

# Model ST-4 Star Tracker Imaging Camera Operating Manual

April, 1990

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# Model ST-4 Star Tracker / Imaging Camera Operating Instructions

## Instrument Overview

The Model ST-4 Star Tracker / Imaging Camera is a multipurpose instrument. It can be used as an automatic star tracker to take long guided exposures of the night sky, or, in conjunction with a personal computer (PC), as a highly sensitive imaging camera. This manual describes the technical concept of the Model ST-4, the interfaces to the telescope and computer, and general operating instructions.

## Tracking Overview

The Model ST-4 uses a charge coupled device (CCD) detector to detect star images. The detector can be understood by examining Figure 1. An array of 192 by 165 detector elements, called pixels, is arranged as shown in the figure. We refer to the horizontal axis as X, and the vertical axis as Y.

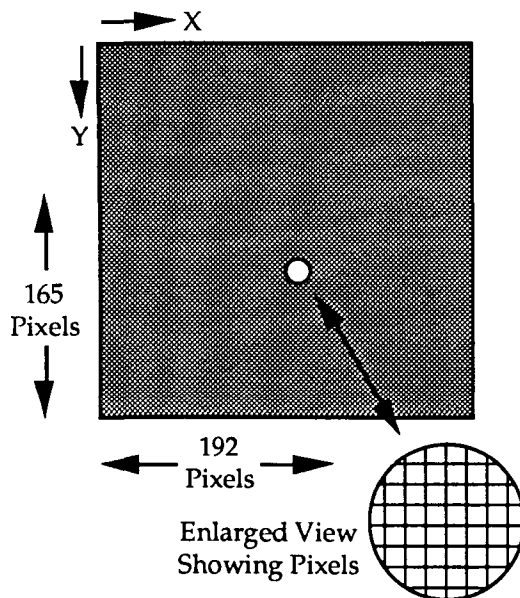


Fig 1 CCD Configuration

In operation the pixels convert photons into electrons, and store them until read out by the ST-4's microcontroller (the ST-4 has memory for two images, one for light frames, and one for dark frames, as explained further below). For example, if a star's image is present at pixel position 121,132 the computer will determine its position by noting the increased signal from that

pixel. If the star is drifting due to guiding errors, it will appear at a different position in the next exposure, say at pixel position 123,132. The computer then calculates how far the star has drifted from the original exposure, and toggles the telescope drive accordingly.

The microcontroller (in the ST-4) can take an exposure (called integration), read out all the pixel values, and calculate the necessary telescope correction in less than a second. The tremendous sensitivity of the CCD enables guide stars as faint as 8th magnitude to be tracked with a 1 second exposure and a 60 mm guide telescope.

The calculating power of the ST-4 enables the star's location to be determined to a fraction of a pixel accuracy, enabling very accurate tracking.

## Imaging Overview

The Microcontroller referred to in the tracking section is built into the ST-4. This microcontroller can communicate to an XT or AT compatible PC, or a Macintosh\*, over the ST-4's RS-232 serial link (the serial interface of the ST-4 is also compatible with the RS-422 ports used on the Macintosh).

A full image can be transmitted at 19.2K baud within 18 seconds and over a distance of 100 feet. Data transfer rates as high as 57.6K baud are supported, and work very well over shorter cable runs. A partial image transfer mode is also supported which sends 1/4 as many pixels (one value for each group of four adjacent CCD pixels)

\* Macintosh is a registered trademark of Apple Computer, Inc.

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in 5 seconds. This mode of operation is very handy for focusing the telescope and finding objects. Finding faint objects is easy using this method; the outline of the Ring Nebula is clearly seen in exposures as short as 10 seconds with an 8" Schmidt Cassegrain Telescope (SCT) operating at f/10.

In imaging mode, the microcontroller in the ST-4 is told to take an exposure by the PC. It does so, and stores the resulting data in memory within the instrument. This data is then relayed over the serial link to the host computer. The data is retained in the ST-4 until the next exposure is captured or power is turned off. The host does all of the extensive data manipulation required by the user, such as contrast enhancement, and also can store data on disk for later study. This is a very attractive feature; the computer allows a quick look to be taken at the image, within seconds of the event, and a more detailed look at any later time, such as a rainy night or during the day.

The CCD can be exposed for integration times longer than five minutes. The pixels slowly fill-up in the dark due to a phenomena called dark current, and they saturate at about the five minute point when the CCD is cooled to a temperature near -30 °C using the single stage thermoelectric cooler used in the ST-4. The waste heat of the thermoelectric cooler (about two watts) is dissipated into the air by convection around the CCD head. The CCD has a sensitivity comparable to ASA 20,000 film, if such a film speed were available. The CCD has a limited resolution due to the small number of pixels; much greater resolution would be degraded by the limitations of most computer graphics screens.

**Note:** With the CCD running at lower than ambient temperatures, you will wonder why dew and frosting aren't a problem. First of all, the chamber containing the CCD is small, and only a small volume of air surrounds the CCD. The small volume minimizes the total amount of water vapor in the air, which will frost onto the coldest surface inside the head (which is the bottom of the CCD). Although frost may initially form on the top of the CCD, in a matter of minutes it will migrate and be trapped at the back of the CCD.

## *System Interfaces*

The following equipment is a prerequisite to running the ST-4 CCD Star Tracker / Imaging Camera.

1. A Telescope with pushbutton or joystick slow motions in at least Right Ascension and and hopefully also Declination.
2. A guide telescope, 50mm aperture or larger, or an off axis guider arrangement.

For pushbutton type controllers the ST-4 tracker controls the telescope the same way you do; through the RA and Declination slow-motion adjustment switches, the interface to which is shown in Figure 2. Four relays in the ST-4 are used to operate the switches. Most telescope drives have two Declination motor adjustment switches which are normally in the 'open' position. Pushing the button or closing the relay both apply voltage to the motor. Study Figure 2 carefully, along with your pushbutton control, to determine the correct configuration.

Most telescopes have one Right Ascension switch which is normally closed; opening this switch slows down the drive. The other Right Ascension switch is normally open; closing this switch speeds up the drive. It is apparent that the relay contacts which are brought out on the cable, 4 groups of three (normally open, normally closed, and common) are all that is necessary to control the telescope. The cable pinouts are described in Appendix A.

When the ST-4 tracker is connected to the telescope, the hand controller is not disabled, and still operates normally. If the telescope control is modified for the ST-4, and the ST-4 is unplugged, the drive may not run since the normally closed connection in the ST-4 has now been removed. If this situation is a problem it is best to build up a mating connector to replace the ST-4 box that has the appropriate pins shorted together (usually just two are required to enable the RA drive to work).

For joystick type controllers, the four relays in the ST-4 are used to simulate the joystick being pushed to its limits. Two relays are used for each axis or rheostat of the joystick as shown in Figure 3. For the Right Ascension rheostat you would use the +X and -X relays, and for the Declination rheostat you would use the +Y and -Y rheostat.

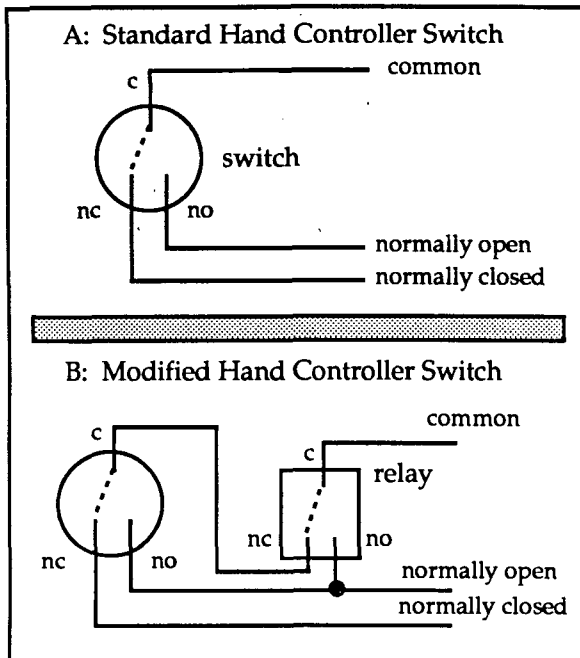


Figure 2 Pushbutton Interface

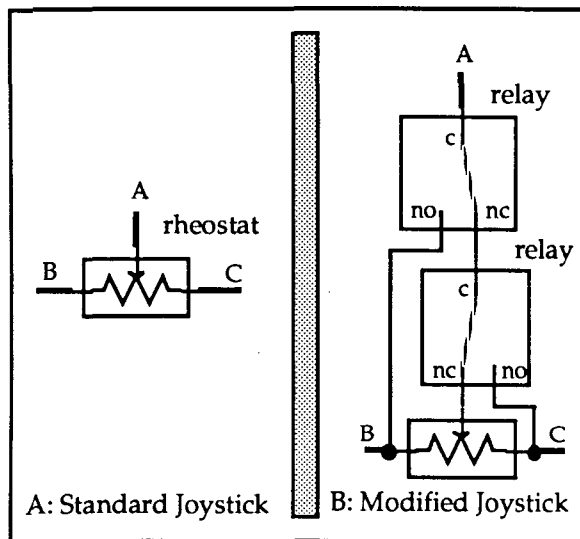


Figure 3 Joystick Interface

## Star Tracking Operation

The instrument panel is illustrated in Figure 4. The ST-4 instrument is furnished with a power cable, a cable to the CCD, and a third cable for the telescope's hand controller. There is no power switch; plugging in the power turns the instrument on. The instrument will come-up in FIND AND FOCUS mode, which displays the greatest pixel value found in the readout of the CCD array, and the location of that pixel. The greatest pixel reading will drop as the CCD cools in temperature. After about 2 minutes, the CCD will have cooled to its optimum temperature.

**Note:** The display values range from 0 to 99 corresponding to percentage. Pixel X and Y values of 50 correspond to a pixel centered within the CCD, while a brightness value of 99 corresponds to a completely saturated pixel, i.e., the star is too bright for tracking.

## Instrument Startup for Tracking Purposes

1. Insert the CCD head into the eyepiece tube such that it seats accurately against the tube. The CCD will not be damaged by light when powered, so it can be easily handled.
2. Begin calibrating the CCD by completely blocking the open end of the telescope to remove all light (the CCD is very sensitive - it will saturate in very low ambient light levels).
3. Observe the VALUE reading. This reading should fall to a reading of around 10 and stabilize within two minutes of the instrument being powered-on. Press the INTERRUPT button to halt the FIND AND FOCUS mode (or any other mode for that matter).
4. Push the TAKE DARK FRAME button. The microcontroller will readout the CCD and put the data in the dark frame memory.

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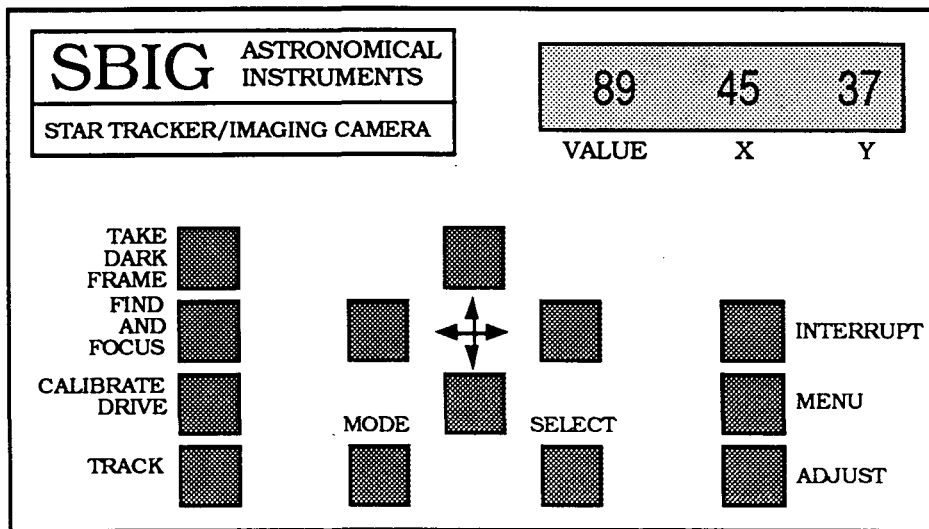


Figure 4 Instrument Panel

5. Push the FIND AND FOCUS button and uncover the telescope to begin the collection of light by the ST-4. The instrument will automatically begin taking frames of CCD data, subtract the dark frame stored in memory, and display the maximum value. Direct the telescope to a star and adjust the telescope's position to approximately center the star image on the CCD by noting the reading on the X and Y displays.
6. If the star is too bright (VALUE reading 99) then either the exposure must be reduced, or a fainter star chosen for tracking. In order to correct this condition, press the INTERRUPT button to stop the collection of data, and return control of the ST-4 instrument to the keyboard.

