence of images, set the number of images in the **Series of** drop-down list on the **Take Image** tab of the Camera Control Panel.
2. If you want automatic dark frames, be sure to choose **AutoDark** in the Reduction box of the **Take Image** tab.
3. Check the **AutoSave** option (**AutoSave tab**, Camera Control Panel) and enter a prefix so you can readily identify the images in the sequence. Create a folder for the images, and set it as the AutoSave folder.
4. Click the Take Series button on the Take Image tab. Each image will be saved to disk automatically.
5. If you did not choose **AutoDark** on the Take Image tab, you can perform image reduction when the series of images is completed.
6. You can open each of the images and examine it to make sure that image quality is acceptable. Delete any images that show evidence of tracking errors or other problems. This step was not available using Track & Accumulate, which automatically included all images in the final result.
7. Use Combine Folder of Images (click **Images | Combine | Combine Folder of Images**) to combine the images. Select the folder where you saved the images as the input folder for the combination. See details in the section “Combine Folder of Images” later in this chapter.

Aligning Images

Before you can combine images, you need to align them. CCDSoft provides four alignment tools, each with different levels of precision:

- **Align Centroids** – This aligns several images to sub-pixel accuracy using star centroids. This only shifts images. It doesn't rotate them. It provides a quick, simple way to align images.
- **Align Folder of Images** – This aligns any number of images to sub-pixel accuracy. It rotates and shifts the images as necessary. It is a powerful, accurate, and full-featured tool.
- **Shift** – Manually shifts an image in whole pixel increments.
- **Rotate** – Manually rotates an image.

Align Centroids

You can align several images by clicking **Image | Align | Align Centroids**. Click the Mark Centroid tool in the Astrometry toolbar (see figure 4). The cursor changes to a crosshair (see figure 5).



Figure 4: The Mark Centroid tool.

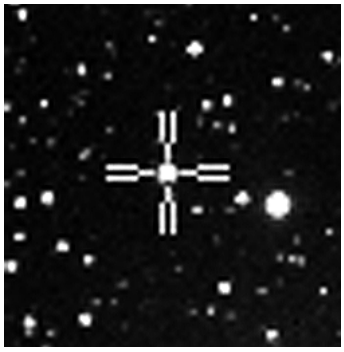


Figure 5: The Mark Centroid cursor.

Before you can perform an alignment using centroids, you must click in two or more images to mark the centroid of the same star. Clicking on the star places an "X" in a box over the star. Figure 6 shows two images of M16 with the centroid of the same star marked.

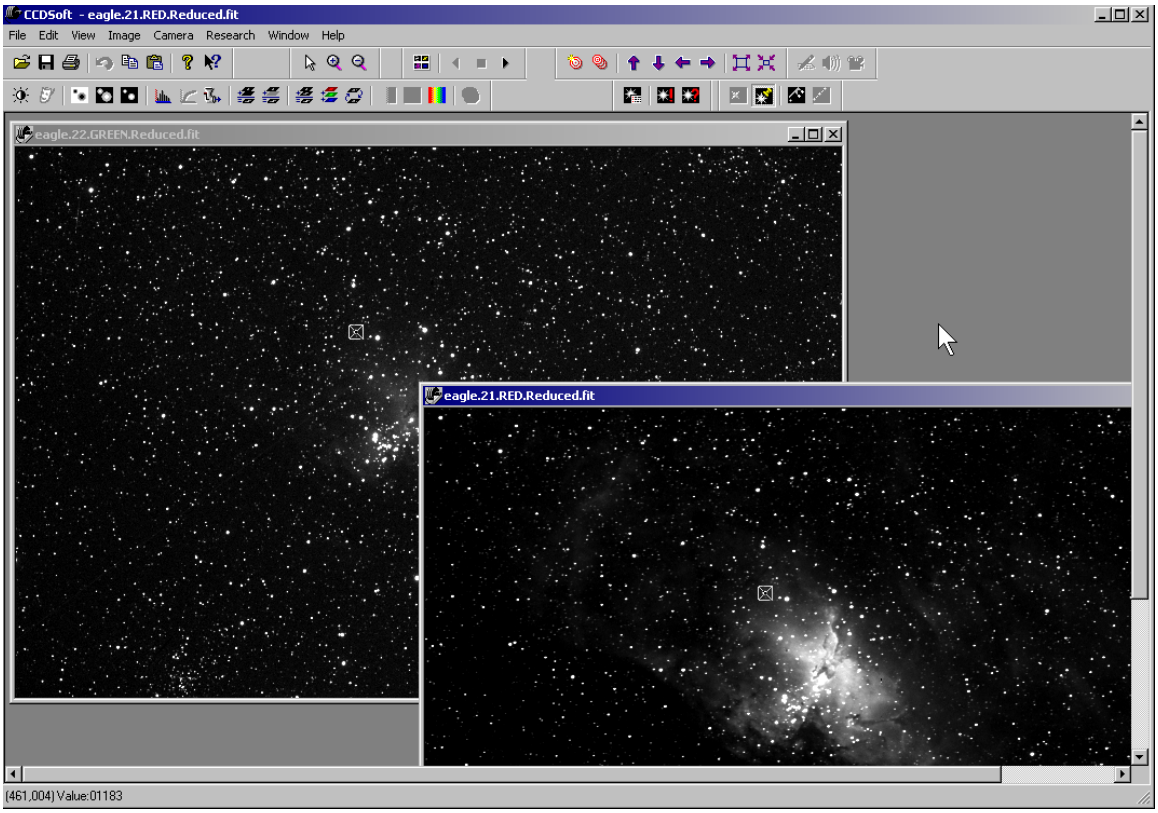


Figure 6: Star centroids have been marked in two images.

To align the two images, click **Image | Align | Align Centroids**. The active image remains unmodified. The second image (behind the active image) is shifted to align its centroid to that of the active image. Once the two images are aligned, you can use the **Image | Combine | Combine Images** to combine them in various ways. See the section “Combining Images” later in this chapter for details.

Align Folder of Images

CCDSoft uses a sophisticated pattern-matching technique to align an entire folder of images down to the sub-pixel level. It both rotates and shifts the images as necessary.

NOTE	To see the objects CCDSoft identifies in an image, open the image, and then click **Research	Show Inventory**. CCDSoft uses many of these objects to align the image.

To align a folder of images, you must first copy the images you want to align into a folder. Only the images you want to align should be in the folder. For example, if you have taken three images of M16, you could create a folder called “M16” and copy just those three images into the folder.

The images to be aligned can have different bin modes. For example, if you have taken a luminance image binned 1x1, and red, green, and blue images binned 2x2, you can align these four images. CCDSoft will cope with the different bin sizes. The images will not be resized, since CCDSoft's Color Combine (see "Chapter 10: Color Combining") automatically resizes the images for you.

Open the Align Folder dialog box by clicking **Image | Align | Align Folder of Images**. Figure 7 shows the Align Folder dialog box. The top section indicates the folder of images that will be aligned. The bottom section indicates the output folder, where the aligned images will be saved.

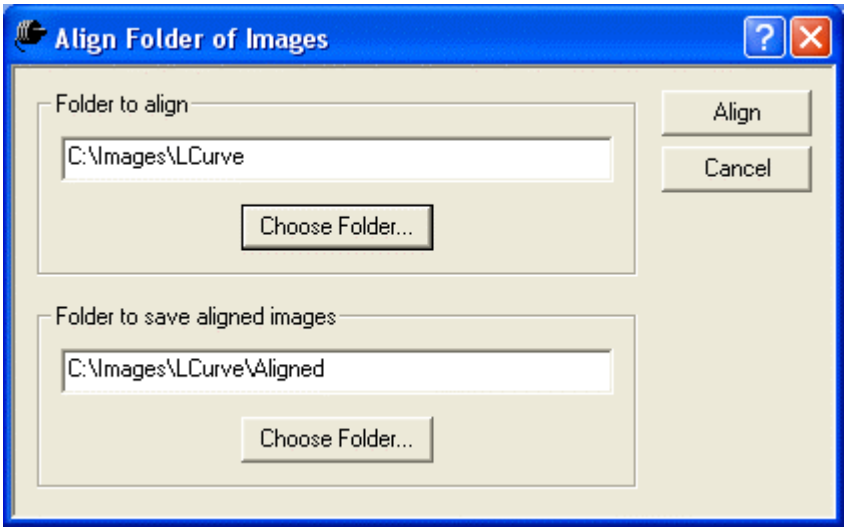


Figure 7: The Align Folder of Images dialog box.

Click the upper **Choose Folder** button to select the source folder.

Click the lower **Choose Folder** button to select the folder where you want the aligned images saved. You can create a new folder or navigate to an existing folder as appropriate. You can also type folder paths directly into the dialog box. If you type a folder path into the lower text field, and that folder doesn't exist, then CCDSoft will ask to create it for you when you click **Align**.

To start the alignment process, click **Align**. A progress dialog box appears, indicating which image is currently being processed. When the alignment is finished, the aligned images are saved to the indicated folder.

Images that are very different from each other may not be aligned properly. For example, if the stars in one image have significant blooming, and the stars in another image don't have blooming, CCDSoft might not be able to align the images. It will report a "Pattern Match Error" when this occurs.

Shift an Image

You can shift an image in whole pixel increments using the Shift dialog box, shown in figure 8. To open the Shift dialog box, click **Image | Align | Shift** (keystroke: `Alt + S`). For the horizontal offset, positive numbers will shift the image to the right, and negative numbers will shift the image to the left. For the

vertical offset, positive numbers will shift the image down, and negative numbers will shift the image up. The space between the border and the offset position of the image is filled with black pixels.



Figure 8: Shifting an image 5 pixels to the right, and 3 pixels down.

Rotating Images

CCDSoft will automatically rotate images if necessary when aligning a folder of images. You can also rotate an image manually, or rotate a folder of images.

Rotate an Image

You can rotate the current image by amount 90º increments by clicking **Image | Rotate | Rotate 90º Clockwise,** or **Rotate 90º Counterclockwise**. To rotate an image at any arbitrary angle, click **Image | Custom Rotate** to open the Custom Rotate dialog box shown in figure 9. Enter the angle of rotation, or use the spinner arrows at the right of the **Angle** text box. You can type in the angle, or use the following keys to increment or decrement the value while clicking on the spinner arrows.

- **No key** – one click changes the value by +/- 1.0
- **Shift key** – one click changes the value by +/- 0.1
- **Control key** – one click changes the value by +/- 10.0
- **Shift + Control keys** – one click changes the value by +/- 0.01

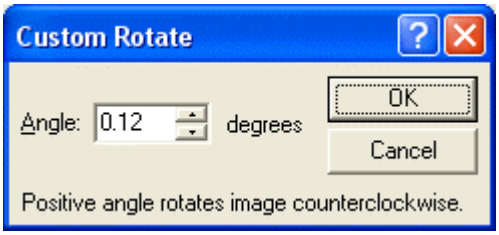


Figure 9: Rotating an image.

Rotate a Folder of Images

To rotate all of the files in a folder, click **Image | Rotate | Rotate a Folder of Images**. This opens the dialog box shown in figure 10. Enter the angle of rotation, and click **Clockwise** or **Counterclockwise** as appropriate. Use the upper **Choose Folder** button to select the input folder, and the lower **Choose Folder** button to choose the output folder. You cannot use the same folder for input and output.

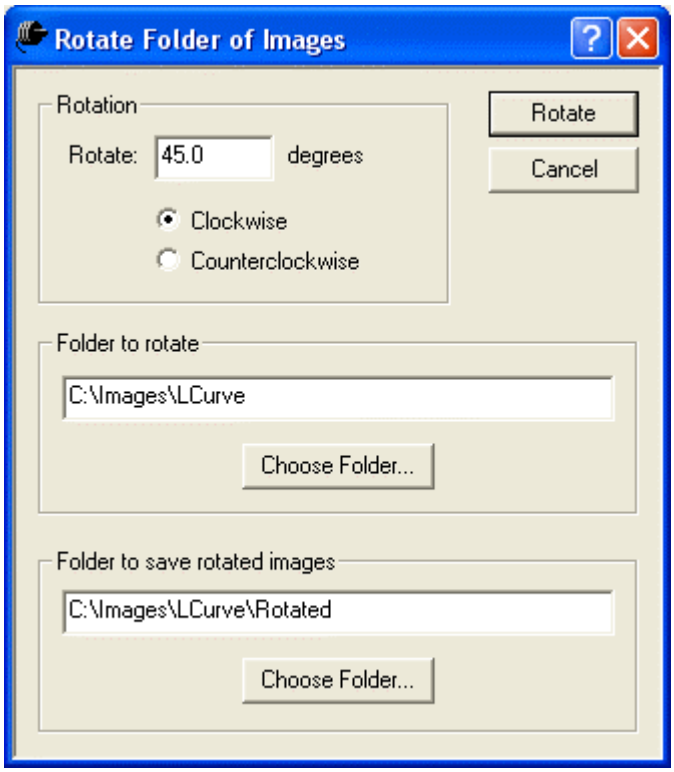


Figure 10: Rotating a folder of images.

Combining Images

CCDSoft includes two different ways to combine images:

- Combine Images – Combines two images using a variety of methods. This includes Add, Subtract, Multiply, Divide, Blend, Dark Subtract, and several others.
- Combine Folder of Images – Combines any number of images using averaging, median combine, or summing.

Combine Images

You can combine two images, or manipulate a single image, by clicking **Image | Combine | Combine Images**. You can choose from a wide variety of combination functions. Figure 11 shows a typical Combine dialog box involving two files, a source and an operator. The dialog box can be resized to show long filenames. The list of files for source and operator images will only include images that are the same size as the currently active image. You cannot combine images of different sizes.

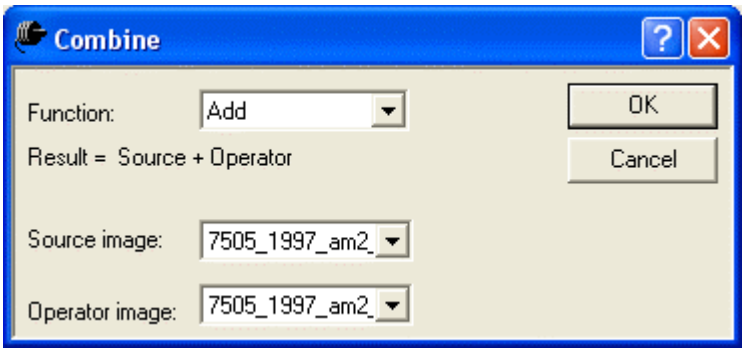


Figure 11: Combining two images using the Add function.

Figure 12 shows an example of a Combine dialog box that applies a multiplication factor to a source image. In this example, all pixels in the image will be multiplied by 10. This is useful if you had a one-minute image and a 10-minute image, and wanted to scale up the one-minute image to match the 10-minute image.

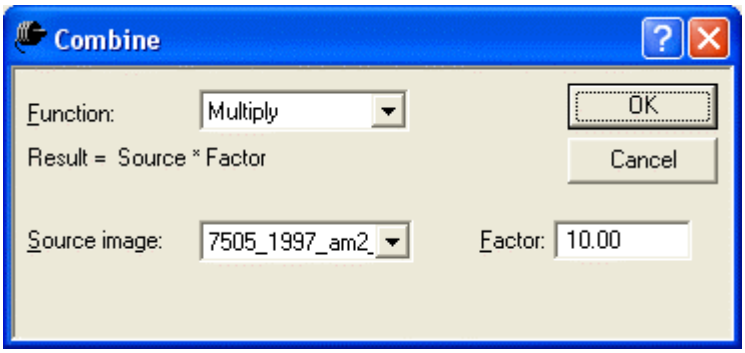


Figure 12: Multiplying the pixels in an image by a factor of 10.

To combine two images:

1. Open both images.
2. Open the Combine dialog box (`Ctrl+K`).
3. Select the Function you want to use for the combine (Add, Subtract, etc.)
4. Select the source image and, if appropriate, operator image.
5. Set any necessary parameters, and then click **OK**.

A new window opens with the result of the combination. The following table describes the functions that are available for combining images, along with the formula used to create the final result.

Combination Method	Description
Add	Pixel values in the operator image are added to pixel values in the source image. Formula: *source + operator*
Subtract	Pixel values in the operator image are subtracted from pixel values in the source image. Formula: *source - operator*
Multiply	Each pixel value in the source image is multiplied by the multiplication factor. Formula: *source * factor*

Divide	Each pixel value in the source image is divided by the input divisor. Formula: *source / divisor*
Blend	Performs a weighted average sum of the source and operator image. Formula: *(source * percentage) + (operator * (100-percentage))*
And	The source and operator image are combined using the logical AND function. Formula: *source & operator*
Or	The source and operator image are combined using the logical OR function. Formula: *source | operator*
Exclusive Or	The source and operator image are combined using the EXCLUSIVE OR function. Formula: *source ^ operator*
Dark Subtract	Each pixel in the operator image (dark frame) is subtracted from the source image (light frame). Formula: *source - operator*
Flat Field	Each pixel in the source image is multiplied by the operator sensitivity. Use this option to combine a flat field with a light frame. Formula: *source * operator_sensitivity*
Add by Track List	Builds a flat field image according to a Track & Accumulate track list. This option creates a flat field for a Track & Accumulate image by shifting and adding the flat field using exactly the times and shifts from the track list. The resulting flat-field image can be applied to a Track & Accumulate image to reduce it.

Combine Folder of Images

Before you can combine a folder of images, you must first copy the images into a folder. Only the images you want to combine should be in the folder. If you used the Align Folder of Images command to align the images previously, they are already in a folder and you can proceed to combine those images. For example, if you have aligned three images of M16 in the folder `/m16/aligned`, you could use that folder as the input folder for combining. The result of the combine appears in a new window.

The images to be combined must have the same size and bin mode. Images of different sizes or bin modes cannot be combined. If necessary, resize your images first by clicking **Image | Resize | Resize Folder of Images**; see “Chapter 9: Image Processing” for details.

Open the Combine Folder dialog box by clicking **Image | Combine | Combine Folder of Images**. Figure 13 shows the Combine Folder dialog box.

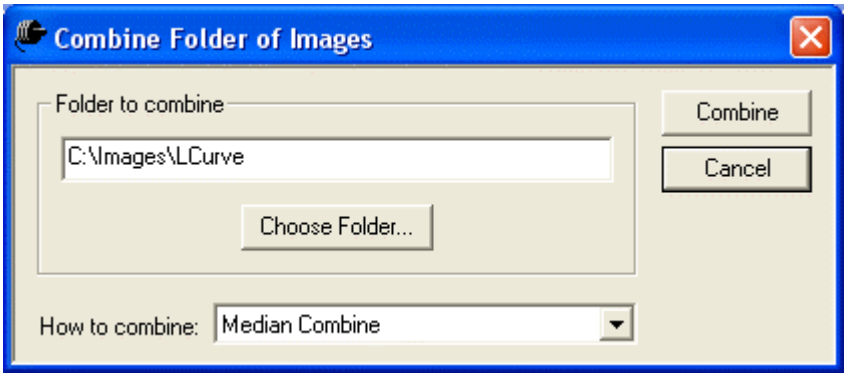


Figure 13: Combining a folder of images.

Click **Choose Folder** to select the source folder. Then select a combination method: add, average, or median combine. The following table describes the advantages and disadvantages of the various combination methods.

Method	Advantages	Disadvantages
Add	· Provides best signal-to-noise ratio. · Fast.	· Retains extreme values in final image, such as from satellites or cosmic ray hits.
Average	· Works well with large numbers of images. · Fast.	· Retains extreme values in final image, such as from satellites or cosmic ray hits. · Slight reduction in signal-to-noise ratio.
Median Combine	Removes extreme values in the final image, such as those from satellites or cosmic ray hits. Slight reduction in signal-to-noise ratio. Usually produces the best results.	Uses a large amount of memory. Slower (very slow if virtual memory required).

When the images are very clean (they do not contain any satellite tracks, serious cosmic ray hits, etc.), use the **Add** option to obtain the best possible signal-to-noise ratio. If you do have satellite tracks or other problems in your images, and you have at least three images, use a median combine. If you have large numbers of images, or a limited amount of memory, an average combine will be much faster than a median combine.

Chapter 4: Autoguiding

Version 5 of CCDSoft incorporates some radical new features for autoguiding. Many of these new features are mostly “under the hood,” but they make CCDSoft a more flexible and more powerful autoguiding program.

This chapter describes how to use CCDSoft to autoguide using camera with and without built-in autoguiders. You'll learn how to:

- Determine how well your mount can autoguide.
- How to fine-tune your mount for autoguiding.
- How to use the autoguiding features in CCDSoft effectively.
- How to customize the autoguiding settings to meet your needs.

Quick Start for Experienced Users

For this chapter, an experience user is someone who has already used CCDOPS or another camera control program to autoguide.

If you have been using CCDOPS to do your autoguiding, the most important new feature in CCDSoft is the ability to resume guiding automatically after downloading an image. This allows you to take multiple images without restarting autoguiding. The autoguiding process runs independently of the imaging process. In fact, if you have a physically separate autoguider, autoguiding is continuous.

Another nice feature: if you are using CCDSoft with TheSky Level IV version 5 or later to control your telescope, the telescope’s current declination is automatically used to scale guide corrections.

To calibrate and perform autoguiding, open the Camera Control Panel (click **Camera | Autoguide**, or press `Ctrl+W`, and then click the **Autoguide** tab), and follow these steps:

Calibration:

1. Position a bright guide star on the guide detector. For best results, there should not be any stars of similar brightness on the detector, or within one detector width, of the guide star.
2. Click **Take Image**, and then click on the guide star.
3. Click **Calibrate**. If calibration fails due to insufficient guide star movement, click **Settings** and increase the X and Y calibration times.
4. To view the results of calibration, on the **Autoguide** tab, click **Settings | Calibration Results**. If Calibration Results button isn’t visible, click **Advanced>>** first.

Autoguiding:

1. Compose your image, and position a guide star on the guide detector. See the section “Choosing a Good Guide Star for Calibration” for details.
2. Set an exposure time.
3. Click **Take Image** to confirm the brightness/presence/location of the guide star. Next, click on the guide star.
4. Click **Autoguide** to start autoguiding. Observe the X error and Y error values during calibration. When they are low enough, click the **Take Image** to begin your exposure(s).

Principles of Autoguiding

The fundamental idea behind autoguiding is simple: CCDSoft measures the position of a star image on the tracking CCD detector every few seconds. If the image of the star moves from one exposure to the next, CCDSoft sends signals to the mount to move east/west or north/south (or some combination of the two) to correct the pointing error.

CCDSoft is very flexible for cameras that contain both imaging and tracking CCD detectors. You can use either detector to image or to autoguide. A radio button in the various tabs on the Camera Control Panel determines which detector gets used for which function. Both detectors are capable of all functions built into the Camera Control Panel; it's up to you to decide which arrangement best suits your needs.

The basic steps involved in autoguiding are:

1. Calibrate your mount (CCDSoft determines how fast the mount moves, and in which exact directions).
2. Select a guide star.
3. Autoguide, moving the mount so the guide star remains at a fixed position.

Movement of the guide star typically results from three sources:

- Inexact polar alignment, which causes a slow drift of the field of view as well as a slow rotation of the field.
- Periodic error in the mount's tracking rate, which causes star images to elongate as the mount speeds up and slows down by very small amounts during rotation of the worm gear.
- Random errors due to variations in gears, dirt in the gears, dents in an equatorial platform’s bearing surfaces, etc.

Various complexities creep into the seemingly simple autoguiding operation (i.e. slewing the telescope to a star and guiding on a star over a long period):

- The pointing accuracy required is very high, usually on the order of several arcseconds. Since one arcsecond is 1/1,296,000th of a circle, the degree of pointing accuracy required isn't just high; it's extraordinary.
- The longer the focal length of your telescope, the greater the accuracy required for accurate, successful guiding.
- Mounts have some degree of repeating error, called periodic error. This error results from, among other things, gears that are ever so slightly out of round. Some mounts have built in periodic error correction (PEC); some do not.
- Mounts also have greater and lesser degrees of random error. If the random errors are large enough and fast enough, they may make accurate autoguiding impossible.
- If the mount is even slightly misaligned from the celestial pole, telescope drift over time is introduced and will cause pointing errors. The greater the misalignment, the greater the drift. A good polar alignment makes autoguiding easier.
- Any mechanical looseness in the mount can contribute to pointing error. There are many potential sources of looseness, including backlash (slop) in the gears, and endplay of a worm gear. Some looseness can create counterintuitive movements, such as a movement in declination causing a movement in right ascension. You can diagnose these types of problems by using a high-power reticle eyepiece to observe what happens during tracking and guiding.

- The tripod, mount, and telescope assembly are subject to different amounts of flexure as the weight of the telescope moves over time. This can contributes to guiding errors, and to pointing errors as well.
- If all of the parts of the mount aren't exactly aligned with each other, pointing error is the result. For best results, you want your telescope orthogonal to the mount, especially when polar aligning.
- Turbulence in the atmosphere can change the apparent position of the star used for reference in a random manner over time. This makes it look as if a guiding correction is needed even when it is not, or depending on timing, it could also mask the need for guiding corrections. The worse the seeing, the harder it is to guide accurately. Longer guide exposures can compensate for poor seeing, to some degree.

In short, keeping a telescope pointing at an object over the length of time involved in a CCD exposure is not a trivial task. Any given mount will have a certain level of accuracy that it can reach. Pushing a mount past this point will result in guiding and tracking errors that will at the very least reduce the quality and sharpness of your images, and at worst turn stars from round circles into lines. Generally speaking, if you find that your mount simply cannot track or guide accurately enough for your equipment, try shortening your focal length with a focal reducer, or switch to a telescope with a shorter focal length.

Assessing Mount Accuracy

A mount has two axes, and most mounts today can guide by making adjustments to both axes. However, the right ascension and declination axes behave in fundamentally different ways.

The right ascension axis is always moving to keep up with the apparent motion of the stars. This rate of motion is called sidereal, and the rate is very nearly one revolution per day. You will often see reference to some fraction of the sidereal rate, such as 1x (exact sidereal rate), 0.5x (one-half sidereal rate), etc.

Because the right ascension axis is always moving, you have an opportunity to eliminate many (but not all) sources of error by simply making guiding corrections at speeds slower than the sidereal rate. For example, it is common to make right ascension adjustments using either 0.5x sidereal (slow the mount down to half speed to move it further east), or 1.5x sidereal rate (speed the mount up to 150% of sidereal rate to move it further west). Depending on the focal length of your telescope, you may get better results at 0.75x/1.25x (shorter focal lengths), or at 0.25x/1.75x (longer focal lengths).

The declination axis, on the other hand, is stationary until a correction needs to be made. If there is substantial looseness in the declination axis at any point (motor bearings, reduction gears, worm endplay, or worm mesh with the worm gear), the mount may literally be unable to guide adequately in declination.

The result of these differences is that special attention must be paid to the state of the declination axis components to obtain high-quality guiding results. See the section of this chapter, “Assessing Autoguiding Possibilities,” for detailed information about getting the best autoguiding results out of your mount.

Mount (Drive) Calibration

Once your mount is tuned to minimize backlash and/or correct any other problems, you can use it for autoguiding. See the section “Adjusting and Tuning Your Mount,” for details on getting the most out of your mount.

Autoguiding makes small corrections to maintain a constant pointing direction. This corrects for small errors in polar alignment; for periodic error that results from slight eccentricity in the worm or worm gear; and non-periodic errors that results from minor variations in the gears. The pixel size of your CCD detector, the focal length of your telescope, and the length of your guide exposures all affect the rate and amount of movement during a correction.

The correction speed also changes with declination. At the celestial equator, movement is rapid because the lines of equal Right Ascension are far apart. Closer to the poles, movement is slower because the lines of equal right ascension are closer together.

Before you can autoguide, you need to perform a calibration. Calibration allows CCDSoft to model your system's behavior during corrections. CCDSoft uses the calibration data to determine how long to move the mount (at whatever guide speed you are using) to make an appropriate correction. You can perform a single calibration, and CCDSoft will scale the data for other declinations. If you choose this method, you should perform the initial calibration near the celestial equator so that the scaling will be most accurate. You can also perform a new calibration whenever you move the telescope to a new declination in order to achieve the highest level of accuracy. The longer your focal length, the more you have to gain from performing new calibrations when you change declination.

The basic steps in calibration for autoguiding:

1. Connect the hardware. This is typically a cable between the camera and the mount, but may also be a cable from the serial port of your computer to the mount.
2. Move the telescope so that a suitably bright star falls on the autoguider detector.
3. Take a reference image to verify the presence, location, and brightness of the guide star you intend to use for calibration.
4. Click on the guide star in the reference image to select it, or use the **Auto** button instead.
5. Adjust calibration settings, if necessary.
6. Perform the calibration.

How often should you perform a calibration? Calibration frequency depends on your imaging session and your equipment. If you move the mount across the meridian, the direction of movement in declination changes direction. For example, if you are guiding while pointing to the east, an upward correction is a move toward the west horizon. If you are guiding while pointing to the west, an upward correction is a move toward the east horizon. There is a checkbox that directs CCDSoft to flip declination corrections, and you can check this box when the mount crosses the meridian. However, for optimal results (especially with longer focal lengths), a recalibration is recommended. The longer your focal length, the greater the sensitivity to changes, and the more likely you are to need to recalibrate whenever you point to a new location.

To calibrate CCDSoft for your mount, telescope, and camera, click **Camera | Autoguide**. This displays the Camera Control Panel with the **Autoguide** tab active (see figure 1). For an overview of all of the controls on the **Autoguide** tab, see “Chapter 1: Camera Control.”

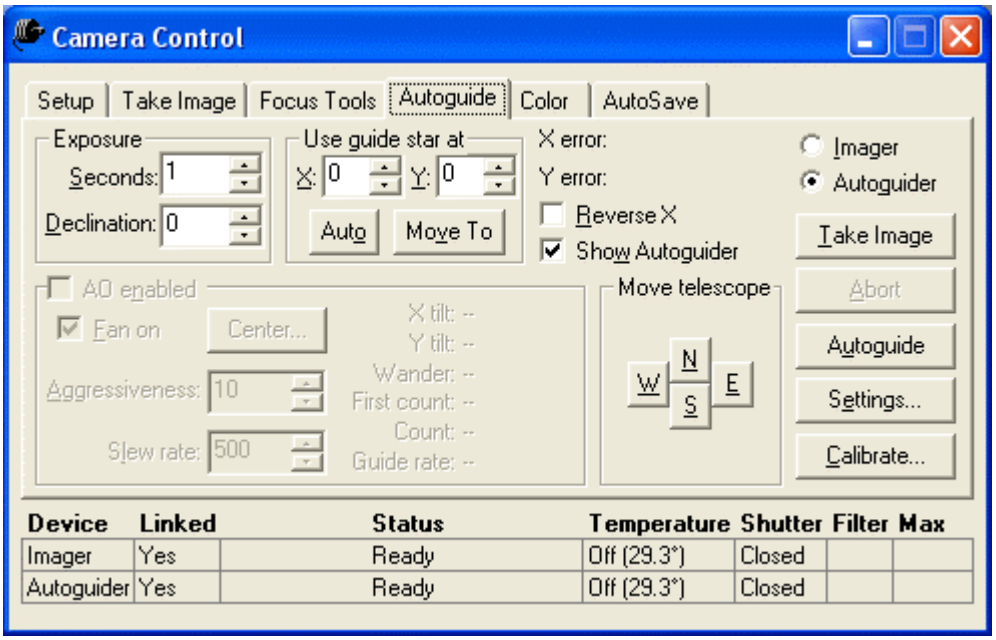


Figure 1: The Autoguide tab

Make sure the hardware is connected

To autoguide, you need either a camera that will be dedicated to autoguiding, such as an ST-237, or a camera that has its own built-in autoguiding detector, such as an ST-7/8/9/10. Consult the camera documentation for instructions on how to connect the autoguider cable to the camera. The other end of the autoguide cable attaches to your mount; consult your mount documentation for the location of the autoguider connection.

Not all mounts support an autoguider connection. Contact the mount manufacturer for information on how to build an interface box or cable to fit such a mount. SBIG cameras come with a standard autoguider cable. If the standard cable doesn't fit your mount (such as for a Takahashi mount, or a Vixen Sky Sensor-equipped mount), consult the mount documentation for information about building or buying a suitable cable. Some mounts require the use of the SBIG Relay Box to provide appropriate guide signals; read your camera and/or mount documentation for details.

Choosing a Good Guide Star for Calibration

Whether you are calibrating or autoguiding, selecting the right guide star is important. As you will see shortly in the list of possible errors, the brightness and location of the star image used for guiding and calibration play a major role in the success or failure of the operation. Here are some tips in picking a good guide star. Most apply whether you are autoguiding or calibrating; a few relate specifically and only to calibrating:

- The guide star should be bright enough to show clearly against the background. You can run the cursor over the star and the background to see how bright they are; the brightness values

appear at the left of the status bar at the bottom of the CCDSoft window. The longer your guide exposure, the brighter the stars and background, but star brightness will increase faster than background brightness. If you can't find a suitable guide star for a given exposure, increase the exposure time to see if any good candidates emerge from the background. In absolute terms, the guide star should be at least 1,000 counts brighter than the background (more if you are doing tricolor imaging, since color filters will reduce the star's brightness, and the brightness of the star will often vary with the filter used).

- The guide star should not be more than 50% of the camera's saturation level (4,000 units for ST-237; 60,000 units for the guide detector on the ST-7/8E). Random variations in brightness can easily take a bright guide star into saturation, creating false readings and incorrect corrections.
- The guide star should be away from the edges of the tracking CCD detector. This is critical when calibrating, since CCDSoft will move the mount during calibration. If the guide star moves within 10 pixels of an edge, calibration will fail. You can use the Move To button on the Autoguide tab to center a suitable guide star: click on the guide star, click **Move To**, and then click on the position of the image you want the guide star to move. You must perform an initial calibration before you can use the Move To button. If you haven't calibrated yet, use TheSky, your mount's hand controller, or the NSEW buttons on the Autoguide tab to adjust the position of the guide star. If your image composition makes it impossible to put the guide star near the center for autoguiding, you can still get good results as long as the star is at least 10 pixels from an edge. However, you increase the risk of losing the guide star during downloading. CCDSoft will attempt to reacquire the guide star after a download, but cannot do this if the guide star has moved off the detector. The greater the periodic and random errors of your mount, the greater the chances of losing the guide star during a download.
- The guide star should usually be the brightest star in the image from the tracking CCD detector. This allows CCDSoft to find the guide star on each exposure. When in doubt, click **Auto** on the **Autoguide** tab to allow CCDSoft to select the guide star for you. If the brightest star is too close to a similarly bright star, or is a double star, select another bright star instead.
- No other star in the tracking detector's image should be close to the brightness level of the guide star when calibrating. Otherwise, CCDSoft can get confused about which star is the guide star. When autoguiding, a star of similar brightness should not be within the small autoguider window, or CCDSoft may jump between the two stars during autoguiding.
- If you are calibrating, you also need to make sure that a brighter or similarly bright star doesn't move onto the CCD detector as a result of a calibration move. You can use TheSky to visually inspect the area around your selected guide star. Check for a distance equal to the 1.5 times the width of the area covered by the tracking CCD detector at a minimum. See the section "Select a Guide Star," in this chapter, which explains how to use TheSky to help you select a guide star.
- Good focus is critical to accurate guiding. Even a small variation in focus position can soften the guide star image enough to make its exact position less certain.

Take an Image as a Reference

Typical autoguide exposures range from 1 to 10 seconds. Shorter and longer exposures can be used, but are not often necessary. Guide exposures shorter than 1-2 seconds can be affected by atmospheric turbulence. When the guide exposure is very short, you often wind up measuring fluctuations in the atmosphere rather than actual movement that needs to be corrected. If the guide interval is too long, the guide star could move so much that corrections will be too large, and star images will become elongated in the direction of the corrections.

CCDSoft can scale the calibration results for autoguiding at different declinations. To use this feature, you must enter the current declination that the telescope is pointing to in the box labeled **Declination**. An accuracy of one-tenth degree is sufficient to use this feature effectively.

NOTE	If you are using TheSky Level IV version 5 or later to point your telescope, the declination will be set automatically; you do not need to enter it manually. This is one of many ways in which these two applications interact to make imaging simpler and more productive.

The image you take as a reference image should be long enough to clearly acquire a star suitable for guiding. If you are using TheSky, you can determine the proper exposure based on the magnitude of the stars in the field of view. If you are unsure, start with an exposure of 5 to 7 seconds. You can always adjust the exposure length as needed.

Click **Take Image** on the **Autoguide** tab to expose an image. Figure 2 shows the result for the guide detector on an ST-8E camera. The guide detector is much smaller than the imaging detector, so download times are short. By default, a dark frame is automatically taken and subtracted from the light frame.

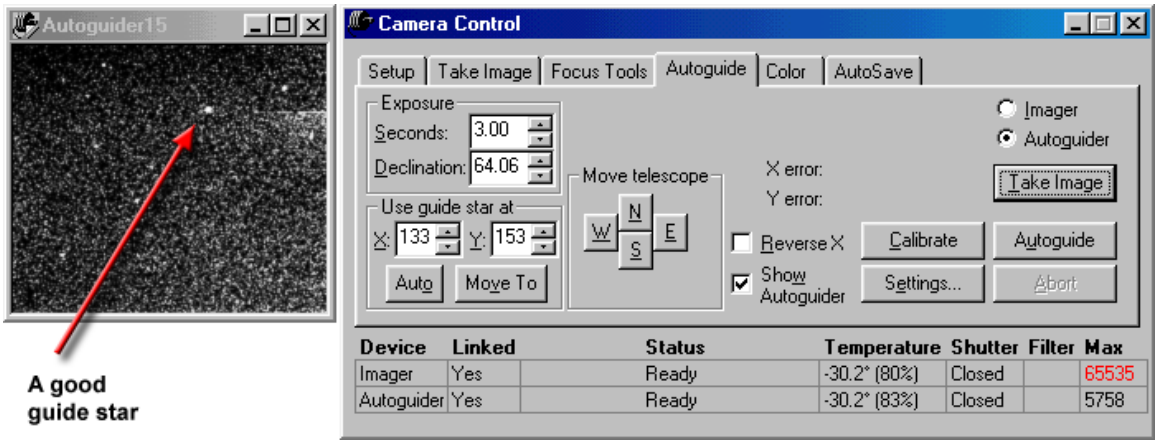


Figure 2: An autoguide image taken for reference. Note that there is one star significantly brighter than the others; this is a good choice for a guide star.

Evaluate the image to determine if the exposure time provides a suitable brightness level for the guide star. Use the criteria listed earlier in this chapter: at least 1,000 units over background level, and less than 50% of saturation.

Select a Guide Star

You can either click **Auto** on the Autoguide tab to have CCDSoft pick the brightest star to use as a guide star, or you can click in the image to select a guide star. A white box flashes briefly around the star to indicate that it has been selected. The coordinates of the selected star appear in the X and Y boxes of the Autoguide tab. Please note that when calibrating, the guide star should always be the brightest star in the image, and that there should not be any brighter stars lurking outside the frame ready to move into the frame during calibration. If you are using CCDSoft with TheSky, you can easily check for the

presence of good guide stars in the vicinity of your current location. For best results, we recommend moving the telescope to find a bright, isolated star for calibration, and then moving back to your object of interest to begin autoguiding. This is not to say that you can't perform a good calibration using any handy star, but you can virtually guarantee a good calibration by using a bright, isolated star.

TheSky can project the coverage area of the CCD detector (ST-237 and similar cameras) or both the imaging and tracking CCD detectors (ST-7/8/9/10) on the map of the sky. Figure 3 shows the projection for an ST-8E camera. The inner rectangle is the imaging detector; the small rectangle above it is the tracking detector. The circles show the position of the tracking detector if you rotate the camera. These circles can help you find an alternate guide star just by rotating the camera, instead of moving the mount. CCDSoft does not require that the camera be orthogonal (square) to the mount. It will calibrate and guide successfully at any camera angle.

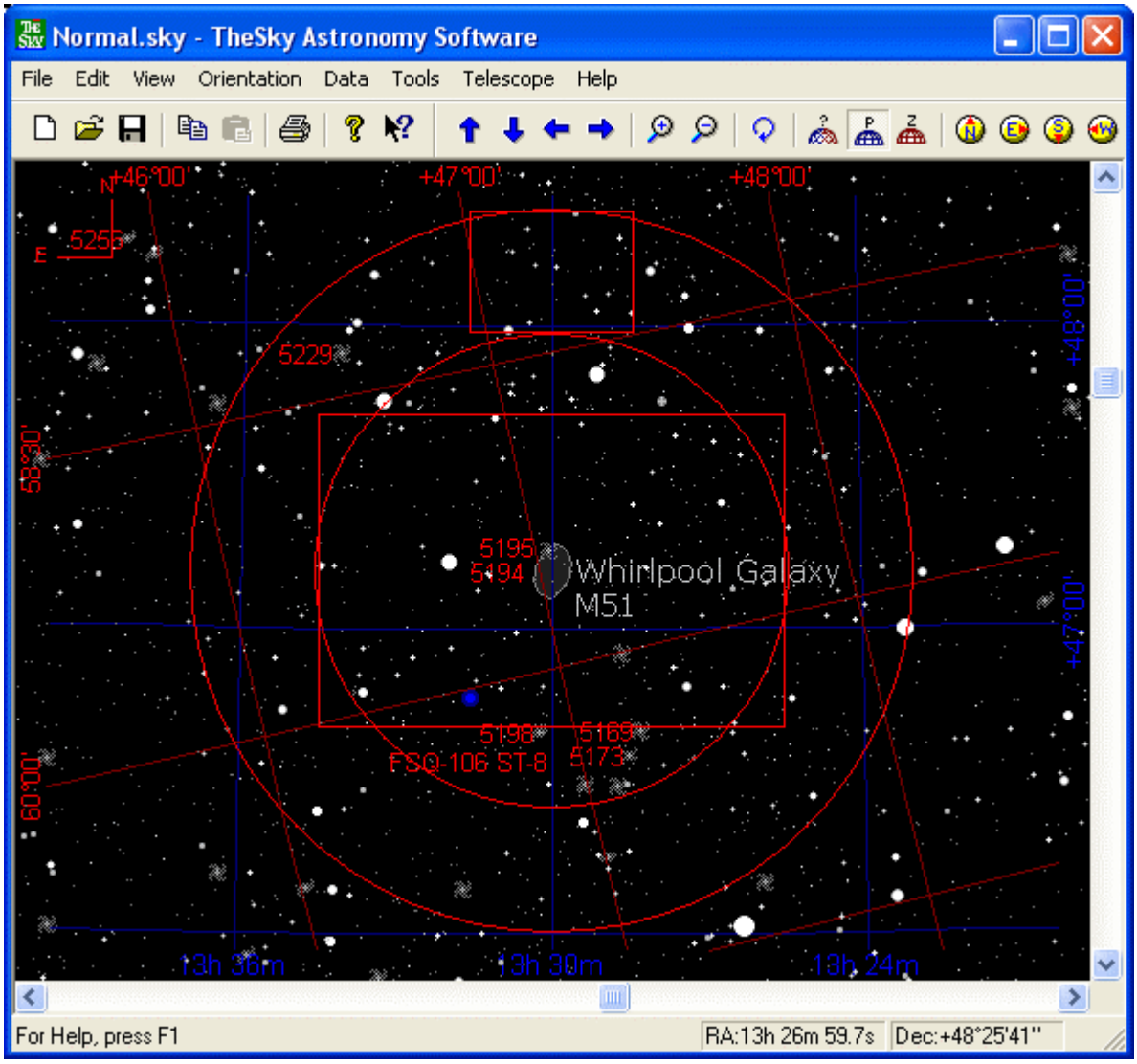


Figure 3: The imaging and guide detectors of an ST-8E with an ST-237 guider camera shown in TheSky.

To set up your camera's field of view indictor, follow these steps in TheSky.

1. Click **View | Field of View Indicators**.
2. Click **Add**.
3. Type in a description, such as the name of your camera and the telescope.
4. Select the type of indicator to use (rectangular, ST-7, ST-8, etc.)
5. Click **Compute**.
6. Click the **CCD** tab.
7. Select the appropriate camera/CCD detector from the drop-down list.
8. Enter the focal length of your telescope (inches or millimeters).
9. Click Compute.
10. Click **OK** three times in the three nested dialog boxes to finish.

The field of view indicator will only appear at magnifications large enough to see it. Zoom in if necessary to see the field of view indicator. See TheSky's manual for details about Field of View Indicators.

In figure 3, the pair of interacting galaxies known as Messier 51 is centered on the imaging detector, and celestial north is straight up. The box at the top shows that there are a few dim stars on the tracking detector, but none are very bright, and none are near the center. The two galaxies form a nearly vertical line with each other, and several dimmer galaxies are also in the frame. You could try to guide using the star at the eight o'clock position on the tracking detector, but for calibration you should move the mount to bring a brighter star onto the tracking detector.

A brighter star allows you to use a shorter guide exposure time. If your mount is very stable and accurate, you can use longer guide exposure times and therefore dimmer guide stars are suitable. If your mount has poor polar alignment, larger periodic error, or suffers from random movements during tracking, brighter guide stars are more important to success.

Figure 4 shows one approach to finding a nice, bright guide star: move the mount so that a bright star falls on the guide detector, while M51 remains in the same orientation. M51 has been moved away from the center of the imaging detector. If you want M51 near the center, you can also rotate the camera to bring a guide star onto the guide detector. If your mount has goto features, you can connect it to TheSky and control the mount from the computer. Camera orientation requires a trip out to the telescope, however.

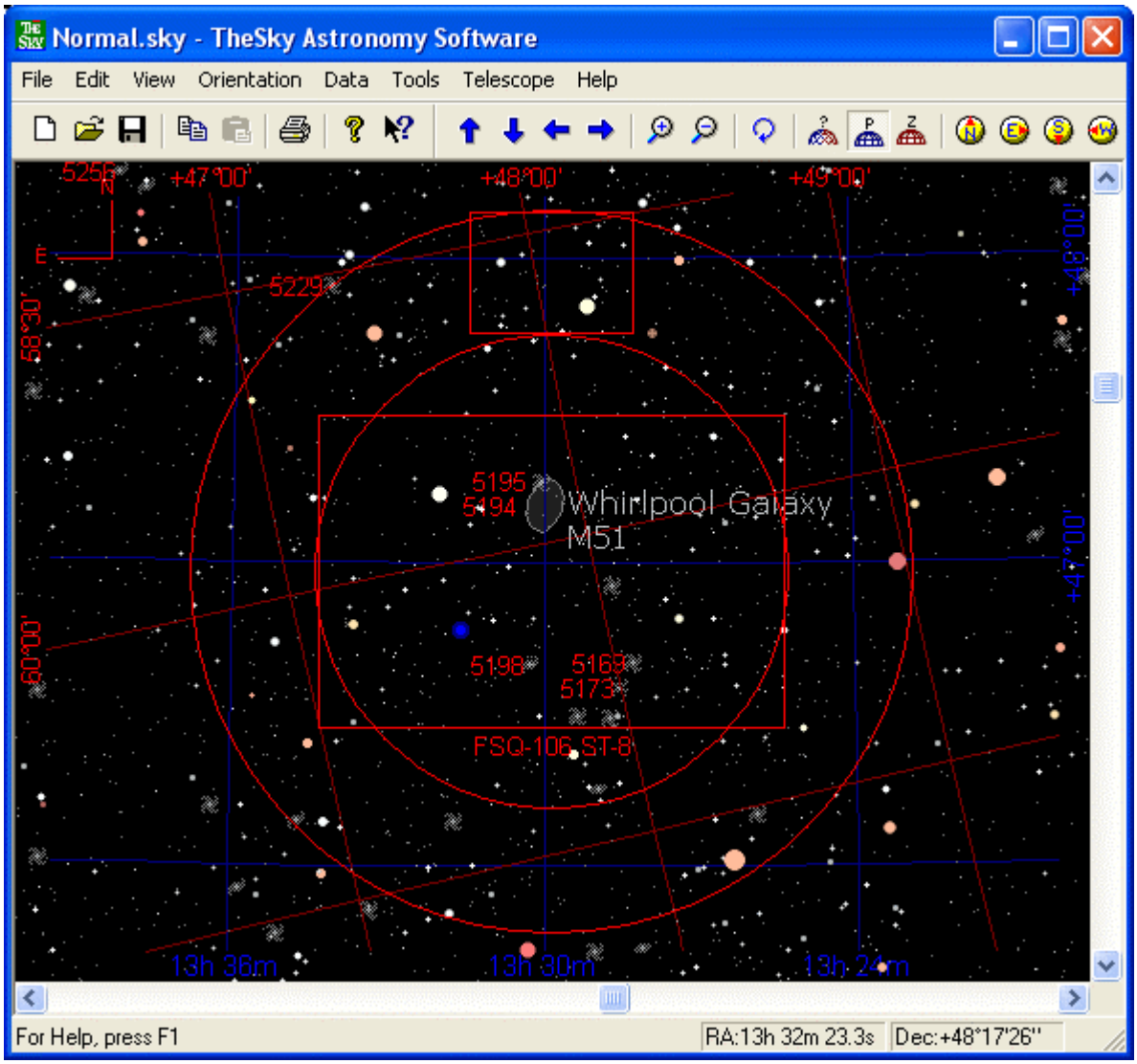


Figure 4: Placing a guide star on the tracking detector.

If you were performing a calibration, the bright star in figure 4 is clearly brighter than others in this field. It's an ideal star for calibration, in fact. You would use a very short exposure time for such a bright star, which also will speed up the calibration process. In general, you should expect to move your mount away from the object you intend to image to do a calibration, because putting a very good guide star on the center of the detector is the key to successful calibration. With TheSky available to position the mount, you can move, calibrate, and return to your object very quickly.

If you want to keep M51 at or near the center for taking the actual image, rotating the camera to bring a guide star onto the tracking detector works well. Figure 5 shows that a rotation that puts north at about eight o'clock puts a reasonably bright star on the tracking CCD detector. You can experiment with TheSky to find the right rotation angle, and then physically adjust the camera to the new orientation.

Because CCDSoft can guide accurately at any angle, even 45 degrees away from orthogonal, you have complete flexibility in framing your images.

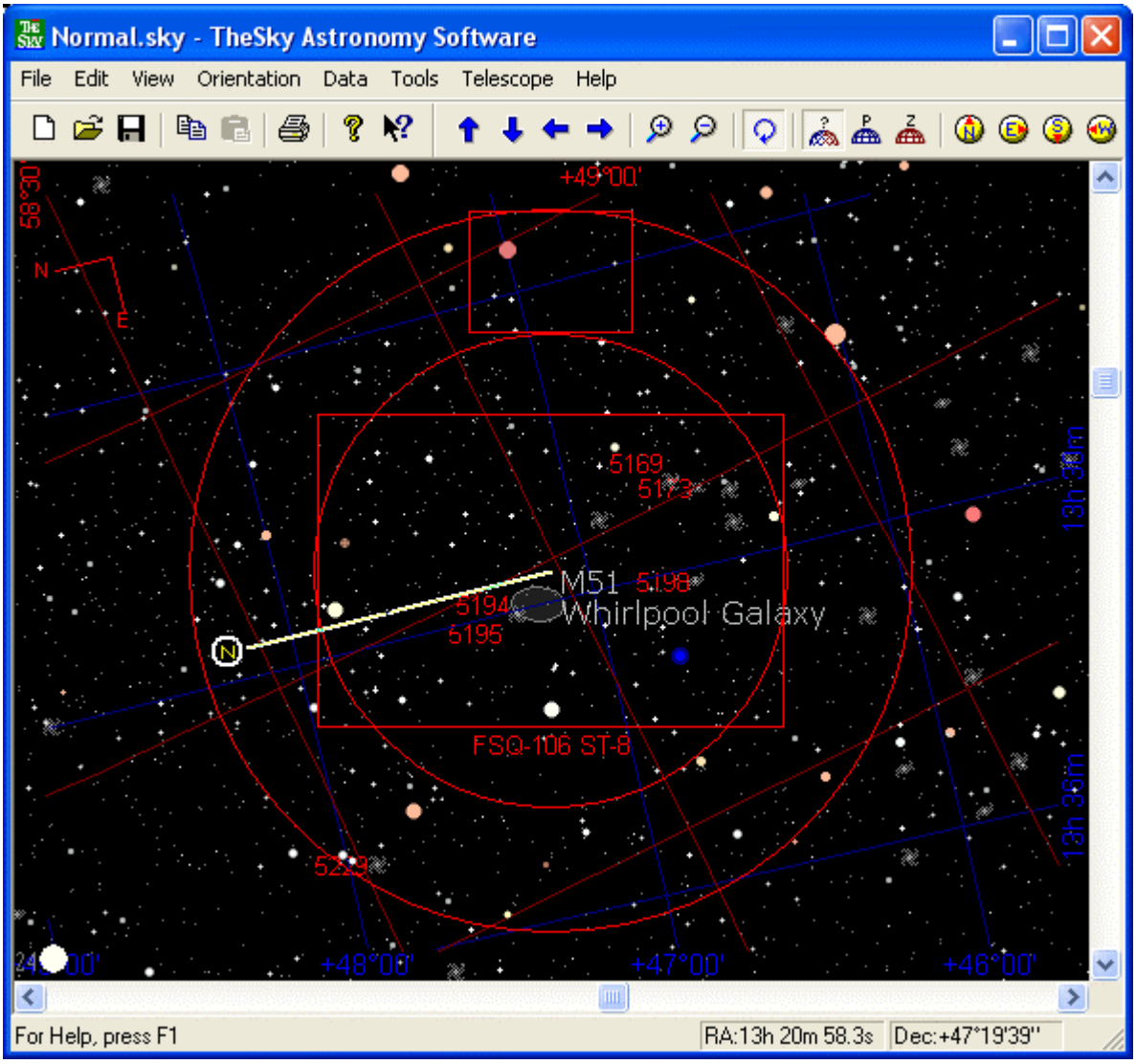


Figure 5: Rotating the view to look for a suitable guide star.

Adjust Calibration Settings

During calibration, CCDSoft will move the mount for a period of time, then take another image and compare it to the first image to measure how far the mount has moved. Each image is displayed in a window so that you can follow along. These images are a useful tool for diagnosing any trouble that occurs during calibration.

The software measures the amount of movement from one exposure to the next. The exact sequence of moves is as follows:

1. Move in a positive X direction.
2. Move in a negative X direction, measure movement.
3. Move in a positive Y direction.
4. Move in a negative Y direction, measure movement.

An ideal mount concludes this sequence with the guide star in the exact same position as at the start of the calibration procedure. In most cases, there will be at least a small difference in starting and ending position due to whatever backlash remains uncompensated for in the mount. In addition, unless the camera is perfectly square to the mount's right ascension and declination axes, a movement in one axis will involve at least a small movement in the opposite axis. CCDSoft not only tolerates non-square camera placement; it can cope with a completely non-square camera position. This gives a great deal of flexibility in selecting a guide star.

To set the time interval for calibration, as well as other related settings, click **Settings** on the **Autoguide** tab. See figure 6 for the default appearance of the Autoguide Settings dialog box. The calibration time is measured in seconds.

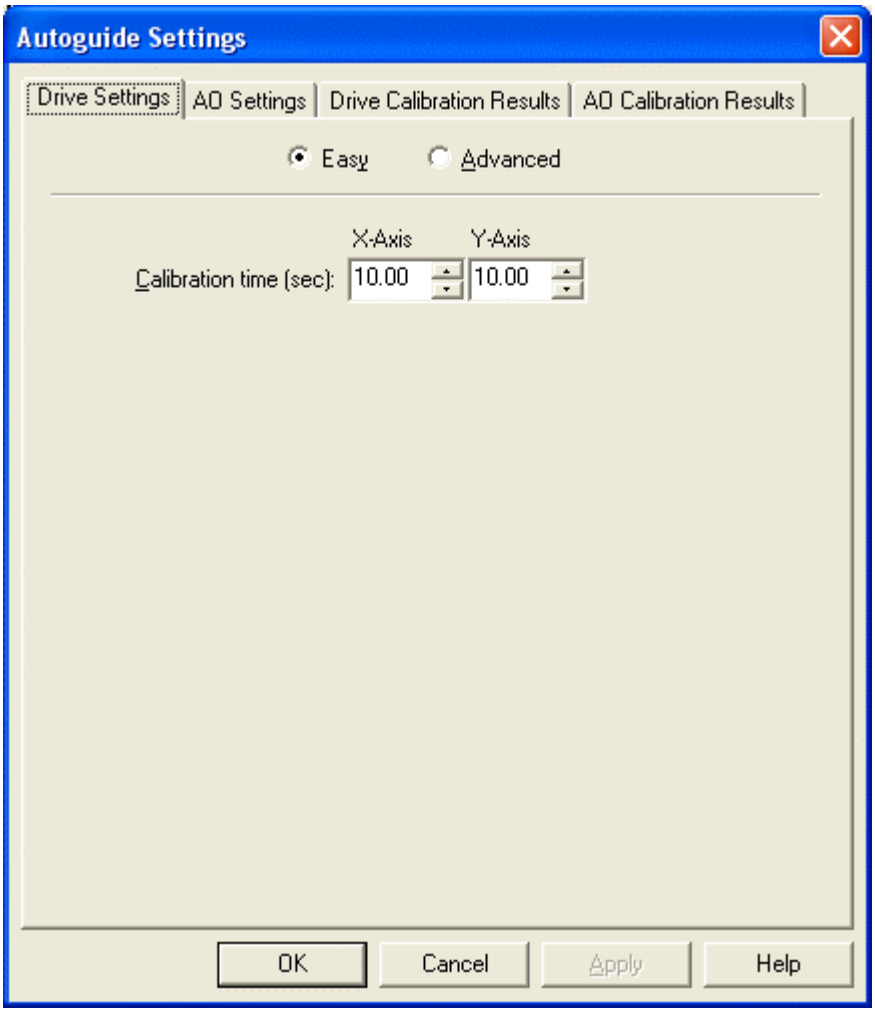


Figure 6: The default Autoguide Settings dialog box.

In most situations, simply enter a time interval for each axis, and then click **OK**. The time you enter depends on the focal length of your telescope and the pixel size of your camera. If the camera is reasonably well matched to the telescope (a camera with anywhere from 1 to 4 arcseconds per pixel), the values shown in the following table are useful starting values for calibration time:

Focal length (mm)	**Suggested calibration time (seconds)**
100-300 (typically a camera lens)	30
300-500	20
500-1000	10
1000-2000	7
2000-3000	4

To control more calibration parameters than just the time interval, click **Advanced**. This displays a version of the dialog box shown in figure 7.

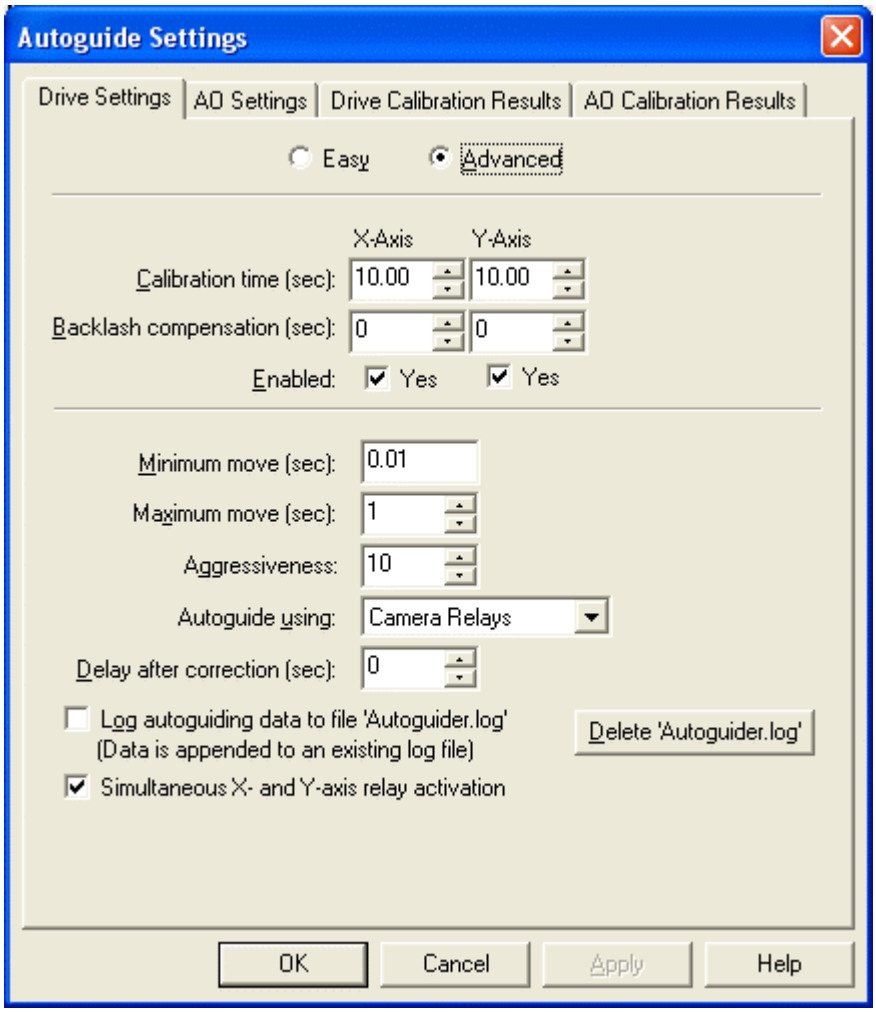


Figure 7: The advanced Autoguide Settings dialog box.

This allows you to set the following additional parameters for calibration:

Backlash compensation – Backlash exists when the motors on the mount must turn for some period of time after a change of direction before the gears fully engage and actually move the mount. Backlash compensation is the time that CCDSoft should turn the motors to take up backlash when the direction reverses. Since guide speeds in right ascension are typically less than sidereal rate (0.5x is commonly used), no reversal occurs and you should not set a backlash compensation time for right ascension backlash compensation unless you are using a guide speed of 1x sidereal or faster. You should always slightly under compensate for backlash; over compensation leads to over correction and can make guiding impossible.

Enabled – Determines whether corrections are applied to the indicated axis. For example, if the mount's polar alignment is good, you can turn off corrections to the declination axis to avoid spurious corrections that result from atmospheric turbulence.
Minimum move – This specifies the minimum move that CCDSoft will make. If a smaller correction is indicated, no correction occurs. When a correction of this length or greater is indicated, the correction will be made.
Maximum move – The longest time to move the mount during a correction. If you find that the mount is too active no matter how you change other settings, this can force CCDSoft to use shorter corrections. However, if at all possible, you should find the source of the problem and fix it.
Aggressiveness – A number from 1 to 10, indicating the relative aggressiveness of the corrections. With a setting of 10, CCDSoft will make the full, indicated correction. With a setting of 5, CCDSoft will make 50% of the indicated correction. With a setting of 1, only 10% of the indicated correction occurs. If the mount is responding too much to corrections, you can reduce the amount of the correction with this setting and smooth things out. For example, when pointed near the zenith, your mount may be more responsive to corrections due to changes in balance. You can use a lower aggressiveness setting to compensate if your mount behaves in this manner.
Autoguide using – Determines how CCDSoft should communicate with your mount. If the camera is connected directly to the mount (or connected through the SBIG relay box), then use the **Camera Relays** setting. If you are using a special arrangement via the serial port of the computer running CCDSoft, then choose **RelayAPI (serial)**. If your mount supports **DirectGuide™**, that is, CCDSoft communicates directly with the telescope's control system and bypasses the camera's relays, choose this option. The Paramount is currently the only telescope mount that supports DirectGuide™.
Delay after correction – If your mount tends to vibrate or bounce slightly after a correction is applied, a delay can help damp this oscillation. This is usually true only of lighter mounts, but it can also occur with larger mounts that are balanced too equally on the east and west sides. A slight imbalance to the east is not only good for keeping the right ascension gears meshed; it also helps prevent unwanted oscillations from occurring during guiding.
Log autoguiding data to file "Autoguider.log"– When checked, the log data is written to the file `autoguider.log`. See the section "Examining Data from an Autoguiding Run in a Spreadsheet" later in this chapter for information about the log file.
Delete Autoguider.log – Deletes the existing autoguider.log file from the CCDSoft folder.
Simultaneous x- and y-axis relay activation – Mark this option to allow CCDSoft to send x- and y-axis corrections to the telescope control system at the same time. Losmandy mounts cannot perform simultaneous corrections. Make sure to clear this option if you plan to autoguide with your Losmandy mount.

Aggressiveness is the most likely used advanced setting. For your first autoguiding efforts, leave the aggressiveness set to 10. If the corrections are too aggressive, try a lower number. It is better to have too low a number than one that is too high, since the software will eventually catch up and make the necessary corrections if you are reasonably close with your polar alignment. If the aggressiveness is set too low, however, the corrections will not be able to keep up with changes to the position of the guide star and elongated stars will result.

Calibration Procedure

Once you have set the Autoguide Settings, click **OK** to save them. Click **Calibrate** to start the calibration process. You will see information reporting the progress of the calibration in the Camera Control Panel, such as "Moving X Plus." The calibration procedure starts with a new reference image and dark frame. It then moves plus and minus in the X and Y directions, measuring the number of pixels the mount moves in each of the four directions.

If there are any problems during the calibration, the error is reported in a popup and the calibration halts. The following table lists common problems and explains what you can do to fix the problem.

Calibration Problem	Solution
Error message: Star too dim. Lost during +X, -X, +Y, or –Y	The star you chose for calibration was too dim, and could not be found on one or more of the images taken during calibration. Use a longer exposure, or choose a brighter star. A star is too dim not just when it is too dim to be pulled from the background, but also when the brightest star in a calibration image is less than 25% as bright as in the preceding image.
Error message: Motion too small during +X, -X, +Y, or -Y move. Increase calibration time.	The calibration time was too short to move the star far enough to get a valid result. The solution is to use a longer calibration time. For a valid calibration, the star must move at least 5 pixels.
Error message: Star too close to edge after +X, -X, +Y, or -Y move.	The guide star is too close to the edge of the image after a move. You can reduce the calibration time to causes less movement, and you can also begin calibration with the guide star at the center of the frame. This error will occur when the guide star moves to within nine pixels of the edge.
Error message: Invalid motion in X- or Y-axis.	This error typically occurs when: · The brightest star in a calibration image is a star other than the original guide star due to random variations in brightness. The guide star should be significantly brighter than any other star in the image. · A brighter star moves into the guide frame during calibration. The guide star should be isolated from similarly bright stars by at least 1.5 times the width or height of the guide frame in arcseconds. · The mount is very inaccurate, with motion in X resulting in motion in Y, or vice versa. Check the Calibration Results graph to see if it provides any clues about what kind of invalid motion is contributed by the mount.
Error message: Unable to calibrate, both axes are disabled. At least one axis must be enabled to calibrate.	With both axes disabled, no calibration is possible. To enable one or both axes, go to the Autoguide tab on the Camera Control Panel and click on Settings. Click in the checkbox next to “Enabled” for one or both axes.
Problem: no calibration in one axis	If an axis is disabled, no calibration will occur for that axis. To enable an axis, go to the Autoguide tab on the Camera Control Panel and click on Settings. Click in the checkbox next to "Enabled" for the disabled axis.
Problem: Guide star moves out of frame	This can cause several different error messages to appear, depending on what happens when the guide star moves off of the image frame. You might see “Star too dim” if another star winds up being interpreted as the guide star, or you might see “Star too close to edge” or another message depending on where the brightest star winds up. CCDSoft displays the images taken at each step in the calibration process; watch these images to see if the guide star is moving out of the frame. Use a shorter calibration time to keep the guide star in the frame, and start with

	the guide star as close as possible to the center of the frame. Severe mount errors can also move the star out of the frame at longer focal lengths.

Once you have calibrated the mount, you are ready to begin autoguiding. If you moved the mount to find a good calibration star, move it back to the object you want to image.

Autoguiding in Action

Once your system is calibrated, you can start autoguiding. CCDSoft supports autoguiding independent of imaging. This means that you can start an autoguiding session, and then take a succession of images while the autoguiding continues. If the autoguider is integrated into the camera, such as with an SBIG ST-7/8/9/10 camera, autoguiding is suspended during image downloads. The shutter is closed during a download, and autoguiding can only be done with the shutter open.

If you have a good polar alignment – always a good idea when imaging anyway – the guide star will be more likely to remain in the autoguide window when autoguiding resumes. If the guide star moves, CCDSoft will perform corrections to move it back to the center of the autoguide window. If this move tends to be large, you can add a delay to your exposures. This will give CCDSoft time to make corrections before the next exposure begins. The larger the corrections, the longer the delay should be to give the autoguider time to settle down. For most applications, use a delay that is a few seconds longer than two times the autoguide exposure. For example, if your guide exposure is 4 seconds, then use a delay of about 10 seconds. The extra time allows for downloading the autoguider images and processing time. If you find that your particular mount requires shorter or longer delays, adjust accordingly.

Once you have calibrated the autoguider, you can begin autoguiding. A typical autoguiding session includes the following steps:

- Adjust the position of the mount if necessary to put a suitable guide star on the autoguider detector.
- Click **Take Image** on the **Autoguide** tab, and verify the location of the guide star using an appropriate exposure length. If you aren't sure, try 10 seconds.
- If the brightness of the guide star to too high or too low, adjust the exposure time. Aim for a brightness level between 1000 units minimum and 50% of saturation maximum.
- If the guide star is close to an edge, click **Move To** to move it. A dialog box opens; click on the new location, and then click **OK**. CCDSoft will move the telescope and take additional images as needed to move the guide star to the new location. This can only be done after a successful calibration. You can also move the telescope using TheSky, the telescope's hand paddle, or with the N/S/E/W buttons as appropriate.
- Enter the current declination of the telescope. If you are using TheSky to point your telescope, this will be filled in automatically when you click **Autoguide**.
- Click **Autoguide** to begin guiding.

If you have TheSky installed and running at the same time, and you are using it to point your telescope, CCDSoft will automatically get the current declination of the telescope from TheSky and use it to scale your calibration. If you move a large distance across the sky, or if you cross the meridian, then you may want to do another calibration. If you are imaging at longer focal lengths (2500mm and larger), you can calibrate before every image if necessary to get the best possible modeling of your system.

During autoguiding, CCDSoft updates a small window (se figure 8) with the latest image of the guide star. This window is updated by default. If you do not want the update, clear the **Show Autoguider** option in the **Autoguide** tab. The current position error appears near the center of the Autoguide tab, showing the number of pixels that the guide star has moved from the original position (X Error and Y Error). These numbers may be positive or negative, and are reported for both X and Y directions to the nearest hundredth of a pixel. Each exposure of the detector used for autoguiding shows a progress bar in the line for the autoguider at the bottom of the Camera Control Panel.

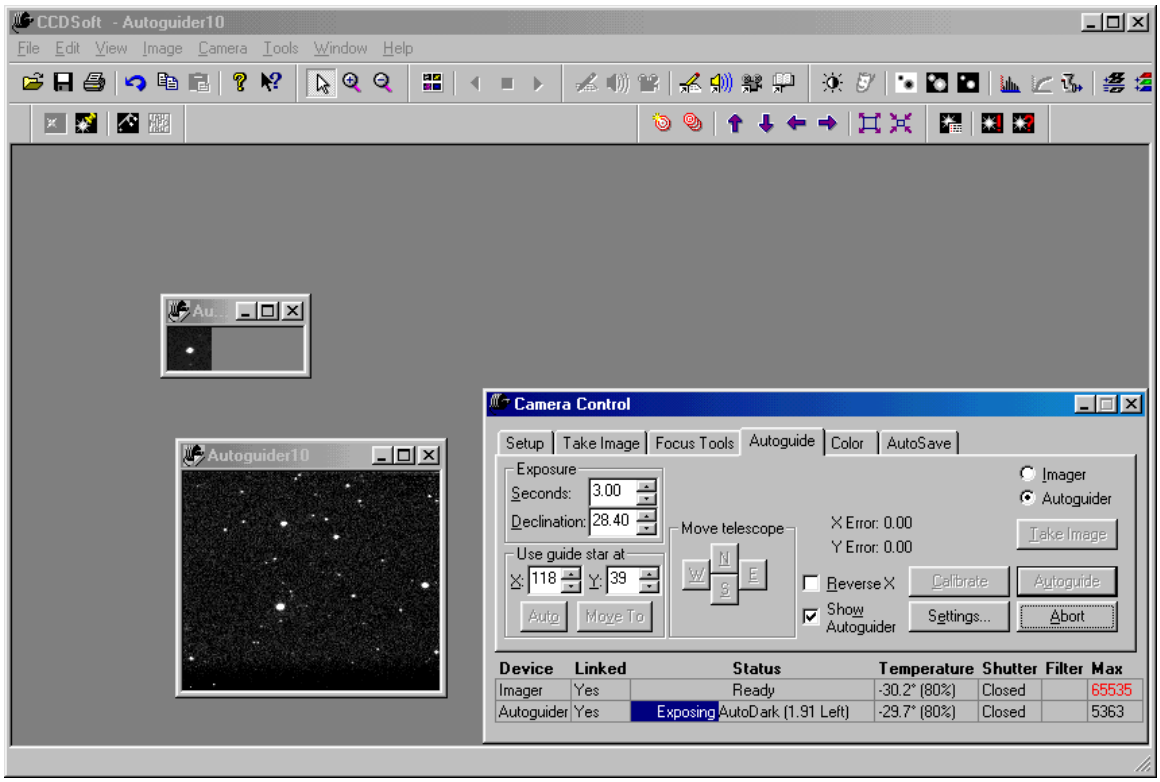


Figure 8: The appearance of CCDSoft when autoguiding is active.

Autoguiding will continue until the **Abort** button is clicked. If there is an error during autoguiding, autoguiding will continue anyway. For example, if the star is lost, CCDSoft will continue to expose the tracking detector, but it will not make any corrections until the star appears again. For example, if the star was lost because of a passing small cloud, autoguiding will resume when the cloud has passed. If the star is lost and will not return (such as when the telescope is bumped), abort autoguiding and start over.

If the CCD camera has a shutter, it will be closed when an image is being downloaded from the camera. Autoguiding is suspended while the shutter is closed, and will resume after the download is complete. If your polar alignment is good, the guide star will still be visible, and autoguiding will resume. You can enter a delay value in your exposures to allow for any corrections that happen right after the guide star is reacquired.

Recalibration

When should you recalibrate? The simplest way to tell is to start an autoguiding session and observe what happens. Since you can autoguide without taking an image, you can start autoguiding when the telescope moves to a new position. Observe what happens to the X error and Y error numbers. If the both stay within +/- 1.0 pixel, you will likely have good results. If both stay within +/- 0.5 pixel, then the seeing is very good, and you should get excellent results. If one or both shows values greater than +/- 1.0, either the seeing is poor, or you need to recalibrate for the new position. The need to recalibrate varies greatly from mount to mount, and only experience will show you what works best for your particular mount.

Sometimes, autoguiding will not work as expected. Common problems, and possible solutions, include:

Autoguiding Problem	Suggested Solution
No corrections occur, and the X and/or Y Error numbers continue to increase	Most likely, guiding corrections are not getting to the mount. Check the Advanced Settings dialog box, and make sure that corrections are enabled for the appropriate axes. Verify that the autoguide cable is connected at both ends. Verify that the guide speed is set to an appropriate value (usually 0.5X sidereal). You can test connections by setting a slewing speed instead of a guide speed, and observe if the mount moves when you press the N/S/E/W buttons in the Autoguide tab.
Corrections tend to oscillate between positive and negative values (for example, +1.3 and -0.9)	If the load on your mount is too carefully balanced, the mount will be unusually sensitive to guide corrections, and may overshoot. You want a slight but definite excess of weight on the east side. This keeps the gears meshed, and reduces the tendency of the mount to over-react to corrections. Oscillations can also occur when working near the zenith. You can also simply reduce the aggressiveness setting to see if that will eliminate the oscillation. Sometimes the mount will simply have a resonant period similar to the exposure duration and certain correction speeds; try a shorter or longer guide exposure length to see if it will eliminate the oscillation.
The mount suddenly makes large movements, and then comes back to zero.	A “large movement” is any sudden movement of two pixels or more. This usually results from irregularities in the mount's bearings or gears, and may limit the success you will be able to achieve with autoguiding. Shorter exposures can help by allowing you to complete an image before you hit one of the large movements. Contact your manufacturer to see if you might need to replace a worn or damaged part. Dirt or grit in the gears can also cause this problem. Another possibility: wind. If it's very windy, you may not be able to guide or track successfully, as the mount will bounce around. The larger and/or longer your telescope, the more likely it is to catch wind and cause deflections that will show up as guiding errors. In some cases, if the movements are not extreme, you may be able to guide successfully by shortening the guide exposure so that CCDSoft can detect these movements sooner and correct for them more often. Guide exposures of 1-3 seconds can give you better results on less-expensive mounts, but not all objects will have a

	sufficiently bright guide star for you to try this option.
The guide star suddenly disappears	The most common cause for this is simply clouds. Guide exposures are short enough that many stars will simply disappear if even a thin cloud moves through that part of the sky. If your mount is well aligned to the pole, and tracks accurately, you can sometimes simply wait out the cloud and guiding will resume when it passes. Any exposure you were taking during the time the cloud was in the way may or may not be salvageable. The guide star can also disappear if the mount is disturbed, in which case you probably have also lost your polar alignment. You might have touched your mount accidentally, but even a stray cat rubbing against a tripod leg has been known to cause trouble!
Corrections occur, but the X and Y errors are large and random	This could be a sign of over correction. The first thing to try is a lower aggressiveness setting. Try lowering the aggressiveness one unit at a time and see if you get any improvement. Stop lowering the aggressiveness when you get into the range of +/- 1.0 pixels (average seeing) to +/- 0.5 pixel (good seeing). Problems with your mount's bearings or gears are another potential source of trouble; consider tuning your mount if you get wild changes in the X and Y errors. For any given mount, there is a limit to how accurately it will track and autoguide; if tuning and/or service won't improve your results, you may need to upgrade your mount to work at a given focal length.
The guide star keeps trying to move in a specific direction.	If the move is always in declination, this is most likely the result of a polar misalignment that is fairly large (more than 0.5 degree). If the autoguider is able to handle the movement in declination and keep it within a trouble-free range, the only concern is field rotation for long (one hour or more) images or sequences of images. If the autoguider fails to make the corrections and keep the error in a reasonable range, you can usually solve this problem by refining your polar alignment. See the section “Camera-Assisted Drift Alignment,” later in this chapter.
The guide star wanders slowly back and forth.	Typically, this happens in right ascension, and you are seeing the periodic error of your mount. If your camera is oriented with north up, this will be a side-to-side motion in the guide window. If the camera is turned 90 degrees (east or west up), then the motion will be up and down. Periodic error usually results in slow, steady changes that go back and forth, so it is relatively easy for the autoguider to compensate. If your mount has the ability to record periodic error and then compensate for it (usually called PEC, for Periodic Error Correction), you can use it or not, as you wish. It will not harm the performance of the autoguider if PEC and the autoguider are operating at the same time. However, the autoguider is completely able to compensate for periodic error on its own, and you do not need to engage your PEC feature to get accurate guiding. You can also use the autoguider to feed corrections to your mount when recording periodic error.

Assessing Autoguiding Possibilities

Once you have mastered enough CCD imaging skills to take focused images, the next step is to lengthen your exposures so you can take deeper, more detailed, and clean images of your favorite celestial objects. The accuracy of your mount determines how deep you can go. The more accurate your mount, the easier it will be to take long exposures.

Some mount manufacturers specify the accuracy of their mounts. This accuracy is expressed in arcseconds. An exceptional mount can guide with accuracy of 2-3 arcseconds or less. A very good mount can guide to about 5-6 arcseconds. The average low-cost mount guides to within 15-20 arcseconds. Mounts with even less accuracy are less suitable for CCD imaging unless the focal length of the telescope or lens is exceptionally short.

Whatever the accuracy of your mount, the key to success is matching the focal length of your telescope or camera lens to the abilities of the mount. For example, consider a CCD detector with pixels that are 9 microns square, such as the ST-7E. The angle on the sky covered by each pixel varies with the focal length of your telescope:

ST-7E (9-micron pixels)	
Focal Length of the Telescope (mm)	Angle of Sky (arcseconds)
300	6.2
500	3.7
700	2.6
900	2.1
1100	1.7

For example, imaging with a 300mm camera lens, at least 6 arcseconds of error are tolerable because a single pixel covers just over 6 arcseconds. Imaging with a refractor that has 1100mm focal length, a single pixel covers only 1.7 arcseconds, and the need for tracking accuracy is almost four times higher.

In actual practice, star images cover more than one pixel due to atmospheric scattering, the same process that causes stars to twinkle, so you would have more leeway than shown here. The important concept is that the shorter your focal length, the less the need for tracking accuracy in your mount.

A short focal length alone won't necessarily solve the problem, however. Smaller or larger pixels on your CCD detector alter the numbers. As shown in the following table, large pixels cover more sky for a given focal length, and smaller pixels cover less sky:

ST-9E (20-micron pixels)		**ST-237 (6.8-micron pixels)**	
Focal Length of Telescope (mm)	Angle of Sky, (arcseconds)	Focal Length of Telescope (mm)	Angle of Sky, (arcseconds)
800	5.1	300	4.7
1000	4.1	500	2.8
1200	3.4	700	2.0
1500	2.7	900	1.5
2000	2.0	1100	1.3

For best results, match the focal length of your telescope to both your CCD camera and your mount. Most CCD imagers aim for a camera/telescope combination that yields from 1.5 to 4 arcseconds per pixel. Your choice of mount should match the capabilities of whatever combination you select. You can calculate the arcseconds per pixel of your camera/telescope combination using the following formula:

(<pixel size in microns> / <focal length in mm>) * 206

Experience shows that, to get good results, your mount error should be no more than +/- 2 pixels. For high-quality images, one and a half times the arcseconds per pixel value is a safer limit. Very high precision results demand a value of a single pixel. For very long focal lengths (2500mm and up), local seeing and other conditions becomes more important and the calculations are not so straightforward; experience of local conditions is needed to assess the requirements for the mount.

In general, then, for high-quality images, a mount should be able to guide to within 2.25 and 6 arcseconds, depending on the pixel size of the CCD camera in relation to the focal length of the telescope.



If your mount isn't providing the pointing accuracy needed by your telescope, you can either use a focal reducer to shorten the focal length of your telescope, or take steps to increase the pointing accuracy of your mount, or both.

If you already own a mount, and want to assess its approximate pointing accuracy, you can follow this procedure.

Adjusting and Tuning Your Mount

Mounts come in a variety of designs. Most mounts intended for use with film and CCD cameras involve a worm and worm gear, as shown in figure 9. There is normally one pair for right ascension, and another pair for declination, but some mounts are only driven in right ascension.

A motor drives the worm gear, and there will usually be gears between the motor and the worm to reduce the speed of rotation at the worm. The worm in turn drives the worm gear, which is attached to the shaft. The right ascension shaft turns at sidereal rate, which is the rate stars appear to move across the sky (approximately one revolution per day). The motor speed and gear ratios are set to track accurately at the sidereal rate. Some mounts provide a way to adjust the tracking rate for the highest possible accuracy, but most do not.

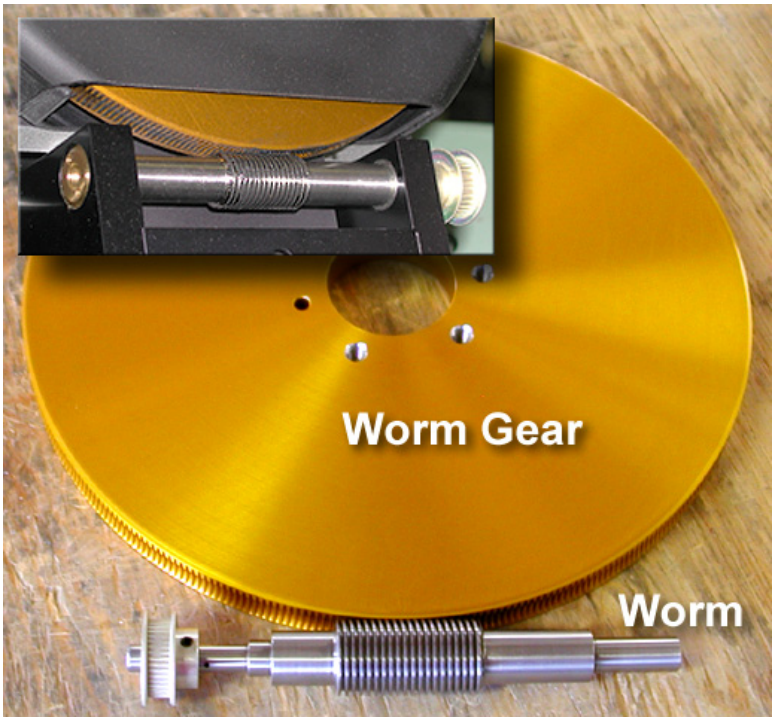


Figure 9: A worm and worm gear

To track and autoguide accurately, a worm-driven mount must often be adjusted or tuned in several ways. Before using a mount for autoguiding, we suggest the following; please consult your mount's documentation or the manufacturer for specific procedures on making these adjustments:

- Verify that the worm and worm gear are properly seated. If the end bearings of the worm are too tight, the worm will bind and could be damaged. If the worm is too loose between its end bearings (end play), reversals of direction will be erratic. Endplay in the worm gear is the usual cause if you observe that the mount initially and briefly moves in the wrong direction when reversing directions.
- Verify that the mesh between worm and worm gear is appropriate. Some mounts are made from harder materials and to closer tolerances, and these will typically require a very tight mesh between the worm and worm gear. Other mounts are made of softer metals, or to looser tolerances, and will require a looser mesh. If the mesh is too tight for the design, the gears will bind and could overheat or be damaged. If the mesh is too loose, there will be excessive backlash. Some mounts have built-in backlash compensation that allows you to keep the gears appropriately loose; CCDSoft provides software backlash compensation that serves the same purpose. During backlash compensation, the motor is run at a higher speed to take up slack in the gears. Too much compensation will result in a jerky movement; too little compensation will result in a delay before a guiding correction is effective. It is always better to have too little rather than too much backlash compensation. If in doubt about how tight to mesh the gears, err on the side of being too loose. See the section “Assessing Mount Accuracy” in this chapter for information on how to measure backlash.
- A slow-turning motor usually has less torque (that is, less force available to move the mount). This means that a slowly turning motor is more likely to stall than one that is turning quickly. If

the worm and worm gear are too tightly meshed, the slowdown to 0.5x sidereal that occurs during autoguiding could cause the mount to stall, or move at the wrong speed.

- Cold conditions can cause some lubricants to become stiff, and this can alter the behavior of your mount. If you need to operate your mount in very cold conditions, or if you observe increased stiffness in cold weather, check with the manufacturer to find out whether you will need to use different lubrication for cold conditions.
- Some mounts, after tuning and adjustment, will have a large enough residual error that it will limit the focal length telescope you can use successfully. The larger the error (from periodic and non-periodic sources), the shorter the focal length of the telescope you can use for imaging. The actual limit depends on the weight of your telescope and its overall physical length as well as its focal length. Long, heavy telescopes require more careful balancing and tuning for successful guiding. Focal reducers are available to help with this situation. Otherwise, you will need to use a telescope with a shorter focal length.
- Test the balance of your mount in various positions. Off-center equipment, such as a finder offset from the centerline of your telescope, or a camera attached piggyback fashion onto your telescope, can dynamically alter the balance of your mount as you point at different areas of the sky. A mount should always be loaded so that there is slightly more weight on the east side of the mount. This keeps the right ascension axis loaded at all times, eliminating backlash as a factor in right ascension autoguiding (as long as the correction speed is less than sidereal rate). If off-center equipment does cause the balance to change at different pointing angles, you can either rearrange equipment and/or counterweights after pointing to a new area of the sky, or you can incorporate sliding weights or some other weight-shifting system into the design of your setup. An out of balance mount can oscillate or wander unpredictably, or require a new calibration when pointing to different parts of the sky even if the declination remains similar.
- You can calibrate your setup at a higher correction speed than you use when autoguiding. This tends to mask some errors, but it isn't a cure-all. It slows down the correction process, and if your mount tends to be over-responsive, it can eliminate unnecessary corrections and provide smoother autoguiding.

More than any other single factor, the ability of your mount to track accurately and to respond quickly and smoothly to guiding corrections determines the success of your imaging. It is well worth measuring the accuracy of your mount, and tuning and adjusting it to improve that accuracy to the greatest degree possible.

Polar Alignment

In order to track accurately, your mount needs to be aligned close to the celestial pole. Many mounts include a polar telescope (also called a bore telescope or bore sight) to help you polar align. There are many different kinds of polar telescopes, but most contain some kind of reticle that allow you to point the mount at specific stars to achieve alignment. Most mounts also contain provisions for aligning in either the northern or southern hemispheres.

Although you do not need perfect polar alignment for autoguiding, there are some issues to be aware of with respect to polar alignment. If you are taking single images of less than five minutes, even a rough polar alignment will be satisfactory if you are using autoguiding. The lack of a perfect alignment will cause the field of view to drift and rotate slowly during the exposure, but the autoguider will detect the drift and correct for it. The field will rotate a small amount during the exposure, but if the exposure is short enough rotation will be a problem.

Autoguiding can correct for small misalignments to the celestial pole. If the misalignment is too large, however, the autoguider will have to make large, frequent corrections and the likelihood of error increases. The larger the misalignment, the shorter your guide exposures must be in order to make corrections before they become too significant.

If your exposures are longer than five minutes, rotation of the field over time becomes a more important issue. If you are combining short-duration images for better signal-to-noise ratio or for color, CCDSoft's Rotate Folder of Images command can rotate a series of images so you can combine them.

Very short focal lengths are more sensitive to field rotation because the image covers a larger area of the sky. You can minimize field rotation by taking the time to polar align your mount very carefully. Use the polar telescope for rough alignment, and then use drift alignment to refine alignment. You can do drift alignment manually, or you can use the CCD camera to assist. You can also use TPoint, a Software Bisque software tool that increases telescope-pointing accuracy, to achieve extremely accurate polar alignment.

Manual Drift Alignment

1. Level the base of the mount if possible. A level mount is not required, but it makes adjust easier by reducing interplay between altitude and azimuth adjustments.
2. Locate a bright star near the celestial equator and near the meridian (the midpoint between east and west). Center the star in the crosshairs of an illuminated reticle eyepiece.
3. Observe the star until it drifts north or south; ignore drift to the east or west. If the star drifts north, adjust azimuth so the mount points more to the east. If the star drifts south, adjust azimuth so the mount points more to the west. Repeat until north/south drift becomes negligible over a 5-minute observing period.
4. Locate a bright star near the celestial equator and near either the east or west horizon. Center it in the crosshairs of an illuminated reticle eyepiece.
5. Observe the star until it drifts north or south; ignore drift to the east or west.
   If you are looking **east:**
   - If and the star drifts north, adjust altitude downward.
   - If the star drifts south, adjust altitude upward.

   If you are looking **west:**
   - If and the star drifts north, adjust altitude upward.
   - If the star drifts south, adjust altitude downward.

   Repeat until north/south drift becomes negligible over a 5-minute observing period.



To determine which way is north in the eyepiece, move the telescope toward the south and note the direction the stars move; they are moving toward the north.

Camera-Assisted Drift Alignment

1. Calibrate your autoguider as described earlier in this chapter.
2. See if the camera is currently orthogonal (square) to the mount. If you have performed a calibration, you can use CCDSoft to tell you how close the camera is to orthogonal. On the **Autoguide** tab of the Camera Control Panel, click **Settings**. This opens the **Autoguide Settings** dialog box. Click the **Drive Calibration Results** tab. This displays a graph showing how the camera is oriented with respect to the right ascension and declination axes of the mount. Ideally, the X- and Y-axis of the camera will line up closely with the X- and Y-axis of the

mount (see figure 10). The +X angle should close to zero, and the +Y axis should be close to 90. If your camera is rotated with respect to the mount axes (see figure 11), you will not get accurate readings for camera-assisted drift alignment.

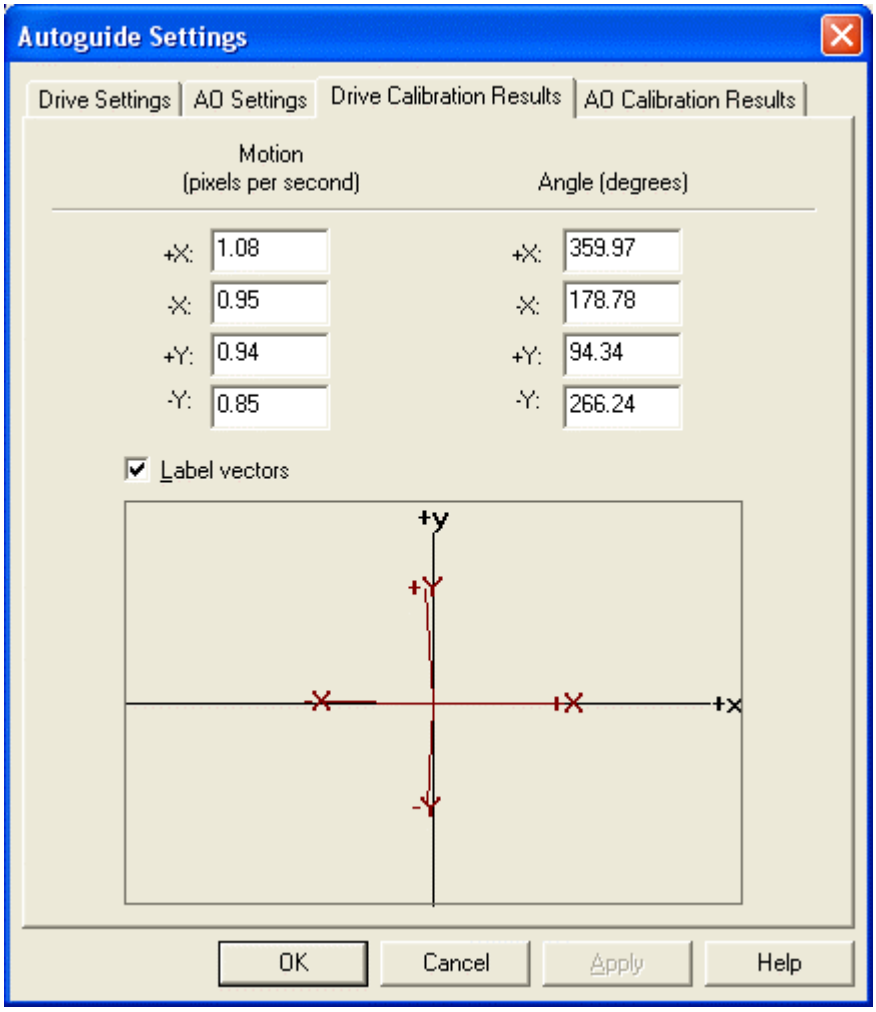


Figure 10: Calibration results that show the camera is ready to assist with drift alignment.

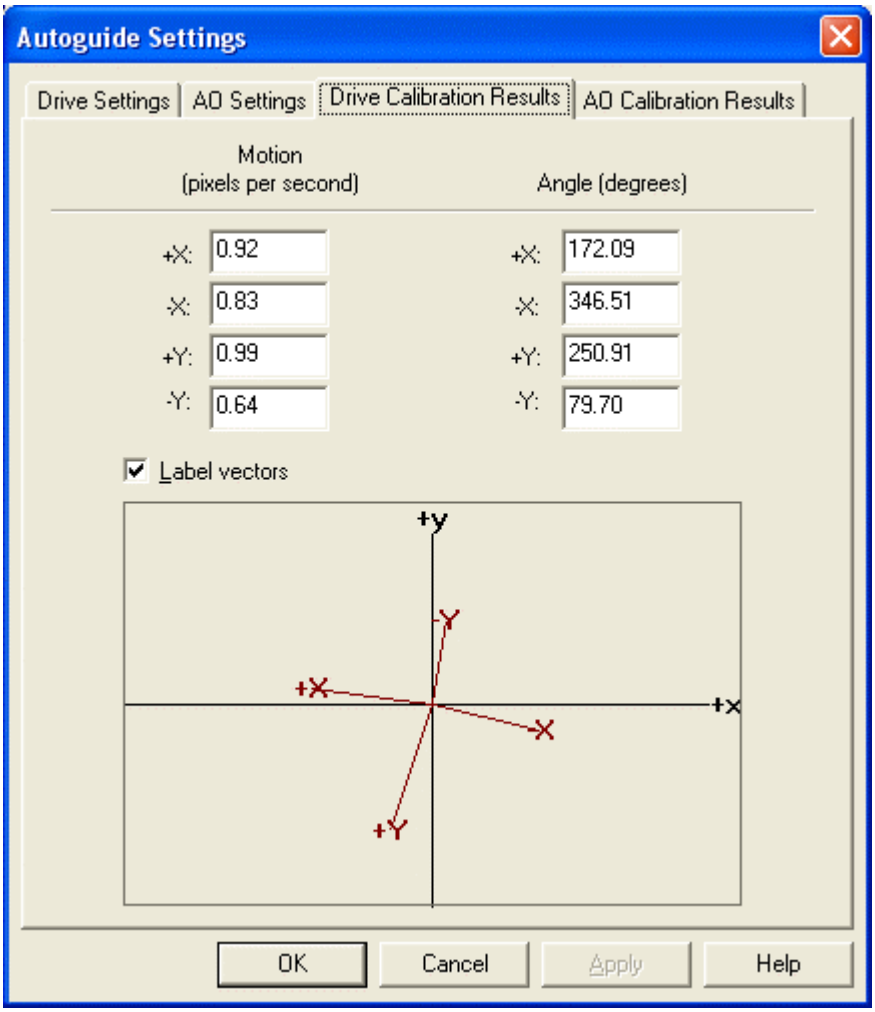


Figure 11: The camera axes are not square to the mount axes, and the X and Y values of the mount and camera are opposite. The camera is not well situated for assisting with drift alignment.

3. If the camera isn't square with the mount, adjust the camera so that the top of the CCD detector points toward north. For the greatest accuracy, repeat calibration to verify alignment of the camera. Repeat until you've got everything lined up to your satisfaction.
4. Using the **Autoguide** tab, set an appropriate exposure time (for example, 5-10 seconds), and then click **Take Image**. Check your results, and adjust the exposure time as needed. Click on a suitable guide star.
5. Click **Settings** and then select the **Drive Settings** tab. If the advanced settings are not visible in the **Drive Settings** tab, click **Advanced**. Click the checkbox **Log autoguiding data to the file autoguider.log**. This allows you to examine your data later if you have any questions about the progress you are making toward polar alignment. The log file is named `autoguider.log`, and can be found in the CCDSoft installation folder. See the next section, “Autoguider Log,” for a list of the fields contained in the `autoguider.log` file.

6. To measure drift, you need to turn off corrections. From the **Drive Settings** tab, uncheck the **Yes** checkboxes for enabling the X-and Y-axis. Note: Remember to re-enable corrections when you are done.
7. Click **OK** to close the Autoguide Settings dialog box.
8. Click **Autoguide** on the **Autoguide** tab. You can now observe the Y (declination) error to measure drift very accurately and very quickly. You can examine the log file at any time to determine the total amount of drift versus elapsed time. Positive Y error values are northward drift; negative Y error values indicate a drift to the south.
9. Once you have a measurement of the current amount of drift north (+Y) or south (-Y), adjust the mount as for manual drift alignment and repeat the autoguiding process,
10. For optimal results, continue drift aligning until you can autoguide for several minutes with a Y error no larger than +/- 1.0. For critical applications, continue until you can autoguide for five minutes with a Y error no larger than +/- 0.5.

Autoguider Log

You can turn on logging of autoguider operation using the **Settings** button on the **Autoguider** tab of the Camera Control Panel. Click on the checkbox at the bottom of the **Drive Settings** tab, **Log autoguiding data to the file 'autoguider.log'**. New autoguiding data is always appended to any existing data. To clear the log file, click the **Delete 'Autoguider.log'** button.

A sample `autoguider.log` file is shown below. The lines are wrapped because the data content is too long to fit on a single line here. In the file itself, each line of data is a single line.

```
CCDSoft Tracking Report
Camera: SBIG ST-237
X Axis: Enabled:
Y Axis: Enabled:
ExposureTime = 0
Aggressiveness Factor = 10

Calibration Determined Velocity Vectors (pixels/sec)
 XPlus  Speed=  1.00000 (XPlus  X=   1.00000, XPlus  Y=   0.00000) Angle=    0.00000
 XMinus Speed=  1.00000 (XMinus X=  -1.00000, XMinus Y=   0.00000) Angle=  180.00000
 YPlus  Speed=  1.00000 (YPlus  X=   0.00000, YPlus  Y=   1.00000) Angle=   90.00000
 YMinus Speed=  1.00000 (YMinus X=   0.00000, YMinus Y=  -1.00000) Angle=  270.00000

|Elapsed Secs|RefCentroidX|RefCentroidY|CurCentroidX|CurCentroidY|GuideErrX   |GuideErrY
|TotGuideErr |XPlusRelay  |XMinusRelay |YPlusRelay  |YMinusRelay |
|      0.0000|     16.0000|     16.0000|     20.0000|     24.0000|      4.0000|      8.0000|
8.9443|           0|         400|           0|         800|
|     12.9490|     16.0000|     16.0000|     16.0000|     16.0000|      0.0000|      0.0000|
0.0000|           0|           0|           0|           0|
|     14.3410|     16.0000|     16.0000|     16.0000|     16.0000|      0.0000|      0.0000|
0.0000|           0|           0|           0|           0|
```

The top portion of the file record the camera used, as well as which axes are enabled. The exposure time and the aggressiveness setting are also recorded.