Push the MENU button. The brightness display will then read "EA" (exposure adjust) and a "1" will appear on the X pixel display (indicating a default exposure time of one second).

Repeatedly pushing the ADJUST key will scroll through a list of exposure times, from 0.1 second, to 20 seconds. Adjusting the exposure time to shorter times will reduce the star brightness, while choosing a longer exposure time will increase star brightness. When the desired exposure time has been chosen, press the MENU button again (the ST-4 will display "CA" (Calibration Adjust), and then press it several more times until you see a bA displayed in the value box. bA stands for brightness adjust; two modes are available, A for average, or F for faint. F

increases sensitivity by 9 times. You should set this parameter to A for initial familiarization. Press the MENU button again until you see the boost (b) parameter displayed. This is a boost factor, where greater values mean greater gain. Initially set this value to 1. Press the MENU button again to return to the normal operating mode (after being interrupted "HELLO" appears on the display).

**Note:** You must take a new dark frame if you change the exposure time, the brightness adjust, or the boost factor.

7. When the brightness level has been adjusted to an acceptable level, focus the telescope by turning the focus knob and observing the VALUE display. At best focus, this number is maximum. Be careful to take your hand off the telescope between adjustments or the telescope vibration will smear the star image over multiple pixels within the CCD, reducing the brightness. Atmospheric turbulence will also tend to smear the image, so it may be helpful to watch several sequential exposures when critically focusing the image.

A table of typical VALUE readings for different magnitude stars is shown below in Table 1. This assumes a 1 second exposure and a typical response of the CCD. Use this as a reference for determining whether the system is properly focussed.

Star	ST-4 VALUE Reading
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Magnitude	60mm Refractor	8 inch SCT
4	99	99
5	60	99
6	24	99
7	9*	80
8	4*	32
9	1*	13
10	-	5*

*Table 1 Typical VALUE readings*

8. When the focus is adjusted, remove the CCD and insert an eyepiece into the tube, sliding the eyepiece in the tube until the image is in sharp visual focus. With a knife or other sharp object, scribe the eyepiece on its side at the end of the tube. This eyepiece can then be used to quickly center and focus the CCD in the future. Place the CCD back into the tube so that it seats against the tube as before.
9. Position the star image approximately in the center of the CCD (X=50, Y=50) using the telescope controls. Push the UP, DOWN, LEFT, and RIGHT buttons for a few seconds to make sure that each relay control is correctly interfaced to the telescope hand-held controller unit. If the buttons are working correctly, the star image will move in four different directions (but not necessarily up, down, left, and right).
10. Push the CALIBRATE button. The ST-4 will automatically drive the telescope in each direction, determine which direction corresponds to +X and +Y, and calculate the correction speed of your drive in all four directions (in pixels moved per second). This process takes about 30 seconds. This is a four-step process with the ST-4 exercising the four relays, and after each step the ST-4 will momentarily display the location and brightness of the brightest object in the field of view. If the image moves too little (less than 2 units) or too far (greater than 30 units) the relay closure time should be adjusted by pressing the MENU key twice to get to the "CA" option, and then repeatedly pressing the ADJUST key to scroll through the time adjustment values (1 to 20 seconds).
11. If no errors are displayed at the end of the CALIBRATE procedure (E1 or E2 in the Value

\* Use an increased boost factor and the faint star mode when working at these levels.

display), then position the guide star on the center of the CCD, adjust the exposure time if necessary, and then press the TRACK button. The ST-4 will automatically guide the telescope until the INTERRUPT button is pressed.

**Note:** The ST-4 constantly corrects drive adjustment times to try to improve tracking. The visual X and Y displays show the tracking error seen during each exposure in units of 0.2 pixels (i.e. a displayed Y value of -3 indicates that the star moved 0.6 pixels in the -Y direction during the exposure). The number displayed after the A in the value location is the average error for the last 16 correction periods.

If the star is completely lost during an exposure, the unit will stop tracking and the display will display the brightness and location of the brightest object in the field of view (like the FIND AND FOCUS mode), and the track lost relay will be activated for one second after 5 consecutive misses. The telescope will not be corrected again until the star reappears.

Calibration steps 10 and 11 should be repeated whenever the telescope is substantially re-positioned in Declination (to correct for longer RA adjustments near the poles). Calibration should also be repeated if the telescope mount is of German Equatorial design and the telescope tube flips from one side of the mount to the other (reversing adjustment directions). Care should be taken to orient the CCD head so the RA and Declination axes line-up with the sides of the CCD head (you can tell by looking through the glass window at the CCD or by noting the orientation of the Serial Number tag on the rear of the head which is oriented like the CCD). This adjustment is not critical. The tracker will work in any orientation. It just makes it easier to make sense out of the x and y readings and to use the pushbuttons if the axes are lined up to the RA and Declination axes.

### *Explanation of Menu Items*

The menu choices which can be adjusted to a particular telescope's configuration can be viewed by pressing the MENU button repeatedly. The different menu items have the following effect:

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**Note:** For each menu item, pressing the ADJUST button repeatedly will scroll through the choices, finally jumping back to the lowest value choice. There is no way to back up.

**EA: Exposure Adjust.** The exposure (integration time) used by the ST-4 in the tracking mode can be set to be from 0.1 to 20 seconds. The readout time of the array is 0.14 seconds; the smearing produced by the readout time for short integration times is not significant in the tracking mode.

**CA: Calibration Adjust.** The amount of time (in seconds) the drive is left on during each move when the CALIBRATE mode is executed. If the time is too short the move will not be accurately determined. If it is too long the star will move off the array. Set this parameter such that a move of 5 to 30 units result.

**SA: Scintillation Adjust.** The ST-4 modifies the correction factors determined in the CALIBRATE mode, if necessary, to improve the tracking. This modification is performed only if errors greater than the SA factor are seen (the SA factor is in pixels). Telescopes with extremely long focal lengths (>10 feet) may find the tracking is improved if this value is increased. Also, its setting should be increased if the ST-4 shows any tendency to "run away" during tracking.

**bA: Brightness Adjustment.** Setting this to A is the normal mode. If this parameter is set to F the ST-4 will set each pixel equal to the sum of the 3 x 3 pixel box centered on that pixel prior to performing the tracking calculation. Since star images are often smeared over several pixels, this collects more light from a faint star. A new dark frame should be taken after altering this value.

**H1: Hysteresis (backlash) Adjustment, X-axis.** This parameter sets the amount of extra time that the drive is operated when the direction of adjustment is changed. Many telescopes have severe backlash, and the star image may not move for several seconds after a correction is made. The parameter is the number of tenth second increments added to the calculated move when the move direction is reversed from the previous move.

**H2: Hysteresis Adjustment, Y-axis.** This parameter is identical to the H1 parameter above except for the Y-axis.

**b: Boost factor.** This parameter boosts the internal gain of the ST-4, enabling fainter stars to be tracked with short exposures. Care must be taken that thermal variations of the CCD head do not cause the star to be lost when working with very faint stars. If this value is altered a new dark frame must be captured.

Please review the problem section at the end of this manual if problems are encountered during tracking.



## *Imaging Camera Operation*

The ST-4 works quite well as an electronic imaging camera when connected to either an IBM PC or compatible or an Apple Macintosh. Some details concerning the operation of the CCD in this mode are necessary to understand all the controls and features available in this mode.

## *CCD Pixel Dimensions*

The CCD pixels are not square. Their dimensions are 0.01375 millimeters wide in the X-direction and 0.016 millimeters tall in the Y-direction. Note that the CCD active area is therefore 2.64 by 2.64 millimeters, or exactly square (about one tenth inch on a side).

## *Caveats of CCD Readout*

The CCD is read out electronically by shifting each row of pixels into a readout register at the Y=0 position of the CCD, and then shifting the row out through an amplifier at the X=0 position. The entire array shifts down one row when a row is shifted into the readout register, and a blank row is inserted at the Y=165 position. Note that the CCD elements are still collecting light as they step down to the readout register. Most commercial CCD cameras use a more expensive CCD which has what is known as a frame transfer readout mode, where all active pixels are shifted very quickly into a pixel array screened from the light by a metal layer, and

then read out slowly. The SBIG ST-4 CCD minimizes the effect of not having a frame transfer buffer by reading out the array very quickly, in about 0.14 seconds. As long as the CCD exposure is greater than about one second this technique will reduce streaking of the stars to acceptable levels.

Planets pose a particular problem to the CCD since they are so bright that exposures of 1 second at  $f/10$  are badly overexposed. The ST-4 has a Half Frame mode for planets and bright stars to solve this problem. In the Half Frame mode the upper half of the CCD is used as a frame buffer for a bright image positioned in the lower half of the CCD. A short exposure can be taken (down to 0.01 seconds) and the bottom half of the array shifted rapidly up to the upper half. The 82 lines of short exposure data can then be readout at the normal rate. This method works quite well, and uses enough pixels such that 0.5 arcsecond per pixel scale factors can be achieved while viewing an entire planet.

Unfortunately, this technique does not work for the moon, since the moon's image typically fills the CCD. The only way to image the moon is to use neutral density filters to attenuate the light down to where the CCD can be used for a 1 second exposure without saturating. The same holds true for images of terrestrial scenes during daylight.

When a long exposure is taken, a glow will be noticed in the upper left corner of the image, near pixel (1,1). This is apparently due to heating of the array by the readout electronics increasing the dark current. This glow can saturate the array in the corner in exposures several minutes long and cause a blank region to appear in the subtracted data. Using exposures short enough that saturation does not occur in the corner will reduce this cosmetic problem to acceptable levels.

### *Dark Current*

The CCD can not take an unlimited exposure. During an exposure in the dark the pixels will slowly fill up due to an effect known as the dark current of the device. This dark current is reduced by cooling, and this is why the CCD is mounted on a single stage thermoelectric cooler in the CCD head. The window is used over the CCD to keep moisture from the CCD while it is powered. If the window is removed the CCD

will frost rapidly (in seconds). In a room temperature environment the cooled CCD pixels take about 5 minutes to fill up due to dark current. At lower ambient temperatures the CCD will take longer (maximum exposure time doubles for roughly every 20 °F drop in temperature) until around 32 °F, where the cooler power is reduced to avoid damaging the CCD with excessive cold. The dark current can be subtracted from images as described in a later section, but the effects of the dark current filling the CCD can not be avoided.

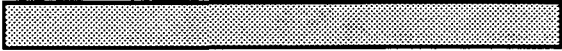
### *CCD vs Film*

The CCD is very good at the most difficult astronomical imaging problem; imaging small, faint objects. For such scenes long exposures are typically required. The CCD based system has several advantages over film; greater speed, quantitative accuracy, ability to increase contrast and subtract sky background with a few keystrokes, the ability to co-add multiple images to increase sensitivity without tedious darkroom operations, wider spectral range, and instant examination of the images at the telescope for quality. Film has the advantages of a much larger format, color, convenience, and independence of the wall plug (the ST-4 can be battery operated in conjunction with a laptop computer, though). After some use you will find that film is best for producing sensational color pictures, and the CCD is best for planets, small faint objects, and general scientific work such as variable star monitoring and position determination. It is for this reason that we designed the ST-4 to support both efforts, as a stand-alone tracker, or as an imaging camera. Our reliance on serial communications slows down the image update rate, but allows the use of portable laptop computers which seldom will accept a PC card.



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## Host Computer Software Overview

This section describes the features of the host software used to interface the ST-4 to either an IBM PC or compatible or a Macintosh. You will want to read this section independent of the type of computer you have, and will also need to read the section below dealing with the type of computer you own.

### Displaying Images

One of the obvious features of the software is its ability to display the images taken with the CCD camera. There is much latitude in the processing of the images due to the "digital" nature of the images and the availability of personal computers with graphics displays.

### Adjusting the Contrast

Any image taken by the ST-4 consists of an array of 192 x 165 pixel values, with each pixel value having 8 bits of accuracy or in other words values from 0 (completely dark) to 255 (saturated). Although any one pixel can have this dynamic range, typically the interesting aspects of an image will be constrained to a more limited range.

There will usually be a background level associated with the image, which is like a spatially uniform intensity level, due to dark current, sky background, or uniform luminosity. In addition, the bright stars in an image may saturate, or you may be interested in examining low-level luminosity (such as nebulosity). For these reasons, the image's contrast can be enhanced with the use of two parameters: *Background* (sometimes abbreviated as *Back*) and *Range*.