The next section lists the calibration details. This is a text version of the information you see in the Calibration Results dialog box (see figure 10).

The bottom section contains a record of all guiding corrections. The example above shows only a few lines. You could have hundreds of correction entries for a long exposure. The following data is included for each correction; for X/Y coordinates, the origin is the upper left corner of the detector:

Heading	Description
Elapsed Secs	Total number of seconds that have elapsed since the start of the current autoguiding session.
RefCentroidX	The X coordinate of the starting position of the guide star centroid. Usually 16, but can be modified by scripting.
RefCentroidY	The Y coordinate of the starting position of the guide star centroid. Usually 16, but can be modified by scripting.
CurCentroidX	The current X coordinate of the guide star, in pixels.
CurCentroidY	The current YX coordinate of the guide star, in pixels.
GuideErrX	The number of pixels the guide star has moved from the starting position along the X-axis. Equal to $(CurCentroidX - RefCentroidX)$
GuideErrY	The number of pixels the guide star has moved from the starting position along the Y-axis. Equal to $(CurCentroidY - RefCentroidY)$
TotGuideErr	The total current guide error in pixels, measured in a straight line from the origin. Equal to $\sqrt{(GuideErrX^2 + GuideErrY^2)}$
XplusRelay	Time in milliseconds that the X-plus relay was on to make the correction.
XminusRelay	Time in milliseconds that the X-minus relay was on to make the correction.
YplusRelay	Time in milliseconds that the Y-plus relay was on to make the correction.
YminusRelay	Time in milliseconds that the Y-minus relay was on to make the correction.

Examining Data from an Autoguiding Run in a Spreadsheet

If you turned on logging of autoguiding information, you can open the log file in a spreadsheet program to visualize the guiding performance.



If you turn off corrections during autoguiding, the log file will contain a record of the periodic error of your mount. Let autoguiding proceed for one full revolution of the right ascension worm. This is usually in the range of four to seven minutes. Consult your mount documentation if you aren't sure, or contact the mount manufacturer. To turn off corrections, click **Settings** on the **Autoguide** tab. If the advanced settings are not visible in the **Drive Settings** tab, click **Advanced**. Uncheck the **Yes** checkboxes for enabling the X- and Y-axis. (Refer to figure 7.)

To examine the autoguiding data, open the file `autoguider.log` in a spreadsheet, such as Microsoft© Excel™. In Excel, click **File | Open** to open the file. Excel automatically shows the Text Import Wizard, a three-step process for importing data.

1. In step 1 of the wizard (see figure 12), select Delimited as the Original data type. Start import at row 14, and use Windows (ANSI) as the File origin setting. The data appears in preview form at the bottom of the import wizard. Click **Next**.

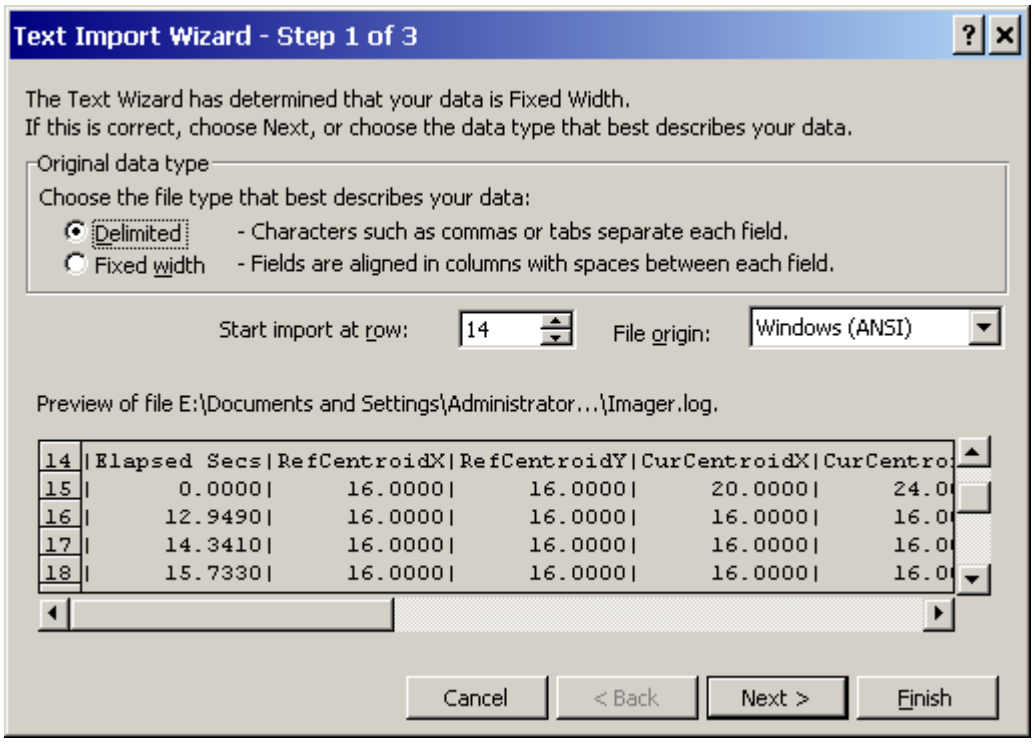


Figure 12: Step 1 of the Text Import Wizard.

2. In step 2 of the wizard, choose **Other** as the delimiter type, and enter the vertical bar character as the delimiter (|), and set the Text qualifier as {none}, as shown in figure 13. The data columns reformat when you choose the correct delimiter character, showing solid black dividers between the columns of data instead of the vertical bar character. Click **Next**.

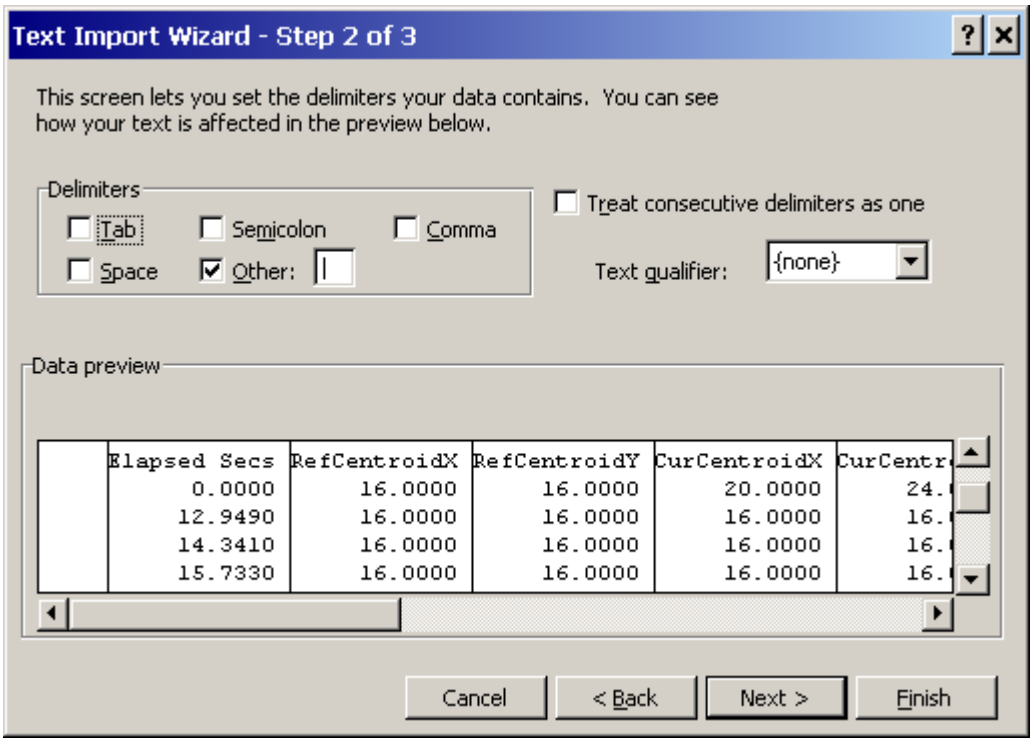


Figure 13: Step 2 of the Text Import Wizard.

3. Step 3 of the wizard allows you to set a data format for each column. This is not necessary for the log data, so click **Finish**, and the data appears in as a spreadsheet.

To visualize the data, you can create a chart that graphs the X and Y errors. The columns you pick for graphing will depend on what you want to know. To visualize your mount's periodic error, for example, select the GuideErrX column (guiding error in right ascension). To compare the guiding errors for both X and Y directions during a typical guiding session (with corrections turned on), select both the GuideErrX and GuideErrY columns. To evaluate the actual guide error distance from the centroid of the originally selected guide star, choose the TotGuideErr column. Figure 14 shows a graph of the X and Y errors with corrections turned off.

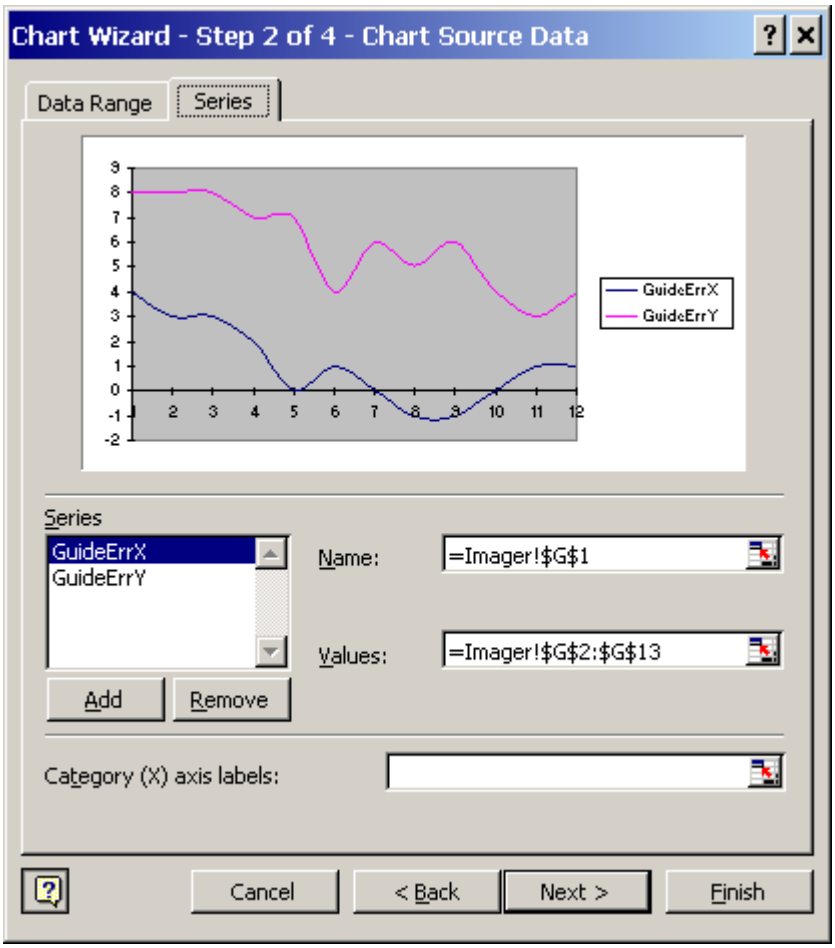


Figure 14: Graphing X and Y errors using data from the autoguider.log file.

Chapter 5: Guiding with the AO-7

There are three types of guiding available to CCDSoft users:

- Autoguiding with a separate camera (in a guidescope or using an off-axis splitter)
- Self-guiding with a guide chip built into the camera (for example, SBIG ST-7/8/9/10)
- Autoguiding with adaptive optics (for example, the SBIG AO-7)

The first two methods work similarly: the guide corrections are calculated and CCDSoft makes corrections by moving the mount. This section assumes you are familiar with conventional (mount-based) guiding, and that you understand the concepts covered in “Chapter 4: Autoguiding.”

With the AO-7, an internal mirror tilts rapidly to make the guide corrections.



Guide corrections to the mount (via camera relays) can still occur when using the AO-7. The mirror tilt of the AO-7 has a limited range. By default, if the mirror reaches 50% of maximum tilt in any direction, CCDSoft will “bump” the mount using the camera relays to bring mirror tilt back within range. Typically, polar misalignment causes drift that requires periodic mount movements.



Since guiding with the AO-7 still involves use of the camera relays to move the mount when necessary, you should always confirm that you are able to successfully autoguide using the camera relays alone. Verify that the mount moves via the camera relays, and that guiding is accurate and satisfactory. Otherwise, when the AO-7 “bumps” the mount, you may loose your guide star and not get the result you want.

Quick Start

If you are already familiar with CCDSoft and the AO-7, follow these steps to start guiding with the AO-7. This section assumes that you are familiar with conventional guiding and with “Chapter 4: Autoguiding.” For more details, please read the following section “Autoguiding with the AO-7.” The AO-7 must be connected to the camera and all cabling in place between the computer, camera, and AO-7 before you start.

Camera Control Panel, Setup tab

1. Click **Camera | Setup** and then choose **SBIG with AO…** as your imager camera. The correct autoguider selection will be made for you automatically when you choose your imager (“Imager’s built-in Autoguider”).

Camera Control Panel, Autoguide tab

2. Perform a drive calibration with the autoguider as you normally would when autoguiding without the AO. You do not have to uncheck **AO Enabled**. To access drive calibration, click the **Calibrate** button on the Camera Control panel, then click the **Calibrate drive** radio button.



Even if you calibrated your drive with your CCD camera or autoguider without the AO-7, you must recalibrate. The existing settings are no longer valid once you connect the AO-7.

3. Click the **AO Settings** tab. Click the **Use Defaults** button to set the default values for the parameters. For fine-tuning the device, see the section “AO-7 Settings” below. Click **OK**.
4. Click **Take Image** to get an image using the guide chip. Adjust telescope pointing and exposure time until you have a suitable star for calibration. A good calibration star must be the brightest star in the field of view, and there must not be similar bright stars nearby that will move into the field of view during calibration. You can use TheSky to locate suitable calibration stars.
5. Click **Calibrate…**. Click **Calibrate AO**. Verify that the **AO deflection…** setting is 100%. Click **Calibrate**. The AO-7 will move its mirror, take exposures of the calibration star, and measure the movement in each direction.
6. Click **Take Image** to download an image using the guide chip. Adjust telescope pointing and exposure time until you have a suitable guide star. See “Chapter 4: Autoguiding,” for information about what makes a star suitable for guiding.
7. Click a star in the downloaded image to select it as the guide star, or click the **Auto** button to have CCDSoft select it for you.
8. Click **Autoguide** to start autoguiding. You can monitor progress using the information on the Autoguide tab, including X/Y tilt, wander, etc. See following sections for details.

Autoguiding with the AO-7

Once the AO-7 is installed and connected according to the instructions from SBIG, you must do the following before you can start using the AO-7:

- Make the correct camera choice on the **Setup** tab of the Camera Control Panel.
- Verify that the AO-7 is enabled on the **Autoguide** tab.
- Calibrate the AO-7 ***and*** your mount’s drive.



Even if you calibrated your drive with your CCD camera or autoguider without the AO-7, you must recalibrate. The existing settings are no longer valid once you connect the AO-7..

Figure 1 shows the correct camera choice for using the AO-7: **SBIG with AO (ST-7/7E/8/8E…)**. This setting will work with any of the listed SBIG cameras. If you choose any of the individual cameras instead, the AO-7 will not be active or available.

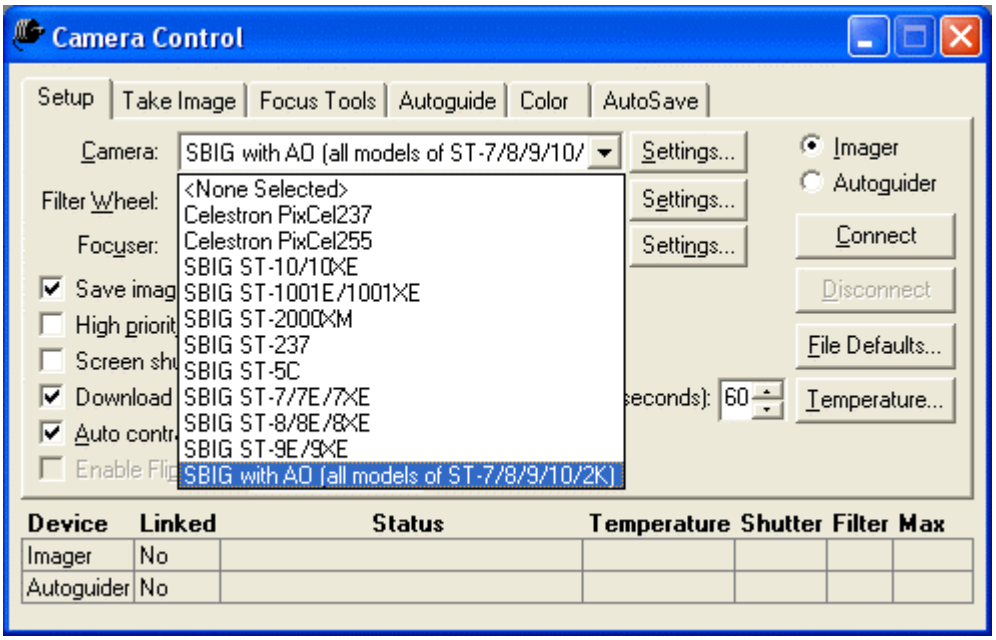


Figure 1: Choosing the camera type for AO operation.

If you have been using another autoguider, take a moment to verify that the Autoguider selection is correct. Click the Autoguider radio button (at top right of the Setup tab). Make sure that **Imager's built-in autoguider** is the selected camera (see figure 2). Click the **Imager** radio button, and then click **Connect**.

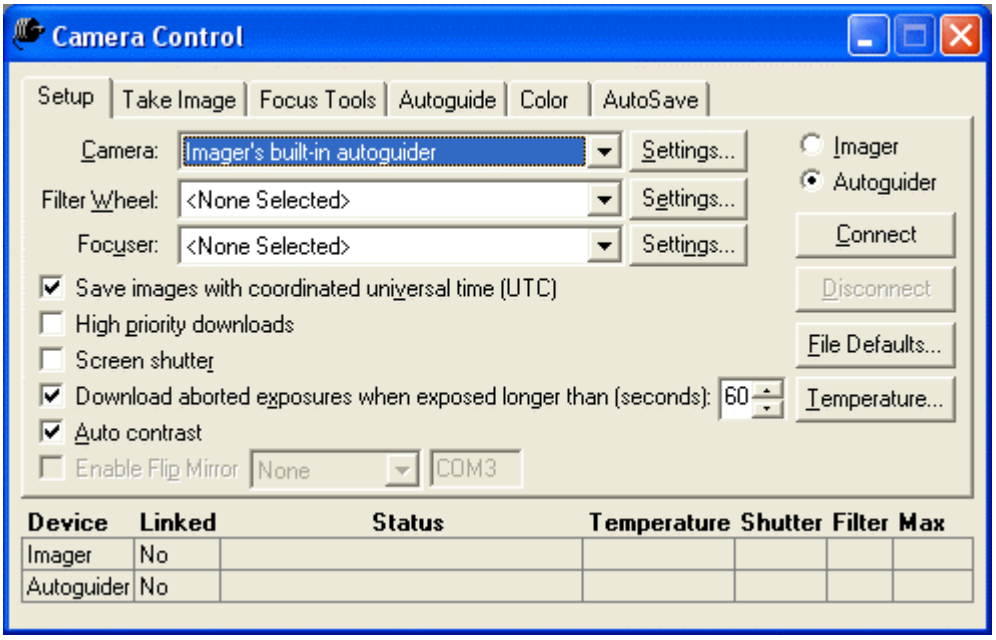


Figure 2: Selecting the Autoguider.

TIP: If you are having trouble seeing the guide star, uncheck **Auto Contrast** when using the AO-7. It is common to use dim guide stars and/or short exposures with the AO-7. If you turn off auto contrast when guiding with the AO-7, bring up the histogram window (`Ctrl+H`) while guiding and manually set the contrast so that you can see the guide star. The guide algorithm doesn't care about the contrast setting – it will pick out the guide star if it is bright enough, even if you can't see it. The best measure of how well the AO-7 is guiding is Wander (see next section for details).

AO-7 Settings

To access CCDSoft's AO-7 features, click the Autoguide tab to make it active (see figure 3).

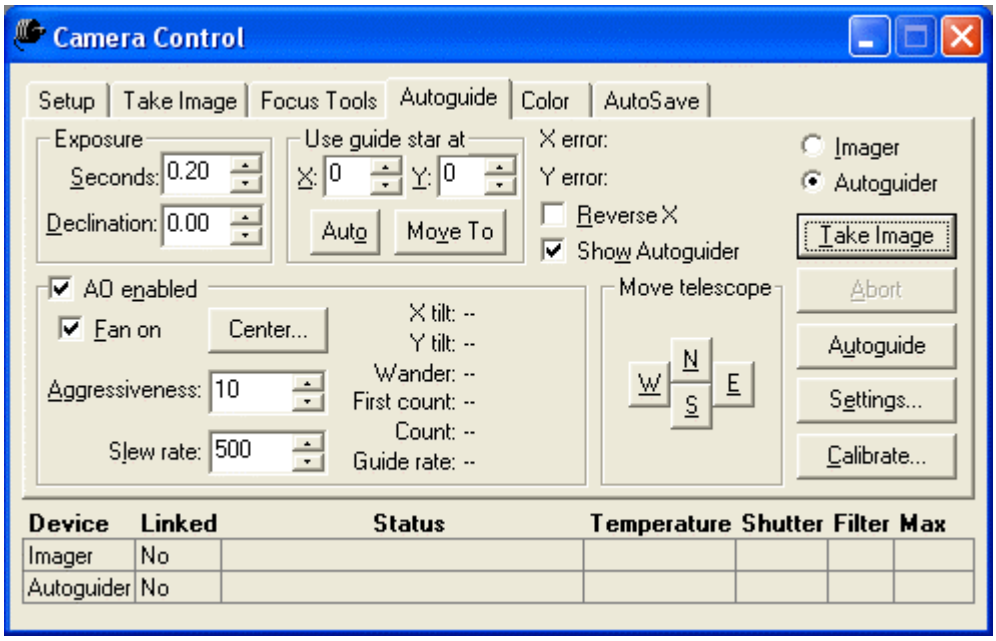


Figure 3: The Autoguide tab.

The most frequently used AO settings are found at the lower left of the Autoguider tab. Check **AO enabled** to turn on the AO-7 for guiding. Unlike most other features of CCD Soft, **AO enabled** (and **Fan on**) are real-time controls. This allows you to turn AO guiding and the camera fan on and off as appropriate. The following list explains all of the features found in this area.
Note: If you have **AO enabled** checked the AO will "do its thing" *and* the relays will kick in as needed. If you do not have **AO enabled** checked, the AO will not perform any corrections *and* no relay adjustments occur. In other words, when **AO enabled** is not checked, no guiding of any kind occurs. If you want to do normal guiding, disconnect and switch to your regular camera setting (for example, a specific SBIG camera by name).

Control	Description
AO enabled	When checked, the AO-7 will operate during autoguiding. This checkbox can be changed during an exposure. Unlike most other CCDSoft controls, this control

	remains active in real time during autoguiding. When not checked, no guiding occurs (no AO-7 mirror tilt; no "bumping" of the mount with the camera relays).
Fan on	When checked, the camera fan operates. Unchecking this box causes the camera fan to stop. The camera fan can cause a small amount of vibration; turning it off may improve your image sharpness at long focal lengths and high magnifications. The fan checkbox can be changed during an exposure. Unlike most other CCDSoft controls, this control remains active in real time during autoguiding. **Note:** Your camera cooler may have to work harder to maintain its temperature if you shut off the fan. Keep an eye on the Temperature block at the bottom of the Camera Control Panel and monitor the percentage of cooling capacity in use. It should stay below 90% for effective cooling.
Center button	Click this button to center the AO-7's mirror. The center position is the 50%/50% position, at the middle of the range of motion for both X- and Y- axes. There is a warning dialog box if you click this button; click **OK** to center the mirror. Why a warning dialog box? Centering will change the field of view, so you should re-take any reference image before proceeding after centering the mirror. Otherwise, a guide star currently in the field of view could move out of the field of view, or be at a slightly different position.
Aggressiveness	This functions like the aggressiveness setting when guiding the mount with camera relays. A value of 10 means that 100% of a correction (mirror tilt) will be made. A value of 5 means that 50% of the indicated correction will be made, and so on.
Slew rate	Controls how the AO reacts to large error corrections. The units are arcseconds/second. If a correction would exceed this value, it is limited to this value. In order for this option to work correctly, you must enter your telescope focal length using the Camera Control Panel's **Setup** tab | **File Defaults**. For example, a slew rate of 250 arcseconds/second at 5 Hz would result in a maximum 2-arcsecond correction.
X tilt	The current tilt of the mirror in the X-axis (left to right with respect to the camera, if the AO-7 is mounted to the camera according to the instructions from SBIG). The mirror tilts in the X-axis from 0% to 100%, with 50% being the middle position. At 50%, the mirror is square (perpendicular) to the incoming light.
Y tilt	The current tilt of the mirror in the Y-axis (top to bottom with respect to the camera, if the AO-7 is mounted to the camera according to the instructions from SBIG). The mirror tilts in the Y-axis from 0% to 100%, with 50% being the middle position. At 50%, the mirror is exactly at 45 degrees to the incoming light.
Wander	The amount of guide star position error left ***after*** the AO makes a correction. In other words, this is the amount of error that the AO couldn't correct for. It will be higher if the seeing is bad, the guide rate is too low, or when the AO is oscillating from over-correction. It is useful to compare the **Wander** value with and without the AO-7 enabled. The **Wander** value without the AO-7 is controlled by the seeing; the **Wander** value with the AO-7 shows the improvement obtained using the AO-7. You can tune the **Slew Rate** and **Aggressiveness** settings to minimize **Wander** with the AO enabled.
First count	The flux (total brightness) of the guide star. All the pixel values in the star above the background are summed to find the star's flux.
Count	The current flux (total brightness) of the guide star. Compare this to the **First Count** value during guiding. If this value changes by a large amount following a download, the current guide star might not be the same as the original. If the value drops slowly over time, focus may be shifting. If the value jumps erratically, seeing may be poor, or clouds may be passing through.

Guide rate	The rate at which the AO-7 is guiding. This will sometimes be slower than the actual exposure time suggests. For example, if you are using an exposure time of 0.25 seconds, you might expect a guide rate of 4Hz (4 times per second). However, the download time, display time, and computer processing time slow this down. A very fast computer could hit a maximum guide rate as high as 60Hz with a sufficiently bright guide star and a small track box. Dimmer stars and slower computers will achieve lower rates. A relatively slow 300MHz laptop was able to achieve a guide rate of 8Hz, for example.

Mount (Drive) Calibration

When guiding with the AO-7, there are actually two types of guiding going on. The AO-7 tips and tilts its mirror to make rapid, precise guide corrections. Over time the guide star may drift and the AO will compensate for this drift as it guides. If the star's drift is large enough, the mirror will have a larger tilt. When the tilt reaches a certain value, CCDSoft will move the mount using the camera relays. This puts the AO mirror closer to the center of its range of motion.

These two types of guiding (mirror tip/tilt and camera relays) are the reason that you must have both the mount's drive and the AO-7 calibrated before you can use the AO-7.
TIP: If you have a Paramount mount and you have the TPoint kernel turned on, CCDSoft will probably never need to bump the relays to keep the AO within its range of motion as the TPoint kernel accounts for nearly all of the stellar drift.

Note: The aggressiveness setting for the mount applies when using the AO-7. A lower mount aggressiveness setting on the **Drive Settings** tab will result in smaller (but more frequent) mount movements. A high aggressiveness setting for the mount will result in larger (and less frequent) mount movements. Too-frequent mount movements can reduce the value of the AO-7. Too-large mount movements can result in elongated stars. Find a mount aggressiveness setting that balances these two extremes.

CCDSoft with AO-7 support has a separate dialog box for Autoguide settings (see figure 4). The entries on the dialog box are similar to previous versions, but the **Simultaneous X- and Y-axis relay activation** setting is new. Some mounts will not guide properly with simultaneous XY corrections; contact your mount manufacturer for guidance if you have problems with simultaneous XY setting checked. The new layout puts tabs at the top of the dialog box for quick navigation to both mount (drive) and AO-7 settings and results.

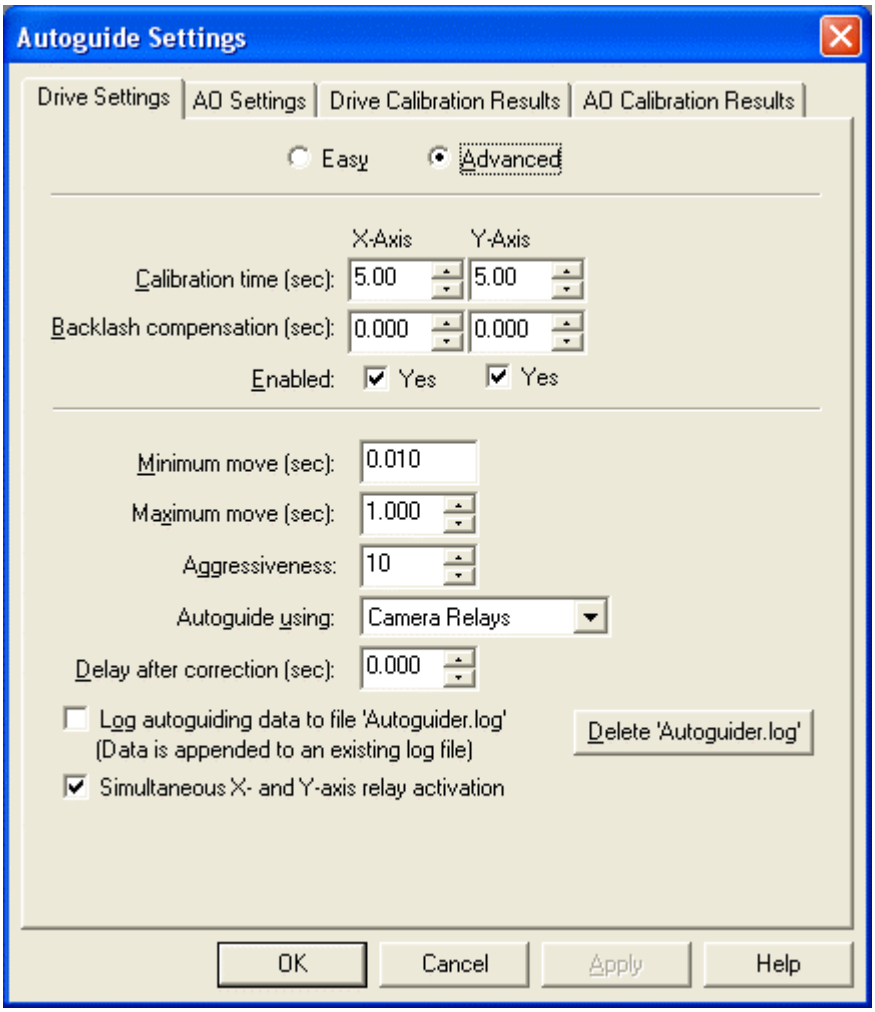


Figure 4: The new Autoguide Setting dialog box, showing the Drive Settings (mount) tab. (See also figure 5.)

For more details on mount calibration for autoguiding, please see section “

Mount (Drive) Calibration" in Chapter 4: Autoguiding.

Additional AO Settings

Figure 3 showed the basic AO settings available on the Autoguide tab. In most cases, you will not need to adjust any other settings to get good results with the AO-7. However, additional AO parameters are available on the Autoguide Settings dialog box's **AO Settings** tab (see figure 5). You can use these settings to refine the accuracy and performance of the AO-7. To access this dialog box, click **Settings** on the Camera Control Panel's **Autoguide** tab (refer to figure 3).

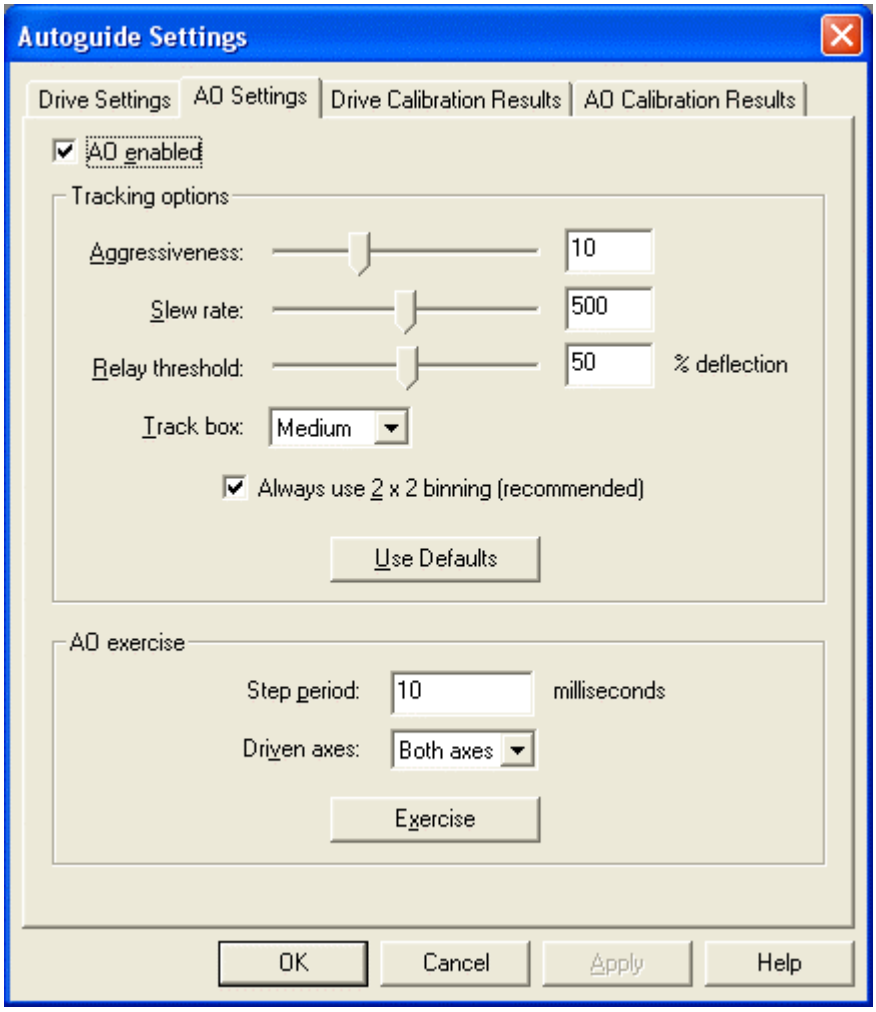


Figure 5: The AO Settings tab on the Autoguide Settings tab.

The **Tracking Options** section of the **AO Settings** tab contains the following settings:

Control	Description

Aggressiveness	This is the same as the aggressiveness setting for the AO-7 on the Autoguide tab.
Slew rate	This is the same as the slew rate setting for the AO-7 on the Autoguide tab.
Relay threshold	The amount of mirror tilt that must occur before the mount is moved with the camera relays. The default value is 50%, and this will work for most situations. If the seeing is very steady, and you would like to see less frequent mount movement, set this to a higher number. Never set the number so high as to cause the mirror to reach the end of its travel; the mirror cannot make corrections beyond 100% movement. Always leave a margin of safety. If seeing is poor, you can increase the safety margin by lowering this value.
Track box	The size of the subframe used for guiding. Available values are small (4x4 pixels), medium (8x8) and large (16x16). A smaller track box allows for faster downloads and thus faster guiding. However, if the track box is too small, seeing-induced movement may cause the star to be lost, resulting in poor guiding. On any given night, the seeing will limit the size of the track box you can use.
Always use 2x2	Binning the guide chip 2x2 increases its sensitivity. For a given star, the guide rate will be slower with 1x1 binning than with 2x2 binning. Since AO corrections are limited by exposure length, the shorter exposures possible with 2x2 binning allow you to use faster guide rates. A faster guide rate means the AO can work more effectively. **Note:** The increased sensitivity for 2x2 binning comes from an increase in signal to noise ratio. Signal increases 4 times (2^2), and noise only increases ~1.4 times (square root of 2). Therefore the best possible signal to noise increase is from x to (4x/1.4) or 2.85x.
Use Defaults	Click this button to restore the default values.

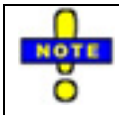
The AO Exercise section allows you to test the movement of the AO-7 mirror. You should remove the AO-7 from the telescope when testing and observe whether the motion actually occurs. The AO-7 will make a high-pitched sound while it is being exercised.

The AO Exercise section contains the following settings:

Step period	How long to move the AO-7 for each step. Default value is 10 milliseconds.
Driven axes	You can test the X- or Y-axis alone, or both axes together.
Exercise	Click this button to begin exercising the AO-7. A dialog box appears during exercising, showing the current X and Y position of the mirror. Click **Cancel** to end the exercise.

When you are finished making changes to the **AO Settings** tab, click **OK** or **Apply** to save them, or **Cancel**.

AO Calibration



Even if you are using the AO-7 for guiding, you must still perform a mount calibration as well. See the section above, “Mount (Drive) Calibration,” for information. The mount calibration must be done prior to guiding with the AO-7. If you fail to calibrate the mount, the AO-7 may be unable to guide accurately, because movement of the mount via camera relays during guiding will be inaccurate.

During drive calibration, CCDSoft takes an image, moves the mount in a given direction, and then takes another image. The difference in position of the calibration star between the two images tells CCDSoft how fast the mount moves in each of the four directions. Once calibrated, CCDSoft can issue guide corrections that are as accurate as the mount will allow. Various factors, such as backlash and rough gear surfaces, can reduce the accuracy of mount-based guiding.

With the AO-7, corrections are made by tipping and tilting a small, lightweight mirror. There are no gears to worry about, and the mass of the mirror is tiny compared to the mass of a mount. In addition to its adaptive optics capabilities, the AO-7 provides very accurate guiding and can compensate, up to a point, for an inaccurate mount. The mount must be accurate enough to move via the camera relays. You can use a larger track box (see preceding section) to compensate for some of the mount's inaccuracies - a larger track box makes it less likely that a mount error will push the star out of the track box.

As with any calibration, the key to success is finding a suitable star for calibration. A good calibration star must be the brightest star in the field of view, and there must not be similar bright stars nearby that will move into the field of view during calibration. You can use TheSky to locate suitable calibration stars. For more information about selecting stars for calibration, please see the section "Choosing a Good Guide Star for Calibration" in "Chapter 4: Autoguiding."

Adjust the telescope position to put the calibration star roughly in the center of the image. This will prevent it from moving out of the field of view during calibration. Then click **Calibration** on the **Autoguider** tab of the Camera Control Panel. This displays the dialog box shown in figure 6.

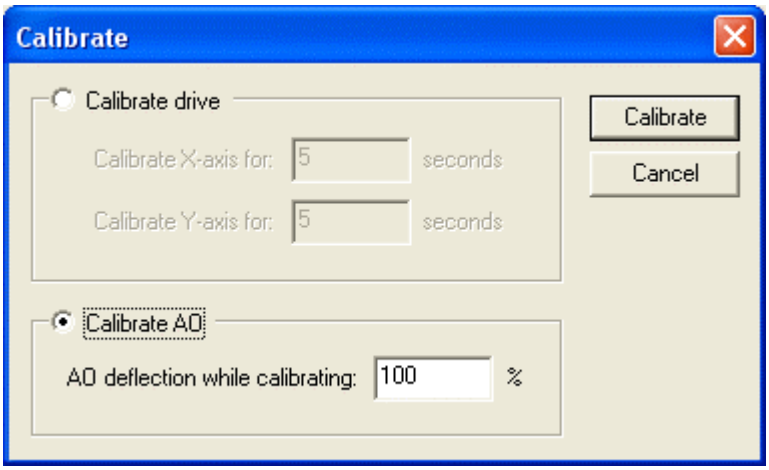


Figure 6: Calibrating the AO-7.

Click the **Calibrate AO** radio button to active it. For most applications, use 100% as the AO deflection while calibrating. You can reduce this number to see if it improves the perpendicularity of calibration. Use the **AO Calibration Results** tab of the **Autoguide Settings** dialog box to evaluate AO calibration (see figure 7).

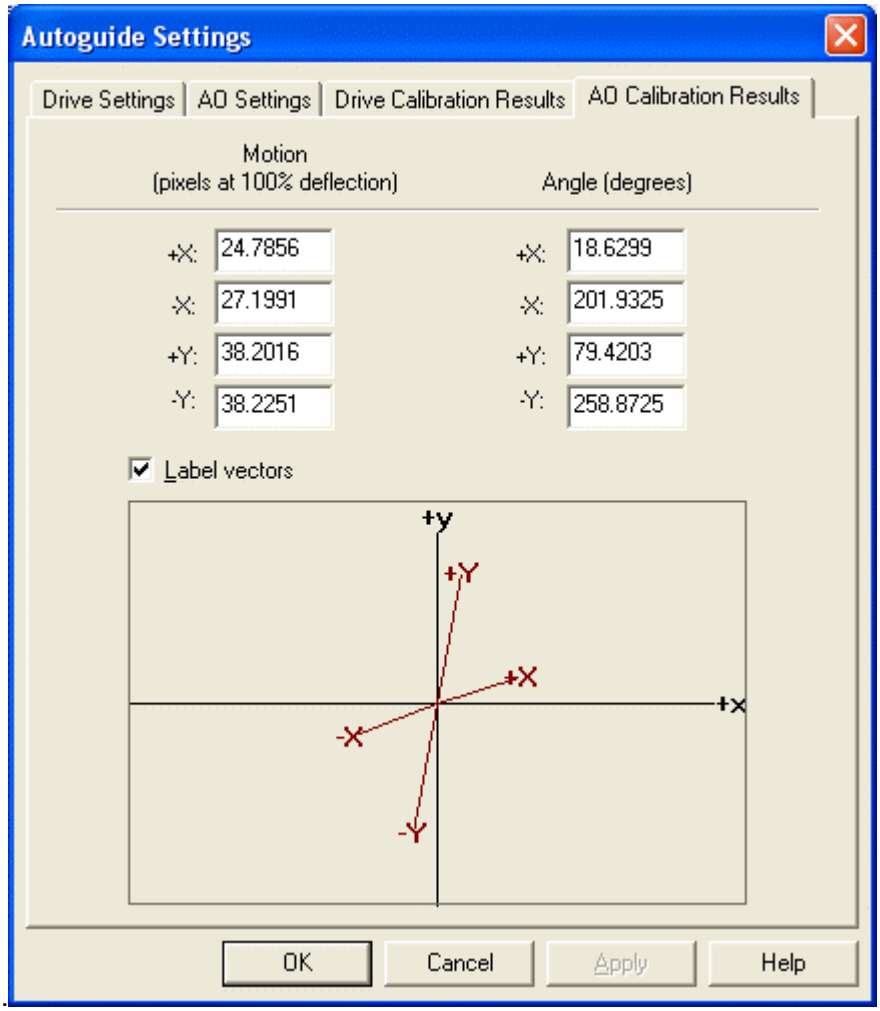


Figure 7: AO Calibration results.

Note that the X/Y axes of the calibration results (red arrows) are not necessarily square to the reference X/Y axes. This is normal. Even if the camera and AO-7 are installed exactly orthogonal to the mount's axes, the vector showing AO movement will typically be non-orthogonal because of how the mirror moves. CCDSoft takes this into account and will guide accurately with the AO-7.

Autoguiding

Once you have calibrated your mount's drive and the AO-7, you can use the AO-7 for guiding. Start by clicking **Camera | Take Image | Take Image**.

As with calibration, the key to success is finding a suitable guide star. The guide star should be away from the edges of the chip, and if you are using color filters it should be bright enough to remain visible through all filters. The brighter the guide star, the faster the guide rate you can use. Since the AO-7

works best with the brightest available guide star, it's usually worthwhile to find the brightest one you can.

You can use TheSky to locate suitable guide stars. You can adjust the framing of your main image, or rotate the camera, to find the best available guide star. For more information about selecting stars for guiding, please see "Select a Guide Star" in "Chapter 4: Autoguiding."

Adjust the telescope position to put the guide star at least 10 pixels away from the edges of the guide window (5 pixels in 2x2 mode). This will make it less likely that the guide star will move off of the guide chip during guiding. You can adjust the guide star's position using the mount's hand paddle; TheSky; or using the **NSEW** buttons on the **Autoguide** tab. The **NSEW** buttons will move the telescope at the current guide rate using the camera relays, and you can use them to make very small adjustments to position.

Before you start autoguiding, you can make final adjustments to guide parameters. Settings for **Aggressiveness** and **Slew rate** can be made right on the **Autoguide** tab. You may also need to adjust the Track box size to adjust for seeing conditions. The better your seeing conditions, the smaller the track box you can use. Figure 8 shows the appearance of the three track box sizes. Note that different zoom levels are used for the track boxes, so the track box stays the same size, but the relative size of the star changes. From left to right, they are Small, Medium, and Large. The Small track box requires very good seeing (steady skies), or the star will move out of the track box. The Medium setting is good for more typical seeing conditions, and the Large track box allows you to use the AO-7 on nights when the seeing is below average.

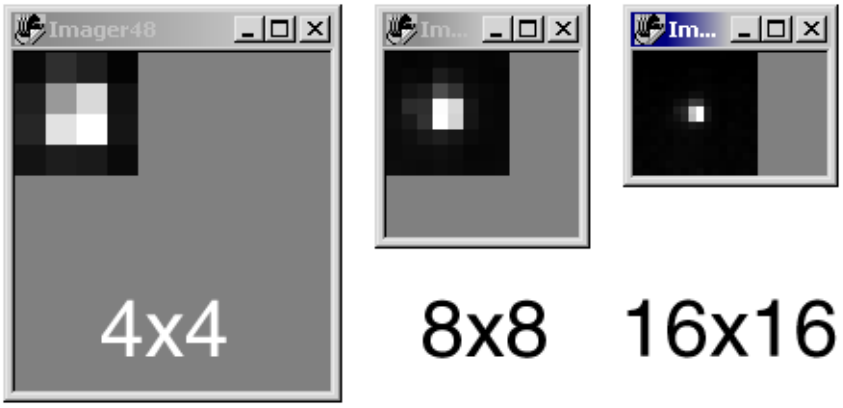


Figure 8: Different sizes of track box. From left: Small, Medium, and Large.

Once the guide star is properly positioned, click **Autoguide** to begin guiding. CCDSoft takes multiple dark frames and averages them to reduce noise in the dark frame. This master dark is subtracted from all light frames to provide as clean an image as possible during guiding. If your exposure time is long (for example, 5 seconds), it will take longer to capture the multiple dark frames before the start of guiding. A 5-second exposure will not give you any benefits of the adaptive optics, but could be used instead of conventional guiding if your mount doesn't handle guide corrections effectively.

During guiding, you can monitor the effectiveness of guiding by watching the values in the **AO Enabled** section of the **Autoguide** tab. **X** and **Y tilt** values show the current tilt of the AO-7 mirror. These values

should change over time as the mirror tilts to accommodate drift. When tilt reaches the maximum value allowed (default is 50%), CCDSoft will bump the mount and the tilt should go down. The amount it will go down depends on the aggressiveness setting of the mount. With low aggressiveness settings on the mount, smaller bumps will occur, and the bumps will therefore be more frequent.
Wander indicates how accurately the AO-7 is guiding. If the AO-7 aggressiveness is too low, wander will be high because the AO-7 will under-correct. If the AO-7 aggressiveness is too high, over-correction may occur and this will also increase the **Wander** value. Adjust **Aggressiveness** and **Slew rate** to obtain the optimal **Wander** value.

Note: Seeing conditions also affect **Wander**. Compare the Wander value with and without AO-7 guiding so that you know the contribution to Wander from seeing.
You can also use **First count** and **Count** to monitor guiding. If the **Count** value drops, you may have clouds moving in or a focus shift. Focus can shift from changes in temperature, or from a physical slippage of the focuser.

The **Guide rate** may be lower than you expect, depending on the processing speed of your computer. For example, if you are using an exposure of 0.02 seconds, you might expect a guide rate of 50Hz (50 exposures per second). However, it takes time to download and display images, and it takes additional time to perform calculations on your computer. This time is added to each exposure, resulting in the actual guide rate. In this example, the guide rate might be anywhere from 6 to 40Hz depending on your equipment.

Autoguiding will automatically suspend during downloads from the main imaging chip. Autoguiding will resume when the download is complete. If you are using a Small or Medium track box, the guide star may have drifted out of the field of view during the download. Cameras with USB download are much faster, and it is more likely that you will retain your guide star using a USB-equipped camera. An extremely accurate polar alignment will also help you retain your guide star following a download.

If the guide star is lost, or if a different guide star is found, you can **Abort** the guiding and restart it with the desired star. Re-center the mirror if tilt is large. Click **Take Image** to get a new image using the guide star, click to select the guide star, and then click **Autoguide** to begin again. If you are taking a sequence of images, you may need to monitor the downloaded images and the guide star window to determine if the guide star is still available.

Note: If stars in the downloaded images have one or more small “ears” or are elongated, this could indicate over-correction. Reduce the aggressiveness setting and try again. A too-high mount aggressiveness setting can also cause this error.

Chapter 6: Taking Color Exposures

Version 5 of CCDSoft marks a major advance in ease of use for taking color images. At the same time, the interface is also powerful and flexible enough for experienced users. You can set up all aspects of your color images in the Camera Control Panel and CCDSoft will do the rest.

CCDSoft allows you to take complete sets of color images (typically luminance, red, green, and blue) automatically. Each filter can be set active or inactive, so it's easy use special-purpose filters, to take partial image sets (such as red/blue Jupiter images), or to fill in missing images in a set.

This chapter describes how to use CCDSoft to take color images using the various SBIG color filter wheels and cameras. You'll learn how to:

- Select the right camera/filter wheel combination.
- How to set up for both LRGB and RGB imaging.
- How to take sequences of color images.
- How to customize the color settings for special situations.

Quick Start for Experienced Users

For this chapter, an experienced user is someone who has taken luminance, red, green, and blue images using a color filter wheel.

CCDSoft puts all of the controls you need for color imaging into a convenient control panel. You can quickly adjust exposure times, binning modes, filters and other settings. You can also control how many images are taken with each filter. For example, you could take three luminance, one red, one green, and two blue images as an image set. You can then set the total number of image sets that CCDSoft will take.
This allows you to use two approaches to taking the component images for a color image set:

- Use the exposure time to balance colors. For example, if you are using an ST-7E camera with a CFW-8 filter wheel, the exposure times would be set using the ratio 1:1:1.6.
- Use the number of exposures to balance colors. For example, if you are using the same camera and filter wheel, you could take two red, two green, and three blue images in each image set. You would then sum the images for each color to achieve color balance before doing a color combine.

To take color images with CCDSoft, open the Camera Control panel's Color tab by clicking **Camera | Color**. If appropriate, start an autoguiding session (see "Chapter 4: Autoguiding") before you start taking color image sets.

1. The Color tab shows the current settings for four filters (default: Luminance, Red, Green, and Blue). To change settings for a filter, click on **Edit**.
2. Determine which filters you will be using, and make sure they are set to **Active**. Make sure filters you are not using are inactive.
3. Set the following properties for each active filter:
   - Exposure (minutes and seconds).
   - Delay between exposures (typically used to allow re-centering of guide star).
   - Bin mode.
   - Filter to use.

- Whether the filter will be active.
- The number of exposures to take with the filter for each image set.

When you have set the appropriate properties for each filter, use the **Series of** drop-down list to pick the number of image sets to take. Click **Take Color** to start taking images.

Principles of Color Imaging

The color filter wheels supplied with SBIG cameras provide four filters; red, green, blue, and clear. For the last several years, the color filters have incorporated infrared blocking (IR blocking) filters as well as the color filters so that a separate IR blocking filter is not needed. All SBIG filters are interference filters, which admit a very precise band of wavelengths of light, and block all unwanted wavelengths.

IR blocking is used for red, green, and blue images to remove infrared light from the color images. Otherwise, the infrared light would contaminate the color images and provide false results. The clear filter does not have IR blocking, since infrared light can help increase the detail in your luminance images. If you have a color filter wheel that does not include IR blocking, you can use a single IR blocking filter on the nosepiece of your camera to achieve the same results. However, in that case infrared light will not pass through the clear filter, and longer clear filter exposure times are necessary. Check your filter documentation for information on exposure times.

To create a color image, you acquire component images in red, green, and blue, and then combine them with CCDSoft. Just as the eye synthesizes color images using red, green, and blue receptors, you can create color images using these same ingredients. The varying proportions of the three colors create all of the other colors in the spectrum. For example, red plus green creates yellow, and blue plus red creates magenta. Mixing various shades creates further in-between colors, such as red and a darker green to create orange. Combining all three colors in equal amounts creates white.
Figure 1 shows the three basic colors and how they combine in equal proportions to form magenta, cyan, yellow, and white. When taking color images with CCDSoft, you take separate images through each filter and then combine them to create the final color image.



Figure 1: Using red, green, and blue to create other colors.

Figure 1B shows an image of the Trifid Nebula broken down into its component color images. From upper left, moving clockwise, the images shown are the red, green, blue, and RGB combined images. Each image was taken separately, and then combined to create the color image.

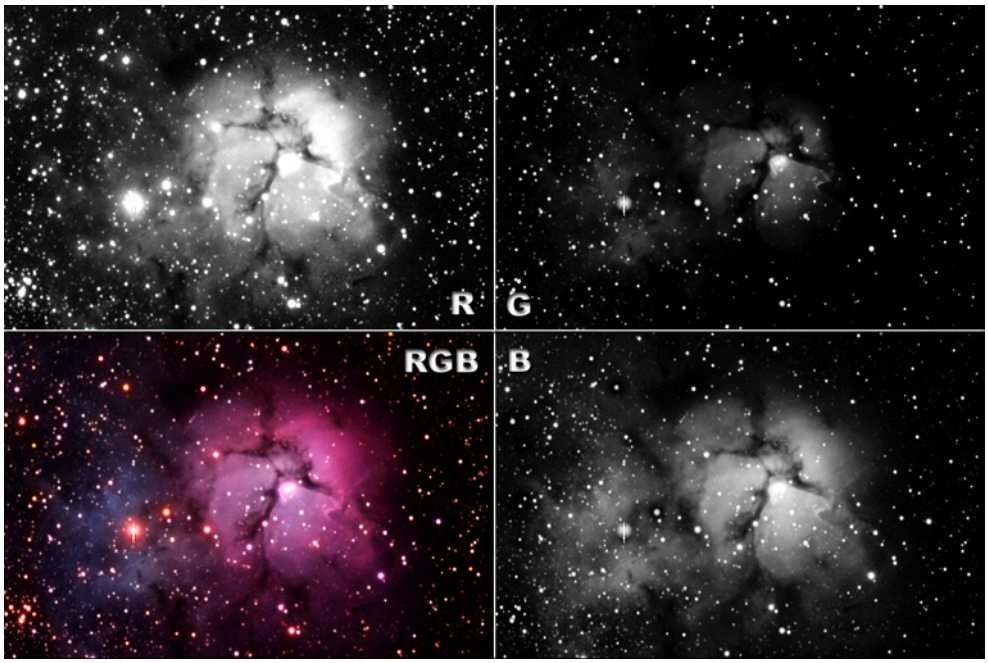


Figure 1B: The Trifid Nebula's component color images.

CCD detectors are not equally sensitive to all wavelengths of light. Figure 2 shows the response curve for an ST-8E detector. The graph measures the quantum efficiency of the detector, showing how efficiently it turns photons into electrons. Different CCD detectors have different response curves. The response peaks in the visible range (roughly 400 to 700 nanometer wavelengths), and falls off toward the ultra-violet and infrared portions of the spectrum. Note, however, that the CCD detector is sensitive to both infrared and ultraviolet (UV) light. Figure 2 illustrates why it is important to use an IR blocking filter when imaging in color. Many CCD detectors are very sensitive to these wavelengths of light. The ST-8E, for example, is 50% efficient at capturing near-infrared photons.

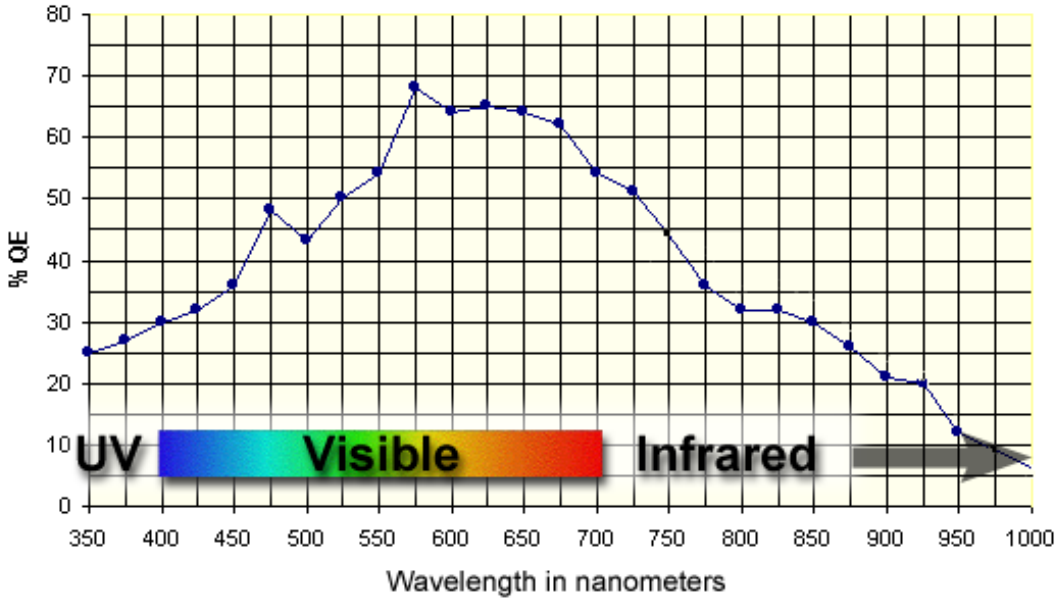


Figure 2: CCD detectors respond differently to different wavelengths of light.

Because of the variation in response with wavelength (color) of light, many CCD detectors require different exposures for red, green, and/or blue. Other factors can also affect color component exposures, including:

- Natural variations in sensitivity from one chip to the next.
- Elevation of the object in the sky when imaged. Blue extinction occurs closer to the horizon, so that objects appear redder. You see this visually at sunrise and sunset, when the sun becomes much more red close to the horizon.
- Light pollution adds light at various wavelengths. The color of light pollution depends on the source of the pollution. Sodium vapor lights, for example, emit strongly in the green portion of the color spectrum. Mercury vapor lights emit strongly in the orange. If light pollution from such sources is a problem for you, a light pollution suppression filter can remove a significant portion, but not all, of the light pollution and restore a better color balance.

The following table shows approximate ratios for red, green, and blue exposures with several SBIG cameras.

Camera	Red Component	Green Component	Blue Component
ST-7E, ST-8E	1.0	1.0	1.6
ST-7, ST-8	1.0	1.5	2.0
ST-237	1.0	1.0	1.1
ST-9E	1.0	1.0	1.6
ST-10E	1.0	1.0	1.6

These exposure ratios are a good starting point; experiment to see what works best for your camera. The numbers shown are relative exposures. For example, if you are using an ST-7E, and the red exposure is 2 minutes and 30 seconds, then the green exposure should also be 2 minutes and 30 seconds, and the blue exposure should be 4 minutes (2:30 times 1.6).

Exact exposure times are not critical. CCDSoft provides tools for adjusting color balance after you take your component images. The most important thing is to get long enough component exposures for each color so that you get good signal-to-noise ratios in each image. See “Chapter 3: Aligning and Combining Images” for details on the effects of signal-to-noise ratio on image quality, as well as for some times on how to obtain good signal-to-noise ratios.

Graininess is the visual appearance of poor signal-to-noise ratio. It means that your color exposure is too short. You can overcome this either by taking longer component exposures, or by combining multiple images for each color. Either technique will reduce noise effectively; see “Chapter 3: Aligning and Combining Images” for details.

Smoothing techniques, covered in “Chapter 9: Image Processing,” can clear up graininess in the dimmest portions of an image. When working with color, apply image processing after you combine the component images to create a full-color image. The exception to this is gradient removal; you’ll get the best results if you correct for any gradients before you combine colors. Otherwise, your processing could disturb the color balance. If you need to use image processing prior to combining, test the results of your processing frequently to see what effect they have on color balance. The Preview window available when color combining is the ideal test method; see “Chapter 10: Color Combining.”

Selecting Camera and Filter Wheel

In order to take color images automatically, you must have a color filter wheel attached to your camera. CCDSoft supports the following camera and filter wheel combinations:

Filter Wheel	Supported Cameras
CFW-6A (Motorized)	ST-6 and Homeyer filter wheels.
CFW-8	ST-7, ST-7E, ST-8, ST-8E, ST-9E, ST-10E, ST-1001E
SBIG Internal 2 Filter	ST-237, ST-5C, PixCel 237, PixCel 255
SBIG Internal 5 Filter	ST-237, ST-5C, PixCel 237, PixCel 255
CFWAPI	DFM Engineering, Finger Lakes and True Technology filter wheels.

CCDSoft will be updated to support additional cameras and/or filter wheels as they become available.

To select a color filter wheel for your camera, first select the camera type using the **Setup** tab on the Camera Control Panel. If the control panel isn't visible, click **Camera | Setup** to open it.

Figure 3 shows the drop-down list of filter wheels available; the contents of this list will vary as additional filter wheels are added.

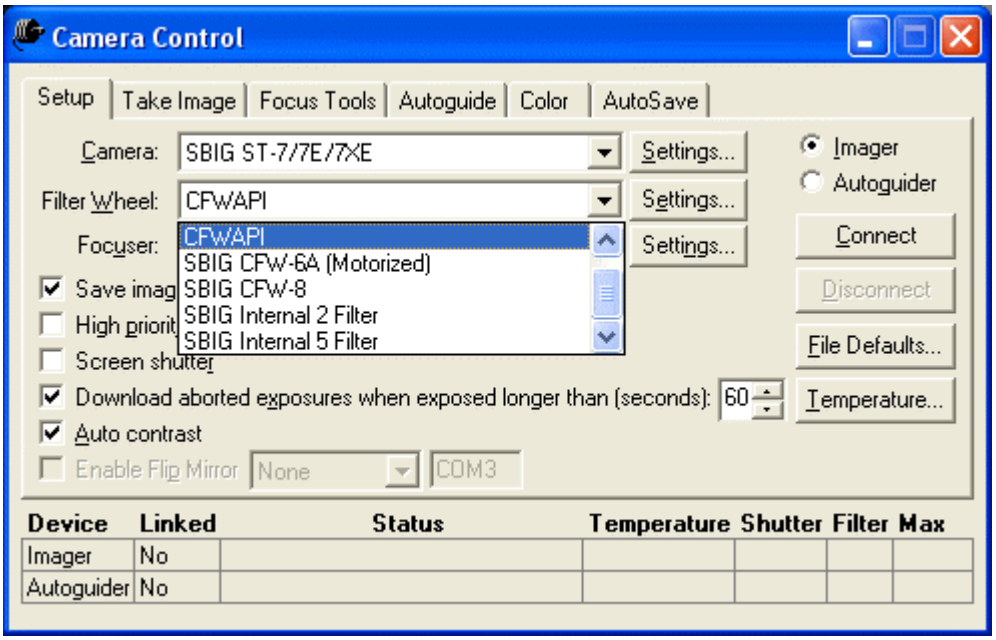


Figure 3: Selecting the type of filter wheel installed.

Note that there is a **Settings** button next to the list of filter wheels. After you select the type of filter wheel, click **Settings** to adjust the descriptions of the filters installed in the filter wheel. If you are using the default filters in the default locations, as installed at the factory, you do not need to make any changes to the settings.

Figure 4 shows the settings available for the CFW-8 filter wheel. Figures 5 and 6 show the available settings for the SBIG Internal 2 and 5 filter wheels, respectively.

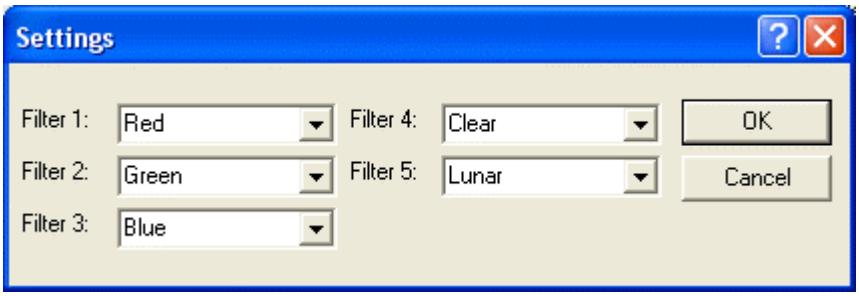


Figure 4: Settings for the CFW-8.

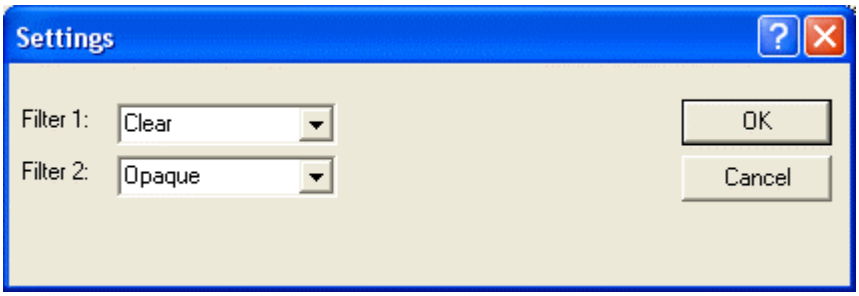


Figure 5: Settings for the SBIG Internal 2 filter.

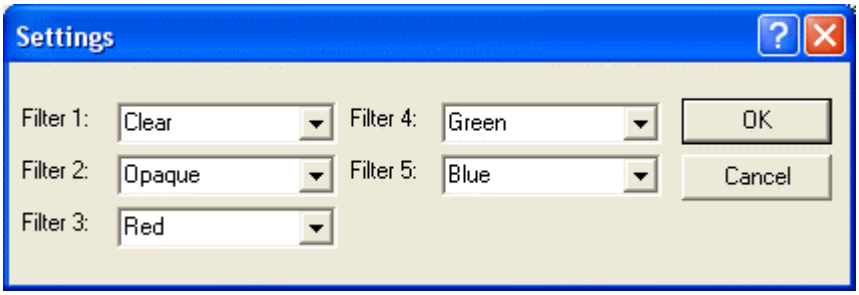


Figure 6: Settings for the SBIG Internal 5 filter.

For each filter position, you have the following available settings for the filters:

- Clear
- Opaque
- Red
- Green
- Blue
- Infrared
- Violet
- Lunar
- Deep Sky

Please note that not all filter choices are available for all filter wheels. Consult your filter wheel documentation to see if there are optional filters available.

When you have selected and configured your camera and filter wheel, click **Connect** to establish a connection with the camera and filter wheel. The camera functions the same as it does without a filter wheel (see “Chapter 1: Camera Control”), but now you can also access the color-specific features in the **Color** tab of the Camera Control Panel. You can also select a filter when you image using the **Take Image** tab. The filter list appears below the **Exposure** section of the Take Image tab (see figure 7).

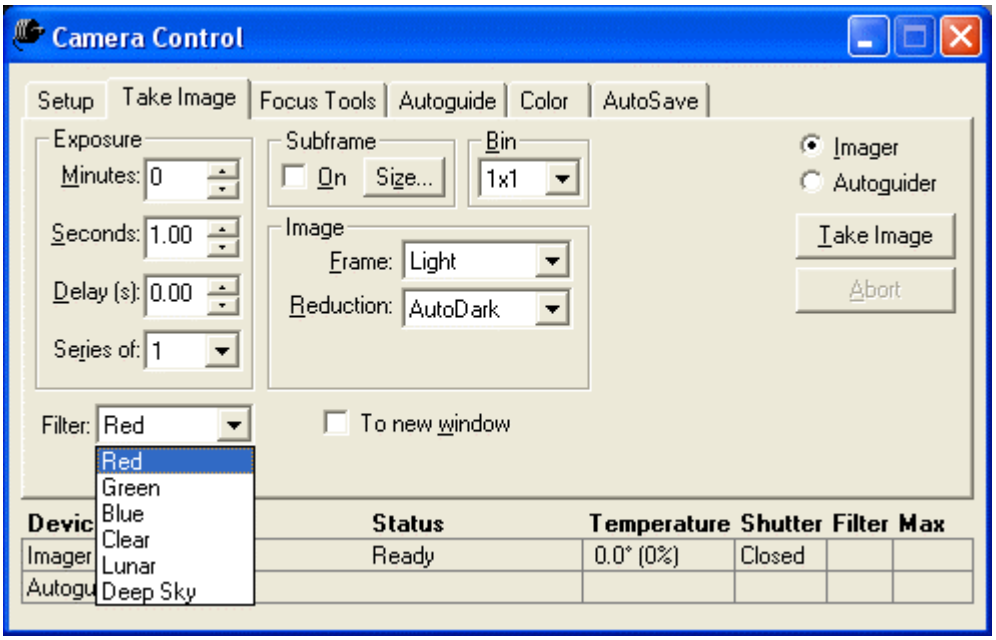


Figure 7: You can select color filters on the Take Image tab.

Using the Color Tab

Once you have set up and connected to your camera and filter wheel, you will normally use the **Focus Tools** tab and, optionally, the **Autoguide** tab before you are ready to take color images. See “Chapter 1: Camera Control” for complete details on getting ready to image. If you use autoguiding, you will be able to take longer and more component images, which will improve the quality of the final color image.

When you are focused and autoguiding (if available), click the **Color** tab to display the color imaging interface shown in figure 8. This interface automates the process of taking multiple exposures using different filters, which you later assemble into color images.

You can easily perform any of the following functions with the Color tab:
LRGB images – This combines a luminance (black and white) image with red, green and blue images. The eye is more sensitive to luminance information than to color information, so an LRGB image is a good choice when the details of the object are the most important consideration. When taking an LRGB series, you set up all four available columns on the **Color** tab. In typical use, the luminance image is the longest exposure. In addition, the luminance image can be taken at 1x1 binning, while the color images can be taken at 2x2 binning to shorten the total time needed for the exposures. This works because the luminance image dominates. However, 1x1 binning of color component images provides the sharpest results at the cost of longer exposure times.
RGB images – This combines red, green and blue images to create a color image. This type of image is faster to take since there is no luminance image. It is often useful for nebulas or other objects where color is the dominant feature, not fine detail. You always have the option of taking multiple sets of R, G and B images to increase the signal-to-noise ratio and obtain finer detail. Unless you are binning for focal length considerations to achieve an optimal arc-seconds per pixel value, RGB images are taken with 1x1 binning.

Special Purpose Filters – There are many other filters available besides the conventional Clear plus RGB set. You can purchase narrow-band filters that transmit wavelengths of light characteristic of certain emissions, such as hydrogen-alpha, OIII, SII, etc. No matter what kind of filter you use, you can use the **Color** tab to control exposures and other filter properties easily.

If you need a special series of images taken through particular filters, you can activate or deactivate any individual filters on the **Color** tab. Click **Edit** for the filter, and check or uncheck the **Active** checkbox as appropriate.

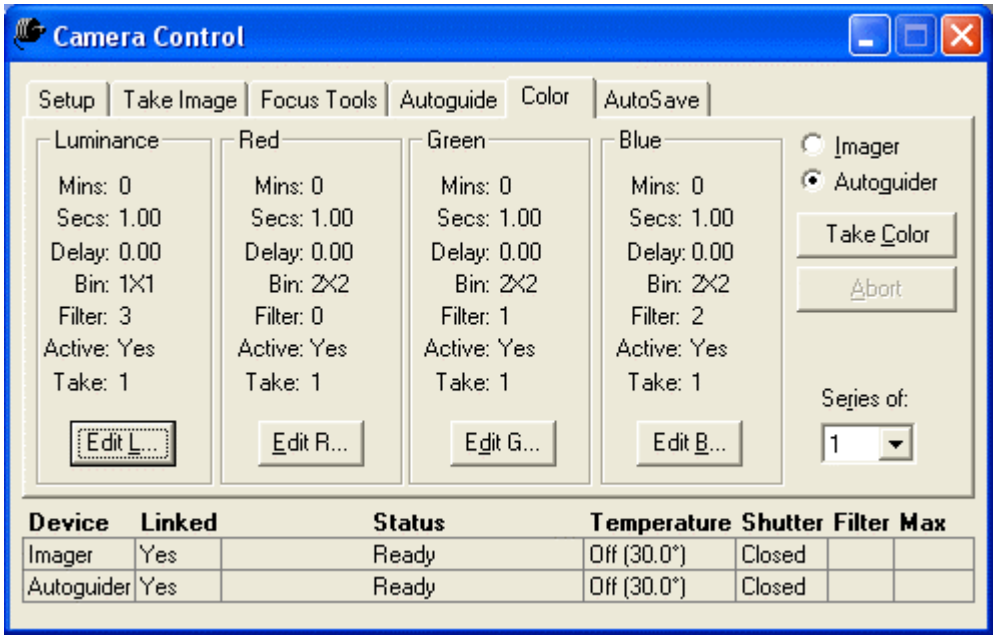


Figure 8: The Color tab on the Camera Control Panel.

The four columns on the color tab correspond to the four types of filters commonly used for color imaging: luminance (clear), red, green, and blue. If you have different filters installed and configured using the Settings tab, the names at the top of each column may be different from what appears in figure 8.

The Color tab shows the current settings for each filter. To change the settings for any filter, click **Edit** immediately below the settings information for that filter. Figure 9 shows the dialog box that appears when you click the **Edit L** (luminance) button; the other three dialog boxes are identical in all but name.

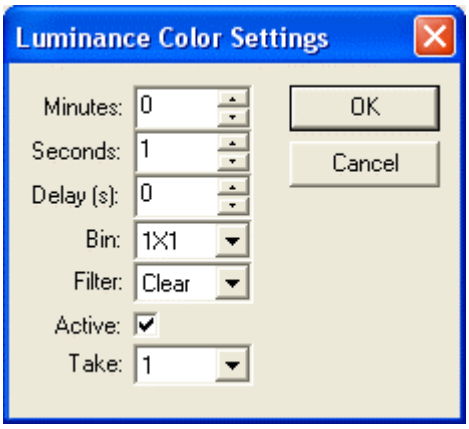


Figure 9: Changing settings for the Luminance image.

From top to bottom, the settings for each filter are:

Minutes – Minutes of exposure time. Used with **Seconds** to specify the length of exposure through the filter. Color filters reduce the amount of light striking the CCD detector, so exposure times using the same bin mode are usually longer for color than for luminance. With the SBIG RGB color filters, start with a red exposure length that is approximately twice the luminance exposure at the same bin mode. If the luminance exposure is binned 1x1 and the red exposure is binned 2x2, start with the same exposure as the luminance image.
Seconds – Used with **Minutes** to specify the length of exposure for the filter.
Delay – The delay is the length of time to wait before starting the exposure. This is used when you are autoguiding. Autoguiding is suspended during download of an image. The guide star may move during this time. When the download is complete, autoguiding will send larger than usual corrections to the mount to re-center the guide star. The delay provides extra time while re-centering is going on. It prevents streaking of stars in your image should the re-centering move the star a significant amount. See the chapter on Autoguiding for details on how to select the appropriate delay time. You can use two to four times the length of the guide exposure as a guideline. The better your polar alignment and the smaller your mount's error, the less the guide star will move during a download.
Bin – The bin mode to use for this filter. CCDSoft will list the available bin modes for your camera. See “Chapter 1: Camera Control” for detailed information about bin modes. For fastest results, use 1x1 binning for your luminance image, and 2x2 binning for your color filter images. For higher resolution overall but longer exposure times, use 1x1 binning for all images. If you are using RGB instead of LRGB, use 1x1 binning for color filters. Note: If 1x1 binning provides higher arcseconds per pixel than is optimal for the seeing conditions and your focal length, substitute an appropriate binning mode for luminance and color filters. For example, when using an 8-inch SCT at f/10 with an ST-7E or ST-8E camera you might use 2x2 binning for luminance, and 3x3 binning for color filters in order to get 1.85 arcseconds per pixel instead of 0.93 arcseconds per pixel.
Filter – Specifies which filter to use. If no color filter wheel is attached, this will be grayed out. Even though you won't be able to take color images without a filter wheel, you can make use of the Color tab for shooting sequences of images at different exposures times and bin modes. For example, if you are unsure of the optimal exposure that will balance blooming and depth of exposure, you can use the color tab to take several exposures of different length, which you can compare to see what exposure length you prefer.

Active – When checked, the filter will be active and the exposure(s) will use the settings you have entered for the filter.
Take – Indicates the number of images to take with this filter. For example, you can elect to take three luminance images and one each of red, green, and blue. This constitutes a single image set. You can use the **Series of** drop-down list to take multiple image sets.

The Color Imaging Process

As with any CCD image, color imaging demands an accurate mount. Autoguiding is not a requirement, but it greatly simplifies the color imaging process. If you do not have an autoguider, and wish to do color images, a very good polar alignment is necessary. Otherwise the object of interest may move a great deal during the long time required to take all of the images in the color image set. The smaller the amount of drift due to polar misalignment, the longer your exposures can be, the more exposures you can take because there will be less movement during and between exposures. With a poor polar alignment, your subject might even drift out of the frame before you have collected enough images to create your color image. Autoguiding locks the images into place, and allows you to maximize the quality of the final color image.

If you fail to expose your color images long enough, you will see graininess in the image as shown in figure 10. The image of M101 shows a poor signal-to-noise ratio. When you combine such images to make a color image, you wind up with obvious dots of color instead of a smooth blend. You can use various techniques to make sure you get good signal levels: take longer exposures; use a faster focal ratio; and/or take and combine multiple images. All of these techniques will improve the signal level with respect to the noise, as described in Chapter 3: Aligning and Combining Images. The dimmer the subject the more consideration you need to give to this issue. M101, the example in figure 10, is a galaxy with low surface brightness that requires long, multiple exposures to get good results in color.

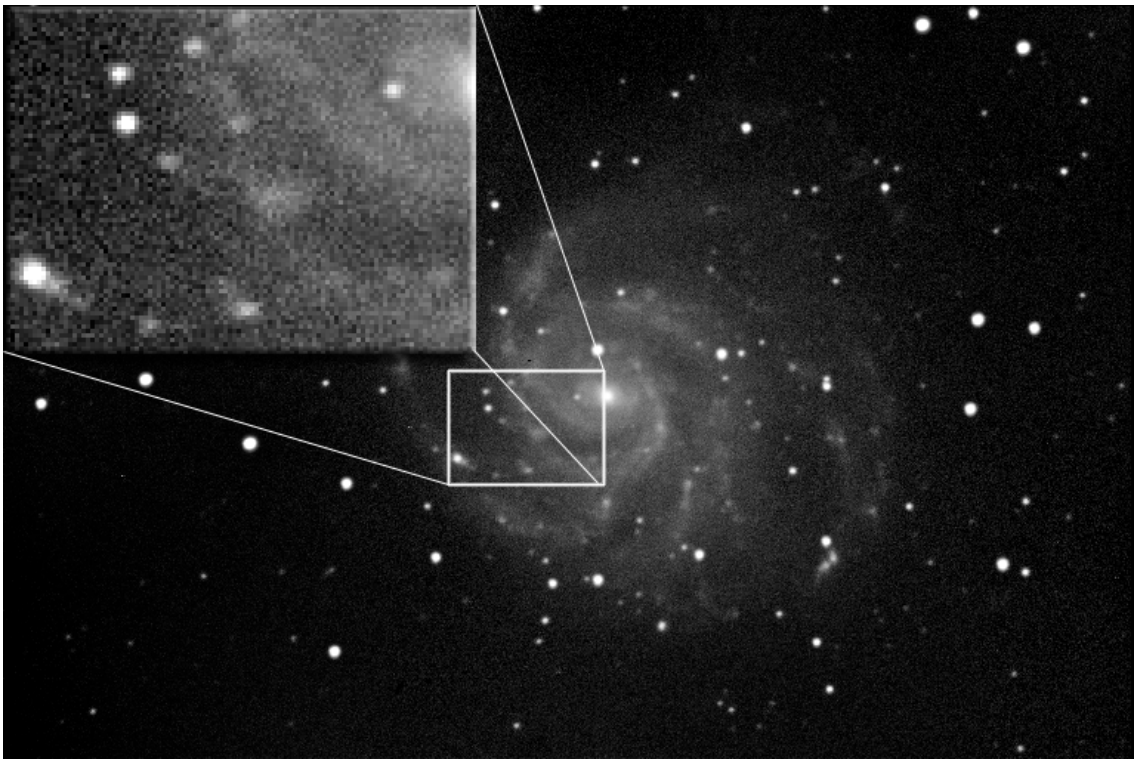


Figure 10: An image of Messier 101 with poor signal level. The inset shows a magnified sample of a noisy part of the image.

Figure 11 shows an image of M101 that has a much better ratio of signal to noise. Multiple images were used to improve the signal-to-noise ratio. The same portion of the galaxy (rotated 90 degrees counterclockwise) has been enlarged to show that there is much less noise in this image. This image is an average of four exposures. Combining multiple images, which is covered in detail in “Chapter 3: Aligning and Combining Images,” is one of the most effective ways to get really good component images for your color images.

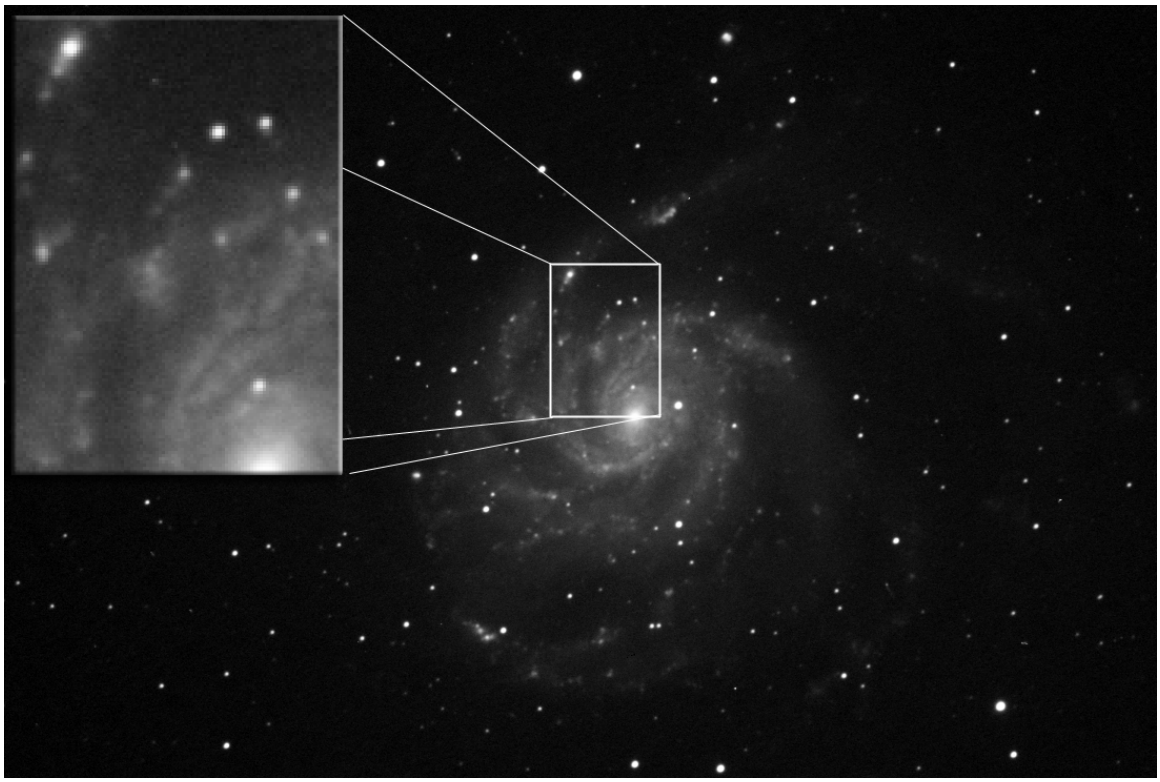


Figure 11: An image of M101 with excellent signal-to-noise ratio.

If your red, green, blue, and luminance component images end up with poor signal levels, the background in the final image will be excessively grainy. You can improve the appearance somewhat by blurring/smoothing the grainy areas. Use the smoothing filters (click **Image | Smoothing**) in CCDSoft to smooth the component images prior to combining. Use different amounts of smoothing based on the level of graininess in each component image.

To avoid graininess, use the **Series of** drop-down on the **Color** tab to take at least three sets of RGB or LRGB images. Make sure the exposure times for the individual filters are long enough to provide good signal-to-noise ratios. If you are taking LRGB images, you can take five or more luminance images to increase the signal level where it matters the most. The eye judges sharpness mostly by luminance.

Why at least three images? Combining is very effective at reducing the most noticeable sources of noise, such as cosmic rays striking the CCD detector, or even satellite tracks running through your image. It requires at least three images to be effective at reducing noise. If your images are clear of such problems, use **Add** instead of **Median** combine for a slightly better signal-to-noise ratio.

Color Imaging Steps

Once you have the appropriate settings for each filter, click the **Color Series** on the **Color** tab to start the color sequence. A complete color imaging session includes the follow steps:

1. Connect to your camera, autoguider, and color filter wheel as appropriate. (See “Chapter 1: Camera Control” for details about the Camera Control Pane’s **Setup** tab)
2. Turn **AutoSave** on, and select the folder where you want the component images stored.
3. Focus in the usual manner. (**Focus Tools** tab, see “Chapter 1: Camera Control”)
4. Frame your subject using test exposures. Determine your luminance exposure duration. (See “Chapter 1: Camera Control” for details about the Camera Control panel’s **Take Image** tab)
5. If you are autoguiding, calibrate if necessary and start autoguiding. (See “Chapter 4: Autoguiding” for details about the Camera Control Panel’s **Autoguide** tab)
6. Choose your image reduction options. (See “Chapter 1: Camera Control” and “Chapter 6: Taking Color Exposures” for details about image reduction options.)
7. Adjust the settings for each filter on the **Color** tab.
8. Select the number of color image sets using the **Series of** drop-down list.
9. Click **Color Series** to begin acquisition.

You may need to monitor several things while the color series is in progress:

- Is the delay you set adequate? Does it allow the guide star to get close to the 0,0 position before the next image starts?
- Is your polar alignment good enough to keep the guide star visible after image downloads?
- Is autoguiding working properly? Look for star trails, multiple images, or other signs of trouble on the first few images.
- Is the guide star sufficiently bright when the color filters are in the optical path? For example, a red star may not be bright enough when the blue filter is in place. If so, choose another star, or increase exposure time for autoguiding. The same autoguiding exposure time is used for all filters. If you require different autoguiding times, you can use CCDSoft’s scripting capabilities to write a script that provides this functionality. See Software Bisque’s Orchestrate documentation (Orchestrate is sold separately) for information about scripting.
- Does the guide star become too bright with any of the filters? If you use a blue star as a guide star, for example, it may be fine with a red filter, but excessively bright (saturated) when the blue filter is used.
- Is the guide interval appropriate? Does the mount drift too far during the guide interval, leading to trailing of star images?

Figure 12 shows what can be done with the color tools in CCDSoft. The image of M16, the Eagle Nebula, was built up from three luminance images of 10 minutes each, plus one set of red, green, and blue images with exposures of 10:10:16 minutes. To learn how to combine component images into a color image, see “Chapter 10: Color Combining.”



Figure 12: An example of a color image built up from luminance, red, green, and blue images.

Chapter 7: Image Reduction

Image reduction allows you to clean up images to better reveal the data in them. You can in effect take pictures of some of the noise in your imaging equipment, and then use those pictures to remove much of the noise.

Noise is the error in the brightness levels in an image. Noise can occur from a variety of sources. Some noise is random and unpredictable. Such noise can be limited, but never removed. This type of noise is defined as the level of uncertainty in brightness levels. For example, if you took four images of an object, you might see brightness levels of 98, 97, 103, and 102. That variation in brightness reflects the error level.

Other types of noise are inherent to the imaging equipment, and this type of noise is called system noise. System noise can be subtracted from your images to clean them up. It builds up while you are taking your image, and while reading the image off of the CCD detector. By taking steps to limit noise in the camera (mainly by cooling the detector), and by removing the repeatable noise that is left, you can achieve very high-quality images. Image reduction, however, can only clean up an image so far. The quality of the image itself determines that limit. Longer exposures, or combined exposures, when reduced properly, will give you the highest level of quality possible.

All noise by nature creates uncertainty in the brightness levels of the pixels in your image. If a picture has a lot of noise in it, you can see this visually. There will be variations in brightness in areas that you expect to have a more uniform brightness. Words commonly used to describe this effect are “grainy” and “gritty.”

Some common sources of system noise in CCD imaging include:

- **Readout noise**– results from collecting, amplifying, and converting pixel data to electrons inside the camera.
- **Dark current** – results from electrons accumulating in pixels even in the absence of light.
- **Optical dust** – bits of dust in the optical path that cast shadows on the CCD detector.
- **Background noise** – results from sky glow.
- **Reflections** – light that reflects off of various surfaces in the telescope, focuser, or CCD camera, and falls on the CCD detector.
- **Image Processing noise** – results from processing the image using various techniques.

Removing the system noise from your images is a form of **data reduction.** The term “calibration” is sometimes used to refer to this process, but data reduction is a more accurate description of the procedures involved. Calibration involves comparing values to a known accurate reference, such as calibrating the brightness of a star in an image using its known magnitude, or determining how far your mount moves in 10 seconds (autoguider calibration).

Even when you take steps to remove noise, you also add some noise back into the image at the same time. For example, when you subtract a dark frame (see section “

Dark Frames" later in this chapter), you add the dark frame's noise to the image. You are usually removing much more noise than you add, providing a net gain from this and most other noise reduction processes. Thus, there is no way to remove all of the noise from an image. You can remove a lot of noise with careful technique, however. Figure 1 shows two halves of an image. The top half shows the original image; the bottom half shows the same image after data reduction.

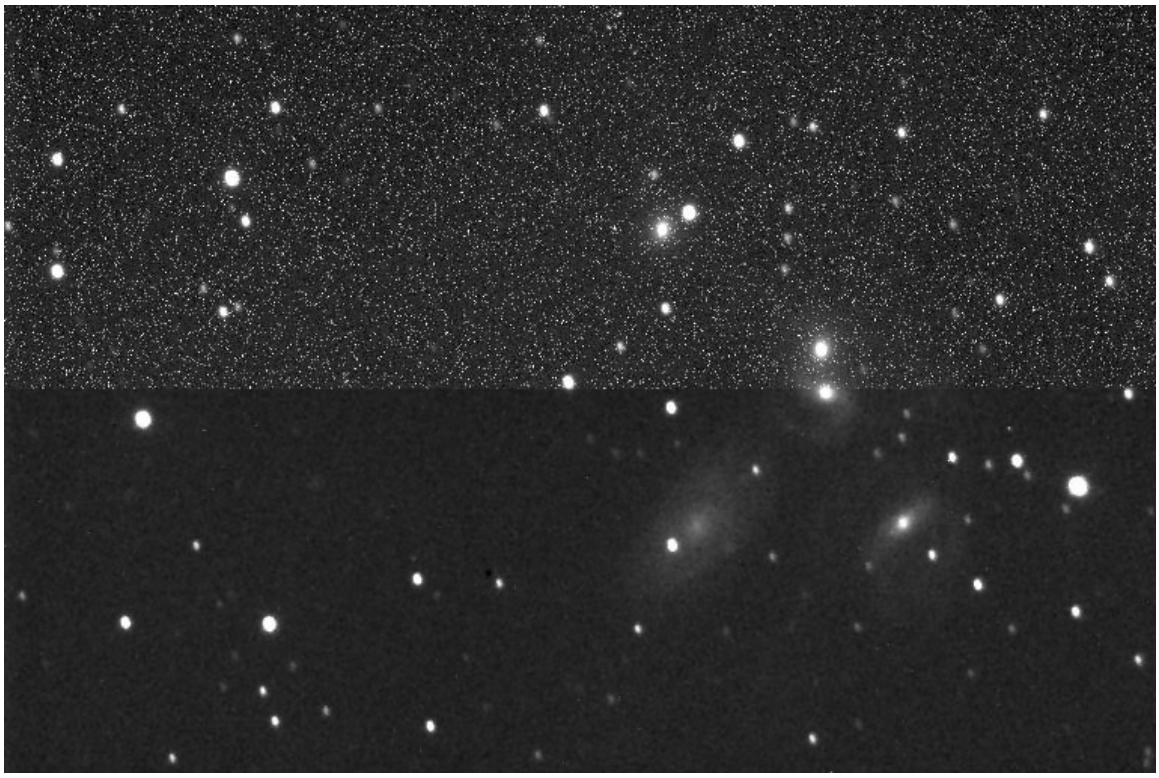


Figure 1: The benefits of data reduction on an image of Stephan's Quintet.

This chapter describes how to use CCDSoft to remove noise from your images, leaving them cleaner and ready for further processing. In this chapter, you will learn how to:

- Acquire bias frames.
- Acquire and apply dark frames.
- Acquire and apply flat-field frames.
- Create and manage groups of bias, dark, and flat-field frames.
- Manually and automatically apply data reduction to images.

Quick Start for Experienced Users

For this chapter, an experienced user is someone who has experience creating and applying bias frames, dark frames, and flat field frames to CCD images.

The most powerful way to apply reduction is to create **reduction groups,** consisting of any number of bias, dark, and flat-field frames. You can apply reduction groups to individual images, to a folder of images, or automatically to each image as you acquire it.

1. Create a reduction group, and add images to it. To begin, you must have appropriate bias, dark, and flat-field images to add to the group. Follow accepted guidelines for optimal creation of these files:
   - Bias and dark frames should be taken at the same temperature as the light frames.
   - Bias frames should be taken using the shortest possible exposure time.
   - Dark frames should be taken with same exposure as the light frames.
   - If matching exposure temperature and duration is not practical, CCDSoft can be set to compensate for these differences.
   - Flat fields can be taken at different times and temperatures than light and dark frames. If appropriate, you can use separate dark frames for flat fields.
2. Click **Image | Reduce | Image Reduction** to open the Image Reduction dialog box (or press `Ctrl+R`). Click **Add Group** to create a new group. Try using a name that includes the date, detector temperature, and/or other items that can help you with later re-use of the group.

3. The new group will have placeholders for bias frames, dark frames, dark frames for flats only, and flat frames. Click on the placeholder, and then click **Add Frames**. Navigate to the folder with the files you want to add. Highlight the frames you want to add (use Ctrl and Shift keys to select more than one), and then click **Open**.
4. Continue until you have added all of the images you desire to any or all of the four placeholders.

You now have several options for using the newly created reduction group:

- If you have one or more images open that you want to reduce, click **Reduce**, select the images to reduce, then click **OK**. The reduced images appear in new windows, so there is no risk of accidentally overwriting your original unreduced data.
- If you have a folder of images you would like to reduce, click **Reduce Folder** and navigate to that folder. Then select the output folder and click **Reduce**. This is a powerful feature that can save you hours of effort. For example, in just a few minutes you could apply bias, dark, and flat frames to hundreds of images. Note: every file in the folder must be an appropriate image for the reduction group. For best results, copy images with the same reduction characteristics into a folder.
- If you are taking new images, and want to apply the reduction group to each image as it is acquired, start by making sure that **AutoSave** is active (to activate AutoSave, from the Camera Control Panel, click the **AutoSave** tab). Switch to the **Take Image** tab, and select **Bias, Dark, Flat** as the Reduction option in the Image section. Then select the desired group from the Group option just below the Reduction option. Note: The Group option isn't active unless you choose the appropriate Reduction option. The group you select will automatically be applied to each image. Since **AutoSave** is on, the original image and the reduced image are both saved to disk. The reduced image will have the keyword "REDUCED" added to the filename.

You can also perform individual reduction steps, including darks and flat fields, if you so desire. Open the image you want to reduce, right click on the image and then click **Dark Subtract** or **Flat Field**. In the Dark Subtract or Flat Field dialog box pick the appropriate reduction frame from the workspace or from disk.

Principles of Image Reduction

There are many sources of noise in the data collection process. There are three things you can do that will remove the majority of the noise from most images, and they all involve taking a picture that captures the noise you want to remove. These are bias, flat-field, and dark frames. Figure 2 shows an example of each type of frame.

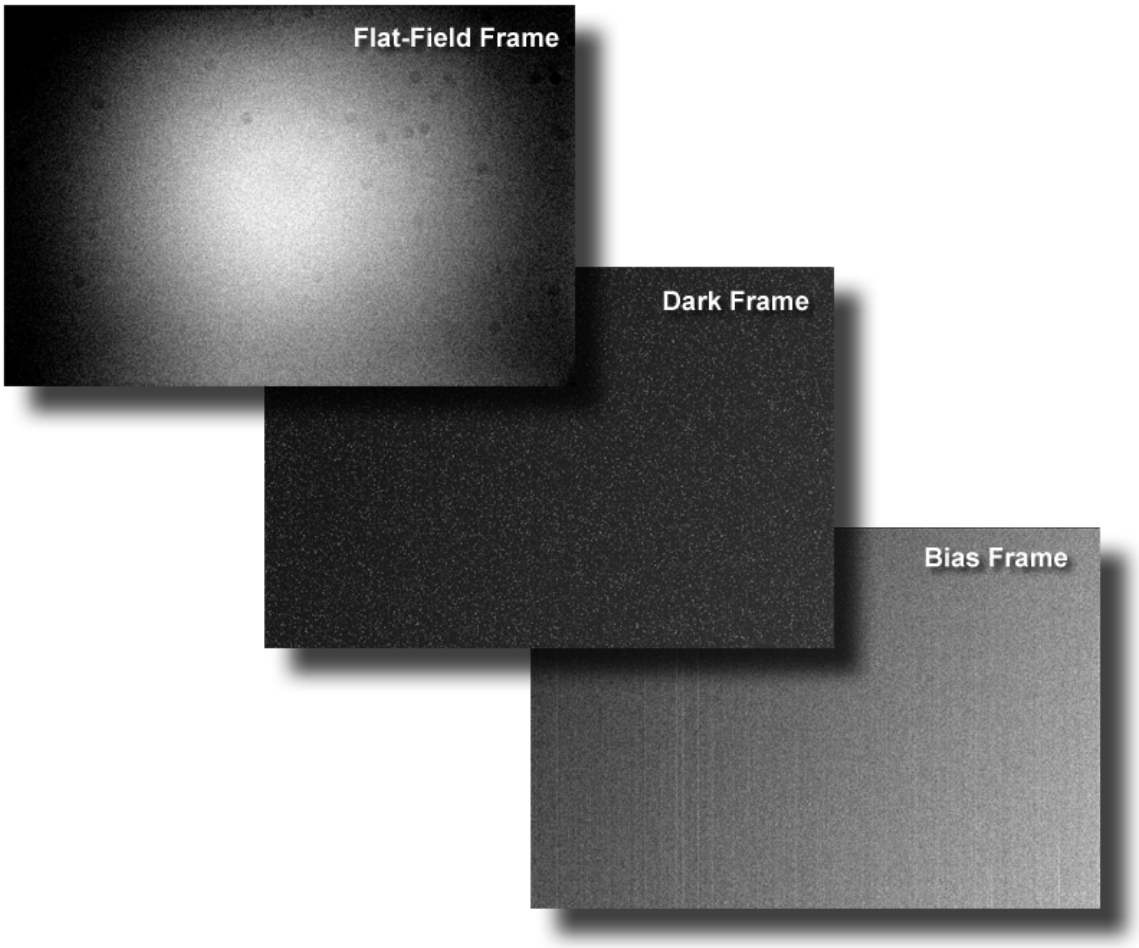


Figure 2: Samples of bias, flat-field, and dark frames.

Bias Frames – Bias represents pixel values that occur on your CCD detector even if the exposure time is zero (or as close to zero as possible). In other words, even a zero-length exposure still delivers non-zero brightness values. This means that pixels do not necessarily start with a zero value at the beginning of an exposure. Note: SBIG cameras include a 100-unit pedestal (that is, 100 units are added to the value of every pixel). This is true not just of bias frames, but of all frames (bias, dark, flat-field, and light). CCDSoft appropriately subtracts the pedestal during data reduction. You will find instructions for taking bias (and other types of data reduction frames) in later sections of this chapter.

Dark Frames – Even if no light strikes the CCD detector, the individual pixels change value over time, building up an electrical charge consisting of electrons that accumulate in the pixels. Most of this energy comes from heat, and it is called thermal noise or dark current. Most CCD detectors are cooled to reduce this type of noise, but there will always be some level of dark current. The greater the cooling, the lower the dark current will be. Each pixel responds to dark current differently. Some are more sensitive, and will be brighter as a result of dark current. Others are less sensitive, and may change very little. The top half of figure 1 shows many hot pixels from dark current. Dark current varies slightly from image to image, but it is highly consistent. Thus, as with a bias frame, you can take an image with the shutter closed (or your hat over the front of the telescope if your camera has no shutter) to create a dark frame. CCDSoft subtracts dark frames from light frames to remove most of the effects of dark current.

Flat-Field Frames – As light comes through the telescope and CCD camera, several things can happen. Under the best of circumstances, the light will come through unobstructed and perfectly distributed. This ideal situation is seldom the case, however. For example, the center of the focal plane is often brighter than the edges. Also, dust can get on the optical surfaces, casting shadows that affect the amount of light reaching each pixel. In addition, internal reflections can cause unwanted light to fall on the CCD detector. A flat-field frame records these variations in brightness. To create a flat-field frame, take an image of an evenly illuminated surface. Various parts of the optical path add or subtract light from the evenly illuminated surface, and the flat field records the variations.

Taking Reduction Frames

Bias frames are easy to take, and require no special technique. You simply take the shortest possible exposure that your camera provides. Dark frames are also relatively simple, though you should match the temperature and exposure length of the light frame(s) reasonably well. Flat-field frames are the trickiest to master. It's not as easy as it sounds to create an evenly illuminated surface. You'll learn some useful techniques for creating good flat fields later in this chapter.

Bias Frames

Figure 3 shows the Take Image tab set up to take a series of three one-minute light exposures. Binning is 1x1, and no automatic image reduction will occur because the Reduction option is set to **None**. See the section "

Automatic Reduction" later in this chapter for information about automatic image reduction.

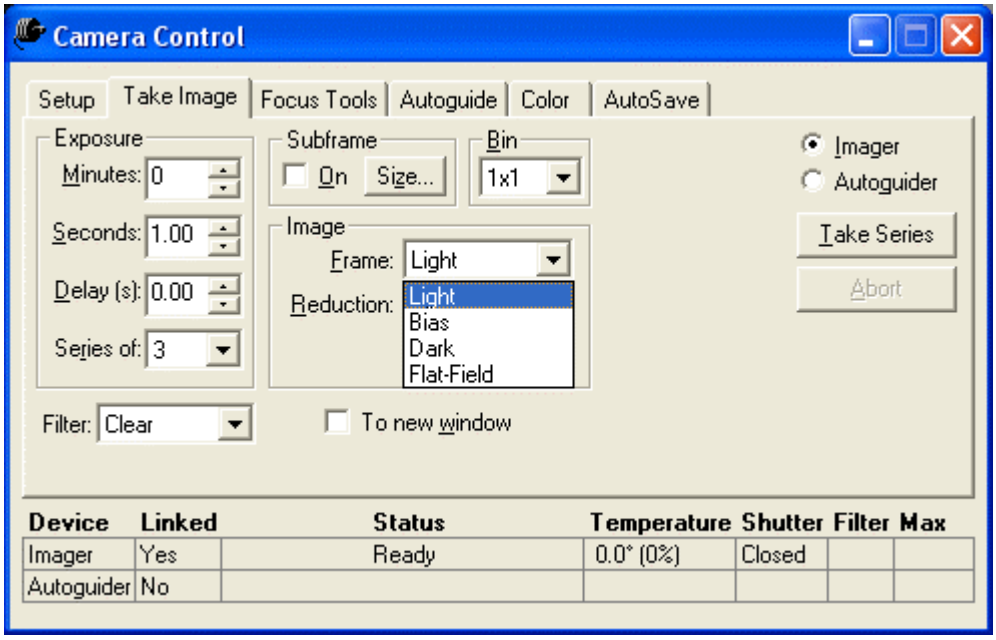


Figure 3: The light frame to which the sample bias, dark, and flat-field frames will be applied.

To take a bias frame for this image, set up the **Take Image** tab as shown in figure 4. Since the bias frame is the shortest possible exposure, the exposure duration settings (**Minutes** and **Seconds**) are disabled (grayed out). The **Reduction** drop-down list is also disabled, since it does not apply to a bias frame. CCDSoft will automatically use the shortest possible exposure for your camera when it exposes a bias frame.

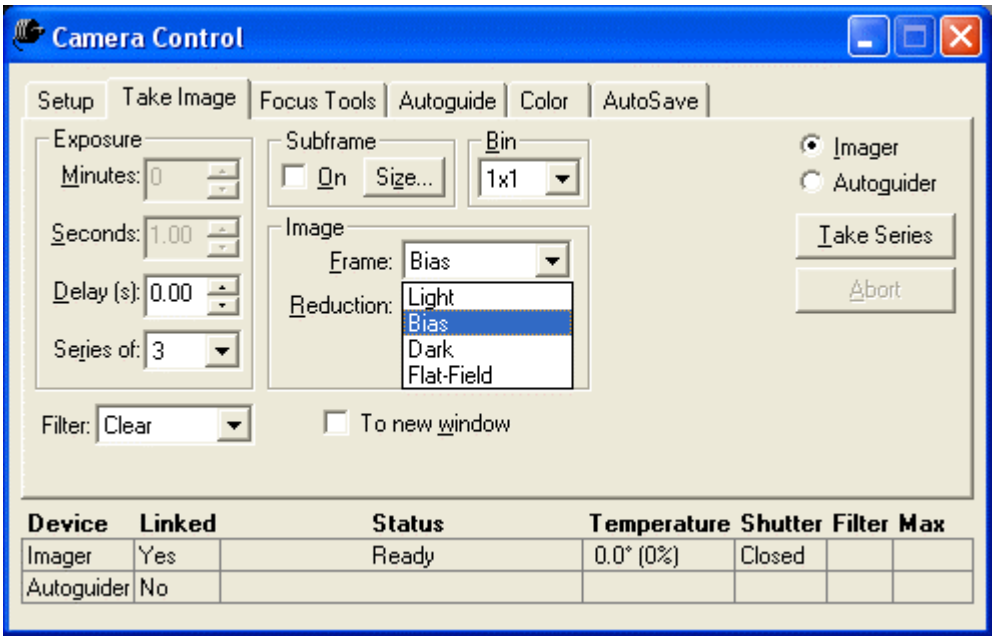


Figure 4: Taking a bias frame.

Note that the **Series of** setting is set to 3. We recommend taking at least three bias frames. These can be averaged to reduce noise. The images you take for image reduction have their own levels of random noise. Combining images is one of the most effective ways of reducing the random noise in your reduction frames and your images. This occurs automatically when you use reduction groups with multiple frames. See the section “Using Groups for Reduction” later in this chapter for details.

When you are ready to take your bias frame(s), click **Take Image** (it becomes **Take Series** when more than one image has been set in **Series of**). If you have set **AutoSave** on, the filename will contain the word BIAS in it so you can readily distinguish your bias frames. For most situations, we recommend leaving **AutoSave** on to make sure that no images or reduction frames are accidentally lost. As with any image, you can cancel the bias frame or its download by clicking **Abort**. The Abort button is only active when imaging or downloading. Figure 5 shows an example of a bias frame.

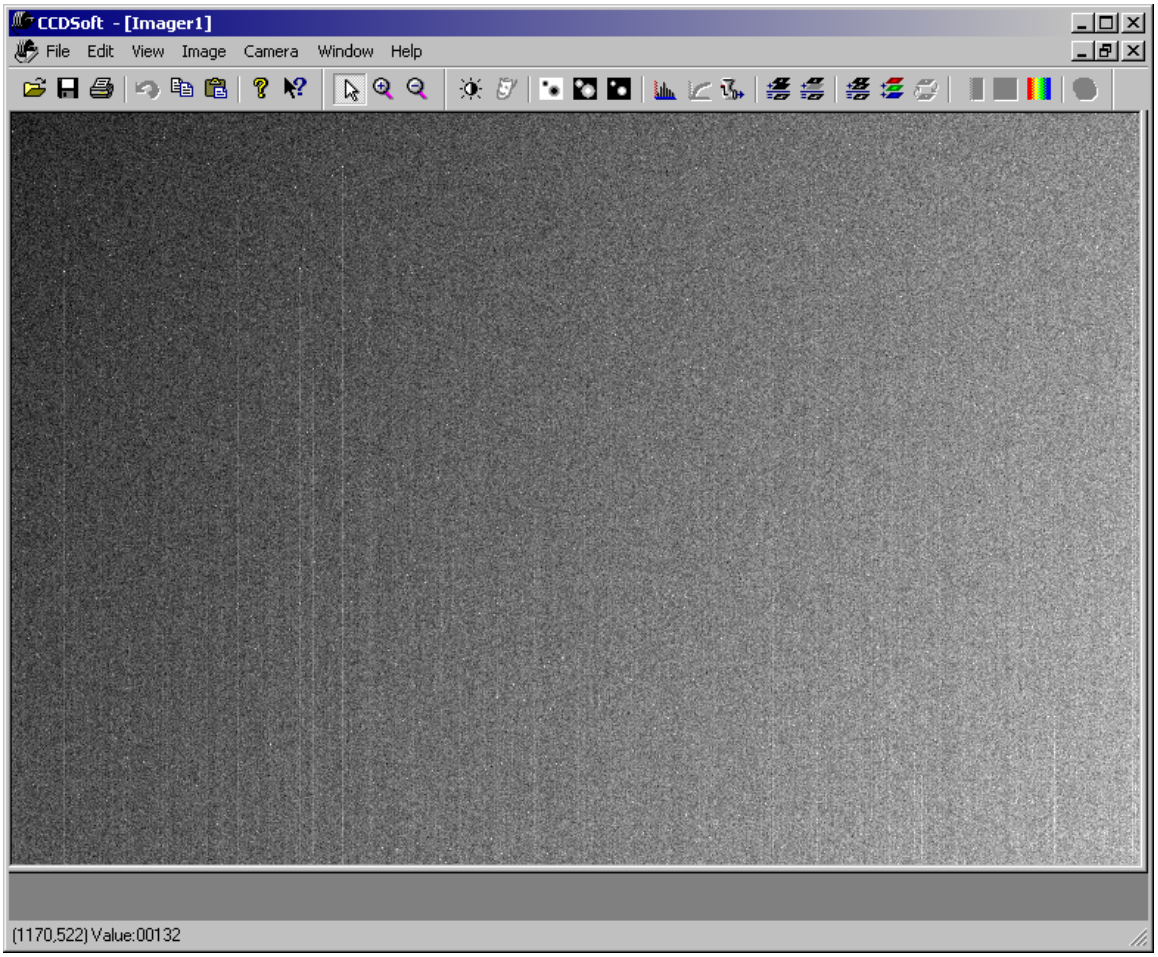


Figure 5: A sample bias frame.

The appearance of your bias frames may be similar or different, as there are variations from detector to detector and camera to camera. The image in figure 5 may look disturbing because of the many lines and the grainy appearance, but these are normal features to expect in a bias frame. The ST-8E used to take the bias frame delivers outstanding images. The noise in the bias frame is at an extremely low level – so low that many CCD imagers don't bother to apply a bias frame to their images. For astrometry, photometry, or just to get the best possible results, use a bias frame along with your dark and flat-field frames. For critical applications, four or even eight or more bias frames will provide some additional noise reduction.

Bias frames can only be applied as part of a group; there is no command for applying only a bias frame to an image.

Time saving hint: If all of your dark frames and light frames have the same exposure duration, then you don't need to take bias frames.

Dark Frames

Dark frames are a important tool for image reduction. Dark current varies with the temperature of the CCD detector. Most CCD cameras cool the detector, some by as much as 35 degrees Celsius or more. The warmer the CCD detector, the greater the dark current and the greater the need for dark frames. For optimal noise reduction, take at least three dark frames and use them in a reduction group.

Each CCD detector has a pattern of hot and cold pixels that varies minimally from image to image. The intensity of the hot pixels varies with exposure length and temperature, however. For this reason, you should, whenever possible, take dark frames that have the same temperature and exposure length as your light frames. If you are unable to do so, CCDSoft will scale dark frames to fit the exposure of a light frame. The results will not be quite as good as when you match temperature and exposure length precisely. The greater the difference in exposure time, the less likely this compensation will be effective. For example, if you have a light frame with a two-minute exposure, a dark frame of 90 seconds or three minutes will be reasonably effective. A ten-minute dark frame, however, will probably add substantial noise to the image. The colder the CCD, the less of a problem this will be, since the total noise in the image will be less.

Figure 6 shows the settings you would use to take a series of three dark frames matching the light frame from figure 3. Note that the exposure time matches that of the light frame, and that the temperature is the same. There will often be small fluctuations in CCD detector temperature (less than a quarter degree, typically), and these can be safely ignored. The Frame has been set to **Dark**. Note that the Reduction drop-down list is disabled, since there can be no reduction of a dark frame.

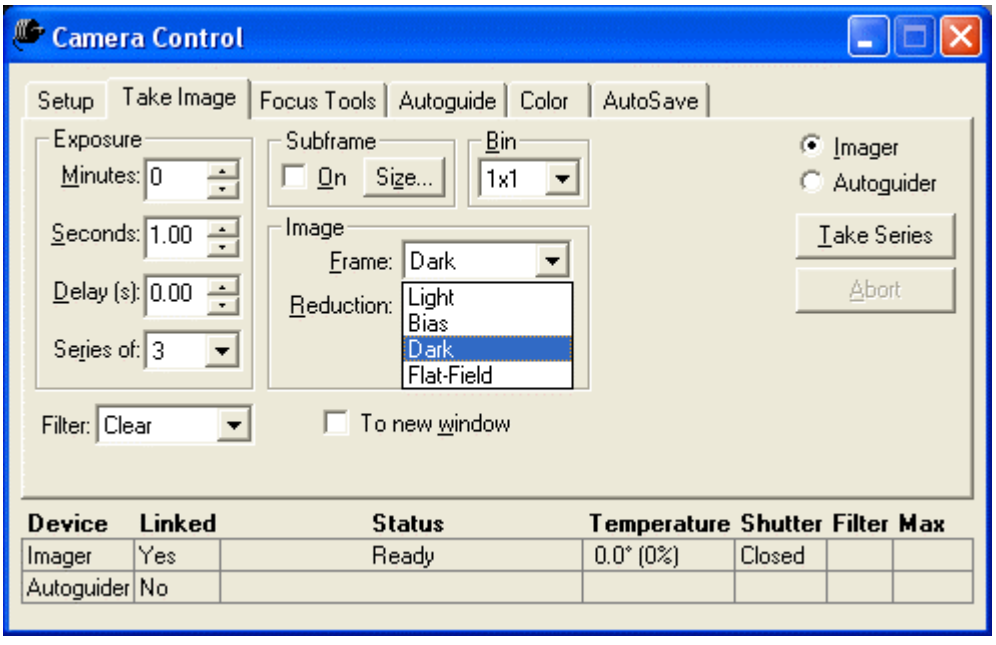


Figure 6: Settings for taking a series of three dark frames.

When you are ready to take your dark frame(s), click **Take Image** (it becomes **Take Series** when more than one image has been set in **Series of**). If you have turned **AutoSave** on, the filename will contain

the word DARK so you can readily distinguish your dark frames. For most situations, we recommend leaving **AutoSave** on to make sure that no images or reduction frames are lost accidentally. As with any image, you can cancel the image or the download by clicking **Abort**, which is only active when imaging or downloading. Figure 7 shows an example of a dark frame for an ST-8E camera. This sample was taken at -5°C. Figure 8 shows an example of a dark frame taken with the same camera at -35°C, using the same background and range settings as figure 7. Notice how much less noisy the resulting dark frame is. There is no substitute for a cold CCD detector!

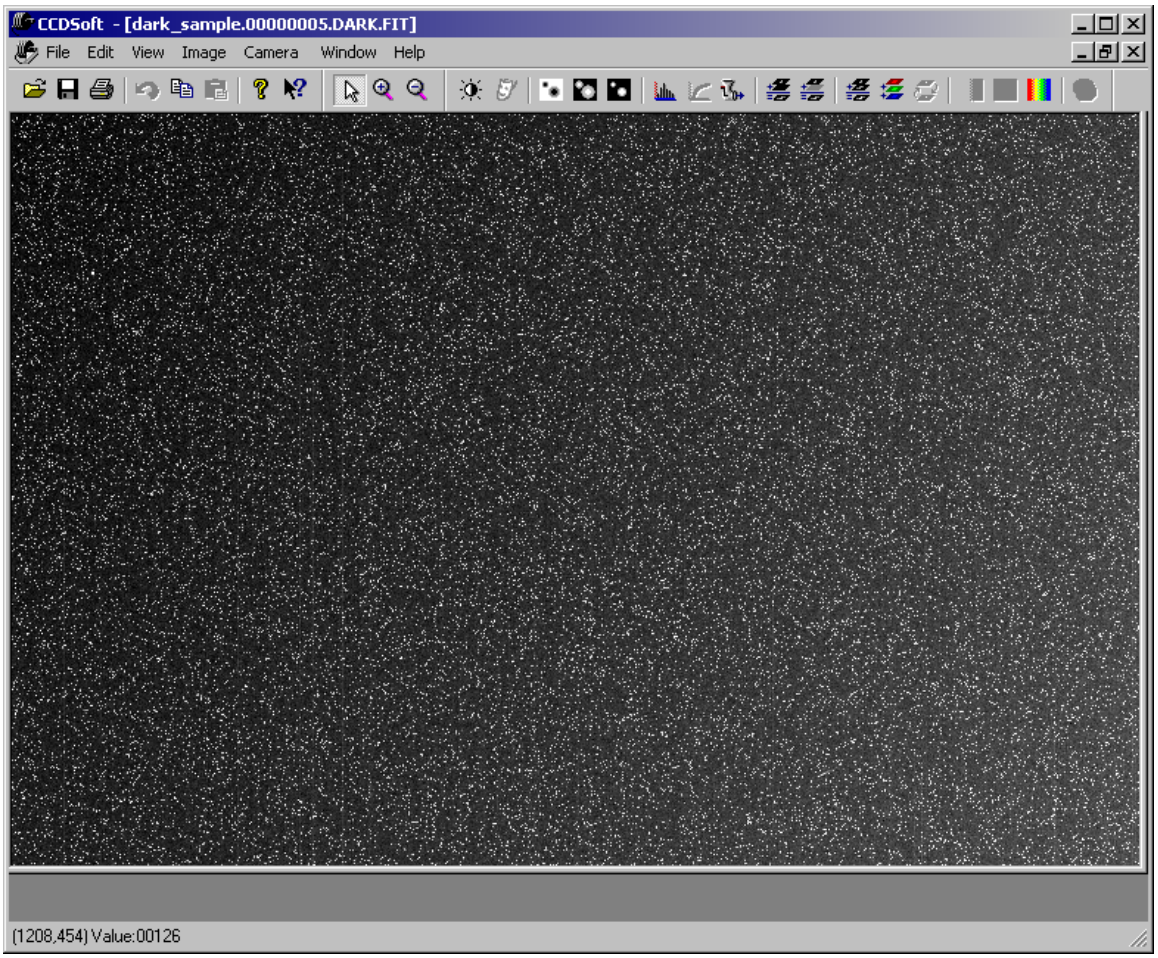


Figure 7: A sample dark frame from an ST-8E camera at -5ºC.

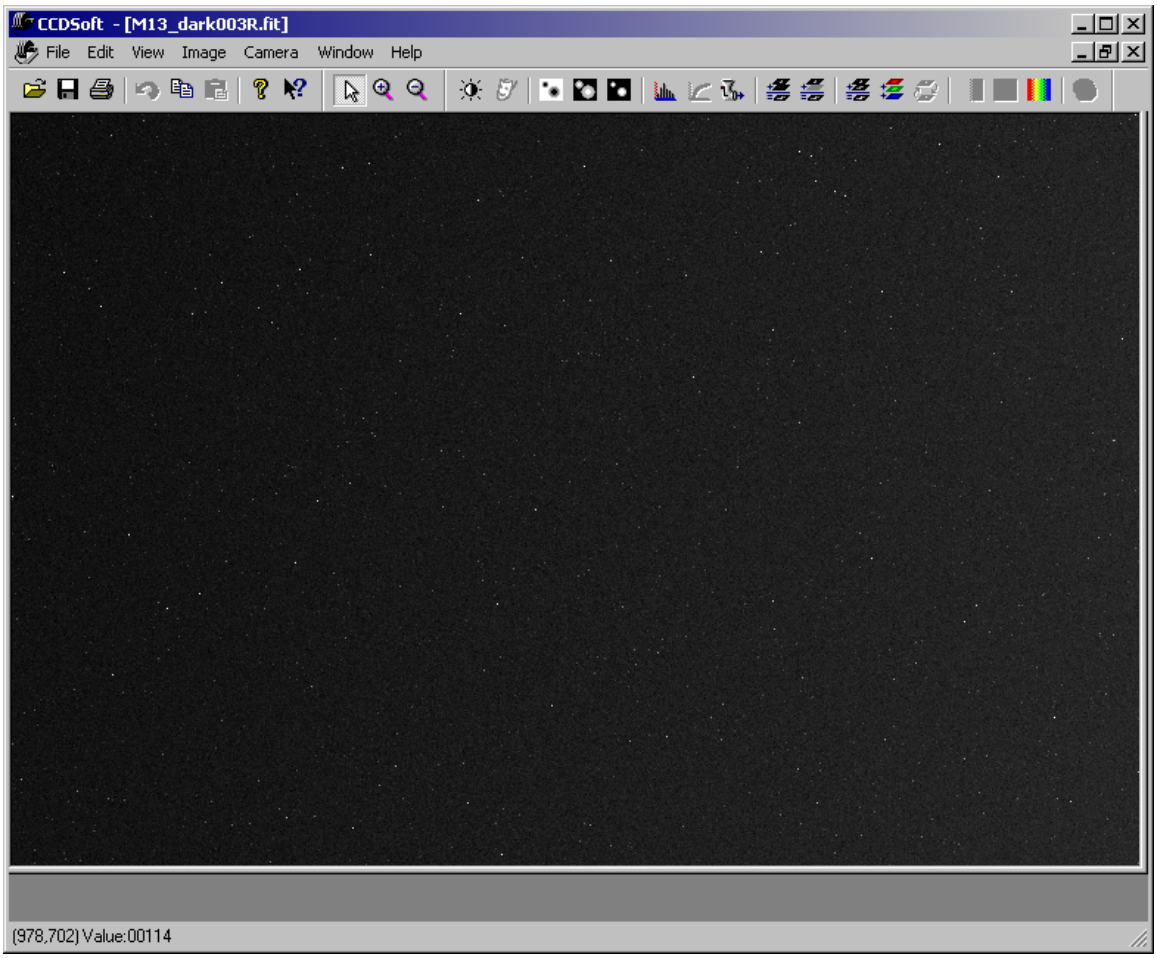


Figure 8: A sample dark frame from the same ST-8E at -35°C.

Taking multiple dark frames, which can then be averaged as part of a group, helps keep the noise down in your reduced images. Figure 9 shows a median combine of five dark frames taken at -5C. Compare to figure 7, and notice that the graininess is noticeably reduced. In addition to reducing camera noise sources, such as readout noise, median combine with multiple dark frames also reduces noise from one-time problems such as cosmic ray hits. A cosmic ray can cause dots, streaks, arcs, and other artifacts in dark frames. When you apply such a dark frame to a light frame, you get a black splotch where the cosmic ray hit. By using at least three dark frames, you can greatly reduce the impact from such problems. For critical applications, four or even eight or more dark frames will provide some additional noise reduction.

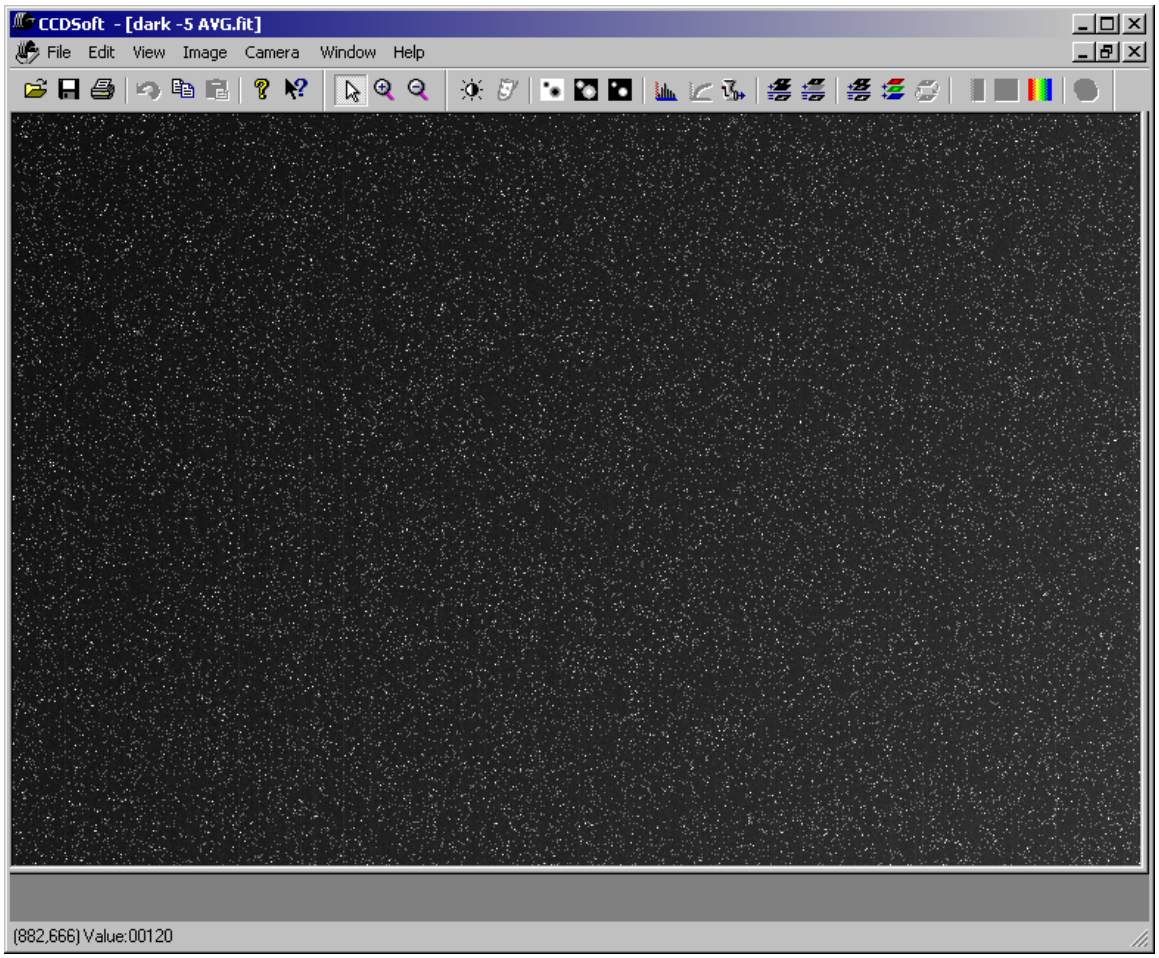


Figure 9: Example of combining dark frames to reduce noise.

You may notice on some cameras that one side of the dark frame is a little brighter than the other. This is normal. It may take as much as a minute or more to download the data from cameras with very large pixel arrays, and during this time dark current continues to build up on the CCD detector. Since this gradient occurs in both the light frame and the dark frame, it is automatically removed during image reduction. Cameras that transfer the image instantly via frame buffers will not show this effect.

You can apply a single dark frame to an image, or you can apply multiple dark frames as part of a group. Since the thermal noise (dark current) in dark frames is also present in the light frame, the idea is to simply subtract the dark frame from the light frame, leaving a clean record of the light that struck the CCD detector. CCDSoft automatically handles the 100-count pedestal that is added to images acquired with SBIG cameras (see bias frame section above for details).

To apply a single dark frame to a single image, you can:

- Press the `Control + D`, or
- Right click on the image and then click **Dark Subtract**, or

- Click **Image | Reduce | Dark Subtract**.

All of these choices display the Dark Subtract dialog box (see figure 10). You select the light frame in the top of the dialog box, and the dark frame in the bottom. You can select either a currently open image, or a file on your hard disk for either the light or dark frame. In figure 10, the light frame is a file currently open in CCDSoft, and the dark frame is a file on the hard disk. If no images are currently open, the **File** radio buttons will be selected automatically.

If you check the **Create new window** checkbox, CCDSoft will display the result of applying the dark frame in a new window, leaving the original light frame untouched. If you leave it unchecked, the changes will be applied to the original light frame.

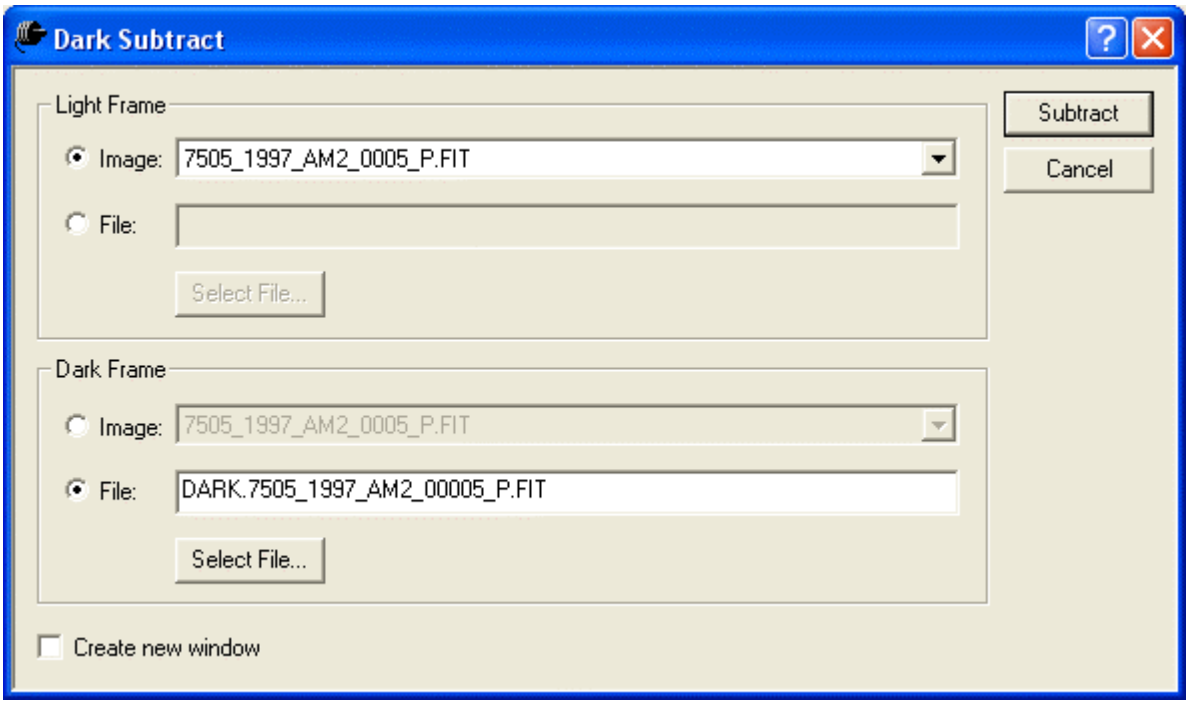


Figure 10: Subtracting a single dark frame from a single image.

Figure 11 shows a raw image of M51. The intent was to get a nice, deep exposure of M51. This caused some blooming of the brightest stars. The image was taken at a temperature of -33ºC, so there is only minor dark current noise in the image. The inset portion of figure 11 shows a close-up of the image, illustrating the low but visible noise level. There are numerous white dots in the inset image, caused by dark current. These are called hot pixels. Note: the central portion of the image is brighter, a problem that can be solved by applying a flat field (see next section). The image exposure is five minutes at -33ºC.

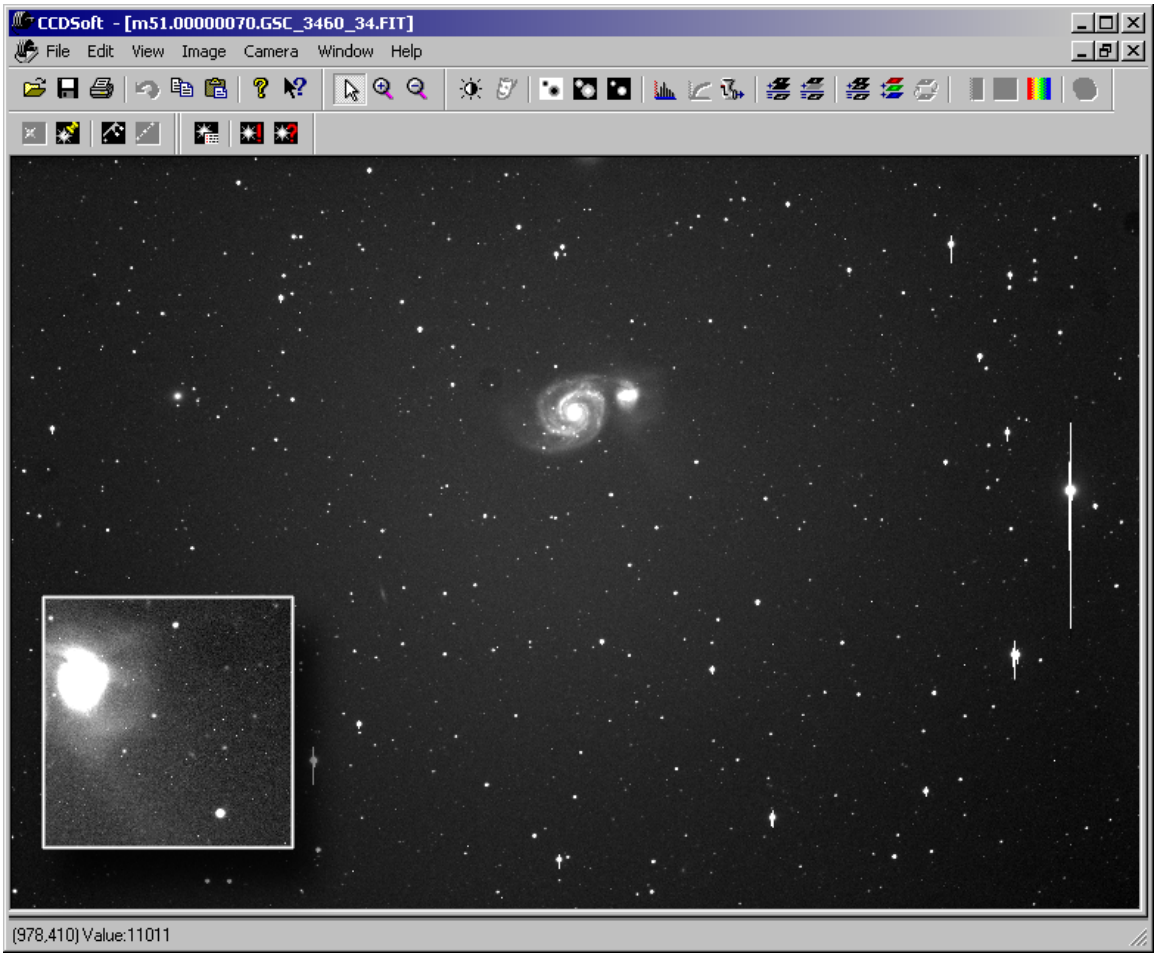


Figure 11: A raw image of M51, taken with an ST-8E at -33°C.

The dark frame for figure 11 was also taken at -33°C for five minutes, and is nearly identical to the dark frame in figure 8. Applying the dark frame to the raw image, using the technique outlined earlier in this section, results in a cleaner image. Compare the inset portion of figure 12 with the inset portion of figure 11. The background is darker and less noisy. The hot pixels that are very clear in figure 11 are much less so in figure 12. Subtracting the dark frame removed nearly all of the hot pixels.

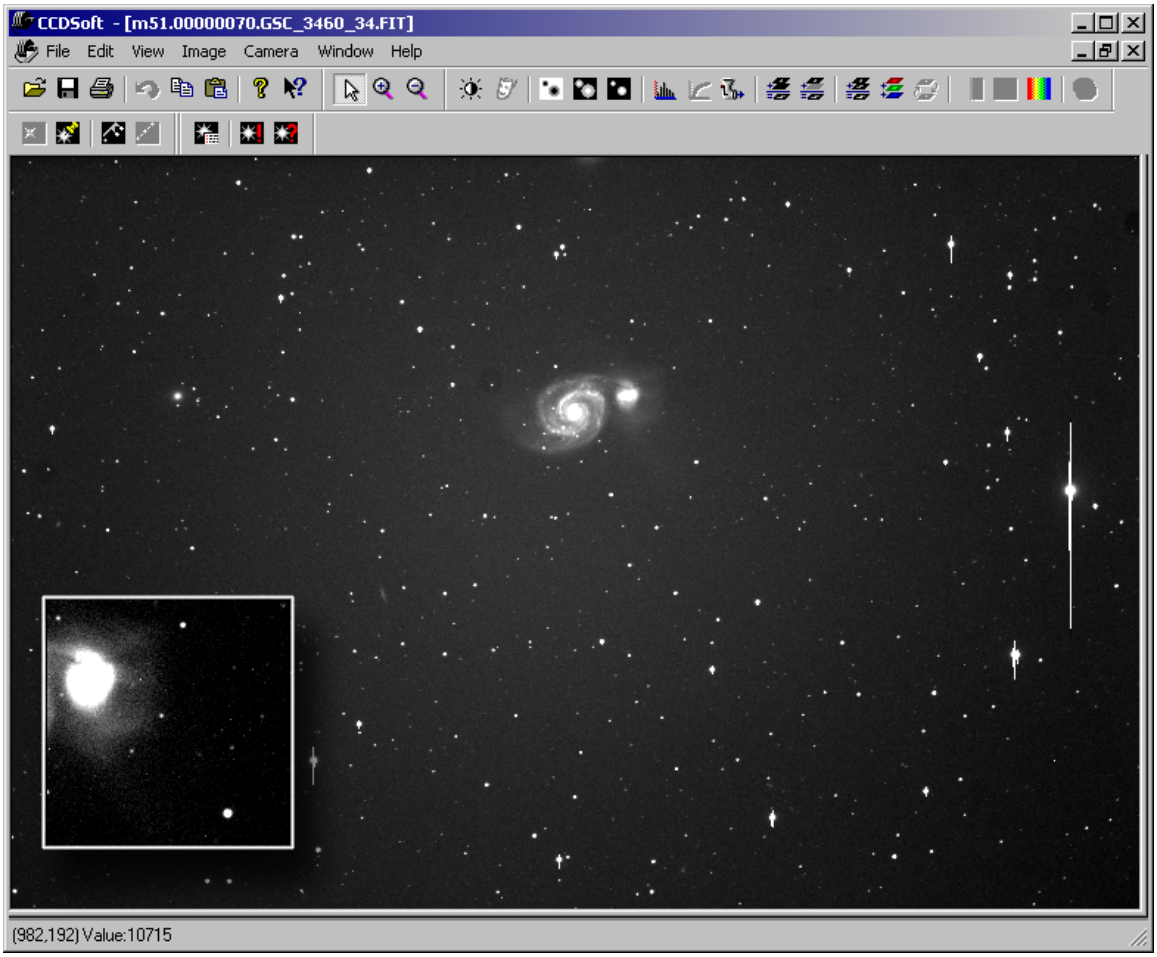


Figure 12: An image of M51 with a dark frame subtracted from it shows hot pixels removed.

Why didn't the dark frame completely remove the hot pixels? In a word: noise. Even though the dark frame and the light frame were the same in terms of exposure length and temperature, the random noise in the two images caused a small variation in values. This means that a single dark frame is unlikely to completely correct the hot and cold pixels in a light image, but it will improve the image markedly. To reduce noise in both the light frame and the dark frame, multiple exposures are required. See the section "Using Reduction Groups" later in this chapter. Compare figure 12 to the final result of image reduction using a reduction group with multiple bias, dark, and flat-field frames in figure 29.

Flat-Field Frames

Like dark frames, flat fields can make a big difference in the appearance of your images. Flat, in this case, means "evenly illuminated." Unlike dark frames, which simply require you to take an image to record the dark current, taking a good flat field requires much more operator involvement. You should expect to spend some time perfecting your technique in making high-quality flat-field frames. It's not as easy as it might seem to evenly illuminate a surface. Stray light and reflections outside the optical tube are a challenge to control.

The flat-field frame is a record of the optical path's characteristics (see figure 14 for an example of a flat field). Anything that casts a shadow or causes a reflection leaves its imprint on the flat-field image. This includes dust on any of the optical surfaces; lint hanging from the inside of the tube into the optical path; light reflecting off of any surfaces within the tube, focuser, filter wheel, and/or camera, etc.

If you rotate your camera, change filters, use a different dew shield, or make any other changes to your system, you'll probably need a new flat field. You'll also want to take new flat fields periodically to account for any new dust that settles on the optical surfaces, or that moves or falls out of the system.

Quality Issues for Flat Fields

The best way to judge the quality of a flat field is to apply it to a test image. The ideal test image is of a sparse star field unaffected by light pollution, without any large galaxies or nebulas in the field of view. This allows you to examine the effects of the flat field on the entire background of the image. If applying the flat field removes shadows from dust particles, and provides a flat, even background in your images, then it is an effective flat field. If you do not have an area of sky unaffected by light pollution, you may have to use your best judgment on the quality of your flat field.

Several things can get in the way of this simple test of a flat field, however:

- If there is a moon or other bright light source, the sky background may not be flat. It will be brighter on the side toward the light source, and darker away from the light source. This gradient may be very small, but after you apply a flat field the gradient will be much more visible. A bright full moon, a nearby streetlight, or lights from an urban area near the horizon can all create severe problems that are a major challenge to solve. It's difficult to test a flat field when such a gradient is present, and the flat field won't solve this type of gradient problem because the source is outside the optical system. In some cases, such as when the light is very bright or the dynamic range of your CCD detector is small, the gradient will overwhelm the image completely.
- Off-axis light sources can pollute a flat field. For example, suppose you are using a dew shield, and that there is a neighbor's security light to the left of the telescope's optical axis. If that light reflects off of the dew shield, it could make it down the optical tube and hit the CCD detector. As a result, one side of the flat field image will be brighter than the other. The off-axis light source prevents you from getting even illumination. Similarly, if you are using a translucent panel to create the even illumination, an off-axis light source could reflect preferentially at some angles and create bright spots in the flat field.

All of these obstacles can be overcome. You need to invest some time to discover the ways in which undesired light is interfering with even illumination. Once you eliminate the extraneous light sources, you wind up with a very high quality flat field that will give you much better looking images.

Flat fields have particular value for scientific research. A properly executed flat field will remove distortions in brightness levels from an image, and allow you to make accurate measurements of the relative brightness of objects in the image. Without a good flat field, your calculations will contain a larger amount of error.

But flat fields are also important for taking "pretty pictures," too. It is difficult – sometimes impossible – to process an image that has variable levels in the background. Dim areas of an image get lost in the brighter portions of the background. A properly executed flat field can completely solve such problems. Getting to a flat, even background is very important no matter what kind of images you take.

A good flat field will correct for any shadows and reflections in your optical system. Any gradient in the background that remains after a good flat field is either caused by brightness in the sky itself, as from the moon or a bright planet; light pollution; or by off-axis light sources that cause additional internal reflections. Creating a counter gradient and subtracting it can remove gradients, but you will almost always loose some image quality in the process.

Flat Fields

Figure 13 shows the settings to use for taking a flat field. The exposure time need not (and mostly will not) match the exposure time of the original image. Likewise, the temperature need not be the same. You will need to take a separate dark frame (or set of dark frames) that match the temperature and exposure time of your flat field frames. If you apply a flat field individually to an image, apply the flat's dark frame first. If you use reduction groups, the dark frames for the flat field frames are part of the group, and will be applied to the flat frame automatically. In figure 13, the Frame type has been set to "Flat-Field," and the Reduction drop-down list is automatically disabled.

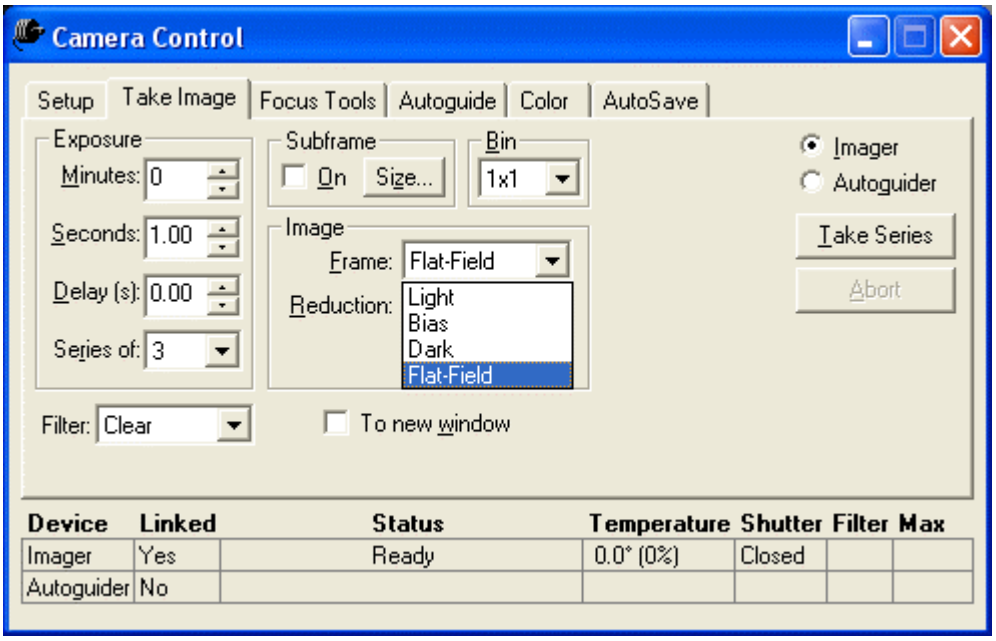


Figure 13: Setting for taking a flat-field exposure.

The obvious question about a flat field is how to long to expose. The goal is to have a flat-field image with an average value that is about 33-50% of the CCD detector's saturation level. The table below summarizes the ideal range for flat-field images for various SBIG cameras binned 1x1. For other camera brands, or for binned images, you will need to calculate the saturation level yourself, using the following formula:

$$\frac{full\ well\ capacity}{electrons\ per\ ADU}$$

The full-well capacity is the largest number of electrons that a pixel can hold, and is normally available in the technical specifications for the CCD detector. “Electrons per ADU” is called the gain of the camera. “ADU” stands for Analog to Digital Unit, and is a single brightness level.

Each camera also has a certain number of bits that are used to perform the analog to digital conversion. The ST-7E, for example, uses 16 bits, which provide a maximum value of about 65,500 units. The ST-237 uses 12 bits, with a maximum value of 4096. If the saturation level is greater than the maximum value based on the number of bits, use the number based on the number of bits.

Table: Saturation values for flat-field frames
Average value of the brightest area should fall between 33% and 50% of saturation.

Camera/ Guider	Full Well Capacity	Gain *	Calculated Saturation	Effective Saturation	33% *** Saturation	50% *** Saturation
ST-4 8 bits	80,000	150	533	533	175	250
STV 10 bits **	20,000	4.0	5,000	1024	350	500
ST-5C 16 bits	50,000	2.0	25,000	25,000	8,500	12,500
ST-237 12 bits	20,000	4.0	5,000	4.096	1350	2000
ST-6B 16 bits	400,000	6.7	59,700	59,700	20,000	30,000
ST-7E ABG 16 bits	50,000	2.3	21,740	21,740	7,250	11,000
ST-7E NABG 16 bits	100,000	2.3	43,500	43,500	14,500	21,750
ST-8E ABG 16 bits	50,000	2.3	21,740	21,740	7,250	11,000
ST-8E NABG 16 bits	100,000	2.3	43,500	43,500	14,500	21,750
ST-9E 16 bits	200,000	2.8	71,400	65,000	21,600	32,500
ST-10E 16 bits	77,000	1.5	51,000	51,000	17,000	25,500

** Electrons per ADU*
*** Varies with binning mode; see SBIG documentation*
**** Rounded values for easy memorization*

Note: CCD detectors and CCD cameras have natural variations in their full-well capacity and gain settings. The numbers shown in the table for saturation are only approximate.

Note: When measuring brightness of a flat-field image, be sure to average a small group of pixels so that a single bright pixel won’t throw off the reading. To find the value of a pixel in CCDSoft, pass the mouse

cursor over the image. The coordinates and brightness value appear on the status bar at the bottom of the CCDSoft window.

Figure 14 shows a flat-field frame that illustrates several things you might find in your own flat fields. The center is brighter than the edges. Figure 14 makes this look fairly dramatic, but the background and range have been adjusted to emphasize the variations to make them clearer. The actual brightness variation between the center and the corners is actually quite small, about 30 ADU (brightness levels). The small circles are shadows of dust or dirt on the front of the ST-8E camera. Small shadows generally indicate dust that is very close to the chip. Larger shadows are cast by dust further away, such as on a filter in a filter wheel.

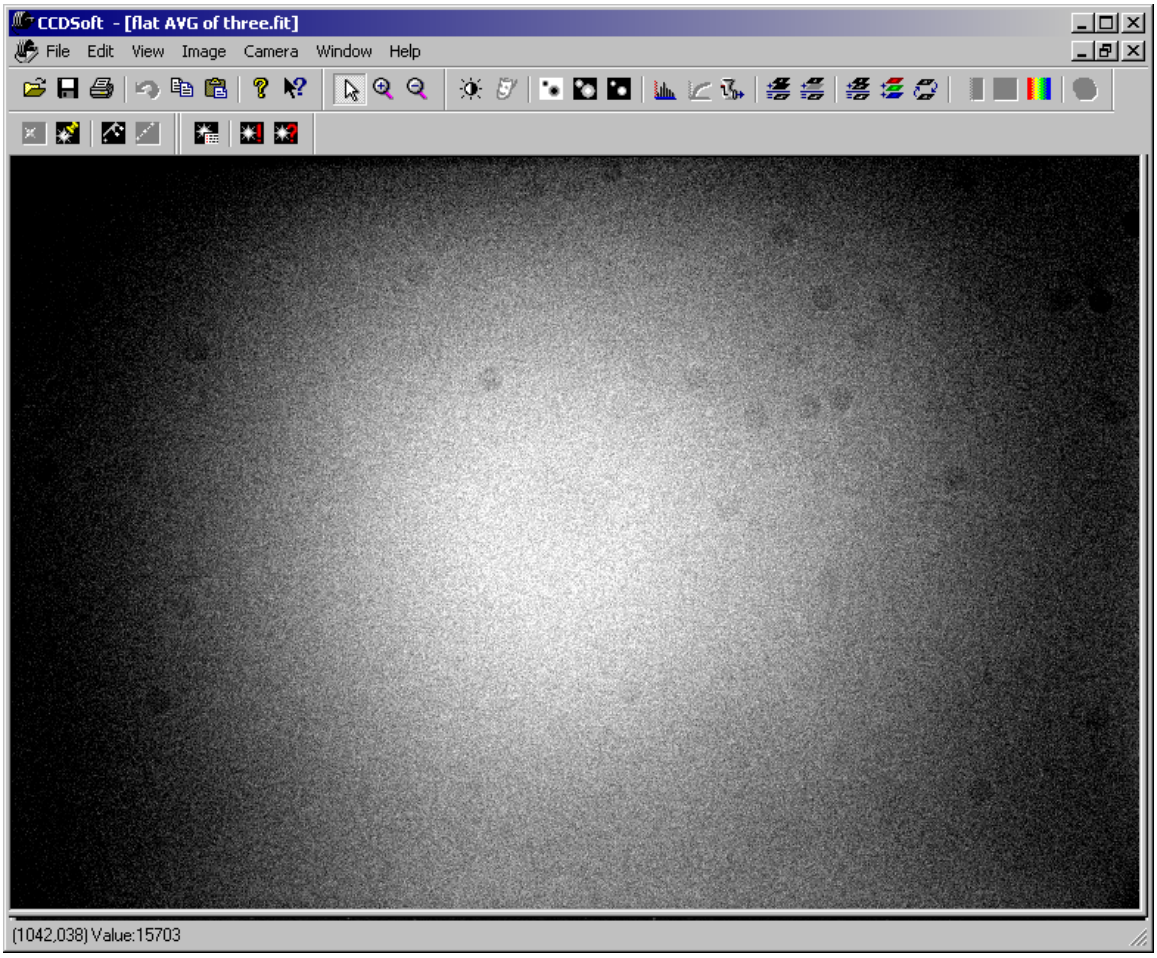


Figure 14: An example of a flat-field frame.

Figure 15 shows a flat field from an anti-blooming version of the ST-8E camera, using a different optical setup. The brightness pattern is completely different from figure 14. In figure 14, there was a CFW-8 filter wheel in the optical path, and it caused some vignetting (darkening near the edges) because the telescope had a focal ratio of f/5. Figure 15 shows a bright center and a bright ring, as well as some dust that is a little heavier than in figure 14.

Also prominent in figure 15 are horizontal bars. These are natural artifacts of some anti-blooming CCD detectors. They are completely removed by a good flat field.

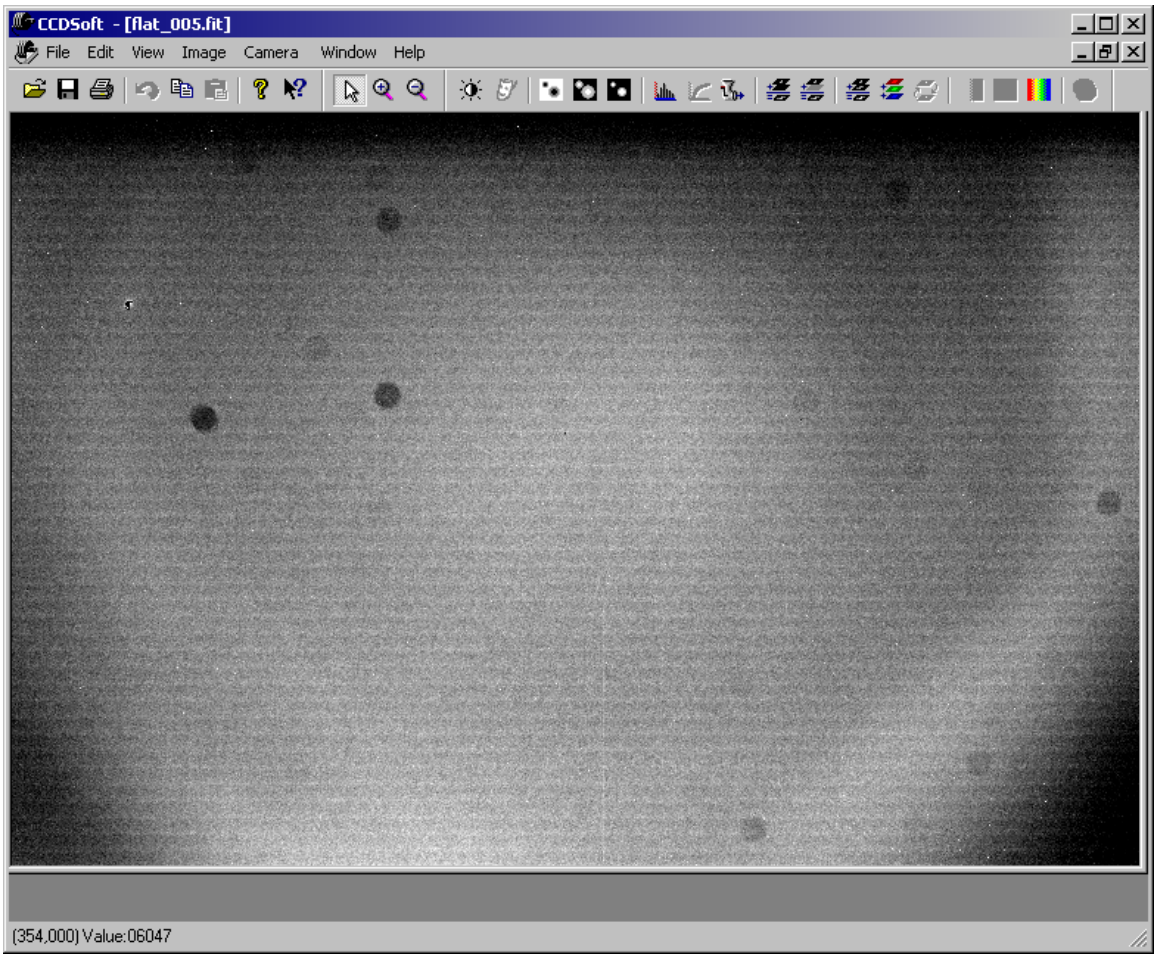


Figure 15: An example of a flat field taken with an anti-blooming camera.

The best way to take a flat field depends on your telescope and overall optical configuration. Here are some suggestions for different ways to take a flat field; you can try them to see which provides the best results for you.

Taking a Flat Field Image

The idea behind a flat field is simple: Using the same focus position you use for taking light images, take an image of an evenly illuminated surface so that you achieve approximately one-third to one-half the saturation level of the CCD chip. Here are some things to keep in mind when taking a flat field:

Same focus position – The flat field is a snapshot of your optical system in a particular arrangement. If you change the focus position, the relative positions of the optical elements

change, and any dirt or dust will cast different shadows, and reflections will change as well. To get a useful flat field, the optical system must be in the same position as when used for astronomical imaging.
Take an image – The flat field is an image of something. That means that it must be treated like any other image: it will need a dark frame, for example.
Evenly illuminated surface – Whatever it is that you are taking a picture of when you take a flat-field image, the surface needs to be evenly illuminated. Otherwise, the flat field isn't really flat. The flat field represents the variations from flat illumination caused by your optical system. If the surface you are imaging is not evenly illuminated, then the flat field is only an approximation, not a true flat field. You can get away with some unevenness at times, but the more even your illumination, the better your flat field will work.

If you normally use a dew shield when imaging, make sure you also use it when you take the flat. Otherwise, off-axis illumination can cause internal reflections that vary from those that occur when you image.
Here are some things you can try for making flat field images.

- The **Two-Surface Flat** (see figure 16) involves shining a light on a flat object so that it reflects off of another flat object and into the front of the telescope. The main disadvantage to this method is that it frequently takes two people to get enough distance between the two diffusing surfaces.

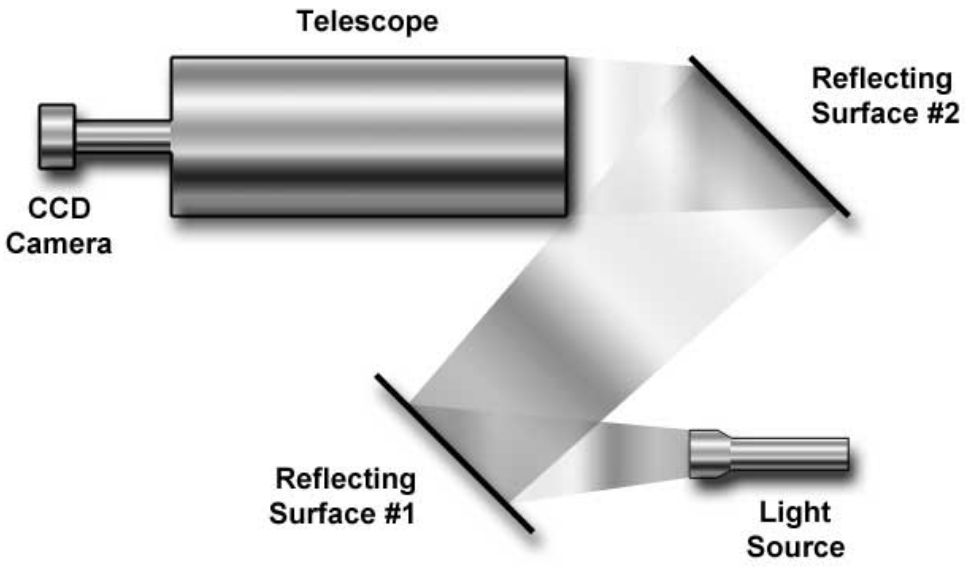


Figure 16:Taking a flat using two surfaces to diffuse light to create even illumination.

- The **Dome Flat** involves imaging the inside of an observatory or the wall of a nearby house, shed, or fence. You can use any evenly lit surface to take this kind of flat, but getting even

illumination can be tricky. Try moving the scope slightly between images, and average multiple images to improve evenness.

- The **Sky Flat** involves taking many images of the sky at twilight, and averaging them to create a flat field. You may get some dim stars, but taking 8 or 12 or even 16 images, and moving the mount between images, will allow you to combine the images by averaging to remove the stars. Figure 17 shows a typical twilight flat; figure 18 shows how averaging a dozen such images can remove any trace of stars.

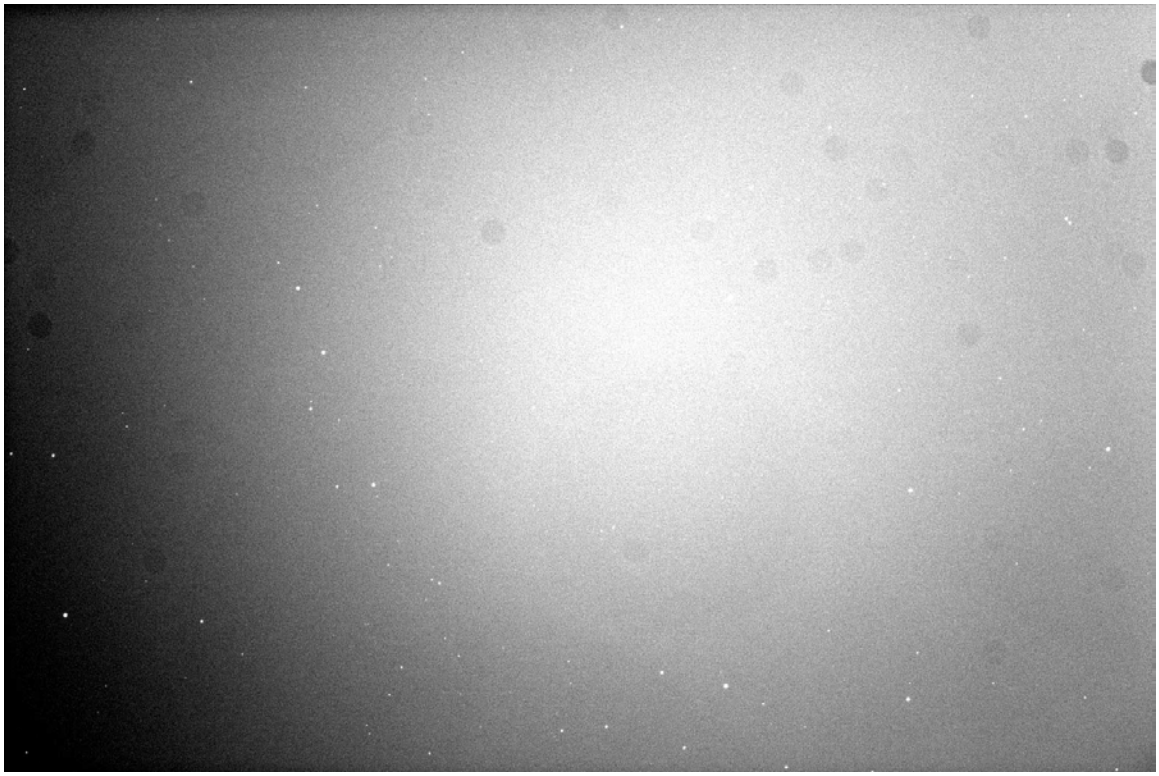


Figure 17: A single sky flat taken at twilight.

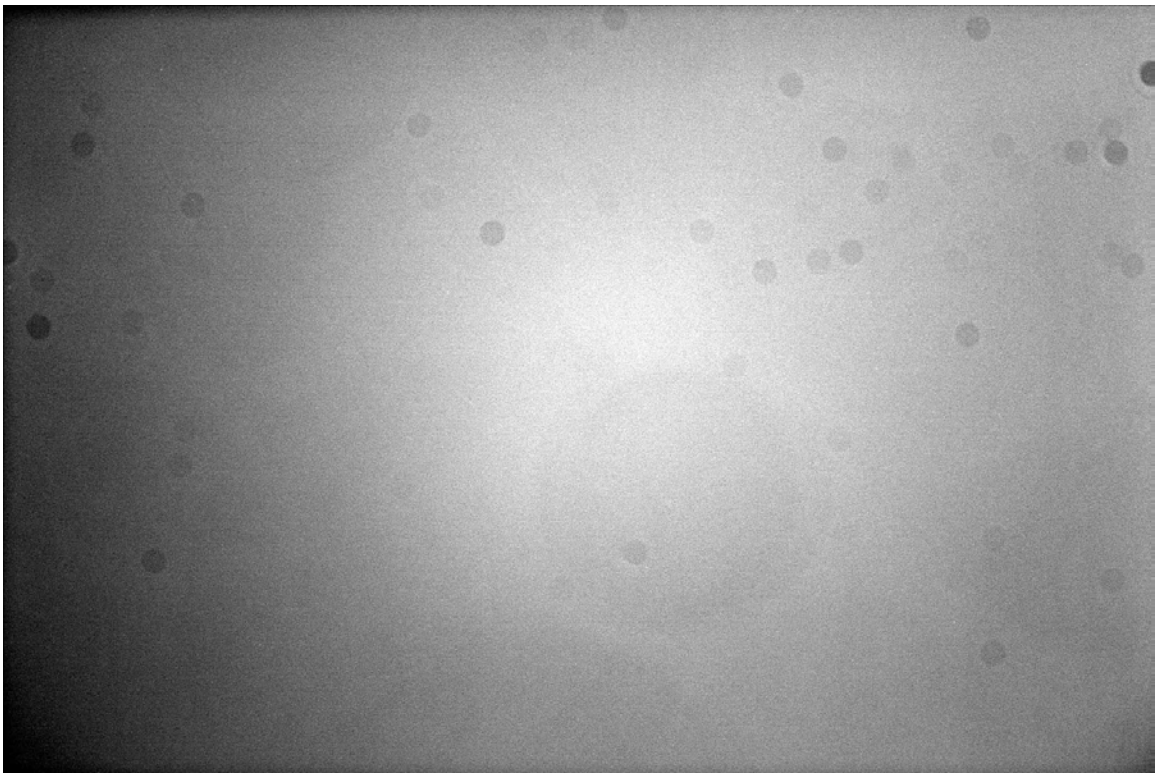


Figure 18: An average of 20 twilight flats.

- The **Light Box Flat** involves a box with a light source and a diffuser, which is placed on the end of the telescope. These are available commercially, or you can build your own. Numerous plans for light boxes can be found on the Web.
- The **T-Shirt Flat** uses a T-shirt or other white cloth over the front of the telescope. Figure 19 shows this in operation. It may not be pretty, but if you are very careful about off-axis light sources, this method can generate very high-quality flat field frames. Make sure the cloth is stretched as flat as possible across the aperture. Point the telescope away from bright lights (toward the ground in daylight) to get the most even illumination possible. The goal is to get a perfectly even, indirect light falling on the cloth. If you use a dew shield, attach the cloth, and then put the dew shield on before you take your flat field.



Figure 19: Using a T-shirt to take a flat in daylight. Be sure to point the scope away from bright sources of light.

Figure 20 shows a comparison between a good flat and a great flat. The important point is that the difference is actually very small. The sky flat in figure 20 has a brighter right edge. The T-shirt flat has a distinctly darker right edge. How do you determine which is the “better” flat field image? You apply each to a test image as described earlier in this chapter. The sky flat created a gradient in the test image, while the T-shirt flat left an even background. It is important to make sure that your flat-field setup doesn’t allow any off-axis light into the telescope. Off-axis light can reflect off of the flat surface and/or interior surfaces of the optical system and make a mess of a flat field. A dew shield can help prevent off-axis

light from being a problem. If you use a dew shield for imaging, be sure to also use it for creating your flat fields.

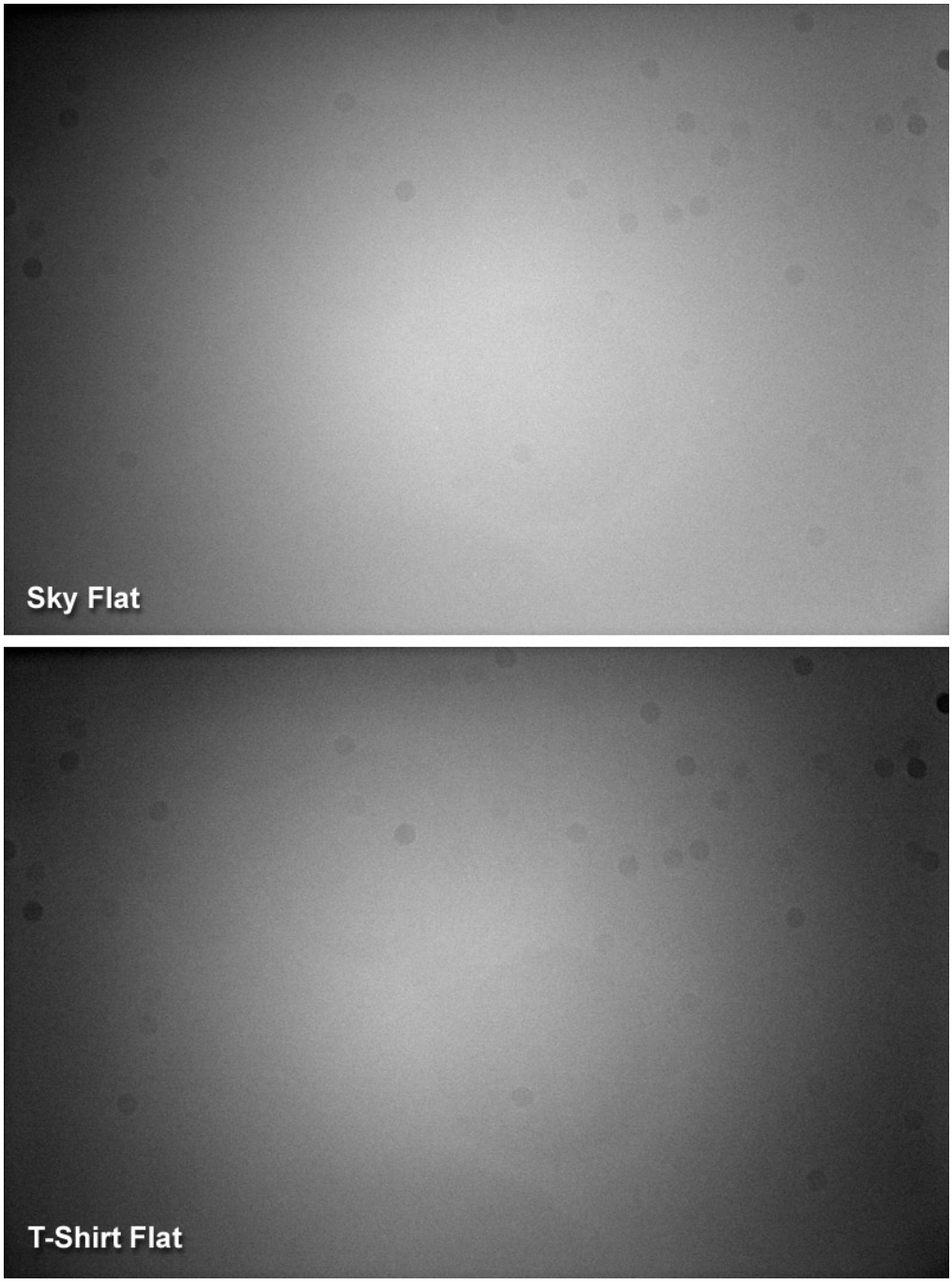


Figure 20: Comparing the results from two types of flat fields.

Figure 21 shows some examples of evaluating the quality of flat fields. Take an image that is near the zenith on a night with good transparency and minimal sky glow. Now apply your dark frame(s) to the light image. Measure the variations in the background levels. If the levels vary by only a small amount, then you have a good test image for your flat field. If you are having trouble evaluating the quality of the background numerically, you can also adjust the background and range to give you useful visual feedback. Set a low background and a very small range. This will reveal variations in the background clearly. Adjust the background and range settings (click **Image | Brightness & Contrast | Background & Range**, or press `Control + B`) to provide a fairly bright background, and then reduce the range until it is grainy and any brightness variations present show up clearly.

Figure 21 shows the differences between the results obtained with the two flat fields. The upper left image is the raw image. The upper right image had the sky flat applied to it. Note that the right side of the upper right image is darker, which indicates that the bright right edge of the sky flat was probably the result of some off-axis illumination. To get a good sky flat, the off-axis source would have to be identified and removed. If it was a streetlight, for example, putting a stepladder with a tarp over it between the telescope and the streetlight should solve the problem.

The lower left image shows the results of using the T-shirt flat. The background is almost completely even, so the T-shirt flat does a better job, and was the more accurate flat field of the two. The “optimized” version of the T-shirt flat at lower right has had the background and range adjusted for best results. The T-shirt flat in this case is the better flat because it does a better job. But with appropriate adjustments during exposure, a sky flat or any other type of flat could do just as well.

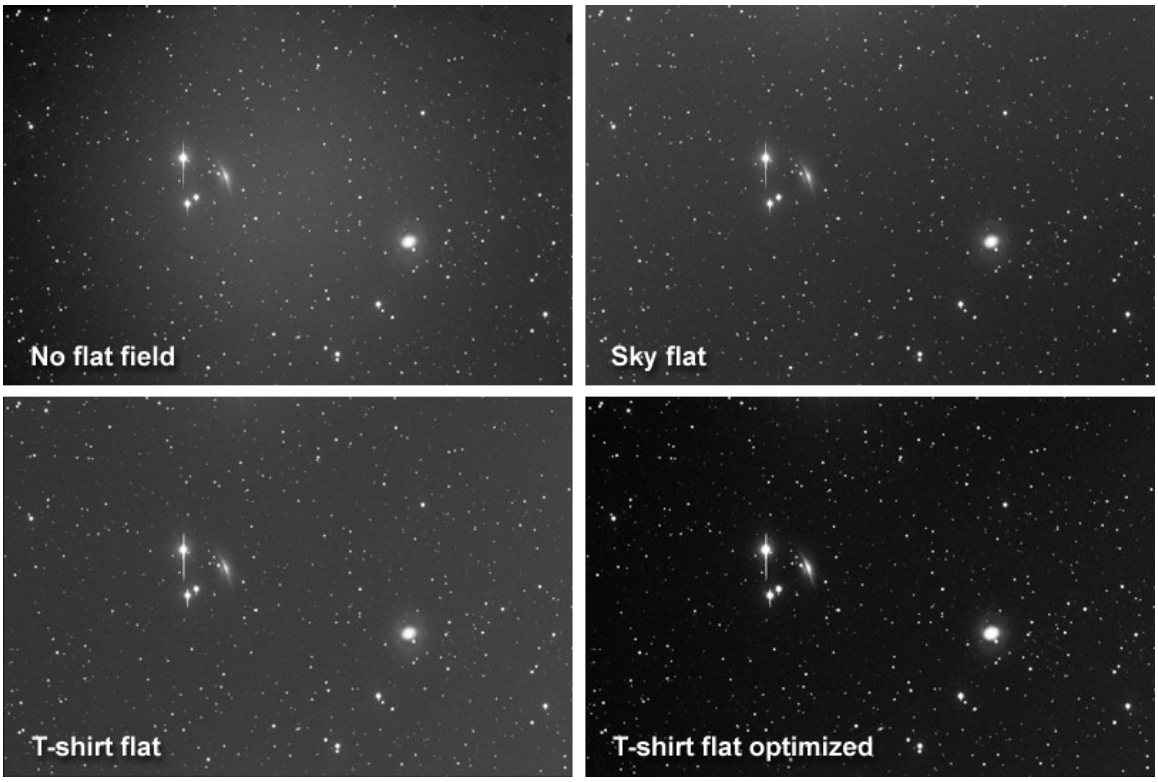


Figure 21: A comparison of results from applying two different flat fields.

Ultimately, it's a good idea to take lots and lots of flats using different methods and different equipment attached to your telescope. There is no substitute for having a deep knowledge of how light passes through your telescope. For example, the telescope used for this example does not have one edge brighter than the other; any such variation is due to off-axis light. Typically, off-axis sources are well off-axis, and it's easy to miss them, yet they can have a noticeable affect on your results. The more flat fields you take under different conditions using different techniques, the sooner you will develop the skills you need to take and apply flat-fields to your images effectively.

You can apply a single flat-field frame to an image, or you can apply multiple flat-field frames as part of a group. Unlike a dark frame, which is simply subtracted from a light frame, the flat-field frame is applied to the light frame in a more complex manner. A dark frame represents simple offsets from the accurate value, and is therefore simply subtracted from the light frame. For example, if a light frame pixel has a value of 800, and that same pixel in the dark frame has a value of 500, then the corrected value of the pixel after dark frame subtraction is 300.

For a flat field, the pixel values in the light image are adjusted using a more complex formula based on the average brightness level and the corresponding pixel in the flat-field frame. There isn't a simple relationship between the pixels in the light frame and the pixels in the flat-field frame; the entire image is used to effectively apply the flat field.

To apply a single flat-field frame to a single image, you can:

- Press `Control + F`, or

- Right click on the image and the click **Flat Field**, or
- Click **Image | Reduce | Flat Field**.

All of these choices display the Flat Field dialog box (see figure 22). This dialog box behaves similarly to the Dark Subtract dialog. You select the light frame in the top of the dialog, and the flat-field frame in the bottom. You can select either a currently open image, or a file on your hard disk for either the light or flat-field frame. In figure 22, the light frame is a file currently open in CCDSoft, and the flat-field frame is a file on the hard disk.

If you check the **Create new window** checkbox, CCDSoft will display the result of applying the flat field in a new window, leaving the original light frame untouched. If you leave it unchecked, the changes will be applied to the original light frame.

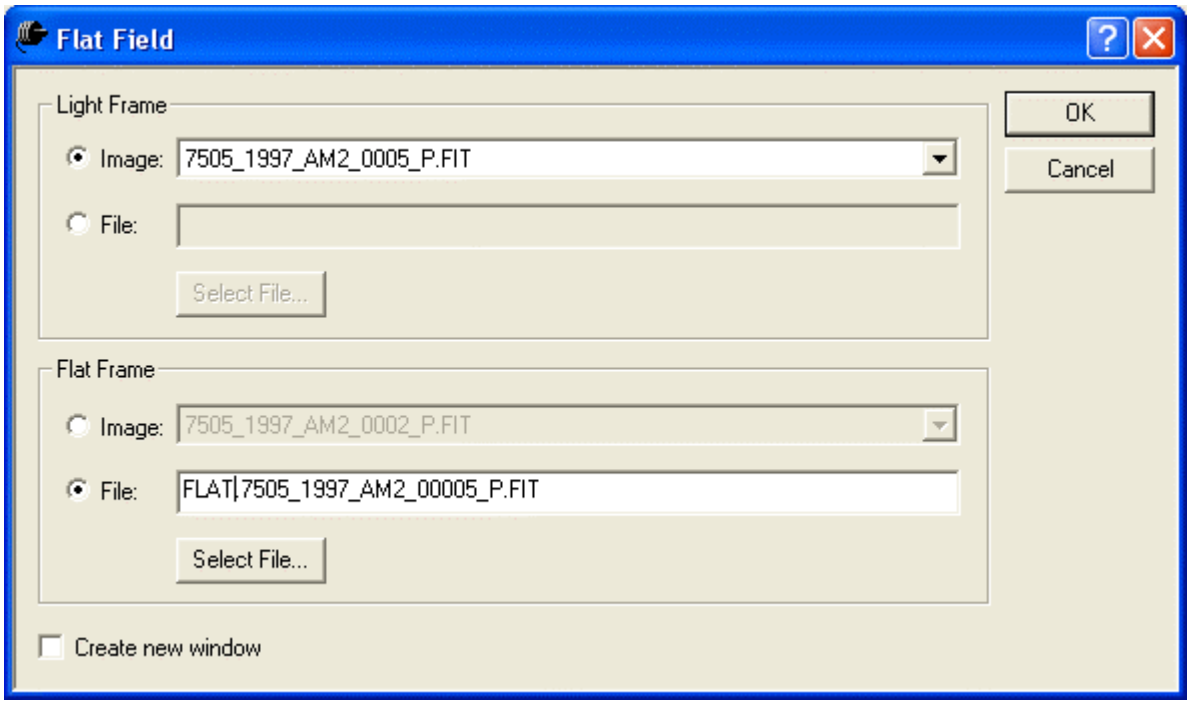


Figure 22: Applying a single flat-field frame to a light frame.

Figure 23 shows the result of applying a single flat-field frame to the image of M51 that has already had a dark frame applied to it. Note that there is a slight left-to-right gradient remaining in the image, indicating that this particular flat field isn't quite perfect. Better results can be obtained by using multiple flat-field frames, as shown later in this chapter.

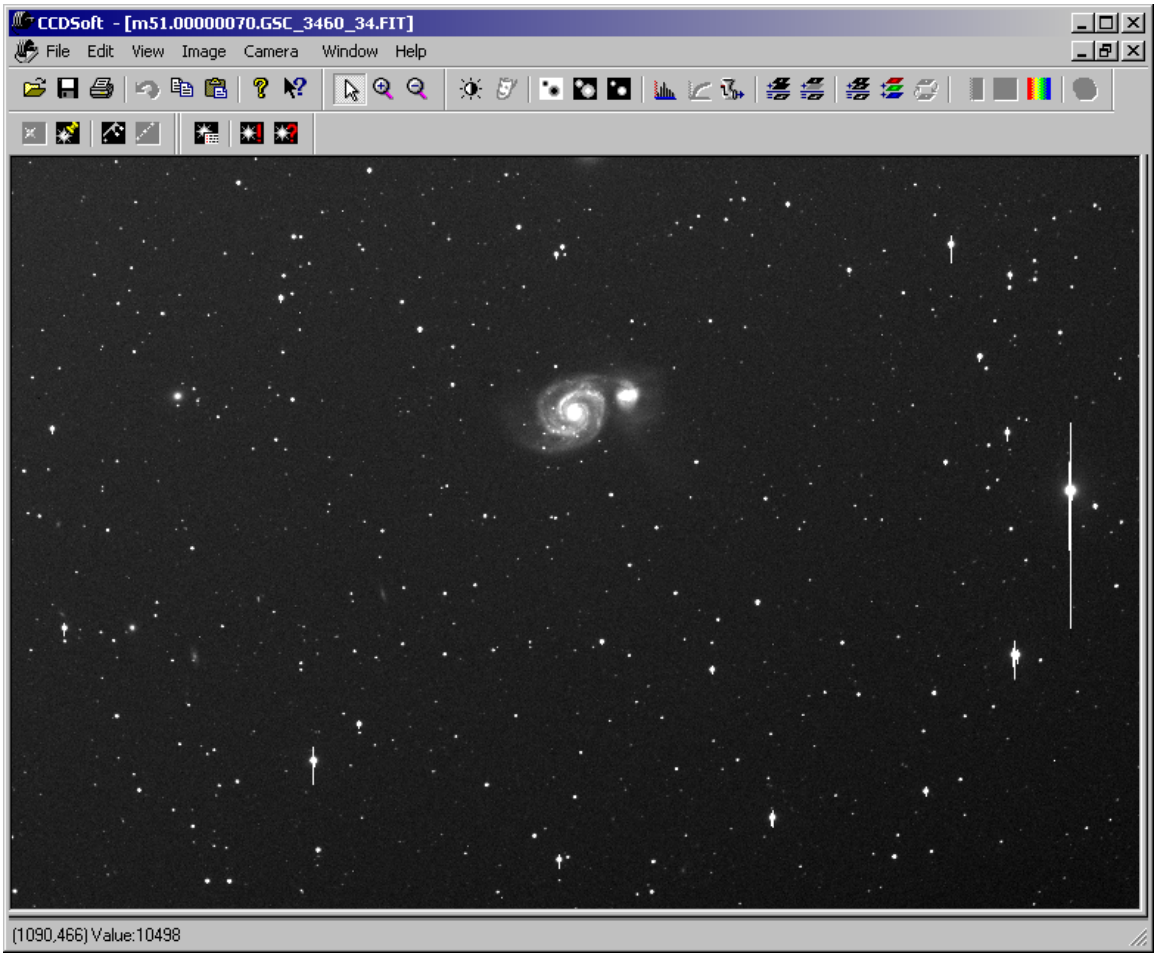


Figure 23: The results of applying a single flat-field frame. Compare to figures 11-12.

Using Reduction Groups

A single bias, dark, or flat-field frame helps considerably in improving your images. But the improvements come at a cost. Everything you do to the original image adds noise even as it removes various system effects. The ideal situation would be to take bias, dark, and flat-field frames that have as little noise as possible.

You can accomplish this by taking multiple bias, dark, and flat-field images. CCDSoft can combine these images in ways that reduce overall noise. It can even apply the combined images automatically when you are taking images with the camera (see the next section).

Creating Reduction Groups

Before you can create a group, you must take the bias, dark, and flat-field frames you plan to include in the group. To build the group, click **Image | Reduce | Image Reduction,** or press `Control + R`. Figure

24 shows the Image Reduction window. By default, there are two groups: Imager and Autoguider. You can add bias, dark, flat-field, and darks for flat-field frames to these groups, or create your own groups.

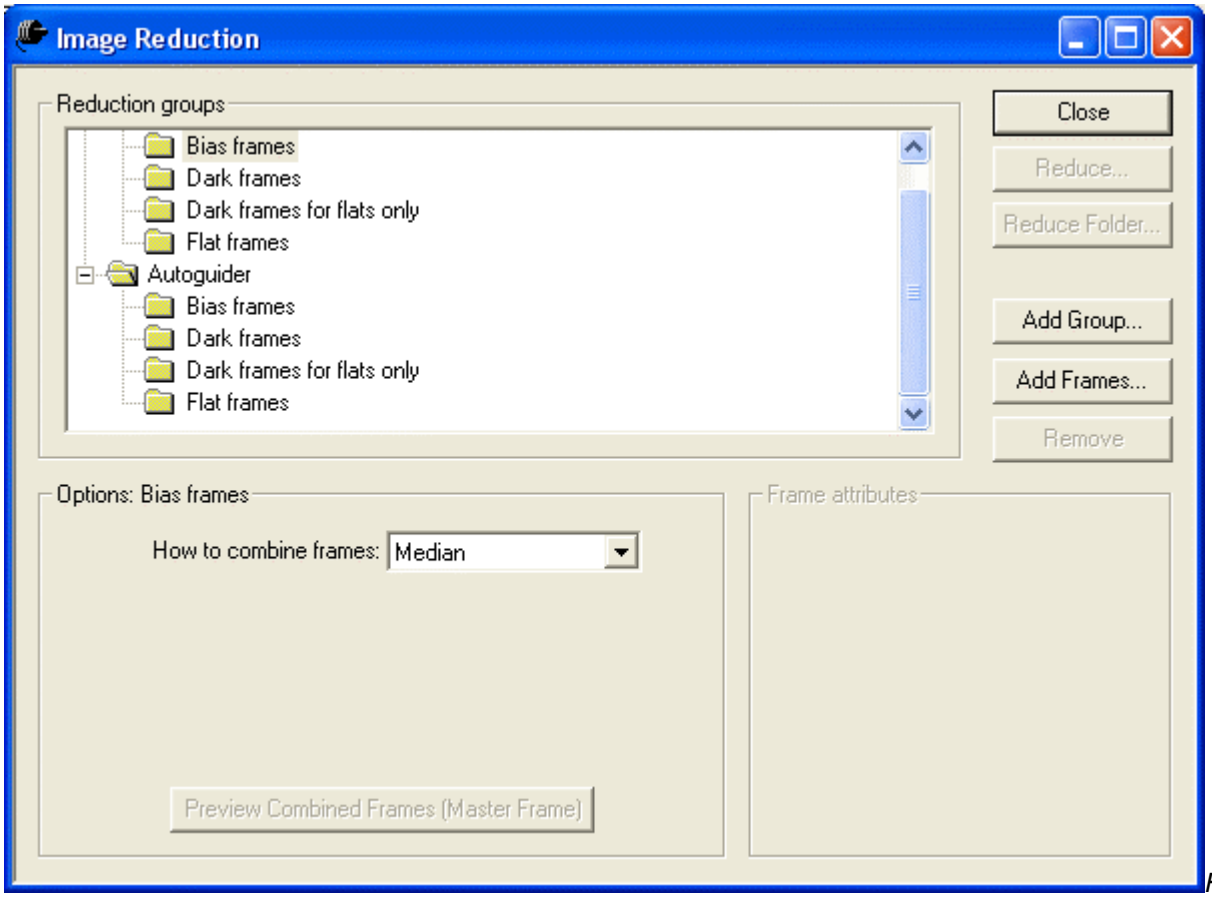


Figure 24: The Image Reduction Window.

To create a new group, click **Add Group**. This displays the Add Group dialog box (see figure 25). Type in the new group name, and click **OK** to add the group to the list. The new group will automatically contain folders for bias frames, dark frames, dark frames for flats only, and flat frames.



Figure 25: Adding a new group.

To add individual images to your group, click on the sub-group name (Bias Frames, Dark Frames, Flat Frames) to highlight it, and click **Add Frames**. This opens the appropriate Select Frames dialog box. Navigate to the folder that contains the desired files, and click to highlight them. You can add more than one frame at a time; use `Shift+Click` and/or `Control+Click` to select multiple images. Click **Open** to add the files. Figure 26 shows multiple files added to all four sub-groups. You can resize the Image Reduction window to see long filenames, or you can pause the mouse over a specific file to see the entire name in a popup. Click on the plus and minus icons at the left of the sub-group names to view or hide the files in the sub-groups.

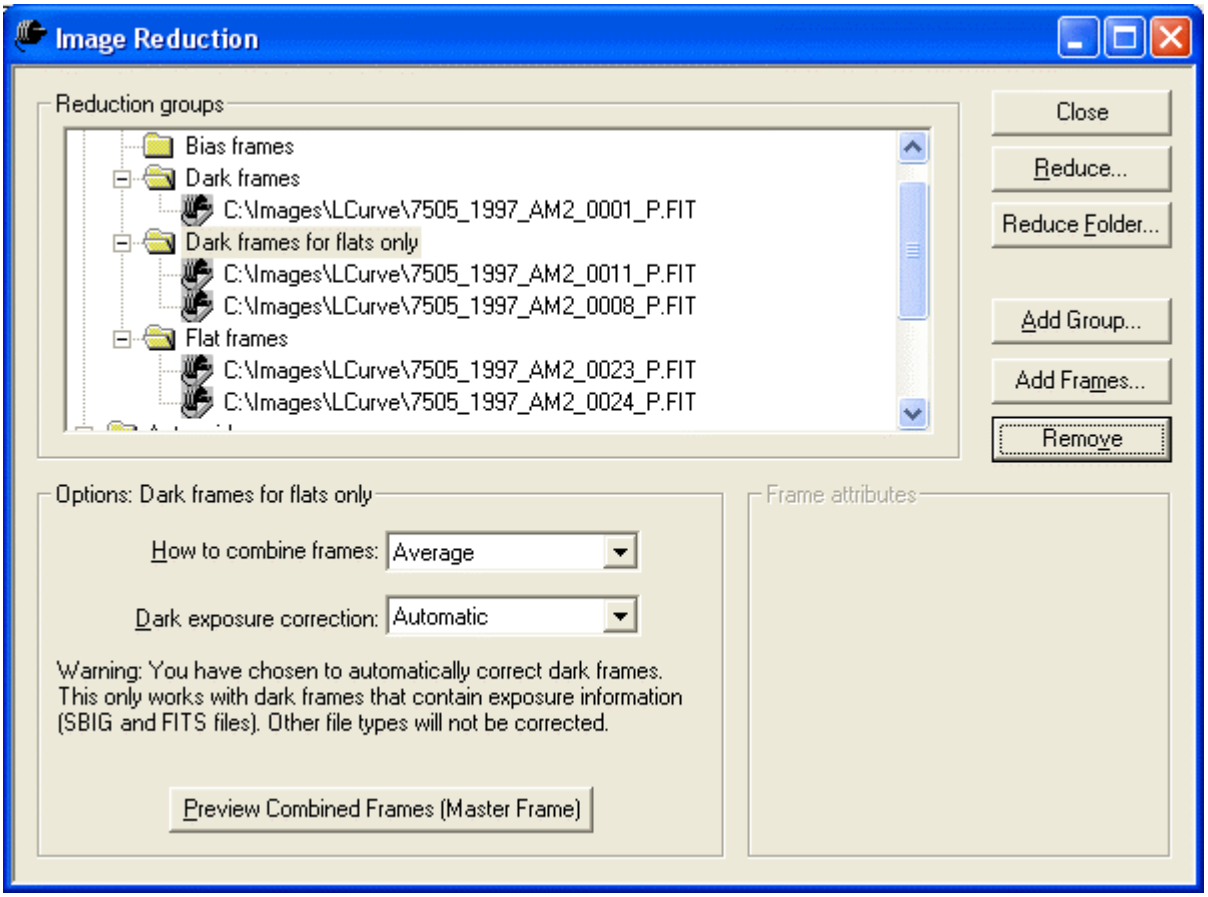


Figure 26: Files added to the bias, dark, dark for flats, and flat frames sub-groups.

When you apply a reduction group to an image or a folder of images, CCDSoft will create master frames by combining the images. A master frame is the result of combining all of the frames of a given type. There is a master frame for the bias frames, a master frame for the dark frames, etc. The master frames are created automatically the first time you use a reduction group. The master frames are also updated automatically the first time you use a reduction group after adding, deleting, or otherwise changing the frames in a reduction group.

You can create a copy of the master frame for any one sub-group at any time by clicking **Preview Combined Frames (Master Frame)** near the bottom of the Image Reduction window. A copy of the master frame appears in a window, and you can examine it to make sure it meets your requirements.

The **Remove** button acts differently depending on what you highlight in the Image Reduction window:

- If a single frame is highlighted, the frame is removed from the group.
- If a sub-group is highlighted, the frames in the sub-group are removed. The sub-group itself remains.
- If a group name is highlighted, the frames in all sub-groups of the group are removed. If the group is a default group (Imager and Autoguider are the default groups), the empty group remains. If the group is one you created, the group is also removed.

If you double-click on a file in a sub-group, the file opens in a new window.

Setting Reduction Group Properties

You can specify how CCDSoft should combine frames in a sub-group. For example, if your sub-group contains 4 dark frames, you can choose how to combine them: average or median.

Average – The brightness of each pixel in the combined image is the average of the values in the same pixel in all of the images in the group. Summing the pixel values, and dividing by the number of images in the sub-group calculate the average.

Median – The brightness of each pixel in the combined image is the median of the values in the same pixel in all of the images in the group. The median is the value in the middle of the distribution of brightness levels. There are equally many values larger than the medium as there are smaller.

In addition, the Image Reduction dialog box contains options for how dark frames are applied to your light images and flat frames:

Option	Values/Description
Dark Exposure Correction	**None** – No exposure correction occurs. The dark frame is simply subtracted from the light frame. It's up to you to make sure that the exposure times for light and dark frames are the same.
	Automatic – CCDSoft reads the file header to obtain exposure and temperature information, and uses this information to scale the dark frame before applying it to the light frame. Only file types that contain header information, such as FITS and SBIG files, work with this option.
	Manual – The dark frame is scaled using numeric values that you supply, using either duration or a multiplier.
Manual Correction	**Duration** – Enter a number specifying the exposure length of the dark frame. This value will be used by CCDSoft to scale the dark frame for light exposures that have a different exposure length. This option is useful for file types that do not store exposure information in a file header, such as TIFF files.
	Multiplier - The dark frame will be scaled by the specified amount before it is subtracted from the light frame. Use this option when you know the exposure time of the dark frame and the light frame, and can calculate the multiplier yourself.

To set the options for Bias, Dark, and Flat Frames, click to highlight the sub-group or any file in the sub-group; the options appear in the area below the list of files in the group (see figure 27). Note that, when an individual filename is highlighted, the attributes for the file appear in the Frame Attributes area at lower right. The attributes can help you identify which file is which, and can help you determine whether you have the correct files included in the group. The Frame Attributes are especially helpful long after you take images or create reduction groups.

Note: the dark frames you add to a group should all have approximately the same exposure duration. If you try to combine dark frames with very different exposure durations, you will add a lot of noise to your images. For the cleanest, lowest-noise reduction, use dark frames with identical exposures.

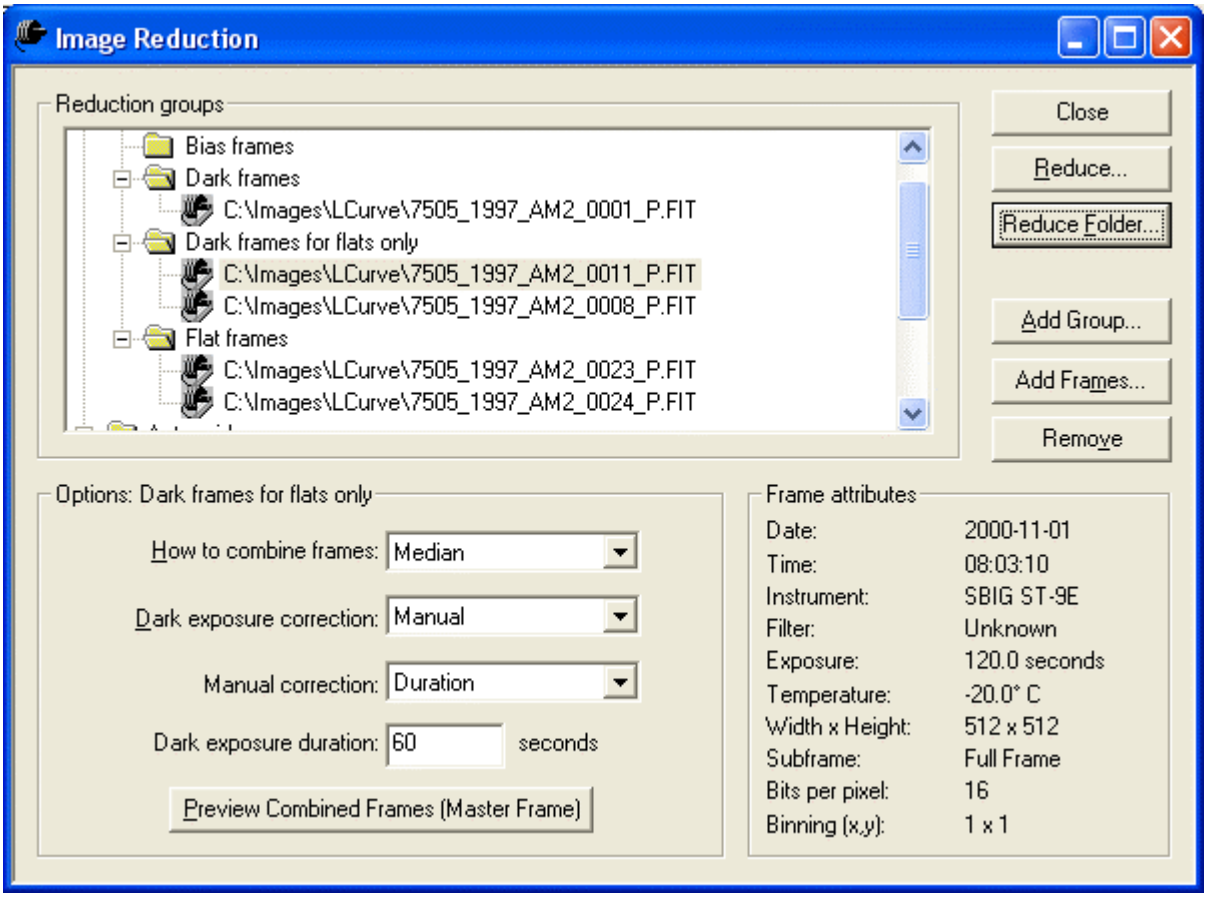


Figure 27: Setting Dark Frame options.

Reducing a Single Image

To reduce a single image, open the image in CCDSoft and then open the Image Reduction window (press `Control + R`). Click **Reduce** to open the Reduce Now dialog box (see figure 28). If this is the first time you have used the group for reduction, there will be a delay while CCDSoft builds the master bias, dark, dark for flat, and flat-field frames.

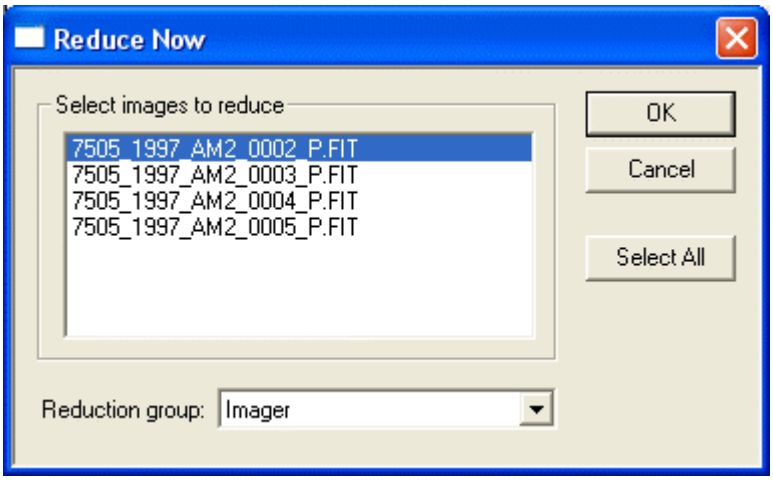


Figure 28: Reducing open images.