The *Background* parameter specifies an intensity level at which any pixel below that intensity will appear black in the image. Increasing the *Background* parameter will have the effect of masking or hiding the uniform background, or low-level intensities. The *Range* parameter is then used to specify the range of pixel values above the *Background* level that will cause the image to saturate on the display. As an example setting the *Background* parameter to 25 and the *Range* parameter to 50 will cause

any pixels with intensity less than 25 to be displayed as black, any pixel values between 25 and 75 (25+50) to be displayed with a gray scale, and any pixels above 75 to be completely white.

You will want to experiment with the settings of the *Background* and *Range* parameters to get a good feel for how they affect the image. These parameters do not physically change the image data, but only affect the way the image is displayed. We will refer to the processing of the data to increase the contrast as "stretching the data".

The software can automatically pick an appropriate set of values for the *Background* and *Range* parameters using an Auto-Contrast feature. It does this by noting the number of pixels at each of the 256 possible intensity levels (called a Histogram) and setting the *Background* and *Range* parameters based upon that calculation. This works quite well for images of extended objects (nebulae, the moon, etc.). For images of star fields you can try Auto-Contrast, but will probably get better results by manually adjusting the *Background* and *Range* parameters.

One other feature of the host software in the image display mode is Presentation Mode, where the image is centered on the screen (horizontally and vertically) and the non-image areas of the screen are blacked-out. This Presentation Mode is quite handy for taking photographs of the screen for presentations, etc.

### Image Smoothing and Inversion

Another image processing technique available for the displayed images is image smoothing. Visually, image smoothing reduces the effects of noise by smoothing out rapid variations in pixel brightness. This is accomplished by making each pixel in the displayed image be a weighted average of its own pixel value and the values of its eight neighbors. Finally, the displayed images can be "Inverted", meaning black areas become white and vice versa. Visually this is like looking at a negative, and can produce good results with images showing subtle nebulosity. Also, it seems that you can push the contrast harder on Inverted images without the saturated regions detracting from the image appearance.

### Crosshairs and Photometric Analysis

Due to the linear properties of CCDs and the digital nature of the image data, photometric

analysis of CCD images is easily achieved when compared to techniques used with film. This section discusses the photometric capabilities of the ST-4 and its host software.

## Scope Factors

Several telescope and calibration factors are required by the computer software to correctly calculate star brightnesses and separations. The telescope focal length in inches and aperture area in square inches are required, as well as a calibration factor. The focal length is usually just the focal length of the telescope, but can be adjusted for such things as barlows and image processing techniques such as image zooming. The calibration factor is the reading that would be produced from the CCD by a zero magnitude star focused onto one pixel by a lens with 1 square inch of area, with an integration time of 1 second (with a gain factor of 1). Its value is typically around 12000, but will vary due to atmospheric and telescopic transmission, and CCD device variations. The calibration factor should also be scaled with the *gain* (described in the "Baseline and Gain Parameters" section below), doubling it for a gain of 2x, tripling it for a gain of 3x, etc.

**Note:** Atmospheric transmission varies with the elevation of the star, so careful work will require attention to this detail as well as to the stellar temperature.

## Pixel Coordinates and Intensities

The CCD is configured as illustrated before in Figure 1. An array of light sensitive detectors, called pixels, are arranged in an array of 192 by 165 pixels. In this manual and in all other references we will refer to the 192 pixel wide dimension as the X-direction and the 165 pixel tall direction as the Y-direction (see Figure 1). When an image is displayed on the computer screen pixel number (1,1) refers to the pixel with the (x,y) location corresponding to the upper left hand corner of the screen. X increases to the right, and Y increases toward the bottom of the screen. The position of pixel 1,1 on the CCD can be physically determined by referring to the placement of the serial number tag on the rear of the CCD head as shown below in Figure 4.

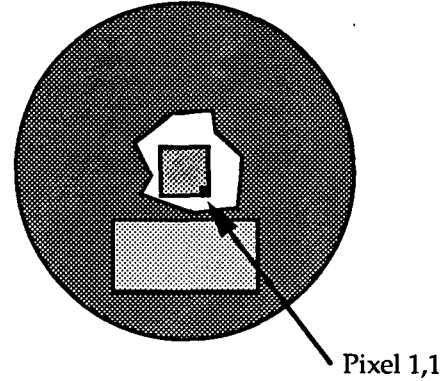


Figure 4 Pixel 1,1 location

The host software allows a crosshair to be moved across the image, and the coordinates of the crosshair (in pixels) and the brightness of the pixel under the crosshair are displayed. Additionally, a weighted average intensity of the pixel under the crosshair and its eight neighbors is also shown. These values of the coordinates, intensity, and average intensity are the simplest form of photometry available in the host software. They are quite handy for setting the *Background* and *Range* parameters and for determining the image background level (due to sky background or dark current) and determining the optimum exposure time.

## Magnitudes and Separations

The host software can also measure stellar magnitudes as well as diffuse magnitudes and angular separations between objects.

The determination of stellar magnitudes involves measuring the total light emitted by a star, or in other words adding the intensity contributions of all the pixels illuminated by the star. Star images will rarely be constrained to a single pixel, hence the requirement for accumulating the intensity from all illuminated pixels. In practice, a 5 x 5 box of pixels is used in determining the magnitude although other size boxes (3 x 3, 7 x 7, etc.) can sometimes be specified. Since the magnitude scale is logarithmic (an increase of 1 magnitude corresponds to a star which is roughly 2.5 times as faint) the calculation of stellar magnitude involves taking the log of the accumulated pixel intensities. Finally, to accurately measure magnitudes the background level must be subtracted. This is done by moving the crosshair to a dark area of the image and specifying that region as being typical of the background intensity for the image. This

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specification of the background allows the magnitude calculations to be independent of effects such as dark current or sky background. The factors that affect the calculation of stellar magnitude are: Exposure time, Aperture area, and Calibration factor.

The diffuse magnitude (also called surface brightness) of diffuse objects is the magnitude per square arc-second, and is calculated identically to the magnitude calculation discussed above except that the accumulated pixel intensities are divided by the area of the 5 x 5 box in square arc-seconds. The factors that affect the calculation of diffuse magnitude are: Exposure time, Aperture area, Focal length, and Calibration Factor.

The host software also allows you to measure the angular separation between objects in an image. This is done by moving the crosshair to the first object, establishing that position as a reference position, and then moving the crosshair to the second object. The software then displays the angular separation and orientation (in degrees, clockwise of vertical) of the crosshair's position relative to the fixed reference position. The calculation of the separation between two objects is only dependent on the dimensions of the CCD pixels and the focal length of the telescope used (which must be accurately entered). This usually requires experimental determination using known double stars for precision. The direction corresponding to east-west in a setup can be determined by taking an image of a star, letting the image drift for a few seconds, and taking another image. The images can then be co-added and the line between the two images of the same star delineates the East-West direction.

## *Other Image Processing Techniques*

The host software uses other image processing techniques besides contrast enhancement, smoothing, inversion, and photometric analysis. These other techniques are discussed in this section.

### *Flipping the Image*

Some inspection will reveal that the screen image is flipped about a horizontal axis relative to the CCD. The horizontal and vertical flip commands enable a picture to be oriented correctly no matter what combination of

telescope and prisms is used to form the image. Also, the flip commands are quite useful for making an image's orientation match that of published images. These commands actually modify the image data, and hence the results of using these commands are retained if the image is saved after these commands are applied to an image.

### *Zooming*

The host software allows you to zoom in on an area in the image by moving a zoom-box over the image until the zoom-box is positioned at the desired region where the zoom may be completed. The zoom-box is quarter sized (48 x 41 pixels), and the pixels within it are then zoomed to a full 192 x 165 sized image and interpolation used to fill in the "missing pixels". The zoomed image can then be used with all the photometric analysis software, etc., and can also be saved. Depending on the amount of host memory available when the zoom is performed, the zoom either writes over the original image data (you are warned first) or the original data is retained and the image can be un-zoomed later (unless the zoomed data is saved on disk in which case the original un-zoomed data is discarded).

Zooming can be quite handy for examining close binary stars, and small detail, but is no substitute for higher magnification images since the zooming process doesn't contain any more information than the original 192 x 165 pixel image contained.

### *Histograms*

The host software can also calculate and display an image's histogram, which is a count of the number of pixels at each of the 256 possible (0 through 255) intensity levels. The histogram can be useful for determining the settings of the *Background* and *Range* contrast parameters (like the Auto-Contrast does), for determining the dark current or sky background level, and for determining the optimum exposure time.

### *Dithering*

Although the images from the CCD camera can have 256 possible intensity levels or gray-scales, not all computers have the ability to display such a wide range. Some graphics displays can only display two colors; black pixels and white pixels (Hercules adapters and Mac Pluses for

example). Something must be done on these displays or else images would not look good due to their ultra-high contrast or lack of gray scale. In these cases a technique called dithering is used to increase the number of gray scales available.

Dithering involves using a cell of display pixels (2 x 2, 3 x 3, etc.) for each image pixel, and strategically turning on combinations of pixels within that cell to simulate the gray scale. This works well because the eye does a good job of averaging the intensity over the entire cell. The trade-off is that you require a larger number of pixels for an image, or must decrease the spatial resolution of the image to accommodate a fixed number of pixels.

Dithering can also be used to increase the gray-scale capabilities of displays with more than two but a limited number of gray-scales or colors. For example, a 2 x 2 dithering cell gives 61 different gray scales on a display adapter with only 16 shades of gray (such as the high-res VGA mode and some Macintosh II video cards).

## *Making the Camera Connection*

An important aspect of the host software is its ability to interface to and communicate with the ST-4 over the serial port. If you have ever dealt with serial interfaces you should be happy to know that much effort has been given to make the host to ST-4 interface as easy as possible while maintaining a high degree of compatibility and flexibility.

On power-up, the ST-4 wakes up at 9600 baud, which is quite safe in terms of being able to establish a reliable communications link with the camera, but which is also a bit taxing of your patience in terms of image download times. The host can however program the ST-4 to communicate at any baud rate from a lowly 1200 baud to the highest rate of 57.6K baud. The actual baud rate used will depend on how you configure the host program and/or the environment in which the host and ST-4 exist (mainly the cable length between the host and the ST-4). The host software can be configured to talk to the ST-4 at the fixed baud rates of 1200, 9600, 19.2K, and 57.6K or can be configured for Auto Baud mode.

In the fixed modes, the host software will program the ST-4 to the selected baud rate and always attempt to communicate at that rate. In

some circumstances it may be possible to pick too high a baud rate for reliable communications, and a lower rate may need to be selected. This is described further below.

In the Auto Baud mode the host software will sequentially program the ST-4 for the highest possible baud rate (57.6K baud), and then test the communications link, lowering the baud rate as necessary to establish a link with the camera. The only times this "auto baud" process will occur is when the host software is first run or when the Establish link command is executed under user control. Another feature of the Auto Baud mode is that if the host ever loses the communications link with the ST-4, it will search around (in baud) until it finds the camera or gives up. In this case however, it will not try to change the ST-4's baud rate, but will continue to communicate at the discovered rate.

We suggest you use the Auto Baud mode, and let the computer determine the best communications rate. If you do, you should always make sure the communications link is established with the ST-4 prior to downloading images, by either having the ST-4 connected to the selected port and powered-up when the host software is first run, or by explicitly establishing the communications link using the Establish link command. Also, if you ever turn off the ST-4 or lose contact with it you will need to use the Establish link command to re-program the highest possible communications rate. If however you always use the same configuration (cable length, environment, etc.) then selecting one of the fixed rates may slightly speed up the start-up phase of the host software since it won't have to run the "auto baud" process.

**Important Note:** The ST-4 sends a check digit with each line of data. The host software verifies the data using this check digit. If it does not agree, the computer requests that the line be sent again. After four sequential failures a communications link failure is indicated. Under no circumstances will garbage data be transmitted and displayed without the operator knowing it.

## *Images and Image Modes*

This section discusses the different types of

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images you can take, and the different image modes that the host software and ST-4 support to make it easier to take images of the variety of celestial objects.

## *Light and Dark Frames*

Taking a typical long exposure requires several steps. The simplest technique is to take a long exposure of the object, save the image, and then take an exposure of identical length with the telescope blocked, and save this image also. The image of the object will be referred to as the light frame, and the blocked frame as the dark frame.

When the dark frame is subtracted from the light frame (using the host software) the random variations in the dark current from pixel to pixel are eliminated and the picture quality improves considerably, becoming much smoother and less noisy. Exposures longer than 10 seconds can generally be improved by this technique. The only drawback with this technique is that the range of the data is reduced. The 8 bit readout electronics produce a value ranging from 0 to 255 for each pixel, and if the dark scene has an average value of 191, only 64 units of range are left in the image. This is more than adequate for producing an attractive image, but better performance can be achieved by boosting the gain as discussed in the "Baseline and Gain Parameters" section below.

## *Co-Adding Images*

In addition to subtracting dark frames from light frames, the host software allows you to add images together. You will typically use this on long exposure images to reduce the noise or smooth the data by increasing the signal level.

As previously mentioned, you can not take infinitely long exposures because the CCD will eventually saturate from the effects of the dark current. You can however add several long exposures (after subtracting the dark frames from each of the light frames) to make an image which, while not exactly the same as a longer exposure, will have the added benefits of greater signal to noise (S/N) and show less graininess.

In practice, you will typically add three or four images together. Adding more is not much help because the improvement in S/N goes as the square-root of the number of co-added images; two co-added images increases the S/N to 141%, three increases it to 173%, four increases it to

200%, and nine would increase it to 300%. Also you will typically only be able to add a few images before large areas of the image saturate since the sum of the images is still restricted to an 8-bit number (0 through 255).

When co-adding images, you must tell the host software how much (if any) to offset the 2nd image by (in both X and Y) to correctly line up with the 1st. You can determine these offset amounts by noting the pixel position of some star or particular feature on each of the images you wish to co-add.

## *The Anti-Blooming Gate*

CCDs suffer from an effect called blooming that occurs when photons continue to strike pixels that are saturated. The effect manifests itself as streaking around objects which are roughly five times as intense as a star which just saturates the pixels (for a given exposure time). This effect varies from device to device, and the CCD used in the ST-4 has some special electronic circuitry to reduce the effects of blooming. The ST-4 and the host software allows an "Anti-Blooming Gate" to be selectively enabled during exposures which will inhibit blooming of objects up to 100 times the saturating brightness level.

You will typically want to use the Anti-Blooming Gate on long exposures. It bleeds off charge from the CCD pixels, and reduces the CCD dark current, allowing longer exposures. Its only deleterious effect is that it tends to slightly broaden bright objects (such as stars), which is far more appealing than the detracting streaks associated with bloomed objects.

## *The Baseline and Gain Parameters*

As previously mentioned, long exposures will reduce the dynamic range of images with the background level due to dark current taking up a good portion of the overall dynamic range available. Again, this is because with the dark current background using say 191 counts, only 64 remain for the image data itself. This can be avoided using a technique where one first takes a dark exposure of the intended duration, sets the electronic readout baseline level (referred to as the *baseline* in the host software) slightly lower than the background level value in the dark image, and then boosts the *gain* by 2, 3 or 4 times to reduce the effects of digitizing the data. The light frame and dark frame are then captured and subtracted as before.

This technique is also useful for short exposures of faint objects, which do not begin to saturate the CCD (levels of 255). Set the *baseline* to the dark sky level, and boost the *gain* by 4 if short exposures are unavoidable due to drive errors, etc. The noise of the CCD is greater at higher pixel values; a boost of four is useful for images in which the CCD pixel does not reach one quarter of saturation, while a boost of two is all that is useful at pixel levels near saturation.

**Note:** The CCD has occasional "hot" pixels which saturate first in a long exposure. These hot pixels can show up in a subtracted image as a black pixel, since the saturated value is the same in light and dark exposures. Keeping the maximum exposure below that required to fill the CCD pixels 50% of the way will effectively eliminate this problem.

### *Automatic Dark Frame Subtraction*

As mentioned previously, the ST-4 has memory for two image buffers, a light buffer and a dark buffer. The host software allows you to capture a dark frame and retain it in the ST-4, then on subsequent light images, you can have the ST-4 subtract that dark frame from the light images immediately after the image is readout from the CCD and prior to it being sent to the host.

As always, you must manually cover the telescope when you ask the host software to take the dark frame. This is handy for searching an area for an object of interest, but for your final images (the ones you really want to keep) you will want to capture and download both light and dark frames and let the host software do the subtraction. This is so the time difference between the light and dark frames will be as small as possible and hence any possible change in the CCD's temperature and dark current will be minimized.

### *Focusing and Special Imaging Modes*

To facilitate focusing, imaging planets using the half frame mode alluded to above, taking a series of images and selecting the best, etc., the host software supports the following image sub-modes in a grouping under a mode of operation called the Focus Mode:

**Full Frame Mode:** In this mode the host software continually takes full frame images, and downloads them from the ST-4 and displays

them.

**Half Frame Mode:** This mode allows using the upper half of the CCD as an image buffer for bright objects as described in the "Caveats of CCD Readout" section before. Because only half of the image is downloaded from the ST-4, the data transmission time is only half as long as in the full frame case. Finally note that the only way you can take Half Frame mode images is through the Focus Mode.

**Quarter Frame Mode:** In Quarter Frame Mode, the host software first takes and downloads a full frame image. The user then specifies an area of the full image equal to a quarter frame by positioning a square on the full frame image. The host software then takes full frame images but only downloads the pixels within the quarter frame specified by the user, resulting in a transmission time which is 1/4th as long as for full frame images.

**Low-Res Mode:** This mode, also called one of four mode, is also faster than the full frame mode at the cost of image resolution. After each image is taken, the ST-4 reduces the image to 1/4th the number of pixels by replacing each group of 2 x 2 pixels by the average of the group. The host software then downloads that 1/4 sized image, which only takes 1/4th the transmission time of a full frame image. Prior to displaying the image, the host software expands the image up to its full size by interpolating between pixels. The resulting image has 192 x 165 pixels but has lower resolution than a full frame image due to the image reduction and expansion. This mode is very handy for finding faint objects since the entire field is transmitted and the update time is fast.

**Spot Frame Mode:** In this mode, after each image is taken, the ST-4 searches through the image and locates the brightest pixel. It then reports that value to the host, which in turn downloads a small subset of the image pixels surrounding the bright spot (33 x 27 pixels). The greatly reduced number of pixels drastically reduces the data transmission time which is quite handy for focussing on stars.

**Track Frame Mode:** Like Quarter Frame Mode, in Track Frame Mode the host software first

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takes and downloads a full frame image. The user then specifies an 33 x 27 pixel area of the full image by positioning a square on the full frame image. The host software then takes full frame images but only downloads the pixels within the 33 x 27 pixel area specified by the user, resulting in a short transmission time and hence a rapid frame update rate. The image is displayed with a cross hair drawn through the center, and while the screen is in the continuous update mode you (through the host software) can move the telescope (if the relays in the ST-4 are hooked up) or the telescope can be moved manually. The telescope can be guided on a faint star by viewing the screen and making corrections, which is much less fatiguing than guiding through an eyepiece in an awkward position. This mode can be used to guide on stars too faint for the ST-4 to lock on, since the eye-brain combination is better at recognizing a faint stellar image in the presence of grainy readout noise.

In all the Focus sub-modes described above, the host software displays the coordinates and intensity of the brightest pixel in the CCD. Additionally the host software can be configured to pause between images, until the user gives the go-ahead, and the host software can be configured to use the Auto-Contrast feature when displaying the data or can use *Background* and *Range* values set by the user. Although the host software has commands for simply taking an exposure and downloading the image you will find yourself using the Focus mode the majority of the time. Table 2 below shows typical pixel values you should see for various magnitude stars for a well focussed image. These assume a 1 second exposure and typical value of 10000 for the CCD calibration factor.

Star Magnitude	Star Intensities	
	60mm Refractor	8 inch SCT
4	255	255
5	150	255
6	60	255
7	24	208
8	10	83
9	4	33
10	1	13

Table 2 Typical Star Intensities

## Capturing and Viewing an Image

Capturing and viewing an image at the telescope usually requires the following procedure:

- 1) Find a bright star.
- 2) Focus the star.
- 3) Center the telescope on the desired object.
- 4) Grab an exposure of the object.
- 5) Grab a dark exposure if desired.
- 6) Subtract the dark exposure from the light.
- 7) Display the image and optimize the contrast.

Start by inserting the CCD camera head into the eyepiece tube of the telescope and entering the Focus Mode. Configure the Focus Mode for an exposure time of 1 second, full frame, automatic update, no auto-contrast, and set the *Background* to 0 and the *Range* to 255.

The computer will begin displaying the field, updating the screen about every 10 seconds. Position a bright star (magnitude 3 to 5) in the center of the field and focus the image to achieve the smallest spot. It is usually best to maximize the peak value of the star image, which is displayed in this mode, rather than rely on the size of the spot to define the best focus.

Some difficulty may be encountered in finding the star in the field of view. Use an eyepiece in the tube to center the star before inserting the CCD head. The CCD is quite small, so try to position the star within the center 10% of the field of view of a low power eyepiece. When the star has been found, centered, and focused take the time to accurately center the star in the guide scope to make finding objects easier in the future. Also, remove the CCD head, insert an eyepiece in the tube, and focus the eyepiece by sliding it within the tube. When best visual focus is found scribe the side of the eyepiece so the telescope can be quickly set close to the optimum focus the next time. Replace the CCD head, taking care to always seat it securely against the tube.

Now that you have found an object, exit the Focus Mode, and vary the *Background* and *Range* parameters to modify the display. Small values of *Range* have the effect of increasing the contrast. Stars get fatter due to the fact that the stray light near the main image is being seen, but nebular detail becomes more visible. The

*Background* should typically be set to correspond to the levels of the black regions in the image (these levels can be determined using the crosshairs).

Try out the different frame modes. Position the star in the bottom half of the display screen and then try the Half Frame mode. You will note that the star image appears in the upper portion of the screen. Move the star off the screen to the top by moving the telescope and you will note that the star reappears, but badly smeared (for a bright star). This is important. If, in the Half Frame mode, you have a badly smeared image it means that you need to move the star or planet down in the field to correctly position it for optimum imaging. Finally try out the Quarter Frame and Low-Res modes, and try out the two 33 x 27 pixel modes.

## Using the ST-4 with an IBM PC or Compatible

This section describes the PC host software for using the ST-4 as an imaging camera. You will want to read it if you plan on connecting the ST-4 to an IBM PC or compatible computer. Also, prior to reading this section you should read the "Host Computer Software" section above.

### *Making the Camera Connection*

The ST-4 is connected to the computer using the serial cable provided with the unit. The cable should be connected between the ST-4 and the computer serial port, either COM 1 or 2. RS-232 serial connectors on PCs and compatibles generally come in 2 varieties, with either a 25 or 9 pin connector. Hopefully you specified the type you require when you placed your order and you have the necessary adapters in the box. If you did not, please contact SBIG or go to your local Radio Shack, and obtain the necessary adapters.

**Note:** As the software comes on the distribution disk it is configured for using COM 1. If COM 1 is available you should initially use that port. Otherwise you can use the COM 2 port but the software will have to be configured for it (described later but for now don't worry about it). Also the software remembers the port for which it has been configured and will only have to be changed if you switch COM ports.

### *Running the Program*

Before running the ST4 program, please make a backup copy of it following the procedures described in the DOS manual, and save the original in a safe place. After successfully connecting the ST-4 to your computer, power up the ST-4 and computer, and run the program.

**Note:** The PC version of the ST4 program (CCD.EXE) requires several other files found on the floppy disk to run. The CGA.BGI, EGA.BGI, etc. files are



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graphics drivers for the various types of graphics cards supported by the program, and the CCD.CFG file retains the settings of key parameters (exposure time, etc.). If you wish make an additional running copy of the program (say to run on your portable computer, etc.) make sure you copy these files in addition to the CCD.EXE file.

After you have made a backup copy of the program and stored the original away you may run the program by doing the following:

*If you do not have a hard disk:*

Insert the program disk into the disk drive, and get into the drive directory by typing:

A: (and then hit enter)

You can then run the program by typing:

CCD (and then hit enter)

*If you have a hard disk:*

You can transfer the program and configuration files to your hard disk using the DOS copy command as described in your DOS manual.

After copying the files to your hard disk you can run the program by first getting into the directory that contains the CCD.EXE file, and then typing:

CCD (and then hit enter)

Once you are in the program, the program automatically initializes the serial port, and searches for the ST-4. Since the software has been configured (by the factory) for the Auto-Baud mode, if it finds an ST-4 it increases the baud rate up to the maximum the hardware will accept. A screen message will then inform you that communication has been established and show the baud rate.

If you get a communication failure message, recheck your cables, make sure the ST-4 is powered on (red numbers should appear on the display). Ignore any problems until you have read the section below describing the PC command. Then check the configuration of the COM port and use the Establish link command.

## *Elements of the User Interface*

This section describes the user interface of the CCD program. We hope you will find the user interface to be both friendly and efficient.