Figure 29 shows the results of applying a reduction group to the image of M51 used for earlier examples in this chapter. There is very little noise in the enlarged inset portion of the image, and the overall effectiveness of the flat field is better because variations from one flat field exposure to the next have been averaged. There is still a light gradient from left to right (brighter on the left), which was due to light pollution from a nearby streetlamp and cannot be fixed by image reduction.

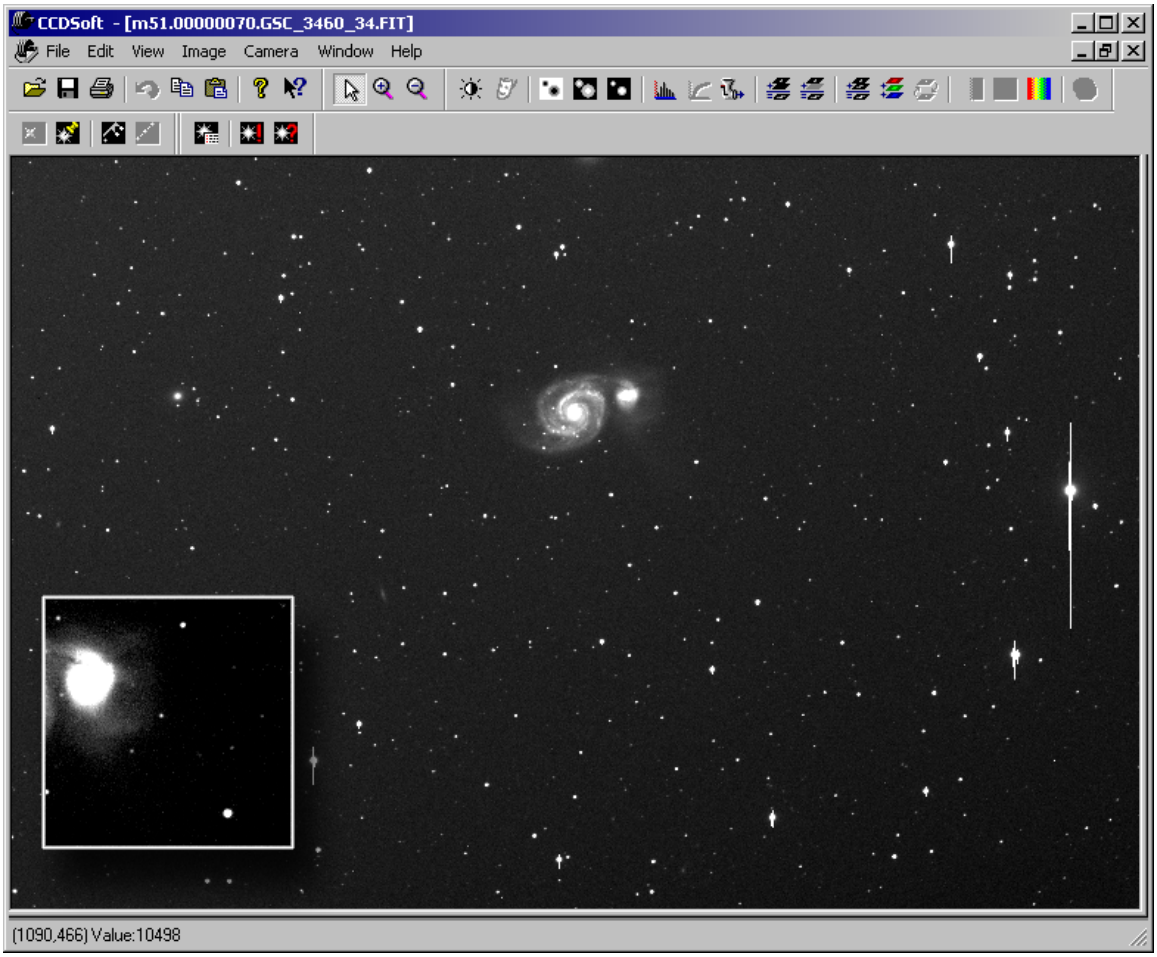


Figure 29: Results of applying a reduction group to the M51 image. Compare to figures 12 and 23.

As with a single flat field, you can evaluate the correction of an image reduction group by examining the background brightness values. Pass the mouse cursor over the image, and look for consistent brightness levels in the background. Gradients due to sky glow, moonlight, or light pollution make it harder to evaluate the quality of a reduction. Use an image that has a known flat background to evaluate the quality of your reduction, such as an image from a dark site taken near the zenith.

Reducing a Folder of Images

You can also use the Image Reduction window to reduce all of the images in a folder. This is convenient for many imaging situations – color images with many images taken at the same time and temperature, for example, or an evening's worth of images when hunting for supernovas, comets, or minor planets. Click **Reduce Folder** to open the dialog box shown in figure 30.

- Click on the top **Choose Folder** button to locate the folder with the images you want to reduce.
- Click on the lower **Choose Folder** button to locate the folder where the reduced images are to be saved.
- Choose the **Reduction group** from the drop-down list at the bottom of the dialog box.

- Click **Reduce** to start the reduction process.

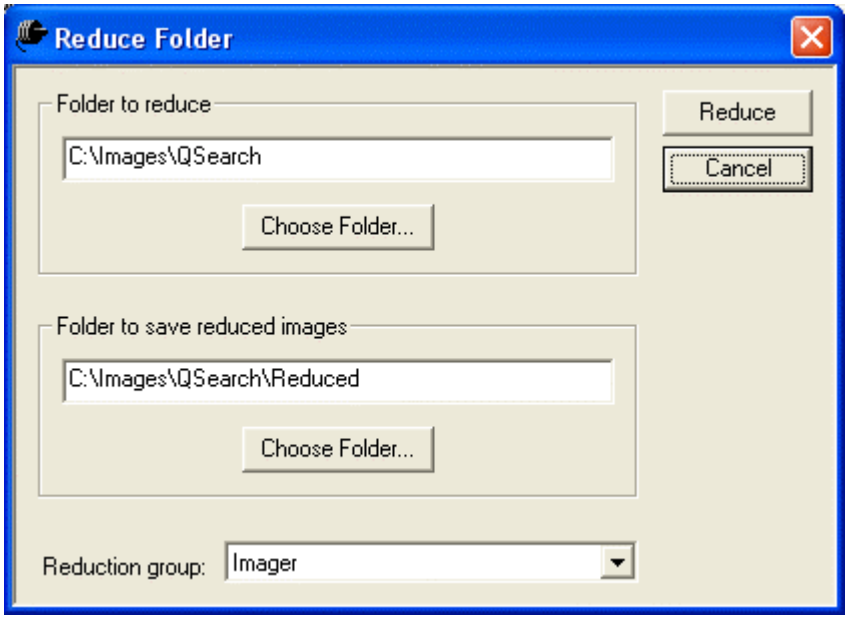


Figure 30: Reducing all of the image in a folder

Reduction Group Strategies

A reduction group is simply a collection of bias, dark, flat-field, and dark-for-flat-field frames. You can use dark frames taken at any exposure or temperature, so it is up to you to make sure that the right files go into each group you create. It is typical to create a number of groups for a given night's images, with each group being used for one or more of your light images.

For example, suppose you took the following images in one night:

- Ten one-minute images of M51.
- Ten two-minute images of the Owl Nebula.
- Four 10-minute images of M101.

You could create two or three reduction groups. If you created two groups, you would use 90-second darks in one group, and 10-minute darks in the second group. You could reduce both your M51 and Owl Nebula images with the first group, and your M101 images with the second group. CCDSoft would scale the dark frames in the first group for the differences in exposure times. The 90-second exposure for dark frames is halfway between the exposure times of the M51 and Owl Nebula images.

Note: Bias frames are optional. However, if you scale dark frames, you should include bias frames in your reduction groups. The bias frames allow CCDSoft to scale the dark frame more accurately.

Flat fields typically require exposures that are different from light frame exposures. As a result, you will often use a separate dark frame for your flat fields. There is a special heading in the Reduction window where you can add dark frames that are for flat fields only. If you do not add any dark frames for the flat-field frames, no dark is subtracted from the flat fields.

Color imaging often involves taking images that have different exposure times. You should normally use several reduction groups for a single set of color images. The ST-7E camera with a CFW-8 color filter wheel, for example, generally works best with exposures having a ratio of 1:1:1.6. If you intended to image the galaxy M101 in color, you might plan to take the following images:

- 5 luminance images with an exposure of 5 minutes each, binned 1x1.
- 3 red and 3 green images with exposures of 10 minutes each, binned 1x1.
- 3 blue images with exposures of 16 minutes each, also binned 1x1.
- 4 flat-field images at 40% of saturation, with exposures of 10 seconds each.

You could create one, two, or three reduction groups for these images. The difference between the groups would be the exposure time for the dark frames:

- **Method #1**: Create one group, with an average dark frame exposure time suitable for all light images. Use dark frames with an exposure time between the shortest and longest exposures: 10 minutes, for example. Your darks would not perfectly match all of the light images, and there would be some additional noise in the final image as a result. A good reduction group using this approach could include:
  - 3 dark frames at 10 minutes each.
  - 3 bias frames.
  - 3 dark frames at 10 seconds each for the flat-field frames.
  - 4 flat-field frames at 10 seconds each.
- **Method #2**: Create two groups, with each having an average dark frame exposure time suitable for some of the light images. Use darks of 5 minutes in one group (for the luminance images), and 13 minutes in a second group (for the red, green, and blue images). The two groups could look like this:
  Group one:
  - 3 dark frames at 5 minutes each.
  - 3 bias frames.
  - 3 dark frames at 10 seconds each for the flat-field frames.
  - 4 flat-field frames at 10 seconds each.

  Group two:
  - 3 dark frames at 13 minutes each.
  - 3 bias frames.
  - 3 dark frames at 10 seconds each for the flat-field frames.
  - 4 flat-field frames at 10 seconds each.
- **Method #3**: Create three groups, with each having a dark frame exposure matched to specific light images.

Which method should you choose? It depends on your needs. If you want to get the greatest possible benefit from your dark frames, then use method #3 with three groups. If you are working at very cold temperatures (for example, -33ºC), you might feel that the noise levels are low enough to use method #1 with a single group of darks. CCDSoft will scale the darks to match the actual exposures, but this scaling introduces some inaccuracies into the process. If you are imaging at a warmer temperature (for example, -22ºC), then you might choose method #2.

Automatic Reduction

There is a third way to do image reduction: automatically when you acquire an image. The **Take Image** tab in the Camera Control Panel (see figure 31) provides a **Reduction** drop-down list in the Image section, with options for:

- No automatic reduction (choose **None**).
- Take a single dark frame (choose **AutoDark**) and apply it to each image.
- Apply a reduction group to images as they are downloaded (choose **Bias, Dark, Flat**).

If you select **Bias, Dark, Flat**, the Group option appears. Pick a reduction group from the list of available groups.

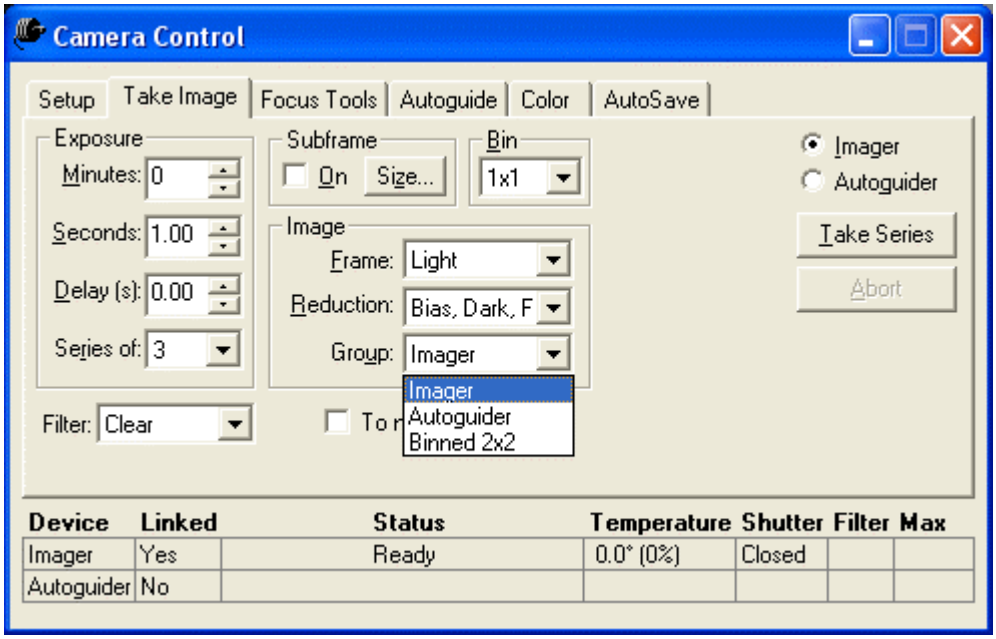


Figure 31: Setting up automatic image reduction.

We recommend turning **AutoSave** on if you are automatically applying a reduction group to your images as they are downloaded. If **AutoSave** is turned on, two versions of the file are saved: the raw image, and the reduced image. If an error occurs during reduction, the raw data is still saved to disk.

For example, if you were imaging the Antennae galaxies, then the two filenames could be:

```
00000045.Antennae.FIT
00000045.Antennae.REDUCED.FIT
```

If you have TheSky running on the same machine, the filename will also include information supplied by TheSky about the current pointing position of your mount. If AutoSave is turned off, only the reduced version of each image appears in a window in the CCDSoft workspace. If an error occurs during reduction, the original data is lost.

Chapter 8: Research: Astrometry and Photometry

The tools included in CCDSoft version 5 open new doors into the world of astronomical research. Professional-level tools are now available to the amateur astronomer. This includes both behind-the-scenes algorithms to "crunch the data," and tools that allow you to visualize your data.

This chapter describes how to perform various research tasks using the astrometric and photometric tools available in CCDSoft. You'll learn how to:

- Add astrometric data and object inventories to your images (pre-analysis).
- Search for minor planets and supernovas.
- Generate light curves for minor planets and variable stars.
- Generate minor planet or comet observation reports to submit to the International Astronomical Union.
- Analyze data visually, using tools such as the blink comparator, sky charts, and Digitized Sky Survey images.

The object inventory is created using Source Extractor, an advanced data source extraction tool. Source Extractor scans your image for objects, and it is effective at finding faint stars in CCD images. Professional astronomers also use Source Extractor, but when combined with the visual tools built into CCDSoft it offers unprecedented ease of use and power for amateurs.

For Experienced Users

For this chapter, an experienced user is someone who has previous experience creating astrometric solutions for CCD images, or who has taken CCD images and used them to search for minor planets or supernovas, or who has constructed light curves using CCD images.

CCDSoft allows you to perform astrometry and photometry with unprecedented ease. For example, you can:

- Search for minor planets and comets (moving targets).
- Search for supernovas (stationary targets).
- Create light curves for minor planets and comets (moving targets).
- Create light curves for supernovas, novas, and variable stars (stationary targets).

To perform research on your images, follow these steps:

- You must have TheSky version IV level 5.00.014 or later installed to perform astrometry and photometry.
- Acquire a series of images appropriate to the task:
    - When searching for moving targets, at least three images for each area of the sky are required.
    - The time interval between subsequent images depends on your image scale. See the formula in the section, "Searching for Minor Planets and Supernovas." Typically, time intervals of 15 to 45 minutes are adequate.
    - For light curves, obtain data covering about 125% of the expected cycle time to get a clear picture of the period.
    - For light curves, make sure that the two reference stars you will use are on all of the images.

- Pre-analyze the images. This finds objects in each image, creates an astrometric solution (also called a plate solution), stores astrometric data in the image header, and optionally creates an inventory file (with a .SRC extension).
- Once pre-analysis is complete you can perform searches and create light curves.

The astrometric, photometric, and research functions break a lot of new ground and we suggest you read through this chapter before you start collecting data. These tools are sophisticated, and the vast majority of functions are automatic. But we have also included the ability to adjust the automatic settings, and this chapter contains the information you need to make those adjustments to suit your own observing program.

Principles of Astrometry and Photometry

Astrometry allows you to determine the coordinates of the objects in your images. Photometry allows you to measure the magnitude (brightness) of the objects in your images.

CCDSoft stores astrometric information in the image itself (as part of the FITS header). Photometric information is saved in source extraction files created by the **Research | Show Inventory** command. A source extraction file is created in the same folder as the image, and it is given the same name as the image file, except it ends with `.SRC`. A source file contains centroids of all objects in the image. A "source" is any object in an image (star, galaxy, etc.), and the process of finding them is called "source extraction."



CCDSoft performs astrometry and photometry in conjunction with TheSky Level IV version 5, a sky-charting program available separately from CCDSoft. If the TheSky Level IV version 5.00.014 or later is not present, functions that rely on astrometry and photometry are unavailable.

You can use astrometric data to determine the location of suspected minor planets or comets. You can even find objects when they are below the level of visual detection. You can also determine the position of supernovas, or measure the separation or position angle of any two objects.

Astrometry gives you a precise street map that allows you to perform any kind of position-dependent task. For example, you can take a series of images of an area of the sky, and if you find something that could be a minor planet, you can use CCDSoft to prepare a report that can be submitted to the Minor Planet Center.

You can use photometry to measure the brightness of stars. This allows you to provide accurate information about the magnitude of a suspected supernova, or create a light curve that allows you to determine the rotation period of a minor planet. You can also use photometric data to create a light curve for an eclipsing variable star, or create light curves for longer-term phenomena such as novas and supernovas.

In the past, a lot of detailed work was required to turn images into useful data. Now you can perform many steps automatically. You may still need to do some fine-tuning to fit your hardware and sky conditions, and this chapter shows you how.

CCDSoft performs astrometry by first passing the image to TheSky Astronomy Software. TheSky performs an Image Link, a feature that matches the center of the image to a specific right ascension and declination. (The image may already contain right ascension and declination information, but it might not be accurate, depending on the polar alignment accuracy of the mount when the image was taken.) TheSky then passes information about the stars in the image back to CCDSoft. This includes the stellar catalog identification numbers (for example, GSC 5554:910), the equatorial coordinates (right ascension and declination), and the magnitudes of the known stars.

CCDSoft uses this information to create what is called an **astrometric solution.** This is sometimes called a **plate solution**. It includes a list of the stars in the image, as well as an assessment of how accurately the stellar positions in the image match the stellar positions in the databases used by TheSky. CCDSoft stores the stellar information in the image header in World Coordinate System (WCS) format. The following example shows some stars from the header of an actual image. From left to right, the data shows the object sequence number, the object type, the object ID, right ascension, declination, and magnitude.

```
OBJCT000= 'Star         GSC1300:433      5.33333654  +17.13898000  10.43'
OBJCT001= 'Star         GSC1287:1351     5.31937607  +17.17525999  10.44'
OBJCT002= 'Star         GSC1287:1589     5.32955783  +17.25793699  10.56'
OBJCT003= 'Star         GSC1300:321      5.33427773  +17.12234268  10.63'
…
OBJCT040= 'Star         USNO             5.33356426  +17.06085833  15.10'
OBJCT041= 'Star         USNO             5.31935759  +17.23015556  15.20'
```

Note that stars with a “USNO” (U.S. Naval Observatory) ID use right ascension and declination for identification, so only “USNO” shows up as the ID.

Once the astrometric information is stored in the image header and the source (.SRC) file (a process we call “pre-analysis”), you can search for various kinds of objects. You can also perform operations that combine information from multiple images to generate useful data, such as light curves. CCDSoft also aligns all images in a folder using a sophisticated pattern recognition algorithm. The alignment is extremely precise, to the sub-pixel level. CCDSoft can even identify moving objects, such as minor planets, and call them to your attention if desired.



Most of the research tools that operate on a folder of images require that the images include astrometric data in the image header. For convenience, CCDSoft includes a “pre-analyze” tool that will add the astrometric information to all images in a folder. If the data quality of an image is poor, CCDSoft will alert you to the problem, and you can remove that image from the folder, then continue with pre-analysis.

You can usually get the best results from the astrometry and photometry tools by taking a series of images. The most efficient approach is to use a robotic mount such as the Paramount, with software aids like TPoint (accurate, repeatable pointing) and Orchestrate (scripting). This allows you to take multiple images of the same area or adjoining areas of the sky with excellent precision.



Most astrometry and photometry commands require that files be saved to disk in FITS format. The data reduction and research tools are designed to use certain features of the FITS format.

Here are examples of research tasks that can be performed with CCDSoft. Each of these operations takes as input a folder of images. CCDSoft organizes the images from the folder into groups. Each group consists of images that cover a common area of sky. The celestial position of each image doesn't have to match perfectly. If the image centers are within five arcminutes of each other, CCDSoft will group the images.

Minor Planet Search – CCDSoft can locate moving objects in a series of images. You can search for minor planets by taking a series of images separated by an appropriate time interval. The actual time interval depends on the apparent motion of the minor planet and the focal length of your telescope, but intervals of 15 to 45 minutes are commonly used. Shorter intervals work best for fast-moving minor planets and longer focal lengths (greater than 2500 mm). Probably the most efficient technique is to take a series of images across the sky, and then repeat the series at least two more times. This gives you three images of each portion of the sky. At least three images are needed to decrease the likelihood of false identifications.

Figure 1 shows how you can use TheSky's mosaic feature to scan for moving targets such as minor planets. The example mosaic covers an area of approximately 0.75 x 0.75 degrees. There are sixteen image areas in the mosaic. If it takes two minutes to take each image and download it, that is a total of 32 minutes to cover the entire area. You could then take a second and third set of images, and use CCDSoft to search the trio of images for minor planets.

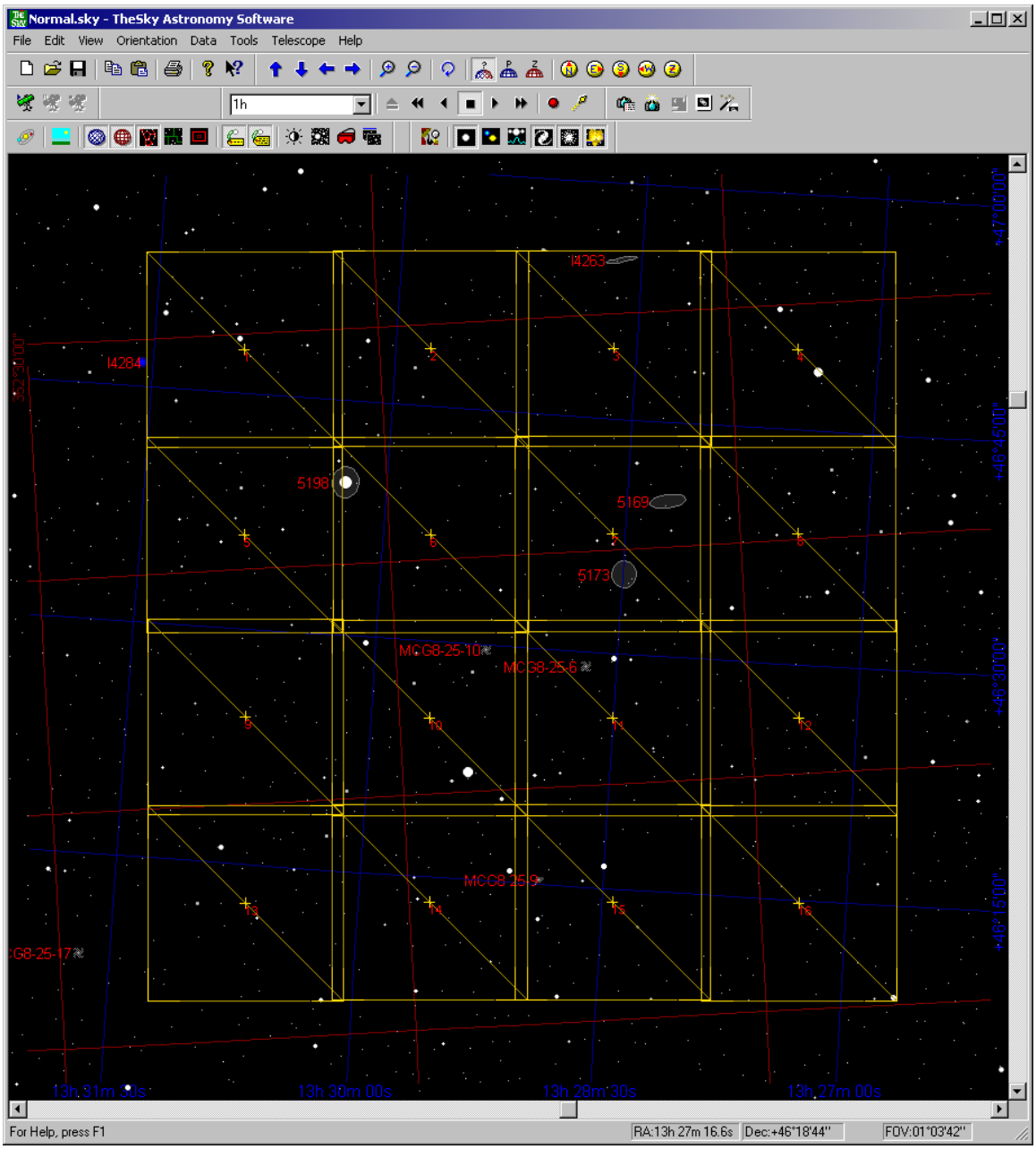


Figure 1: Using TheSky's mosaic feature to scan for minor planets.

As with any task involving multiple images, you can also use Orchestrate (a scripting tool available separately from Software Bisque) to create a script that will control the telescope and camera to collect data. After the third pass, you can process your images to look for minor planets.

Supernova Search – The mosaic technique will also work for supernova searches in areas of the sky that are thick with galaxies, such as the Virgo-Coma cluster. You can also write an Orchestrate script to

image specific galaxies. Images that do not show a supernova are still useful; you can build a library of images taken with your own equipment to use as a comparison when you suspect that you have found a supernova.

There are many other checks to perform when searching for supernovas, such as taking other images to confirm that the suspected supernova isn't just a cosmic ray hit on the CCD detector. It is often convenient to process supernova search images as they are taken so that you can re-image if necessary.

Minor Planet Light Curve – CCDSoft can measure the magnitude of both moving and stationary objects. Typically you will extract magnitude information from three objects: two reference stars whose magnitudes do not vary (one is used to check the validity of the other's brightness), and the star or minor planet you wish to analyze.

For example, you can analyze a folder of minor planet images taken over a period of time. CCDSoft works with TheSky to plot the right ascension and declination of the minor planet in each image, and then measures the magnitude of the object relative to the reference stars. Figure 2 shows an actual minor planet light curve created with CCDSoft. There were a total of 55 images of minor planet 7505 1997 AM2 taken during a three-hour imaging session. The curve at the top shows the variations in brightness between the two reference stars (noise level), and the curve with crosses shows the magnitude calculated for the minor planet. The typical interval between the start of each exposure was 3 - 4 minutes. It is not necessary that the timings be exact, since the time of the exposure is stored in the image header. The rotational period of the minor planet is easily seen in the plotted light curve (about 2.5 hours). If the minor planet moves more than the width of your field of view, you can use Orchestrate to write a script to follow the motion of the minor planet during image acquisition.

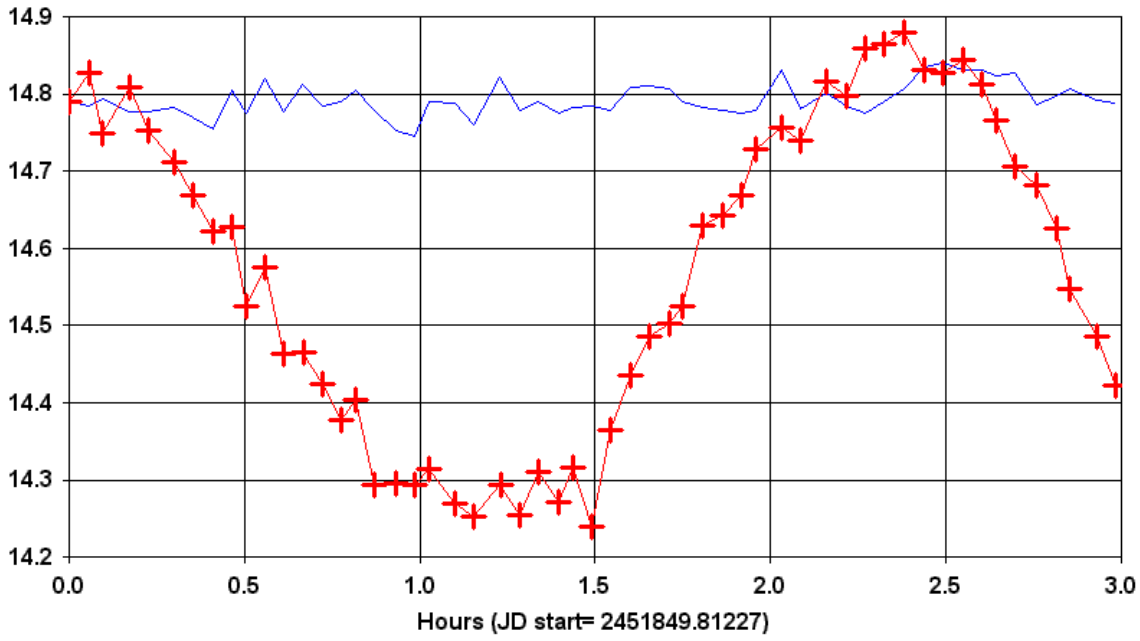


Figure 2: A light curve for a minor planet.

Variable Star Light Curve – You can also take a series of images of a variable star, store them in a folder, and CCDSoft will analyze the images and product a light curve. The procedure is nearly identical to that for a minor planet, except the object being analyzed is stationary. You can also create light curves for any object that changes in brightness, including supernovas and comets, as long as the two reference stars are present in all of the images. If the object moves too fast, you can create the light curve in sections and combine the data manually using a spreadsheet.

CCDSoft has several other useful tools in the Research menu:

- Insert the World Coordinate System (WCS) and perform automated astrometry for an image.
- Insert minor planets into an image (using TheSky's minor planet database).
- Generate a three dimensional surface plot for an image.
- Blink compare two or more images using variable blink speeds.
- Generate a star chart that corresponds to your image.
- Generate a Digitized Sky Survey (DSS) image that corresponds to your image.
- Generate a DSS image for any arbitrary area of the sky.
- Create and run a slide show of images.
- Display the stars in your image used for astrometry.
- Display the objects found in your image.
- Display the minor planets found in your image.

Research Requirements

Astronomers who have performed the above calculations using traditional methods are quick to ask, "What's the catch?" Of course, there are certain requirements for your imaging system and the data it generates before all of the time saving can be realized. You must take good images, for example, and you must have the right tools installed to perform specific tasks. The table below lists some requirements on the left and the time saving functions on the top. An **X** mark in the intersection of the two indicates that to perform the function on the top you must have the **X** marked requirements to the left.

Requirement	Auto-Group	Auto-Align	Auto-Movement Detection	Auto-Astrometry	Auto-MPC Report
TheSky				**X**	**X**
CCDSoft	**X**	**X**	**X**	**X**	**X**
Equatorial coordinates in the FITS header	**X**			**X**	**X**
Time in the FITS header			**X**		**X**
Date in the FITS header			**X**		**X**
Six stars from the GSC catalog				**X**	**X**
Six or more objects on the image		**X**		**X**	**X**

A Note about ST-6 CCD Camera Images

ST-6 images must be resized before you can generate automatic Minor Planet Center reports. Use the **Image | Resize | Resize Image** command to resize a single image or the **Image | Resize | Resize Folder of Images** command to resize multiple images. The **Resize Folder of Images** command even has a button that will enter the proper values for an ST-6 camera.

Image Pre-Analysis

The first step in analyzing your images is to add astrometric information. You can add this information to the current image by clicking **Research | Insert WCS/AutoAstrometry**. Adding astrometry to multiple images is covered later in this chapter.

The image shown in figure 3 is used to demonstrate how to perform AutoAstrometry. The image was taken with CCDSoft, and the right ascension and declination of the center of the image are stored in the image file header. Note that the stars are not perfectly round, indicating a small amount of tracking or polar alignment error. Unless the stars are seriously out of round, AutoAstrometry will still be successful. AutoAstrometry is also reasonably tolerant of cosmic ray hits.



Figure 3: An image used for AutoAstrometry.



The right ascension and declination stored in image headers may or may not be exactly correct. If the mount was not aligned with the pole, pointing will be slightly off. This can also happen if the mount is moved accidentally, or if an incorrect synchronization with the sky occurs. As long as the coordinates are close to the correct value, AutoAstrometry will succeed.

AutoAstrometry for a Single Image

Figure 4 shows the Insert WCS/AutoAstrometry dialog box. If you took the image with CCDSoft version 5 with TheSky Level IV version 5 or later also present, the image coordinates are already stored in the image header, and will appear in the dialog box in the **Image equatorial coordinates** box. You can also click **Get Previously Entered Coordinates** to recall the last set of coordinates you used. If you took the image with an earlier version of CCDSoft or another camera control program, you can manually enter the image coordinates using the format shown in figure 4.



You can also use the FITS Header Editor (click **View | File Information | Edit Header** tab) or the FITS header modifier (click **Research | Analyze Folder of Images | Pre-Analyze** and then click the **FITS Modifier** tab) to add or change equatorial coordinates in an image or folder of images.

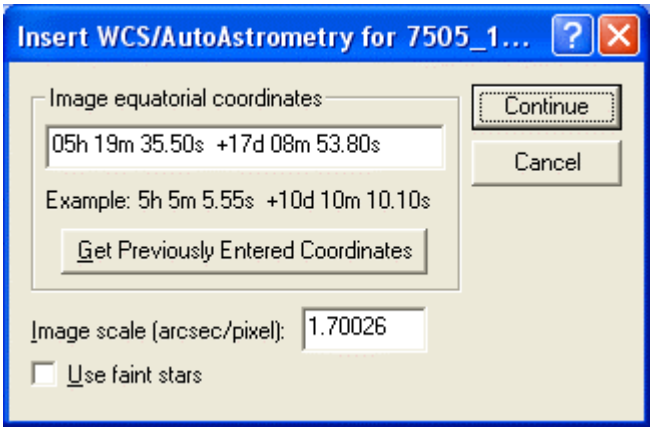


Figure 4: Adding astrometry and World Coordinate System (WCS) information to an image.

You must specify the image scale of the image in arcseconds per pixel. You can calculate the approximate image scale for your camera and telescope combination using the following formula:

$$\left(\frac{pixel_size}{focal_length}\right) * 206$$

where *pixel_size* is expressed in microns, and *focal_length* is expressed in millimeters. For example, to find the arcseconds per pixel for a 10-inch f/5 telescope with an ST-8E CCD camera:

$$\frac{9}{(25.4 * 10 * 5)} * 206 = 1.46$$

The focal length is calculated using 25.4 (the number of millimeters per inch), 10 (the aperture in inches), and 5 (the focal ratio). If the ST-8E is binned 2x2, the calculation then uses 18 microns as the pixel size, with the result:

$$\frac{18}{(25.4*10*5)}*206 = 2.92$$

You can find the pixel size of your CCD camera in microns in your camera documentation, at the manufacturer's web site, or by contacting the manufacturer.



The image scale you get from this calculation is only approximate, but it should be close enough to allow AutoAstrometry to perform an Image Link with TheSky. You can get the exact image scale calculated from your images by clicking on the image in TheSky, and choosing **Image Link Information** from the Object list. See figure 5, where the image scale is shown as 1.70 arcseconds per pixel.

Image scale can be the "Achilles heel" of the AutoAstrometry process. If your image scale is wrong, Image Link will fail, and so will AutoAstrometry!

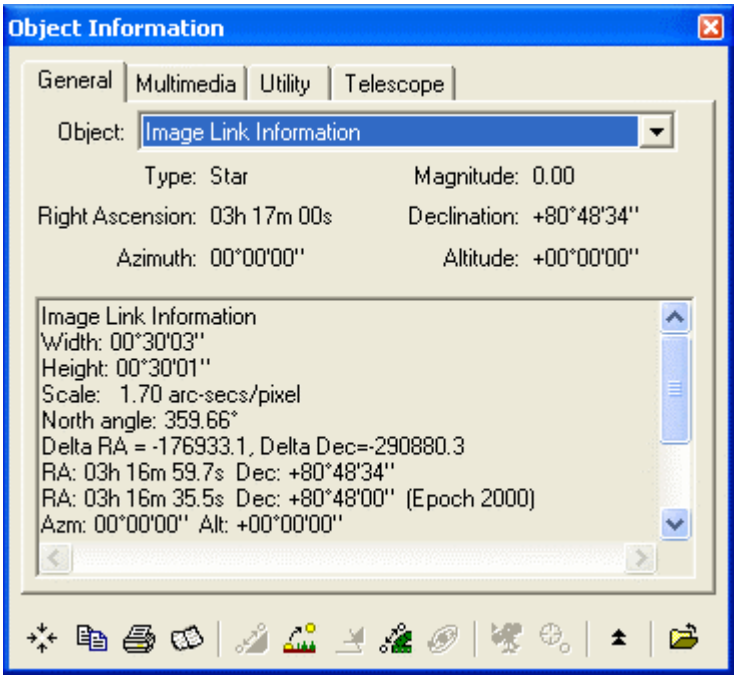


Figure 5: Viewing information about a linked image in TheSky.

If you installed the USNO (U.S. Naval Observatory) stellar database, you can click the **Use faint stars** checkbox. When this is checked, CCDSoft's source extraction functionality is used to find objects in the image. You *must* have the USNO database available and turned on in TheSky to use this feature. To turn on the USNO database, from TheSky, click **Data | File Locations** to open the dialog box shown in figure 6. Make sure that **Plot USNO Stars** is checked. If your field of view is less than 10 - 15 arcminutes on a side, you may find it necessary to use the USNO database to get astrometric solutions, as other catalogs used in TheSky may not contain enough stars. (You would think 19 million stars would be enough, but not always.)

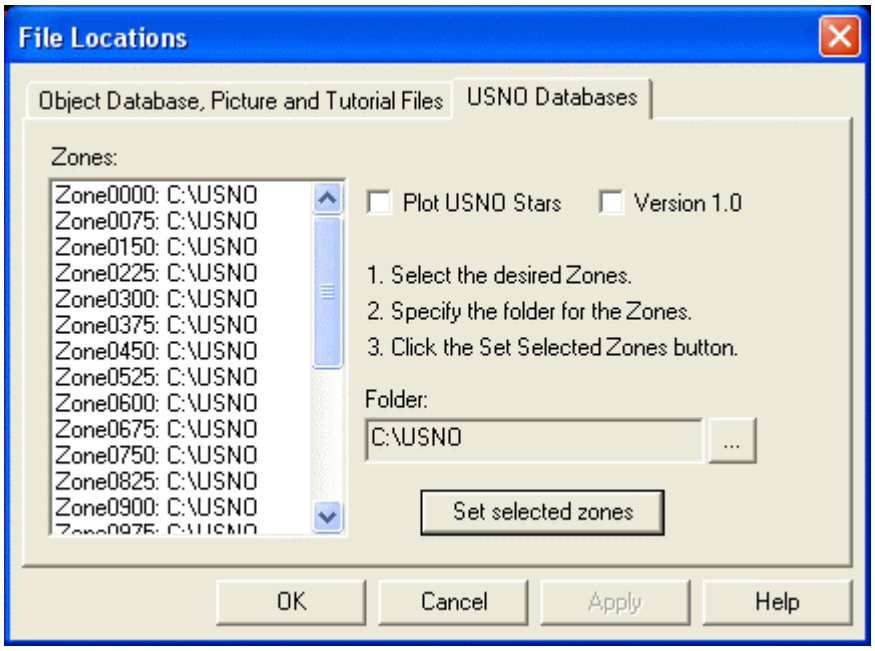


Figure 6: Turning on the USNO database in TheSky.



If you check **Use faint stars**, and astrometry is successful, CCDSoft will create an SRC file with the same name as the image file, in the same folder as the image. The SRC file stores information about all of the objects in a particular image and is accessed whenever astrometric and/or photometric information is required.

If AutoAstrometry is successful, you will see a list of the stars found in the image (see figure 7). For each star, the following information is shown:

- Whether the star is used in the astrometric solution. If the star's position doesn't match the catalog closely, it will not be used.
- The star's catalog identification number. For USNO stars, the right ascension and declination serve as identification.
- The error factor for the star catalog used, in arcseconds.
- The star's coordinates.
- The X- and Y-coordinate of the star in the image, in pixels.
- The residual error for the star, in arcseconds. Residual error is the amount by which the position of the star in the image varies from the catalog position.

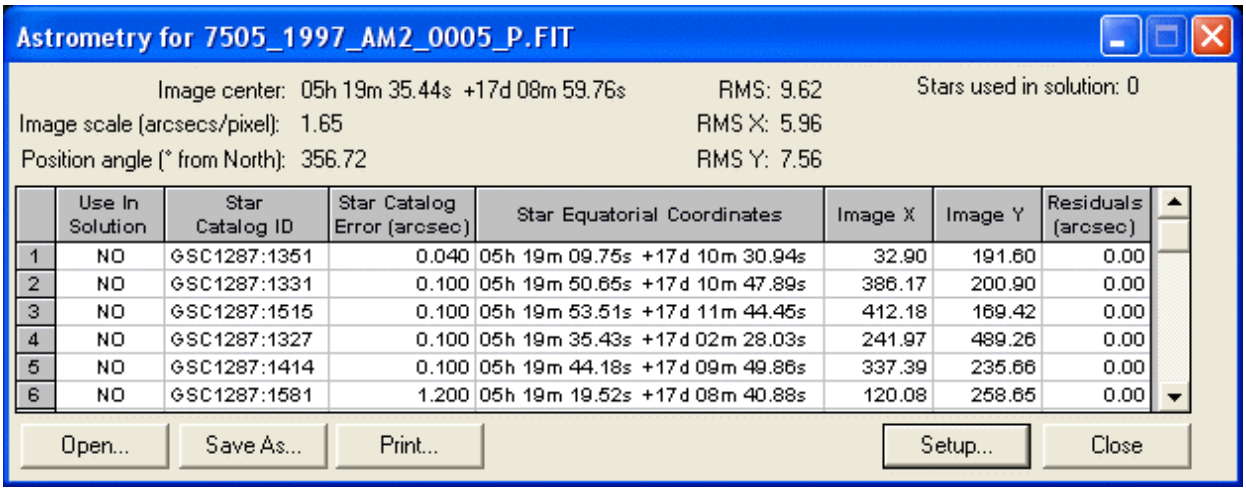


Figure 7: The astrometric solution for the image shown in figure 3.

The numbers at the top of the Astrometry dialog box (figure 7) display information about the astrometric solution. The calculated image center is shown at top left. It may vary from the image center originally stored in the image header if the mount was not perfectly aligned with the pole and positioned at the time the image was taken. Also shown are:

- Image scale in arcseconds per pixel.
- Position angle (the angle, in degrees, by which the vertical axis of the image varies from Celestial North).
- Overall RMS (root mean square) error of the solution. Values under 0.50 indicate a good solution.
- RMS for the X-axis and Y-axis. Values under 0.35 indicate a good solution.
- The number of stars used in the solution. The leftmost column **Used in Solution**, tells you which specific stars were used in the solution. By default, stars with a residual error of 1.5 arcseconds or less are used in the solution.

If the RMS error of the solution is too high for your needs, click **Setup** to specify a different residual error filter. The solution will be recomputed, and stars that have too large of a residual error will be dropped from the new solution. By default, stars with a residual error of 1.5 or less are included in the solution.

Figure 8 shows the Astrometry Setup dialog box. Specify the maximum residual error to allow, and then click **OK**. When 0.7 is used instead of 1.5 for the sample image, the RMS drops to 0.36 in both axes, and 0.25 in the X axis and Y-axis. The number of stars used in the solution drops to 89, which is still more than enough stars to provide a useful solution. The minimum number of stars in a useful solution is typically about 10 - 15. If you have too few stars, the RMS error is usually too high. If you have checked TheSky's **Use faint stars** option, the USNO stars in the solution have a higher level of accuracy and you may get by with using fewer stars than when you use stars from just the GSC catalog.

The USNO catalog has an error factor of 0.1 arcseconds, while the GSC catalog has error factors in the range of 0.2 to 0.4 arcseconds. The larger error factor of the GSC catalog leads to larger residual error on individual stars, and a higher RMS error. As long as your solution provides 0.50 arcseconds of RMS error or better, your results should be acceptable to the Minor Planet Center and other institutions.

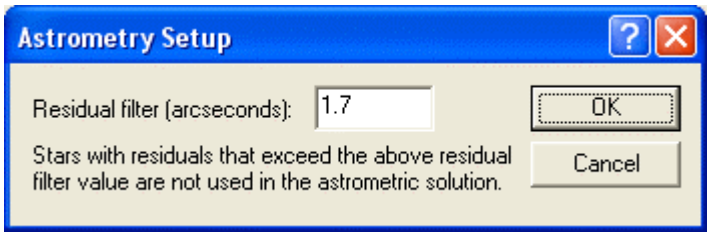


Figure 8: Adjusting the residual filter.

You can also manually add or remove stars from the astrometric solution. In star-rich areas of the sky, you may wish to eliminate stars from the solution to obtain a better RMS error. Click on the **Use in Solution** box for the star you want to change. Then type **Y** or **N** depending on whether you want to use the star in the solution. Press **Enter** to save the change. You can then review the statistics at the top of the Astrometry dialog box to see if the change has given you the results you want. For example, star number 3 in figure 7 has a residual error of 0.94. You could remove this star from the solution, which would change the RMS error to 0.51 instead of 0.52. You might also remove a star if you notice that it is over-saturated, bloomed, or otherwise problematic. To see which star corresponds to a line the astrometry solution, click on the line to highlight the star. A yellow circle appears around the star associated with that line.

The buttons across the bottom left of the Astrometry dialog box allow you to open a previously saved solution; save the current solution to a file; and to print the solution. The buttons at bottom right allow you to access the Astrometry Setup dialog box (figure 8), and to close the Astrometry dialog box.



The stars used in the astrometric solution are added to the image header automatically, and will be saved with the image.

If CCDSoft cannot find an astrometric solution, you will usually receive this error: “Image link failed, no pattern matching found. Check image coordinates and image scale.”

As the error suggestions, verify that the image coordinates (right ascension and declination) are correct, and that the arcseconds per pixel value is within 0.25 arcseconds of the actual value. You can test coordinates and image scale by manually pasting the image into TheSky and perform an image link using the Link Wizard menu option. The Link Wizard can tolerate a large error in right ascension and declination, and can work without an image scale. When the link is successful, you can obtain right ascension, declination, and image scale from the Object Information window.

Once AutoAstrometry is complete, click **View | Cursor Information** to display astrometry-related information about the image. Move the cursor over the image to get detailed information about the objects in the image. Figure 9 shows the image used for astrometry and the Cursor Information window. Note that the object under the cursor (in this case a dim star) has a small yellow cross over it to indicate it is the currently selected object. You do not need to click to select an object; the object nearest to the cursor is automatically selected. The Cursor Information window displays information about this star.

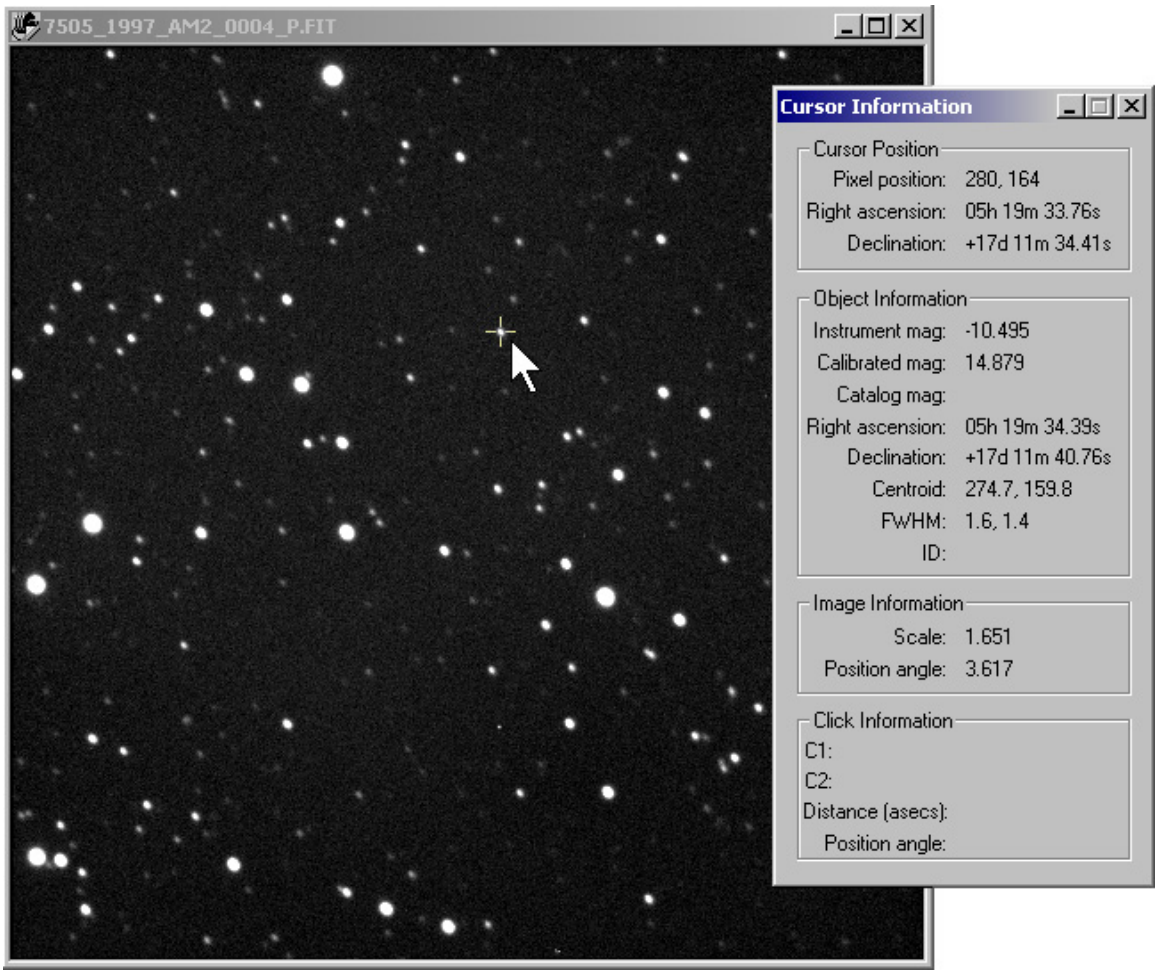


Figure 9: Viewing information about objects in the image.

You can obtain additional information in the Cursor Information dialog box by clicking in the image. The additional information appears at the bottom of the Cursor Information window, in the **Click Information** section. The first click puts the right ascension and declination of the click position to the right of the **C1** item. The second click adds the right ascension and declination of the second click position, as well as the distance between the two clicks in arcseconds, and the position angle (angle from celestial north) of the line connecting the two click points. This allows you to use the Cursor Information window to analyze double stars. Figure 10 shows this additional information, as well as the appearance of the click points (purple circles with crosses).

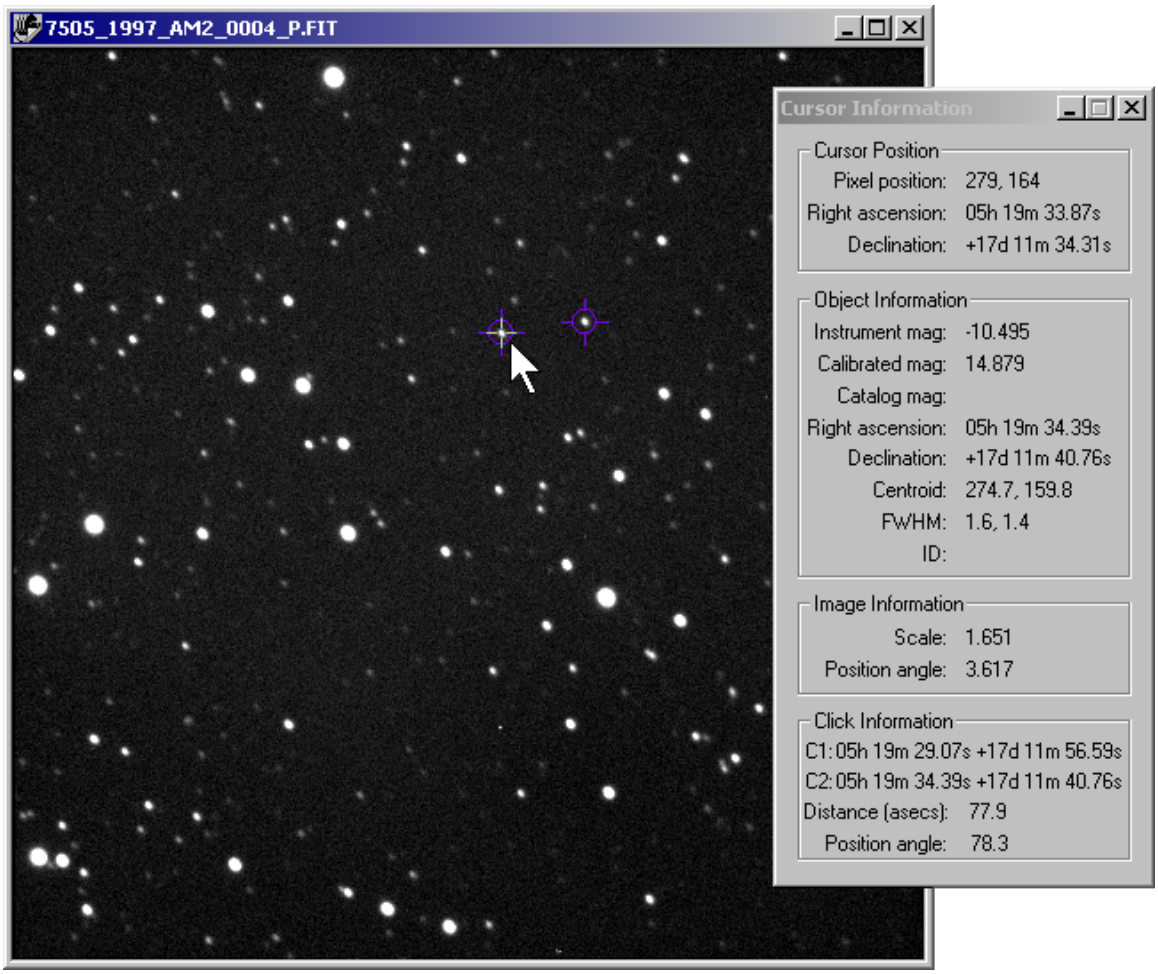


Figure 10: Clicking in the image displays additional information in the Cursor Information window.

When astrometric data is stored in the image header following AutoAstrometry, you will also see additional information about the current cursor position in the CCDSoft status bar at the bottom of the program window (see figure 11). From left to right, the information shown includes:

- Cursor coordinates (X, Y in pixels).
- Brightness value of the current pixel.
- WCS (World Coordinate System) right ascension and declination of the current cursor position.
- Centroid of the current cursor position (X, Y, in thousandths of a pixel).
- Right ascension and declination of the centroid to hundredths of an arcsecond.

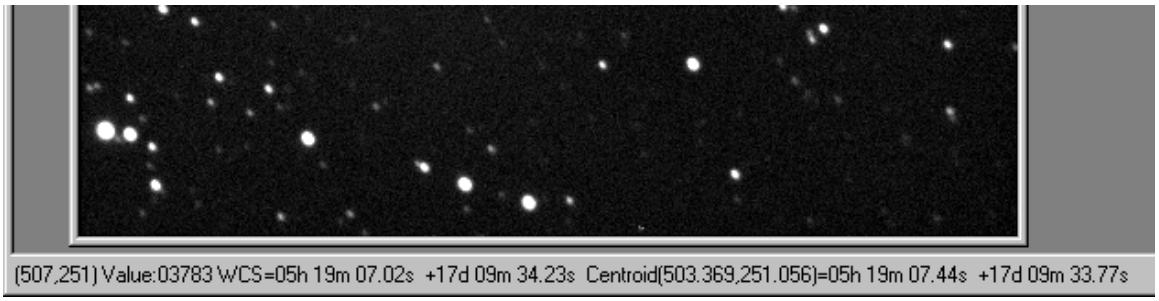


Figure 11: After an astrometric solution is available, additional information appears in the status bar.

When an image has an astrometric solution, you can turn on display of the stars used in the solution by clicking **Research | Show Astrometric Stars**. Figure 12 shows the appearance of the image when this option is turned on – stars used in the solution have small yellow crosses marking the astrometric centroid. Note that other visual cues in the image, such as the two click points shown in figure 12, remain visible. You can toggle this option on an off by clicking **Research | Show Astrometric Stars**.

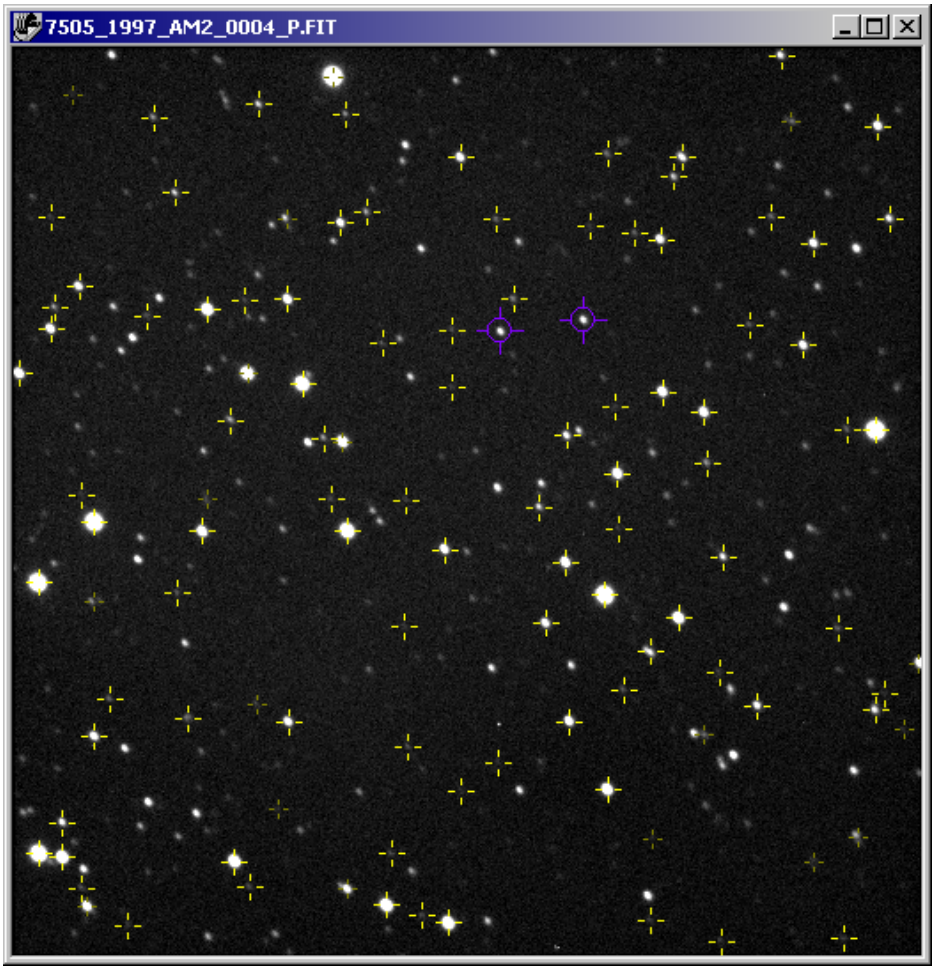


Figure 12: Displaying the stars used in the astrometric solution.

Whether or not you have performed astrometry on an image, you can look at the objects that CCDSoft has found in the image. Click **Research | Show Object Inventory** to display the objects. Figure 13 shows the objects for the sample image. These objects are just that – objects.

The object inventory does not include magnitude or astrometric data. The object inventory is used as input to the astrometric calculations. CCDSoft is especially adept at identifying dim galaxies and faint stars, and is thus able to locate many more objects as input for astrometry operations.

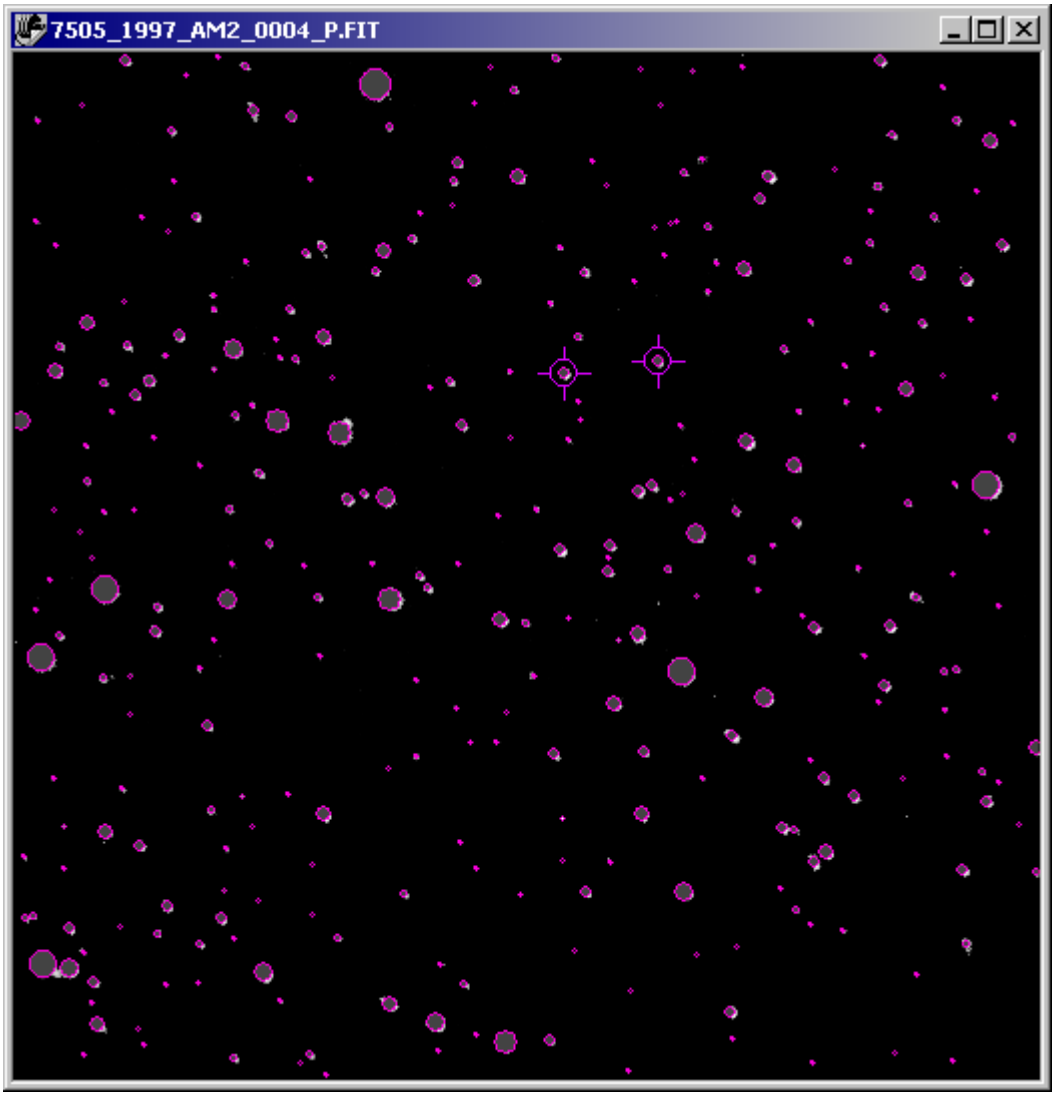


Figure 13: Displaying the objects found by CCDSoft's Show Inventory command.

Troubleshooting AutoAstrometry

If you are having problems with AutoAstrometry, first make sure that you can manually Image Link the CCD image in TheSky.

If you cannot get the image to link, you cannot perform the AutoAstrometry. CCDSoft relies on TheSky to find all stars on the image that match corresponding stars in stellar catalogs. These catalogs include the Hipparcos and Tycho catalogs, the Guide Star Catalog and the optional U.S. Naval Observatory catalog. Although the Hipparcos and Tycho catalogs are preferred because their coordinates and magnitudes are very accurate, most of the time these relatively bright stars are saturated on the CCD image and therefore cannot be used for astrometry.

Here are some common errors that occur while Image Linking, and how to fix them:

Error Code	Description	Solution
651	Not enough points in the Image Link bitmap.	Try adjusting the background and range of the original image to ensure that there are sufficient stars present. The ideal background is uniformly dark, and the range is high enough to show clear edges for the stars.
653	Image Link failed, typically due to an insufficient number of matching cataloged stars. There must be at least six cataloged stars in each image to perform an Image Link. This is also caused if the image scale entered in the **Insert WCS/AutoAstrometry** dialog box is incorrect.	Use the USNO stellar database for more stars. Verify that your image scale is correct.

Insert Minor Planets into a Single Image

Before you insert minor planets into your images, you need to make sure you have version 5.00.014 of TheSky Level IV or later. That version of TheSky introduced new, more detailed support for Extended Minor Planets. You can now track more than 100,000 minor planets at a time.

TheSky displays on-screen vectors for each minor planet that show position for a 24-hour period (see figure 14). This allows TheSky to update the screen more efficiently, while still providing detailed information about minor planet positions.

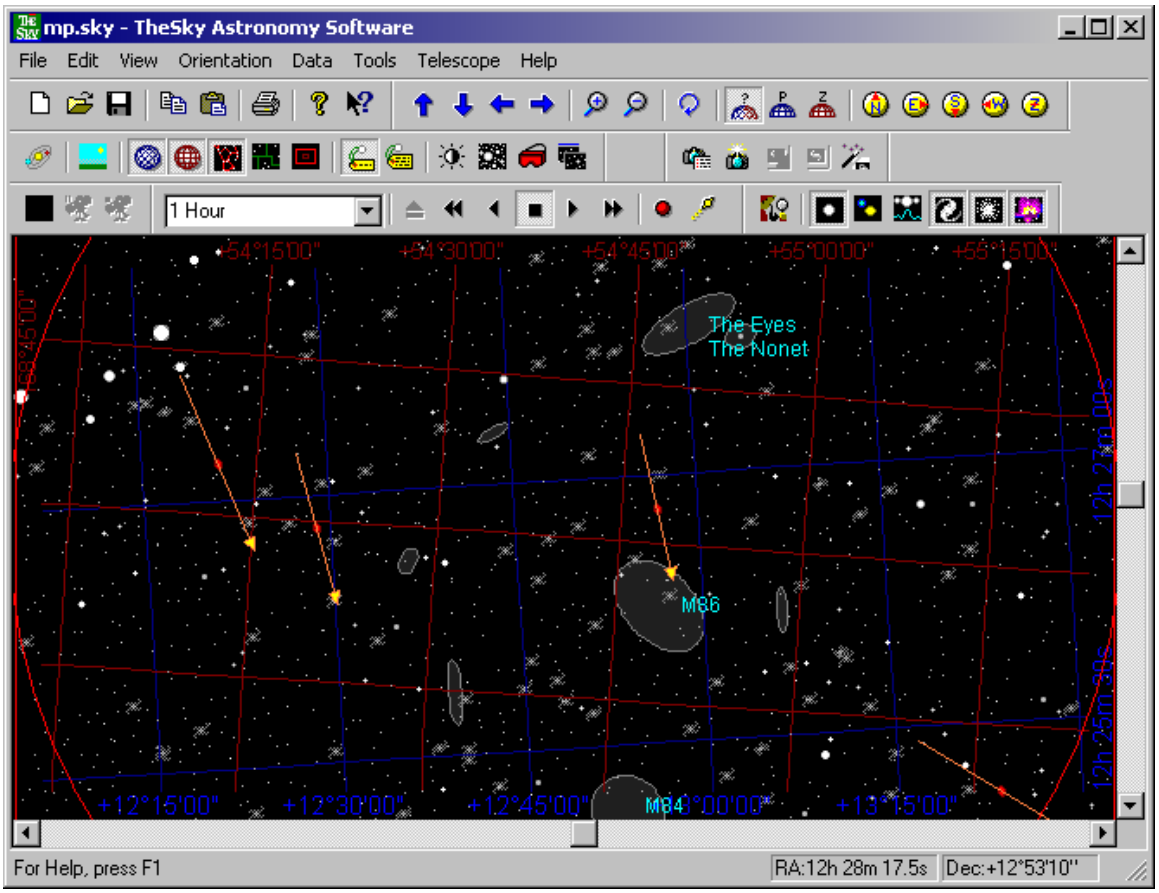


Figure 14: Minor planets with vectors showing position over a 24-hour period (TheSky).

You will also need a current copy of the Minor Planet Center's orbital data file. You can find download locations for this file (MPCORB.DAT) on the Minor Planet Center web site at:

```
http://cfa-www.harvard.edu/cfa/ps/mpc.html
```

Setting Up TheSky Level IV version 5

NOTE	You must have TheSky Level IV version 5.00.014 or later installed on your computer to insert minor planets into your images.

Once you have downloaded the MPCORB.DAT file, copy it to the following folder on your hard disk:

```
\Program Files\Software Bisque\TheSky\User\Minor Planets\
```

From TheSky, click **Data | Extended Minor Planets** to open the Comets and Minor Planets dialog box. Click on the ellipsis button to the right of the box for the Orbital element filename and navigate to and select the MPCORB.DAT file.

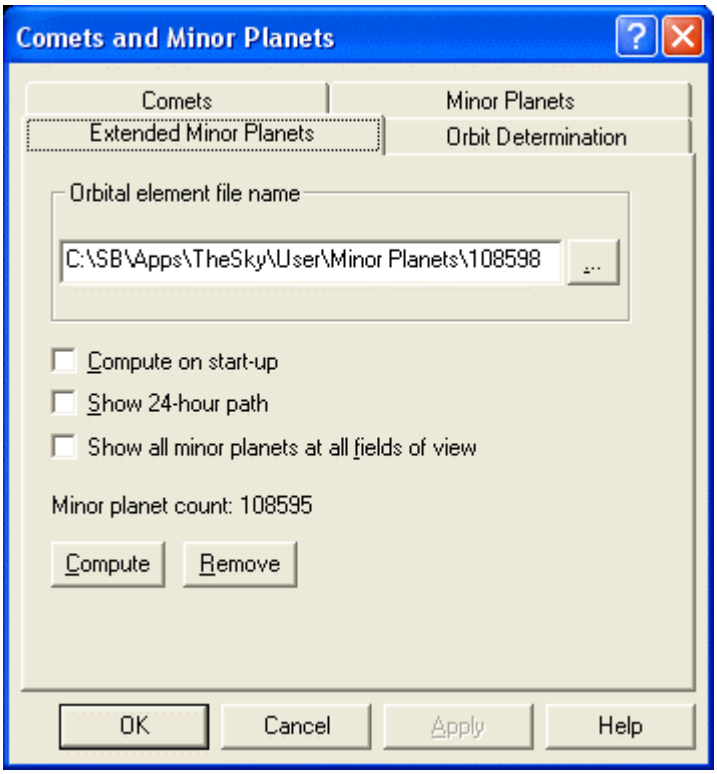


Figure 15: Setting up Extended Minor Planets in TheSky.

TheSky will scan the file for minor planets, and will then compute their positions. This may take several minutes. When the process is complete, the number of minor planets appears on the **Extended Minor Planets** tab. If you need to compute the positions manually at a later date, click **Compute**. You can remove the minor planets by clicking **Remove**.

After the minor planet positions are computed, you have three options to choose on the Extended Minor Planets tab:

- **Compute on startup** – When checked, all of the minor planet positions will be computed each time you launch TheSky. Check this option if you will frequently refer to minor planet positions. Otherwise, click **Compute** on the Extended Minor Planets tab to show the minor planet positions.
- **Show 24-hour path** – When checked, the minor planet position will include a vector (arrow) that shows the position of the minor planet over a 24-hour period. The current position of the minor planet at the time of computation will be shown as well. The 24-hour period is from midnight to midnight of the current day.
- **Show all minor planets at all zoom levels** – When checked, minor planets will be plotted at all zoom levels, from the widest to the narrowest. Large number of minor planets in wide

fields of view may slow down display significantly depending on the speed of your computer. Check this box if you prefer to see minor planets at all times, and will be making frequent reference to minor planet positions. Figure 17 shows how dense the full set of minor planets is at wide fields of view.

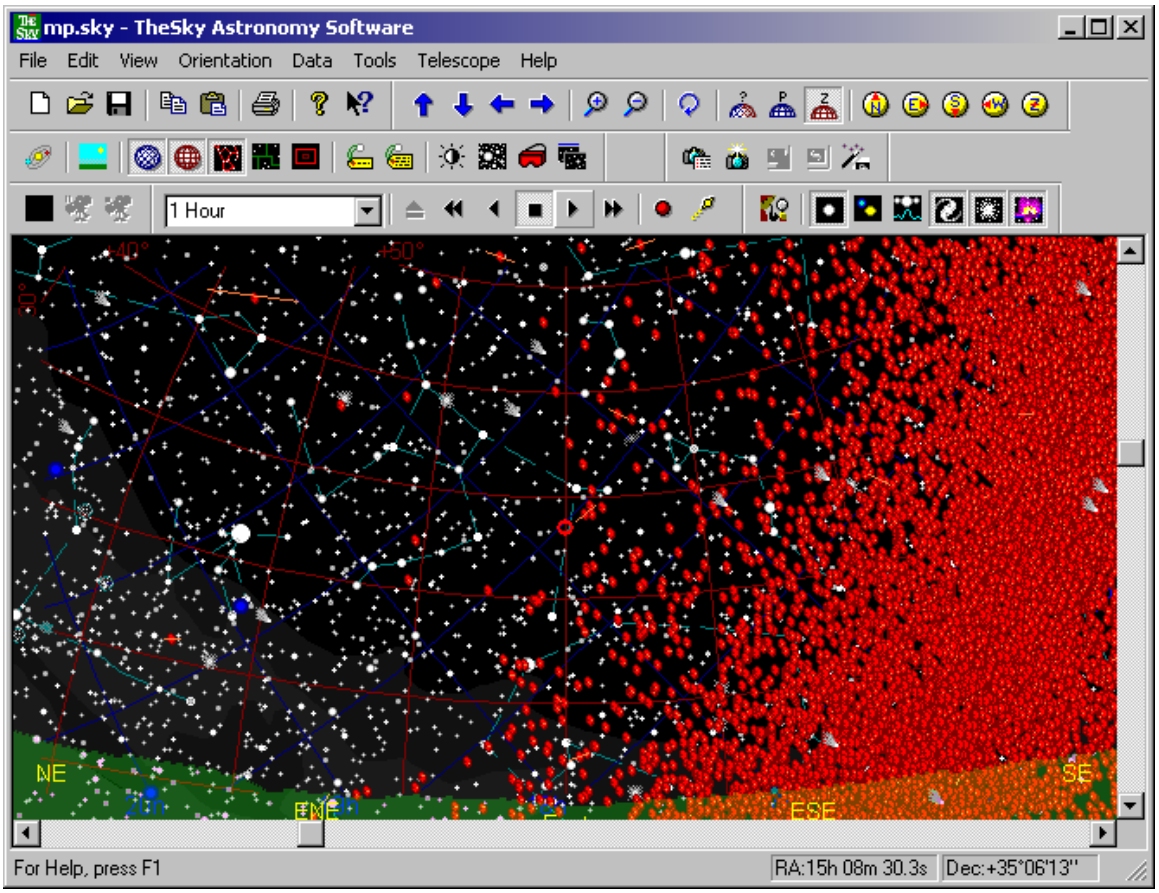


Figure 17: Viewing minor planets with a wide field of view.

Note: You can modify the appearance of the minor planet symbols and vectors using TheSky's **View | Preferences** command. Select Extended Minor Planet in the Object Description list (see figure 18), and edit the Line and Fill properties. See the documentation for TheSky for details on editing preferences.

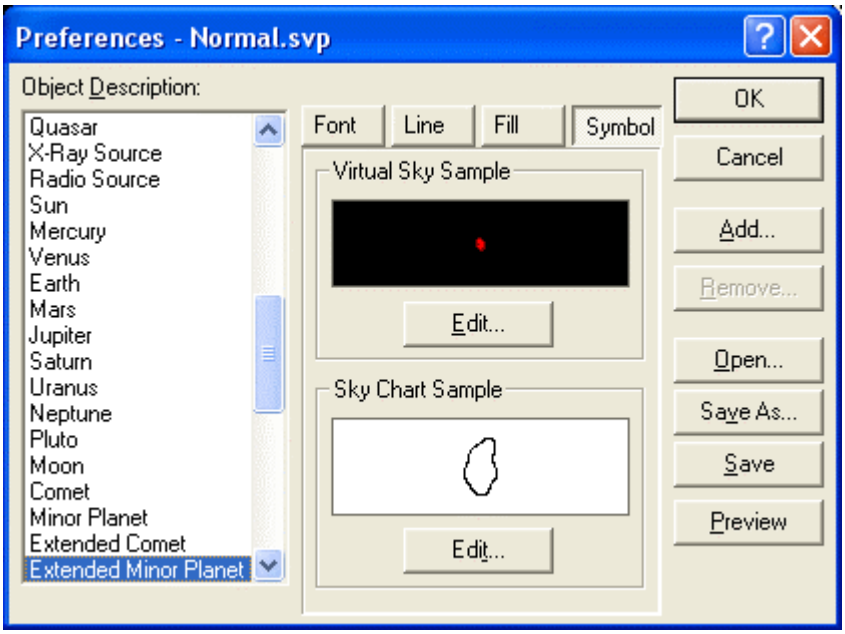


Figure 18: Changing TheSky's preferences for Extended Minor Planets.

Note: Inserting minor planets makes significant changes to TheSky's setup because TheSky is set to the date, time, and location at which the image was acquired (as stamped in the FITS header). CCDSoft renames the current document in TheSky to `External Chart.sky`, which protects you from changing the current document. You can restore your favorite settings easily by loading `Normal.sky` or whatever `.sky` file you normally work with.

Why do these changes occur? In order to find the position of minor planets in your image, TheSky must be set to the same time, date, and location of the image. If you attempt to use TheSky while these changes are in effect, you will not get the appropriate virtual sky for your location. To open your regular document, click **File | Open**.

Inserting Minor Planets

Note: You need to set up and load Extended Minor Planets in TheSky before you can insert minor planets into your images. See the preceding section for setup details.

Note: You need to insert the WCS (World Coordinate System) into an image before you can insert minor planets. Click **Research | Insert WCS/AutoAstrometry** to add WCS. See the section "

AutoAstrometry for a Single Image" earlier in this chapter for full details. Image pre-analysis will also add WCS data to your images (choose **Research | Analyze Folder of Images | Pre-Analyze**).

To insert minor planets into an image, click on the image to make it active, then click **Research | Insert Minor Planets**. This will retrieve minor planets from TheSky's extended minor planet database. When the process is complete, CCDSoft will display a message telling you how many minor planets were inserted. The minor planets will be marked with green circles on the image (see figure 20).

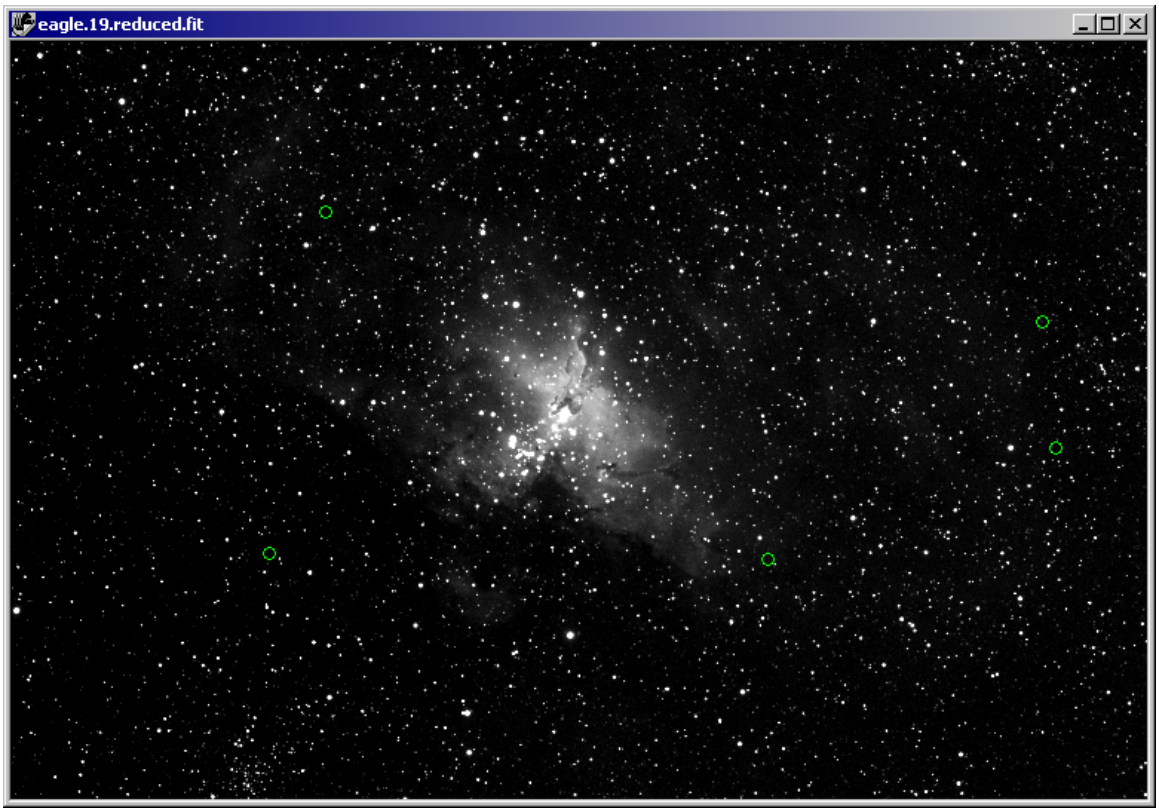


Figure 20: The inserted minor planets are marked with small green circles.

The minor planet data is also added to the FITS header of the image. You can view the minor planet header information by clicking **View | File Information**. Click the **Edit Header** tab to display all of the keywords in the header (see figure 21). If necessary, scroll down to find the minor planet data. To save the minor planet data in the image file, click **File | Save**. You can toggle the display of minor planets by clicking **Research | Show Minor Planets**.

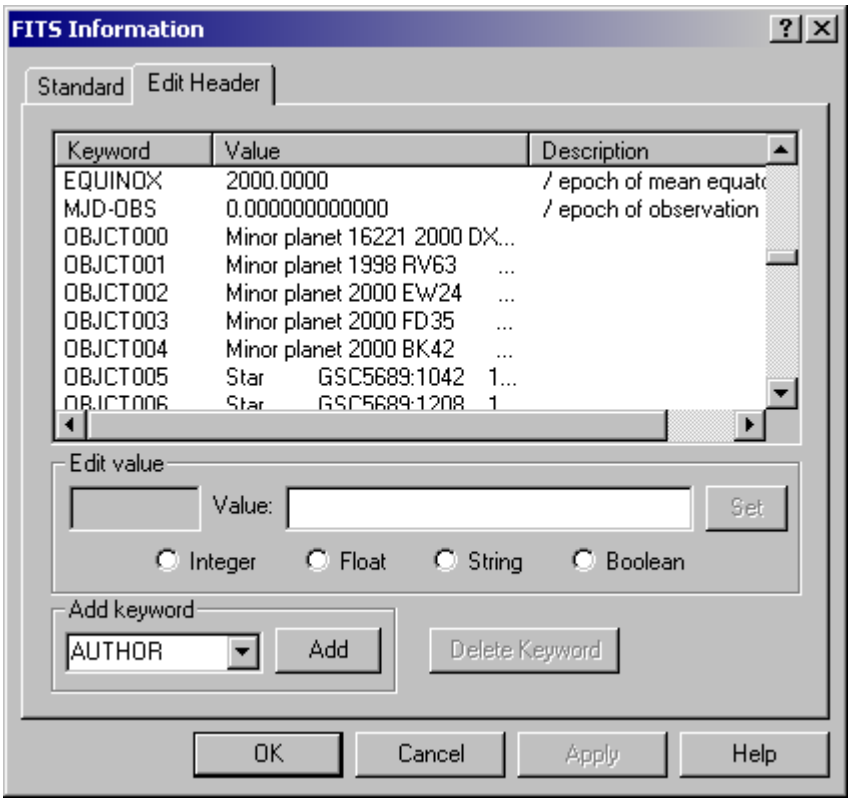


Figure 21: Viewing minor planet data stored in the FITS image header.

If you have turned on the display of 24-hour paths for minor planets in TheSky, click **Research | Comparison | Star Chart** to generate a star chart that shows the paths for minor planets in your image. Figure 22 shows an image of minor planet 7505 1997 AM2 (left) and its corresponding star chart. The minor planet's position is marked with a green circle in the image, and with a red asteroid symbol in the star chart.

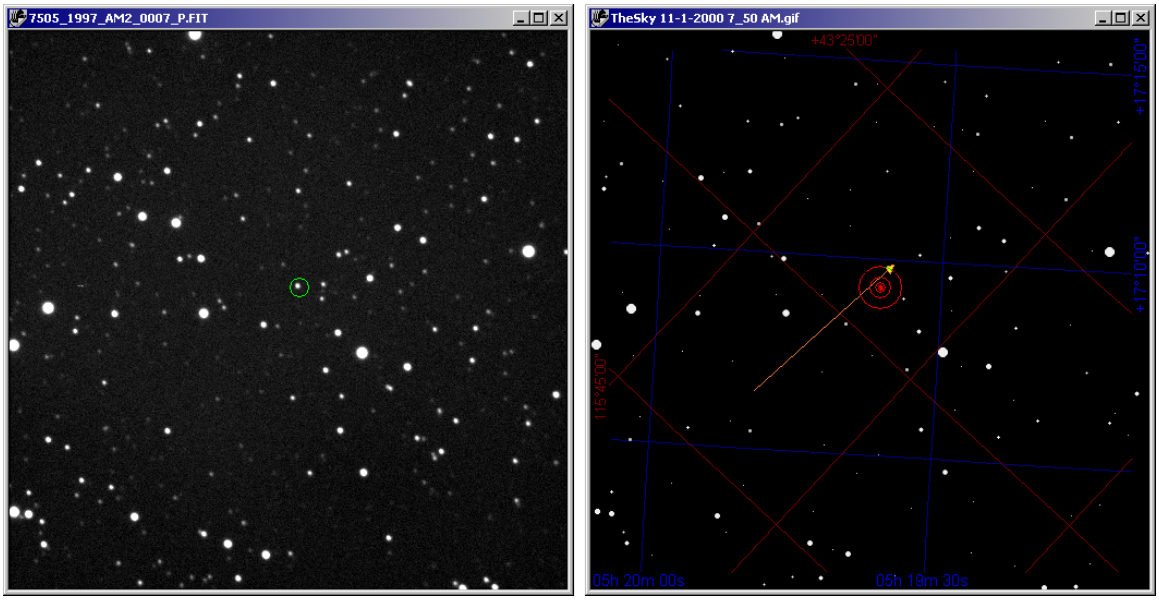


Figure 22: You can generate a star chart for an image.

The star chart shows the direction and 24-hour movement of the minor planet. Note that the minor planet position is slightly offset from the vector. This is due to the fact that when a minor planet is inserted, the orbital elements are numerically integrated to the current date and time to insure the most accurate results, while the 24-hour path is based on the orbital elements supplied in the MPCORB.DAT file (or other file), which may be several weeks or months old.

If the position of the minor planet does not fall precisely on the 24-hour path, the plotted minor planet position you get with the **Insert Minor Planets** command is the correct and most accurate position. The processing power required to integrate all minor planets is great enough that it is impractical to perform each time.

AutoAstrometry for Multiple Images in a Folder

Adding astrometry to each individual image, one at a time, can be a tedious process. To make this faster, many of the tools available on the Research menu can also operate on all of the images in one or more folders. These folder-based tools are located on a submenu of the Research menu, at **Research | Analyze Folder of Images**. The available tools are:

- **Pre-analyze** – Add astrometric and/or WCS coordinates to one or more folders of images and create an inventory of objects in the images.
- **Minor Planet Search** – Scan three or more images (or multiple groups of three or more images) for evidence of minor planets. Optionally generates Minor Planet Center observations reports.
- **Supernova Search** – Scan a folder of images for evidence of supernovas.
- **Minor Planet Light Curves** – Analyze a folder of images, and construct a light curve for a moving object.
- **Variable Star Light Curves** – Analyze a folder of images, and construct a light curve for a stationary object.

The first step for both searches and light curves is always to pre-analyze the image files. The following section explains why this is necessary, and how you do it.

Pre-analyze Images

The research tools in CCDSoft use astrometric and photometric information to accomplish their tasks. For example, the minor planet search identifies the right ascension and declination coordinates of the candidate object in each image, and uses that information to build a submission form, which you can send to the Minor Planet Center (MPC). The MPC uses the coordinate information to help construct an orbital profile for the object, among other things. Without the astrometric information, this would not be possible.

The astrometric and/or photometric data is also used in the analysis itself. For example, when building a light curve for a variable star, the brightness of selected stars in the image is used to build the light curve.

Historically, the process of reducing data from an imaging system involved many separate steps and painstaking attention to detail, not to mention an enormous amount of time. It could take several days to reduce a night's worth of images. This process involved many areas of expertise, and often the use of pencil and paper or calculators.

CCDSoft does away with the drudgery. CCDSoft automates many steps in the process, such as organizing images, performing astrometry, calculating magnitudes, and graphing data. In addition, CCDSoft organizes the data for you. When you do need to be involved, such as when using the blink comparator to locate minor planets, you can rely on CCDSoft to present the information and images to you in a logical fashion.

Most of the research tools operate on folders of images. The first step in the process is to copy the files you want to analyze into one or more folders that contain only the images you want to analyze.

Once your images are in place, click on **Research | Analyze Folder of Images | Pre-analyze**, which displays the Data Analysis dialog box with the **Pre-analyze** tab selected (figure 23). There are several options on the left side, and an **Image list** on the right side. The options on the left are applied to the images on the right.

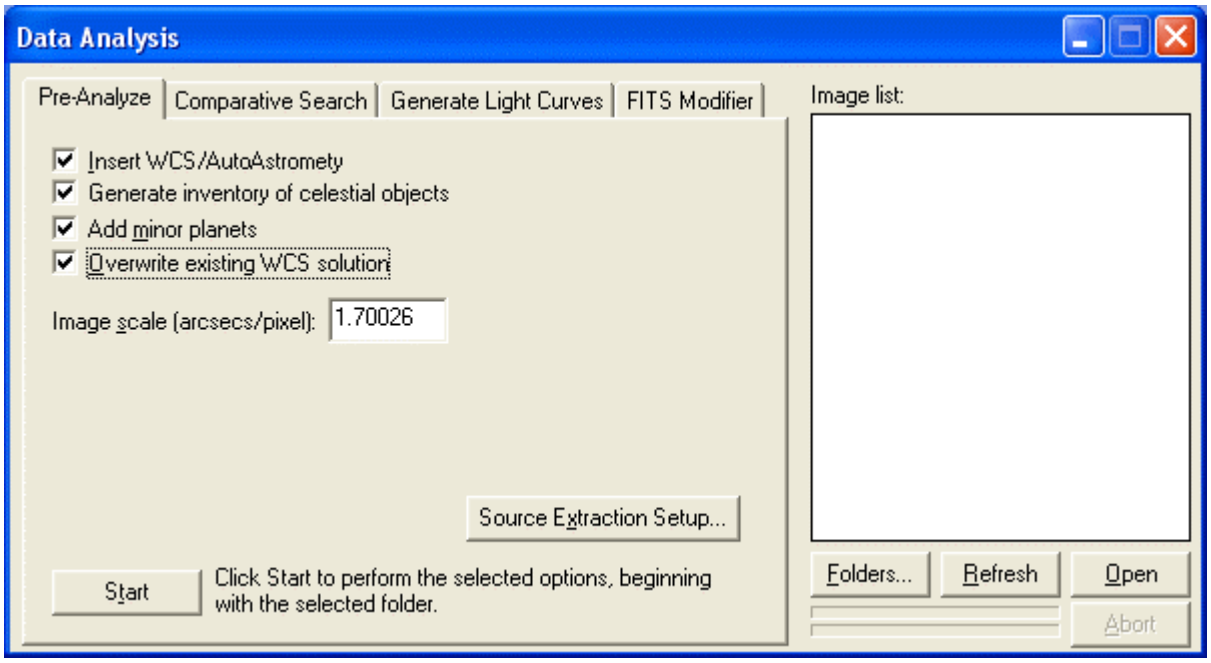


Figure 23: The Data Analysis dialog box, with the Pre-analyze tab selected.

Pre-analysis consists of these steps:

1. Use the **Folders** button to select one or more folders containing the images you want to pre-analyze.
2. Optional: Click **Open** to verify that the images are the ones you want.
3. Set options, including the checkboxes on the left, and the **Image scale**.
4. Click **Start** to begin pre-analysis.

There are several checkboxes and a text box on the **Pre-analyze** tab:

- **Insert WCS/AutoAstrometry** – This is the same as the menu option of the same name. It uses TheSky's Image Link and source extraction to generate an astrometric solution. The **Use faint stars** option is automatically off (but see below). When this box is checked, Pre-analysis will add the WCS information to the header of the image files in the Image List.
- **Generate inventory of celestial objects** – This option causes an SRC file to be created, with a name similar to that of the image file. This is the most time consuming Pre-analyze function. The .SRC file is necessary for performing minor planet searches since it contains a list of objects in the image. You can add WCS coordinates without creating an SRC file, but a less rigorous computation is used for finding objects, and the fainter stars will be ignored. The .SRC file allows for a larger number of stars to be used in the astrometric solution, because it locates even the faintest objects. See below for a sample of the contents of an SRC file.
- **Add minor planets** – This option adds minor planet data to each image.
- **Overwrite existing WCS solution** – When checked, images that already have an astrometric solution are re-analyzed, and the new solution replaces the old solution.
- **Image Scale (arcsecs/pixel)** – This is the same as **Image Scale** in the AutoAstrometry dialog box. See that section earlier in this chapter for details on how to calculate your image scale. The

image scale must be within approximately 0.25 arcseconds of actual image scale for astrometry to succeed.

In addition, there are several buttons on the Pre-analyze tab:

- **Start** – Begin the pre-analyzing process.
- **Source Extraction Setup** – Allows advanced users to customize how objects are detected in an image.
- **Folders** – Opens a dialog box that allows you to choose one or more folders for pre-analysis. The folders should contain only images relevant to the current analysis task. See the information later in this chapter for details on what kinds of images to include for each research task.
- **Refresh** – Rescan the list of files in the current folders. Click this button when you add, remove, or change files in the folders in the Image List.
- **Open** – Open the currently highlighted image file. If no image file is highlighted, the first image is opened. This is a convenient way to check your images visually.
- **Abort** – Stop pre-analysis. Disabled except during pre-analysis.

There are two progress bars just to the left of the **Abort** button. They show progress on the current file and on the entire pre-analysis process.

Pre-analysis starts with selecting the folders where the images are located. To select one or more folders, click **Folders**. This opens the Folder dialog box (see figure 24). Click **Add** to add a folder. You will see a list of drives and folders on your computer. Simply navigate to the folder that you want to add, and click **OK** to add it. The folder path appears in the Folders dialog box, as shown in figure 24. Repeat this process if you need to add more than one folder.

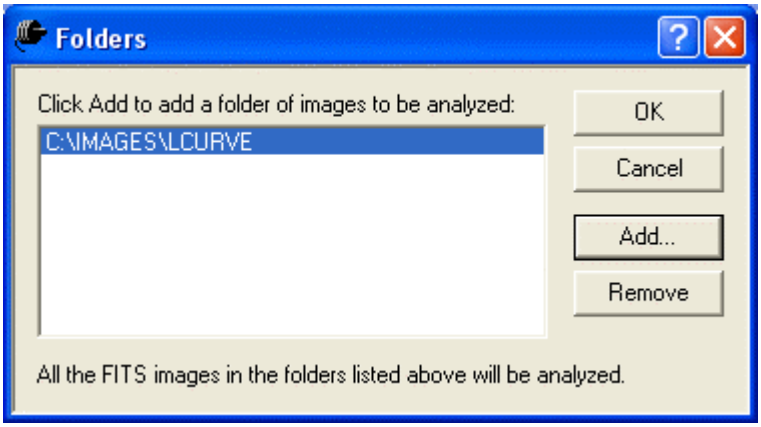


Figure 24: Managing folders.

If you chose an incorrect folder, or if you need to remove a previously selected folder, click on the folder in the Folders dialog box to highlight it, then click **Remove**. You can add as many folders as needed. For example, if you stored minor planet images in separate folders for each of three passes over the same area of sky, you can add all three folders.

When you are done adding/removing folders, click **OK** in the Folders dialog box. Note that the folder name is not what appears in the Image List. You see a list of object names and/or right ascension and declination coordinates. These are pulled from the image headers for each image in the folders.

If there are multiple objects or coordinates in the image headers, you will see a separate entry for each object. In other words, the Image List displays your files by object and location, not by folder. Figure 25 shows two examples of the Image List. The example on the left shows what you see when there is only one object or location, in this case a minor planet. The example on the right shows what you see if there are multiple objects or locations present in the folder, such as when you have a series of images of different positions in the sky, which you intend to search for minor planets.

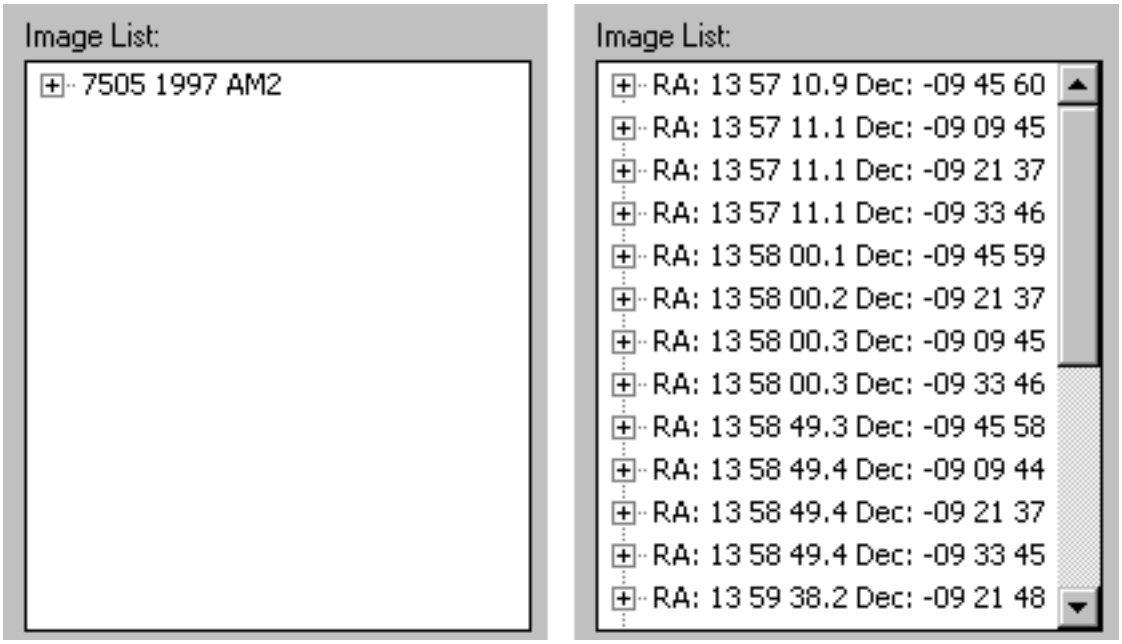


Figure 25: After choosing one or more folders of images, the images are arranged by object name (or by right ascension and declination if no object name is present).

You can click on the plus icon to the left of the object name (or location) to see which images are present for that object, as shown in figure 26. Scroll to the right to see the complete filename.