When you first enter the CCD program you are put into the Command Mode. The top line of the screen displays the main menu of commands and is referred to as the menu bar. A command can be selected by moving the highlighted menu cursor to the command name using the left and right arrow keys. The selected command may then be invoked by pressing the Enter key. An alternative to using the arrow keys to select the command and pressing the Enter key (to invoke the command) is to simply press the first letter of the desired command. To help you remember this, the first letter of each of the commands has been highlighted for you.

Below the menu bar towards the bottom of the screen are two boxed in areas called the Status box and the Data Buffer information box. The Status box is used by the CCD program to communicate passive information to the user such as the introductory message presented when the program is first run. The Data Buffer information box indicates whether any image data is currently held in memory, whether that data has been saved on disk or not, and whether the image has been zoomed (and thus could be unzoomed).

The blank area between the Status box and the menu bar is used for interacting with the commands from the menu bar through pop-up command screens and for important messages from the CCD program which are also shown in pop-up message boxes.

Become familiar with the screen by looking at each of the commands shown on the menu bar, and by invoking the commands to examine their associated command screens. You can exit from a command screen and return to the menu bar by pressing the ESC key. If you hit the ENTER key within any of the command screens, that command will immediately execute.

Each command screen consists of several parameters which can be changed by moving to the desired line and changing the setting. You move the flashing cursor up and down through the command screen parameters using the UP ARROW and DOWN ARROW keys or using the TAB and SHIFT-TAB key combinations.

Also note that the descriptive text to the left of each parameter contains a single highlighted character. The highlighted character indicates that you can move directly to that parameter by pressing the ALT key in conjunction with the highlighted character.

The method used to change a parameter's setting depends on the type of parameter, of which there are two: Ones where you select a single choice from a list of choices and ones where you type in some number or text. To select a specific setting use the LEFT and RIGHT arrow keys to highlight your choice. To change the setting of an entry type item you type in the value or text. You can use the BACKSPACE key to edit a value, or the DEL key to completely erase all the text entered in the parameter.

The *Grab*, *Focus*, *Display*, and *Image I/O* commands are routinely used in acquiring and viewing images, while the *Camera/Scope* and *PC* commands are used to control the computer and ST-4 configuration. Please keep in mind when using the command screens that the cursor keys or the TAB key are used to move around within the screen. Hitting the ENTER key will cause the command to immediately execute, and the ESC key will get you out of the screen and abort most commands.

## *Image Processing and Analysis*

This section describes the commands used for image processing and analysis; the *Image I/O*, and the *Display* commands as well as some portions of the *PC* command.

### *The Image I/O Command*

As its name implies, the *Image I/O* command is used for storing and retrieving images to and from disk, and is also used for co-adding images, subtracting dark frames, and editing the telescope factors and calibration value used when capturing an image and saved with the image on disk.

The path parameter tells the computer which directory to look in for files used in the *Image I/O* command. The path should be blank (or set to ".\") to load and save files to the default directory (the one you were in when you ran the CCD program). Typically you will have a computer with a hard disk, or one with just floppy drives, and should follow the directions in the next two paragraphs:

**If you have a hard disk:** You will probably have the CCD program in a directory called CCD. You could save your files in another directory called DATA (that you had previously created) by using a path definition of C:\DATA\. You could save the files to a floppy disk drive by using a path of A:. Floppy disk drive operations are slower than hard disks, so it is best to save to the hard disk, and later save the valuable files to a removable floppy.

**If you do not have a hard disk:** First load the CCD program into memory from the A: drive, then remove the CCD source disk and insert a formatted blank disk for data storage. Use a path of A: or B:, whichever is appropriate. If you have two disk drives you can keep the source disk in A: and store the data in B:. Remember to reinsert the source disk into the A: drive before exiting the program (if you only have one drive) so that the configuration data can be saved upon exiting.

You can also set a filter in the *Image I/O* command. A filter tells the computer to only look for files with a certain name or extension. A filter entry might be \*.PIC or \*.ST4, where the asterisk is a wild card character. You can use any filter that is valid for MS-DOS, just like with most of the MS-DOS commands like copy, erase, etc.

To load a file with the *Image I/O* command, use the cursor to highlight the Load operation, and hit ENTER. You will be presented with another command screen showing the files in the specified path matching the filter parameter. Select the desired file using the cursor keys, and hit ENTER again. The file will be loaded, the Status box will show an annotation attached to the image, and the values of the telescope parameters associated with the image, and the Data Buffer information box will be updated to reflect that fact that an image has been loaded. After loading an image you would typically use the *Display* command to display it.

**Note:** The directory command screen shows a maximum of 40 files. The files are sorted into alphabetical order, and you can move the cursor by hitting the starting letter of a file name. For

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example, hitting the "T" key positions the highlighting cursor on the first file name starting with "T". This same directory command screen is used whenever the CCD software asks you to pick a file from the disk. Since you will not be able to access any files beyond 40 in each directory, you should try to keep you images arranged with a maximum of 40 per directory.

To save a file that has been downloaded from the camera or has been changed, select the **Save** operation and hit ENTER. You will be asked for the name of the file, and the file will be saved in the directory specified by the Path parameter. If you pick the name of an existing file, the software will ask you if you wish to overwrite the file before it actually performs the Save operation.

The **Add image** operation can be used to co-add an image on disk to the one in memory. Upon invoking this operation you will be presented with the same command screen used in the Load operation where you can select the file you wish to add. After selecting a file you will be presented with a third command screen where you can specify an X and Y offset. The X and Y offsets are the offsets of the image to be added from the one in memory.

The **Dark subtract** operation can be used to subtract a dark frame stored on disk from the light frame currently in memory. A value of four is added to the light image before the subtraction is performed to insure that clipping of the image does not occur due to slight offsets between the two exposures.

Selecting the **Edit parameters** operation allows you to change the file annotation, and edit the telescope factors (aperture area, focal length, and calibration factor) saved with the image.

**Note:** Magnitude corrections made in the crosshair mode described below modify the calibration factor automatically.

## *The Display Command*

The **Display** mode (accessed through the Display command) is used to examine the image stored in the computer's memory by a previous **Focus**, **Grab**, or **Image I/O** operation. Each of the

parameters in the Display command screen and their effects are discussed below:

**Format:** This item allows you to select whether the image itself is displayed (*Image* option) or whether the image's Histogram is displayed (*Histogram* option).

If selected, the Histogram is shown in a tabular format, with the Average intensity level and the 1% intensity levels shown. The Average intensity can be helpful in setting the *Background* parameter for adjusting the image contrast. The 1% Level can be used to determine the proper setting of the *Baseline level* to increase the dynamic range of long exposures as discussed in the "Baseline and Gain Parameters" section above. Finally, if the Histogram is selected in the Display command screen, the settings of the other parameters have no effect, and needn't be changed.

If the *Image* option is selected, then the image is displayed using the graphics capability of your display adapter. In the *Image* mode, the other parameters in the Display command screen affect the image display as described individually below. Also note that some settings in the PC command will affect the image display, which will be discussed later.

**Auto contrast:** Setting this item to *Yes* enables the Auto-Contrast mode where the computer sets the *Background* and *Range* parameters based upon the image's histogram. If you do want Auto-Contrast, don't change the setting of the *Background* and *Range* parameters below or the software will automatically de-select Auto-Contrast before displaying the image. This feature allows you to specify manual contrast mode by merely changing the setting of the *Background* or *Range* parameters and not worrying about whether you forgot to turn Auto-Contrast off.

**Background:** This is the *Background* parameter which determines the "black level" of the image.

**Range:** This is the *Range* parameter which controls the contrast of the image.

**Smoothing:** Setting this item to *Yes* causes the image to be smoothed prior to display, a feature which reduces the graininess of faint nebula, and brings out very faint stars. The

smoothing process slows down the display process slightly and blurs the image slightly, so it is not desirable when close double stars are being examined, for example.

**Negative image:** Setting this item to *Yes* causes the image to be displayed as black on a white background, similar to a photographic negative. This can also be used on LCD type displays popular on portable computers to make the image appear as a positive, negating the effects of the LCD display's inherently "negative" graphics display (pixels turned on are black on an LCD vs white on a CRT).

**Display mode:** When this parameter is set to *Analysis* the image is displayed with its annotation, and several other pieces of textual information, including a Display Mode menu. In this mode you have full access to the crosshair routines, image zooming, etc., as discussed in detail below.

When this parameter is set to *Photo* the special Presentation Mode is activated, and you can not access the crosshairs, etc. In Presentation mode, the horizontal axis of the image is expanded or compressed by the amount specified in the *Aspect ratio* item in the PC command. Once entered, Presentation Mode is exited by hitting any key.

**Color select:** (*VGA systems only*) In color mode, images are displayed with 60 hues using a color table which is like color temperature, using blues for dark colors, progressing through reds and yellows up to white. In monochrome mode (this item set to *Grey scale*), images are displayed with 60 shades of grey. This works correctly even on a color monitor.

### *Display Analysis Mode*

In Display Analysis Mode, the image is shown to the right of the screen with the image annotation displayed above the image, a Display Menu below the image, and a block of text to the left of the image showing the settings of the *Background* and *Range* contrast parameters and whether the image has been smoothed or zoomed.

The Display Menu has four commands described individually below. Each of the commands can be accessed by pressing the first letter of the command which has been

capitalized to help you remember.

**X-Hairs:** Executing this command enters Crosshair Mode used for examining pixel brightnesses and magnitudes. The Crosshair Mode is described fully below.

**Horiz flip:** Executing this command causes the image to be flipped about a horizontal axis, and redisplayed with that new orientation. This command actually flips the image data, and the effect will be remembered if the image is saved after this command is executed.

**Vert flip:** This command is identical to the **Horiz flip** command above except that the image is flipped about a vertical axis.

**Zoom:** Executing this command does one of two things, depending on whether the image had been previously zoomed or not (shown in the upper left of the screen). If the image had been previously zoomed and was not saved on the disk, executing the **Zoom** command restores the image to its un-zoomed state. Otherwise executing this command enters Zoom Mode where a portion of the image can be enlarged to the full size of the image, and is described in more detail below.

**Esc:** Hitting the ESC key while in Display Mode returns you to the Command Mode and redraws the menu bar, Status box, etc.

### *Crosshair Mode*

When Crosshair Mode is entered, the Display Menu below the image is replaced with the Crosshair Menu, the block of text in the upper left corner of the screen is replaced by 8 lines of Crosshair Parameters, and a '+' shaped Crosshair is shown superimposed over the image.

The Crosshair Parameters are updated as the Crosshair is moved around the image and are described individually below. You should refer to the "Crosshairs and Photometric Analysis" section of the host software description above for a description of the the Magnitude and Diffuse Magnitude calculations:

**Pixel:** These are the X and Y coordinates of the Crosshair. Location 1,1 is in the upper left corner of the image.

**Value:** This is the intensity of the pixel directly under the Crosshair as recorded by the ST-4, and is a number from 0 to 255.

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**Sm-Value:** This is the average value of the pixel directly under the Crosshair and all the pixels inside a box centered under the Crosshair. The size of the box can be changed and is shown in the **Boxsize** parameter.

**Mag:** This the magnitude of the star underneath the Crosshair. This value is calculated from the pixel values within the box, and telescope and calibration data stored with the image. In most cases an accurate calculation of magnitude requires the sky background to be subtracted. The Crosshairs should be moved to a dark region of the image, and the B key hit (executing the **Background** command) to take a background reading. The **Mag** parameter then displays a 99. The Crosshair should then be moved to the desired star; the background will be automatically subtracted and the correct magnitude displayed.

**Difmag:** This is the diffuse magnitude, and is used to measure the brightness of diffuse objects such as nebulae or galaxies in units of magnitude per square arcsecond. Using a large box size improves the accuracy of this reading (provided the box is smaller than the object), enabling extremely low surface brightness objects to be measured.

**Sep and Angle:** These are the separation (in arc-seconds) and the angle (in degrees, clockwise of vertical) between the current position of the Crosshair and the reference position fixed using the **Centroid** or **Star** commands in the Crosshair Menu.

The crosshairs can be moved using the cursor keys, or moved faster using the 2, 4, 6, and 8 keys on the numeric keypad (if you have one). The I, J, K, and M keys are also treated as a "pseudo-keypad", and will move the Crosshair in addition to the SHIFTeD versions of those keys. All in all, we find it easiest to keep one hand on the SHIFT key and use the other to work the cursor keys.

Each of the commands in the Crosshair Menu and their effects are discussed below. Each command can be executed by pressing the key corresponding to the first letter or character in that command.

**Star:** Executing this command fixes the reference position for the Separation and Angle

measurements at the current position of the Crosshair.

**Centroid:** This command is like the **Star** command above, but higher accuracy positioning of the reference is achieved for stellar objects by determining the center to subpixel accuracy.

**Background:** This command records the background level used in the magnitude calculations to the average value of the pixels inside the box centered under the current position of the Crosshair.

**Toggle box size:** Executing this command toggles the boxsize used in the average pixel, magnitude, and diffuse magnitude calculations through the possible values of 3 x 3 through 11 x 11. The program goes back to the image point where a background measurement was last made and makes another reading at the new box size when this command is executed.

**+Mag, -Mag:** These commands modify the image's calibration factor so that the calculated magnitude can be corrected as required for stars of known magnitude. The SHIFT + and SHIFT - keys change the magnitude by 0.01 magnitude, while the unshifted keys (= and -) change it by 0.1 magnitude. The keys on the numeric keypad work differently. The calibration factor can be expected to vary slightly with the transparency of the night, or the elevation angle of the stars. Atmospheric absorption is a significant factor when accurate measurements are desired

**Esc:** When the ESC key is pressed in Crosshair Mode the program exits that mode and returns to Display Mode.

## *Zoom Mode*

When Zoom Mode is entered, a zoom-box is drawn superimposed on the image and the Display Menu is replaced with the Zoom Menu. The zoom-box can be moved around on the image using the same keys used to move the Crosshair (cursor keys and 2, 4, 6, and 8). When the zoom-box is positioned appropriately, pressing the ENTER key causes the image data within the zoom-box to be expanded to the size of a full image. The newly zoomed image is displayed, and Display Mode is entered. Pressing the ESC

key while in Zoom Mode merely cancels that mode and returns to Display Mode without performing the zoom.

Zooming actually replaces the image data in memory with the zoomed image. If the CCD program has enough memory, the un-zoomed image is retained, and the image can be un-zoomed later by invoking the Zoom command a second time (unless the zoomed image is saved to disk in which case the un-zoomed image is discarded). If there isn't enough memory, you will have been warned when the CCD program was first started.

## *Fine Tuning - The PC Command*

The PC command contains items for configuring the serial port used in communicating with the ST-4 and for fine tuning the graphics software used for displaying images. The items in the PC command are discussed individually below:

**Serial port:** This item allows you to select which serial port is used to communicate with the ST-4.

**Baud rate:** This item allows you to select the baud rate used in communicating with the ST-4. Please refer to the "Making the Camera Connection" section above for a detailed discussion of how the host software uses the setting of this item in communicating with the ST-4.

**Graphics card:** You can usually leave this item set to *Auto* and the CCD software will automatically determine the graphics capability of your PC and use the best graphics mode for displaying images. Some combinations of PCs and graphics adapters aren't fully compatible with this auto-detection software, and in those cases you can set this item to type of graphics adapter you have. *Strange and unusual results can occur if you specify a graphics card type that you don't have.*

**Note:** Some graphics adapters will support multiple modes such as VGA adapters that will also do CGA and EGA emulation. These adapters can be used in any of their supported modes.

**Note:** Each supported graphics adapter requires a BGI file in the same directory as the CCD program. For

example CGA mode requires the CGA.BGI file. All the necessary BGI files are contained on your master CCD program disk.

**Color display:** In general you will set this item to *Yes* if you have a color display or monitor attached to your graphics adapter. The setting of this item affects whether the Command Mode screens are in color or not, and affects the Display Mode as shown below for the various types of graphics adapter:

**EGA:** In color mode (this item set to *Yes*), images are displayed with 32 hues using blues for dark colors, progressing through light blues and greens up to white. In monochrome mode (this item set to *No*), 60 shades of gray are used. Due to the way EGA cards display colors, monochrome mode will only work correctly with a monochrome monitor.

**CGA:** Images displayed on CGA monitors are displayed using 4 colors. In monochrome mode (this item set to *No*), the order of the colors are rearranged to correspond to gray scale when used with a monochrome monitor.

**Hercules:** When used with Hercules adapters the setting of this item has no affect on the displayed image.

**Aspect ratio:** This item is used in the Presentation Mode of the Display command, and specifies how much the horizontal axis of the image should be shrunk (values < 1) or expanded (values > 1) to produce a square image on the monitor. The required settings will vary depending on the type of graphics adapter and monitor you have.

## *Taking Images*

This section describes the commands used for taking and downloading images from the ST-4, i.e. the *Camera/Scope*, *Grab*, and *Focus* commands.

## *The Camera/Scope Command*

The Camera/Scope command screen allows the

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user to setup the ST-4 and computer for optimum performance in taking images, and for indicating the telescope parameters. The items in this command screen affect images taken with both the **Grab** and **Focus** commands, and are described individually below:

## Camera Setup Parameters

**Establish link:** Setting this item to *Yes* and executing this command causes the CCD program to try to establish the communications link with the ST-4 as described in the "Making the Camera Connection" section before.

**Anti-Blooming gate:** This item allows enabling or disabling the Anti-Blooming gate during exposures as described in "The Anti-Blooming Gate" section before.

**Dark subtract:** This item enables or disables the ST-4's dark frame subtraction at the end of exposures as described in the "Automatic Dark Frame Subtraction" section before. Enabling this item *does not* cause the camera to automatically capture the dark frame. That must be done manually using the **Grab** command.

**Camera baseline level:** Set this item to the desired baseline level as described in the "Baseline and Gain Parameters" section before.

**Gain expansion:** Set this item to the desired gain as described in the "Baseline and Gain Parameters" section before.

## Telescope Setup Parameters

**Focal length:** Enter in this item the focal length (in inches) of the telescope you are using. When images are downloaded from the ST-4 the settings of this item and the two shown below are copied to the image.

**Aperture:** Enter in this item the aperture area (in square inches) of the telescope you are using.

**Response factor:** Enter in this item the desired setting of the calibration factor for the CCD. A typical value is 12,000.

**Note:** Enter in this item any desired annotation for the image. The note can be up to 78 characters long, but note that images displayed on CGA monitors will only show the first 40 characters.

## *The Grab Command*

The **Grab** command allows taking a single exposure, downloading, and displaying that image and is most convenient for long exposures. The exposure is taken after the command is executed (you hit ENTER), and pop-up message boxes indicate the progress of the exposure and image downloading. The parameters in the **Grab** command screen are discussed individually below:

**Exposure time:** This is the exposure time, and allowed settings range from 0.01 seconds through 10 minutes. The value is always entered in seconds.

**Take dark frame:** Setting this item to *Yes* causes the CCD software to have the ST-4 take an exposure and store it in the ST-4's internal dark frame memory (The image is not downloaded). This dark frame can then be subtracted from future images if the *Dark subtract* item in the **Camera/Scope** command is enabled.

**Auto display:** Setting this item to *Yes* will cause the image to be displayed after it is downloaded from the ST-4.

**Auto contrast:** Setting this item to *Yes* enables the Auto-Contrast feature if the image is automatically displayed after downloading.

**Background and Range:** These items are the *Background* and *Range* parameters used in displaying the image if it is automatically displayed after downloading but the Auto-Contrast feature is not enabled.

**Exposure delay:** Setting this to any non-zero value causes a delay to occur after the **Grab** command is executed and prior to the exposure taking place. The software will beep every second until the last three seconds where it will beep every half second.

**Skip exposure:** Setting this item to *Yes* causes the software to not take a new exposure, but download the image in the ST-4's memory (from the previous exposure).

## *The Focus Command*

The **Focus** command allows taking a series of exposures. It is the recommended mode to use when taking short exposures of planets or double stars, since many frames of data can be examined

and the best one, least corrupted by atmospheric seeing, saved to disk. The parameters in the Focus command screen are discussed individually below:

**Exposure time:** This is the exposure time, and can range from 0.01 seconds to 10 minutes. The value is always entered in seconds.

**Auto contrast:** Setting this item to *Yes* enables the Auto-Contrast feature when displaying the images downloaded from the ST-4.

**Background and Range:** These items are the *Background* and *Range* parameters used in displaying the images after downloading when the Auto-Contrast feature is not enabled.

**Frame size:** Set this item to the desired frame mode as discussed in detail in the "Focusing and Special Imaging Modes" section before.

**Note:** The CCD software will only let you save images captured in the Full Frame, Half Frame, or 1 of 4 (Low-Res) Frame modes.

**Update mode:** Setting this item to *Manual* causes the CCD software to pause until the SPACE bar is hit after each image has been downloaded and displayed. This is quite handy when you are trying to select one good image from a series of images, waiting for a stable atmosphere, etc. The CCD software will only let you save a complete image, not one that was paused in mid-frame. Since in some frame modes it is difficult to exit the Focus Mode at just the correct time, using the *Manual* option alleviates this problem. Setting this item to *Automatic* enables Auto-Update mode where the software does not pause unless instructed to by the user.

After all the parameters have been set as desired and the ENTER key has been hit the CCD software goes into Focus Mode.

The Focus Mode screen looks similar to the Display Mode screen and shows a block of text in the upper left corner, a menu at the bottom, and as images are downloaded they are shown on the right edge of the screen, with a white box encompassing the image.

The block of text includes items displaying the frame mode, whether the Automatic update is enabled, the settings of the *Background* and *Range* parameters, and the value and X and Y

coordinates of the brightest pixel (Peak) from the CCD. The Peak parameters are updated after each exposure, before the image is downloaded and displayed.

The menu bar and image will vary depending on the frame mode selected in the Focus command screen. In general the commands in the menu allow the frame mode to be changed (without exiting the Focus Mode), and the Auto-Contrast and Auto-Update features to be toggled on and off. Hitting the SPACE bar momentarily pauses the Focus Mode until it is hit again, and hitting the ESC key exits the Focus mode and returns to Command Mode. Finally, some of the frame modes require some more detailed explanations given below:

**Quarter Frame:** When Quarter Frame mode is first entered, a full frame image is downloaded and displayed. The Focus Mode then pauses, and a quarter frame sized rectangle is drawn superimposed over the image. The rectangle can then be positioned as required using the same keys used with the Crosshair ( cursor keys and 2, 4, 6, and 8). After positioning the rectangle, hitting the ENTER key causes the Focus Mode to resume, taking and downloading the quarter frame images. If the position of the quarter frame image needs to be changed at any point you should switch to Full Frame mode and then back to Quarter Frame mode, starting the process over again.

**Track Frame:** Initially this mode works like the Quarter Frame mode described above, except that the rectangle is not quarter frame sized but 33 x 27 pixels in size. After the rectangle is positioned, hitting the ENTER key causes the Focus Mode to resume, taking and downloading the 33 x 27 pixel images, shown with a crosshair superimposed over the image. Zooming the images 4:1 can be invoked using the **Zoom** command in the Track Menu displayed at the bottom of the screen. Zooming makes it easier to see the image but slows down the display process, so use it as required. Finally, the cursor keys can be used to control the relays in the ST-4, where each key press causes one of the four relays to close for 0.2 seconds. Be careful to not hold the keys down too long or else the keyboard's auto-repeat feature will make it tough to control.



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**Note:** Although each cursor key will close one relay in the ST-4, the orientation of the cursor keys, compared to the direction the star will move as a result of closing the relays may not be correct. Essentially it's like using the hand controller; you will have to determine which cursor key is required to move the image in the correct direction.

## *Using the ST-4 with a Macintosh*

This section describes the Macintosh host software for using the ST-4 as an imaging camera. You will want to read it if you plan on connecting the ST-4 to an Apple Macintosh computer. Also, prior to reading this section you should read the "Host Computer Software" section above.

### *Running the Program*

Prior to running the Macintosh software (called SBIG ST4), please make a backup copy of the distribution diskette and put the original away in a safe place.

After the backup has been made, you should connect the ST-4 to your Modem port using the supplied serial cable, being careful to note the orientation of the cable since it has the same type connector on both ends. The cable supplied with the ST-4 will mate to the older style 9-pin connectors, and if you have a Mac Plus or later model computer you will need one of the mini-din to 9-pin adapters which can be purchased at your local Apple retailer if required.

At this point, the software can be run just like all other Mac programs; by double clicking on the application icon (the one with the telescope) or by double-clicking on any of the image icons (such as the Dumbbell image file). The later is preferred for now so you can try out a few of the image processing commands.

When the program is first started, it will display the About Dialog which can be dispensed with by clicking in the dialog or hitting the Return key. The program will then go out and look for a ST-4. It will tell you whether it finds one or not. If it didn't find one and it should have don't worry for now, but after you read the section dealing with configuring the serial port you should use the **Establish link** command to establish a communications link with the camera.

If you didn't double-click on one of the image files, use the **Open** command in the File menu to open one of the image files such as the Dumbbell image file.

## *Elements of the User Interface*

This section describes the basic elements of the user interface for the SBIG ST4 application program. We hope you'll find the program works like all other Mac programs, taking full advantage of the Mac's user friendly environment.