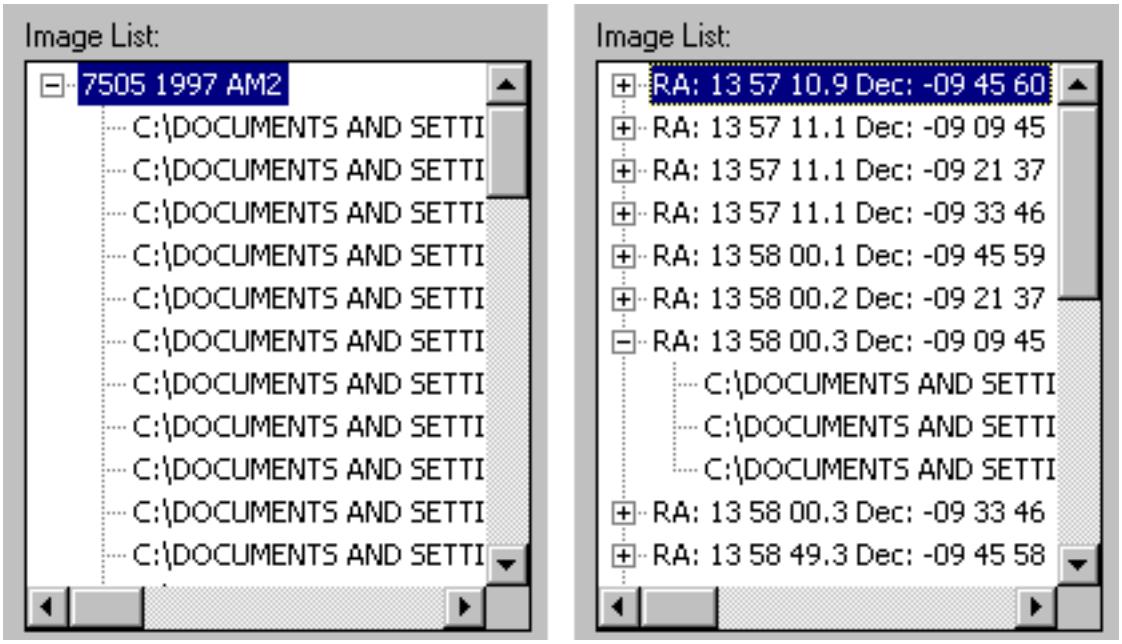


Figure 26: Expanding an object by clicking on the plus icon displays the images present for that object.

Keep in mind that the **Image List** is object-based, and sky location-based, not folder-based. As you add folders, CCDSoft sorts out the objects and locations present, and groups the images based on this information. If the locations of several images are within five arcminutes of each other, CCDSoft treats them as having a single location.

If you have images of the same object, or images that are acquired at the same location in the sky, in different folders, those images will be listed together in the Image List. For example, you might have images of a supernova spanning several days, with each set of images in a separate folder. When you add the separate folders, all of the images will appear in the image list under the same object name.

Once you have selected all of the folders to process, make sure that you enter the correct image scale in arcseconds per pixel. See the section **AutoAstrometry on a Single Image** earlier in this chapter for information on calculating this value. You can also perform an Image Link in TheSky using the Link Wizard to get information about your image scale.

Then, for most applications, you should check both the **AutoAstrometry/Add WCS** and the **Generate inventory of celestial objects** checkboxes. This will identify stars and other objects in your images, and provide the best possible precision in your results.

When you have the settings you want, click **Start** to perform the pre-analysis. The progress bars to the left of the **Abort** button will display feedback on how many of the images have been processed so far. The top bar indicates progress on the current image. The bottom bar indicates overall progress. In addition, the lines of text below the **Image scale** box will display how many files have been processed. Figure 27 shows a view of the Data Analysis dialog box during pre-analysis of 55 images.

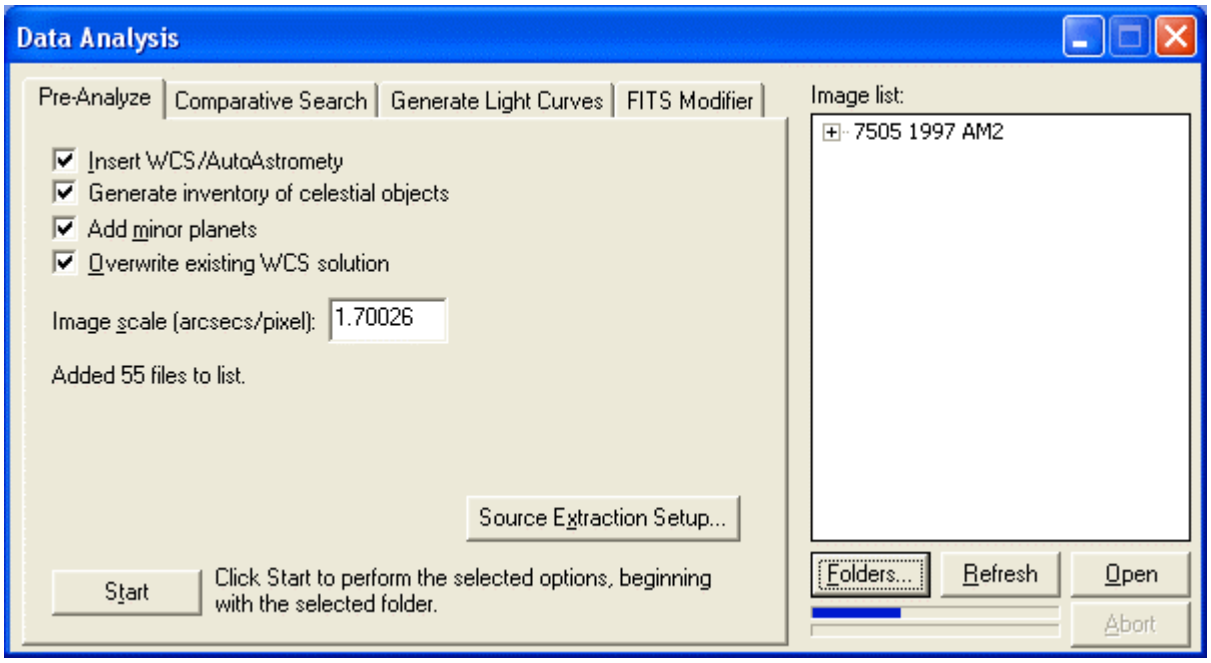


Figure 27: The progress bars and text at center left indicate how many images have been processed.

The .SRC files generated by Pre-analysis contain information about objects in each image. A portion of an SRC file is shown below. There is one line for each object. The header of the .SRC file explains what each entry means, as shown below.

```
#HEIGHT=   512
#WIDTH =   512
#TIME  =  6.494444
#       #
#   1 X_IMAGE         Object position along x                         [pixel]
#   2 Y_IMAGE         Object position along y                         [pixel]
#   3 MAG_APER        Fixed aperture magnitude vector                 [mag]
#   4 FWHM_IMAGE      FWHM assuming a Gaussian core                   [pixel]
#   5 FLAGS           Extraction flags
#   6 CLASS_STAR      S/G classifier output
#   7 ELONGATION      A_IMAGE/B_IMAGE
#   8 ELLIPTICITY     1 - B_IMAGE/A_IMAGE
#   9 A_IMAGE         Profile RMS along major axis                    [pixel]
#  10 B_IMAGE         Profile RMS along minor axis                    [pixel]
#  11 THETA_IMAGE     Position angle (CCW/x)                          [deg]
  190.159  27.684 -14.9815     8.71 004  0.85    1.339    0.253     2.39     1.78  25.6
  125.220  18.350  -9.2625     6.28 000  0.00    1.952    0.488     2.04     1.05  30.5
  442.650  15.721 -10.4130     5.35 000  0.01    1.401    0.286     2.02     1.44  23.2
   65.497  15.580 -10.4943     5.10 000  0.03    1.510    0.338     1.99     1.32  25.1
<...list of astrometric stars continues...>
```

Additional information about these items is shown below.

Item	Keyword	Description
1	X_IMAGE	The position of the object on the x-axis of the image (left/right).

<table>
<tr><td>2</td><td>Y_IMAGE</td><td>The position of the object on the y-axis of the image (up/down).</td></tr>
<tr><td>3</td><td>MAG_APER</td><td>Instrument magnitude. This is based on an “aperture” consisting of a fixed number of pixels. This is a relative magnitude. CCDSoft combines this information with the astrometric solution to calculate a calibrated magnitude.</td></tr>
<tr><td>4</td><td>FWHM_IMAGE</td><td>The full-width at half maximum (FWHM) of the object.</td></tr>
<tr><td>5</td><td>FLAGS</td><td>Extraction flags include the following:
<table>
<tr><th>Value</th><th>Description</th></tr>
<tr><td>1</td><td>The object has neighbors, bright and close enough to significantly bias the photometry (more than 10% of the integrated area overlaps the isophotal area of a detected neighbor).</td></tr>
<tr><td>2</td><td>The object was originally blended with another object.</td></tr>
<tr><td>4</td><td>At least one pixel of the object is saturated (or very close to saturated).</td></tr>
<tr><td>8</td><td>The object is truncated (too close to an image boundary).</td></tr>
<tr><td>16</td><td>The object’s aperture data is incomplete or corrupted.</td></tr>
<tr><td>32</td><td>The object’s isophotal data is incomplete or corrupt.</td></tr>
<tr><td>64</td><td>A memory error occurred during deblending (separation of overlapping objects).</td></tr>
<tr><td>128</td><td>A memory error occurred during extraction.</td></tr>
</table></td></tr>
<tr><td>6</td><td>CLASS_STAR</td><td>A numeric value that indicates whether the source object is a star or a galaxy. A neural network system is used to generate this value. It will give a source a value of -1 if it looks like a cosmic ray, 0 if it is a star and 1 if it is a galaxy. Fractional values between these whole numbers indicate some level of uncertainty about the classification of the object.</td></tr>
<tr><td>7</td><td>ELONGATION</td><td>Indicates the relative elongation of the object.</td></tr>
<tr><td>8</td><td>ELLIPTICITY</td><td>Indicates the relative ellipticity of the object.</td></tr>
<tr><td>9</td><td>A_IMAGE</td><td>A value that is based on the distance from object center to object edge along the major axis.</td></tr>
<tr><td>10</td><td>B_IMAGE</td><td>A value that is based on the distance from object center to object edge along the minor axis.</td></tr>
<tr><td>11</td><td>THETA_IMAGE</td><td>Position angle in degrees, measured from North.</td></tr>
</table>

Once pre-analysis is complete, you can search your images for minor planets and supernovas, or create light curves.

Searching for Minor Planets and Supernovas

Please note: As with all items on the Research menu, you must perform a pre-analysis of your data prior to searching. See the section above for more details.

Searching for minor planets requires three or more images of the same area of the sky. You can have more than one set of images in the image list. They will be scanned one group of images at a time. Each group can cover a different area of the sky. In the example that follows, there are three sets of three

images. The search computation is extremely sensitive, and can locate minor planets that might not be readily visible to the eye.

The time interval between the acquisition of each image within a set should be long enough to show the motion of any minor planet that might be present. Most minor planets move approximately 0.25 to 1.0 arcseconds each minute. Minor planet detection works best if the minor planets moves 5 - 10 pixels between each subsequent image.

For example, if your image scale is 2 arcseconds per pixel, then a minor planet must move through 10 arcseconds to show a 5-pixel movement, or 20 arcseconds to show a 10-pixel movement. The length of the exposure required depends on the rate of movement of the minor planet across the sky. A slow, distant minor planet might move 0.25 arcseconds per minute. That would require a 40-minute delay between exposures to yield a 5-pixel change in position. A faster, nearby minor planet might move 1.25 arcseconds per minute. That would require only a 7-minute delay. In other words, the longer the time interval between exposures, the greater the likelihood of finding a slow-moving, distant minor planet.

If your telescope aperture is small, or the light pollution is poor, you won't be able to image dim minor planets, so you might choose to focus your efforts on nearby minor planets using shorter intervals. If you are using a large aperture instrument, you can make good use of longer intervals.

You can use the following formula to compute reasonable times between exposures: The shortest useful delay in minutes (based on movement of 1.0 arcseconds per minute) is approximately:

$$image_scale*number_pixels$$

The longest useful delay in minutes (based on movement of 0.25 arcseconds per minute) is approximately:

$$\frac{image_scale*number_pixels}{0.25}$$

For example, if you are imaging with an ST-7E on a 10-inch telescope at f/10, your image scale is 0.74 arcseconds per pixel (see the formula near the start of this chapter). If you want to see a 5-pixel movement, and you have dark skies that justify using a long delay that will show dim or distant minor planets, then the computation would be:

$$\frac{0.74*5}{0.25} = 14.8 \text{ minutes.}$$

A delay of at least 15 minutes between exposures of the same area of the sky would give you a good shot at being able to find minor planets lurking in that area.

Tips on Searching for Minor Planets

CCDSoft provides two ways to search for minor planets. The first method, a Quick Search, allows you to quickly scan each set of images using the Blink Comparator (click **Research | Comparison | Blink Comparitor**). CCDSoft automates the process, presenting each set of images in turn for you to view.

The second method, the Detailed Search, presents a magnified view of every minor planet candidate. You can examine just the portion of the image that contains a candidate, and then either generate a report for the Minor Planet Center, or move on to the next set of images.

Exposure Intervals

The most efficient way to take images for a minor planet search is to take a sequence of images at different locations in the sky, and then repeat that sequence at least two more times so that you have at least three images of each location in the sequence. Here are some things you can do to make your hunt more successful:

- Determine the minimum delay between images that you find suitable for your location and equipment.
- Determine the amount of time for a complete exposure. This includes exposure time (see tips below), download time, and time to move the telescope.
- Calculate the number of exposures at other locations that you need to provide the minimum delay. For example, if your minimum delay is 15 minutes, and it takes 2 minutes 45 seconds from the start of one exposure to the next, then you can take six images giving an actual delay of 16.5 minutes. Of course, you could also elect to take 24 images in each sequence, giving you a delay of 66 minutes between images at the same location. The suggested delay is a minimum, not an absolute recommendation. As long as the minor planet doesn't move outside of the field of view, longer intervals are fine, and may provide greater precision.
- It is not important to have the same interval between images or sequences of images. As long as the minor planet stays within the field of view in each exposure, you will get useful results.
- Since things can go wrong, you might consider making at least four imaging sequences. Three images is the minimum number needed to perform a search, and if one of your images is bad then that area of the sky cannot be searched reliably.

If you have very bright or dark skies, or an extremely small or large image scale, you can modify the calculation for recommended minimal interval between exposures of the same area to suit your circumstances.

Exposure Duration

Various exposures can be used, but the following guidelines will help you choose an appropriate exposure:

- Undiscovered minor planets within the reach of amateur instruments tend to have magnitudes in the range of 16 - 20. Your exposure time should be long enough to show objects at this magnitude. You can insert AutoAstrometry into a test image to determine what magnitude your system can reach in a given amount of time, and adjust your exposure duration accordingly.
- Avoid blooming of stars. Blooming can interfere with astrometry by creating false objects, or causing astrometry to miss stars, or even hide a potential find. However, blooming will not necessarily be fatal, since you can still blink-compare the images manually.
- Make sure your exposure is long enough to overcome sky glow and light pollution. Exposures of objects with a known magnitude in the range of 16 -20 will illustrate what your system is capable of with various exposure times.
- The ability of your mount to track accurately may limit your exposure times. If you are performing an automated search without autoguiding, then your telescope's polar alignment and your mount's tracking errors will limit your exposure duration.

- The focal ratio of your telescope determines exposure duration. Slower focal ratios (for example, f/8, f/10) require longer exposures; faster focal ratios (for example, f/2, f/5) require shorter exposures.

In typical situations, exposures of one to five minutes are often used for minor planet searches. You can adjust your exposures to suit local conditions and equipment. For additional suggestions on minor planet searching, see the heading “Minor Planet Searches” in the section “Principles of Astrometry and Photometry” earlier in this chapter.

Performing a Quick Search

Once you have images and have performed the pre-analysis, you are ready to start hunting. The Quick Search steps you through each set of images using the Blink Comparator. The following example shows you how to search for moving objects (for example, minor planets), but the search will work with comets as well. The steps for a supernova search are similar. The only difference is that CCDSoft is not following a moving target.

If you’d like to follow along with the example, copy all 51 images from the `Images\QSearch` folder on the CD-ROM to a folder on your hard disk. Then open the Data Analysis dialog box by choosing **Research | Analyze Folder of Images | Pre-Analyze**. Then add the QSearch folder to the **Image List** using the **Folders** button. If necessary, remove any folders that are already in the Folders dialog box before you work through the tutorial. Set the parameters in the **Pre-Analyze** tab as shown in figure 28 (it is especially important to get the **Image Scale** correct: 1.47 arcseconds per pixel), and then click **Start**. This begins an operation that may require several minutes. At the conclusion of the pre-analysis, your **Pre-Analyze** tab should look like figure 28.

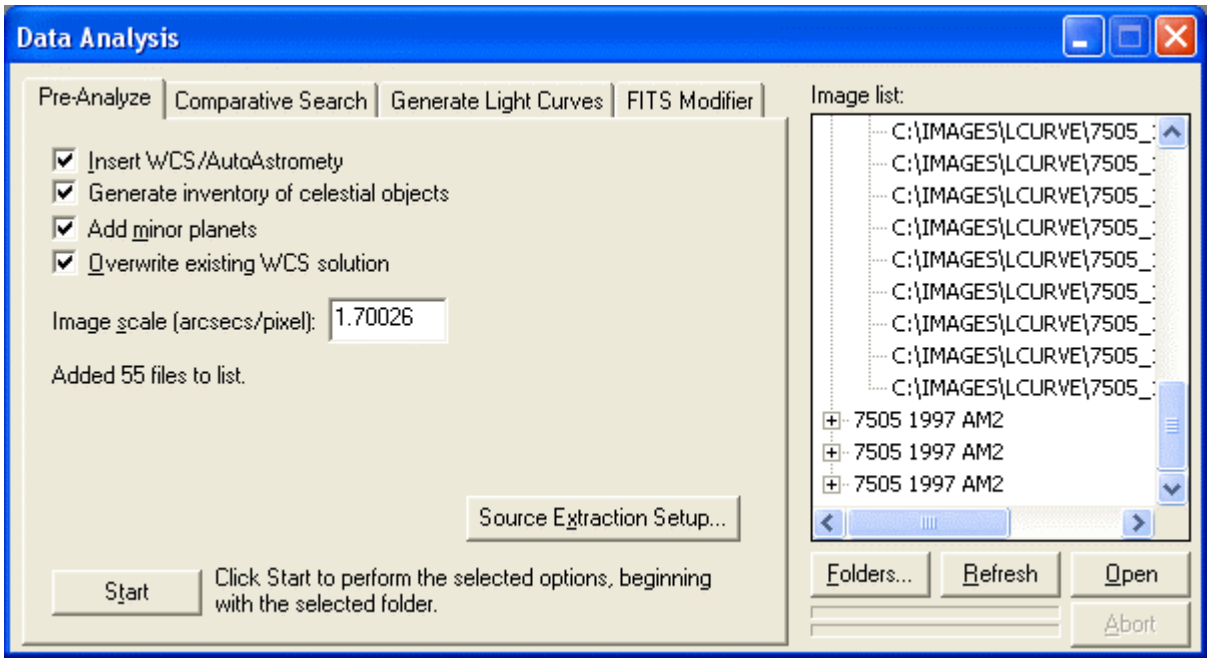


Figure 28: The conclusion of the pre-analysis run.

Now click on the **Comparative Search** tab (see figure 29). This tab supports searches for both minor planets and supernovas. It can also be used to search for comets. The main difference between the **Minor planets** and **Supernovas** option is that the **Minor Planets** button will search for moving objects.

Click the **Minor planets** option in the **Search for** section of the tab. Leave **Create Minor Planet Center (MPC) observations** unchecked for now. Choose **Entire image** in the **Blink** section, and **All images** in the **Examine** section.

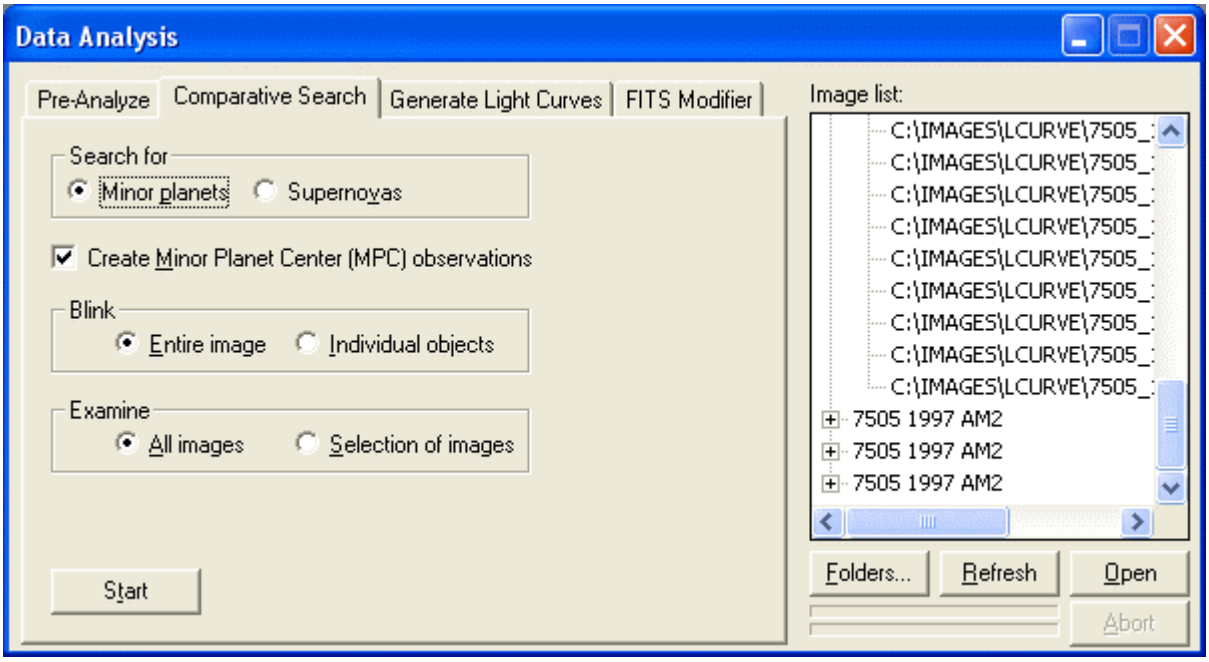


Figure 29: The Comparative Search tab.

The comparative search uses CCDSoft's source extraction features. The default settings will usually work well, but you can modify them if minor planets are not effectively detected.

To access the source extraction settings, click the **Pre-Analyze** tab, and then click **Source Extraction Setup**. Figure 30 shows the large number of settings available (with their default values), which allow you to customize the way that source extraction works for you. The settings you enter here apply to both minor planet (moving object) and supernova searches.

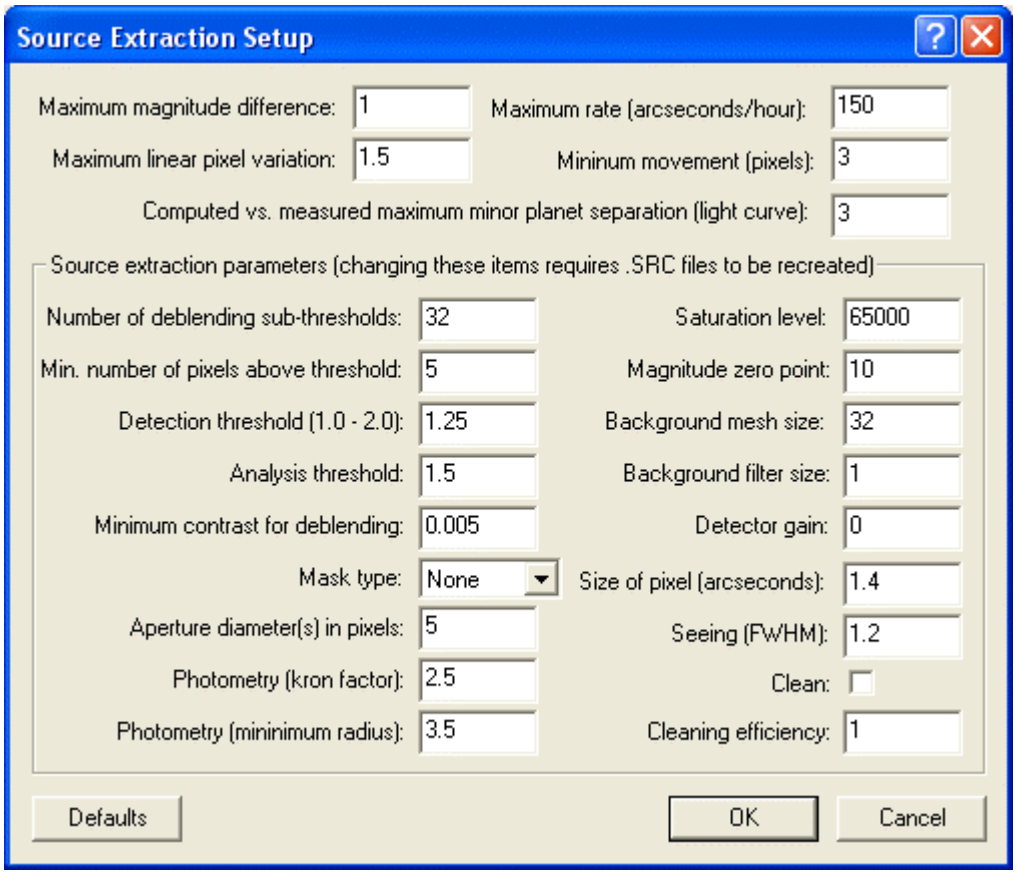


Figure 30: Setting parameters for minor planet and supernova searches.

The following table lists the available settings, their default values, and a brief description of the setting. For complete information about source extraction settings, please visit the ESO Imaging Survey's "Software/Reduction Tools and Tips" web page at:

`http://www.eso.org/science/eis/eis_soft/soft_index.html`

You'll find documents that cover the operation of the source extraction in detail. You can also find more details on the source extraction parameters used in CCDSoft's `Configuration Files` folder, in the file `default.sxt`.

Many of the parameters for source extraction require advanced math skills to determine useful values, but there is no risk in experimenting with various values because you can always restore the defaults by clicking the **Defaults** button. If you change any settings, CCDSoft will recreate the source (.SRC) files for all images the next time you click **Start** to perform a search.

Here are descriptions of each setting:

Setting	Default	Description
Maximum magnitude difference	1	Establishes the maximum magnitude difference from image to image, where the object is still seen as the same object. (Applies to moving objects only.)
Maximum rate (arcseconds/hour)	150	Establishes the maximum movement rate in arcseconds per hour from image to image, where the object is still seen as the same object. Use larger values for near Earth objects. Use smaller values to avoid spurious detections. (Applies to moving objects only.)
Maximum linear pixel variation	1.5	Establishes how far out of line objects can be, and still be considered one object across multiple images. CCDSoft predicts where the object should be on the third and subsequent images, and then looks within a radius equal to this pixel variation to see if it can find an object. If you increase this too much, CCDSoft will find objects that aren't in a line, resulting in spurious detections. (Applies to moving objects only.)
Minimum movement (pixels)	3	Establishes the minimum movement from image to image for an object to be considered a minor planet. If this value is too small, you will find too many spurious candidates. (Applies to moving objects only.)
Computed vs. measured maximum minor planet separation (light curve)	3	CCDSoft computes the next position of the minor planet based on the time of each exposure. If your orbital elements are inaccurate, you might need a higher value for this parameter so that CCDSoft can find the minor planet candidate. (Applies to moving objects only.)
Number of deblending sub-thresholds	32	Deblending is the separation of overlapping objects. 32 is the maximum useful number of thresholds. Smaller numbers can be used to reduce the amount of memory used for deblending, but deblending performance may suffer as a result.
Minimum number of pixels above threshold	5	Specifies an area in pixels that defines the smallest possible object found.
Detection threshold	1.25	Larger numbers mean fewer objects will be detected.
Analysis threshold	1.5	Threshold in brightness (relative to the background) at which star-related parameters operate.
Minimum contrast for deblending	0.005	The useful range of values is between 0.001 and 0.1. Smaller numbers lead to more aggressive deblending, and thus more objects being found. A value of 1 effectively turns off deblending.
Mask type	None	The available mask types are none, blank, and correct. Masking is applied to neighboring objects for photometry. None turns off masking. Blank puts pixels belonging to neighbors to zero. Correct replaces values with pixels at an equal distance on the other side of the object centroid.
Aperture diameter(s) in pixels	5	The aperture, in pixels, used for scanning the image.

Photometry (kron factor)	2.5	A scaling parameter related to the first-order moment.
Photometry (minimum radius)	3.5	Minimum radius is based on the units of A_IMAGE and B_IMAGE (see description of contents of .SRC file earlier in this chapter).
Saturation level	65000	Saturation level for your CCD camera. Defined as the full-well capacity divided by the gain.
Magnitude zero point	10	Zero point offset applied to all magnitudes.
Background mesh size	32	Defines how finely or coarsely the background filtering mask is divided in order to search for objects. If the mesh is too fine, the mesh boundaries can fall on objects too often and lead to locally inaccurate results. The mesh size is the size of the cell in the mesh, in pixels.
Background filter size	1	Size of a median filter applied to the background. 1 means no filtering. Use a filter (for example, 2x2 or 3x3) to compensate for small mesh sizes or in the case of large artifacts in the image.
Detector gain	0	The gain of the CCD detector.
Size of pixel (arcseconds)	1.4	Pixel scale in arcseconds.
Seeing (FWHM)	1.2	The FWHM (full width at half maximum) of the stars in the image.
Clean	unchecked	When checked, faint (spurious) detections are removed from the object catalog before writing to disk.
Cleaning efficiency	1	Determines the aggressiveness of the cleaning.

To perform the minor planet search on the folders you have loaded and pre-analyzed, switch back to the **Comparative Search** tab, and click **Start**. For each location in the Image List, CCDSoft will display the group of three or more images for that location using the Blink Comparator (see figure 31). Any areas in the images that might contain a minor planet are outlined in a box with a dashed edge. In figure 31, there are three such boxes, numbered for convenient reference in the illustration. As the blink comparator rotates from one image to the next, look for a minor planet moving within the confines of each box. If there are no minor planet candidates, there will not be any boxes.

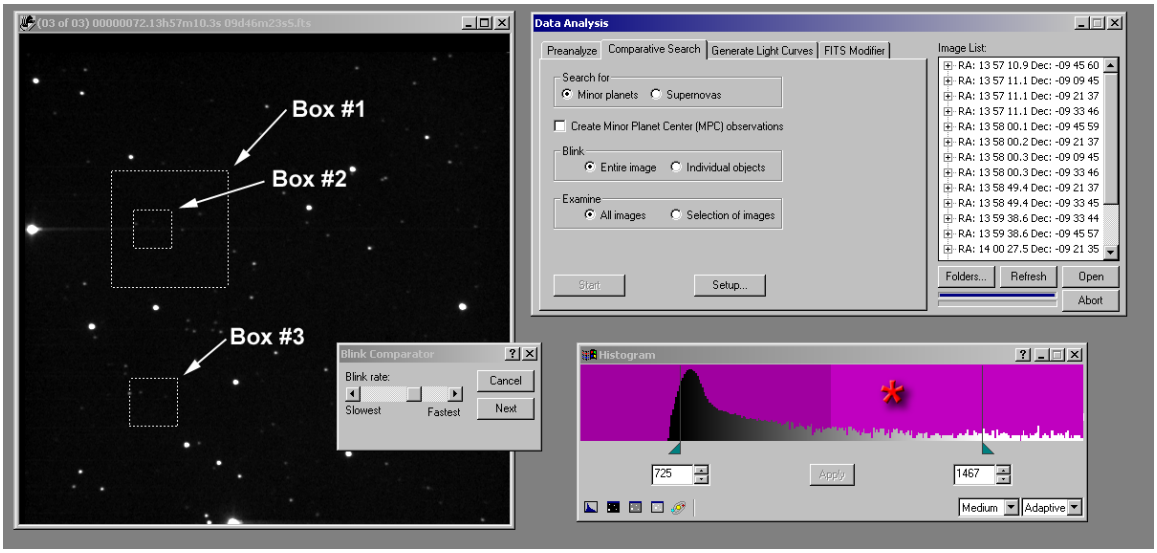


Figure 31: Using the Blink Comparator and Histogram tools.

If you cannot see any objects in the boxes, right click on the image and click **Histogram** to display the Histogram window (shown at lower right in figure 31). Use this tool to lower the white point. Click approximately in the area of the asterisk shown in figure 31 to lower the white point. You may need to do this more than once to see extremely dim objects. The right-side triangle under the histogram graph indicates the current white point. You can also drag that triangle toward the left to lower the white point. See “Chapter 9: Image Processing” for more details on working with the Histogram tool.

The goal is to lower the white point enough to show any objects that may be present in the boxes. Figure 32 shows the effect of lowering the white point. It reveals more dim objects, including a minor planet candidate shown by the arrow in box #3. The minor planet can be seen to move in the three images thanks to the Blink Comparator, as shown later in figure 36.

In figure 32, the white point has been lowered from 1467 to 861. Boxes #1 and #2 are false detections, caused by the bright area streaming away from the bright star at the left of both boxes.

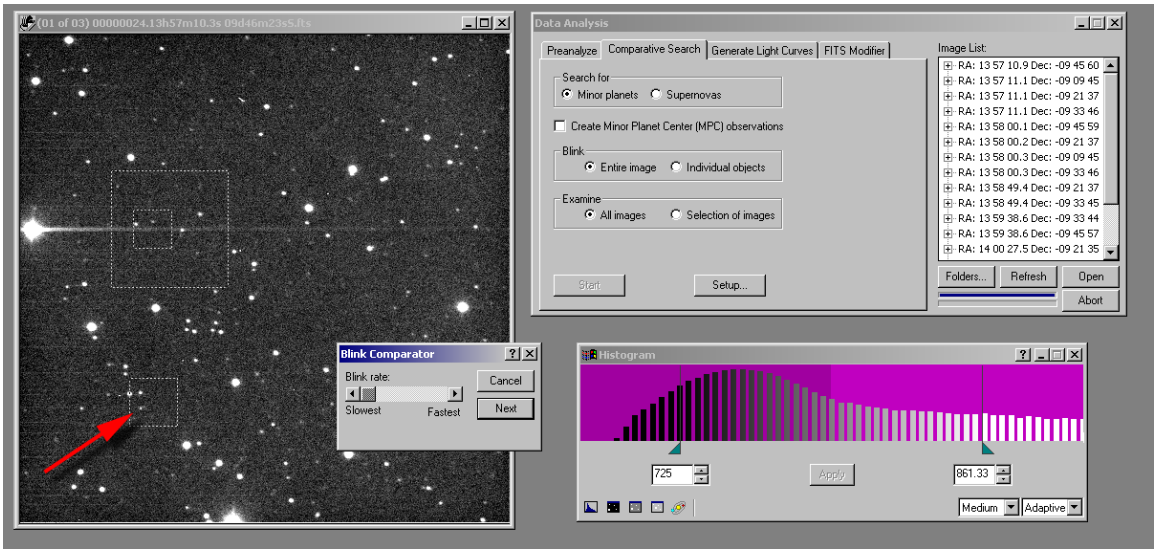


Figure 32: Minor planets are often easier to see when the white point is lowered.

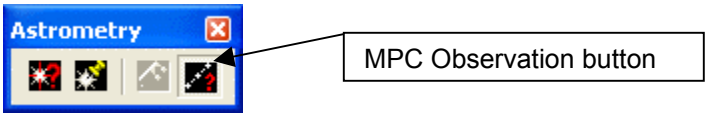
You can change the rate of the **Blink Comparator** by moving its scroll bar left (slower) or right (faster). When you are done examining a set of blinked images, press the **Next** button in the **Blink Comparitor** window to move to the next set of images.

If you find a minor planet candidate while doing a Quick Search, make a note of the filename (you can find this in the title bar of the image window). You can use this information to perform a Detailed Search when the Quick Search is complete. A Detailed Search allows you to create a Minor Planet Center observation report. The Quick Search allows you to quickly scan through your images, but it doesn't include the features available in a Detailed Search.

Creating a Minor Planet Center Observation Report

After you have positively identified a minor planet on three or more images, you may wish to report this observation to the International Astronomical Union (IAU). For each image that contains a minor planet, do the following:

1. Load the FITS image that contains the minor planet(s). Make sure that the image contains World Coordinate System/AutoAstrometry information by clicking **Research | Insert WCS/AutoAstrometry** first.
2. Click the **MPC Observation** button on the Astrometry toolbar. This causes the cursor to change from the pointer arrow to a cross hair.



3. Click on the image to identify the minor planet. You may need to magnify the image by zooming in first. This will display the "Convert Date of Observation" to UTC dialog box. If the date of the

minor planet or comet observation is not specified in Universal Time, enter your **Time Zone** to make this adjustment automatically. Click **Adjust** to modify the FITS header with UTC, or click **Do Not Adjust** to keep image's current time.

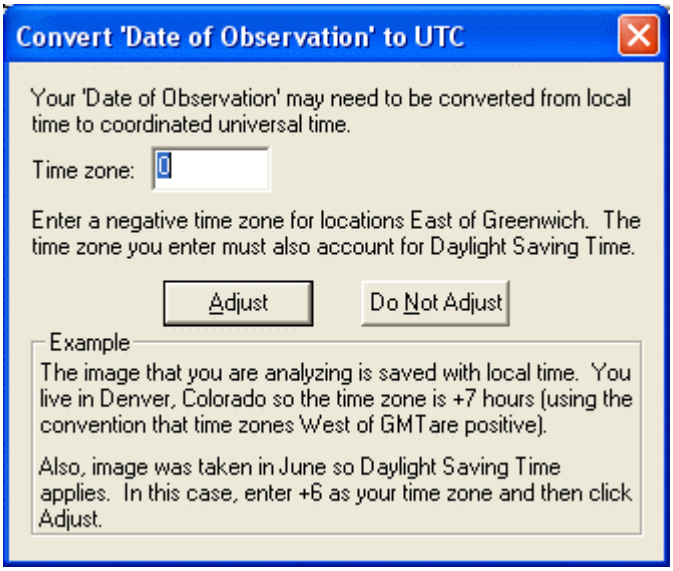


Figure 33: Convert 'Date of Observation' to UTC dialog box

4. The Minor Planet Center Optical Astrometric Observation dialog box contains options for completing the IAU-formatted report. See the following for details.

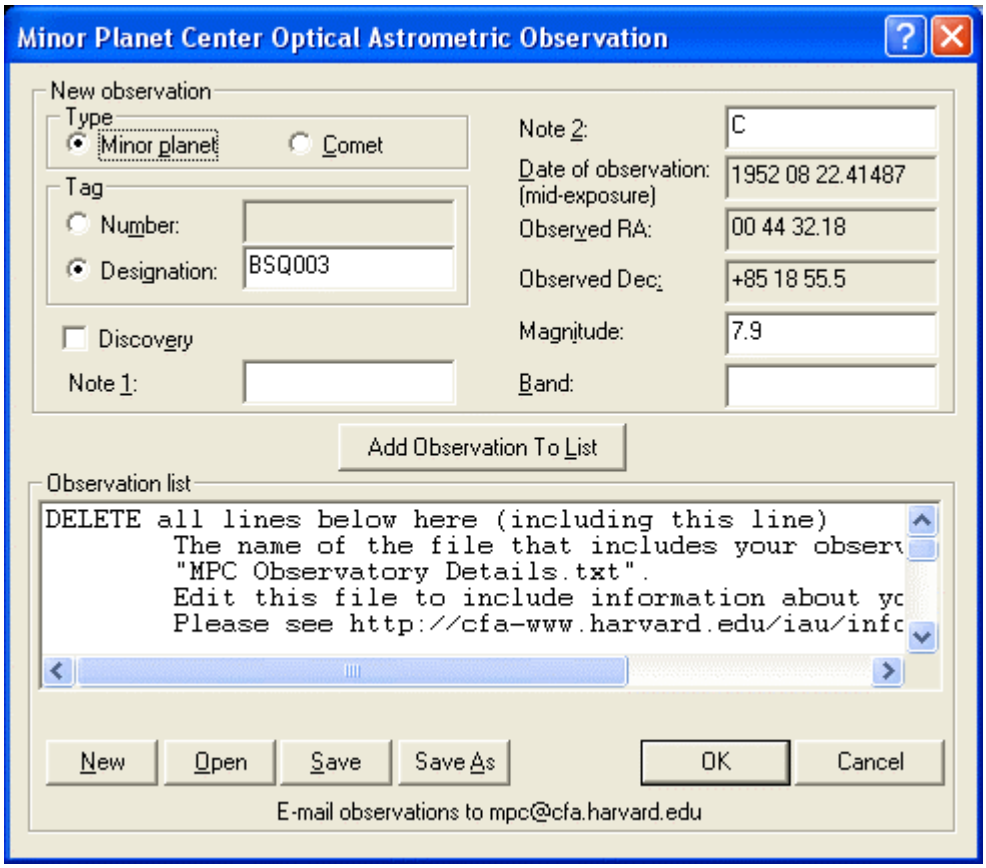


Figure 34: Minor Planet Center Optical Astrometric Observation dialog box

Control	Description
Type: Minor Planet or Comet	Click the type of object to include in the IAU report text file.
Tag: Number or Designation	Click **Number**, then enter the catalog number of the comet or minor planet if known. Click **Designation** and then enter your observatory code here. By default, CCDSoft uses the three letter prefix “BSQ” for the minor planet report designation. To change this setting: 1. Click **Start | Run | Regedit**. 2. Navigate to and highlight the following key: `HKEY_CURRENT_USER\Software\Software Bisque\CCDSoft\MPC` 3. Click **Edit | New | String Value** and the enter `DesignationPrefix` for the name of the string value. 4. Highlight this new value, then click **Edit | Modify**. In the **Value Data** text box, enter the desired three-letter prefix for your report, then click **OK**.

	5. Click **Registry | Exit** (or **File | Exit** under XP).
Note 1	Enter any notes about the observation in this text box.
Note 2	Enter any additional notes in this text box.
Discovery	Mark this option if this observation is a new discovery.
Date of observation	Displays the date of the observation (DATE-OBS FITS keyword).
Observed RA	Displays the right ascension of the center of the image.
Observed Dec	Displays the declination of the center of the image.
Magnitude	Enter the magnitude of the object, if known.
Band	Enter the type of filter used (if any).
Add to Observation List	Click the button to add this object to the current list of objects in the IAU observation report.
Observation list	Displays the contents of the IAU text file.
New	Creates a new report file.
Open	Opens an existing report.
Save	Saves the current report to a text file.
Save As	Saves the current report under a new file name.

The reports should be submitted via email to mpc@cfa.harvard.edu.

Performing a Detailed Search

The Detailed Search displays a magnified view of the area around suspected minor planets or supernovas. In addition, if you check the **Create Minor Planet (MPC) observations** option, the MPC observation report is written to disk each time you positively identify a minor planet candidate.

> MPC observation reports are written to the CCDSoft version 5 “MPC Observations” folder on your hard disk. The default folder location is:
>
> `\Program Files\Software Bisque\CCDSoft Version 5\MPC Observations`
>
> The default filename is
>
> `AutoMPCObservationXXX.txt`
>
> where “XXX” is a sequence number, starting at 1.

To perform a Detailed Search, use the following settings on the Comparative Search tab. This works for both minor planets and supernovas.

- Click the **Individual Objects** option in the **Blink** section. Instead of seeing the entire image in the Blink Comparator, you will be presented with a magnified portion of the image surrounding search candidates.
- If you have previously found an image set that contains minor planet or supernova candidates, then use the mouse to select that image set in the **Image list**. Then click the **Selection of Images** option in the **Examine** section. This will cause only the currently highlighted image set to appear in the Blink Comparator. If you have more than one image set on which you want to perform a Detailed Search, you can either select **All images** or perform multiple searches using **Selection of images**.

- If you are searching for minor planets, and wish to submit your observation, check **Create Minor Planet Center (MPC) observations**. If your Examine setting is **All images**, an MPC observation will be written for each candidate you identify during the Detailed Search.

Figure 35 shows typical settings for a Detailed Search for minor planets. For this example, the highlighted images will be subjected to a detailed search. Any minor planet candidates will be shown in a magnified view, and an MPC observation report will be generated if a minor planet candidate is found.

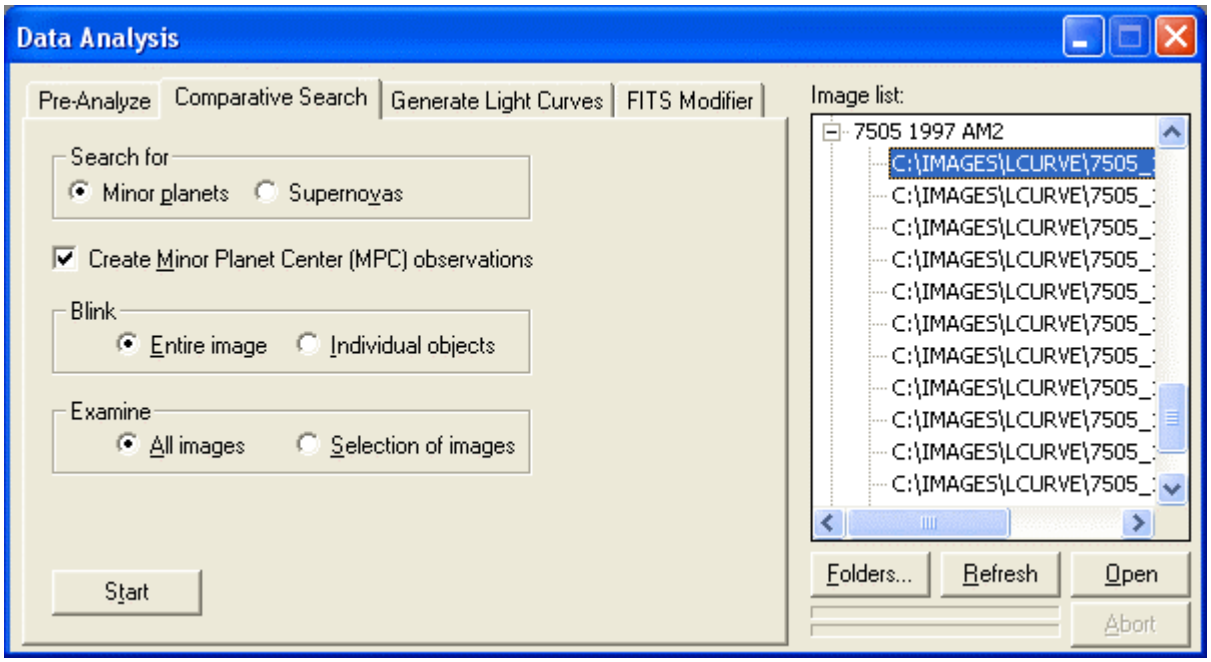


Figure 35: Typical setup for a Detailed Search, in this case for minor planets.

Figure 36 shows what the magnified view looks like. The image contains just the immediate area around the suspected minor planet (or supernova). The arrow points to the suspected minor planet. The arrow is not part of the CCDSoft interface. In actual use, the blink comparator would show the minor planet moving as the images blink, so no arrow is necessary.

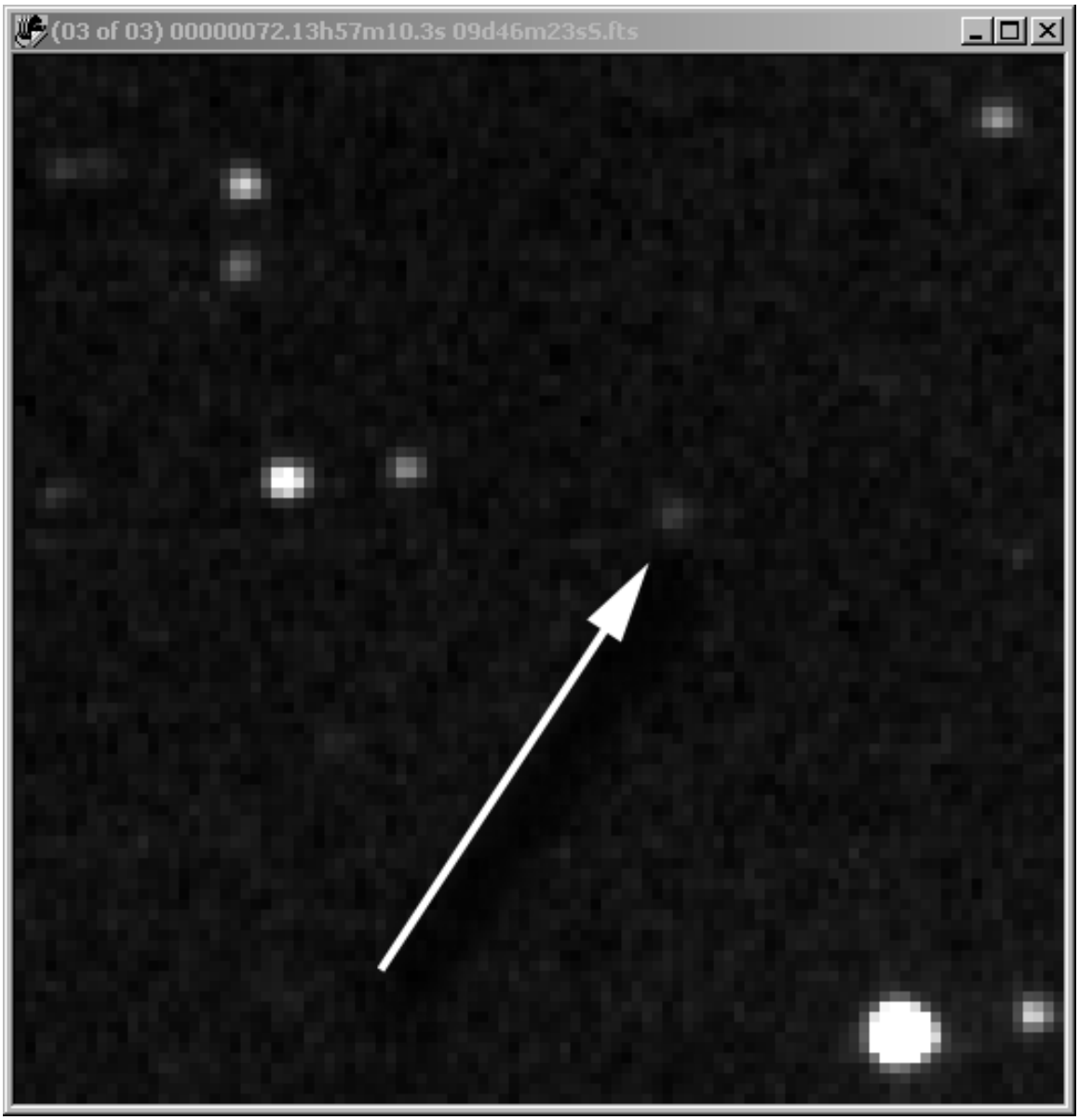


Figure 36:The magnified view zooms in on a suspected minor planet (arrow).

The **Blink Comparator** makes it very easy to identify candidate objects. When you are performing a Detailed Search, the appearance of the **Blink Comparator** dialog box changes, as shown in figure 35 (compare to figure 32). The **Blink Comparator** asks you a question: *Is this a minor planet?* If you click **Yes**, a Minor Planet Center observation report is created in the MPC Observations folder of the CCDSoft folder, and the next object appears for your examination. If you click No, the **Blink Comparator** will present the next object without writing the report. If there is no next object, the **Blink Comparator** closes.

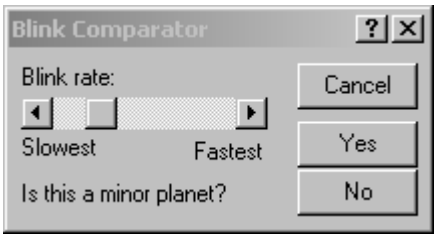


Figure 37: The Blink Comparator asks you to verify if a minor planet candidate present.

Figure 37 shows a typical series of three images that include a minor planet. The minor planet is the only object that moves from one image to the next. The arrows point to the minor planet's position in each image. Using the **Blink Comparator** with the magnified view, the movement of the minor planet is immediately obvious. If you don't see a minor planet, use the Histogram tool as described earlier to lower the white point. You can access the Histogram tool by right clicking on the image and clicking **Histogram**.

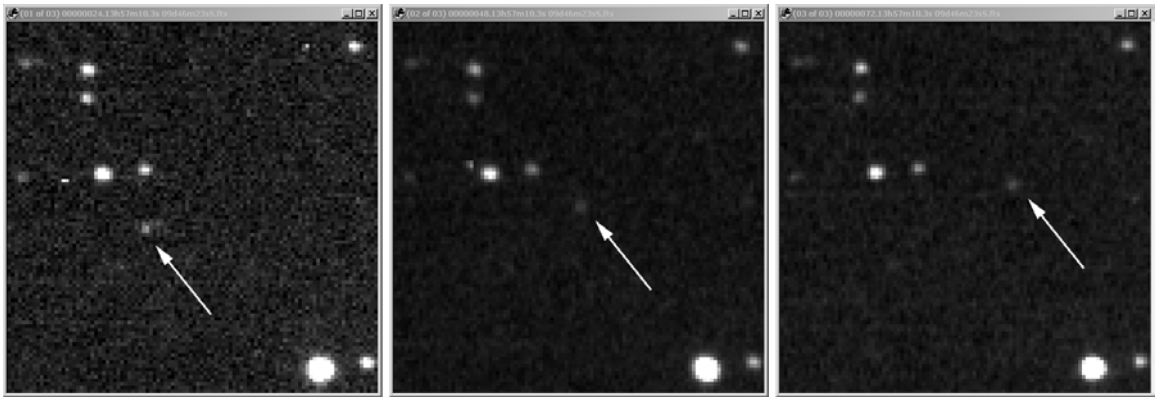


Figure 38: A minor planet changes position between images.

When the **Create Minor Planet Center (MPC) observations** checkbox is checked, CCDSoft writes out a text file with the observation information in it. The filename is

```
AutoMPCObservationXXX.txt
```

where "XXX" is the next sequential number. This number is incremented each time CCDSoft creates a new observation text file. The file is located in the CCDSoft program folder (default location: `\Program Files\Software Bisque\CCDSoft Version 5`) and it contains the report to send to the Minor Planet Center. A typical report is shown below.

```
DELETE all lines below here (including this line)
       The name of the file that includes your observatory details is
       "MPC Observatory Details.txt".
       Edit this file to include information about your observatory.
       Please see http://cfa-www.harvard.edu/iau/info/ObsDetails.html for a
       complete specification of the format of this file.
DELETE all lines above here (including this line)
```

```
COD XXX
CON S. Holmes, 221B Baker Street, London NW1 4JW, England
CON [sholmes@mycroft.holmes.gov.uk]
OBS H. Poirot, P. Mason, L. Columbo, C. Chan
MEA J. Watson
TEL 0.50-m f/3.0 reflector + CCD
NET GSC
ACK Batch 001
AC2 dwatson@mycroft.holmes.gov.uk
     BSQ006   C1999 05 10.22103 13 57 22.91 -09 49 28.9          19.3        XXX
     BSQ006   C1999 05 10.24512 13 57 21.68 -09 49 19.1          19.4        XXX
     BSQ006   C1999 05 10.26865 13 57 20.44 -09 49 09.3          19.3        XXX
```

To verify the position of the minor planet computed by CCDSoft, you can create a visual representation of the observations in TheSky by pasting the information from the observation report file into a file with a standard database header in it. The standard header contains information about how the data is organized in the report file. Here is a header for a minor planet database file, with the object information from the observation report file added to it:

```
>SEARCH 1,31
>RAHOURS 33,34
>RAMINUTES 36,37
>RASECONDS 39,43
>DECSIGN 45,45
>DECDEGREES 46,47
>DECMINUTES 49,50
>DECSECONDS 52,55
>MAGNITUDE 66,70
>PARSE "Designation" 6,14
>PARSE "Date" 15,31
>PARSE "Magnitude" 66,70
>PARSE "Observatory Code" 78,80
>CATALOG CLASS=OBJECTS
>OBJECT TYPE 39
>IDENTIFIER Minor Planet Ephemeris
COD XXX
CON S. Holmes, 221B Baker Street, London NW1 4JW, England
CON [sholmes@mycroft.holmes.gov.uk]
OBS H. Poirot, P. Mason, L. Columbo, C. Chan
MEA J. Watson
TEL 0.50-m f/3.0 reflector + CCD
NET GSC
ACK Batch 001
AC2 dwatson@mycroft.holmes.gov.uk
     BSQ006   C1999 05 10.22103 13 57 22.91 -09 49 28.9          19.3        XXX
     BSQ006   C1999 05 10.24512 13 57 21.68 -09 49 19.1          19.4        XXX
     BSQ006   C1999 05 10.26865 13 57 20.44 -09 49 09.3          19.3        XXX
```

Once you have created a new file by combining the header and the data from the observation text file, save the file in TheSky's Sky Database folder. The default location is `C:\Program Files\Software Bisque\TheSky\User\SDBs`. Save the file with a .txt extension.

To import this new file into TheSky, click **Data | Import**. This displays the Import dialog box, shown in figure 37. Click **Browse**, navigate to the text file you saved as described above, and then click **Open**.

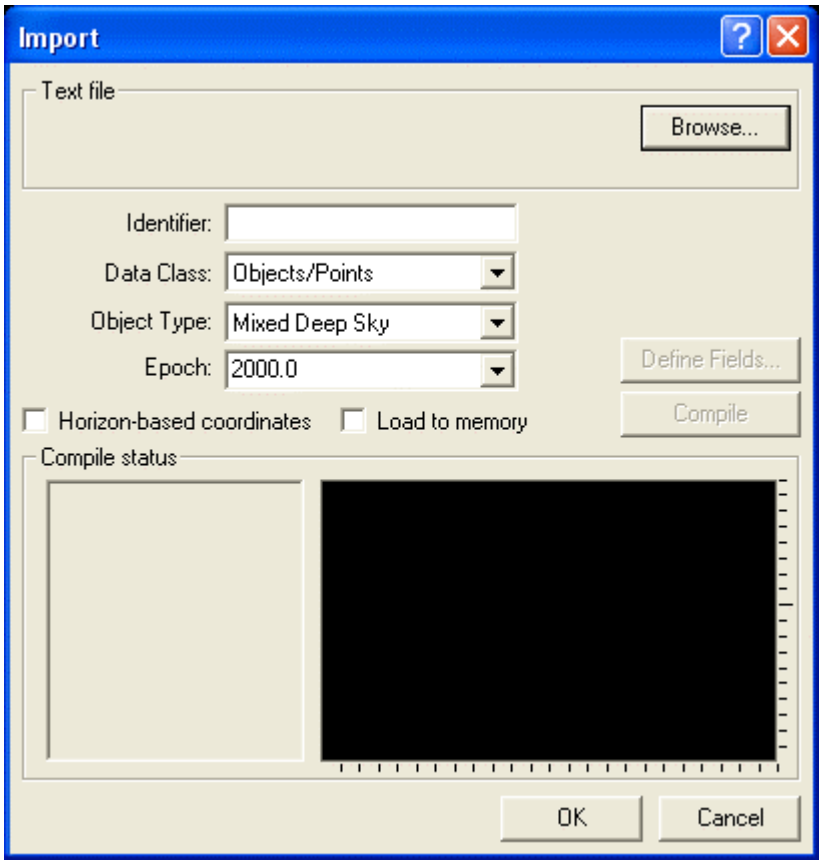


Figure 39: Importing a data file into TheSky.

The path and filename of the text file now appear to the left of the **Browse** button. The **Identifier** is now set to “Minor Planet Ephemeris,” and the **Object Type** is now set to **Extended Asteroid**. See figure 40, which shows the appearance of the Import dialog box after you have opened the text file.

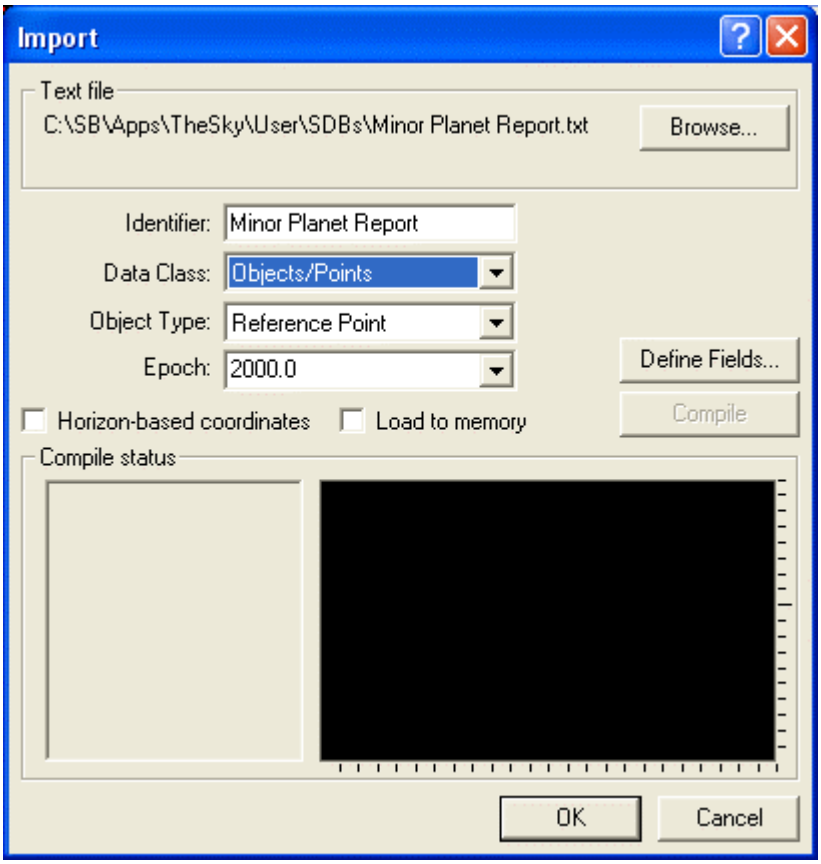


Figure 40: The appearance of TheSky's Import dialog box after a text file has been opened.

The header in the text file describes, among other things, how the data in each line of the text file is organized. To verify that the header field definitions are correct, click on the **Define Fields** button to display the field definitions. If necessary, scroll down to the actual data lines at the bottom of the text file, and make sure that the vertical lines exactly define the data fields, as shown in figure 41. If they do not match, you can get the latest minor planet header from the Software Bisque web site. Consult the documentation and help files for TheSky to learn how to manually define fields. If you want to immediately view the results of the import operation, be sure to check the "**Load to memory** checkbox.

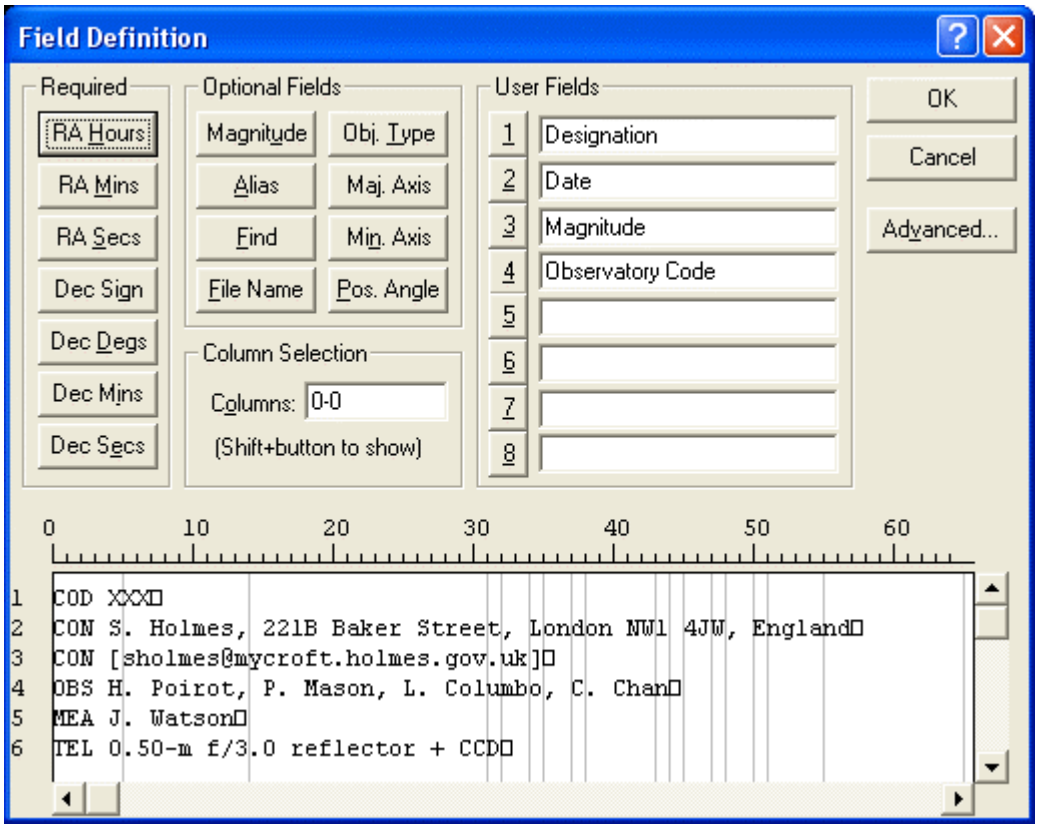


Figure 41: The Field Definitions dialog box.

Once you have verified that the field definitions are correct, you can compile the text file into a Sky Database. Just click **Compile**. If the compile is successful, the **Import** dialog box will show the total number of lines, and the number of objects in the text file, in the **Compile status** section. TheSky will also display a dialog box (see figure 40), which offers to auto load the new database. Select **Yes** or **No** depending on your preference.

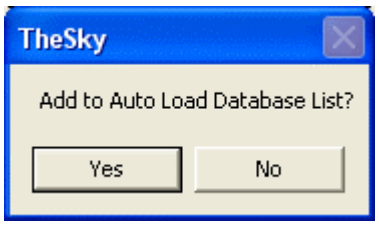


Figure 42: Choosing whether to automatically load the new database when TheSky is launched.

Figure 43 shows the appearance of the Import dialog box after a successful compilation.

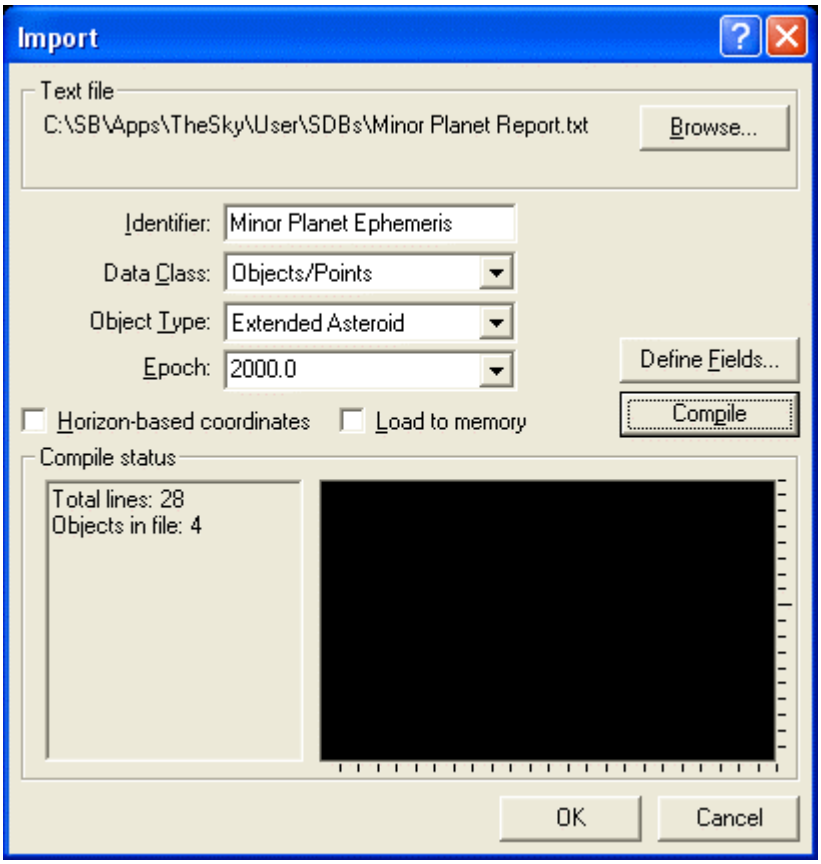


Figure 43: A successful Sky Database compilation.

Once the database is loaded into TheSky (via auto loading or loading into memory), the asteroid positions in the compiled file appear on the virtual sky display, as shown in figure 42. The positions on the virtual sky should match the positions you saw in your images using the **Blink Comparator**.

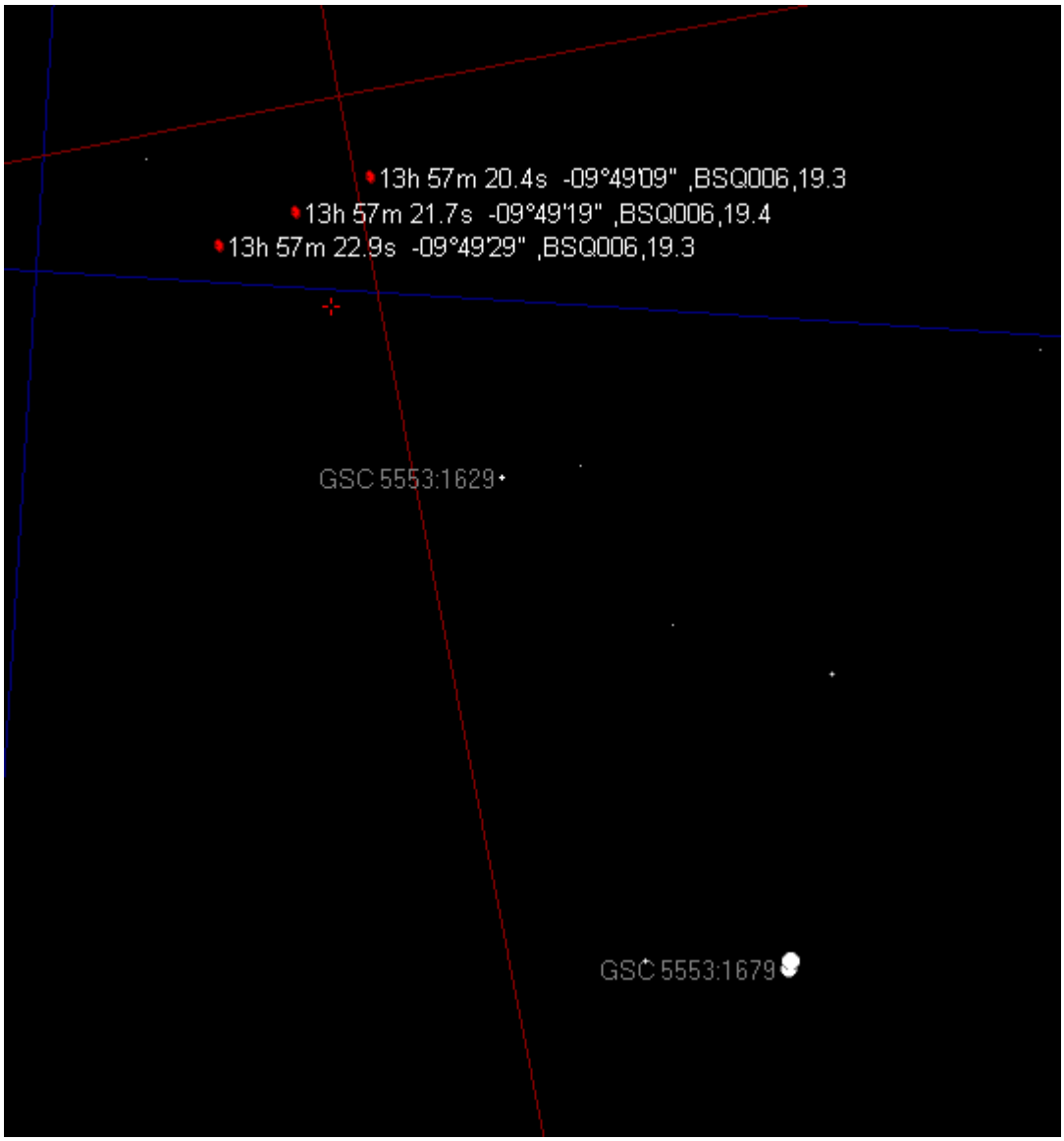


Figure 44: The asteroid positions from your images can be shown in TheSky.

You can also display the asteroid positions in CCDSoft. Open one of the images from the image set containing the minor planet. You can either open it directly by clicking **File | Open**, or highlight the image set in the **Data Analysis** dialog box and click **Open,** below the Image List. To display the asteroid positions in CCDSoft, click **Research | Comparison | Star Chart**. This opens a GIF image of the area in the image, as shown in figure 45.

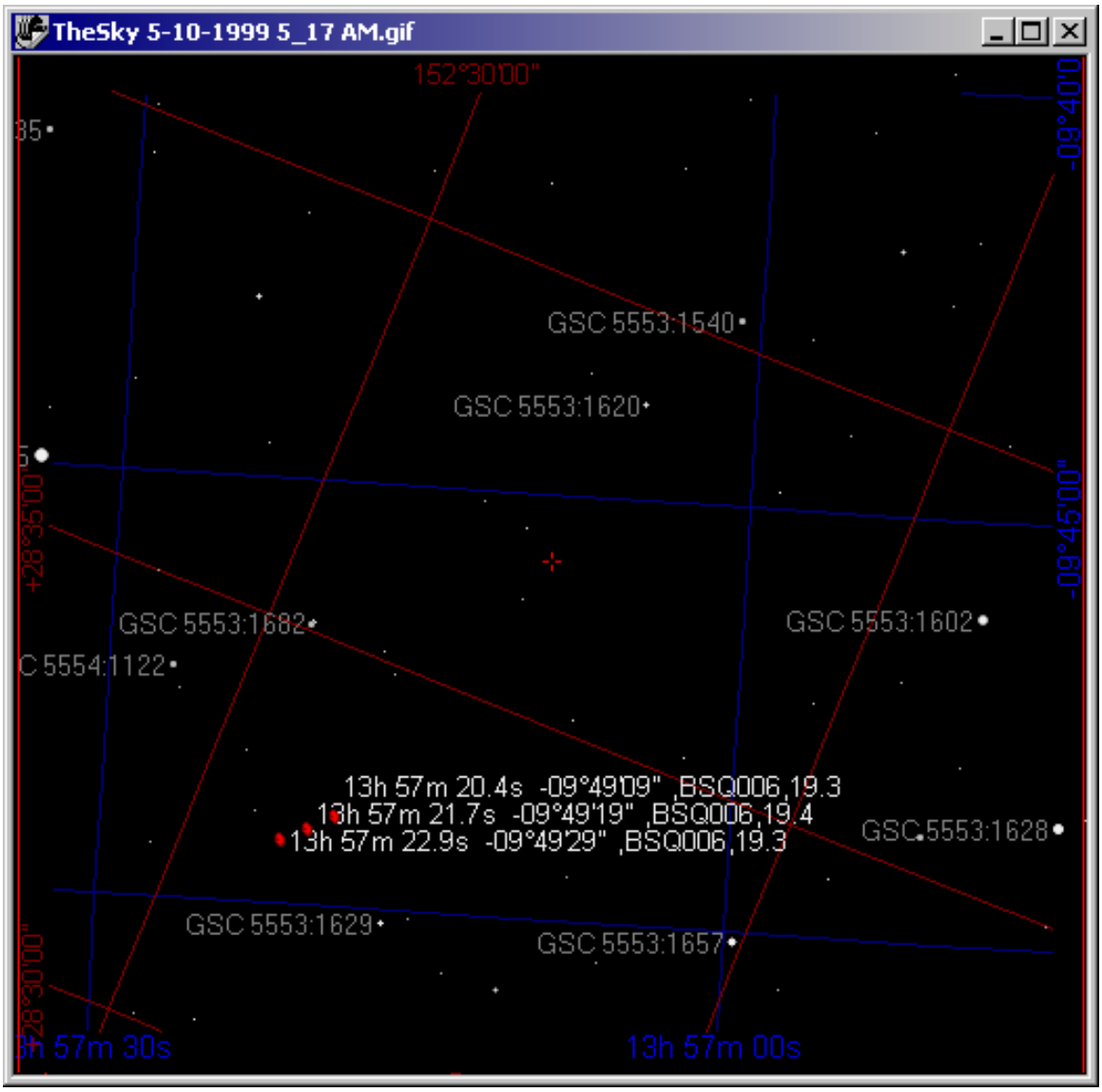


Figure 45: Displaying a star chart from TheSky in CCDSoft.

Figure 43 includes right ascension, declination, ID, and magnitude information. Use TheSky's **View | Labels | Setup** menu item to open the **Labels Setup** dialog box (see figure 44). Highlight **Minor Planet Ephemeris** and check the labels you would like to see. For the result you see in figure 45, check the checkboxes shown in figure 46.

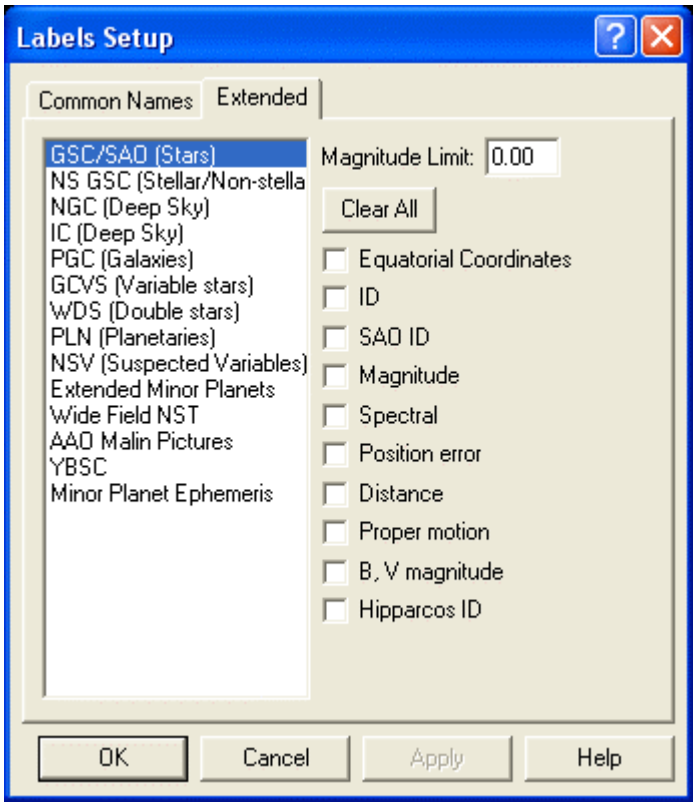


Figure 46: Setting up TheSky's extended labels.

If the labels do not appear in TheSky or your star charts, click **View | Filters,** open the **Filters** dialog box (see figure 47). Make sure that **Extended Minor Planets** is checked, and then click **OK** to save any changes.



Figure 47: Setting TheSky's Filter options.

Supernova Searches

Supernova searches are similar to minor planet searches. The primary difference is in the strategy that CCDSoft uses to find the desired object in each image. For minor planet searches the key indicator is movement. If an object appears in three positions in a straight line, it is a possible minor planet.

As with all items on the **Research** menu, you must perform a pre-analysis of your data prior to searching for supernovas. The supernova search process is very similar to that for minor planets. Simply select the **Supernovas** option instead of the **Minor planets** option in the **Search for** section of the **Comparative Search** tab (**Data Analysis** dialog box). Note: The checkbox for **Create MPC observations** has no meaning when searching for supernovas. Continue as described for minor planets above.

For supernova searches, the key indicator is a star-like object in the vicinity of a galaxy-like object. CCDSoft is able to differentiate between these two types of objects with reasonable effectiveness. However, the trained human eye is still more effective, and is the preferred detector when examining blinking images. If you see too many or too few objects, you can modify the Source Extraction parameters by clicking **Source Extraction Setup** on the **Pre-Analyze** tab of the **Data Analysis** dialog box. Refer to the detailed discussion of this dialog box in the Minor Planet instructions above.

To see the objects identified in your image, click **Research | Show Object Inventory**. This displays your image with identified objects overlaid on the image (see figure 46). There are two problems visible in figure 46. First, the galaxy near the center has been broken down into multiple objects. Second, two large false galaxies are indicated at lower right. There are many ways to fix these problems. Press `Control + Alt + I` to toggle the object inventory on and off.

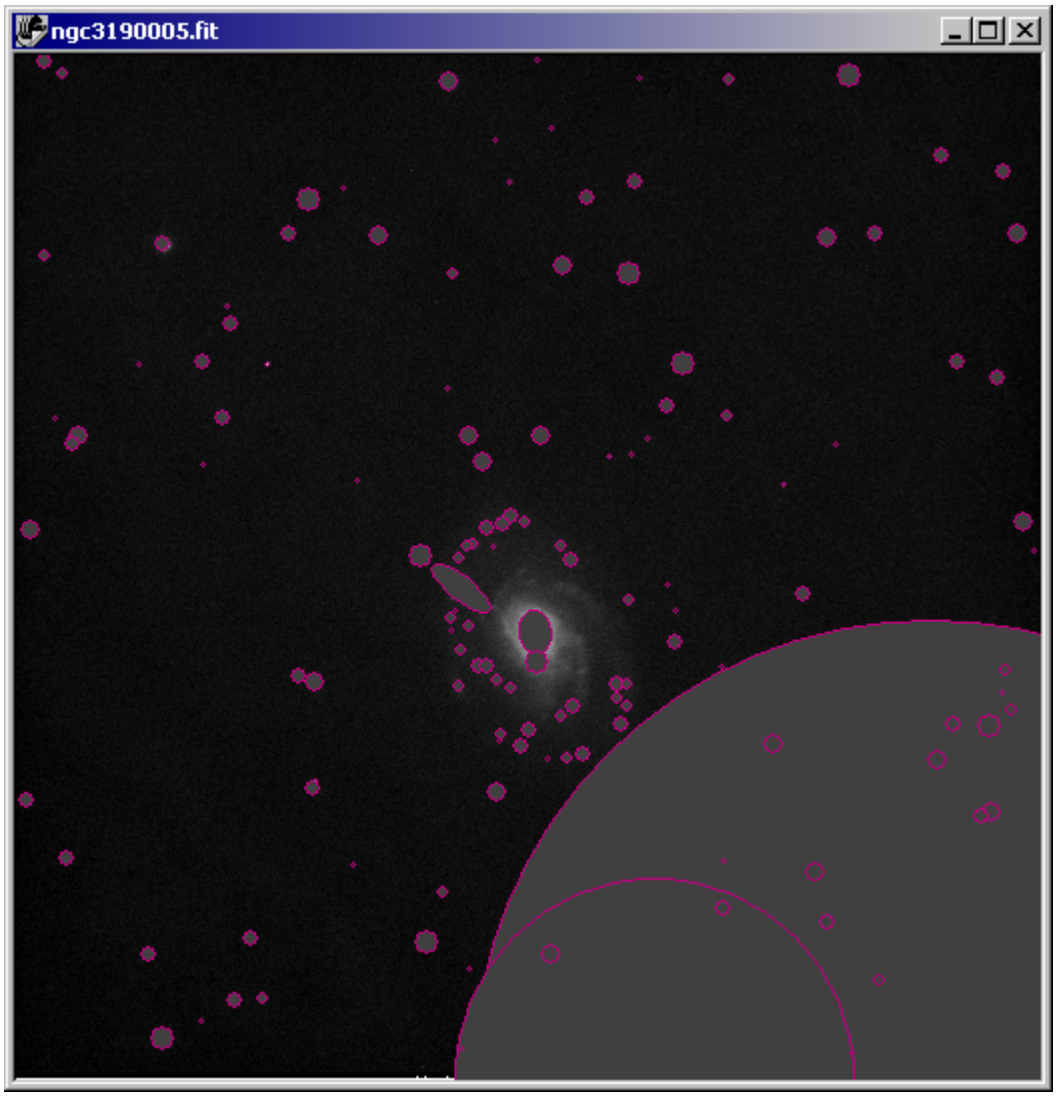


Figure 47: This image has too many objects identified in it.

One way to handle large galaxies is to increase the **Background filter size** parameter in the **Source Extraction Setup** dialog box. A value of 6 (the default is 1) forces CCDSoft to use a larger grid when analyzing images. Figure 49 shows that the galaxy at the center of the image is now correctly identified as a single galaxy. Other non-galactic objects are not affected much by this change. However, the two large false galaxies at lower right remain. The larger background grid didn't help with that problem.

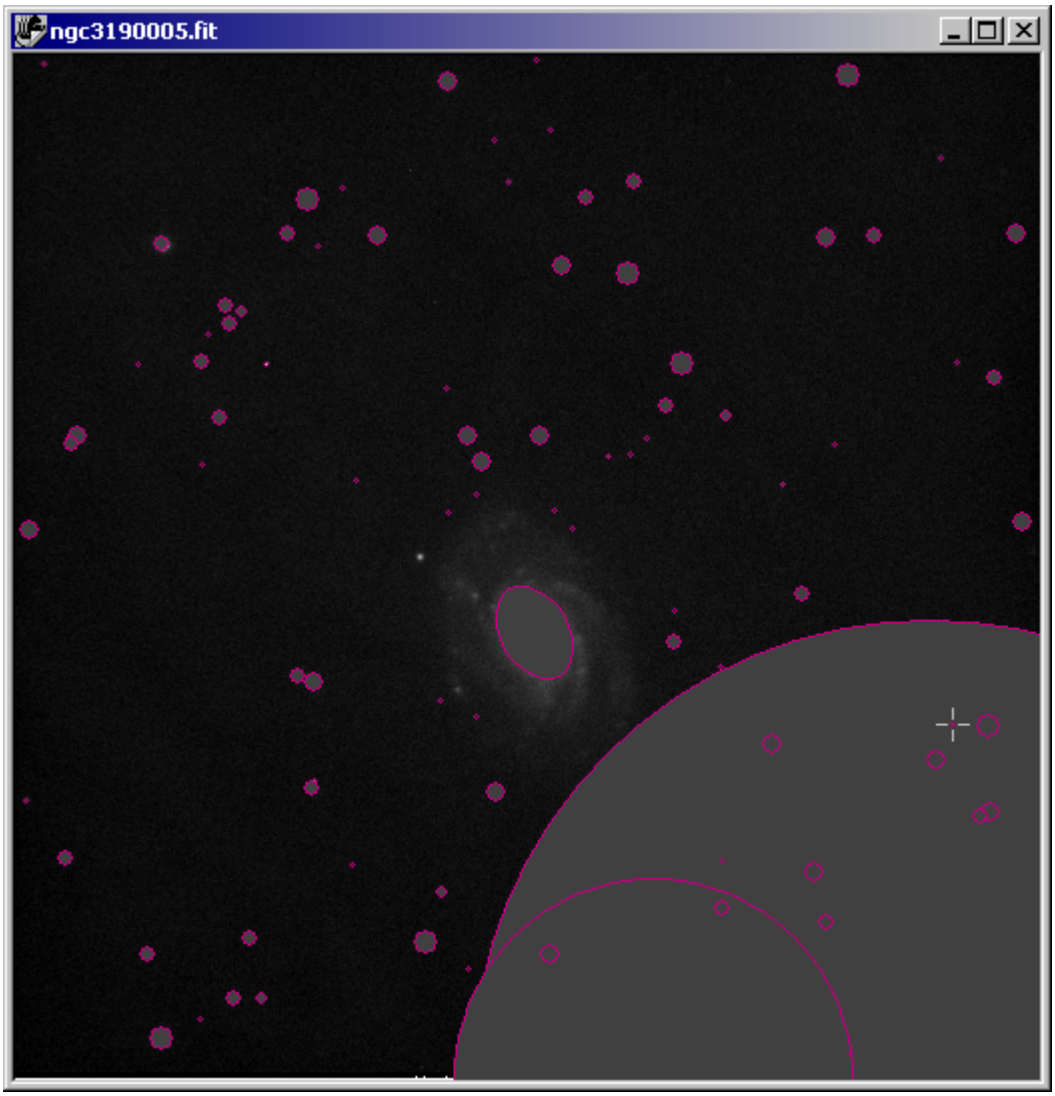


Figure 49: A larger background filter (grid) causes the central galaxy to appear as one object.

Changing the number of de-blending sub-thresholds from 36 to 24 improves the way that CCDSoft handles false galaxies, as shown in figure 50. Instead of the two large false galaxies, there is now only one. Reducing the number of deblending sub-thresholds further, even to a value as low as 6, does not further improve the situation. CCDSoft has a large number of parameters for source extraction, and experimentation is often the best way to tailor it to work best with your equipment and local sky characteristics.

For detailed information about these parameters, please see the extended documentation for CCDSoft's source extraction on the ESO web site at:

`http://www.eso.org/science/eis/eis_soft/soft_index.html`

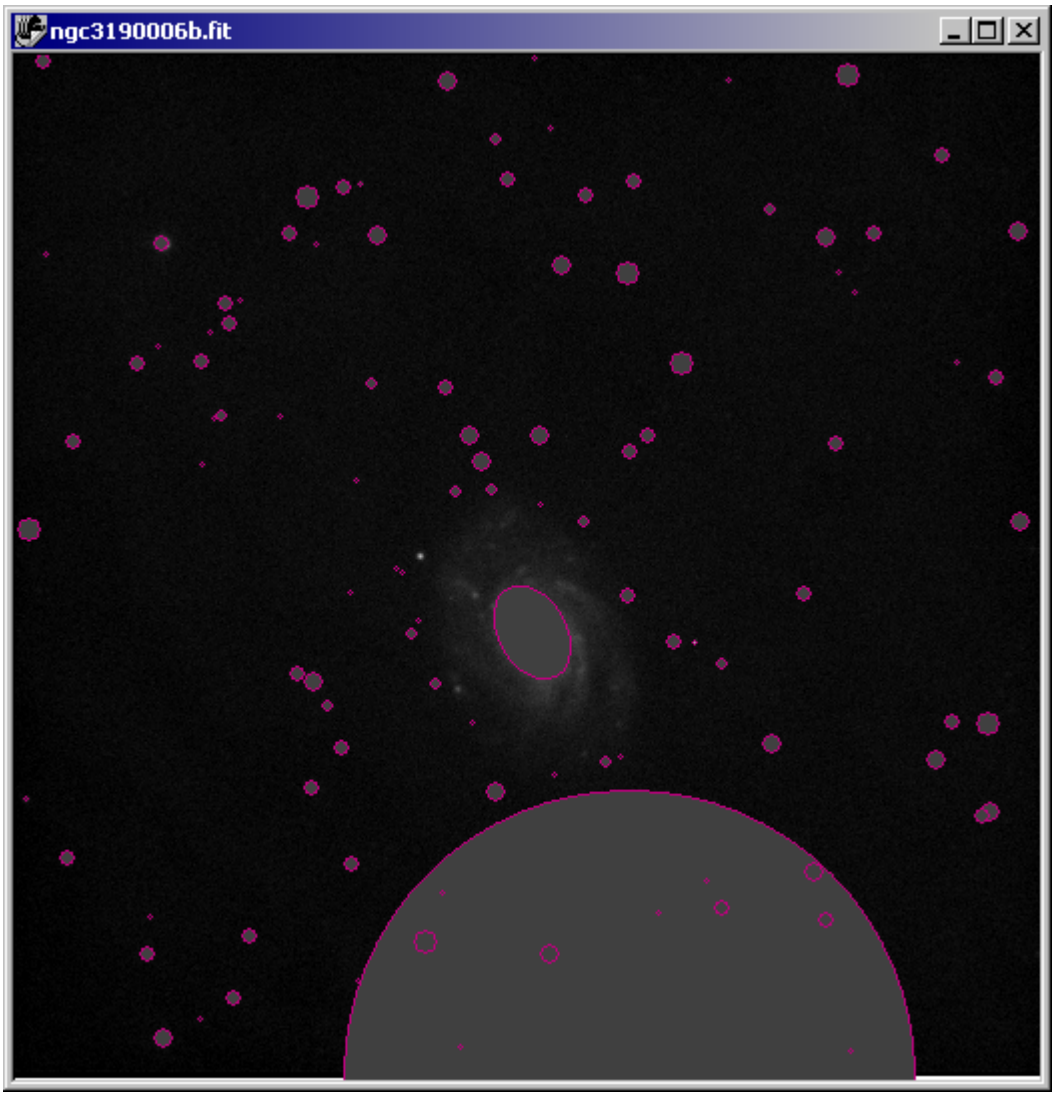


Figure 50: Reducing the number of deblending sub-thresholds improves the situation, but doesn't completely solve the problem of finding false galaxies.

When, as in the example, you find that you are having problems with false object identifications, look more closely at the image itself. Temporarily adjusting the histogram, especially lowering the white point, can reveal subtle variations in the background that may cause false identifications. Figure 51 shows the image with a low white point, revealing a mottled background that is exactly the type of background to create false galactic identifications. Thin, high clouds frequently cause of this sort of trouble. In this case, adjusting the source extraction parameters only goes so far toward solving the problem. The image itself has flaws that create false positives. Fortunately, CCDSoft can tolerate a certain amount of noise and image problems and still find objects successfully.

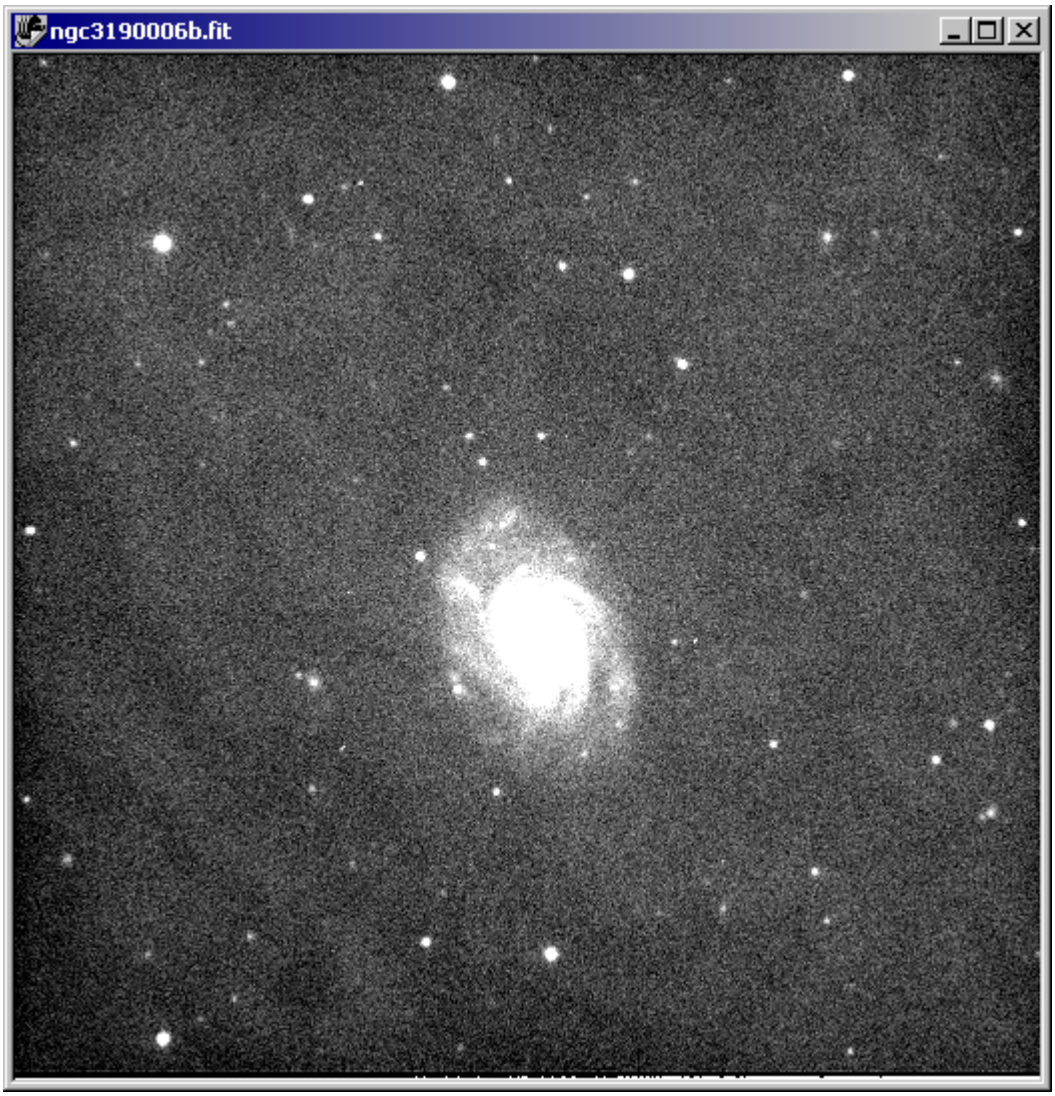


Figure 51: A low white point reveals subtle problems in the image background.

Automatic detection of galaxies and supernova candidates is tougher than automatic detection of minor planets. The criteria for detecting a minor planet are relatively simple: a star-like object that moves in almost exactly a straight line over at least three images. Detection of galaxies is more difficult, and may require considerable effort to find the source extraction settings that match your local equipment and conditions. The better the quality of your images, of course, the easier it will be to identify objects. It takes time and effort to learn how to adjust parameters effectively. But once you learn to work with them, you gain an enormous amount of flexibility in your searching.

For additional suggestions on supernova searching, see the heading “Supernova Searches” in the section “Principles of Astrometry and Photometry” earlier in this chapter.

Light Curves

A light curve shows changes in brightness in a celestial object over time. You can create light curves for moving objects, such as minor planets and comets, and for stationary objects such as supernovas and variable stars. Figure 2 at the beginning of this chapter shows an example of a light curve for a minor planet. The light curve reveals the rotational period of the minor planet.

As with all items on the **Research** menu, you must perform a pre-analysis of your data prior to generating a light curve. Make sure your image scale is correct before you start the pre-analysis.

	If you do not have the right ascension and declination coordinates in the image header, you can use Image Link in TheSky to find the coordinates and image scale. Then click **Research | Insert AutoAstrometry/WCS**. Enter the coordinates in the **Image equatorial coordinates** box, and enter the image scale in the **Image scale** box. For subsequent images, click the **Get Previously Entered Coordinates** to recall those coordinates. The image scale repeats automatically.

The following example of creating a light curve uses a sequence of images of a minor planet. A minor planet presents a moving target, but the differences in processing for moving and stationary targets are minimal. Figure 52 shows one of the 55 images taken over almost three hours of minor planet 7505 1997 AM2.

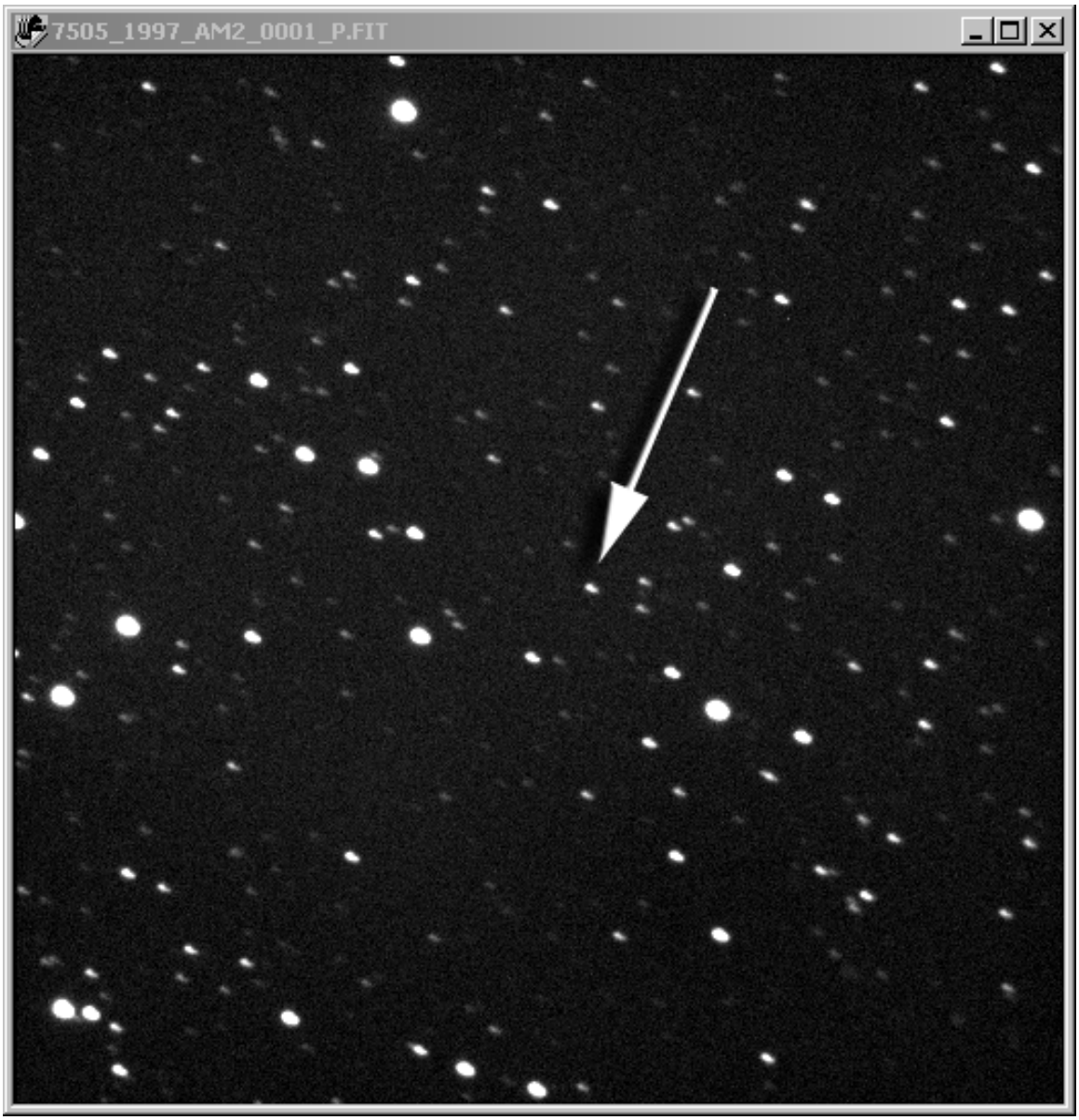


Figure 52: One of a series of images taken of a minor planet.