### *The Standard Windows and Dialogs*

A good portion of the user interface of many Mac programs, and this one in particular, involves the various windows used to let the user communicate with the program. The windows found in the SBIG ST4 program are introduced below and discussed in more detail later:

**Picture:** The **Picture** window is where the image is shown, and the title of the window is the name of the image file. Although this window has no size-icon in the lower-right hand corner, the image and hence the window can be resized using the *Expand 2x* Check Box in the **Contrast** Window.

**Note:** Those users with Mac IIs and gray scale or color graphics will achieve the best image display. The older monochrome Macintoshes (Plus, etc.) produce interesting images, but the lack of gray scale does not allow all the detail in the image to be seen. The photometric capabilities of the device are readily available, though. Also note the the software determines the color or gray scale capabilities of your system when it is first run. If you have a color display card and want to access the gray scale capabilities you will need to make sure your card is configured for more than 2 color or Black & White mode when you start the program.

**Contrast:** The **Contrast** window contains controls which affect the image display.


**Crosshair:** The **Crosshair** window shows several image factors resulting from the use of the **Crosshairs**.

**Histogram:** The **Histogram** window shows the image's histogram in a graphical format.

**Focus:** The **Focus** window is shown in **Focus Mode** and displays information about the status of that mode, and gives the user some control over focusing operations.

### *General Purpose Menus*

The other half of the user interface of any Macintosh program is the menu bar and its menus. This section describes a few of the standard menus in the SBIG ST4 program.

The  menu gives you access to all the desk accessories you have installed in your system, and an **About SBIG ST4** command which shows the information about the program, including the version. Knowing which version you are using is important if you ever have trouble with the program and contact us for technical assistance.

The **Edit** menu is common to all Mac programs, and probably needs no explaining except to say that the commands in this menu are provided for support of desk accessories only. Finally, the **Windows** menu allows you to bring an opened but buried window to the top by invoking the appropriate item in this menu.

### *Image Processing and Analysis*

This section describes the actions and commands used in image processing and analysis. This includes commands from the **File**, **Image**, **Dither**, and **Ops** menus, and elements of the **Contrast** and **Crosshair** windows.

### *Loading and Saving Images*

The commands in the file menu allow you to load and save images files to and from disk. Each of the commands for this purpose are described below:

**Open:** Use this command to load an image file from the disk. When an image file gets opened, the image is displayed in the **Picture** window and the **Contrast** window is opened. You can only have one image file open at a time, so you must close the current one if you want to open a different one.

**Close:** Use this command to close an image file, releasing it from memory. If the image is new or has been changed due to some image processing functions, you are asked if you want to save the changes or not. Unlike some Mac programs that use the **Close** command to

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close the front most window, this command always closes the image, independent of which window is active.

**Save:** Using this command saves any changes you have made to an image, and saves those changes in the original file, replacing the old image with the changed one. If the file is new and hasn't been saved yet you are bounced into the **Save As** command described below.

**Save As:** This command allows you to save the image into a different file than the original. If you happen to pick a name that is used by another file you are asked if you want to replace that file with the image file.

**Revert to Saved:** This command allows you to discard any changes you have made to an image by discarding the image and re-loading it from the disk. This command will only be enabled if some change has been made to the image.

If you haven't already done so, you should use the **Open** command to open one of the image files to try out with the image processing techniques discussed in the next few sections. A good example image is the Dumbbell image.

## The Contrast Window

As previously mentioned, the **Contrast** window contains controls which affect the displayed image, and will always be open whenever an image is loaded (from the disk or downloaded from the ST-4). In order to access any of the buttons or controls in this window, it must be made active first. Like any window, it may be activated by clicking in the title bar (or any other portion of the window).

Hitting the **Do It** button by clicking in it or by hitting the **RETURN** key causes the computer to read the settings of the other buttons and controls in the **Contrast** window and re-draw the image in the **Picture** window based on those settings. You will also have to do this whenever you change the dithering using the commands in the **Dithering** menu.

**Note:** While having to hit the **Do It** button may seem like extra work, changing the image is not instantaneous for all display modes and varies from model to model. You would not be happy if every

time you tried to bump the contrast up you had to wait a few seconds while the **Picture** window was updated.

The *Background* and *Range* parameters are shown and allow the image contrast to be adjusted as described in the "Adjusting the Contrast" section of the host software description above. The setting of these parameters can be changed in several ways. First, the value of each can be entered directly by clicking in the appropriate cell and typing in the desired value. You can also use the **TAB** key to switch back and forth between the *Back* and *Range* parameters. Second, there are four small buttons adjacent to each of the parameters. Clicking in the single or double up-buttons to the right of the parameter will increase its setting by 1 or 10 respectively. Likewise the down-arrow buttons to the left will decrease the parameter by 1 or 10. If you continue to hold the mouse button down, the parameter will continuously be adjusted until it reaches its limit or you release the mouse button.

Clicking the **Auto** button lets the computer determine appropriate settings for the *Background* and *Range* parameters (the **Auto-Contrast** feature) and updates the image display with those settings.

Finally, there are several check boxes in the "Processing" section of the **Contrast** window which are described below:

**Expand 2X:** Selecting this item makes the image be expanded to twice its normal size.

**Note:** Since the pixels on the Macintosh are square, and the pixels from the CCD are not, the software transforms the image into a 192 x 192 pixel image for display purposes. This preserves the image's overall aspect ratio.

**Smoothing:** Selecting this item causes the image to be smoothed prior to display.

**Interpolate:** Selecting this item when both the **Expand 2X** and **Smoothing** options above are selected enables interpolation whereby the "expanded pixels" between the 192 x 192 image pixels are the average of their neighboring pixels rather than just a copy of the neighboring pixels. This removes a fine graininess associated with expanded images.

**Invert:** Selecting this option makes the image

appear as black on a background of white, much like a photographic negative.

## *The Dithering Menu*

The commands in the **Dithering** menu select the type of dithering done on the image displayed in the **Picture** window. Macs with gray scale and color capabilities can choose from 16 and 256 gray scales, and all models can choose from the 2 color (black and white pixels) modes. Each of the options are described below:

**1 x 1 - 256 Color:** This mode is the highest resolution mode, allowing each of the 256 possible pixel values to be represented by a unique color. You will probably want to stick with this mode if you have an 8 bit video card. Technically a 1 x 1 dithering pattern actually corresponds to no dithering at all.

**1 x 1 - 16 Color:** In this mode the image is made by assigning one of 16 colors to each possible pixel value. This mode can produce some interesting displays, but users with only 4 bit video cards will probably want to use the 2 x 2 mode discussed below.

**2 x 2 - 16 Color:** In this mode, a 2 x 2 dither cell is used, with each pixel in the cell having one of 16 colors, yielding 61 hues. This is the best mode for users with 4 bit video cards. Images displayed in this mode without the **Expand 2X** option enabled will suffer a loss of spatial resolution.

**2 x 2 - 2 Color:** In this mode a 2 x 2 dither cell is used, with each pixel in the cell either being black or white, yielding 5 gray scales. This is the fastest display mode for Macs lacking true gray scale capability. Images displayed in this mode without the **Expand 2X** option enabled will suffer a loss of spatial resolution.

**3 x 3 - 2 Color:** This is identical to the 2 x 2 mode above except the dither cell is 3 x 3 yielding 10 gray scales.

**4 x 4 - 2 Color:** This is identical to the 2 x 2 mode above except the dither cell is 4 x 4 yielding 17 gray scales. While offering the greatest gray scale on black and white displays, the large size of the dither cell sacrifices image spatial resolution to provide the increased gray scale.

## *Photometric Analysis*

This section describes how to access and use the photometric capabilities of the SBIG ST4 program. For reference, the photometric capabilities were discussed in detail in the "Crosshairs and Photometric Analysis" section of the host software description above.

Prior to using the the crosshairs to investigate an image you should become familiar with two commands in the **Image** menu: **Edit info** and **Note**.

Invoking the **Edit Info** command brings up a dialog containing the telescope parameters associated with the image (discussed in the "Telescope Factors" section of the host software description above) as well as some image cropping parameters. Each item is discussed individually below:

**Focal length:** This is usually the focal length of the telescope used to take the image but can be changed by zooming, etc.

**Aperture:** This is the aperture area of the telescope used to take the image.

**Exposure time:** This is the image exposure time or integration interval.

**Calibration factor:** This is the calibration factor for the CCD. A typical value is 12000 and will scale with the gain (24000 at 2x, etc.).

**Cropping:** These four parameters determine the amount the image is cropped prior to display in the **Picture** window. The values correspond to the number of pixels to crop from each side, and are handy for removing the sometimes unsightly top line from the images.

These parameters are saved with the image, and the program also has a default set of parameters that are copied to newly acquired images. You can edit the default parameters by invoking the **Edit info** command and selecting the **Scope/Default** check box at the top of the dialog.

Each image can also have some descriptive text or annotation saved with the image. This text can be reviewed or changed by invoking the **Note** command. Also, newly acquired images initialize this text to contain the date and time the image was downloaded.

## *The Crosshair Command and Window*

You can activate the crosshairs when an image is

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open by invoking the **Show Crosshairs** command in the **Image** menu. Doing this opens the **Crosshair** window. When the mouse pointer is moved around in the **Picture** window, it will change its shape to a crosshair and values displayed in the **Crosshair** window will be updated to reflect the position of the crosshair. Each of the parameters are discussed below:

## Pixel Data

**X, Y:** These are the X and Y coordinates of the Crosshair. Location 1,1 is in the upper left corner of the image.

**Value:** This is the intensity of the pixel directly under the Crosshair as recorded by the ST-4, and is a number from 0 to 255.

**5X5 Ave:** This is the average value of the pixel directly under the Crosshair and all the pixels inside a 5 x 5 box centered under the Crosshair.

## Stretched Data

**Value:** This is the intensity of the pixel directly under the Crosshair as stretched by the *Background* and *Range* parameters to a value between 0 and 255.

**5X5 Ave:** This is the average stretched value of the pixel directly under the Crosshair and all the pixels inside a 5 x 5 box centered under the Crosshair.

## Magnitudes

**Absolute:** This the magnitude of the star underneath the Crosshair. This value is calculated from the pixel values within the 5 x 5 box, and telescope and calibration data stored with the image. In most cases an accurate calculation of magnitude requires the sky background to be subtracted. The Crosshairs should be moved to a dark region of the image, and the mouse clicked to take a background reading (also, a square will be drawn on the image to highlight the location of the background). The **Absolute** parameter then displays a 99. The Crosshair should then be moved to the desired star; the background will be automatically subtracted and the correct magnitude displayed.

**Diffuse:** This is the diffuse magnitude, and is used to measure the brightness of diffuse

objects such as nebulae or galaxies.

## Geometry

**Separation and Angle:** These are the angular separation and the angle (in degrees, clockwise of vertical) between the current position of the Crosshair and the background reference marker fixed by clicking the mouse in the **Picture** window.

**Note:** The **Picture** window must be active before clicking in it will place the background reference box/marker used in the **Magnitude** and **Geometry** calculations. This is why it appears that you need to double click sometimes to place the reference marker: The first click is used to activate the window.

If you find that the calculated magnitudes or separations are in error you can correct them by adjusting the telescope parameters with the **Edit info** command in the **Image** menu. Changing the calibration factor or the telescope aperture will change the calculated magnitudes. Changing the telescope focal length will change the calculated separation.

## *The Histogram*

When an image is open, the **Show Histogram** command in the **Image** menu can be used to open the **Histogram** window. The histogram is normalized, with the greatest histogram point representing a vertical value of 100. Also note that the histogram data points corresponding to pixel values of 0 and 255 are never allowed to determine the scaling factor, so half frame images, etc. will not have their histogram hidden due to the large number of zero valued pixels. On Macs with color or gray scale capability, a color bar is shown under the histogram showing the effects of stretching the image with the *Background* and *Range* contrast parameters. The histogram window can be closed by clicking in its close box or by invoking the **Hide Histogram** command in the **Image** menu.

## *Image Processing from the Image Menu*

This section describes the commands in the **Image** menu which have not been described yet: **Color Table** and **Presentation**.

If your Mac has color or gray scale capability

you can use the **Color Table** command to produce some dramatic and vibrant image displays. Using the **Color Table** command you can select from eight different color tables and modify or create them as you wish. A color table is a mapping from the 256 possible pixel values to display colors.