Figure 53 shows the location of minor planet 7505 1997 AM2 on November 1, 2000 at 6:29am local time. The chart was created in CCDSoft by clicking **Research | Comparison | Star Chart**. Prior to creating the chart, the Labels settings in TheSky were changed to show the magnitude of stars, and the ID of extended minor planets. To change Label settings in TheSky, click **View | Labels | Setup**, and then click the **Extended** tab and choose the type of object, and then set the options for that type of object. For star magnitudes, set a magnitude limit just dimmer than the minor planet. Otherwise, your star chart may be too crowded with numeric data.

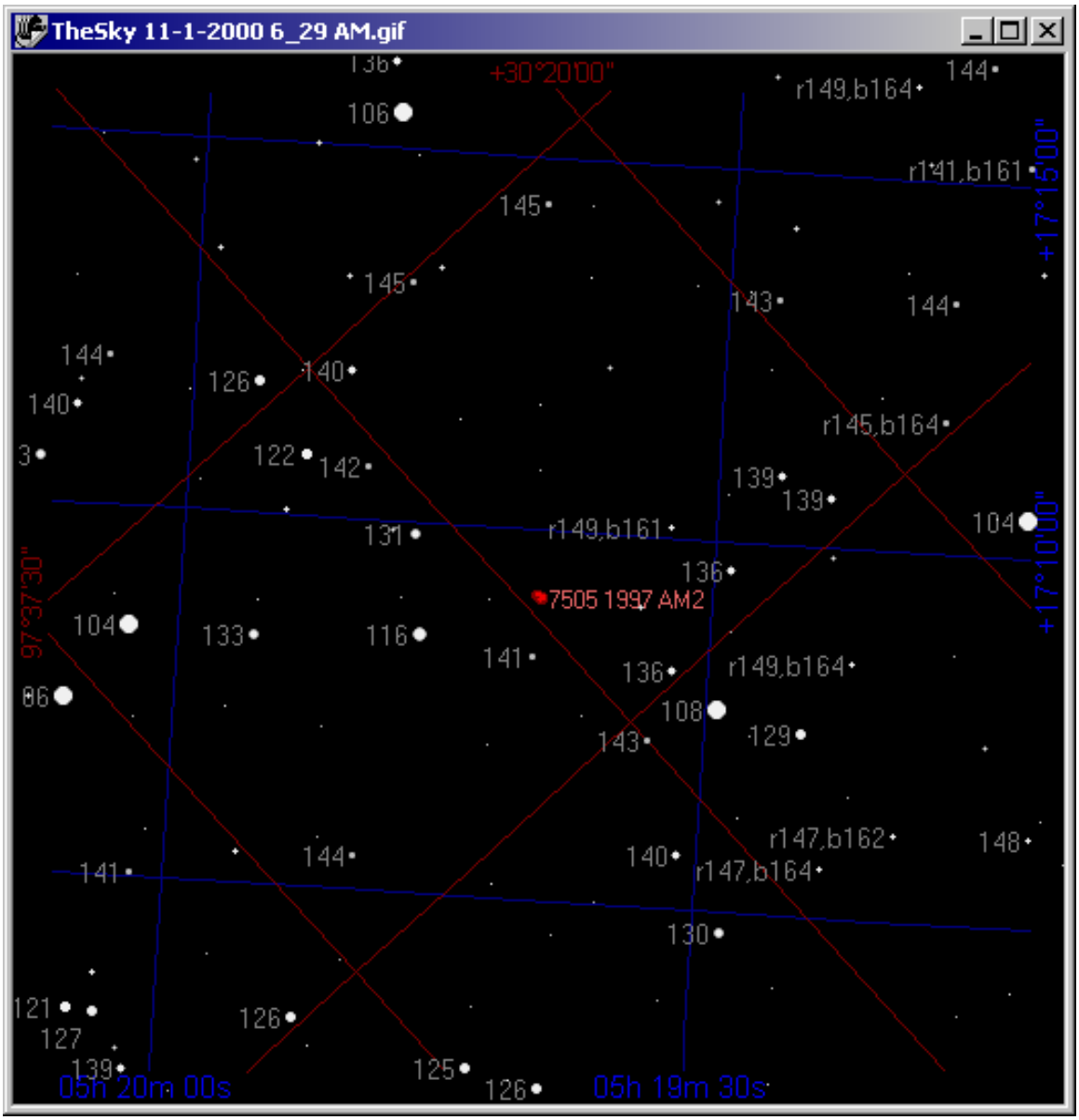


Figure 53: A star chart corresponding to the position of a minor planet.

If you'd like to follow along with the example, copy all 55 images from the folder `Images\LCurve` on the CD-ROM to a folder on your hard disk. Then add this folder to the **Pre-Analyze** tab of the Data Analysis dialog box using the **Folders** button. If necessary, remove any folders that are already in the Folders dialog box before you work through the tutorial. Set the parameters in the **Pre-Analyze** tab as shown in figure 54. Note that the image scale is 1.65. Then click **Start.** This begins an operation that may require several minutes. At the conclusion of the pre-analysis, your **Pre-Analyze** tab should look exactly like figure 54. To see the list of included images, click on the plus sign at the left of the minor planet designation (7505 1977 AM2) in the **Image list**.

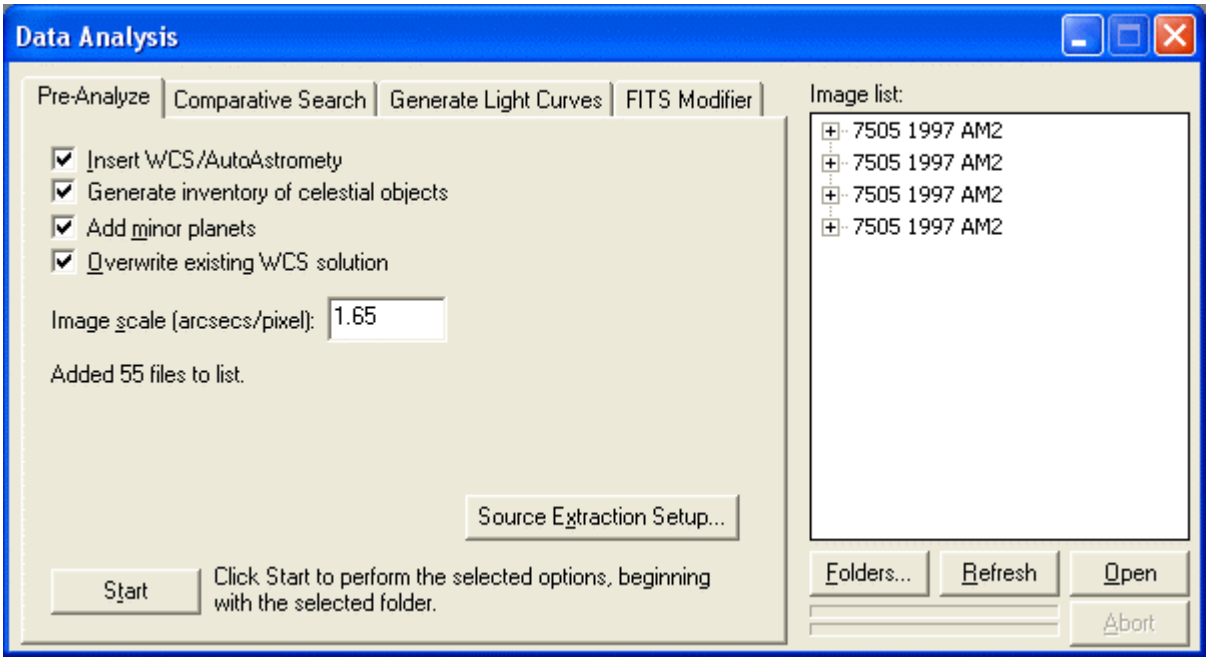


Figure 54: Performing pre-analysis on the minor planet images.

Click the **Generate Light Curve** tab, and enter the name or designation of the minor planet in the **Object name** text box, as shown in figure 55. This name must match the name in TheSky, because CCDSoft will ask TheSky to find this object and get its coordinates at the time of each image in the **Image List**. If you experience a failure to find the object in any of the images, go to TheSky and see what the exact name of the object is there.

NOTE	The object name you enter must be one that TheSky will recognize. To make sure that the object name is valid, go into TheSky click **Edit | Find** and enter the name of the minor planet. If the object is an extended minor planet, use the prefix “MPL” to search. However, you can use the **Utility** tab of the **Object Information** dialog box in TheSky, and click **Copy to Local** if you wish to be able to search for just the minor planet name, without the MPL prefix.

Make sure that the **Moving (minor planet)** option is selected.

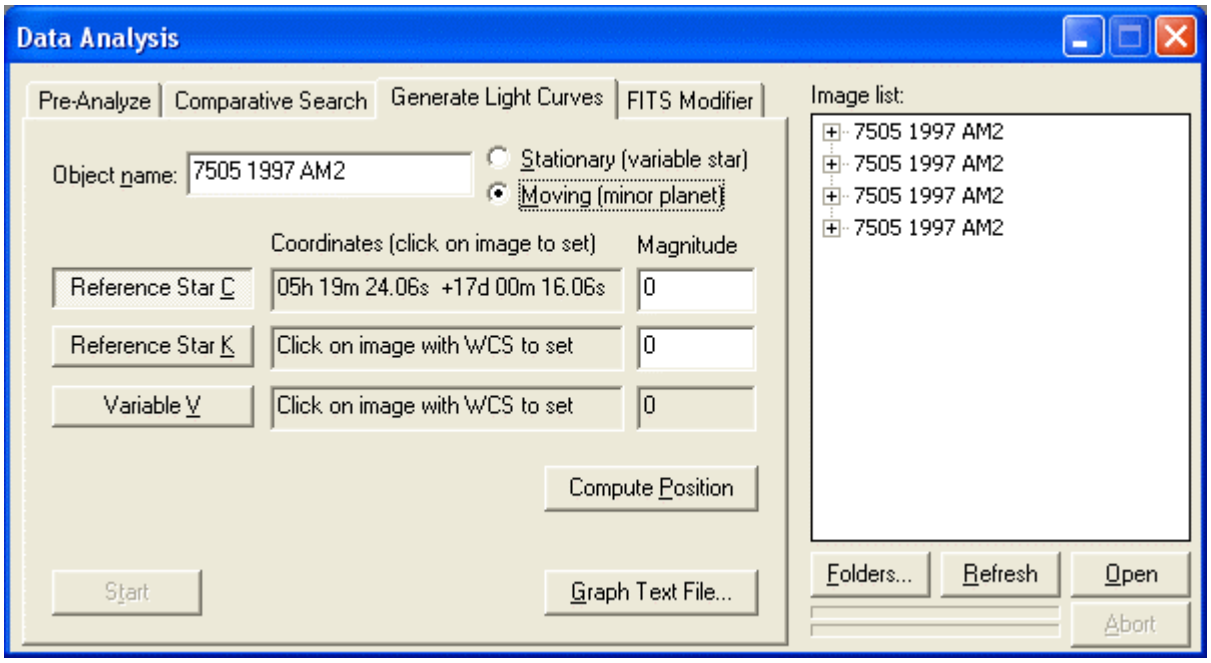


Figure 55: Preparing to generate a light curve.

The light curve will be generated using the brightness of three objects in the images, using a technique called differential photometry:

Reference Star C – A comparison star that does not vary in brightness.
Reference Star K – A check star that does not vary in brightness.
Variable V – The object that varies in brightness.

The difference in brightness between the comparison star and the variable object is used to generate the light curve. The difference in brightness between the comparison star and the check star is also plotted. This second plot shows the variations in brightness from image to image, and allows you to judge the quality of the curve, or to normalize the curve or perform other types of analysis on it.

NOTE	To see actual magnitude values in the final light curve, you can manually enter the magnitude of the C and K stars in the boxes labeled **Magnitude**. The magnitude values will only be as accurate as the figures you enter here. If possible pick stars whose magnitudes are known to be accurate.

You will need an open image to select the C, K and V objects. You can highlight an image in the **Image List** and click **Open**, or you can simply click **Open** to open the first image. Be sure the **Moving (Minor planet)** option is active before you open a file so that CCDSoft will get the coordinates of the object from TheSky, and show the location of the minor planet with a yellow circle.

CCDSoft will automatically fill in the coordinates for the V object. To select the C and K objects:

1. Click **Reference Star C**.
2. Choose a comparison star in the image. Brighter stars are best. You can simply pick a bright star in the image, or refer to the star chart to see the magnitude of nearby stars. There are several stars just a little bit dimmer than magnitude 10, and any of these make a good comparison star.

3. Click on the comparison star. A purple circle with tick marks appears around the object you clicked on. The coordinates of the comparison star appear in the box to the right of the **Reference Star C** button. If desired, enter the magnitude of the C star in the **Magnitude** box.
4. Click **Reference Star K**.
5. Choose a check star in the image. Any of the magnitude 10 stars make a good check star.
6. Click on the comparison star. A purple circle with tick marks appears. The coordinates of the check star appear in the box to the right of the **Reference Star K** button. If desired, enter the magnitude of the K star in the **Magnitude** box.

NOTE	If the field of view changes from one image to the next, one or more of the objects might move outside the field of view. Make sure that the C, K, and V objects are present in all of the images.

If you make a mistake and click on the wrong object, click the appropriate button, and then click on the correct object. If the yellow circle is not on the minor planet, you may not have the correct coordinates for the minor planet. You can obtain current coordinates online from the Minor Planet Center at:

http://cfa-www.harvard.edu/~graff/mpc.html

You can use the FITS Header Modifier to change the time shown in each image of a folder of images by a chosen offset. For example, if the Daylight Saving Time causes all images to have a one-hour offset, this can easily be corrected.

Figure 56 shows two good C and K stars to use. Both are bright, and both are present in all images. The field of view changes so that stars generally move up and to the left. The K star starts close to the edge, but moves away from the edge in subsequent images. The star at the top is also bright, but moves out of the field of view before the last image is reached.

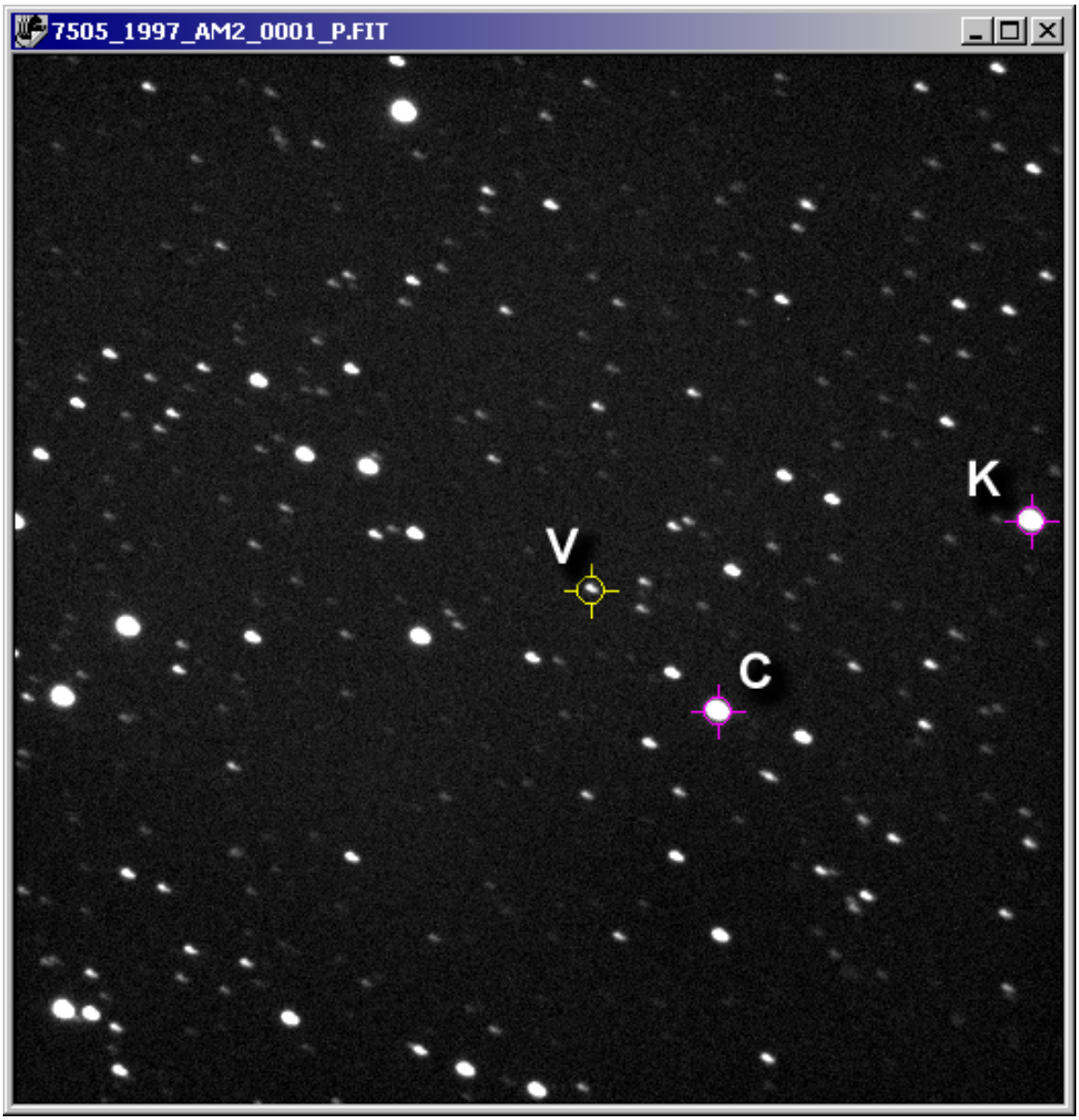


Figure 56: The V, C, and K objects are marked.

The time stamp for all images that contain moving objects must be UTC (Universal Time Code) for TheSky to accurately plot their positions. In other words, TheSky doesn't just look for a moving spot of light on a sequence of images; it actually predicts where in the image the object should be, and uses the brightness at that location to calculate magnitudes. This makes it easier for TheSky to handle stars in the path of the minor planet. However, if the minor planet and the star get so close that their images begin to blend, such images will not report valid magnitudes and should be discarded.

Figure 57 shows what the **Generate Light Curves** tab should look like at this point. The coordinates and magnitudes may be different if you chose different comparison and check stars (C and K objects).

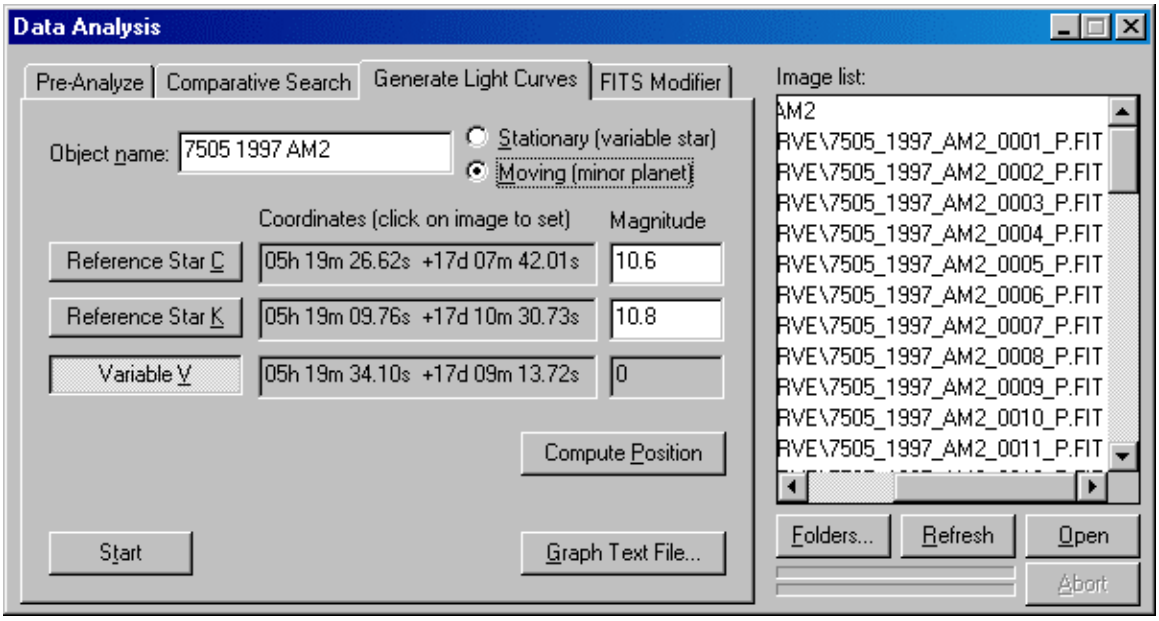


Figure 57: The coordinates for the C, K, and V objects entered.

To generate the light curve, click **Start**. You are asked for a file to save the numeric data for the light curve to. Select a folder where you want the output file saved and enter a filename, such as:

```
7505_1997_AM2_curve.txt
```

And then click **Open**. As each image is processed, data is written to the file. You can examine the contents of this file later using a text file editor. If you want to redisplay a light curve, click **Graph text file** and navigate to the text file that was created for the curve. The following example shows the header and the first three entries in a typical file:

```
Reference One: 05h 19m 26.62s  +17d 07m 42.08s  Mag:     0.000
Reference Two: 05h 19m 09.74s  +17d 10m 30.79s  Mag:     0.000
Variable: 05h 19m 34.21s  +17d 09m 12.94s  Mag:     0.000
Flux Data for Light Curve Generation
                 Date          Ref. C    Ref. K    Var. V    C-K     C-V(meas)+ C
Julian Date    yyyy-mm-dd.ddddd Raw Mag.  Raw Mag.  Raw Mag.  Differ. Differential  File
------- -------- ----- ----- ----- ---- ------- ---
2451849.812269 2000 11 01.31227    -5.128    -5.327    -1.103  0.199        14.625
2451849.814618 2000 11 01.31462    -5.134    -5.333    -1.052  0.199        14.682
2451849.816285 2000 11 01.31628    -5.053    -5.246    -1.055  0.193        14.599
```

If there are any images with excessive star trails or other problems, an error message will let you know. You can remove the problem files, and generate the light curve with just the good images. Progress is indicated with the blue progress bars below the **Image List**. The bottom bar indicates overall progress,

and the top bar indicates progress on individual images. Figure 58 shows the light curve for this minor planet.

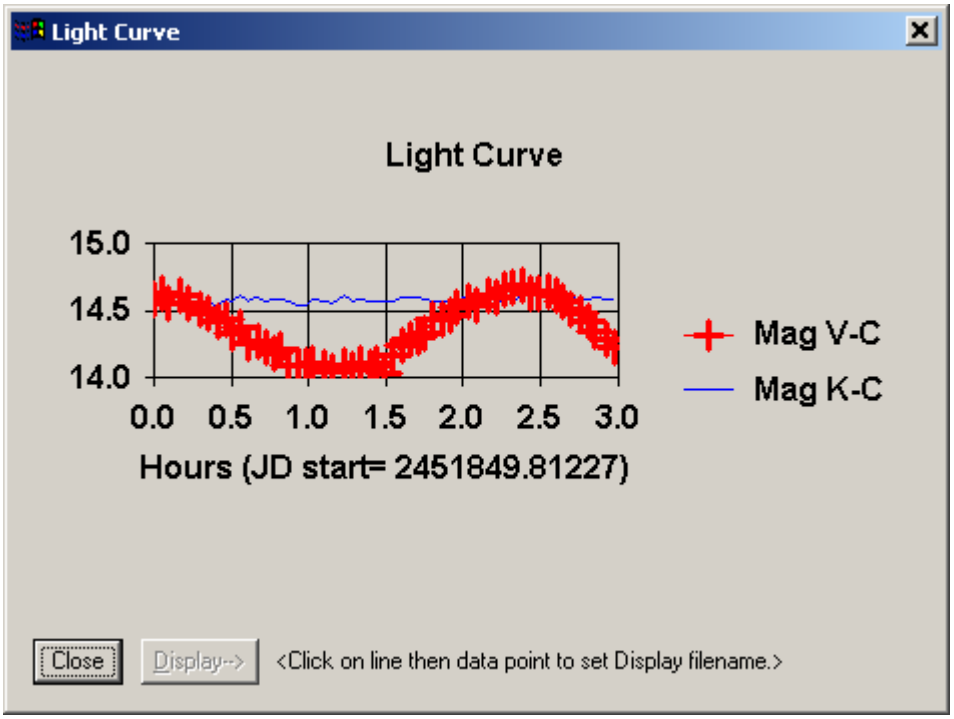


Figure 58: A light curve for a minor planet, showing its rotational period.

You can resize the Light Curve window by clicking and dragging the edges, as shown in figure 59. This allows you to study the information more carefully. The blue line at the top is the difference between the magnitudes of the check star and the comparison star (Mag K - C). The red line is the magnitude difference between the variable object and the comparison star (Mag V - C). Magnitudes are shown at left, and time from the first exposure is shown across the bottom. The start time is also shown in Julian Date format (2451849.81227). To close the curve window, click **Close**. If you want to view the graph again after you have closed the Light Curve window, click on the **Graph text file** on the **Generate Light Curves** tab, and navigate to the text file.

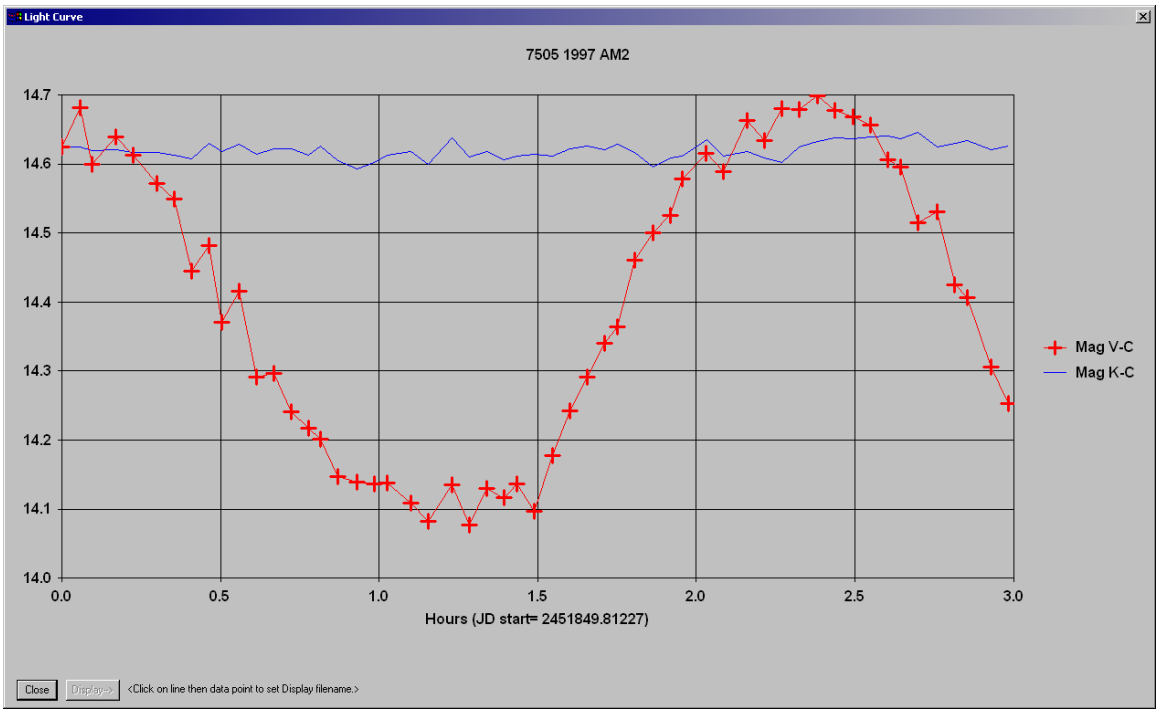


Figure 59: A light curve showing the data in greater detail by stretching the window size.

To further examine the data, click on the red line to highlight it. A small blue circle appears at the center of the crosses to indicate that the curve is selected. To see data for any single point on the curve, click on the cross. Only that point is now highlighted. The bottom portion of the Light Curve window changes to display the Julian date and the magnitude of the C, K, and V objects as shown in figure 60.

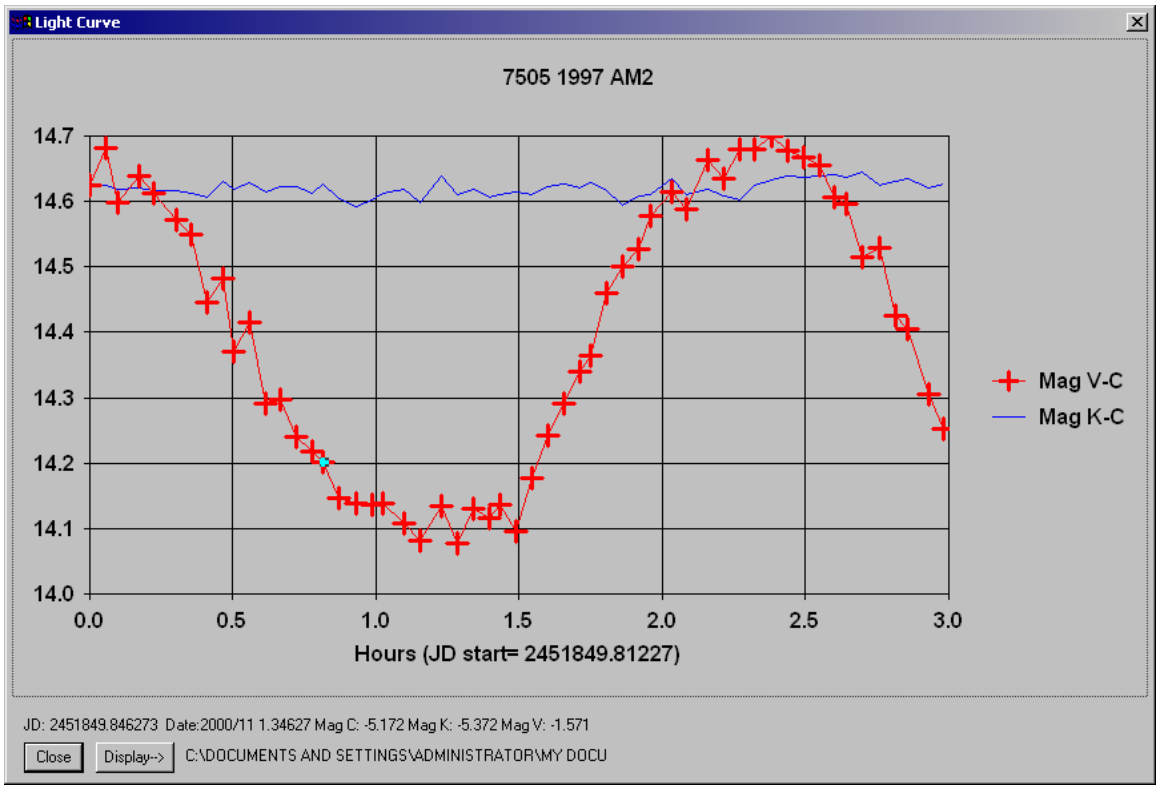


Figure 60: Displaying data for a single data point.

To view the image for the currently selected data point, click **Display**. This allows you to troubleshoot an odd data point, or examine any image quickly and easily. Typical problems with images include:

- Poor focus.
- Bumping of the mount during the exposure.
- Excessive tracking error.
- Excessive guide corrections.
- Failure of guide corrections.
- Poor polar alignment leading to trailing star images.

CCDSoft can tolerate errors and still locate objects on the images, but there may be blips or inconsistencies in the light curve from bad images. An error such as this can be seen just before the second peak in the light curve in figure 60.

Fun with Light Curves

The light curve file saved to disk can be put into a spreadsheet and manipulated in creative ways. The following example shows how to open the file with Microsoft© Excel™, add a few columns with normalized data, and then plot the result. The example has the effect of smoothing the light curve by straightening the C - K curve. This adjusts the magnitude of the light curve for variations in brightness between images.

Reading the Light Curve Data into Excel

Open Excel, and then open the light curve file. To see the file, make sure you select the .txt file type in Excel's **Open File** dialog box. The Text Import Wizard runs automatically. The first step is shown in figure 61.

- Verify that the data type is set to **Fixed width**.
- Set **Start import at row** to 8, as that is the first row of data. The first seven rows are header information.
- Click **Next**.

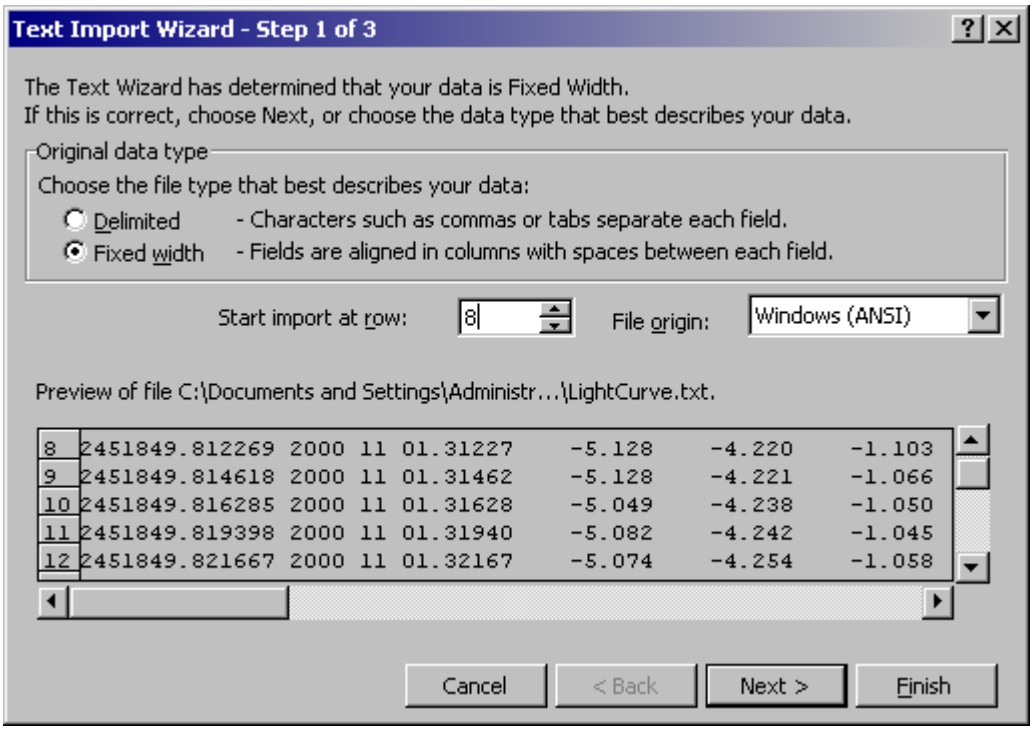


Figure 61: Step one in importing light curve data into Excel.

Step two involves defining the field widths (see figure 62). Follow the instructions for adding, moving, and deleting break lines. Click **Next** when the fields are as shown in figure 62. If the filename contains spaces, delete any field breaks that occur in the filename.

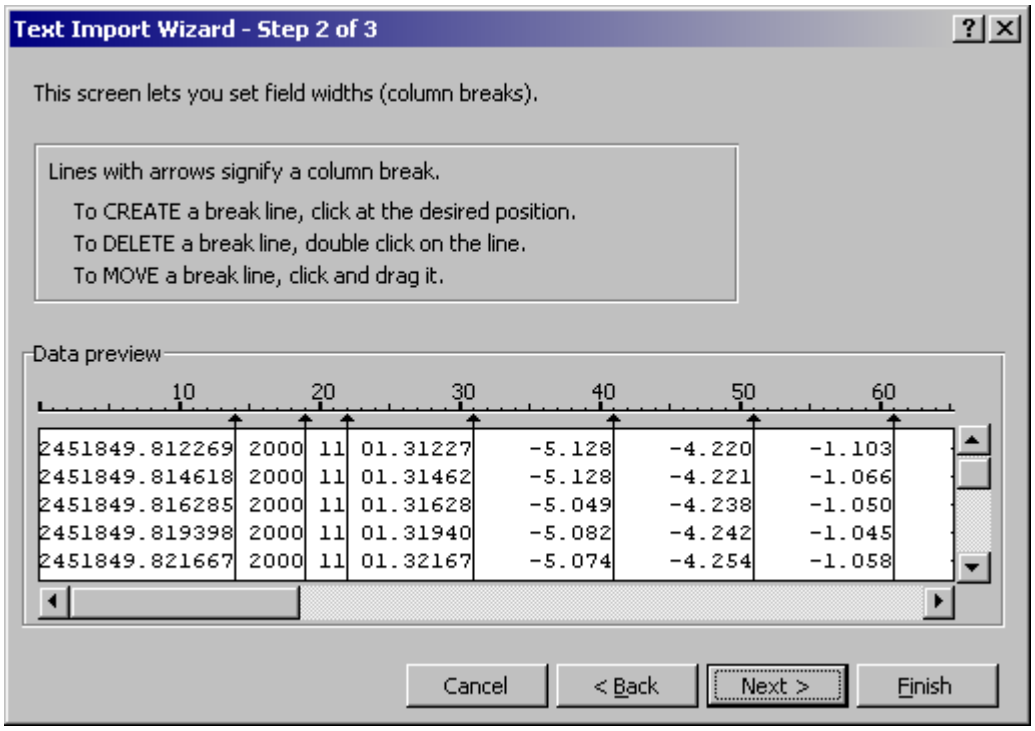
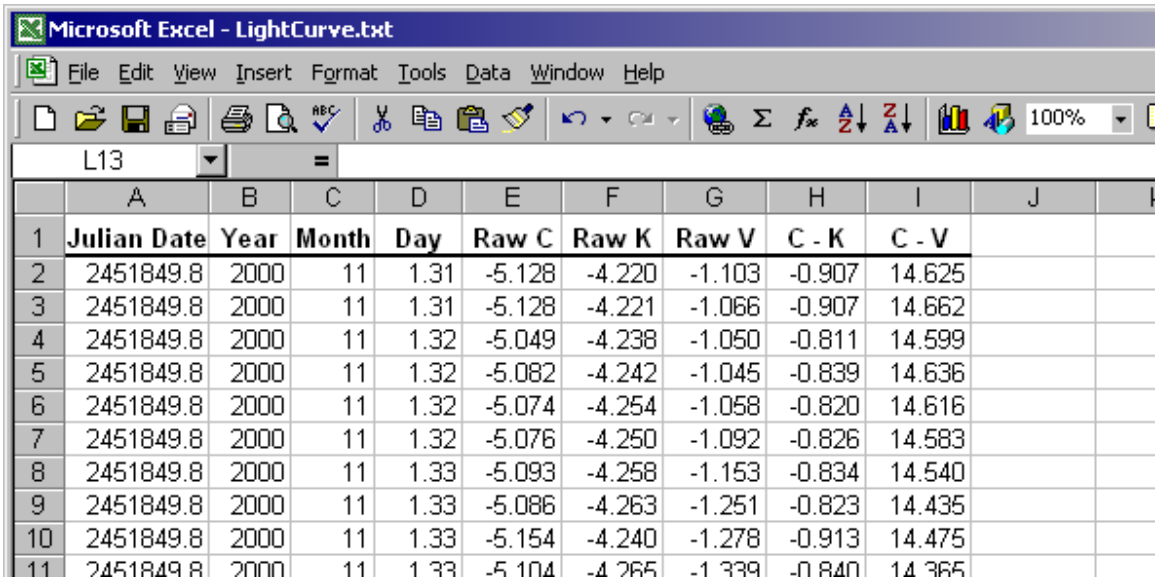


Figure 62: Step two in importing light curve data into Excel.

The third step is to set data types. The default is General, which works, so click Finish on step three without making any changes. The file is loaded into Excel, with the data neatly divided into columns. Insert a row at the top, and add column names as shown in figure 63.



	A	B	C	D	E	F	G	H	I	J
1	Julian Date	Year	Month	Day	Raw C	Raw K	Raw V	C - K	C - V	
2	2451849.8	2000	11	1.31	-5.128	-4.220	-1.103	-0.907	14.625	
3	2451849.8	2000	11	1.31	-5.128	-4.221	-1.066	-0.907	14.662	
4	2451849.8	2000	11	1.32	-5.049	-4.238	-1.050	-0.811	14.599	
5	2451849.8	2000	11	1.32	-5.082	-4.242	-1.045	-0.839	14.636	
6	2451849.8	2000	11	1.32	-5.074	-4.254	-1.058	-0.820	14.616	
7	2451849.8	2000	11	1.32	-5.076	-4.250	-1.092	-0.826	14.583	
8	2451849.8	2000	11	1.33	-5.093	-4.258	-1.153	-0.834	14.540	
9	2451849.8	2000	11	1.33	-5.086	-4.263	-1.251	-0.823	14.435	
10	2451849.8	2000	11	1.33	-5.154	-4.240	-1.278	-0.913	14.475	
11	2451849.8	2000	11	1.33	-5.104	-4.265	-1.339	-0.840	14.365	

Figure 63: Adding column headings.

The raw magnitudes for the C, K, and V objects are instrument magnitudes, not actual magnitudes. If you entered magnitudes for the C and K stars, the C - V value is a calibrated magnitude. Its accuracy depends on the accuracy of the magnitude of the stars you set for C and K objects.

To plot the normalized data, you need to create two new columns. Enter this formula into cell K2:

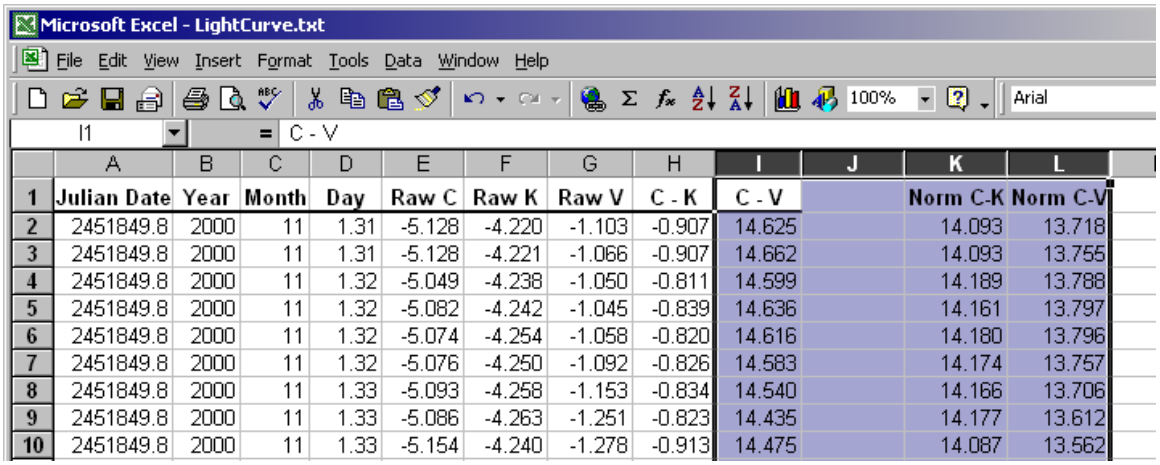
```
=h2+15
```

Copy this equation to the rest of the cells in column K (as far down as there are rows of data). This formula simply adds 15 to the values for C-K, offsetting them so they will plot near the C-V values. Label column K “Norm C-K.”

Enter this formula in cell L2:

```
=i2+h2
```

Copy this equation to the rest of the cells in column L (as far down as there are rows of data). This formula adds the raw C-K value (for example, -0.907) to the C-V value (for example, 14.625) to yield a normalized value for the purpose of plotting a graph. This has the effect of removing image-to-image variations in brightness, making the C-K value in effect zero, and applying the same adjustment to the C-V value. Label column LK “Norm C-V”. Select columns I through L and click **Insert | Chart** (see figure 64).



	A	B	C	D	E	F	G	H	I	J	K	L
1	Julian Date	Year	Month	Day	Raw C	Raw K	Raw V	C - K	C - V		Norm C-K	Norm C-V
2	2451849.8	2000	11	1.31	-5.128	-4.220	-1.103	-0.907	14.625		14.093	13.718
3	2451849.8	2000	11	1.31	-5.128	-4.221	-1.066	-0.907	14.662		14.093	13.755
4	2451849.8	2000	11	1.32	-5.049	-4.238	-1.050	-0.811	14.599		14.189	13.788
5	2451849.8	2000	11	1.32	-5.082	-4.242	-1.045	-0.839	14.636		14.161	13.797
6	2451849.8	2000	11	1.32	-5.074	-4.254	-1.058	-0.820	14.616		14.180	13.796
7	2451849.8	2000	11	1.32	-5.076	-4.250	-1.092	-0.826	14.583		14.174	13.757
8	2451849.8	2000	11	1.33	-5.093	-4.258	-1.153	-0.834	14.540		14.166	13.706
9	2451849.8	2000	11	1.33	-5.086	-4.263	-1.251	-0.823	14.435		14.177	13.612
10	2451849.8	2000	11	1.33	-5.154	-4.240	-1.278	-0.913	14.475		14.087	13.562

Figure 64: Selecting columns to create a chart.

- Select Line as the Chart Type, and **Line with markers displayed at each data value** as the sub-type. Click **Next**.
- Verify that **Series** is set to **Columns**. Click **Next**.
- Enter the chart title: “Normalized Light Curve”
- Category (X) axis: Image number.
- Value (Y) axis: Calibrated Mag. Click **Next**.

- Select **As new sheet**, type in the name “Light Curve,” and then click **Finish**.

Excel inserts a new chart into the spreadsheet, and makes it active. Figure 65 shows the appearance of the chart. The top curve is the original C-V data, with irregularities in it from the variations in brightness from one image to the next. The next curve is the C-K data, showing the variations. The lowest curve shows the C-V data corrected for the brightness variations. Note that the corrected curve is noticeably smoother, especially at the leftmost peak.

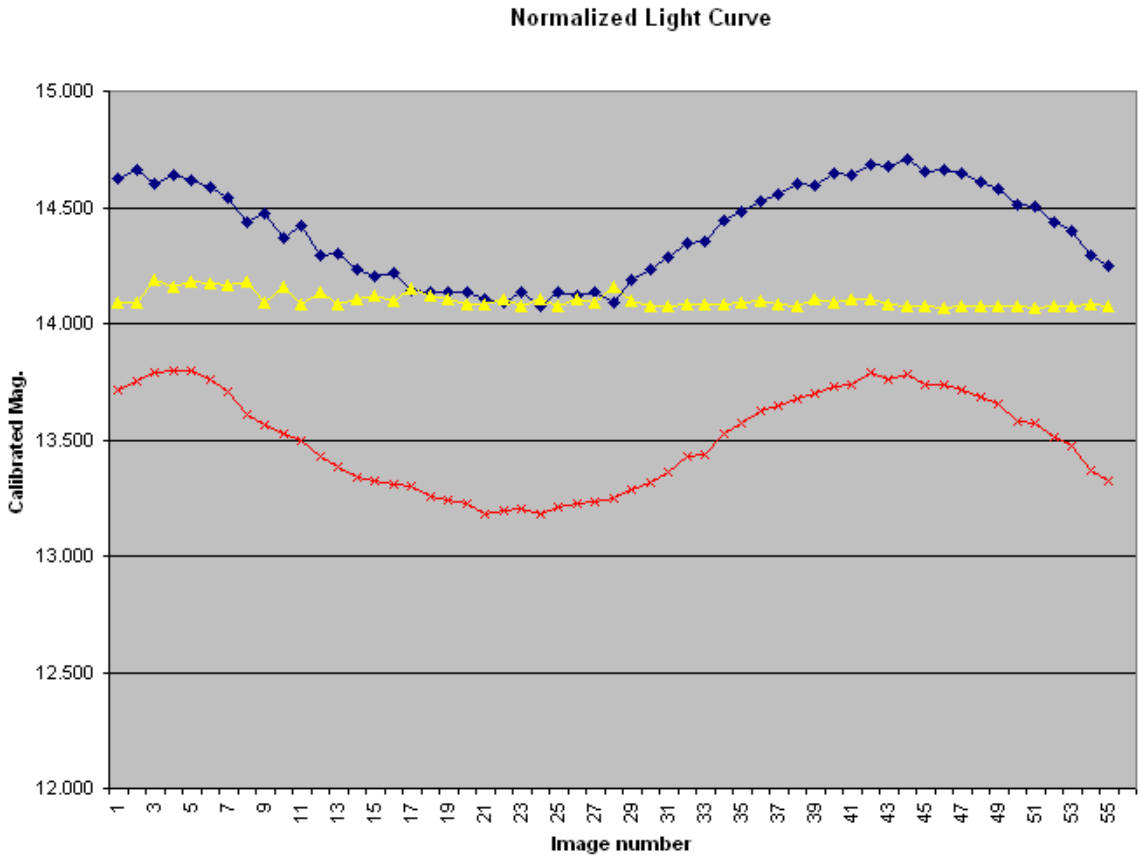


Figure 65: The original light curve (top) and the smoothed/corrected curve (bottom).

You can also click on the smoothed curve to select it, and then right click and choose **Add trend line**. Select the Polynomial type, and set Order to 5. Verify that **Based on series** is set to **Norm C-V**, and then click **OK**. A trend line is calculated to fit the smoothed curve, providing a “best fit” curve for the data (see figure 66).

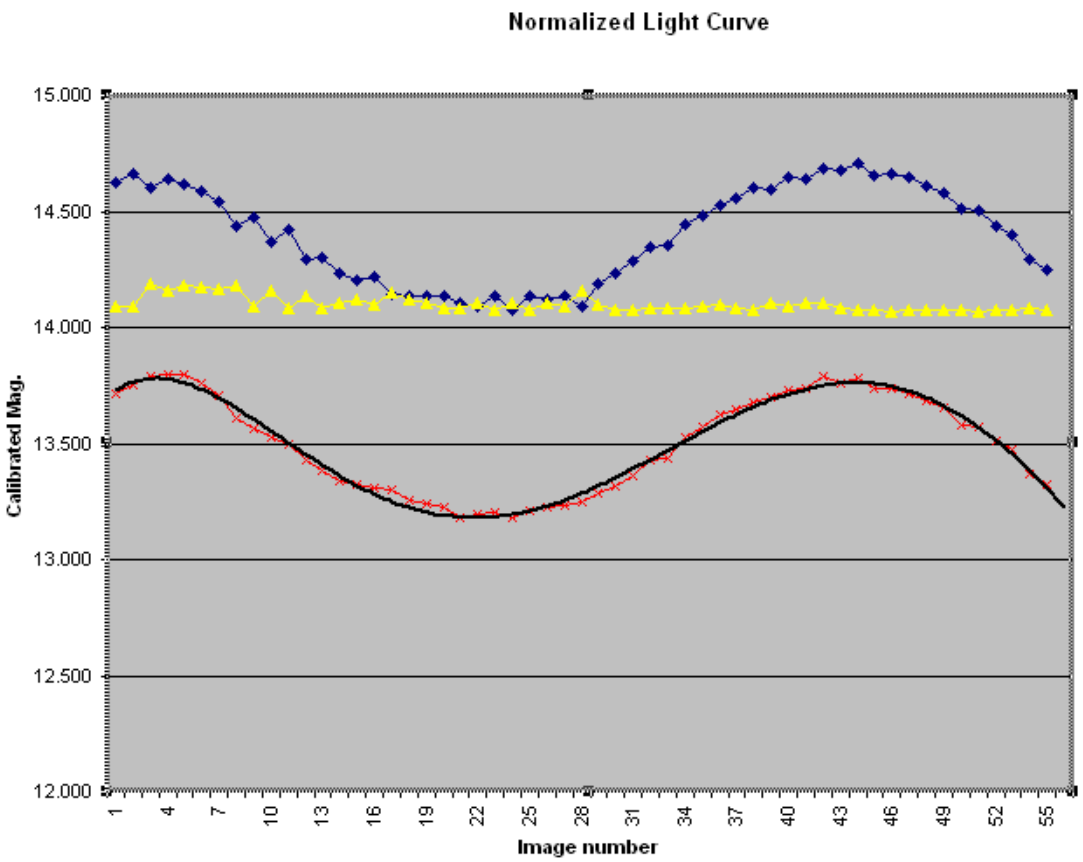


Figure 66: Adding a trend line.

FITS Modifier

The **FITS Modifier** tab of the Data Analysis window (see figure 67) allows you to change the values of keywords in the FITS header for each image in a folder. While this is a general-purpose tool that allows you to change any value for any keyword, the most common use of this dialog box is to:

- Add or correct right ascension and declination coordinates in the FITS header of non-CCDSoft version 5 images.
- Change the time keywords to repair the time in the FITS header.

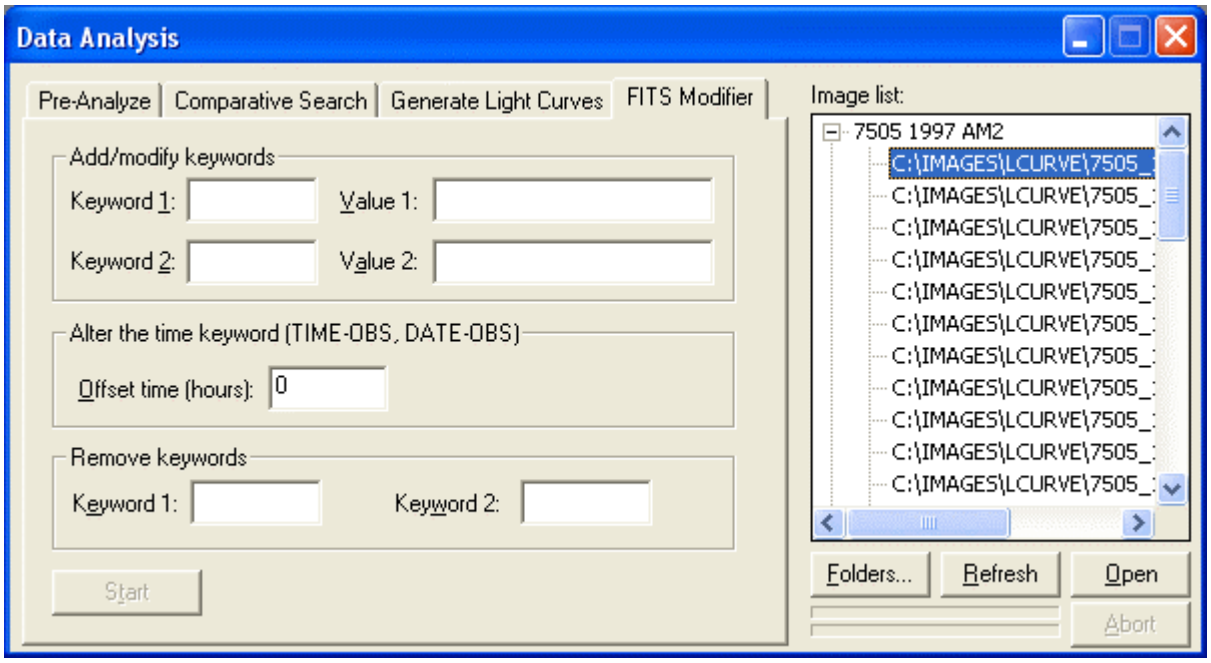


Figure 67: Adding, modifying, and removing keywords in the FITS header.

Adding/Correcting Right Ascension and Declination

If an image was taken with an earlier version of CCDSoft, or with camera control software that does not add the OBJCTRA and OBJCTDEC keywords to the FITS header, you can use the **FITS Modifier** to add them. First, copy the files into a new folder. Then use the **Folders** button below the **Image List** to add that folder to the **Image List**. Delete any existing folders in the **Folders** dialog box before you add the new folder.

The right ascension and declination to use when adding keywords is the right ascension and declination of the center of the image. You can do this with the **Image Link Wizard** in TheSky, or manually. For information about Image Link, consult the documentation for TheSky.

To add or correct the right ascension and declination in the FITS header:

1. Enter OBJCTRA as **Keyword 1**.
2. Enter OBJCTDEC as **Keyword 2**.
3. Enter the right ascension of the image center as **Value 1**, using this format:
   hh mm ss.ss – Example: 18 14 58.06.
4. Enter the declination of the image center as **Value 2**, using this format:
   +/-dd mm ss.ss – Example: -13 49 29.59.
5. Click **Start**.

The right ascension and declination will be added or corrected in the FITS header of all of the images in the **Image List**.

Altering the Time Keyword Values

Some software does not properly handle Daylight Saving Time, or you may have images that use local time instead of UTC, or the time may simply be wrong in the image header. The time and date are stored in the header using the TIME-OBS and DATE-OBS keywords.

The **Offset time (hours)** box allows you to enter a time offset to get to the correct UTC (Universal Time Code). For example, if the time is off by one hour, enter a value of 1 in the **Time offset hours** box. When you click **Start**, the TIME-OBS and DATE-OBS (if necessary) will be revised to reflect the change. The value you enter is the number of hours to alter the time. Both positive and negative numbers can be used. If the day, month, or year changes as a result of adding or subtracting the indicated number of hours, CCDSoft will update the keywords accordingly.

The bottom section of the **FITS Modifier** allows you to remove keywords from the FITS headers of the images in the **Image List**. Enter the exact keyword name, and click **Start**. The keyword is not physically removed from the header. It is set to a blank value.

Other Research Tools

In addition to the tools for searching and plotting light curves, CCDSoft includes several other tools that will assist you in performing research.

Blink Comparator

You can use the blink comparator outside of searches for moving targets. The **Research | Comparison | Blink Comparator** command is available whenever two or more images are open. The Blink Comparator helps you find objects that have moved from one image to the next. You need at least two images to use the Blink Comparator.

Figure 68 shows a typical image comparison using the blink comparator. You can move the slider in the Blink Comparator dialog box to slow down or speed up the blink rate. Experiment to find a rate that works best for you.

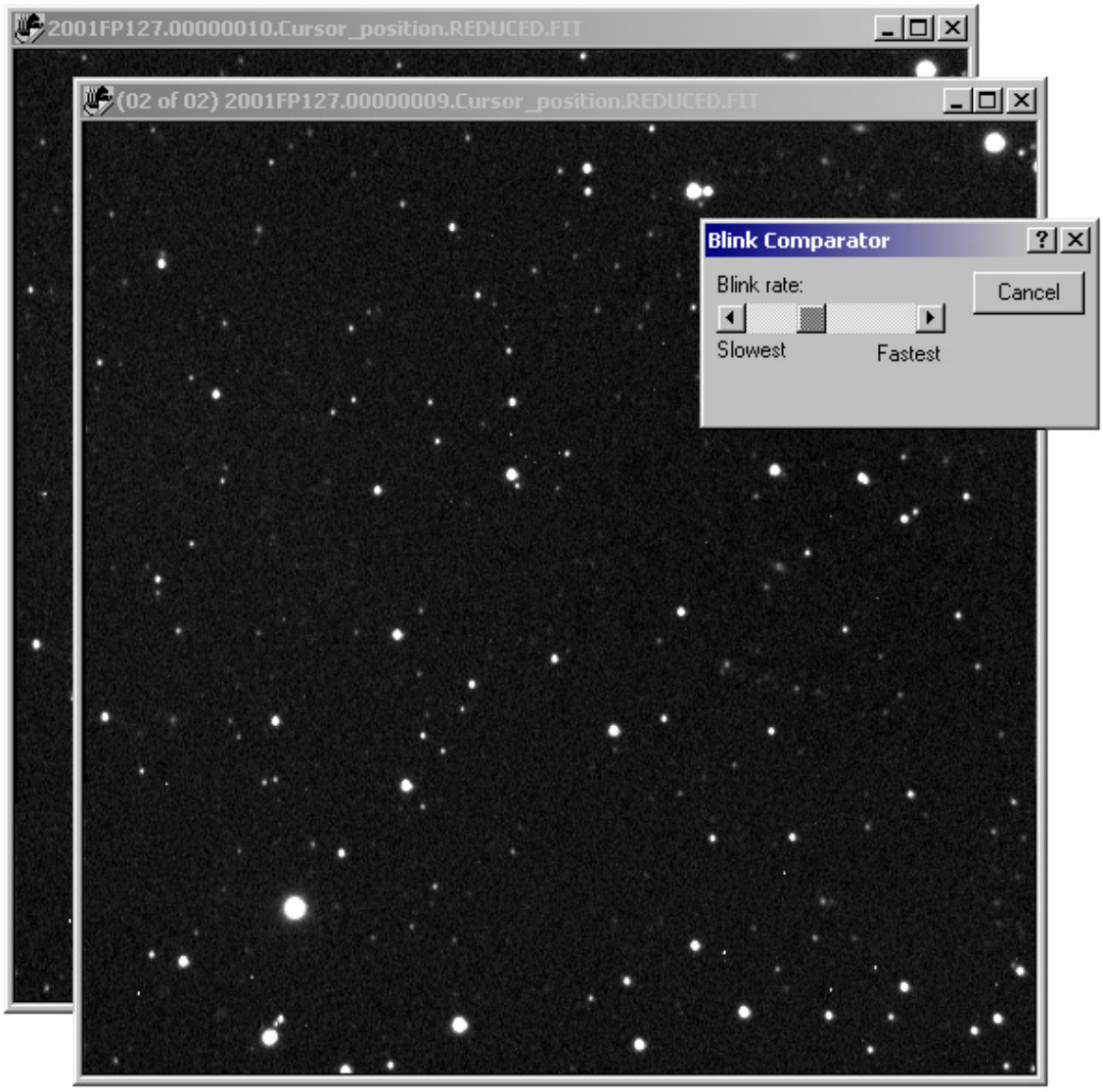


Figure 68: Using the Blink Comparator.

Star Charts

If you have TheSky installed, you can use CCDSoft to generate star charts that match a currently open image. Select the image by clicking on it, and then click **Research | Comparison | Star Chart**. You will see a chart of the sky for the date and time of the selected image. Star charts can be saved to disk like any other image.

If the image does not contain CCDSoft header information, the **Star Chart** command will be disabled. For an example of a star chart, please see figure 45 in the section “Performing a Detailed Search” earlier in this chapter.

DSS Images

If RealSky is installed on your computer, you can generate images based on the Digitized Sky Survey data that correspond to your own CCD images. The process is similar to that for creating a Star Chart to match an image. Select the image by clicking on it, and then click **Research | Comparison | DSS Image**. If the correct disk is not already in your computer, CCDSoft will ask you to insert it. CCDSoft then generates a DSS image matching the current image. Figure 69 shows an example, with the CCDSoft image on the left, and the generated DSS image on the right.



Figure 69: Comparing your own image to a corresponding DSS image.

DSS images are useful for making comparisons. For example, if you suspect that there is a supernova in your image, you can quickly compare your image to a DSS image. DSS images can be saved to disk like any other image.

Digitized Sky Survey Targets and Lists

In addition to generating DSS images that correspond to your own CCD images taken with CCDSoft, you can access RealSky features from inside CCDSoft. Full information on how to setup and access the Digitized Sky Survey is in “Chapter 11: Displaying RealSky Images in CCDSoft” For quick access to DSS data, click **Research | Digitized Sky Survey | Setup** to display the Digitized Sky Survey setup dialog box (see figure 70). Enter the drive letter of your CD-ROM drive at the top of the dialog box. Then click **OK**.

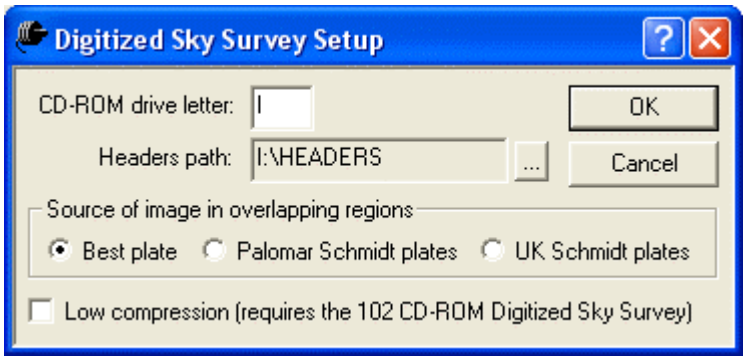


Figure 70: Setting up access to Digital Sky Survey images.

You can view targets by entering the right ascension and declination of the target by clicking **Research | Digitized Sky Survey | View New Target**. This opens the dialog box shown in figure 71. Enter the right ascension and declination coordinates of the area you wish to view, and selected the size of the image in arcminutes. Click **View** to generate the DSS image (see figure 72). If the image data is not on the current disc, CCDSoft will prompt you to insert the correct one.



Figure 71: Enter the coordinates of the area you wish to view.

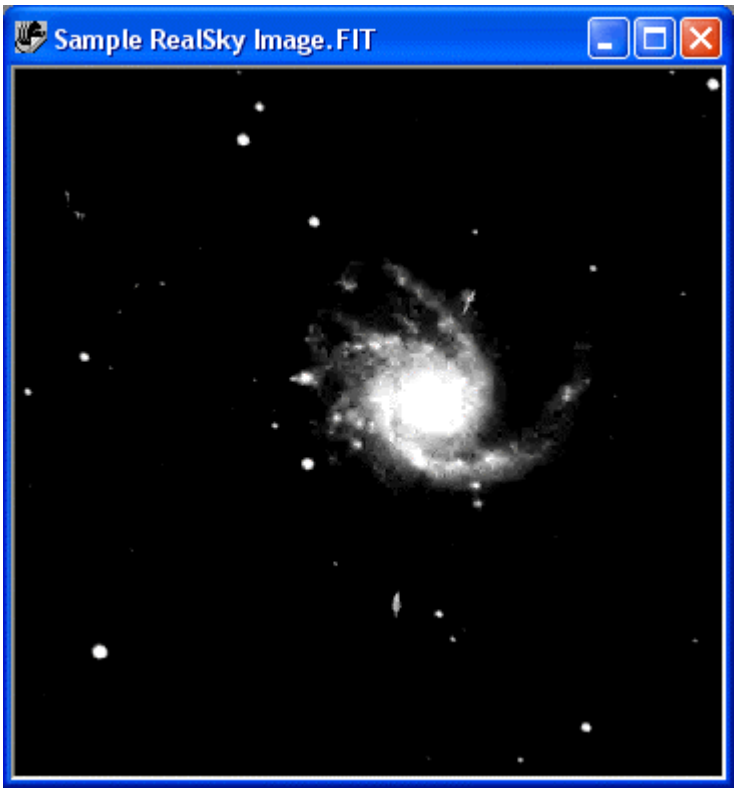


Figure 72: A sample DSS image.

To work with objects lists, click **Research | Digitized Sky Survey | Target Lists**. This opens the dialog box shown in figure 73. Click on a target name to highlight it, and then click **View** to display an image. If the image data is not on the current CD, CCDSoft will prompt you to insert the correct CD. To learn more about how to create, use, and manage target lists, please see “Chapter 11: Displaying RealSky Images in CCDSoft” in CCDSoft.”

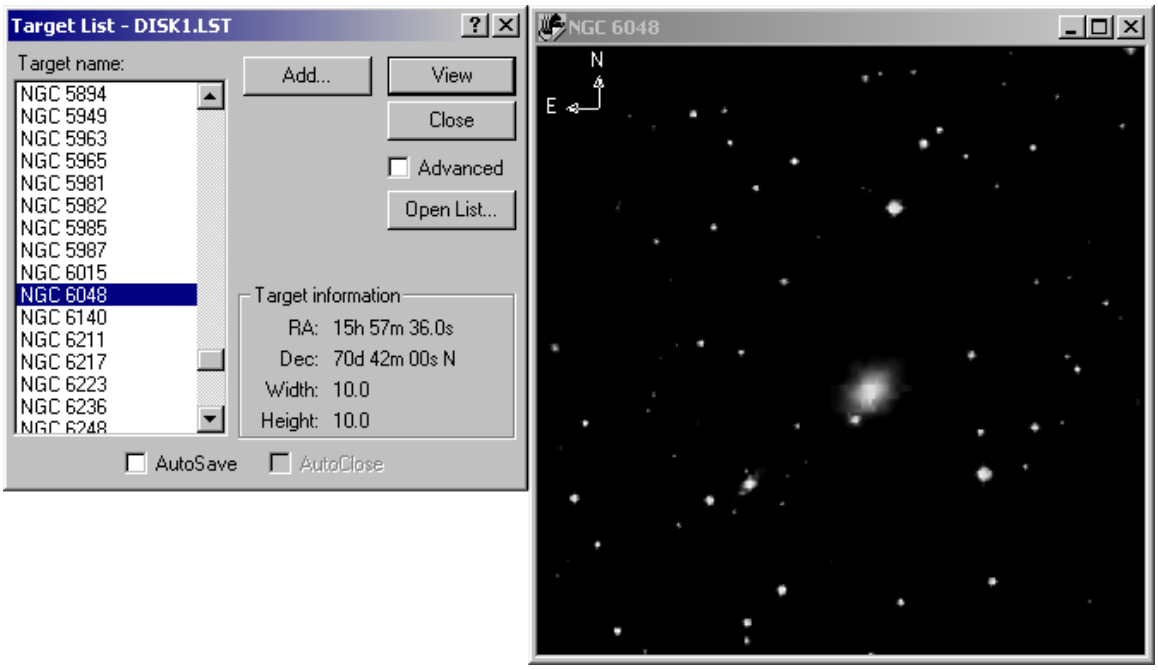


Figure 73: Generating an image from a target list.

Show Astrometric Stars

If you have an image open on which you have performed AutoAstrometry, you can display the stars used in the astrometric solution by clicking **Research | Show Astrometric Stars**. Figure 12, earlier in this chapter, shows the appearance of an image with astrometric stars visible. The stars are highlighted with yellow cross hairs.

Show Inventory

CCDSoft analyzes images and extracts source objects. You can see the objects identified in your image by clicking **Research | Show Inventory**. Both galaxies and stars can be identified, as shown in figure 74. The raw image is on the left. The objects identified in the image are shown at right.

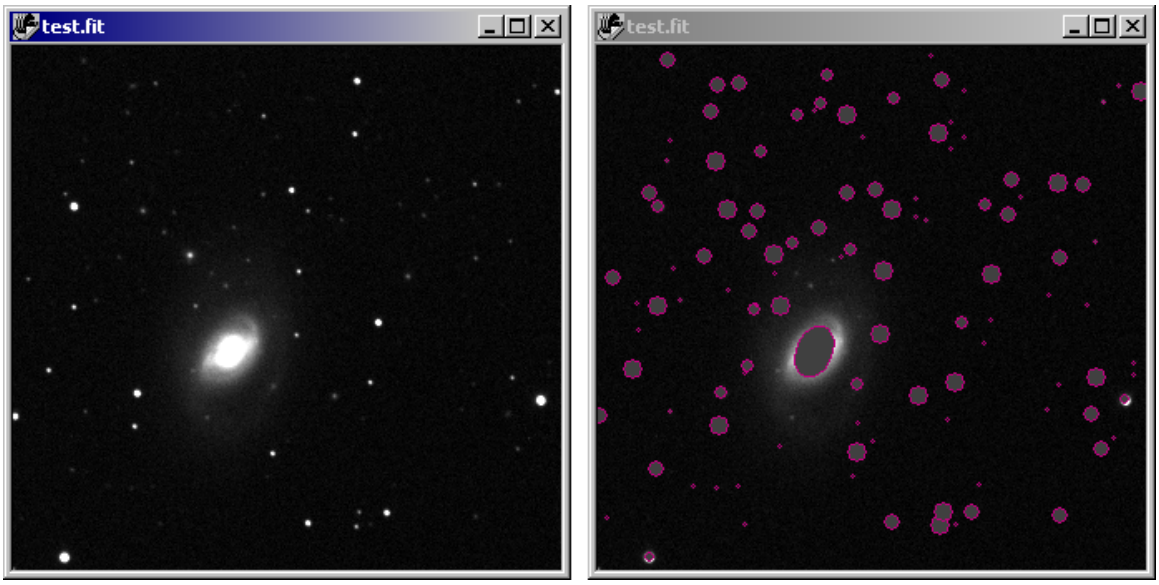


Figure 74: CCDSoft identifies both stars and galaxies.

If the image is large, or contains a large number of objects, you will see the progress dialog box shown in figure 75 while CCDSoft scans the image for objects.

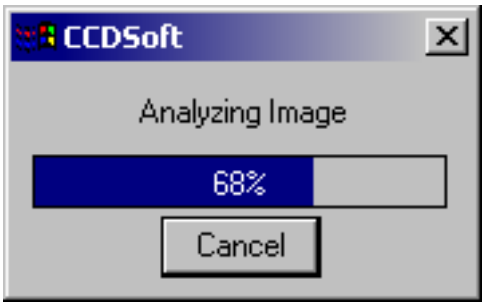


Figure 75: Progress dialog box for Show Inventory.

To fine-tune the source extraction parameters, click **Research | Analyze Folder of Images | Pre-Analyze** and then click **Source Extraction Setup**. See the section “Performing a Quick Search” earlier in this chapter for details on adjusting these parameters.

Chapter 9: Image Processing

Image processing allows you to enhance the appearance of your images. You can also manipulate your images to convert to different file formats, or to repair various types of problems related to CCD imaging.

CCDSoft includes the following image processing tools:

- Format conversions.
- Brightness and contrast (histogram, or background and range) adjustments.
- Flipping and resizing.
- Sharpening.
- Smoothing.
- Hot/cold pixel and column repair.
- Special effects, including negatives and custom filters.

For Experienced Users

For this chapter, an experienced user is someone who has experience processing images using photo- or image-editing tools, or camera control software with image processing tools.

Most of the tools in CCDSoft are similar to other image editing programs. If you are already familiar with histograms and histogram manipulations, including both linear and non-linear histogram transformations, you should be able to use CCDSoft's histogram tools easily. The Histogram tool itself is accessible by right clicking in any image and then clicking **Histogram** (or by clicking **Image | Brightness & Contrast | Histogram**). The tool is extremely flexible, and you might want to read the sub-section "Histogram" in the "Brightness and Contrast" section to learn how to use the Histogram tool to rapidly make adjustments to the black and white points.

CCDSoft includes tools for making repairs that are specific to CCD imaging: hot and cold pixel removal, and bad column repair. The "Repair Images" section near the end of the chapter will quickly acquaint you with these tools.

If you are looking for a tool to visually balance images, the Mid-range Brighten tool is your best bet. It will automatically balance the histogram so as to show both bright and dim details. You can access it by clicking **Image | Brightness & Contrast | Mid-range Brighten**.

You can also use the **Image | Brightness & Contrast | Tune Brightness & Contrast** command to make small adjustments to the histogram. For cases where you need greater control, you can convert your 16-bit images to 8-bit (for example, save as a .BMP format) and click **Image | Brightness & Contrast | Brightness & Contrast Curves** to do a non-linear histogram stretch that balances dim and bright features precisely.

The Image Menu

The Image menu contains a large number of features and options. The list below summarizes the options available, and the key combinations you can use instead of the menu.

Convert To	Black & White (1-bit)	Alt + Shift + 1
	Grayscale (8-bit)	Alt + Shift + 2
	256 Color (8-bit)	Alt + Shift + 3

	RGB Color (24-bit)	Alt + Shift + 4
Align	Align Centroids	Ctrl + A
	Align Folder of Images	Ctrl + A
	Shift	Alt + 5
Brightness & Contrast	Background & Range	Ctrl + B
	Histogram	Ctrl + H
	Tune Brightness & Contrast	Ctrl + T
	Brightness & Contrast Curves	Ctrl + Q
	Histogram Brighten	Alt + Shift + H
	Mid-range Brighten	Alt + Shift + M
	Equalize	Alt + Shift + E
	Posterize	Alt + Shift + P
	Kodalith	Alt + Shift + K
Color	Color Combine	Alt + K
	Color Balance	Alt + B
	Color Palette	Alt + P
Combine	Combine Images	Ctrl + K
	Combine Folder of Images	Ctrl + Shift + K
Flip	Flip Horizontal	Ctrl + Shift + H
	Flip Vertical	Ctrl + Shift + V
Reduce	Image Reduction	Ctrl + R
	Dark Subtract	Ctrl + D
	Flat Field	Ctrl + F
Repair	Remove Cold Pixels	Ctrl + Alt + C
	Remove Hot Pixels	Ctrl + Alt + H
	Repair Column	Ctrl + Alt + L
	Show Dark Pixels	Ctrl + Alt + D
Resize	Resize Image	Alt + Z
	Resize Folder of Images	Alt + Shift + Z
Rotate	Resize Image	Ctrl + Shift + R
	Resize Folder of Images	Alt + Shift + R
Sharpen	Sharpen	Ctrl + Alt + S
	Sharpen Gentle	Ctrl + Alt + G
	Unsharp Mask	Ctrl + U
	Richardson-Lucy	Ctrl + Y
Smooth	Average	Alt + A
	Custom Average	Alt + G
	Blur	Alt + U
Special Effects	Negative	Alt + N
	Outline	Alt + O
	Pixelize	Alt + X
	Custom Filter	Ctrl + Shift + F

Converting Image Formats

Most images that you take with a CCD camera have an internal storage format that allows 16 bits per pixel. This is true even if your camera doesn't use a 16-bit data format. This is the internal format that CCDSoft supports when processing your images.

You can convert from this internal format to several other formats using the **Image | Convert To** command. Not all formats are valid for any given image. CCDSoft disables any menu choices that do not apply to the current image. The conversion creates a new window with the converted image; your original image remains unchanged. If you like the results of the conversion, you can save it to disk.

The available image formats are:

Black & White – Also called 1-bit, the value of each pixel can only be black or white. This is a very limited format, and it is rarely used. We have included it in CCDSoft for backward compatibility. If you do convert to 1-bit format, the image must be dithered to perform the conversion. CCDSoft offers three conversion methods. Test each method to see which provides the most useful dithering:

- Error Diffusion
- Ordered Dither
- Bayer Dither

Grayscale – Converts an image to gray tones only, using 256 possible values (8 bits).
256 Color – Converts an image to a palette of 256 colors (8 bits).
RGB Color – Converts an image to RGB color (8 bits per color channel, or 24-bit color).

Brightness and Contrast

A typical CCD image has much more information in it than can be displayed to the eye. A 16-bit image can have more than 65,000 brightness levels. (Not all 16-bit cameras provide all of these levels due to various limitations.) The human eye can only distinguish a few hundred brightness levels. Often, only a small portion of the available brightness levels contains most of the visual information. It is possible to adjust your images so that only the important range of brightness values shows up on screen.

For example, figure 1 shows an image of M42 with 55,530 brightness levels equally represented. Only the very brightest stars show up, plus a hint of the nebula. The brilliant nebulosity for which M42, the Great Nebula in Orion, is known for is nearly absent. The information is still present; you just can't see it.



The vertical streaks are bloomed stars, created by overflow from one pixel to another due to the brightness of the stars. This occurs in cameras that do not have anti-blooming, or when the exposure length causes saturation.



Figure 1: An image of M42 showing the full range of original data (16-bit).

The stars and the blooming spikes are all extremely bright, and the pixels in these areas have values close to 55,530. The nebulosity near the center of the image is also very bright, and that is why it is visible. But the rest of the image – most of it, in fact, occupies the very dim end of the 55,530 brightness values. You can visualize how many pixels in an image have a given brightness value by examining the image's histogram. To view the histogram choose the command below:

Menu: click **Image | Brightness & Contrast | Histogram**
Keys: `Control + H`

Figure 2 shows the histogram for the image in figure 1. The histogram is a graph of the brightness values in an image. Dim values are shown at left; bright values toward the right. The taller the graph is at any given point, the greater the number of pixels that have that value.

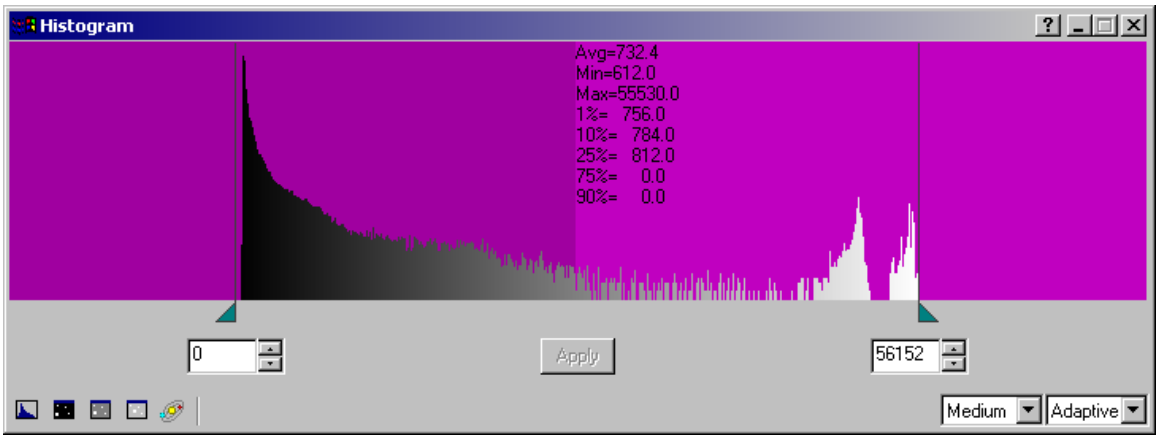


Figure 2: The histogram for the image in figure 1.

TIP	The histogram tool is resizable. If you don't see the statistical values for the image (**Avg**, **Min**, **Max**, etc.), or if the graph is too small to interpret easily, simply resize the window to a larger size.

The histogram in figure 2 tells us several things about the image:

- Most of the data in the image is in the dimmer values. This is true because the highest peak is far to the left, and there is a broad area with fairly high values just to the right of the peak.
- The peak at the far left of the histogram represents pixels that make up the black background in the image.
- The two peaks at the far right represent, from left to right, the brightest nebulosity, and the brightest stars (the ones that have bloomed).
- Other than the bright peaks, there aren't very many pixels in the entire right half of the histogram.

The text above the histogram provides some statistical information about the image:

- The average pixel brightness level is 732.
- The minimum brightness value is 612.
- The maximum brightness value is 55,530.
- The brightness values for various percentages of pixels. For example, in figure 3, 1% of the pixels are dimmer than 756, and 10% are dimmer than 794.

There are two small triangles located just beneath the histogram. These identify the black point (left) and white point (right) of the image. The black point is sometimes referred to as the Back or Background level. The difference between the black point and the white point is sometimes called the Range of the image. In figure 2, the black point is 0, and the white point is 56,152. These values are outside the minimum and maximum brightness values (612 and 55,530, respectively), so the entire range of brightness levels is visible (figure 1).

The black point and the white point are adjustable. Figure 3 shows a change to the histogram. The white point has been moved to the left. The new white point is 9,493. All pixels with a brightness value greater than 9,493 will now show up as pure white in the image. Figure 4 shows the appearance of the M42 image with the new white point.

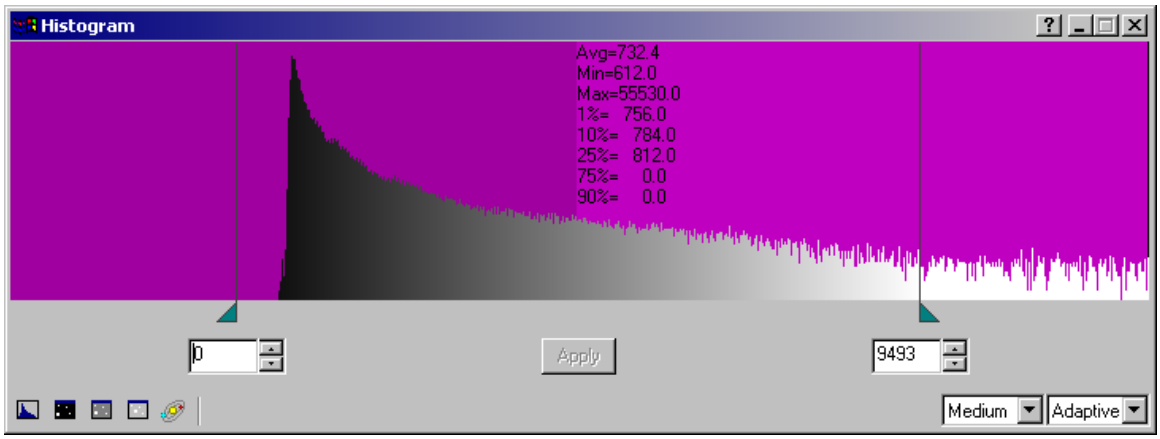


Figure 3: Adjusting the white point in the histogram.



Figure 4:The image of M42 now shows more of the nebulosity, and more stars are also visible.

The black point can be set in the same manner, except you move it to the right. You can drag the triangles for the black point and the white point to make changes. Figure 5 shows further adjustments to the black point and white point. The black point has been raised to 720, and the white point lowered to

1,565 (see figure 6). This reveals a wealth of detail in the dim portions of the nebula. Even NGC-1977 has become visible near the top of the image.

	After these changes to the histogram, the core of the nebula is completely white. This is called a “burned out” core. You’ll learn how to avoid burning out the bright portions of an image later in this chapter, in the section “Brightness and Contrast Curves.” You will often use a combination of changes to the black/white points and the histogram curve to reveal just the right amount of detail in your images.

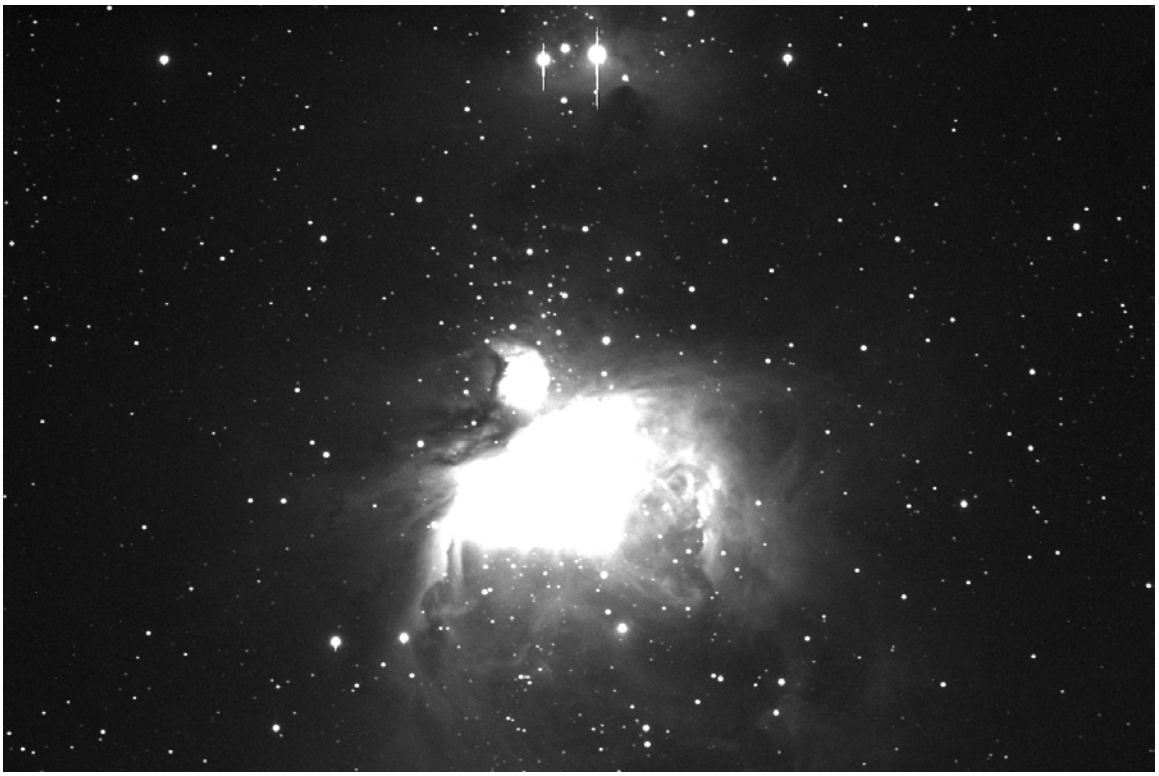


Figure 5: Further adjustments to the black point and white point reveal lots of dim details in the image.

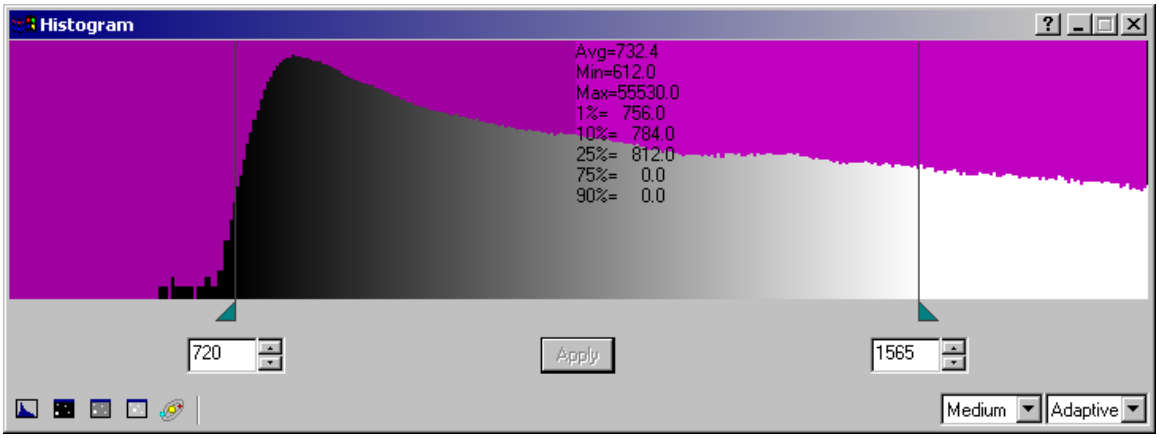


Figure 6: Additional histogram adjustments to raise the black point, and lower the white point further.

The changes you make to the histogram are not destructive. The values to the left of the black point and to the right of the white point are not gone; they simply are not displayed. If you save an image after a histogram adjustment, the black and white points are saved with the image, and will be reapplied when you reopen the image. See the “Histogram” section for detailed information about making changes to the image histogram.

Background and Range

In previous versions of CCDOPS and CCDSoft, the black point and white point were set using values referred to as Background and Range. CCDSoft still offers this option if you prefer to use Background and Range with your images:

Menu: click **Image | Brightness & Contrast | Background & Range**
Keys: press `Control + B`

This command opens the dialog box shown in figure 7. The Background setting is the same as the black point. The range is the distance between the black point and the white point. The preview button applies the **Background** and **Range** settings to the image. The **Auto** button analyzes the image histogram and applies calculated **Background** and **Range** settings. When you are satisfied with the settings, click **OK**. Changes affect only the display of the image data; nothing is lost when you change the **Background** and **Range** settings.

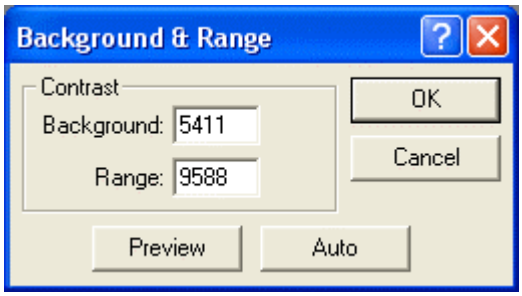


Figure 7: Setting image background and range.

Histogram

Because a CCD image almost always contains more data than your monitor can display, or your eye can perceive, histogram adjustments are often necessary. As shown earlier in this chapter, you can make profound changes in the appearance of your images simply by altering the histogram. If an image doesn't look right, don't panic and don't give up. Try adjusting the histogram to better visualize the information in the image.

Histogram adjustments don't affect the data, just the way you view it on your monitor. You can always change the histogram again if you need to.

Figure 8 shows the default appearance of the histogram panel with numbers next to each feature.

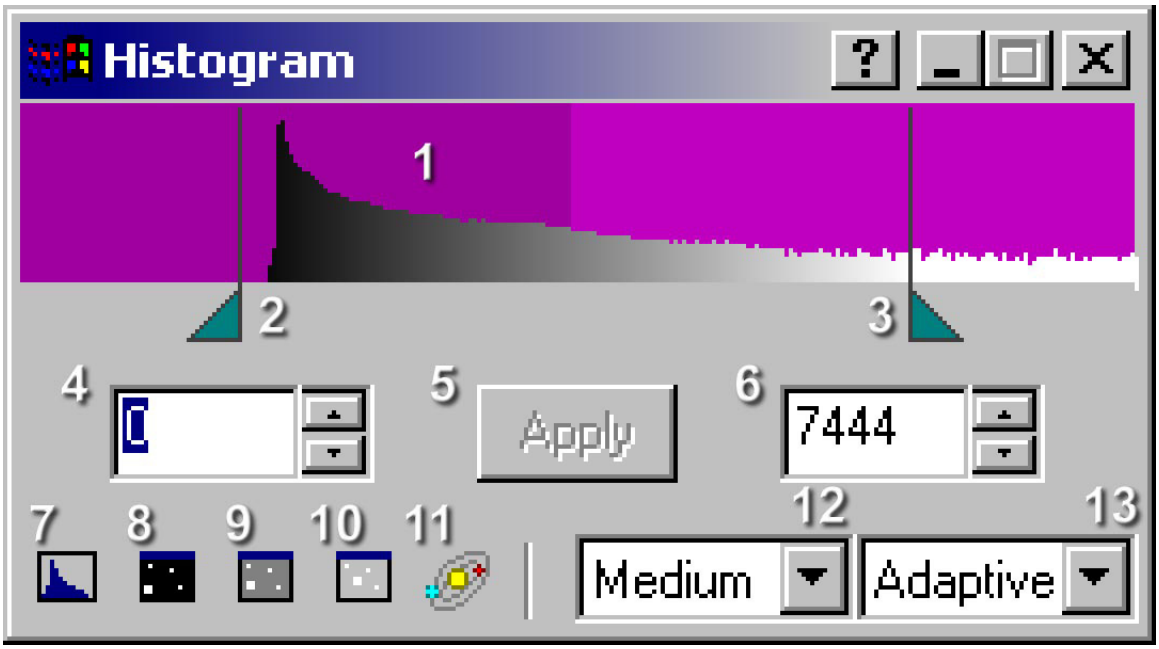


Figure 8: The Histogram panel.

The numbers in figure 8 are keyed to the following table, which explains the various features and controls found in the Histogram panel.

Number	Name	Description
1	Graph	Graphs the distribution of brightness values in the image. The higher the peak, the greater the number of pixels with that brightness value. Dim values are to the left, and bright values are to the right. You can change the histogram by clicking in four different zones; see figure 9 for details.
2	Black point control	Drag this control to increase or decrease the black point.
3	White point control	Drag this control to increase or decrease the white point.
4	Black point value	This text box displays the numeric value for the black point. All pixels with brightness values lower than this are shown

		as black.
5	Apply button	Click this button to apply numeric changes to the image.
6	White point value	This text box displays the numeric value for the white point. All pixels with brightness values higher than this are shown as white.
7	Reset	Click to display the entire histogram, with the black point set to the dimmest pixel in the image, and the white point set to the brightest pixel in the image.
8	Low Contrast	Sets the black point to a relatively low numeric value, and sets the white point adaptively.
9	Medium Contrast	Sets the black point to a medium numeric value, and sets the white point adaptively.
10	High Contrast	Sets the black point to a relatively high numeric value, and sets the white point adaptively.
11	Planetary Contrast	Sets the black point to a medium numeric value, and the white point very high.
12	Black point presets	Allows you to choose from several presets for the black point: none, weak, medium, strong, and very strong. **Weak** provides a low black point, and **Strong** provides a higher black point.
13	White point presets	Allows you to choose from several presets for the white point: **None**, **Weak**, **Medium**, **Strong**, **Very Strong**, **Adaptive**, and **Planetary**. **Weak** provides a high white point, and **Strong** provides a lower white point.

You can click on the histogram graph to alter the histogram. There are four zones you can click in, and the change that occurs is different for each zone.

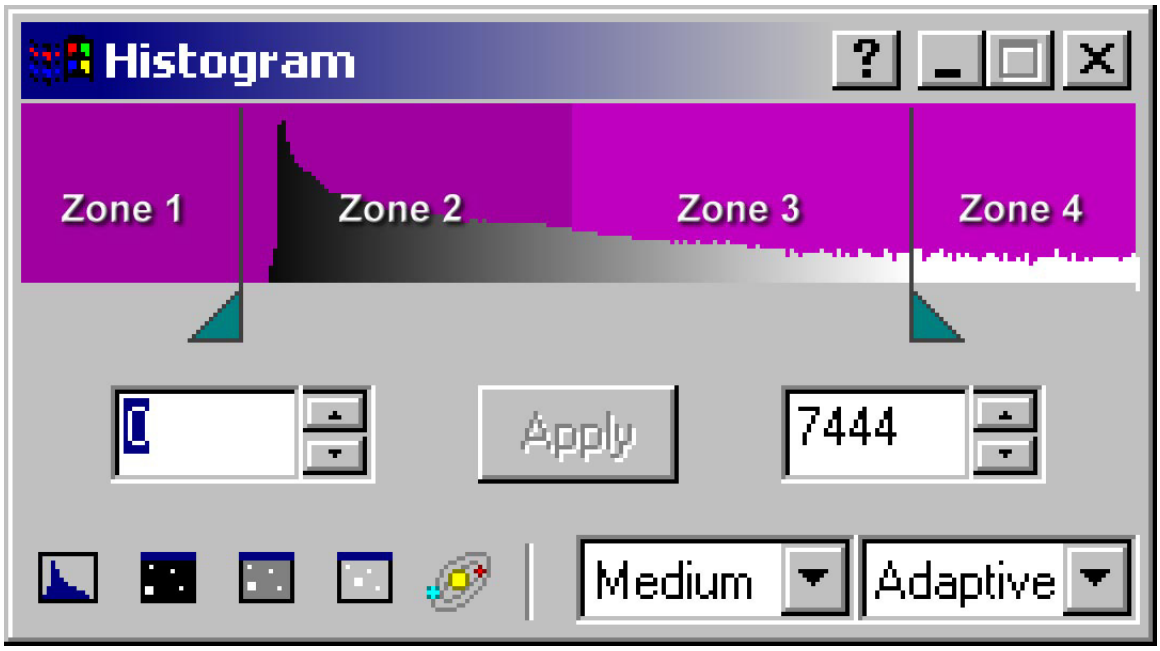


Figure 9: Click the mouse in any of the above Zones to rapidly adjust the histogram.

Zone	Result
Zone 1	Clicking here lowers the black point. The background gets lighter. The lowest possible black point is zero.
Zone 2	Clicking here raises the black point. The background gets darker. If you go too far with this adjustment, dim details also get darker.
Zone 3	Clicking here lowers the white point. Dim details in the image become more visible, and bright areas start to “burn out” as if overexposed.
Zone 4	Clicking here raises the white point. Dim areas darken and become less visible. Detail becomes more evident in the brightest areas of the image.

There is a vertical bar marking the black and white points. The closer you click to one of these vertical bars, the smaller the change in the histogram. This proportional response allows you to make very precise adjustments to the histogram very quickly. Figure 10 shows a typical sequence. The top image shows how the cursor changes when you hover over the graph. The middle image shows what happens when you click. The point in the histogram where you click becomes the new black point when you click in zone 2. The bottom image shows the result of the adjustment: the black point has shifted to a new point in the histogram. The background is now darker; all pixels to the left of the new black point are displayed as black. Watch the current image as you click in the various zones. You can use the zones to make very rapid yet accurate changes to the histogram.

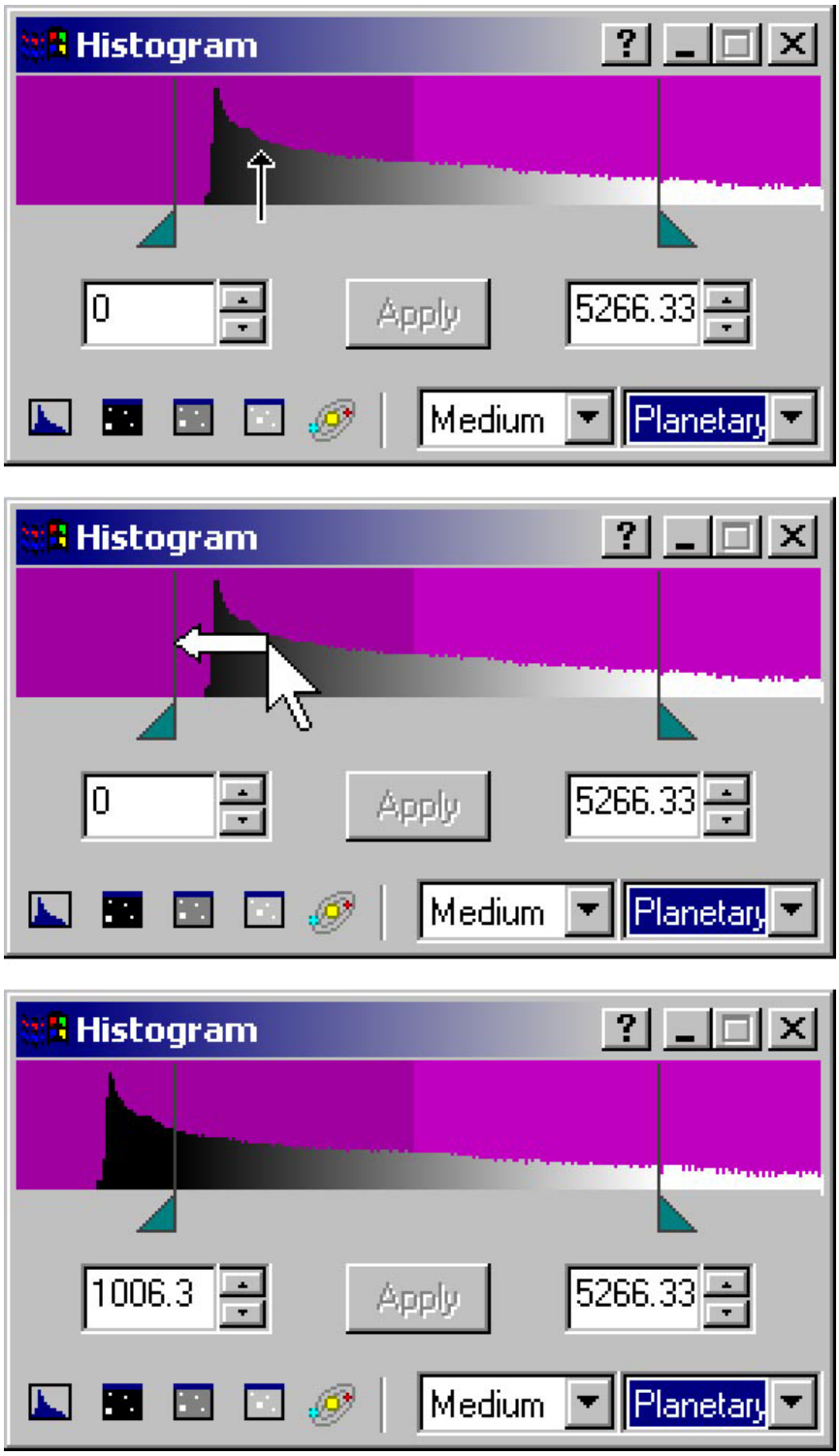


Figure 10: Adjusting the histogram by clicking in the graph area.

For many images, you can simply click on the contrast buttons at the lower left of the Histogram panel (items 7-11 in figure 8), or click on the black point and white point presets using the drop-down lists at bottom right (items 12-13 in figure 8).

Tune Brightness and Contrast

Changing the black point and white point of an image improves an image by eliminating non-critical data from what is displayed on your monitor. You can use the Histogram tool to select the portion of the image data that is most important to you.

If an image has a very large brightness range, however, there may simply be too much data to properly display it. Figure 11 shows an image of the Eagle Nebula.

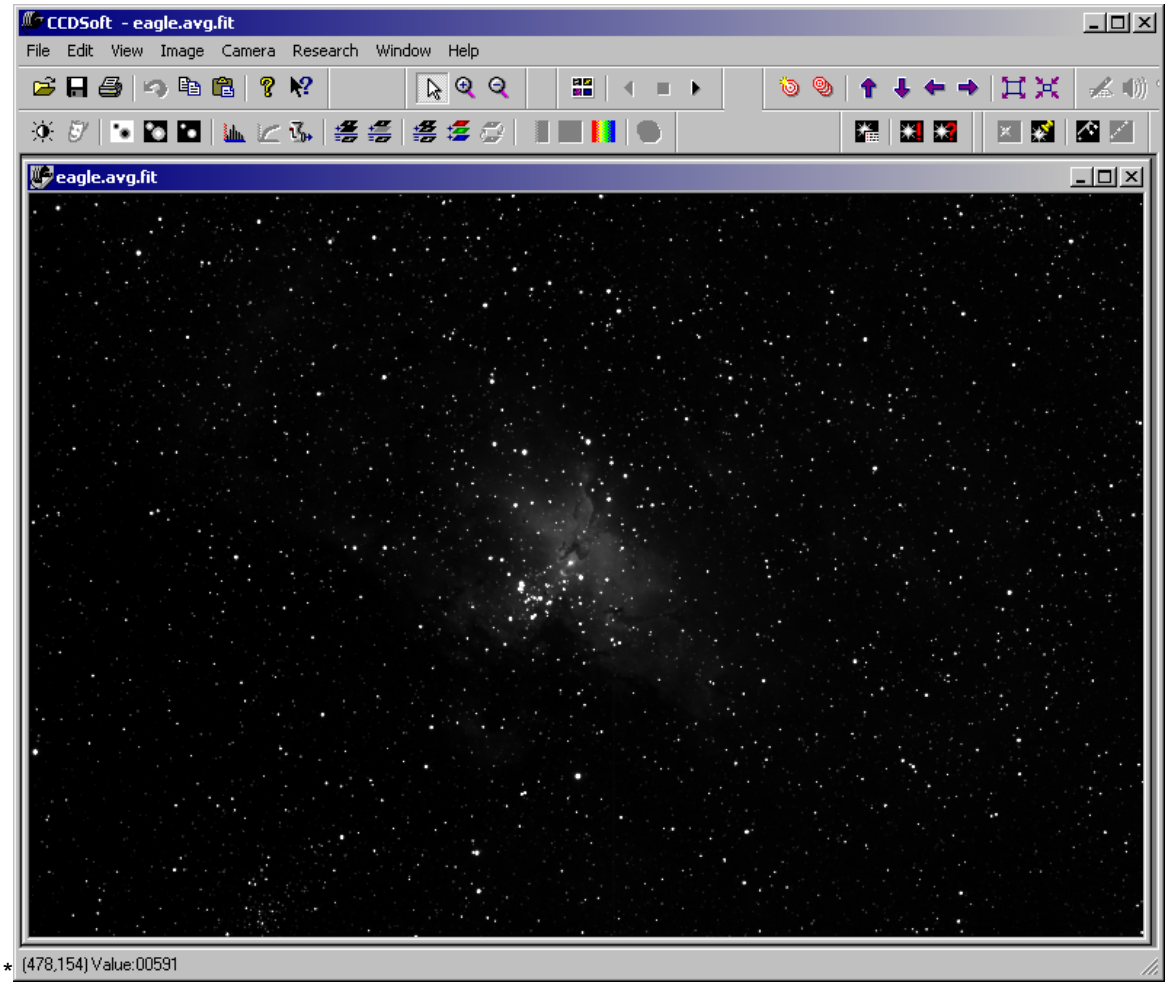


Figure 11: An image of the Eagle Nebula, M16.

Figure 12 shows what happen when the histogram is adjusted to reveal the dim portions of the nebula. The core of the nebula is burned out (completely white).

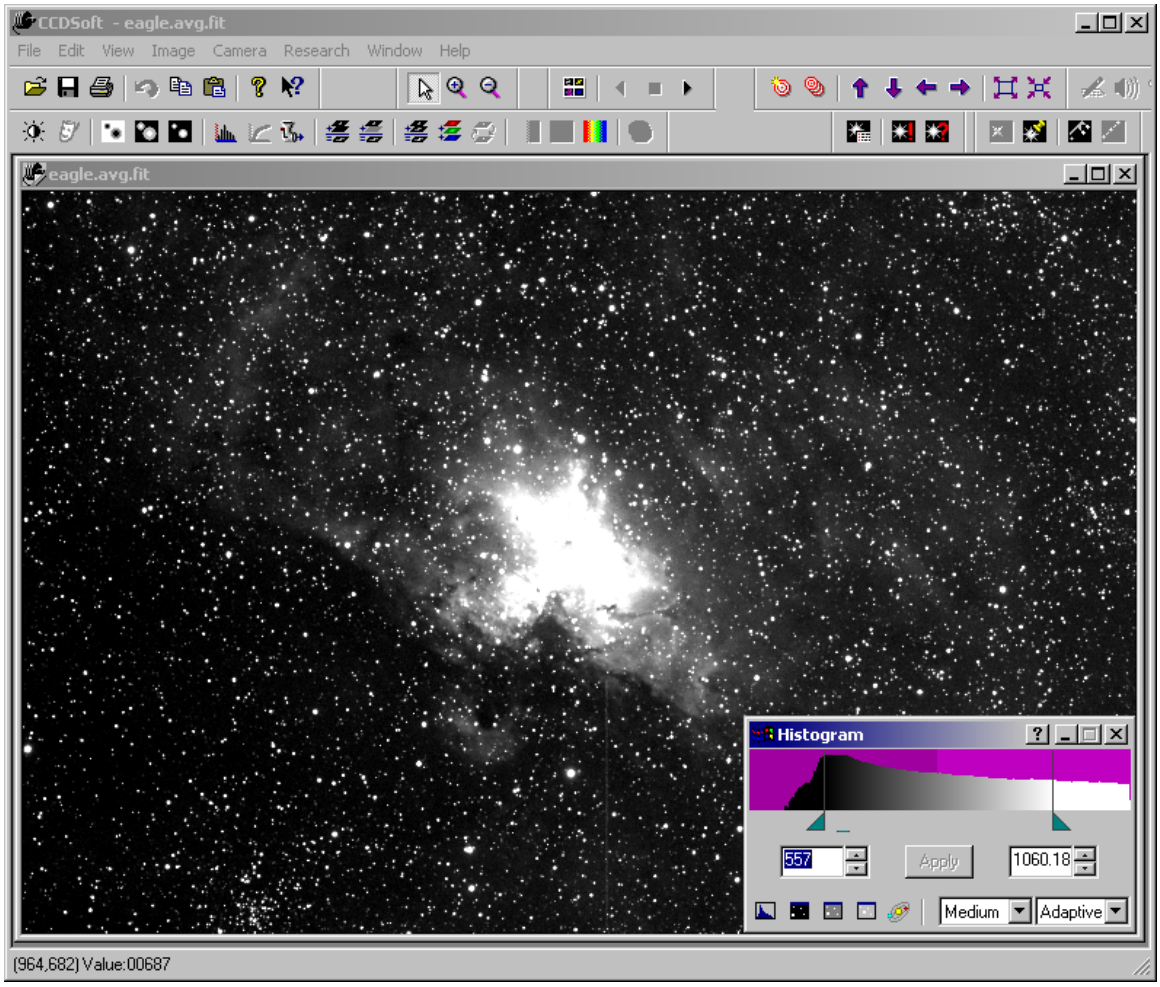


Figure 12: Adjusting the histogram to show dim portions of the nebula turns the nebula core white.

Starting with the image as it is shown in figure 11, you can use the **Image | Brightness & Contrast | Tune | Brightness & Contrast** tool to reveal both dim and bright details in the image. The first step is to brighten the overall image, as shown in figure 13. For this particular image, a 47% brightness increase is needed. The background brightens along with the core of the nebula, but this will be corrected in later steps.

NOTE	Unlike histogram changes, tuning the brightness and contract will permanently change the image.

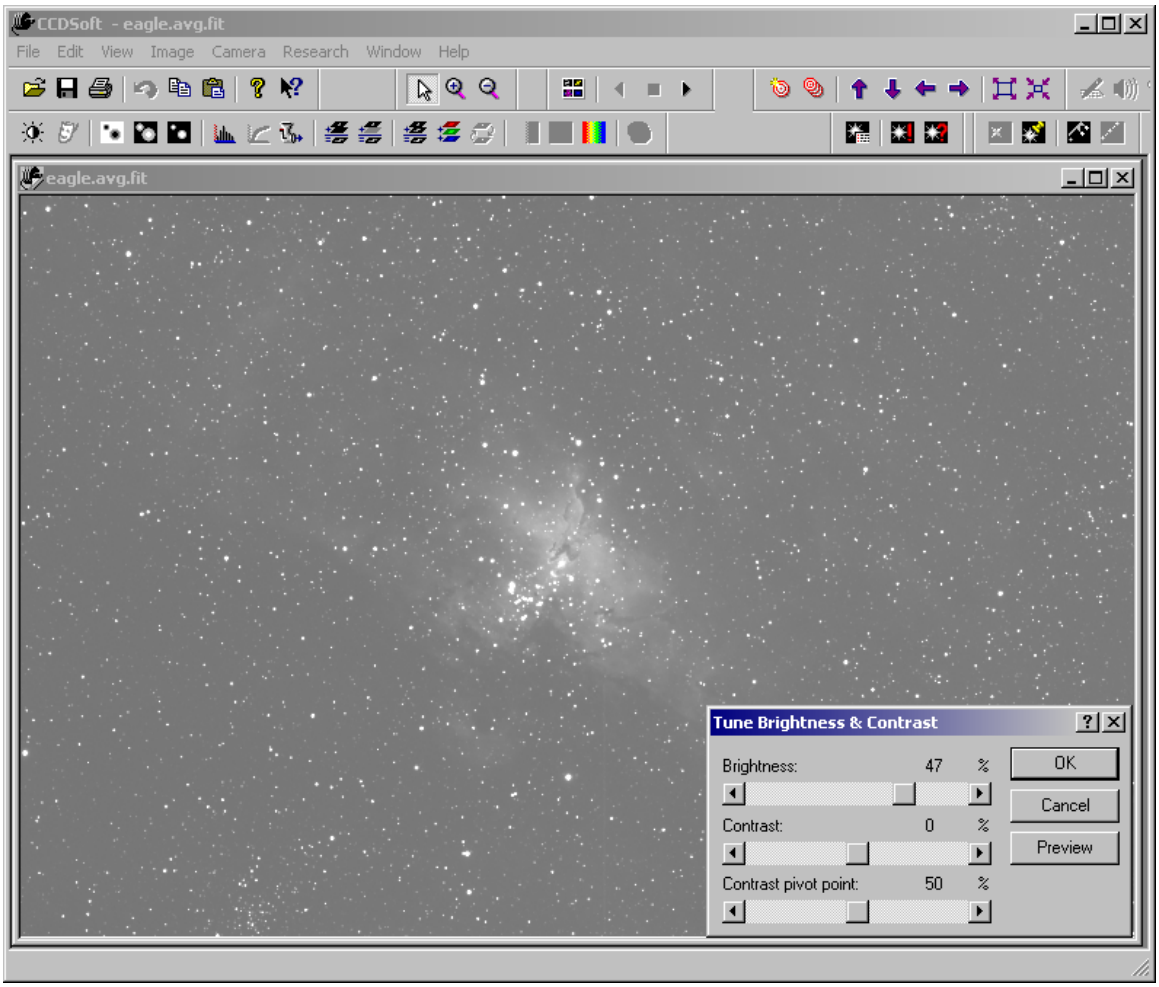


Figure 13: Brightening the image.

Figure 14 shows what happens when the image contrast is increased (by 61%). This brings out the dim details, but it also burns out the core (though not as much as the histogram adjustments did). You can use a combination of brightness and contrast changes to reveal dim details. This example uses increases, but some images will require a decrease. Experiment to find out which works best for a given image.

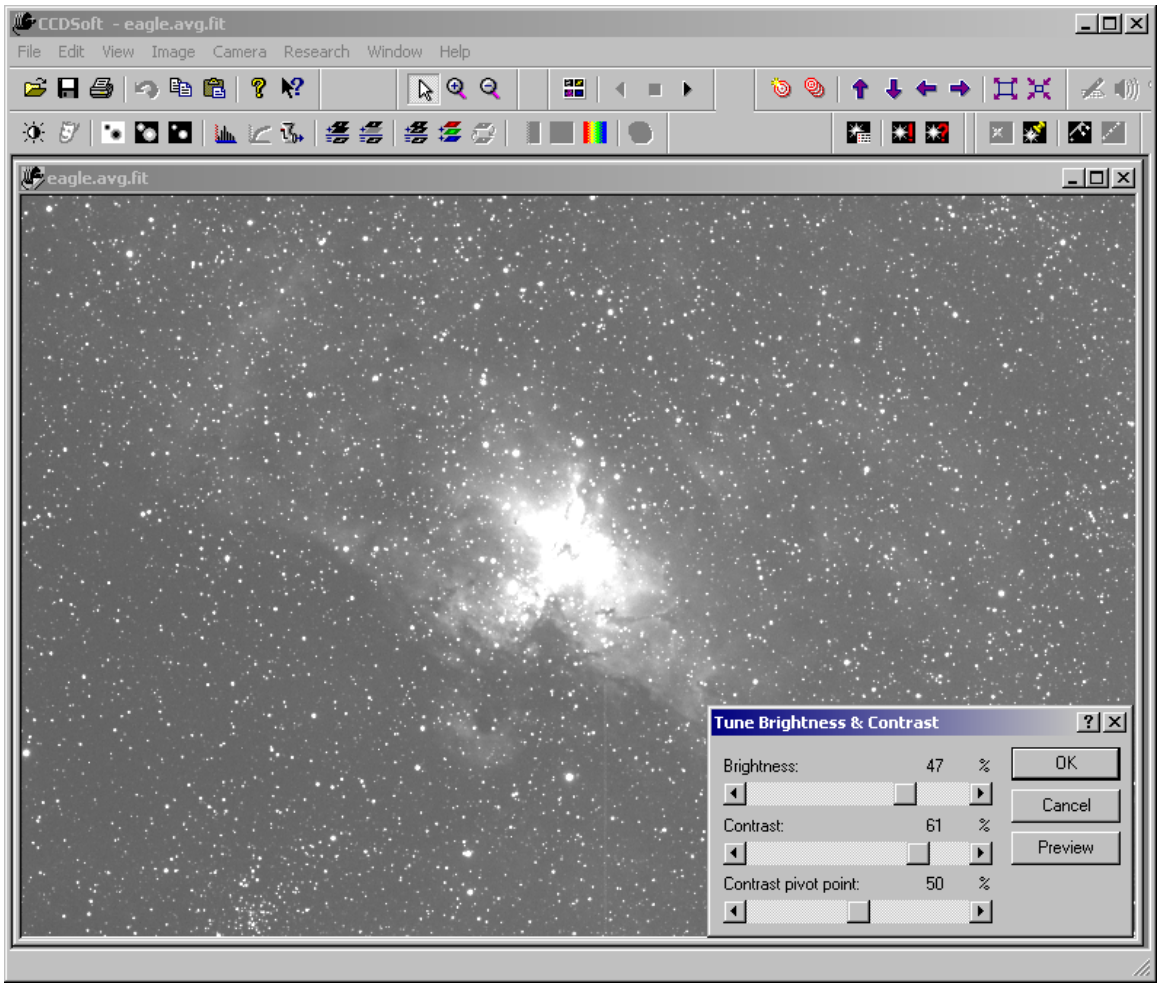


Figure 14: Increasing contrast reveals dim details.

Figure 15 shows how careful use of the “Contrast pivot point” slider can bring everything under control. By moving the pivot point to the right (66%), the mid point of the image’s brightness levels is shifted towards brighter values. This dims the background, but it leaves the dim background details visible. The core of the nebula is properly balanced.

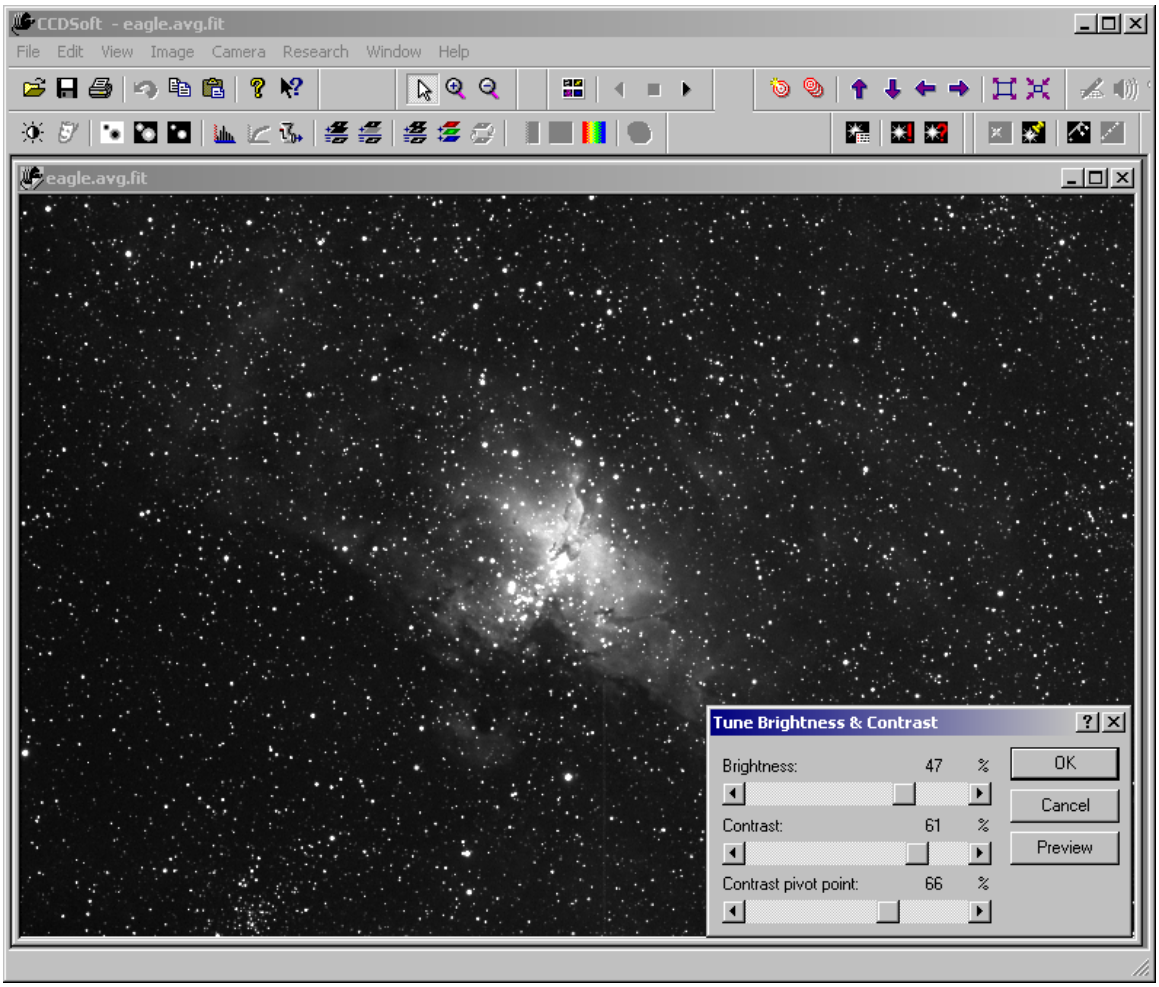


Figure 15: Moving the pivot point has a dramatic effect on the overall appearance of the image.

The starting point of the tuning process has a significant impact on the settings you will use to balance an image. Figure 16 shows the exact same image as in figure 11, but with different histogram settings. The white point has been lowered, so that the nebula starts out brighter overall. The white point has been set so that the bright details in the center of the nebula are just visible. That is, the white point is just short of the position where core burnout would occur.

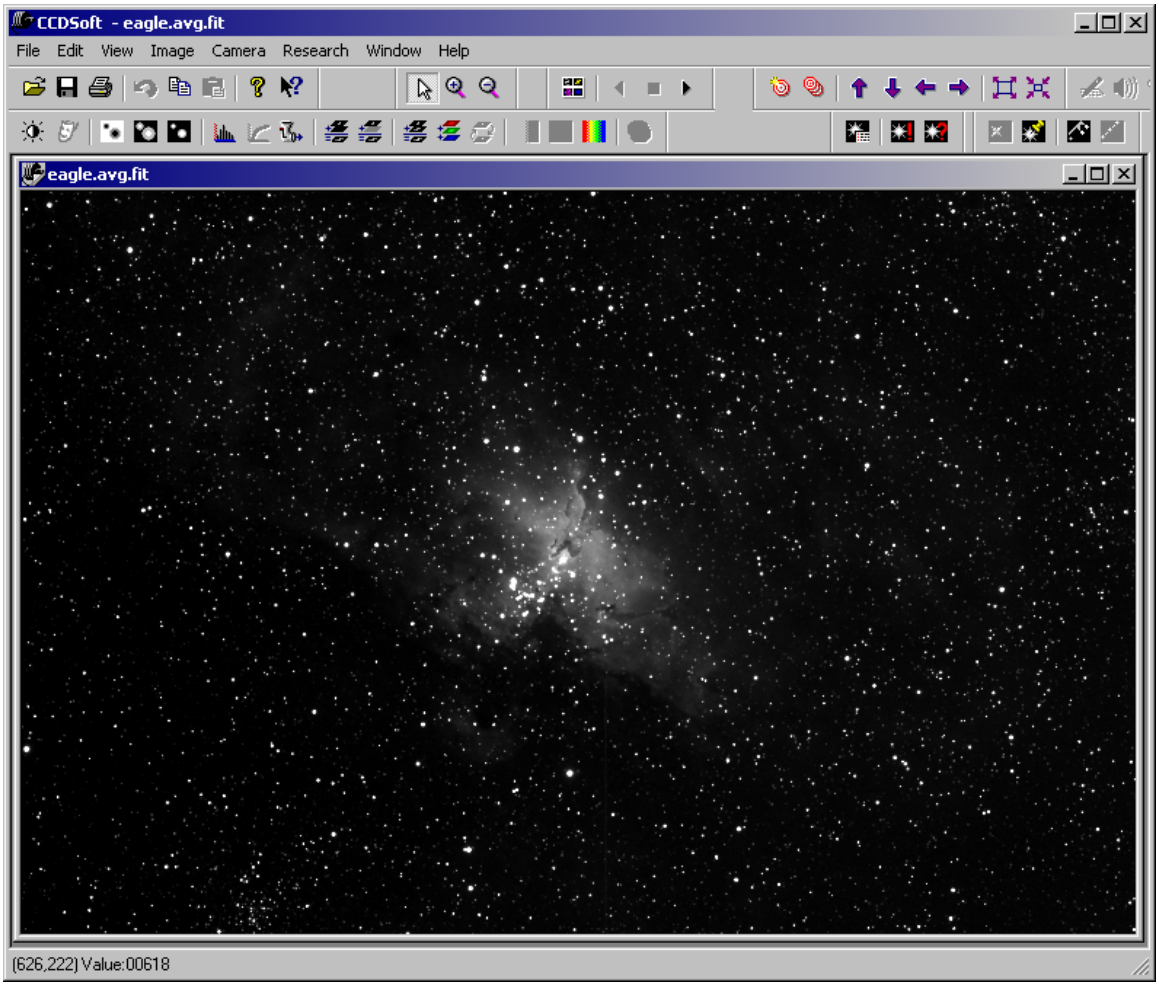


Figure 16: Starting with different histogram settings will result in using different tuning settings.

Figure 17 shows the tuning settings that yield approximately the same amount of dim detail as in figure 15. If you don't get the results you would like from tuning, you can undo the process (click **Edit | Undo**), change the histogram settings, and try again. Generally speaking, the ideal black point will be just a bit darker than the dimmest details you want to show. The ideal white point will be as close as possible to the value where burnout begins to occur. If necessary, use the magnifying glass tool to get a close look at the brightest portion of the image so you can set the best possible white point.

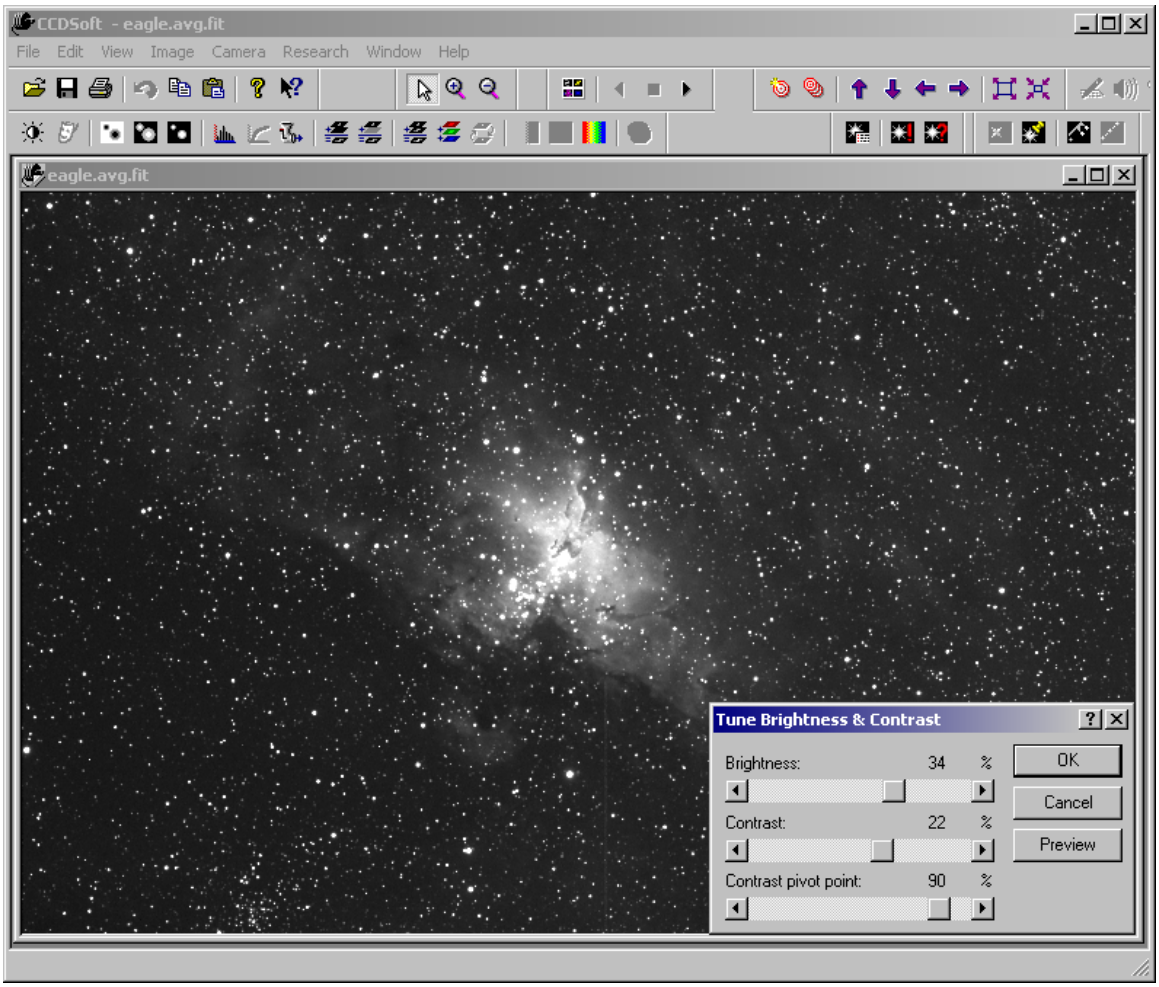


Figure 17: An optimal representation of the Eagle Nebula requires changes to both the Histogram and the Tune Brightness & Contrast settings.

Brightness and Contrast Curves

This tool only operates on 8-bit images. To use this tool, save your 16-bit FITS or SBIG format images as bitmaps, which will automatically convert them to 8-bit images. The **Image | Brightness & Contrast | Brightness & Contrast Curves** command is enabled only when the current image is an 8-bit (grayscale) image. Clicking on this command opens the Transfer Function tool, as shown in figure 18.

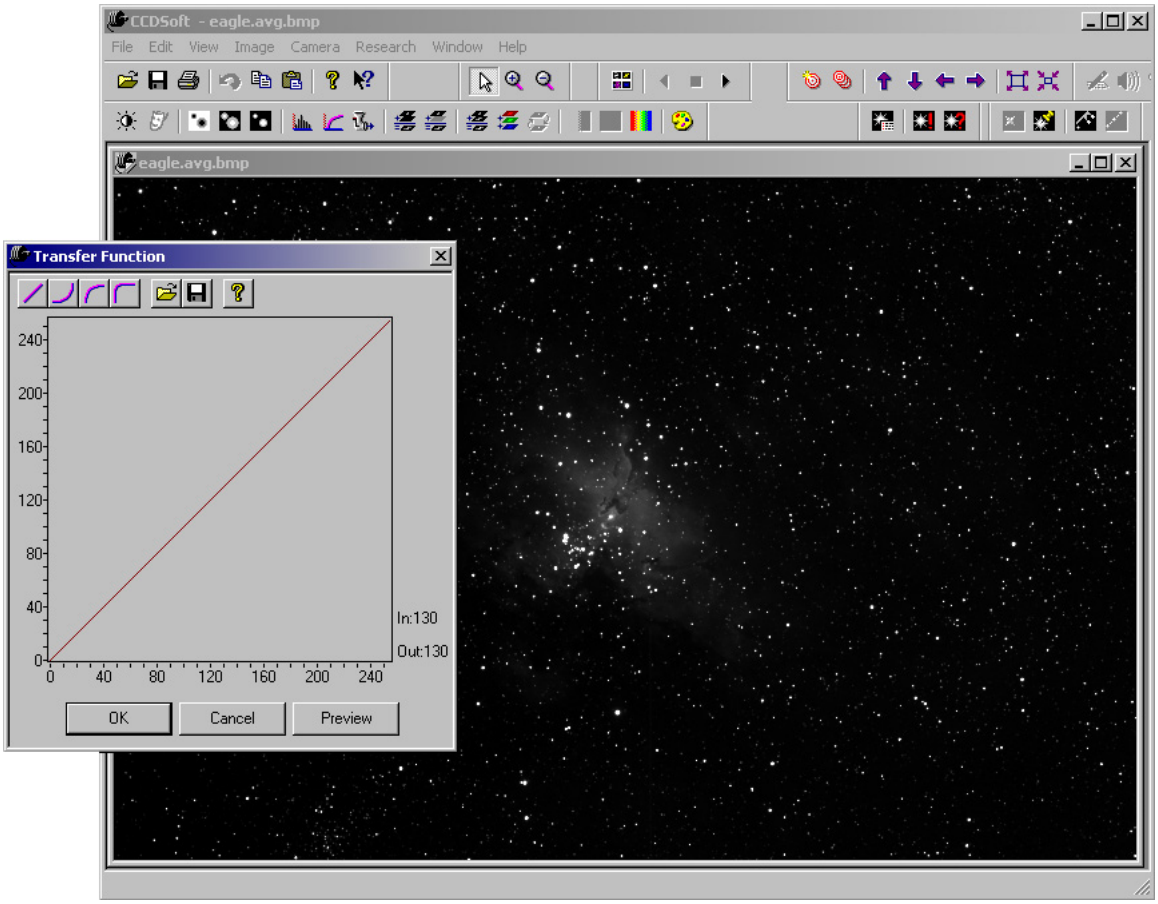


Figure 18: The Transfer Function tool.

There are four buttons at the top left of the Transfer Function tool. From left to right, these buttons have the following effect on your image:

- Restores the original values.
- Darken image.
- Brighten image.
- Brighten image more.

You can quickly adjust the brightness levels in your image by clicking one of these buttons. If the result isn't optimal, you can also draw in the box by clicking and dragging the mouse to customize the transfer function curve.

The curve acts on the image histogram. When the curve is a straight diagonal line (the leftmost button and the default), no change to the histogram occurs. When part of the line is to the left of the default line, brightening occurs. When the curve is to the right of the line, darkening occurs.

Figure 19 shows the effect of clicking the third button, **Brighten Image**. Note that the image of the nebula is brighter, and that more dim details are visible.

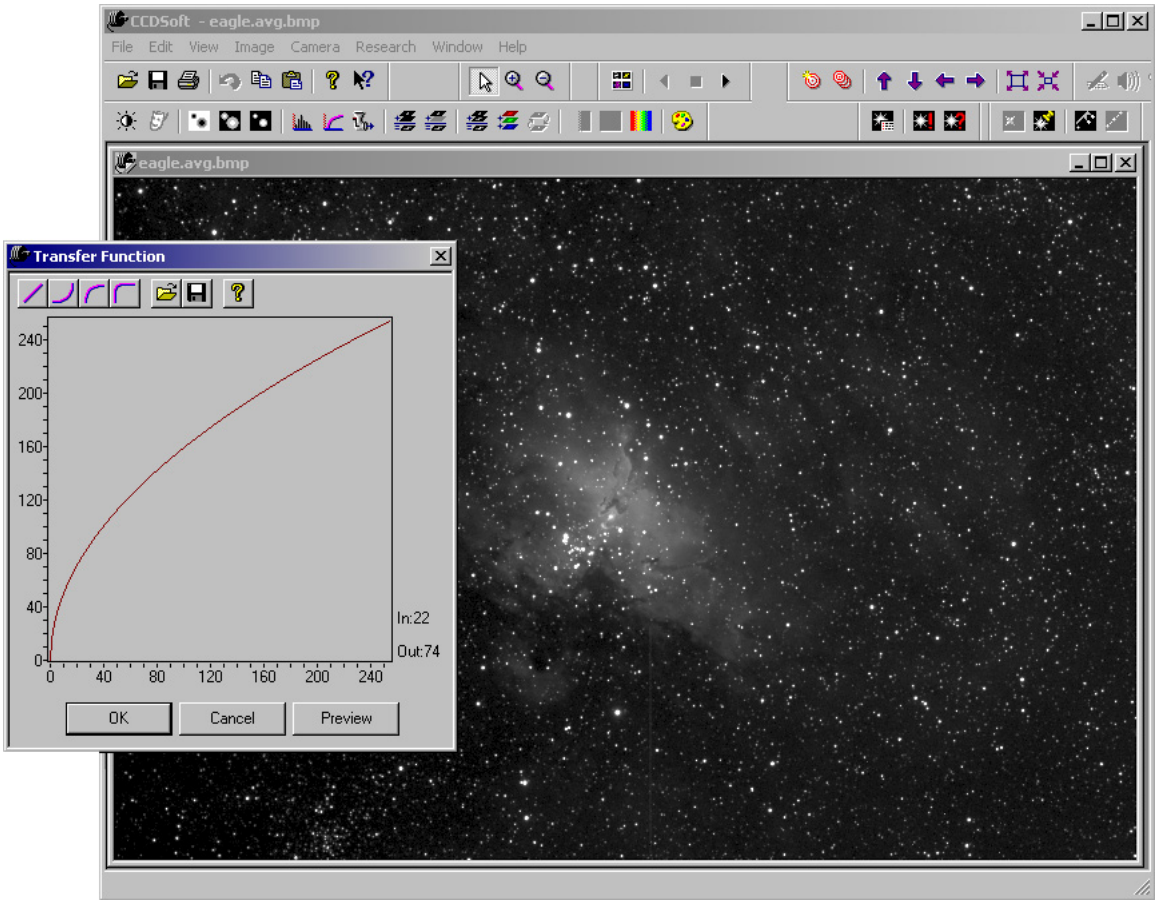


Figure 19: The effect of clicking the Brighten Image button.

The shape of the Transfer Function curve controls which portions of the histogram get brightened. The curve in figure 19 is very steep at bottom left, which means that a lot of brightening will occur in the dim areas of the image. The curve is flatter (closer to the original diagonal) at upper right, so the bright portions do not get much brighter. This works well for some images, but for this particular image of M16, the curve needs to be steeper overall, and particularly steeper at the upper right.

Figure 20 shows the effect of clicking the **Brighten Image More**. The curve is now extremely steep at lower left, and the dim areas are strongly brightened as a result. The curve is a little flatter in the bright regions (top right), so the bright areas of the image are boosted but not as dramatically. The black point and the white point have not changed by applying the transfer function. The curve of the transfer function has been applied to the histogram to increase the brightness. Where the curve is steepest (that is, where it deviates most strongly from the original diagonal), the brightness increase is greatest. Where it is less steep (that is, where it is closer to the diagonal), the brightness change is less.

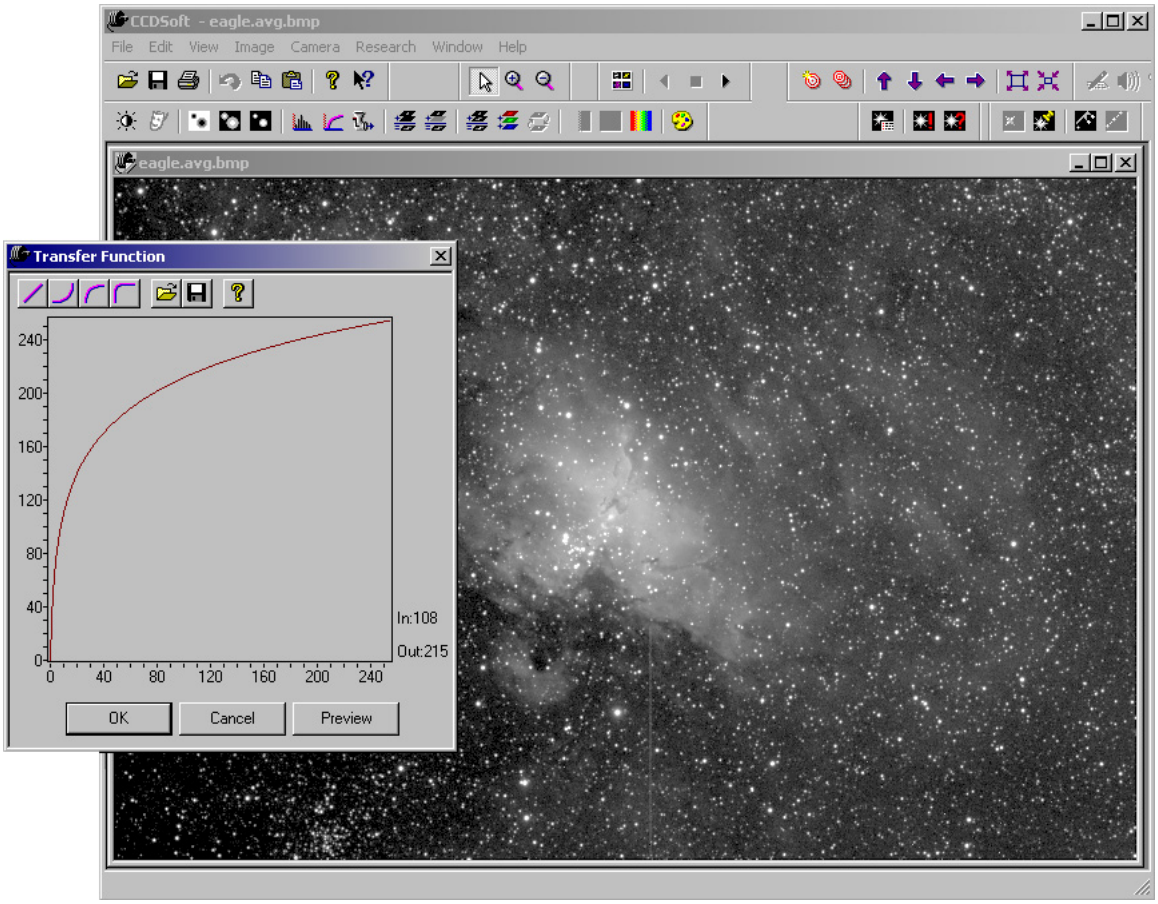


Figure 20: This image displays the effect of clicking on the Brighten Image More button.

Figure 21 shows the effect of clicking the Darken Image button. It isn't the right choice for this image; the nebula has almost completely disappeared due to the darkening.

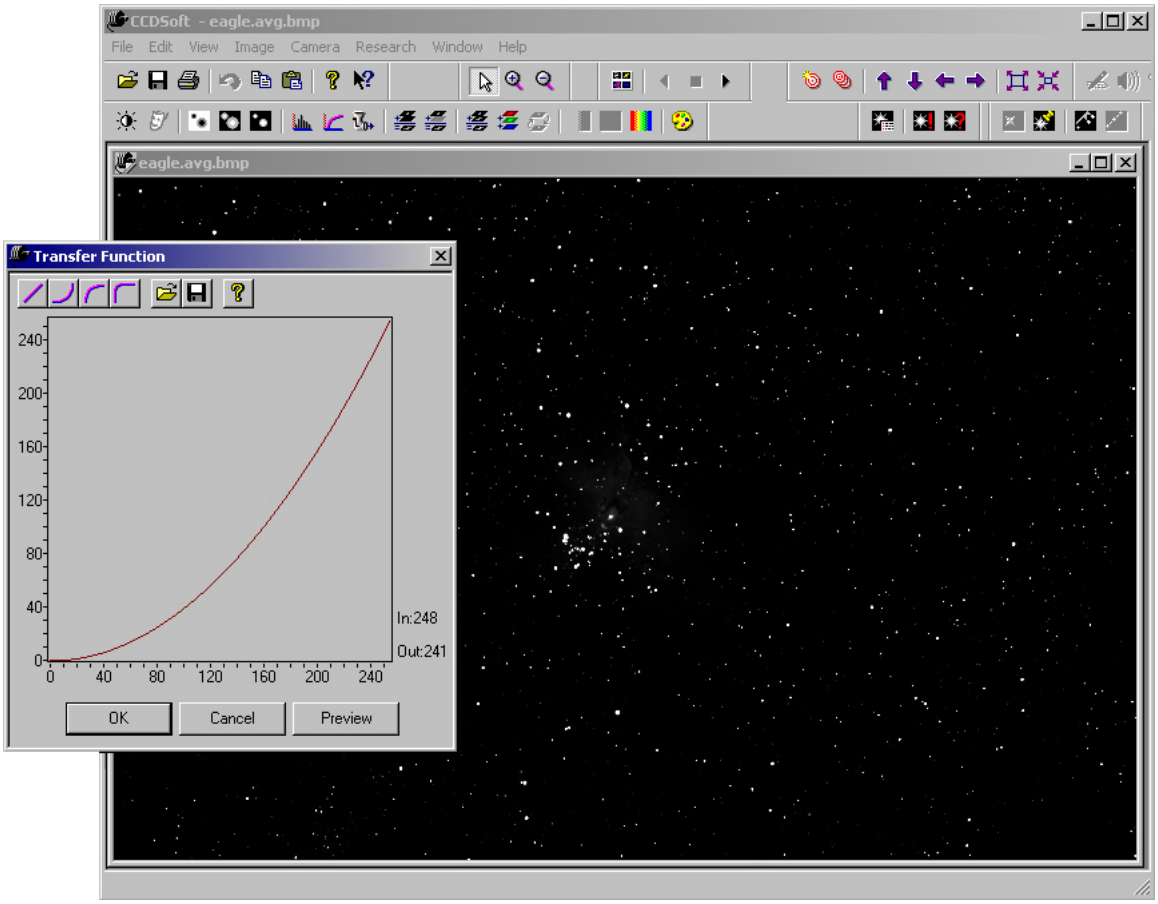


Figure 21: This image shows the effect of clicking on the Darken Image button.

Figure 22 shows a custom-drawn curve. It is about midway between the two built-in curves, and provides a more balanced rendition of the nebula. The core is still a little dark, but this can be fixed by lowering the white point a bit using the Histogram tool (see figure 23).

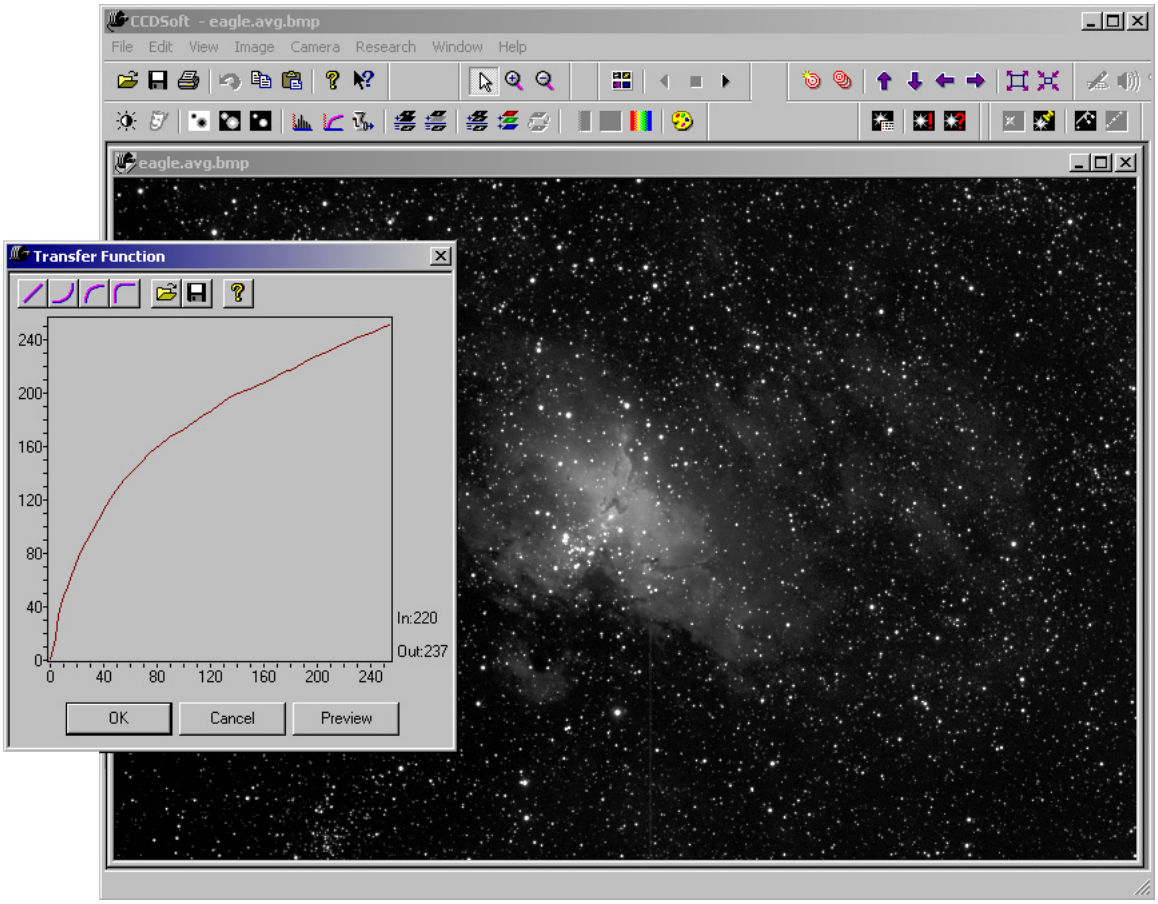


Figure 22: Using a custom-drawn curve.

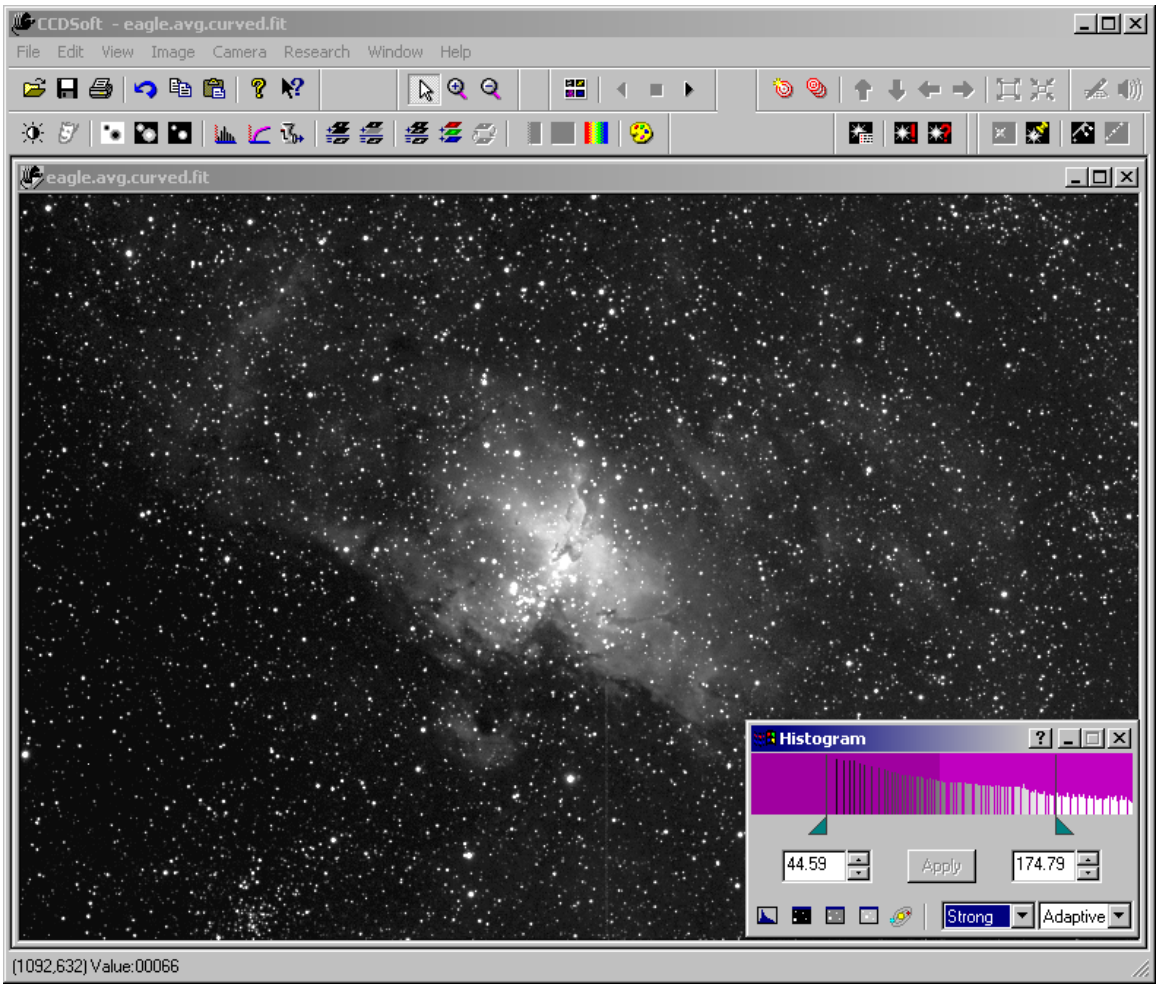


Figure 23: Using the Histogram tool to make final adjustments to the image.

Histogram Brighten

Use the Histogram Brighten command to non-linearly brighten an image. The Histogram Brighten command (**Image | Brightness & Contrast | Histogram Brighten**) increases brightness levels so that the area of the resulting histogram varies proportionally to the square of the brightness level. This emphasizes the dimmest brightness levels the most, as shown in figure 24. The top images use the default histogram. The lower images are the result of a Histogram Brighten.



Figure 24: The effect of the Histogram Brighten command.

While few images will benefit from such severe processing, Histogram Brighten is a useful diagnostic tool. Histogram Brighten creates a new window with the brightened image, so it is non-destructive. The Image of M81 and M82 (left in figure 24) reveals the extent of the two galaxies, and this can serve as a guide in your image processing as you attempt to reveal as much detail in the galaxies as possible. The brightened image also reveals a slight gradient, brighter at the bottom, which you can correct in an external image-processing program.

The brightened image of M13 at right in figure 24 also reveals useful information. The full extent of the globular is much larger than in the default image. This suggests that histogram adjustments and use of the Tune Brightness & Contrast command might reveal the hidden details. Either a poor flat-field, or the lack of a flat-field caused the gradient background. Image reduction with a good flat field will solve that problem.

Mid-range Brighten

Mid-range Brighten can be a one-step image processor for many of your images. For example, figure 25 shows an image of M81and M82. The default histogram doesn't show much detail in the dim portions of the galaxies. These are both bright galaxies, with a lot of detail in dim areas, and a simple histogram adjustment can't show the full range.

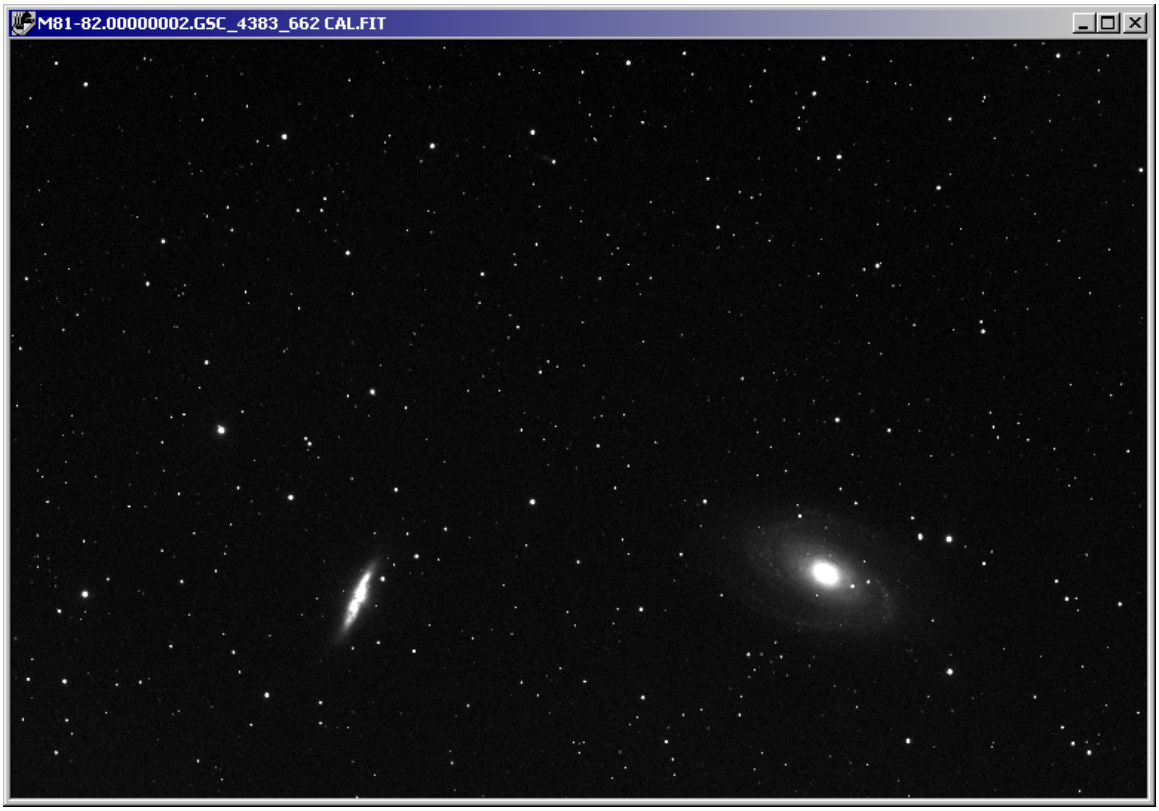


Figure 25: An image of M81and M82 before a Mid-range Brighten.

The Mid-range Brighten command (click **Image | Brightness & Contrast | Mid-range Brighten**) brightens the middle brightness values using a non-linear histogram adjustment. This compresses the brightness values so that a wider range of details, especially dim details, show up clearly (see figure 26).

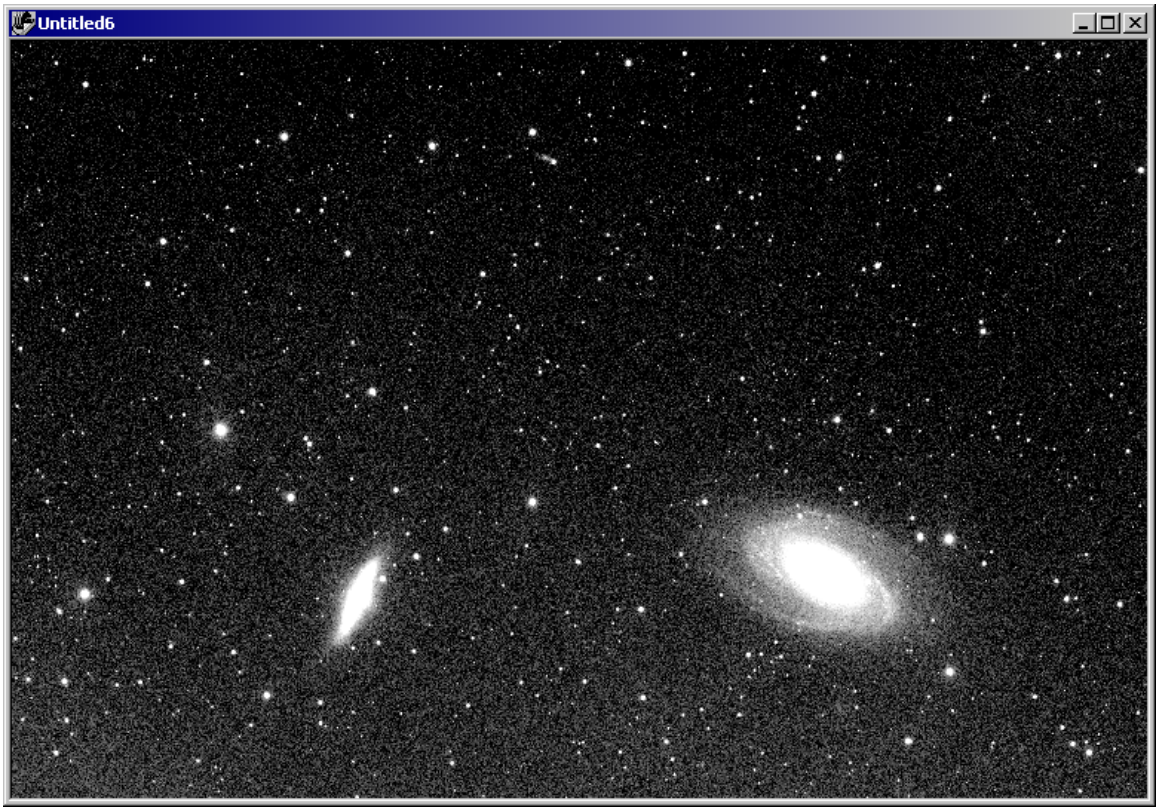


Figure 26: The image of M81and M82 after a Mid-range Brighten.

There is a slight gradient visible from top to bottom of figure 26. It also appears that bright details have been burned out, but this is not the case. Figure 27, left, shows the histogram of the M81and M82 image after a Mid-range Brighten. Moving the black point a small amount to the right, and moving the white point much farther to the right (see figure 27, right) hides the gradient successfully, and reveals much more of the bright detail (see figure 28). Compare figure 28 to figures 25 and 26 to see the effectiveness of the Mid-range Brighten function.

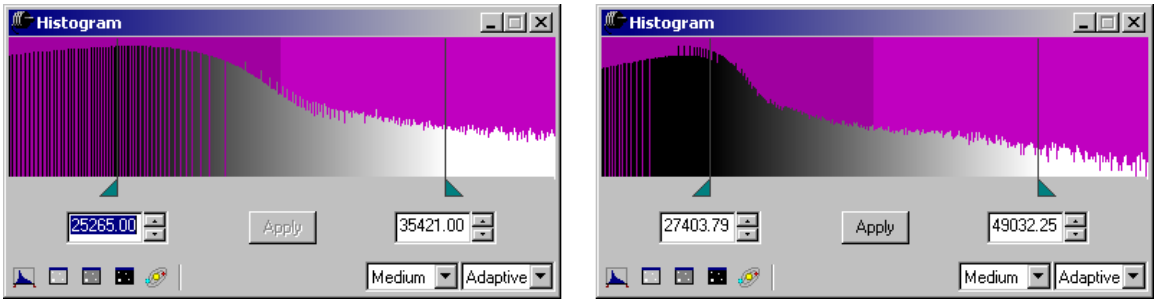


Figure 27: A comparison of the histogram after a Mid-range Brighten (left) and after manual adjustments (right).



Figure 28: A histogram adjustment after a mid-range brightening reveals a wide range of details.

Equalize

Use the Equalization command to reassigning the brightness levels of an image equally across the entire range of pixel values. Equalization, often called “histogram equalization,” works best when used on dark images to bring out faint detail. The best way to see exactly what equalization does to an image is to look at a histogram plot of an image before and after equalization is performed.

Posterize

The Posterize command changes the number of brightness levels in the image. Most CCD images will have anywhere from 256 to 65,536 brightness levels. The Posterize tool (click **Image | Brightness & Contrast | Posterize**) allows you to change the image so it has from 2 to 99 brightness levels. Figure 31 shows the Posterize dialog box. Entering a value of 8 levels changes the appearance of the image as shown in figure 32. If you use a sufficiently small number of levels, you can use the Posterize command to show the brightness contours of the image.

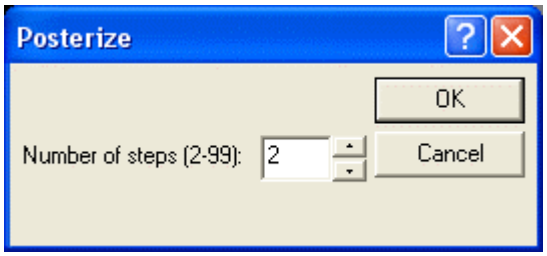


Figure 31: The Posterize dialog box.

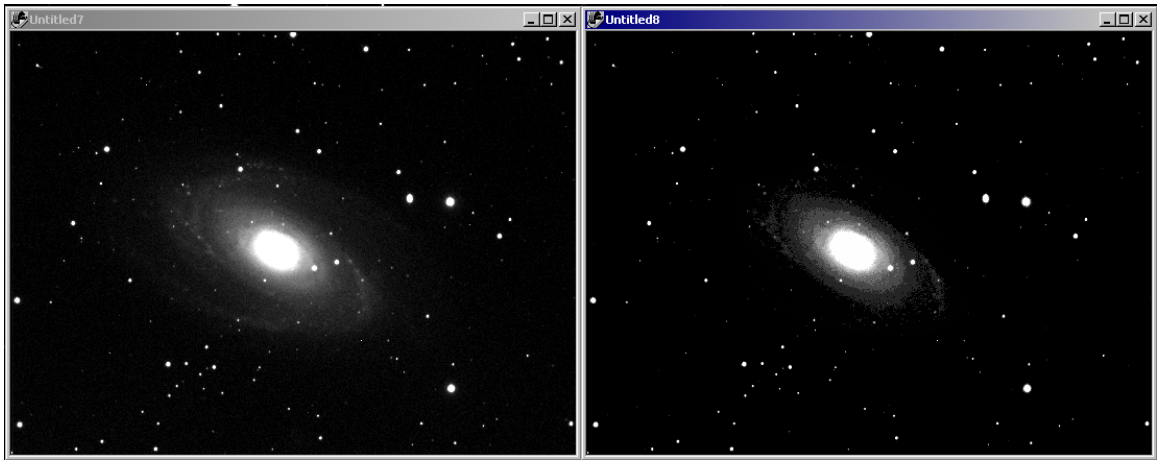


Figure 32: An image of M81 before (left) and after (right) applying the Posterize tool with a setting of 8 brightness levels.

Make any histogram adjustments before you use the Posterize tool, since it converts the portion of the image between the current black point and the white point (i.e., the brightness levels starting at the background, and through the full range).

Kodalith

The Kodalith command (click **Image | Brightness & Contrast | Kodalith**) creates a black and white version of an image at a defined brightness threshold. The brightness range is controlled by the current histogram settings, so make any histogram adjustments before you use the Kodalith tool.

The threshold setting of the Kodalith tool defines the point in the brightness range that divides the image into black and white. For example, in figure 33 the threshold setting is 10%. This means that the dimmest 10% of the brightness values will be converted to black, and the remaining brightness values will be converted to white. Figure 34 shows the result of this threshold setting. A higher threshold setting would convert more pixels to black, and fewer to white. A lower threshold setting would convert fewer pixels to black, and more to white.

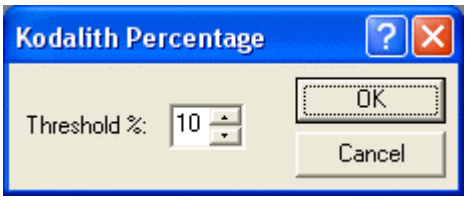


Figure 33: The Kodalith dialog box.

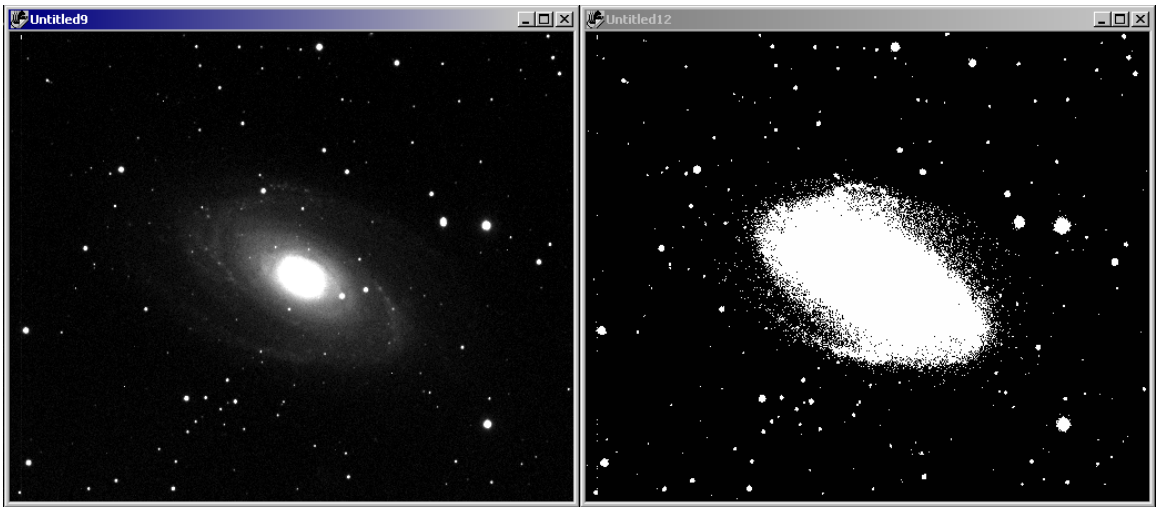


Figure 34: An image of M81 before (left) and after (right) applying the Kodalith tool with a setting of 10%.

Miscellaneous Image Manipulation

Flip Image

You can flip an image either horizontally or vertically. The horizontal flip (click **Image | Flip | Flip Horizontal**) performs a left-to-right flip, through an axis that runs from top to bottom through the center of the image. The vertical flip (click **Image | Flip | Flip Vertical**) performs a top-to-bottom flip, through an axis that runs from left to right through the center of the image.

Resize Images

You can resize an individual image (click **Image | Resize | Resize Image**), or a folder of images (click **Image | Resize | Resize Folder of Images**). Figure 35 shows the dialog box for resizing a single image. If you specify only the width parameter, the height parameter is adjusted automatically to preserve the aspect ratio. However, you can then edit the height parameter if you wish to distort the image.

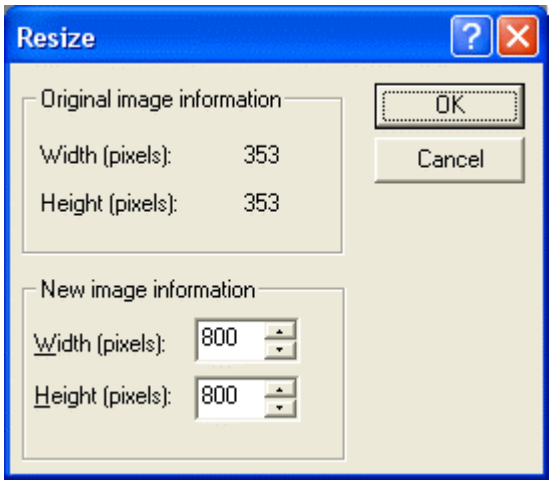


Figure 35: Resizing an image.

When resizing a folder of images, you have the option of automatically maintaining the current aspects ratio – simply check the **Maintain aspect ratio** checkbox, and all changes to either the width or height will automatically affect the other setting. When you have set the width and height, and selected the input and output folders, click **Resize** to start the resize operation.

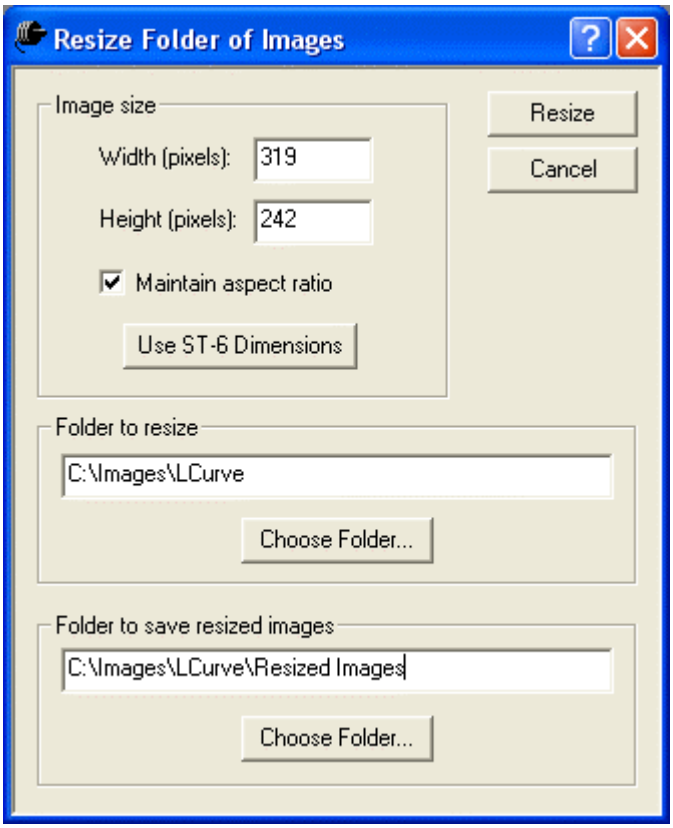


Figure 36: Resizing a folder of images.

NOTE	The pixels of the ST-6 camera are not square. The images must be resized so that the pixels are square. You can use the Resize Folder of Images dialog box to resize images taken with an ST-6 camera. Simply click the **Use ST-6 Dimensions** to fill in the width and height settings that will correct the aspect ratio for this camera (319 x 242).

Sharpen Images

CCDSoft provides four tools for sharpening your images:

- **Sharpen** – Sharpens an image. Only use it with reduced images with good signal to noise ratios. Otherwise, artifacts of the sharpening process will add false details to the image.
- **Sharpen Gentle** – Lightly sharpens an image. It can be used on a wide variety of images.
- **Unsharp Mask** – Uses an averaged version of the image to sharpen the image. It allows you to control the degree of sharpening.
- **Richardson-Lucy Deconvolution** – Uses multiple iterations of a Richardson-Lucy deconvolution filter to enhance the apparent focus of the image. Best when used on images that have an excellent signal-to-noise ratio; otherwise, artifacts of deconvolution can add false details to the image.

Which sharpening method you use depends on the nature of the image you want to sharpen. The better your signal-to-noise ratio (see “Chapter 3: Aligning and Combining Images”), the more options you have to choose from. If an image has poor to average signal to noise, sharpening will bring out not just image details, but some of the noise in the image as well. When your image has a good signal-to-noise ratio, you can sharpen more aggressively without creating artifacts in the image.

Sharpen

Figure 37 shows an image of M51 that has good signal to noise, but poor sharpness due to poor seeing conditions. Atmospheric turbulence has blurred details in the image.

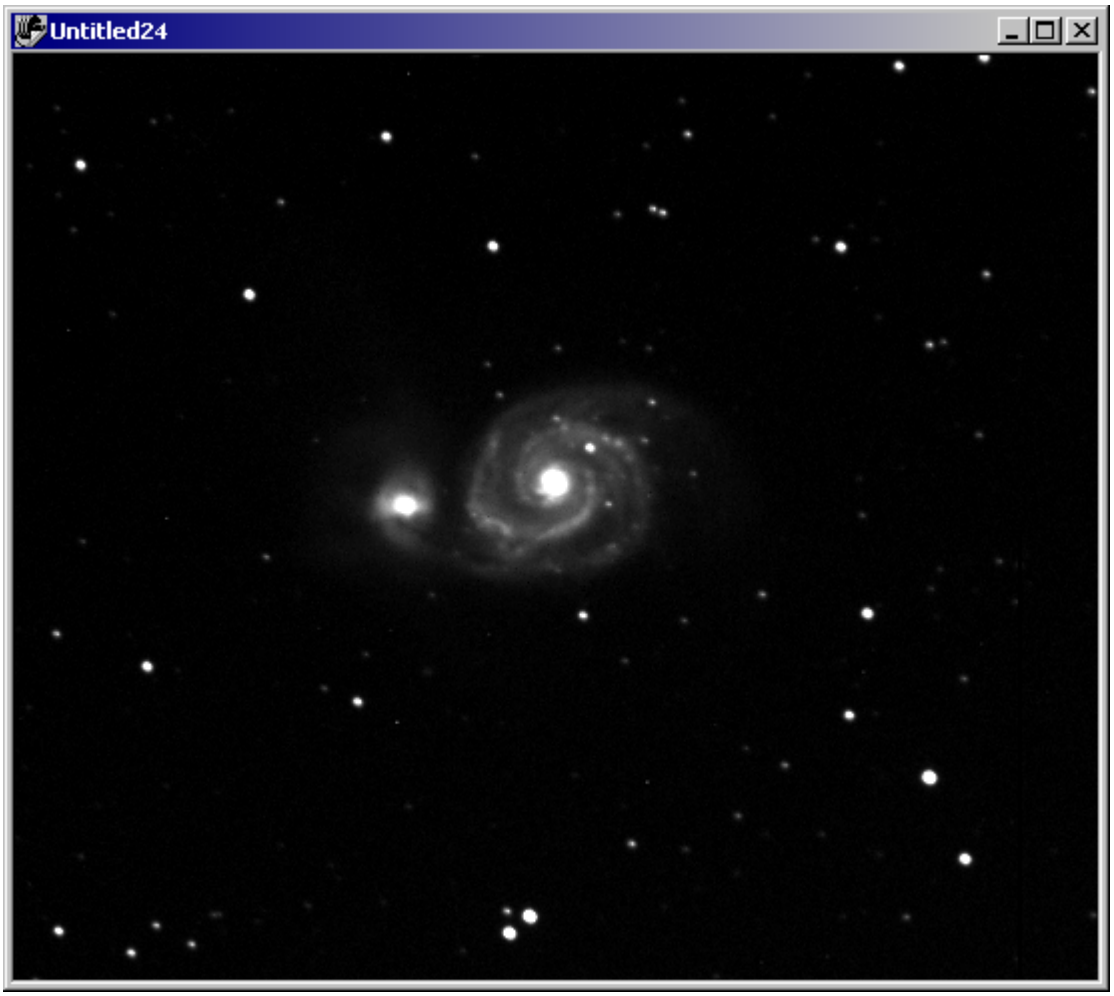


Figure 37: An image of M51 with poor sharpness.

Figure 38 shows the result of applying the Sharpen command to the image of M51 (click **Image | Sharpen | Sharpen**). Sharpening reveals additional detail, but it also introduces graininess. The graininess indicates that the image did not have sufficient signal-to-noise ratio to use the Sharpen command.

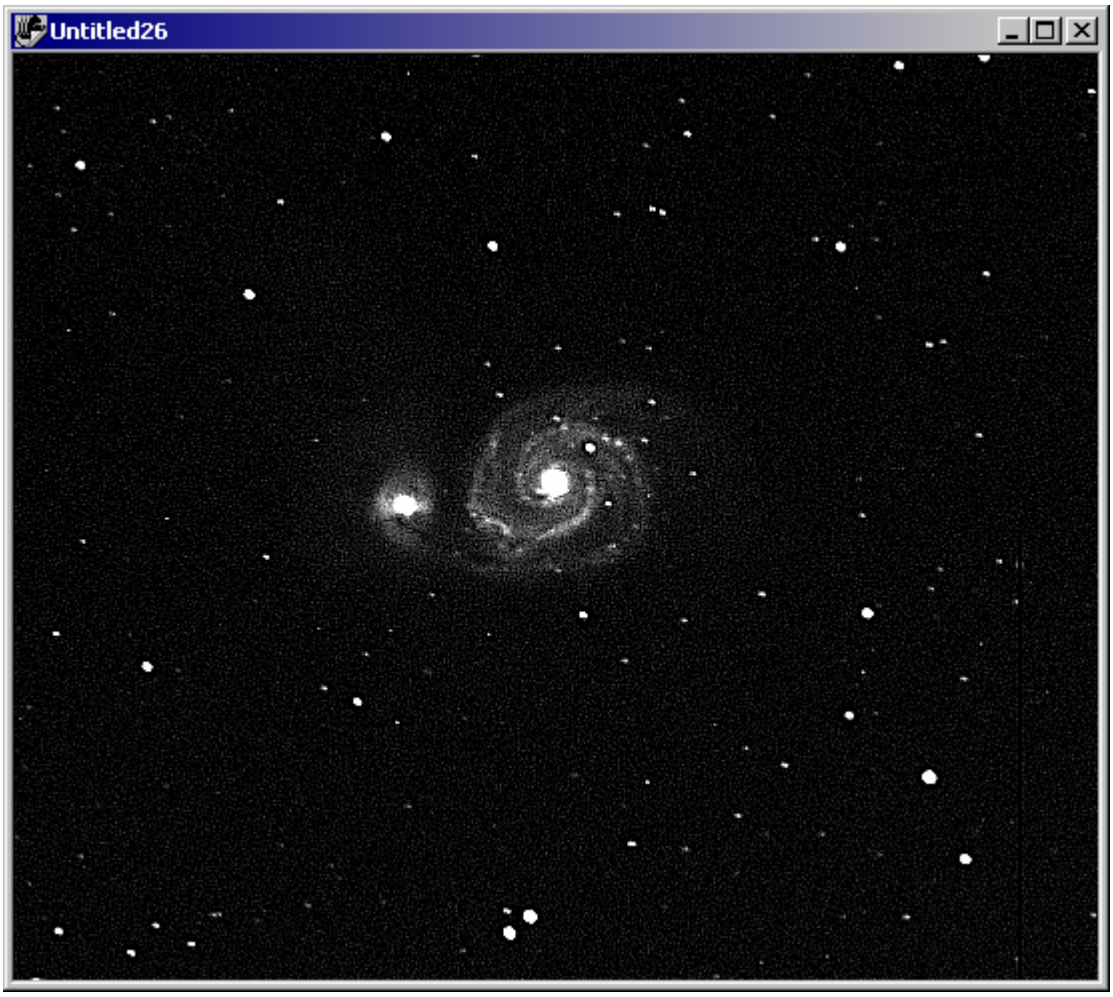


Figure 38: A sharpened version of M51.

Sharpen Gentle

Figure 29 shows the result of applying the Sharpen Gentle command to the image of M51 (click **Image | Sharpen | Sharpen Gentle**). This form of sharpening is more suitable to this image. It increases the level of detail without adding graininess.

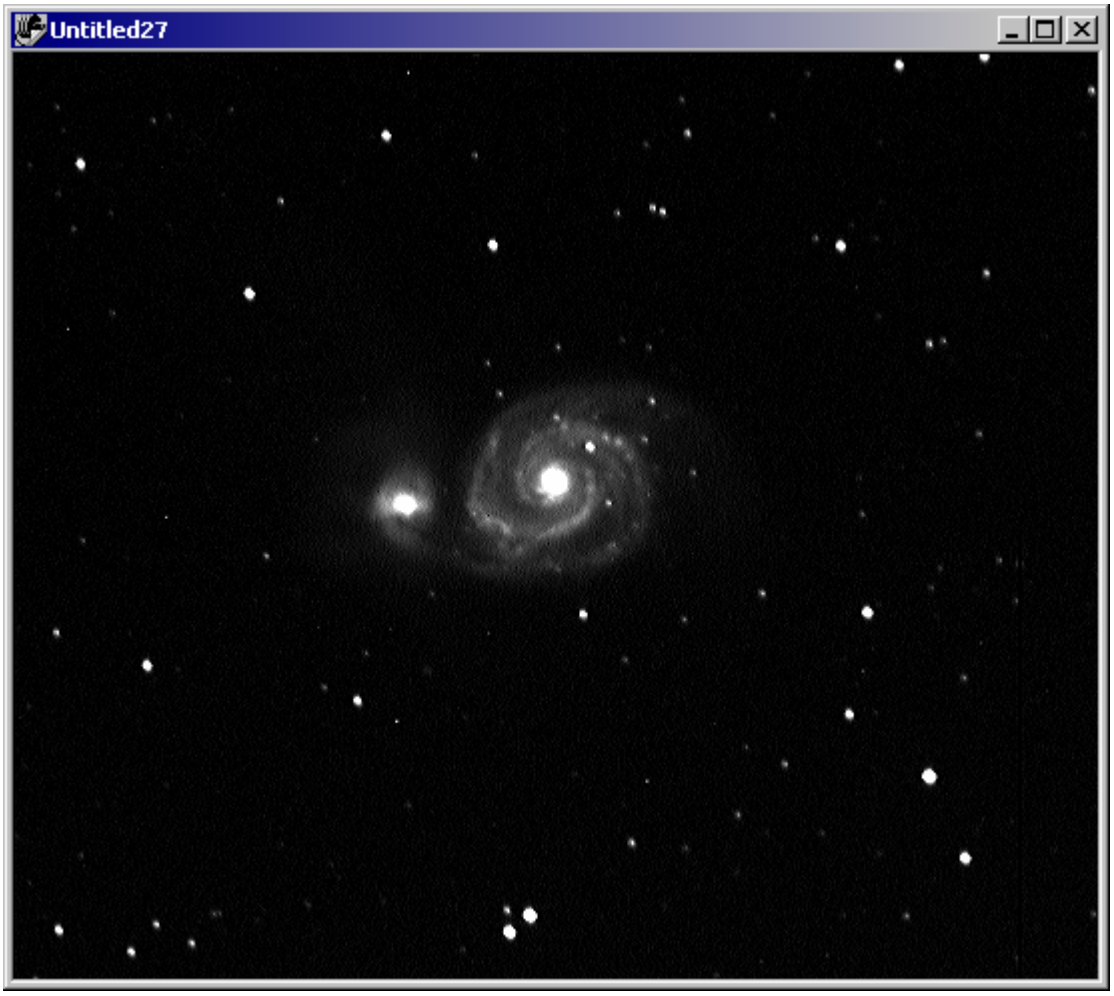


Figure 39: The result of a Sharpen Gentle command.

Unsharp Mask

Unsharp mask lets you control the amount of sharpening. Figure 40 shows the Unsharp Mask dialog box.

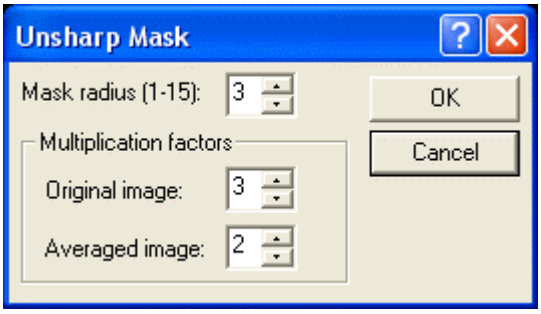


Figure 40: The Unsharp Mask dialog box.

There are three values (parameters) you can adjust to control the result of an unsharp mask:

- **Mask Radius (1-15)** – This is the width of the filter that is used to create the averaged version of the original image (the unsharp mask). This primarily controls the extent and magnitude of the sharpening.
- **Original Image Multiplication Factor** – Controls how much of the original image is used to create the sharpened image.
- **Averaged Image Multiplication Factor** – Controls how much of the averaged (unsharp mask) image is used to create the sharpened image.

Smaller numbers for all three parameters result in less sharpening; larger numbers result in more sharpening. Generally, the better the signal-to-noise ratio of the image, the more sharpening you can use.

Figure 41 shows two examples of Unsharp Mask. The left side of figure 40 shows an unsharp mask using the default parameters (shown in figure 40).

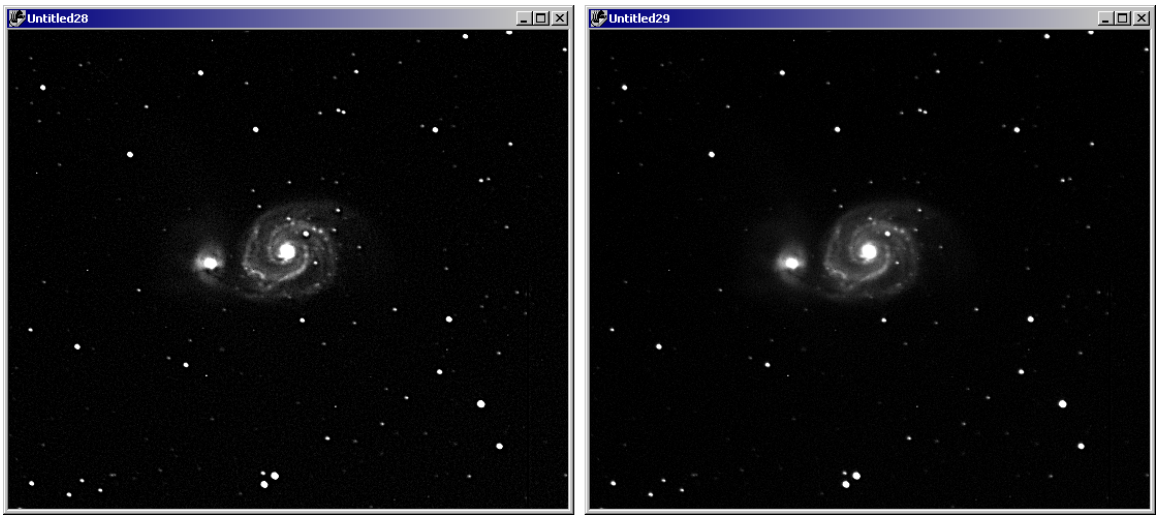


Figure 41: Two examples of unsharp mask. Left: Default parameters. Right: Less sharpening using a mask radius of 2, an original image factor of 2, and an averaged image factor of 1.

Richardson-Lucy Deconvolution

Deconvolution is a powerful and subtle sharpening technique. It uses multiple passes to gradually sharpen an image. This gives you a fine level of control over the amount of sharpening.

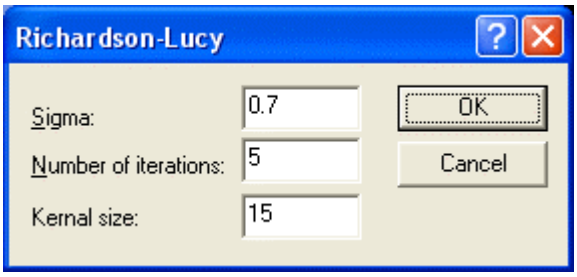


Figure 42: The Richardson-Lucy dialog box.

Richardson-Lucy deconvolution allows you to control three parameters:

- **Sigma (0.0 - 1.0)** - This value corresponds to the harshness of the filter. Use a large sigma value if your image is very blurry. Smaller sigma values can be used for mild sharpening.
- **Number of iterations** - Enter the number of times to apply Richardson-Lucy to the image. Small numbers will result in a mild sharpening; larger numbers sharpen more aggressively.
- **Kernel size** - Enter the size (in pixels) of the area to use for the Richardson-Lucy deconvolution filter.

Richardson-Lucy deconvolution works best on images with excellent signal-to-noise ratios. The better the S/N ratio, the larger the sigma value that you can use for sharpening. Figure 43 shows an example of applying Richardson-Lucy to the image of M51, using the default parameters shown in figure 42.

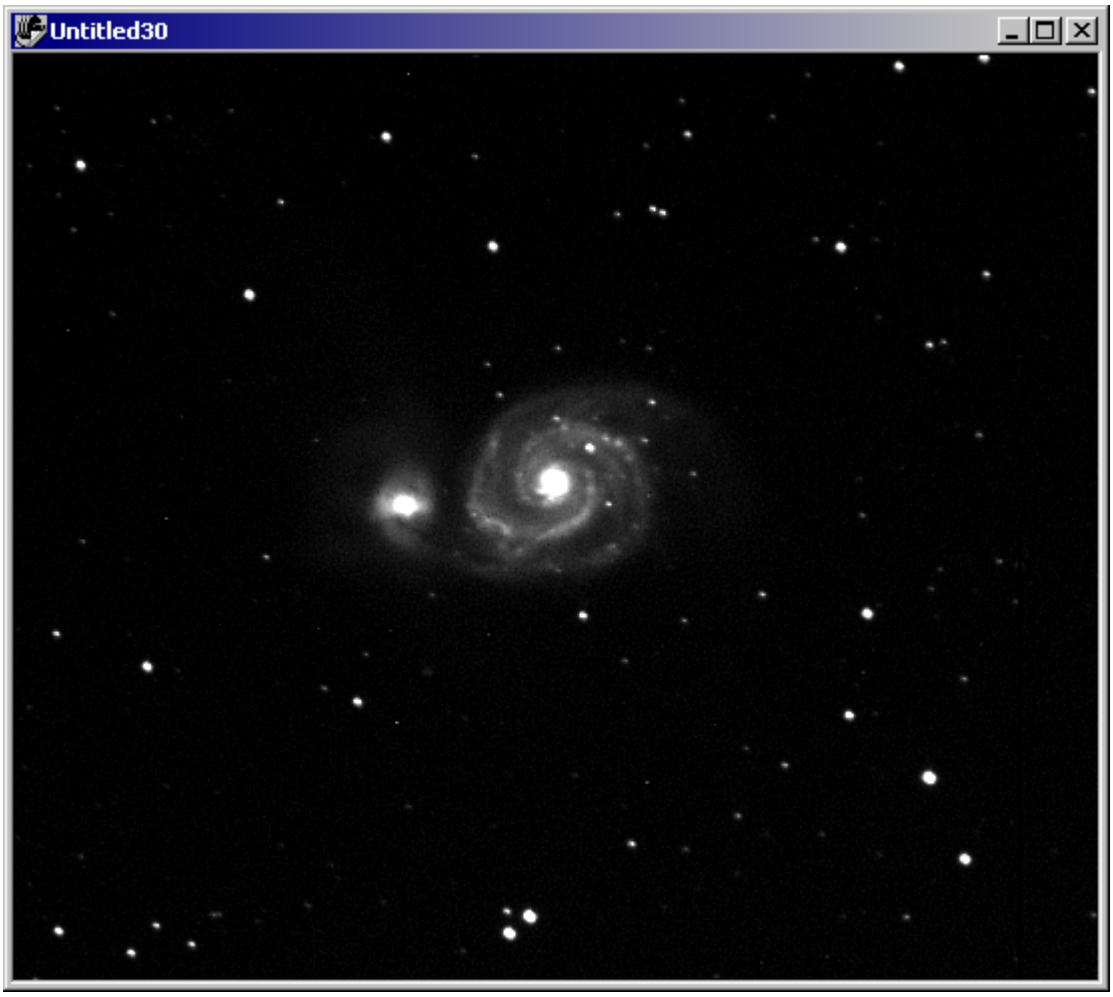


Figure 43: An example of applying Richardson-Lucy deconvolution to the M51 image.

Figure 44 shows what happens when you use too large of a sigma value, or too many iterations of a Richardson-Lucy deconvolution. Stars develop black halos around them, and the details of the image become coarser instead of sharper.

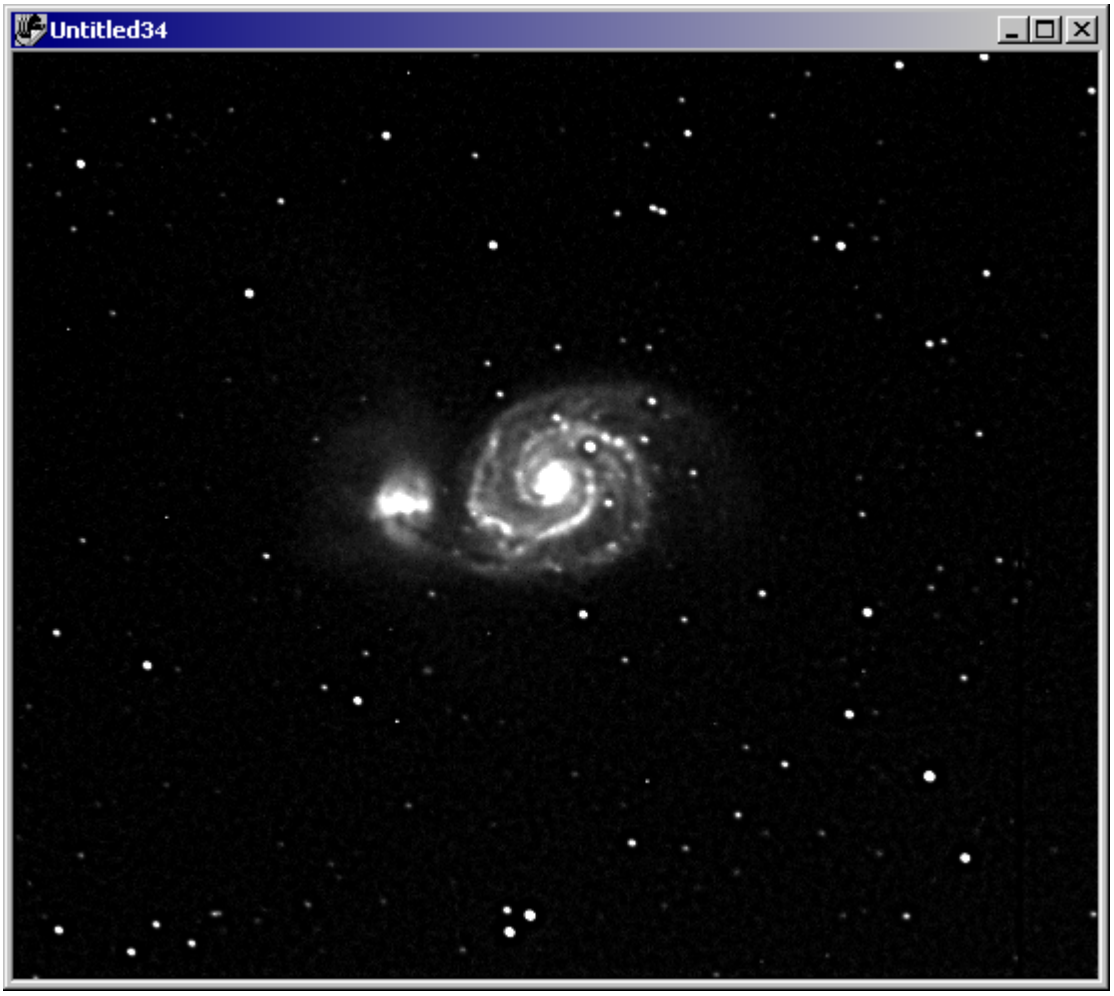


Figure 44: An example of too many iterations, or an overly large sigma value.

Smooth Images

Smoothing filters compensate for noise (graininess) in your images. As with sharpening filters, which smoothing filter you use will vary from one image to the next. CCDSoft includes three smoothing filters:

- Average – Sums the nine pixels centered on a given pixel, and averages them. This filter removes sharp contrast between adjacent pixels.
- Custom Average – Similar to the Average filter, but allows you to select the size of the region that is averaged. A value of 1 is the same as the Average filter. Values up to 15 (severe smoothing) are allowed.
- Blur – Averages the original pixel plus four surrounding pixels. Blur is more gentle than Average because it averages fewer pixels.

Average

Figure 45 shows an image of M51 that displays some graininess. It's a typical candidate for smoothing.

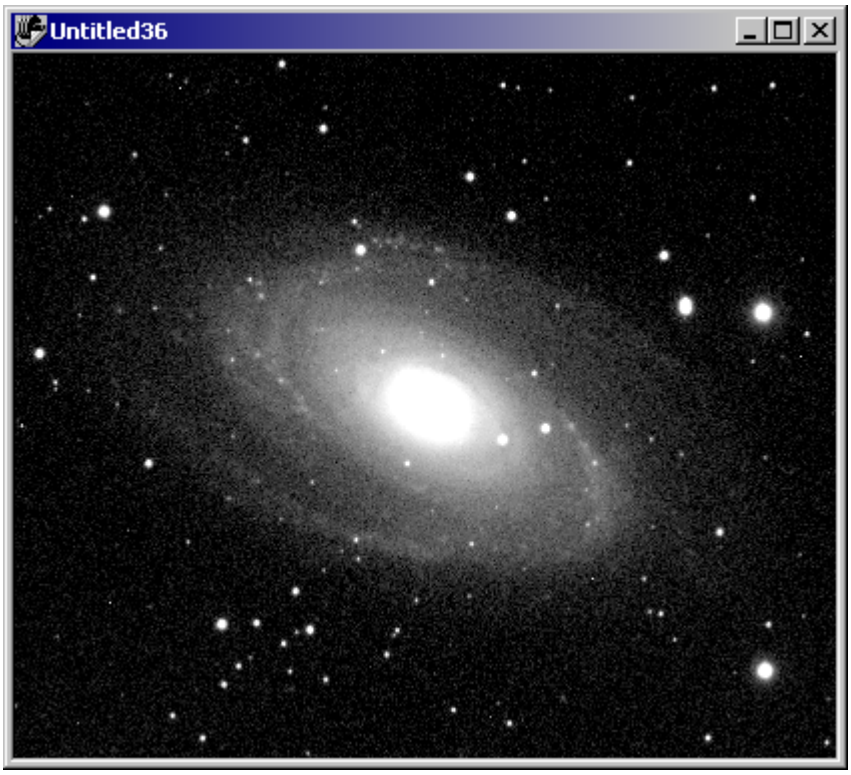


Figure 45: An image of M51 showing graininess (noise).

Figure 46 shows the image with Average applied. The graininess is greatly reduced, but the image is also a little soft. This particular image would benefit from slightly less aggressive smoothing.

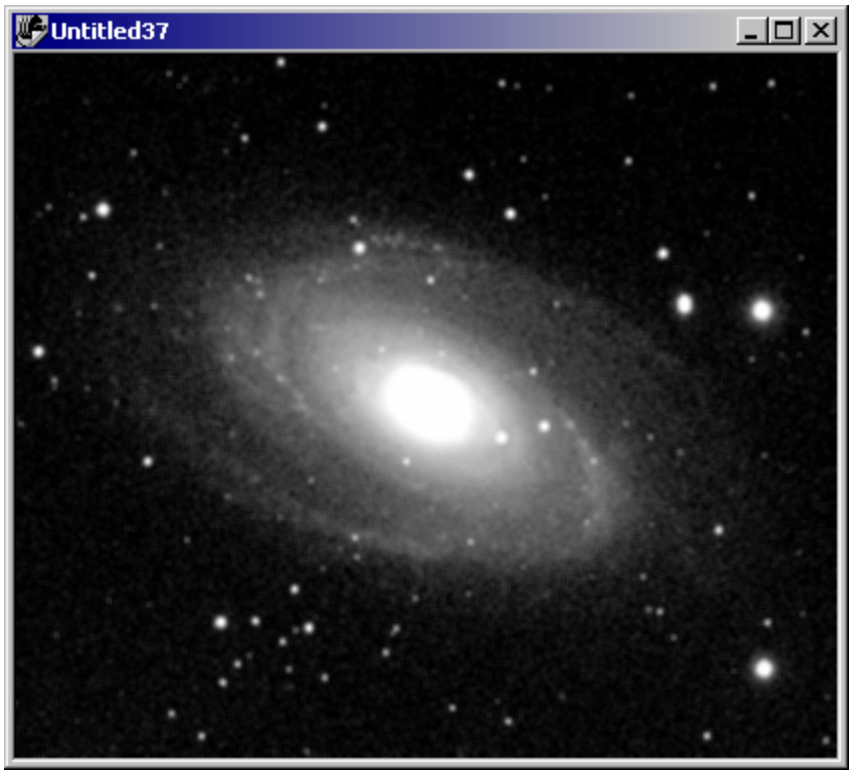


Figure 46: M81 image after applying Average smoothing.

Custom Average

Custom Average is similar to Average, but you can select the radius used (see figure 47). For Average, the radius is one. You can set the radius from one to 15 for Custom Average. Using 1 for the radius gives you a result identical to Average.

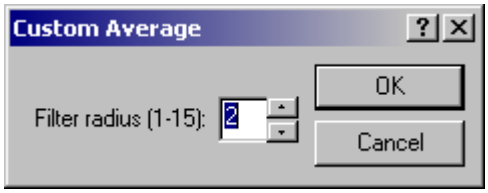


Figure 47: The Custom Average dialog box.

Figure 48 shows the result of applying Custom Average with a radius of 2.



Figure 48: The image of M81 with Custom Average using a radius of 2.

Blur

Blur is the gentlest of the three smoothing commands. Figure 49 shows the result of applying Blur. The smoothing is lighter than for Average, and a small amount of graininess remains visible. However, the image is not greatly softened, so the details in the image remain reasonably clear.

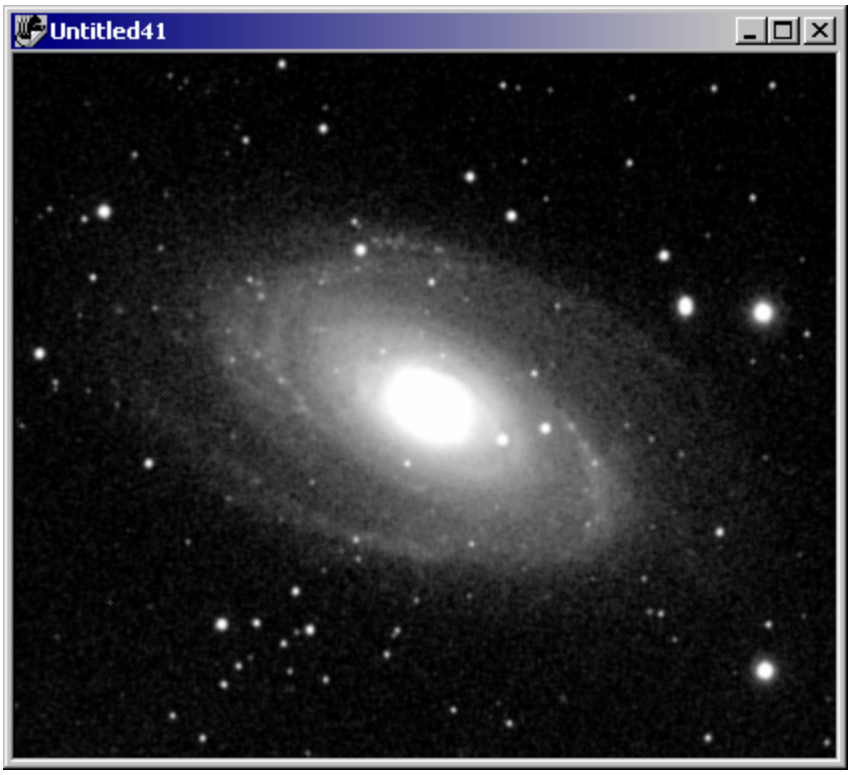


Figure 49: The image of M81 with Blur smoothing applied.

Depending on the graininess of the image and the overall sharpness, the best smoothing command for any given image will vary. Experiment with the various commands to find the one that works best.

Repair Images

CCD detectors are made up of thousands or millions of individual pixels. As described in “Chapter 3: Aligning and Combining Images”, these pixels vary somewhat in their response to photons. Some pixels are hotter than others, while some are colder. In addition, CCD detectors may also have surface defects. The detectors come in a range of classes. The high-quality classes have very few defects, while low-quality classes may have partial or entire rows and columns that are defective. CCDSoft includes tools to remove many of these defects.

The repair tools in CCDSoft include:
Removal of cold pixels – These are pixels that respond less to light. They are darker than they should be in your image.
Removal of hot pixels – These are pixels that respond more aggressively to light. They are brighter than they should be in your image.
Repair columns – These are full or partial columns of pixels that are similar to hot and cold pixels – they respond inappropriately to light. They show up as bright or dark lines in an image.
Show dark pixels – This command produces a monochrome image that displays the dark areas of the image as white, and remaining areas as black. This is useful when selecting a reference star for photometric calculations. A “good” reference star for photometry has a dark background.

Remove Cold Pixels

To remove cold pixels, click **Image | Repair | Remove Cold Pixels**. This opens the dialog box shown in figure 50. Select **Strong**, **Medium**, or **Soft** to determine how aggressively the tool will remove cold pixels. Click **OK**. CCDSoft will then report the number of cold pixels removed.



Figure 50: Removing cold pixels.

Figure 51 shows the result of removing cold pixels from an image of M51. The histogram of the image has been adjusted to show background pixels.

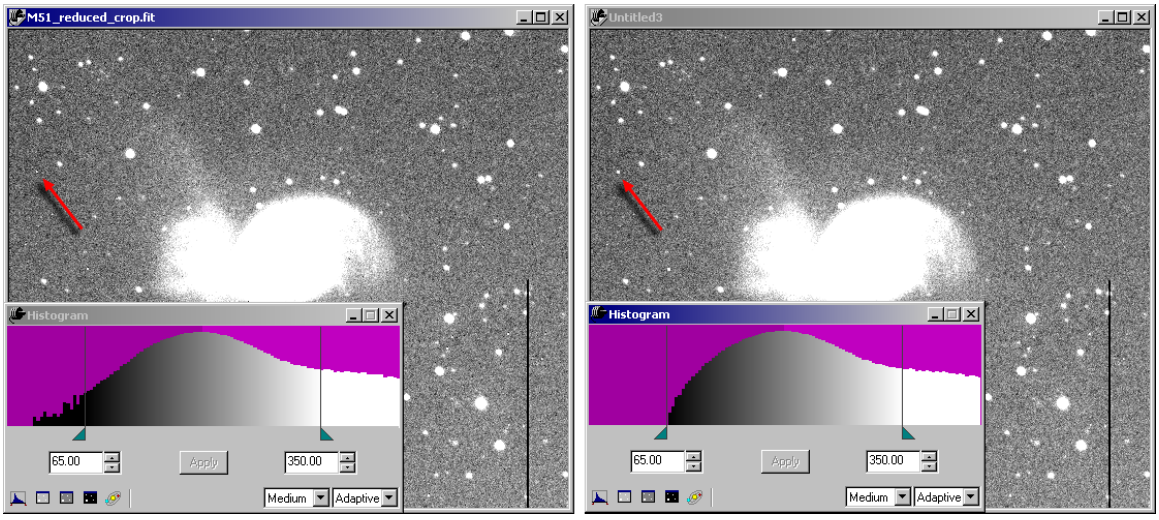


Figure 51: The original image is on the left. The right image has had its cold pixels removed, and its histogram has been adjusted.

There are several things to note about the before (left) and after images:

- Hot pixels (see arrow) can increase in size if the Remove Cold Pixels setting is too aggressive.
- Clusters of cold pixels will be partially but not completely repaired. This tool is optimized to find isolated cold pixels. If it were to repair clusters, it would also remove dark image details. Cold clusters are usually the result of cosmic ray hits on a dark frame, and you can control them by applying multiple dark frames during image reduction.
- The left part of the histogram shows what happens during cold pixel removal. Note that the dimmest pixels in the before image (the left edge of the histogram for the before image) are completely gone in the after image. The histogram for the after image curves down cleanly.
- Removal of cold pixels reduces overall grain in the dimmest areas of the image.

Remove Hot Pixels

To remove hot pixels, click **Image | Repair | Remove Hot Pixels**. This opens the Remove Hot Pixels dialog box. Select **Strong**, **Medium**, or **Soft** to determine how aggressively the tool will remove hot pixels. Click **OK**. CCDSoft will then report the number of hot pixels removed.

Figure 52 shows a before (left) and after set of images. The arrow points to a group of hot pixels in the before image. This is the same group that was increased in brightness by too-aggressive cold pixel removal. Hot pixel removal, on the other hand, reduces the size and brightness of this cluster of hot pixels. Individual hot pixels are also removed cleanly.

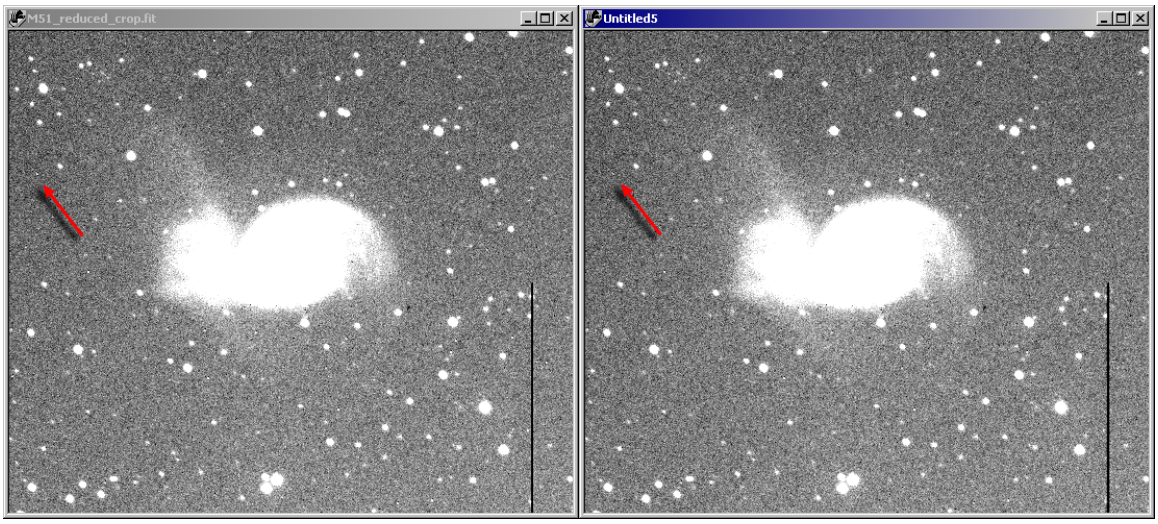


Figure 52: Removing hot pixels. Left: Original image. Right: After removing hot pixels.

Figure 53 shows a close-up of the effect of the Remove Hot Pixels command on a cluster of hot pixels. Remove Hot Pixels is more effective at cleaning up clusters than Remove Cold Pixels.

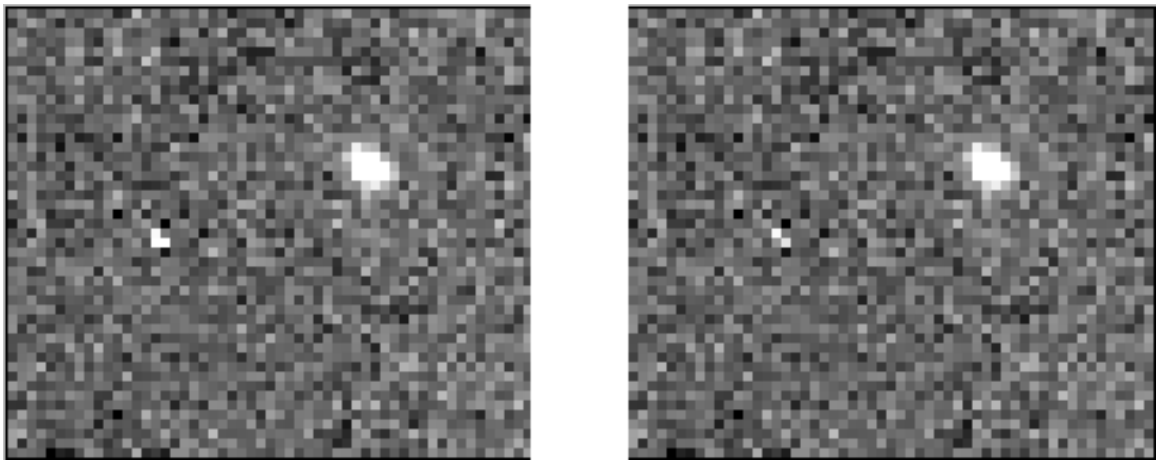


Figure 53: The left image shows a cluster of hot pixels; the right image shows the result of removing hot pixels with a Strong setting.

The Remove Hot Pixels command is also good for removing hot pixels when a dark frame is not available for image reduction. Figure 54 shows a before and after set of images. The image on the left is a raw image of the Owl Nebula, showing a large number of hot pixels. The image on the right shows how the hot pixels are removed with a Medium application of Remove Hot Pixels.

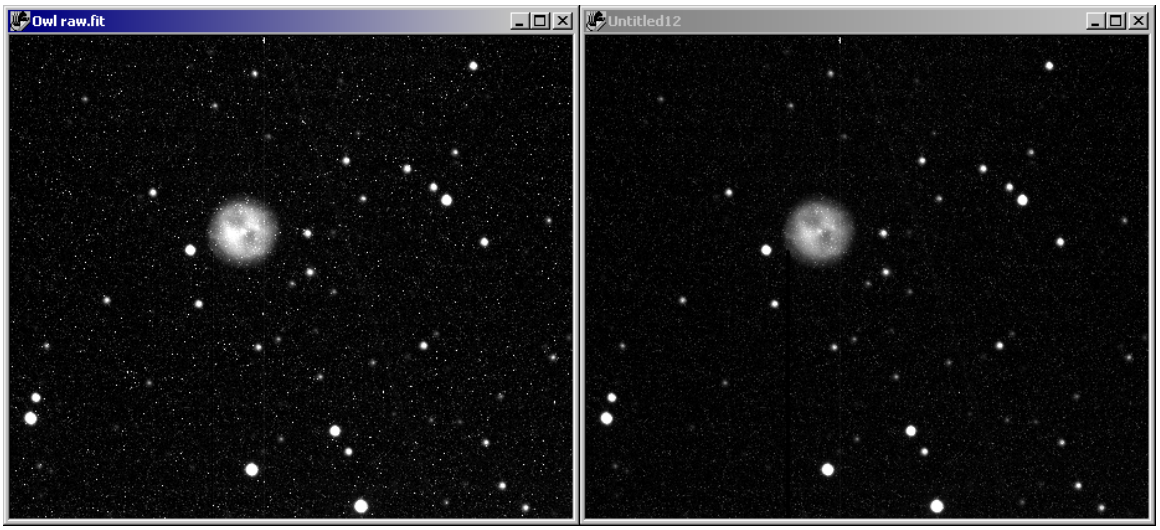


Figure 54: Remove Hot Pixels command is able to remove hot pixels when a dark frame is not available for image reduction.

Repair Column

Some CCD detectors have column defects. These are whole or partial columns of pixels that doesn't respond appropriately to light. The left image in figure 55 shows one example of such a column. In this

example, it is a partial column of completely dead pixels, which leaves a black line in the image. The background and range (histogram) have been adjusted to show the column very clearly.

To repair a column, you must first identify the column number. The status bar of the left-most image in figure 55 shows the column number when you pass the mouse over the image. In this case, the value of 00000 makes it clear when the cursor is over the dead column (501).

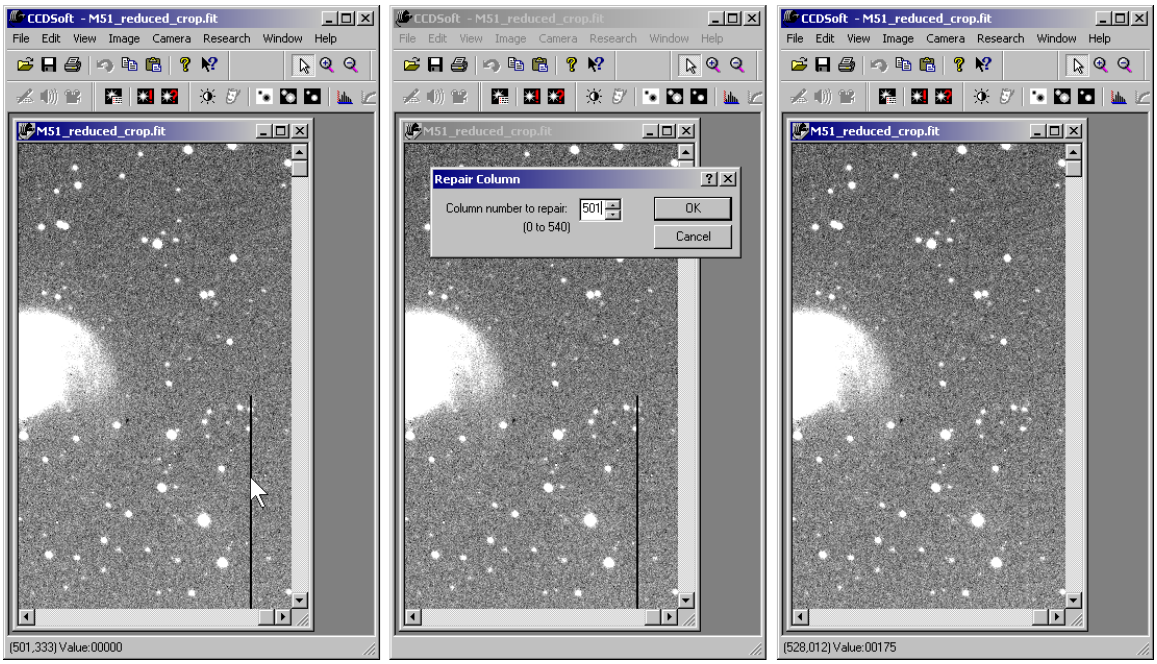


Figure 55: Repairing a bad column. Left: Identify the bad column. Center: Enter the number of the bad column. Right: The result of fixing the bad column.

Once you know the column number, click **Image | Repair | Repair Column** to open the Repair Column dialog box (center image in figure 55). Enter the column number and click OK. CCDSoft averages data from the adjoining columns to repair the bad column (right image in figure 55).

Show Dark Pixels

To show the darkest pixels in an image, click **Image | Repair | Show Dark Pixels**. The darkest pixels in the image are converted to white, and all medium to bright pixels show up as dark (see figure 56). This allows you to visualize the dark pixels clearly, and is especially useful for selecting a reference star for photometric calculations. A “good” reference star for photometry has a dark background. See “Chapter 8: Research: Astrometry and Photometry” for more information about photometry.

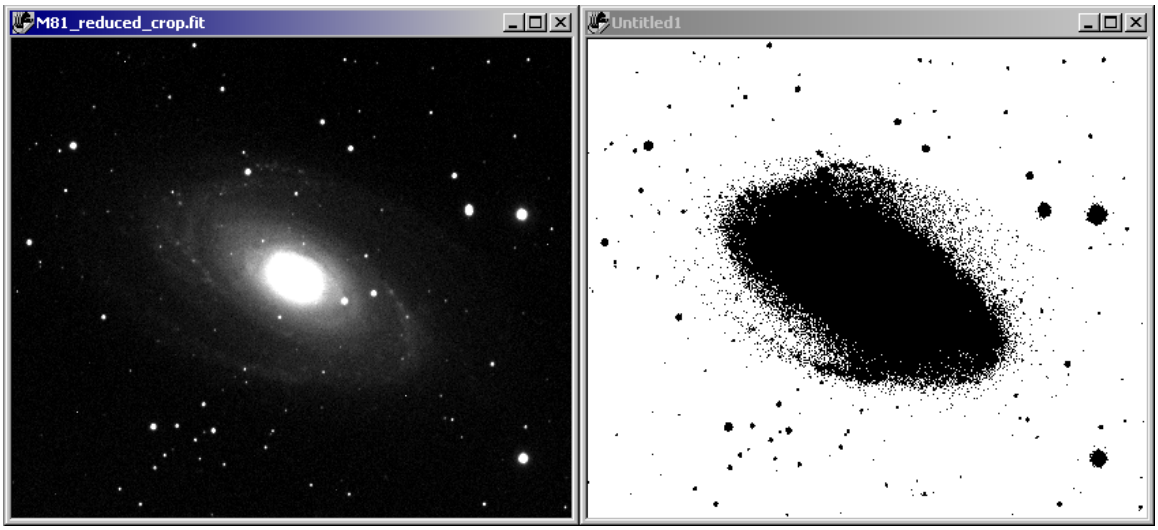


Figure 56: The result of Show Dark Pixels command.

Special Effects

CCDSoft includes four special effects that you can apply to your images:

- **Negative** – Turns the image into a negative. Useful for visualizing faint features and details in an image, especially galaxies and nebulae.
- **Outline** – Emphasizes the outlines in an image.
- **Pixelize** – Averages the pixel brightness values over a specified region. The larger the region, the lower the resolution of the new image.
- **Custom Filter** – Applies a filter you have designed to the image.

Negative

To invert an image, click **Image | Special Effects | Negative**. Figure 57 shows the result of making a negative image of some galaxies. A negative image will often show faint details more effectively than a positive image. The red arrows in the negative image point to faint galaxies that are nearly invisible in the original positive image. A number of faint stars are also visible in the negative image, but not in the positive original.

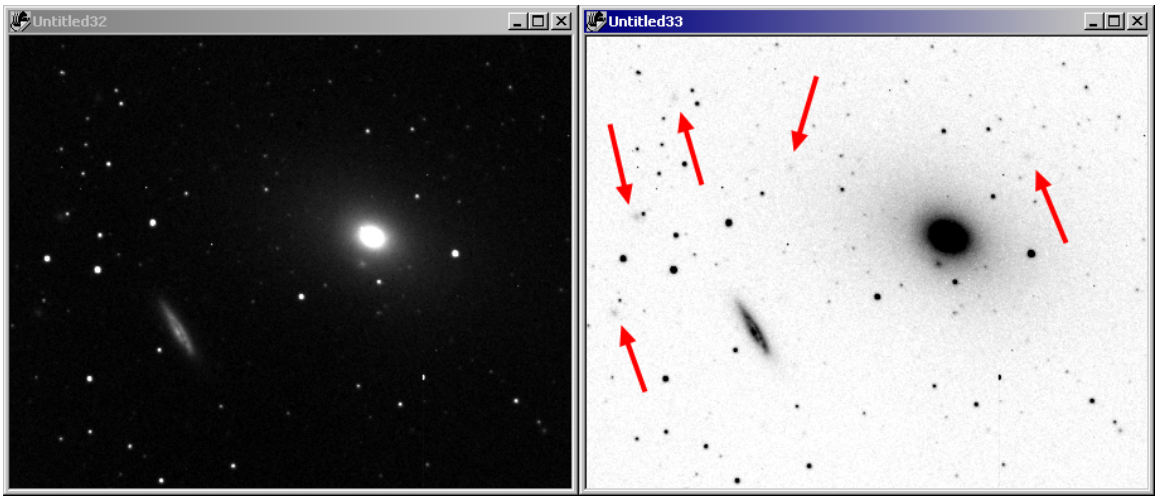


Figure 57: The result of creating a negative version of an image.

Outline

To outline the objects in an image, click **Image | Special Effects | Outline**. Figure 58 shows the result of applying the Outline command to the galaxy image at the left of figure 57.

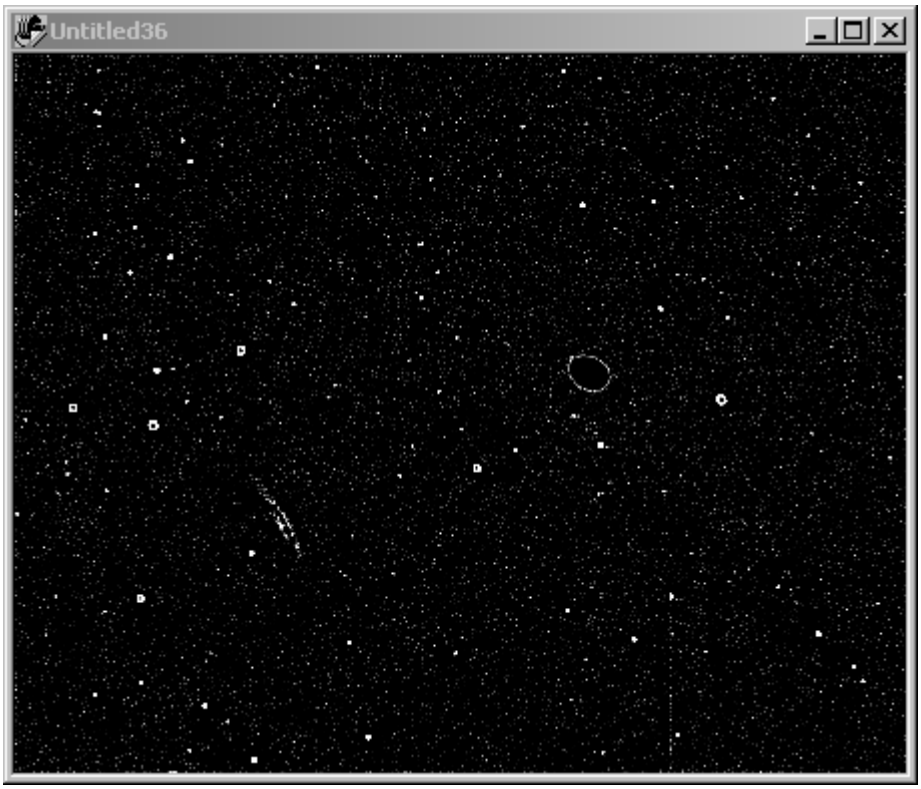


Figure 58: The result of the Outline command.

Pixelize

To pixelize an image, click **Image | Special Effects | Pixelize**. Figure 59 shows the Pixelize dialog box. Select the size of the region to use for pixelizing.



Figure 59 The Pixelize dialog box.

Figure 60 shows an original image of M81 (left), a pixelized image with a region of 2 (center), and a pixelized image with a region of 4 (right).

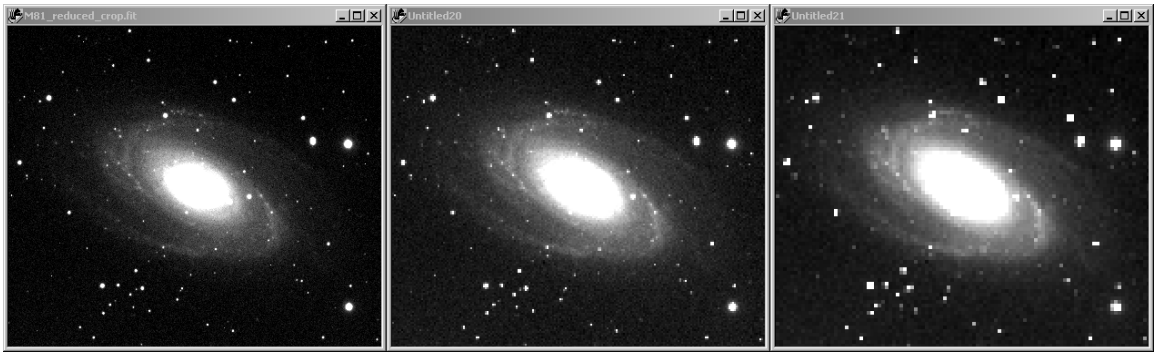


Figure 60: Pixelizing an image of M81.

Custom Filter

Use the Custom Filter command to create your own 5x5 convolution filter. The input values for the 5x5 matrix, called a “kernel,” can range from zero to 99.

When performing a convolution for each pixel in the original image, a new pixel value is computed by multiplying every kernel value of the filter with a corresponding source pixel value, summing these values, then dividing the total by the input divisor.

For even a relatively small image, this translates into thousands of computations. Depending on the speed of your computer, a filter may take a long time to complete.

To perform custom filtering, open the Custom Filter dialog box by clicking **Image | Special Effects | Custom Filter**:

1. Select the image you wish to modify.

2. Input the filter values for the 5x5 kernel. Values can range from -99 to 99 and the divisor value can range from 1 to 99.
3. Click **OK**.

If you wish to preserve the contrast of your original image when applying a custom filter, be sure that the sum of the filter kernel is one. The sum of the filter determines how the filter affects the brightness of your image. If the sum of each of the kernel elements, divided by the Divisor input value, is one, the brightness of the resulting image is the same as that of the original image. A kernel sum of 2 doubles the brightness of the resulting image.

Figure 61 shows one type of smoothing filter. The central box has a value of 2, and the pixels surrounding it have a value of 1. The sum of these values is 10, and that is the number entered as the divisor. Figure 62 shows the result of applying this filter. The left image is the original; the right image shows the smoothing effect of the filter.

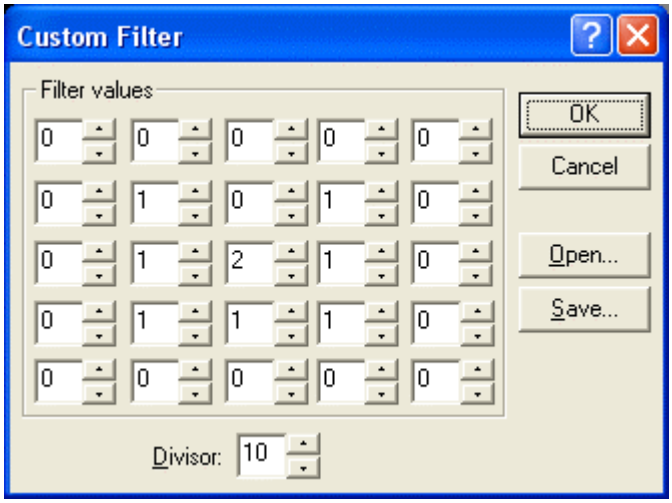


Figure 61: A custom smoothing filter.

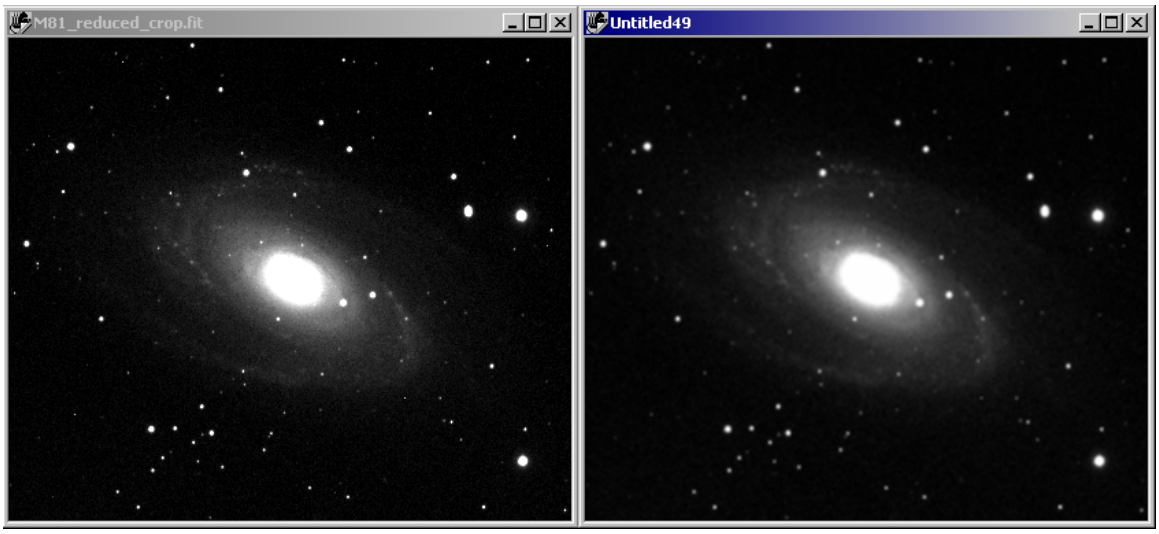


Figure 62: Before (left) and after applying the custom smoothing filter.

Figure 63 shows one type of sharpening filter. The central box has a value of 10, and the surrounding boxes have a value of -1. The sum of these values is 2, and the divisor is 2, so the net brightness of the resulting image will not change. Figure 64 shows the result of applying the sharpening filter. The original is on the left; the result is on the right.

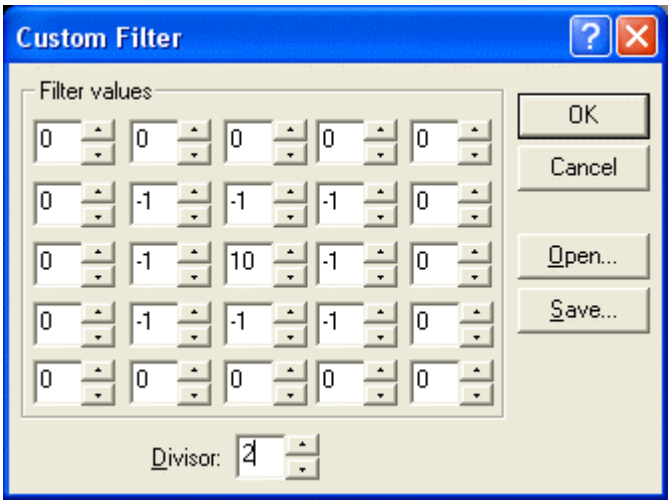


Figure 63: A custom sharpening filter.

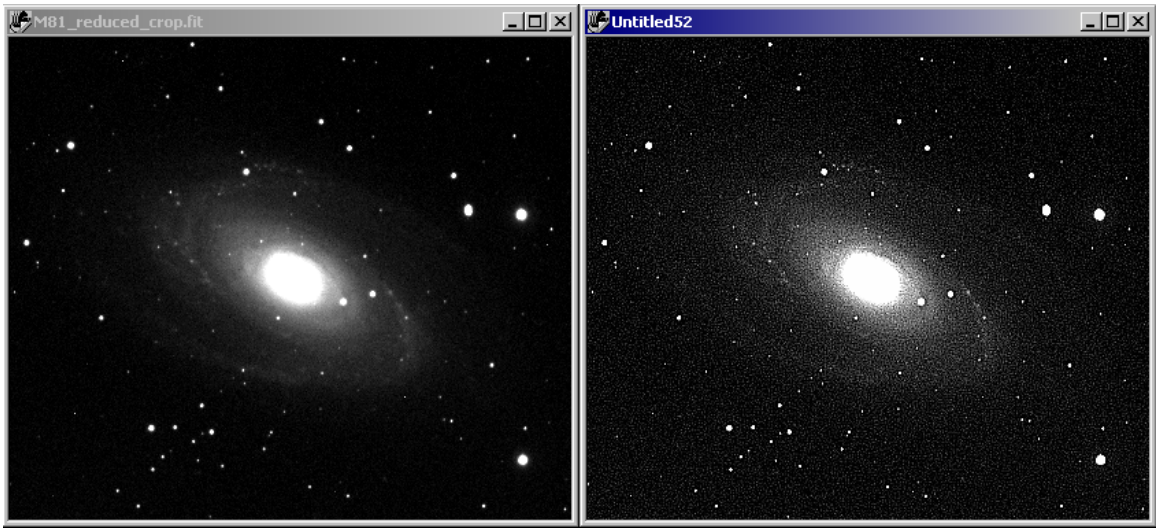


Figure 64: Before (left) and after applying the custom sharpening filter.

Chapter 10: Color Combining

You can combine separate red, green, and blue images into RGB color images with CCDSoft. You can also create LRGB images by including a luminance image during the color combination. For complete information about the theory behind color combining, and instructions on how to take the component images, please see “Chapter 6: Taking Color Exposures.” For information about using and setting histograms, which are often used in color combining, please see “Chapter 9: Image Processing.”

In this chapter, you’ll learn how to combine component images into color images. You’ll need a color filter wheel attached to your camera to take the component images. If you don’t have a color filter wheel, sample color images for practice are included on the CCDSoft CD-ROM.

NOTE	If your images are not already aligned, copy them to a folder and align them automatically with the **Image | Align | Align Folder of Images** command (or press `Ctrl+Shift+A`). See “Chapter 3: Aligning and Combining Images” for more information about aligning a folder of images. You can also align images manually during a combine using the **Shift**, **Align Centroid**, and **Rotate** tools. Planetary images and other images with no or few stars are the most likely to require manual alignment. Information on using these tools can also be found in “Chapter 3: Aligning and Combining Images”.

Figure 1 shows an image of M16, the Eagle Nebula. The component images were taken with CCDSoft’s Camera Control panel, using the **Color** tab. The images were combined with the Color Combine dialog box.



Figure 1: An image of M16 taken with and combined in CCDSoft.

There are two basic types of color combine: RBG and LRGB. An RGB combine includes three images: red, green, and blue. These three images combine to form a full-color image, as explained in "Chapter 3: Aligning and Combining Images." An LRGB combine also includes a luminance image, which is an image taken either without a filter or using a clear filter. To speed the color imaging process, you may take the RGB images binned 2x2, while the luminance is binned 1x1. Luminance is the dominant factor when the eye perceives detail. However, for maximum detail, you can take the color exposures binned 1x1. If the component images are different sizes because of different bin modes, CCDSoft will automatically resize them for you.

Quick Start for Experienced Users

For this chapter, an experienced user is someone who has used camera control software to combine red, green, and blue (or luminance, red, green, and blue) images to create color images.

Note: If your images are not already aligned, you must align them before combining. Copy them to a folder and align them automatically by clicking **Image | Align | Align Folder of Images** (or press `Ctrl+Shift+A`). See "Chapter 3: Aligning and Combining Images" for more information.

To combine RGB images:

1. Open the red, green, and blue filtered images.
2. Click **Image | Color | Combine Color** to open the Color Combine dialog box.
3. If CCDSoft doesn't automatically select the red, green, and blue images, use the drop-down lists in the Images section of the Color Combine dialog box to select the appropriate images.
4. Click **Show Preview** to view a preview of the color combine. You can move, scroll, zoom, and resize the Preview window as needed while you work.
5. Adjust the ratio sliders in the **Mixing Options** section to get balanced, accurate color.
6. If necessary, adjust the histograms (black and white points) for the images. Try the **Normalize Backgrounds** button first. It will adjust the black points of the three images to give you a dark background. Then, if needed, adjust the white points: click on the **Red/Green/Blue** buttons to open the Histogram tool and show the component image.
7. If you adjust one white point, you will probably need to adjust the others as well to get your color balance back.
8. Keep an eye on the Preview window to see what your final image will look like. You can enlarge it, scroll it, or move it as needed. The larger the Preview window, the longer it will take to update changes.
9. When you have the image the way you want it, create the full-color final image by clicking **Combine**.
10. The Color Combine dialog box doesn't close automatically; you can make several versions if you wish by clicking the Combine button after you make changes.

To combine LRGB images:

1. Open the red, green, blue and luminance images.
2. Click **Image | Color | Combine Color** to open the Color Combine dialog box.
3. If CCDSoft doesn't automatically select the red, green, blue and luminance images, use the drop-down lists in the Images section of the Color Combine dialog box to select the appropriate images.

4. Click **Show Preview** to view a preview of the color combine. You can move, scroll, zoom, and resize the Preview window as needed while you work.
5. Adjust the ratio sliders in the **Mixing Options** section to get balanced, accurate color.
6. Adjust the transparency slider to get the appropriate amount of luminance in the Preview window
7. Click **Normalize Backgrounds** button to normalize the backgrounds of the color images. This will adjust the black points of the three images to give you a dark background. You shouldn't need to adjust the white points of the color images for an LRGB combine.
8. Click **Luminance** in the **Histogram Editor** section to open the Histogram tool and show the luminance image.
9. Move images around if necessary so you can see the Preview window and the luminance image.
10. Adjust the histogram of the luminance image as needed. You can also use other tools, such as Mid-range Brighten and Tune Brightness & Contrast, to make non-linear changes to the histogram.
11. Keep an eye on the Preview window to see what your final image will look like. You can enlarge it, scroll it, or move it as needed. The larger the Preview window, the longer it will take to update changes.
12. When you have the image the way you want it, create the full-color final image by clicking **Combine**.
13. The Color Combine dialog box doesn't close automatically; you can make several versions if you wish by clicking the Combine button after you make changes.

The Color Combine Dialog Box

To combine an aligned set of component images into a full-color image, open the images in CCDSoft and click **Image | Color | Combine Color**. This opens the Color Combine dialog box, shown in figure 2.

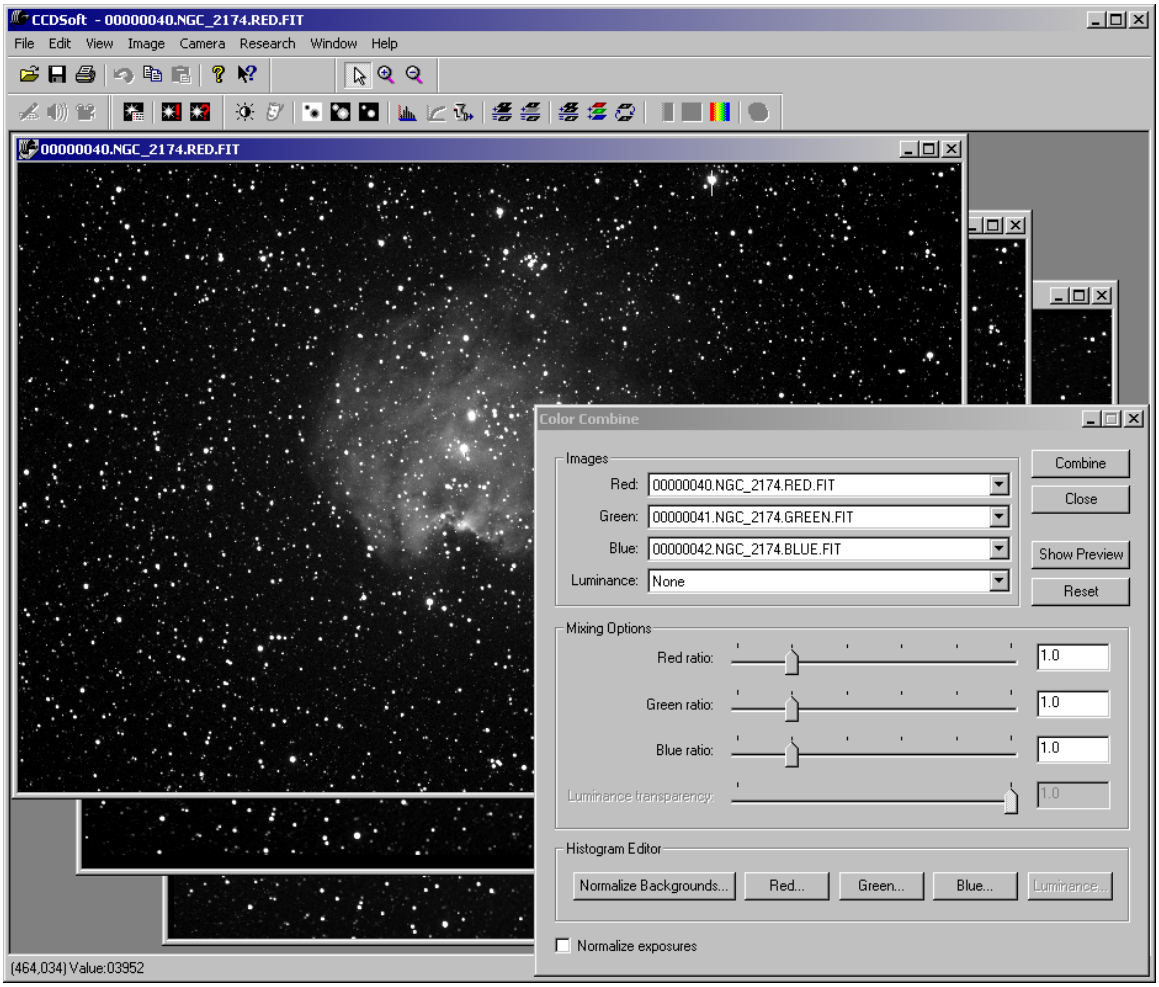


Figure 2: The Color Combine dialog box in action.

The Color Combine dialog box includes the following tools and features:

Item	Description
Red, Green, and Blue drop-down lists	Select the component images from the list of available images. You must have images open in order to see images in the drop-down lists. You may leave any of these set to **None** if desired, but if you do the color in the final image will not be accurate.
Luminance drop-down list	Select the luminance image from the list of available images. You must have images open in order to see images in the drop-down list. You may leave the luminance image set to **None** if you are creating an RGB combine using only red, green, and blue component images.
Combine	Click this button to create the final color image. The Color Combine window stays open, so you can create more than one color version.
Close	Closes the Color Combine window.
Show Preview	Opens a preview window. All changes you make to the component

	images affect the preview. The preview window opens by default at a small size so that it will update quickly as you make changes to the component images. If you have a fast computer, or if you want to see more of the color preview, you can enlarge the preview window as needed. If a component image covers the preview, rearrange the location of the component images so the preview remains visible (see figure 11 for an example). You can use almost any tool or command in CCDSoft on the component images. However, when making changes during an RGB combine (no luminance image), the more changes you make to the component images, the more difficult it will be to maintain a true color balance. You can move, scroll, zoom, and resize the Preview window as needed while you work.
Reset	Resets the controls in the **Mixing Options** section of the Color Combine dialog box.
Red, green, and blue ratio sliders	Sets the ratio of the red, green, and blue component images. By default, the ratios are set to 1.0 so that each color is equally represented in the final combined image. If your exposures match the recommendations of the filter wheel manufacturer, you can leave these sliders at or very close to the default value. For example, the SBIG CFW-8 filter wheel exposure ratio is 1:1:1.6. Balanced exposures would be 60:60:96 seconds for red, green, and blue. If you have exposures that are longer or shorter than the recommended values, you can use the sliders to adjust the amount of color used. This allows you to achieve balanced color even when the component images themselves are not accurately balanced.
Luminance ratio	Determines how much of the luminance exposure is included in the final full-color image. The default value is 1.00, or 100% of the luminance values. If the combined image in the preview window appears over-exposed, you can reduce this value. Alternatively, you can adjust the luminance histogram to achieve the same result.
Normalize Backgrounds	Clicking this button sets the background levels (black point in the histogram) using the **Strong** option of the Histogram tool. This sets the background to nearly black, and is usually the best option for creating a dark background in your color images. Other settings may leave a glow in the background. This glow can reveal slight variations in the background color and reduce the overall appearance of the full-color image. See “Chapter 9: Image Processing” for details on histogram adjustments.
Red, Green, Blue, and Luminance buttons	These buttons bring the appropriate Red, Green, Blue, or Luminance image to the front, and open the Histogram window for that image. You can then adjust the histogram of the image. Changing the black point will affect the brightness of the background. Changing the white point will change the amount of color or luminance detail that shows up in the final full-color image. Adjusting the histogram is an alternative to using the ratio sliders. Unlike the ratio sliders, adjusting the white point can hide or reveal details in the image.
Normalize exposures	Adjusts the exposures of the blue and green images so they match the red exposure time. For example, if the red exposure is 60 seconds, the green exposure is 90 seconds, and the blue exposure is 120 seconds, checking this checkbox will scale the blue and green images so they act as if they are also 60-second exposures.

Combining Color Images: RGB

An RGB color combine requires an aligned set of red, green, and blue images. Open the images first, then open the Color Combine dialog box, and select the images manually if they are not selected automatically. To see how the images will combine, click **Show Preview**. Figure 3 shows the appearance of the Preview window. The size and location of the Preview window and the Color Combine dialog box may be different on your system.

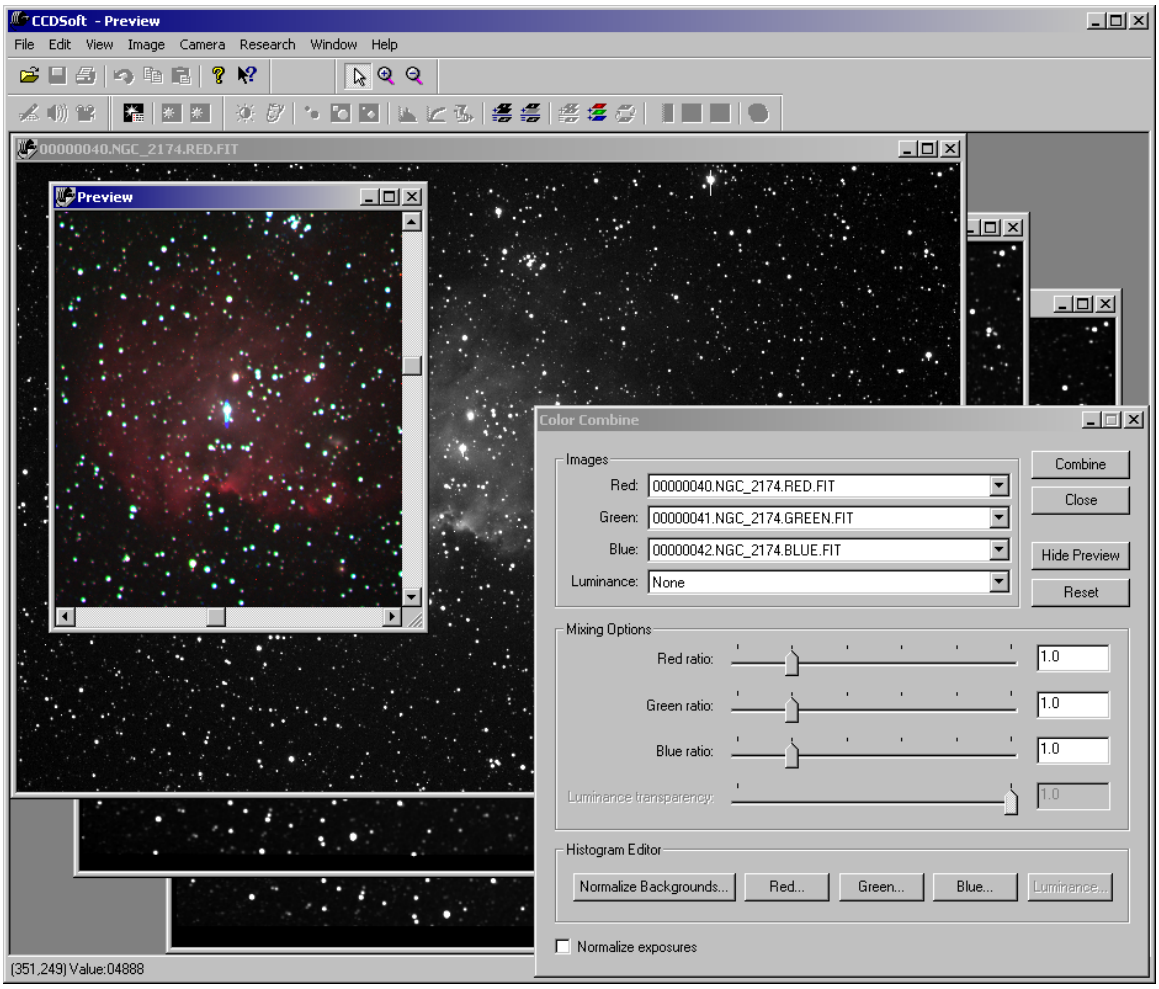


Figure 3: The Preview Window is open.

In this example, the Preview window doesn't show much color. With other images, it may show too much color. The appearance of the Preview window depends on the current histogram settings (background and range) of the images you are combining. You can use the various controls in the Color Combine dialog box to improve the full-color image. You can also leave the Preview window open while you make

changes to the original images using any of the commands in CCDSoft, and the Preview window will update automatically. An example of this is shown in the next section, “Combining Color Images: LRGB.”

If the background of the Preview window isn’t black – and this will be the case whenever the black point of the image is set to a value other than **Strong** using the Histogram window – you can start by clicking **Normalize Backgrounds**. You will see a warning that this will reset the histograms for the component images; click **Yes** to proceed.

This sets the black point very close to the peak value at the low end of the histogram. Figure 4 shows an example. Note that the black point (the left slider below the histogram plot) is very close to the peak of the histogram curve at the left side.

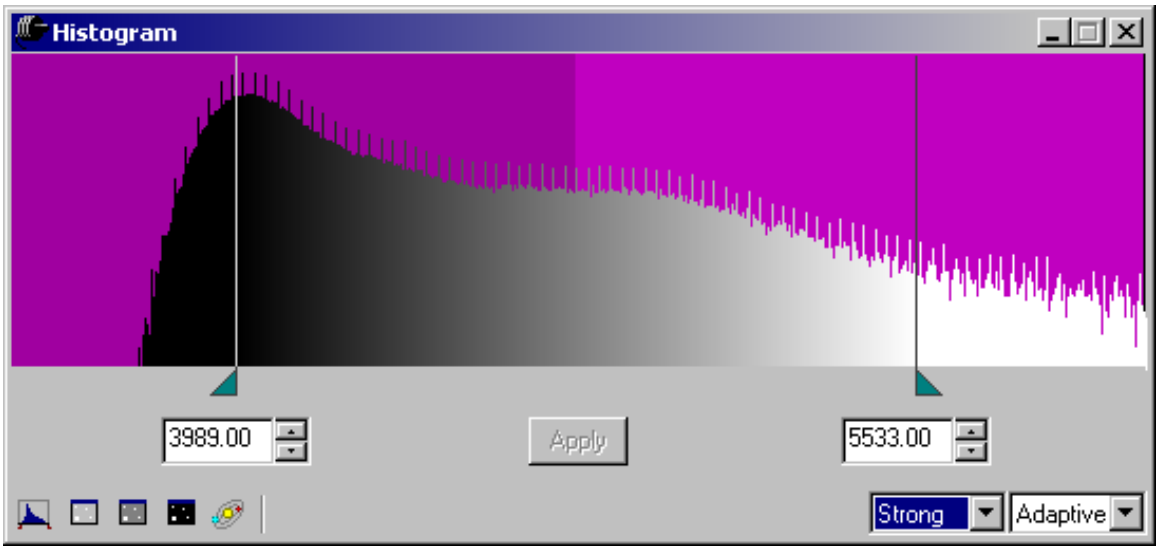


Figure 4: The black point is set to the Strong value.

You can set this value for the black point yourself by selecting **Strong** from the left of the two drop-down lists in the lower right corner of the Histogram tool. For a complete discussion of the histogram tool, black point, white point, etc., please see “Chapter 9: Image Processing.”

Normalizing the backgrounds will usually bring out more color and darken the background, as shown in the Preview window in figure 5.

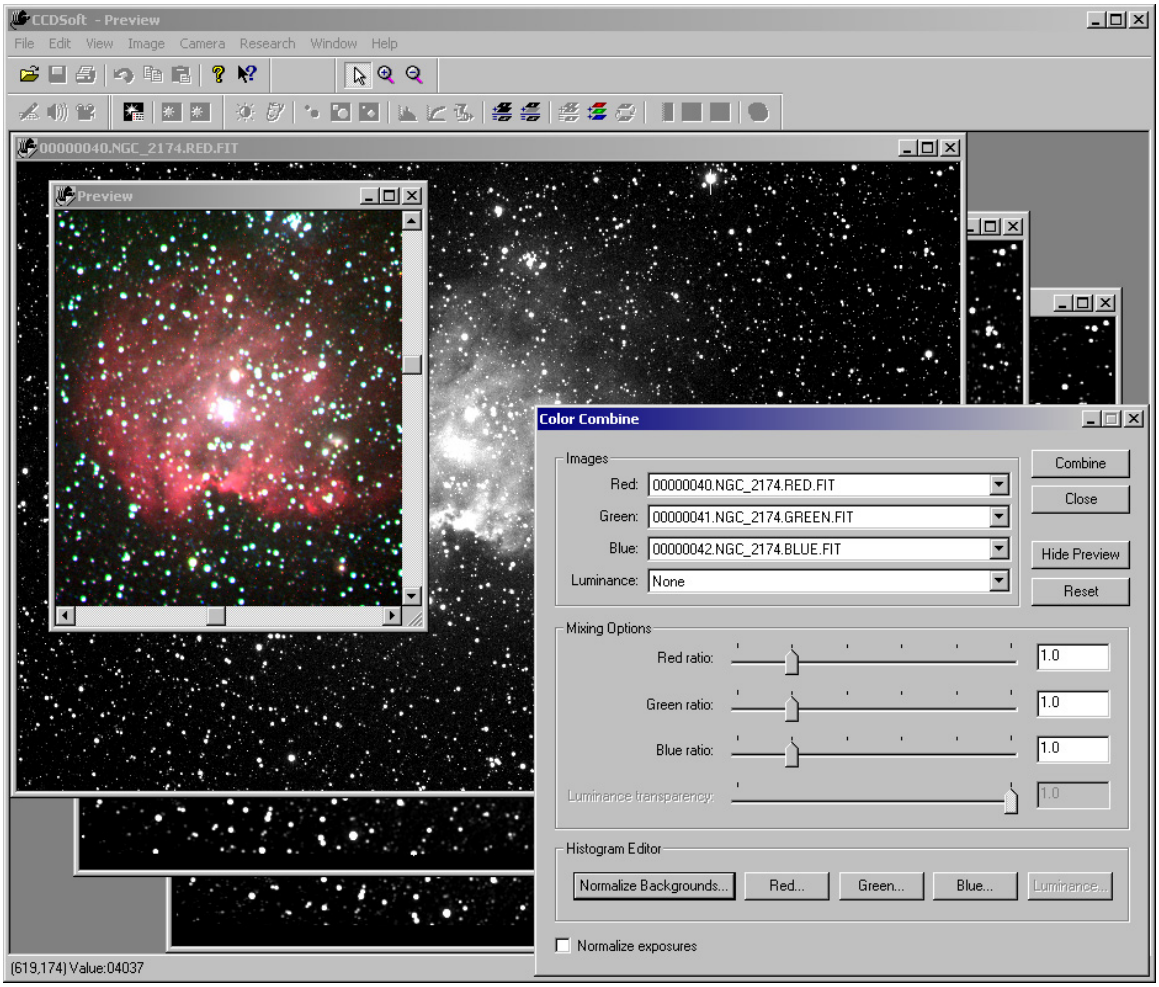


Figure 5: Normalizing background provides better brightness in the image and a dark background.

If the color balance is not correct (usually due to having incorrect exposures ratios for the component images), you can use the color ratio sliders to balance the color. For example, if the image is too blue, you can slide the Blue ratio slider to the left to decrease the contribution of the blue image. Conversely, if there is too little blue in the image, you can slide the Blue ratio slider to the right to increase the contribution of the blue image.

If your component images do not have the recommended exposure ratio, you can search on the web for color images of the object in your images, and use those to determine the correct appearance of the object. You can then use the ratio sliders to adjust the contribution from each component image to match the desired result.

If you look closely at the central star in the Preview window in figure 5, you may notice that the star isn't well defined. If this were a monochrome image, it would be a simple matter to adjust the white point so that the bright area around the star is no longer merged with the star. This leads to a very important point:

When working with a color image, if you adjust the white for a component color image, you will always alter the color balance in the combined image.

If you move the white point higher for the red component, for example, this darkens the red component, and reduces the contribution of the red component to the full-color image. There are two things you can do compensate if you adjust the white point in a component image:

- Use the color ratio slider for the color you changed to rebalance color in the image. For example, if you move the white point for the red image higher, this will darken the red image. Move the **Red** ratio slider to the right to increase the contribution of the red component until color is rebalanced.
- Adjust the white point of the other two color component images to compensate. Observe the changes in the Preview window to get feedback on your changes.

Either method works. Which one you choose depends both on your personal preference and on the effect each has on the image. Changes to the ratio sliders change the color balance only. Changes to the white point affect the brightness and contrast of the component image. The actual results for each technique will vary from image to image, so experiment to see which method works better for a given image.

Figure 6 shows an example of the kind of change you can expect from adjusting a component image's white point. Clicking the **Red** button in the Histogram Editor section of the Color Combine dialog box makes the red image active, and opens the Histogram tool. In figure 6, the white point for the red image has been moved to the right (higher value). This has darkened the red in the Preview window (compare to figure 5).

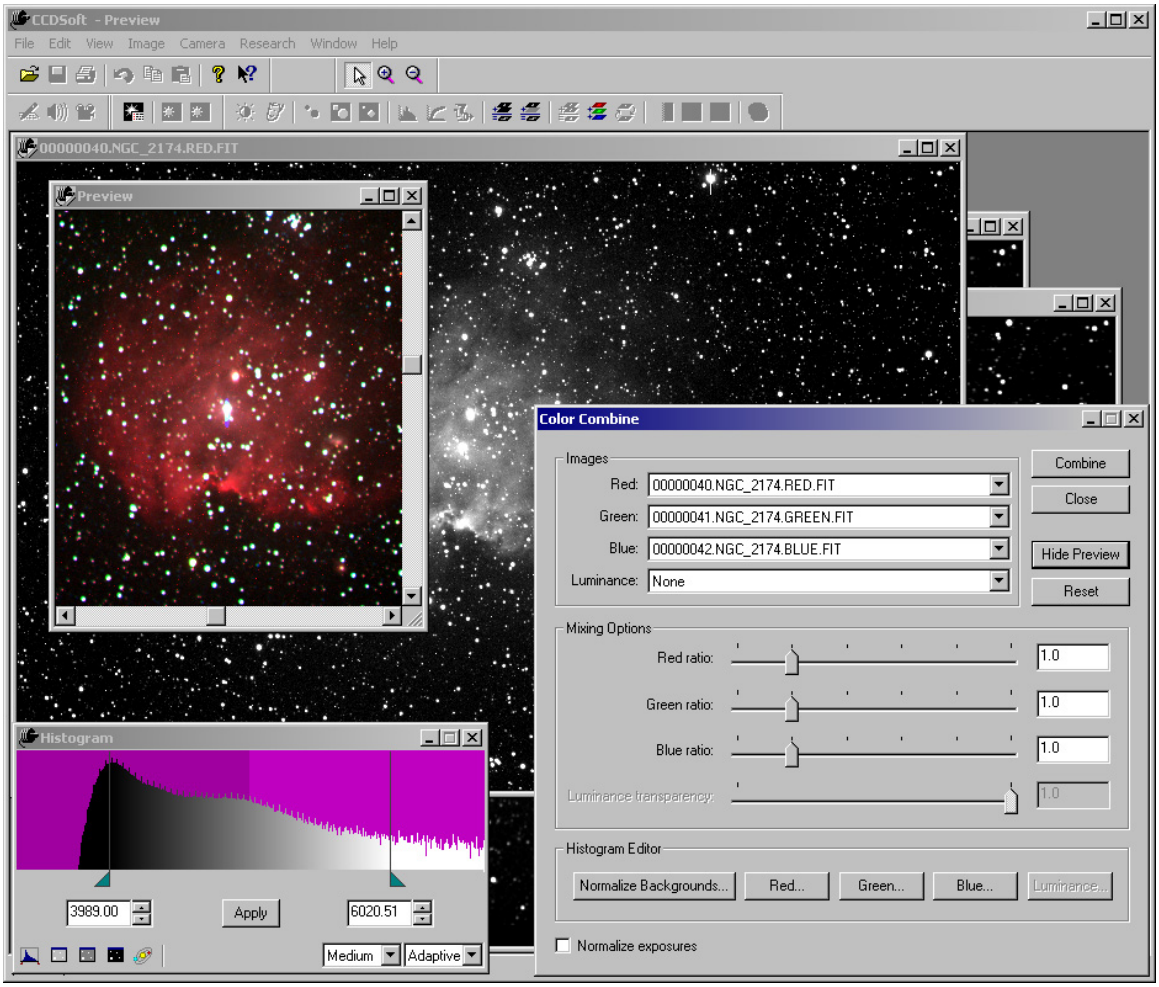


Figure 6: Adjusting the histogram of the red component image.

When the blue and green white points are raised to compensate for the change in the red histogram, the result is a clear, accurate rendition of NGC 2174 in color, as shown in figure 7. There is a small amount of blooming on some of the stars, and some red and green stars are visible at the bottom edge due to alignment of the images prior to color combining. The blooming can be cleaned up in an image editor, such as Photoshop™ or Picture Window Pro™. The fringe where the images do not overlap after alignment can be removed by cropping.



Figure 7: The final color combine of NGC 2174.

Combining Color Images: LRGB

An LRGB combine includes a luminance image as well as the red, green, and blue images, but is otherwise similar to an RGB combine. As with an RGB combine, you start with a set of already aligned images.

The luminance image does add a few additional considerations, but the use of the Color Combine dialog box is very similar. The key issues to be aware of when doing an LRGB combine are:

- The luminance component may wash out the colors in the full-color image. If this is the case, you can move the **Luminance ratio** slider to the left to reduce the contribution of the luminance image to the full-color image.
- The luminance image will not have any impact on color balance. You can balance color as described for RBG combines.
- Once you have good color balance, make all of your editing and histogram changes to the luminance image. This allows you to control the appearance of details in the full-color image without disturbing the color balance. This is a very important advantage of LRGB combine over RBG combine.

Figure 8 shows an example of an image where the luminance image is too bright (the white point is set too low). The image is of M16, the Eagle Nebula, but you can't tell because the core is too bright.

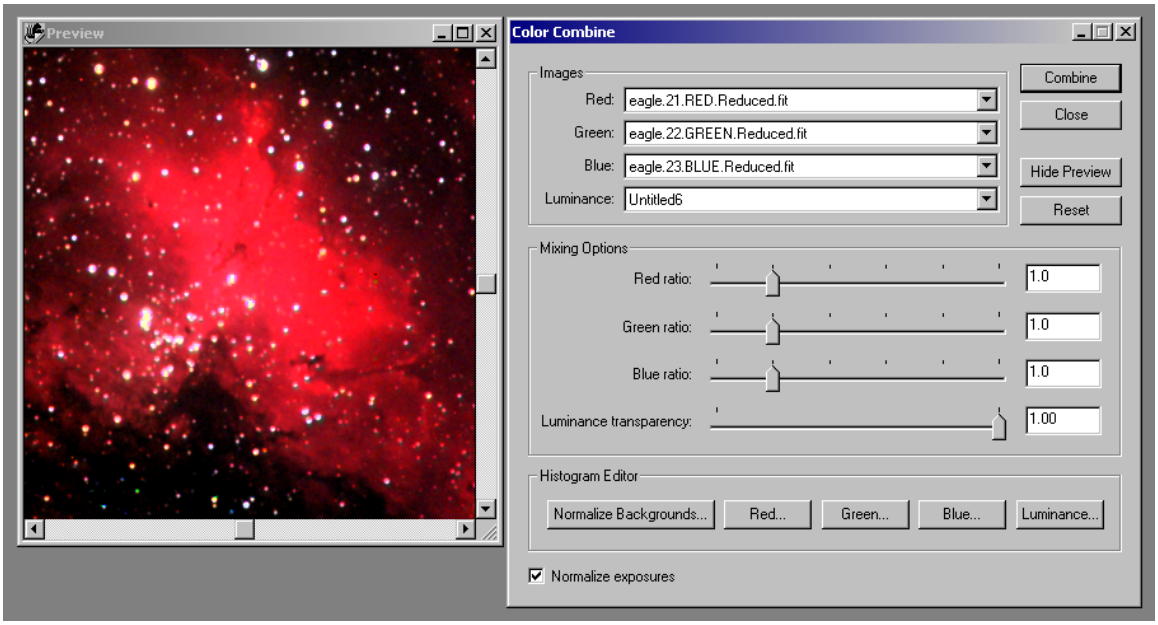


Figure 8: An LRGB combine with too much luminance contribution.

One solution to the problem is to move the **Luminance transparency** slider to the left. Figure 9 shows the result. The brightness of the image is reduced, and the details at the core of the nebula are clearer. You could also make this change by altering the white point using the **Luminance** button in the Histogram Editor section. Which method you use depends on personal preference; there is no single right way to do it.

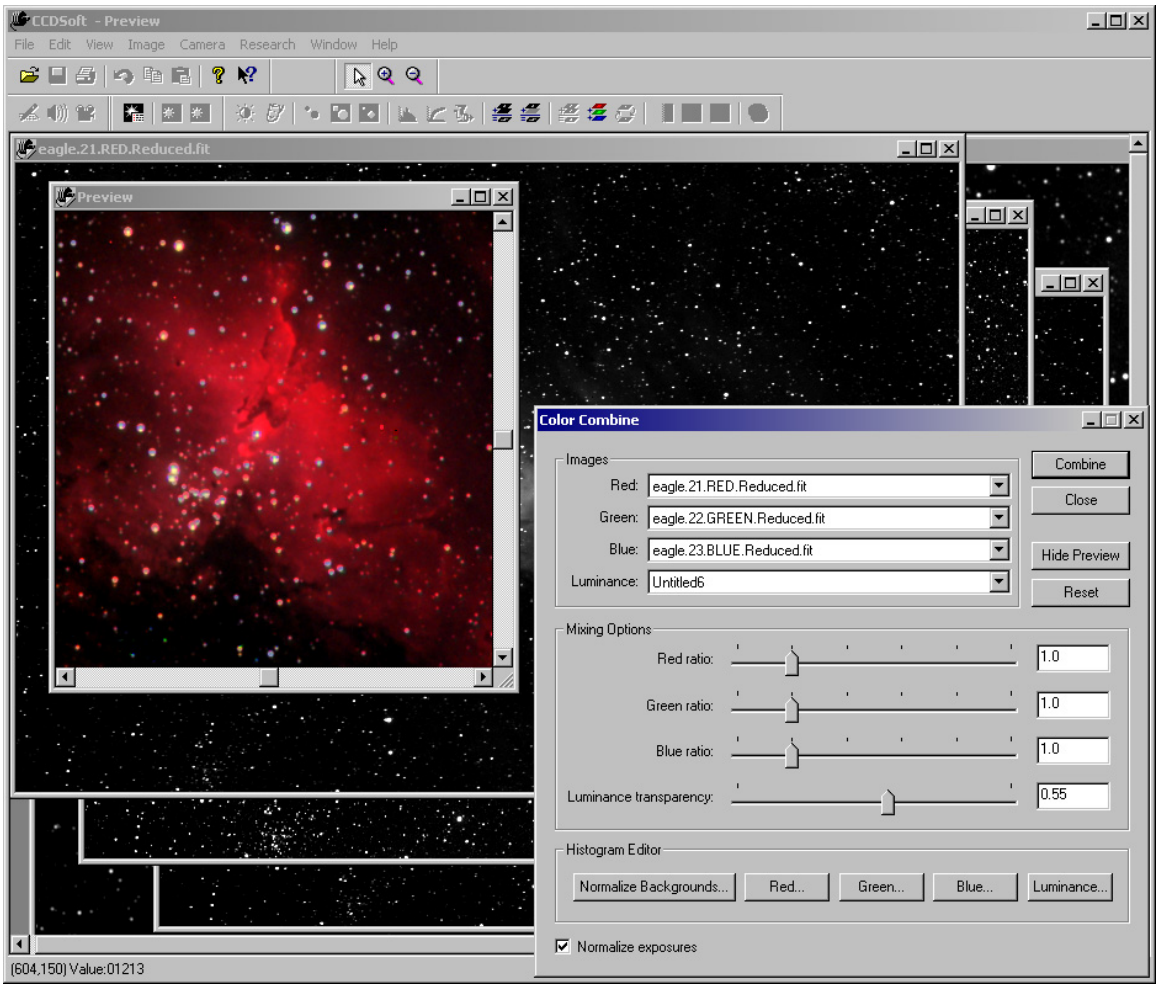


Figure 9: Adjusting the Luminance transparency slider solves the problem shown in figure 8.

Figure 10 shows the result of clicking **Combine**. The image has nice details in the core of M16, but the surrounding nebulosity is not visible.



Figure 10: The result of an LRGB combine.

You aren't limited to using the buttons and controls in the Color Combine dialog box when combining component images to make a full-color image. You can also use any of the available CCDSoft tools to make changes to the component images. This is most useful when you are doing an LRGB combine, since you can make changes to the luminance image without affecting the color balance.

Note: When doing an LRGB combine, all histogram and editing changes should normally be made to the luminance image. Changes to the red, green, and blue images would affect the color balance.

In figure 11, the overall brightness of the luminance image has been reduced by 24%. The contrast is reduced by 15%. And the Contrast pivot point has been shifted dramatically, increased by 100%. These adjustments reveal additional dim details very effectively for this particular image – a different image would require different settings. In addition, the settings depend on the histogram of the luminance image at the time you open the Tune Brightness & Contrast tool.

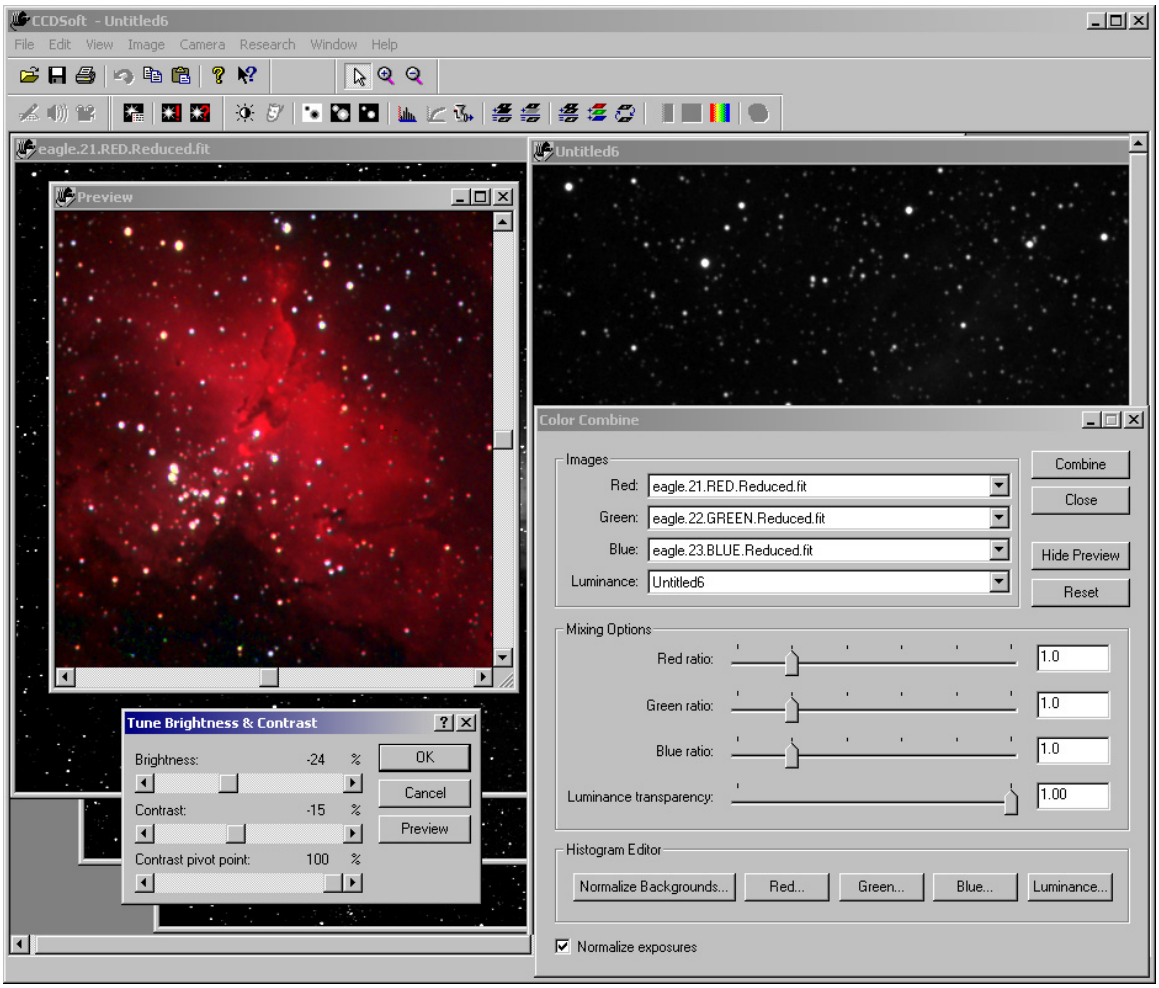


Figure 11: Using the Tune Brightness & Contrast tool to adjust the appearance of the full-color image.

Keep your eye on the Preview window to see the impact of your changes. The results of your changes might make any one of the component images look too dark or too bright. The primary concern in a color combine (RGB or LRGB) is to get the color balanced and the details visible. You can move, scroll, zoom, and resize the Preview window as needed while you work.

For example, the changes to the luminance image using Tune Brightness & Contrast are shown in figure 12. Note that the luminance image is dark, too dark to be used alone. But when combined with the red, green, and blue component images, the result is just right. Figure 13 shows the results of the Tune Brightness & Contrast changes. The nebulosity is now much more extended, yet the details at the core of the nebula are still clearly visible.



Figure 12: The changes to the luminance image do not hint at the effect of the changes on the full-color image (see figure 1).



Figure 13: The final results of the LRGB combine.

There are two reasons why such a dark luminance image works in this example:

- The full luminance image is so bright that it overwhelms the color components.
- The luminance image contains extensive detail of the dim nebulosity around M16

The level of detail in the image is revealed when a non-linear histogram adjustment is applied to the image using a Mid-range Brighten, as shown in figure 13.



Figure 13: Brightening the image reveals the level of nebula detail visible.

Chapter 11: Displaying RealSky Images in CCDSoft

The Digitized Sky Survey (DSS) is available in two formats. The first compresses the data of the entire celestial sphere by a factor of 10:1 and requires 102 CD ROMs. The second version – called RealSky – uses an even higher compression (a factor of 100:1) and requires 18 CD ROMs. There are 8 CD ROMS for the Northern Hemisphere and 9 CD-ROMs for the Southern. The DSS images can be created with CCDSoft using either format. This chapter explains how to set up CCDSoft to create images from the DSS data.

Note: If you currently have the *RealSkyView* application distributed with the RealSky data installed on your computer, remove it before installing CCDSoft. RealSky is a sub-set of CCDSoft and is therefore not required. CCDSoft contains all of the features found in RealSkyView and includes many additional features and enhancements.

If you have created your own customized target lists with RealSkyView, make sure you make a backup-up copy of them before deleting the RealSkyView folder. These target lists are compatible with CCDSoft.

Initial Setup

Before CCDSoft can access the Digitized Sky Survey (DSS), it needs to access "header" files distributed with the data. These header files contain the necessary information for CCDSoft to know which CD-ROMs contain what data for the different parts of the sky.

The 102 CD-ROM DSS and the RealSky use different header files. Note that you can use both the 102 CD-ROM data and the RealSky data on the same computer if desired. However, you will need a copy the contents of both of the headers folders to your hard disk.

If the headers for both the 102 CD and RealSky are going to be located on the same drive you must use a different folder name for each and assign them correctly in the CCDSoft Digitized Sky Survey Setup dialog box. For example, create a folder named "102-Headers" and another named "RealSky Headers." Switching between the 102 CD ROMS and the RealSky is detailed later.

With the 102 CD ROMs the headers folder is located on the CD ROM labeled #102. With RealSky the headers are located on the CD labeled "disc V." Be careful not to confuse the RealSky installation "Disc V" with the RealSky data CD-ROM number five.

The header files for the Digitized Sky Survey (102 CD-ROMs) and RealSky North and South are as follows:

Digitized Sky Survey Product	**Headers Files**
Digitized Sky Survey (102 CD-ROM)	`lo_comp.lis` and all files located in the `Headers` folder on disk 102.
RealSky Northern Hemisphere only	`hi_comp.lis`, `all.hhh` and all files located in the `Headers` folder on disk V.
RealSky Southern Hemisphere only	`hi_comp.lis`, `allns.hhh` and all files located in the `Headers` folder on disk V.
Both Northern and Southern Hemisphere RealSky	`hi_comp.lis`, `allns.hhh` and all files located in the `Headers` folder on disk V.

1. Copy the Headers folder into the CCDSoft folder. The default CCDSoft folder is:

   `C:\Program Files\Software Bisque\CCDSoft Version 5\`

   Note: If you have both the RealSky Northern and Southern Hemisphere Editions (18 CD ROMS) you must use the header files located in the `Headers` folder on the installation "disc V" distributed with the RealSky South. Both the North and South installation CDs look similar. The RealSky disc V with the "Copyright 1997 The Astronomical Society of the Pacific, AURA/STScI" contains the headers needed for the Northern and Southern hemispheres. If you use the incorrect version of the headers you will only be able to create images for one half of the sky and will encounter the message "No Image Found to Extract". See the photograph below for the copyright location on the CD-ROM.



Figure 1: RealSky Disc V

2. Click **Research | Digitized Sky Survey | Setup**.

   The Digitized Sky Survey Setup dialog box appears (see figure 1).

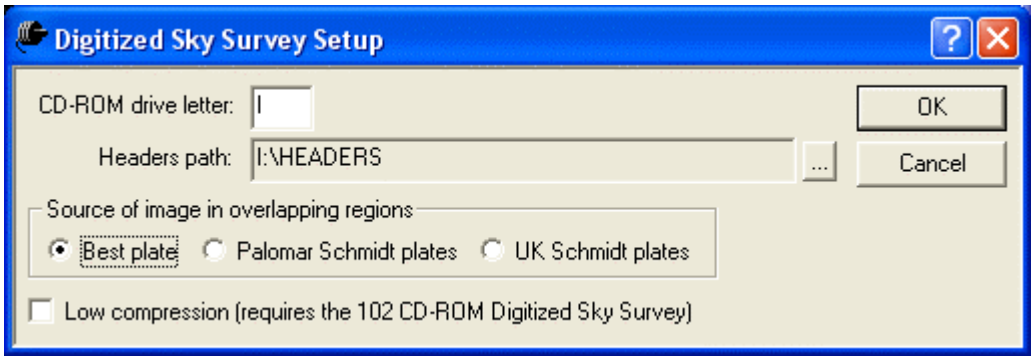


Figure 2: Setting up access to Digitized Sky Survey images.

3. The **CD ROM drive letter** should match the letter of your CD drive. If it doesn't, change it. Note: This drive letter can represent a hard disk drive or shared network drive if the contents of the DSS CD-ROMs have been copied to a different location. Please see the section

entitled “Installing the DSS data on the hard disk” for details. The **Headers path** should specify the folder where you copied the header files.

This is usually:

```
C:\Program Files\Software Bisque\CCDSoft Version 5\HEADERS
```

4. To access the low-compression DSS data on the 102 CD-ROMS check the **Low compression** checkbox. The option for **Palomar Schmidt plates** is used for the Northern hemisphere and the **UK Schmidt plates** option is used for the Southern hemisphere. When using both RealSky Northern and Southern Editions, select the **Best Plate** option. This option will retrieve images from the later sky survey where they overlap.
5. To access the low-compression (102-disk) DSS set, mark the **Low compression** checkbox in the Digitized Sky Survey Setup dialog box.

   You can’t access high-compression and low-compression disks at the same time. To return to the high-compression set, clear the **Low compression** checkbox.
6. Click **OK**.

Note: You can display the Digitized Sky Survey toolbar using the **View | Toolbars** command, then checking **Digitized Sky Survey** in the Toolbar dialog box. Figure 2 shows the Digitized Sky Survey toolbar.



Figure 3: The Digitized Sky Survey toolbar.

From left to right, the tools are:

- View New Target
- Target List
- Pan Up
- Pan Down
- Pan Left
- Pan Right
- Increase Field of View
- Decrease Field of View

Displaying a Target

To access the DSS, you specify the central coordinates and angular dimensions of the area of the sky you want to view. This combination of coordinates and dimensions is called a "target." Once a target has been chosen, CCDSoft prompts you to load the CD for that part of the sky and then creates the corresponding DSS image. Here are the steps to follow:

1. Click **Research | Digitized Sky Survey | View New Target**. The View New Target dialog box will appear (see figure 3).



Figure 4: The View New Target dialog box.

2. Enter the right ascension, declination, and Epoch for the center of the area of sky you want to view. Hours and degrees can be entered as decimal values. When you click in another entry box the decimal entries are automatically converted to minutes and seconds. For example, 20.025 Degrees is converted to 20 Degrees, 1 Minute, 30 Seconds. Declination degrees can be entered as a positive or negative number:
   - If positive, click the **North** or **South** option to select the hemisphere.
   - If you enter a negative value, the South option is automatically selected when you click in another entry box.
3. Enter the dimensions of the area, in arcminutes. The minimum dimension is 5 arcminutes. The maximum is 120 arcminutes. The width and height do not have to be the same. Fractional values are okay. **IMPORTANT**: The size of a decompressed image is limited to 120x120 arcminutes. An image this size requires about 28 MB of free memory.
4. The default Epoch is 2000.0. To enter Epoch 1950.0 coordinates, click on the arrow in the Epoch box and select 1950.0. You can enter any Epoch value from –4712.0 to 10000.0 in this box.

5. Click **View** to open the appropriate DSS image. If the correct data disk is not in the CD ROM drive specified in the DSS setup a message will prompt you to enter the correct CD-ROM. If you select coordinates outside the range of the data you will receive the message, “No image found to extract.” If you have the 102 CD ROM set or the RealSky North and South 18 CD ROM set you will not see this message.

If you’re accessing the RealSky disks using just the Northern Hemisphere, and the coordinates are at or near the –12° declination limit, the image might be incomplete, or include random pixels. If this occurs, select a more northerly declination, then use the pan buttons (described below) to position the image.

The View New Target dialog box remains open until you close it. You can continue to select new targets. Each new target is opened in a separate window.

Orientation

To see the orientation of the DSS image click **Research | Digitized Sky Survey | Orientation**. Two arrows are displayed on the image (see figure 4), indicating the North and East directions. If you flip the image horizontally or vertically the arrows will also change to reflect the new orientation. Click the command again to turn the orientation indicator off.

Most DSS images are oriented with North more or less pointed towards the top of the screen.

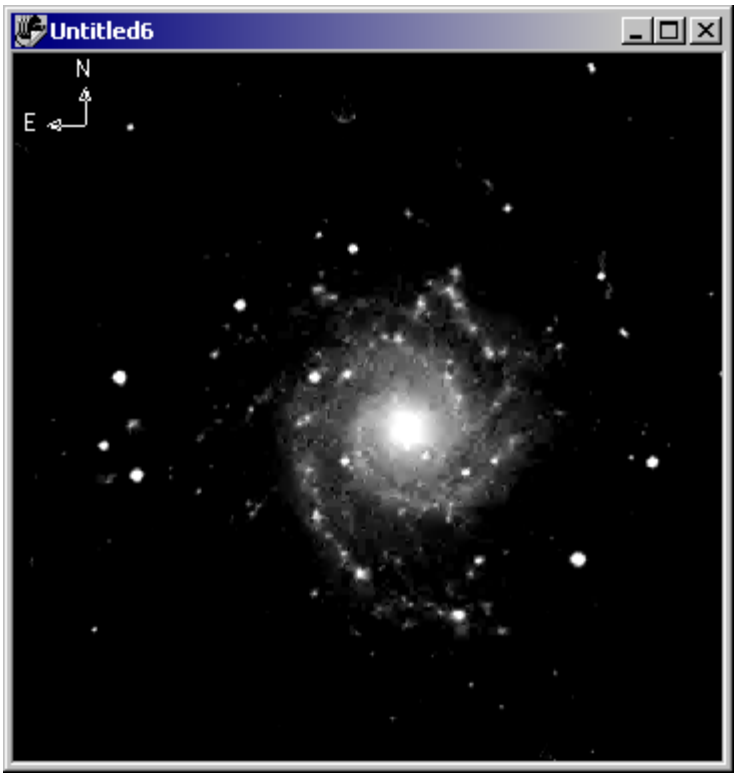


Figure 5: Displaying image orientation.

Saving a Target Image as a File

A target image can be saved as a file. Click **File | Save**, or press `CONTROL+S`. Type in the name you want, and then click **OK**. The default format is FITS. The FITS header in this file should not be modified. The contents of this file are copyrighted. It is for personal use only. It may not be distributed or used for any commercial purpose.

Since the images are standard FITS format they can be used with any of CCDSoft's image processing tools to enhance or process the images. The Histogram tool and the Mid-range Brighten functions are two of the more useful image processing tools for this purpose.

Selecting a Predefined Target

CCDSoft provides pre-defined "target lists" for many non-stellar objects, such as objects contained in the New General Catalog (NGC) and Messier catalog. You can find these lists in the `DSS Target Lists` folder in the CCDSoft folder.

Target lists 1 through 8 (`disk1.lst – disk8.lst`) correspond to the 8 CDs in RealSky North. Target lists 9 through 18 (`disk9.lst – disk18.lst`) correspond to the 9 CDs in RealSky South. For example, all NGC objects listed in `disk1.lst` are found on RealSky CD-ROM 1. All NGC objects listed in `disk2.lst` are found on CD ROM 2, and so on. This grouping by CD allows you to easily view the objects on one CD.

The file `ngc.lst` contains the entire list of NGC objects. To access all NGC objects the entire 102 CD-ROMs or 18 RealSky CD-ROMS are required. If you have only one hemisphere of RealSky (North or South), many objects will display the message, "No Image Found to Extract."

To view a predefined target:

1. Click **Research | Digitized Sky Survey | Target List**. The Target List dialog box appears (see figure 5).

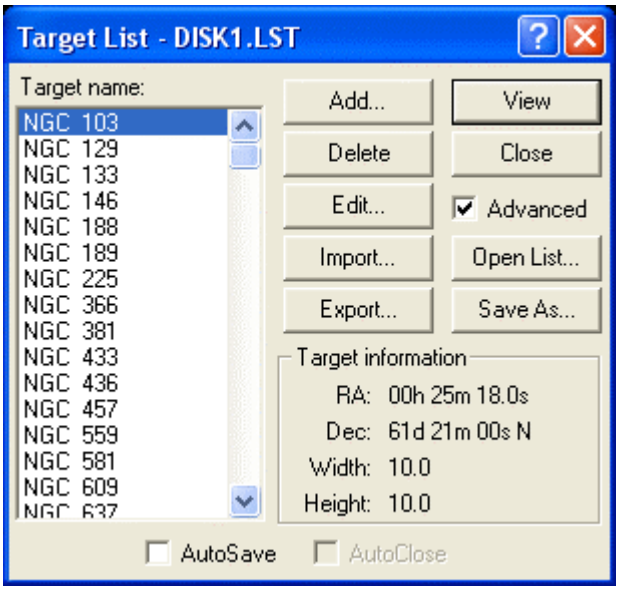


Figure 6: The Target List dialog box.

2. To choose a different list, click **Open List**. The Open List dialog box appears (see figure 6).

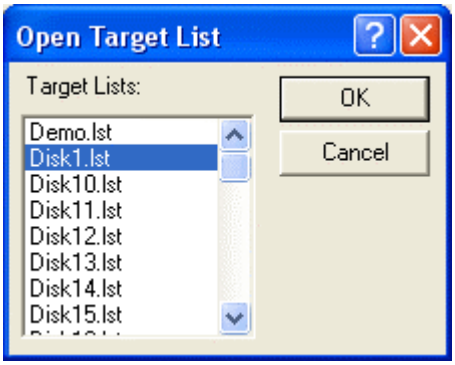


Figure 7: Selecting a target list.

3. Highlight the target list you want. Then click **Open** (or double-click the list name). The Target List dialog box returns.
4. Scroll the **Name** list to find the object you want to view. If the object is not listed click on **Open List**, then select another target list, or use the file `ngc.lst` to see which CD-ROM contains the data.
5. Highlight the target. The coordinates and dimensions of the object appear in the **Target Information** box.
6. Click **View** (or double-click the target's name). If the current CD ROM does not contain the data for the target, you are prompted to insert the CD that does, and the image is displayed.

Adding Your Own Targets

You can create any number of targets, give them names, and add them to existing target lists. (You can also create completely new target lists. This is explained later.)

To add a new target:

1. Open a target list file using the Target List dialog box.
2. Click **Research | Digitized Sky Survey | View New Target**. The Add Target To List dialog box appears (see figure 7).

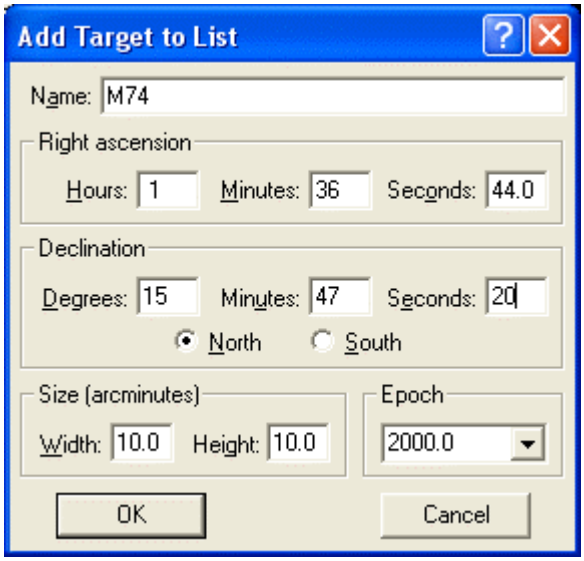


Figure 8: Adding a target to a list.

3. Enter the coordinates and dimensions of the target.
4. Click **Copy To List**. The Target Name dialog box appears (see figure 8).

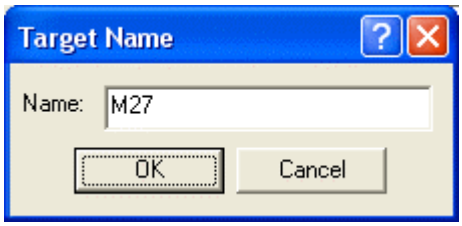


Figure 9: Entering a target name.

5. Type the name you want (up to 30 characters). The name can include numbers, punctuation, and spaces. You can use both upper-and lower-case letters.
6. Click **OK**. The Target List dialog box returns. The new target is added at the end of the list. The target file is automatically updated. You do not have to explicitly save it.

To remove a target (new or predefined):

1. Highlight the target. To select a range of targets, hold down SHIFT when you click. To select or deselect individual targets, hold down CONTROL when you click.
2. Mark the **Advanced** checkbox (if it isn't already marked).
3. Click **Delete**.

When you accept the deletion, the file is automatically updated. You cannot recover deleted targets. They must be manually reentered.

Modifying Targets

You can alter any element of a target:

- Name.
- Coordinates (right ascension and declination).
- Size (in arcminutes).
- Epoch (1950.0, 2000.0, or a manually entered value).

To modify a target

1. In the Target List dialog box, mark the **Advanced** checkbox.
2. Highlight the target you want to modify.
3. Click **Edit**. The Edit Target dialog box (similar to the Add Target dialog box; see figure 7) appears.
4. Make the changes you want, and then click **OK**. When you click **OK**, the target list is automatically updated.

If you change the size or coordinates of the currently displayed target, its image does not change. You need to close the image window, and then reselect the target to see the changes.

Creating New Target Lists

User-created targets are added to the currently open target list. You can also create new target lists using the supplied file `empty.lst`. `Empty.lst` is an empty target list file. To create your own lists, make a copy of this file, rename it, and then start adding your own targets to it.

Importing Target Lists

You can also create a list of targets in a text editor, and import it. Imported targets do not become a new target list, but are added to an existing list.

The target list to be imported should be a plain-text file with the following format:

```
; Ref. Number     Name               RA          Dec                Width Height
;        1         2         3         4         5         6         7         0
;234567890123456789012345678901234567890123456789012345678901234567890123456789
   1              NGC   24           0.16500000 -24.96666667       10.00 10.00
   2              NGC   45           0.23500000 -23.18333333       10.00 10.00
   3              NGC  172           0.62166667 -22.60000000       10.00 10.00
   4              NGC  175           0.62333333 -19.93333333       10.00 10.00
  44              NGC 3109          10.05166667 -26.15000000       14.50 14.50
  45              NGC 3203          10.32666667 -26.70000000       10.00 10.00
  46              NGC 3285          10.56000000 -27.45000000       10.00 10.00
```

The file must match this format exactly, including the starting column of each data item. Two comment lines with column number are included above to help you identify the starting column numbers for each item:

Item	Starting column
Reference number	1
Name	19
RA	37
Dec	49
Width	68
Height	74

Blank lines, and lines starting with a right angle bracket (>) or semicolon (;) are considered comments and are ignored.

To import a target list:

1. Click **Save As** on the Target List dialog box to create a target list with a new name. This is the list to which the imported targets will be added.
2. Mark the **Advanced** checkbox.
3. Click **Import**.
4. In the Import Target List dialog box, select the text file with the data you want to import.
5. You are prompted to “Delete any existing items in list?” Click **Yes** to remove all the existing targets.

Exporting Target Lists

Target lists can also be exported to a text file with the same format. This makes them available to astronomy programs (such as TheSky Astronomy Software).

1. Load the target list you want to export.
2. Mark the **Advanced** checkbox.
3. Click **Export**.
4. In the Export Target List dialog box, enter a name for the file.
5. Click **Save**.

Panning and Changing the Field of View

Once a DSS image is displayed, the six right-hand buttons in the DSS toolbar become active:

- The arrow buttons pan the image in the direction shown. (You can also use the LEFT, RIGHT, UP, and DOWN arrow keys on the keyboard.)

  You are not limited to a single disk. When you reach the “edge” of data on a disk, you are prompted to insert the “adjacent” disk.

- The Increase and Decrease Field of View buttons show more or less of the sky centered on the currently selected coordinates.

  The minimum field of view is 5 arcminutes, and the maximum is 60 arcminutes. When you reach either limit using the Field of View buttons, CCDSoft will beep.

Copying the RealSky Data to a Hard Drive

You can copy the contents of the RealSky CDs to the root directory of a hard drive to speed up access and avoid swapping CDs. You can then enter the hard drive letter as the CD-ROM drive under DSS Setup.

Note: The contents of the DSS CD-ROMs must be copied to the root folder of the hard disk. You can’t copy them into a subfolder.

Windows NT/2000/XP

If you do not want to use an entire hard disk for this purpose, you can partition the hard drive in Windows NT or 2000. Use the Disk Administrator tools to create a partition formatted with 512 byte sectors. This size sector will provide the most efficient storage on the hard drive. See the section “Hard Disk Sector Size” below for more details.

Windows 95/98/Me

The entire disk or partition you will be using for the data should be formatted using the smallest sector size (512 byte sectors, if possible). See the section “Hard Disk Sector Size” below for more details.

Copying Files

The final step is to copy the contents of the RealSky CD-ROMs to the root of the hard drive. The following folders must be copied for proper operation:

- Headers
- S001
- S002
- Snnn through XXnnn

Hard Disk Sector Size

The hard disk space required to hold the RealSky CD-ROM files depends on the sector size of the disk drive (whether the drive has 512, 1024, 2048 or larger sectors).

For example, consider a hard drive formatted so that the minimum sector size is 1024 bytes. This means that the minimum disk space for a given file is 1024 bytes. So, to store 1,000 files that are 1 byte in size would actually occupy 1,024,000 bytes (1 MB). This same type of overhead applies to the RealSky data on your hard drive.

There are over 1.3 million relatively small files (files that occupy less than 10,000 bytes) on the RealSky CD-ROMs. In order to minimize the CD-ROM space required to hold these files, the Space Telescope Science Institute used 512-byte sector formatting on the CD-ROMs. If each 512-sector RealSky CD-ROM holds 650 MB, the total RealSky data is about 12 GB (11.7 GB). Using a 1024-sector formatted hard drive, the RealSky CD-ROMs require approximately 23 GB. A 2048-sector formatted hard drive requires approximately 45 GB.

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