Invoking the **Color Table** command reveals a dialog with a box of 256 color table entries or cells, a pop-up menu, and several buttons. The pop-up menu is used to select an individual table from the 8 (maximum) possible tables. As the mouse is moved around in the box of color cells, a white highlighting rectangle as shown, and text in the lower left corner of the dialog indicates the cell number of the currently highlighted cell. The cell number shows the correspondence between the 256 possible pixel intensities or values and the colors used to display those pixel values. The color of any one cell can be changed using the familiar **Color Picker** dialog by double clicking in that cell. Finally, the buttons are described individually below:

**New:** This button creates and selects a new color table. The color table is initialized to be a gray scale color table. This button will be grayed-out if the maximum number of 8 color tables already exists.

**Delete:** This button deletes the currently selected color table. This button will be grayed-out if there is only 1 color table left.

**Rename:** This button allows you to rename the currently selected color table. Color table names can be up to 16 characters in length.

**Dup:** This button creates and selects a new color table which is an exact copy of the currently selected color table. We suggest you use this command whenever you wish to modify an existing color table since any changes made to a color table can not be undone otherwise. Also this button will be grayed-out if the maximum number of 8 color tables already exists.

**Ramp:** This button can be used to create a blend of colors between two cells. If you click in a cell and drag the mouse, a range of cells can be selected. Once a range of cells is selected, hitting this button causes the cells in the selected range to become a blend of colors between the two endpoints of the selection range. If the **SHIFT** key or the **CAPS LOCK**

key is held down when this button is hit, you are first allowed to pick the color for the two endpoint cells using the **Color Picker** prior to the cells being blended.

**Done:** Hitting this button dispenses with the **Color Table** dialog and uses the currently selected color table for displaying the image in the **Picture** window.

**Note:** You may wonder what causes the interesting effects sometimes visible in the **Picture** window while you are using the **Color Table** command. Essentially it is the Macintosh's system software. Each window can have its own color table, and with over 16 million possible colors, of which only a small sub-set (such as 256) can be displayed at one time, the system software gives the highest priority to the front most window. As the system software juggles the available colors, windows in the background don't get updated when the **Color Table** dialog is open and hence show the effects of the changed color environment. While this produces some interesting looking displays, it is not lasting or repeatable.

Finally, the **Presentation** command can be used to access the **Presentation Mode** where the image is drawn centered on the screen, with all the background (including the menu bar) being hidden and blacked-out. You can exit from **Presentation Mode** by simply clicking the mouse button.

### *Image Processing from the Ops Menu*

This section describes the image processing commands available in the **Ops** menu.

**Note:** The commands in the **Ops** menu modify the image data in memory, so the file will have to be reloaded (using the **Revert to Saved** command for instance) in order to return to the original display (except in some cases of the **Zoom** command).

Images can be co-added to one another using the **Mem+Disk->Mem** command. An offset can be entered to allow two images of the same object to be registered to increase the image quality. The

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**Mem-Disk->Mem** command is typically used to subtract off a dark background reading (to remove dark current fluctuations).

The **Flip Horizontal** and **Flip Vertical** commands allows flipping an image to match some preferred orientation. The **Highpass** command allows a highpass filter to be applied to accentuate the "edges" in the image, or the **Lowpass** command can be applied to smooth the image. The **Highpass** command will tend to bring out stars from an image showing both stars and nebulosity, but once applied to an image, any measurement of magnitudes is not applicable or even accurate.

The **Zoom 4 x 1** command allows a portion of the image to be magnified four times. Move the zoom-box which appears in the **Picture** window when this option is selected to the desired location (the zoom-box follows the motion of the mouse), and click the mouse button to update the display. If enough memory was available to save the un-zoomed image, the **Zoom 4 x 1** command will change to **Unzoom Image** which will restore the image to its un-zoomed state.

## *Making the Camera Connection*

Prior to taking and downloading images from the ST-4 you need to make sure the physical communications link between the Mac and the ST-4 have been established. When the software is first run it will try to find the ST-4. If successful you can probably skip this section unless you desire to change the communications speed, etc.

The **Communications** command in the **Camera** menu allows you to select which of the Mac's two serial ports to use, and the baud rate which is selected from a pop-up menu. Please refer to the "Making the Camera Connection" section of the host software description above for a detailed discussion of recommend baud rates, etc.

**Note:** Not all Macs will actually have pop-up menus, depending on which version of the system software you are using. On those Macs without pop-up menus, clicking (and releasing the mouse button) in the shadowed box to the right of the **Baud Rate** title will reveal a dialog with a list of items that can be used to select the desired baud rate. All other pop-up menus will work the same

way on these machines.

The **Establish link** command in the **Camera** menu will cause the software to go search for the ST-4 and establish the communications link, re-programming the ST-4's baud rate if necessary. This is a good thing to do if the software didn't find the ST-4 when it first started up or if you changed the serial port selection with the **Communication** command.

## *Taking Images*

This section describes the five commands from the **Camera** menu used in taking and downloading images from the ST-4: **Camera Setup**, **Grab Setup** and **Grab**, and **Focus Setup** and **Focus**.

### *The Camera Setup Command*

The **Camera Setup** command is used to select options that apply to both the **Grab** and **Focus** commands discussed below. Each item in the **Camera Setup** dialog is discussed individually below:

**Gain:** This is the *gain* parameter discussed in the "Baseline and Gain Parameters" section of the host software description above. The settings above 1x can be used to reduce the image graininess for exposures where the dynamic range is reduced due to long exposure build-ups of dark current where short exposures are necessary.

**Camera baseline level:** This is the *baseline* parameter discussed in the "Baseline and Gain Parameters" section of the host software description above. Setting a value slightly lower than the background due to dark current or sky background and increasing the **Gain** can reduce image graininess.

**Enable Anti-Blooming Gate:** Checking this option enables the Anti-Blooming Gate feature during the exposure as discussed in "The Anti-Blooming Gate" section of the host software description before.

**Dark Subtraction:** Checking this option enables the automatic dark frame subtraction feature of the ST-4 described in the "Automatic Dark Frame Subtraction" section of the host software description before. Enabling this feature allows you to more easily search for

dim objects with short exposures since the uneven and obscuring background will be removed from the image.

### *The Focus Setup and Focus Commands*

The first operation with the ST-4 is typically to find and focus on an object. This is most easily done by first using the **Focus Setup** command followed by the **Focus** command from the Camera menu.

The **Focus Setup** command brings up a dialog box which has items which control the operation of the Focus Mode. The *Exposure time* should be set to the desired value ranging from 0.01 to 600 seconds. Checking the *Auto Update* check box causes the Focus Mode to not pause automatically between images. Finally, the *Frame Mode* pop-up menu allows you to select the desired frame mode as discussed in detail in the "Focusing and Special Imaging modes" section of the host software description above. Some of the frame modes require further discussion below:

**Quarter:** In this mode, a full image is first downloaded, and the Focus Mode is paused. You then position a quarter frame sized square drawn in the **Picture** window and click the mouse to designate the desired portion of the image to download on subsequent images.

**Track:** Like Quarter Frame mode above, a full image is first downloaded and the Focus Mode is paused. You then position a 33 x 27 box drawn in the **Picture** window and click the mouse to designate the desired region of the image to download on subsequent images. The downloaded images are then blown-up 4:1 for display and shown with a superimposed crosshair. Also the Focus window is expanded to show 4 arrow shaped buttons. Clicking in any of the buttons closes one of the relays in the ST-4 for 0.2 seconds, enabling the drive correction for that button.

**Note:** Although each arrow shaped button will close one relay in the ST-4, the orientation of the buttons compared to the direction the star will move as a result of closing the relays may not be correct. Essentially it's like using the hand controller; you will have to determine which button is require to move the image in the correct direction.

The **Focus Setup** command can also be invoked while in Focus Mode to change the exposure time, frame mode, or Auto-Update feature.

The **Focus** command brings up the Focus window and enters the software into Focus Mode. The Focus window has two bar graphs in the "Progress" box which show the progress of the Exposure and Download portions of the Focus Mode cycle. After each exposure is completed and prior to the image being downloaded, the parameters in the "Max. Intensity" box are updated with the position and value of the brightest pixel in the image.

The **Pause / Resume** button can be used to momentarily pause the Focus Mode. The button's title indicates the function that will be applied. Hitting the **Restart** button causes the Focus Mode cycle to start over at the beginning. For most frame modes, this means just restarting the exposure, but for the Quarter Frame and Track Frame modes, the entire process is started over with the downloading of the full image and specifying the desired region to work with on subsequent images.

Images captured in the Focus Mode can of course be saved using the **Save** or **Save As** commands in the **File** menu. Also, when the Focus Mode is active, several of the other features are unavailable such as image zooming. You can exit from the Focus Mode by clicking in the Focus window's close box or by reinvoking the **Focus** command a second time. Finally, there are some items in the **Customize** command pertaining to the Focus Mode described below.

### *The Grab Setup and Grab Commands*

If you have already focussed the system, and just want to take a single image, fussing with the Focus Mode can be a lot of work. Instead, you might use the **Grab Setup** and **Grab** commands to take, download, and display a single exposure.

Use the **Grab Setup** command to set the *Exposure time* and *Exposure delay* items as desired. Again, the *Exposure time* can range from 0.01 to 600 seconds. Setting the *Exposure delay* item to a non-zero value causes the software to delay by that amount prior to taking the exposure, giving you time to get back to the telescope and prepare for tracking, for example.



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## *The Customize Command*

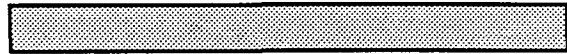
The **Customize** command in the File menu contains items which allow you to customize the operation of the software to your personal taste. The items are individually selectable and are discussed below:

**Auto Show Crosshair:** Selecting this option makes the Crosshair window be opened automatically whenever an image is opened or downloaded from the ST-4.

**Auto Show Histogram:** Selecting this option makes the Histogram window be opened automatically whenever an image is opened or downloaded from the ST-4.

**Auto Contrast on DL:** Selecting this option enables the Auto-Contrast feature for images downloaded from the ST-4.

**Don't Ask to Save on DL:** If you invoke the **Grab** or **Focus** commands when you have an unsaved image in memory, you will be asked if you want to proceed (which will overwrite the image in memory). Selecting this option makes the software skip the warning and overwrite the image.



## *Observing Suggestions with the ST-4 Imaging Camera*

The ST-4 lends itself well to many types of observations. Even a modest 2.4 inch refractor with no drive can be used to do scientific work. As an example, taking several images of the planet Jupiter over a two hour period and then measuring the position of the moons using the crosshairs will allow the relative motion of the moons to be easily determined. The apparent increase in the size of Mars can be measured during an opposition. The diameter and phase of Venus can be determined. Double stars down to 7th magnitude with separations of 5 arcseconds can be measured, using exposures only 0.1 seconds long to avoid blurring of the star due to the earth's rotation. Photometry of variable stars can be performed. If a drive is added, allowing the exposure to be extended to 10 seconds, stars down to 12 magnitude can be detected. Planetary nebula become detectable, along with the center

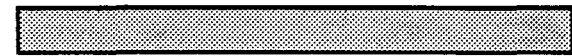
of prominent galaxies.

If a more powerful telescope is available, such as an 8 inch Schmidt-cassegrainian, much fainter stars can be reached. A one second exposure will reveal 12 magnitude stars. A five minute exposure will reveal 18th magnitude stars, and faint nebulosity. Use of a field compressor to reduce the f- number of the telescope to f/4 or f/5 is recommended, since it not only increases the field of view but it reduces the required exposure to see faint nebulosity by at least 4 times. Adding a high quality Barlow lens will allow detail at the limit of the telescope's resolution to be captured. Quite often close double stars can be detected and measured by noting the elongation of the image, a simple measurement when examining an image in the zoom mode at your leisure. The rotation of Jupiter can be easily seen in exposures only a half hour apart; similar measurements can be made of Mars. Use of color filters improves the contrast of planetary surface features. Not as well known is that galaxies also change in appearance when color filters are used. Old pictures of many galaxies were taken with blue sensitive emulsions, and the dust lanes in the arms are very prominent. At red wavelengths, the dust is more transparent, and the galaxy takes on a different appearance. Stars partially hidden by the dust may become more visible. Color filters can also be used to make stellar temperature measurements. This is not mathematically simple. SBIG plans to sell a filter set and program which will make this measurement automatic, allowing an entire field of stars to be portrayed in different colors corresponding to their temperatures, and not their intensities. The temperature of a variable star can be plotted along with its intensity.

The tremendous sensitivity of the ST-4 allows supernova searches to be conducted with greater sensitivity, and less work. The position determination capability enables motions of the planets, asteroids, and faster moving stars to be quantified in a short period of time. Relative motion of double and triple stars can be followed over the years.

Our company philosophy is to put the greatest astronomical capability in the hands of the amateur that we can. We feel this quantitative measurement power in the hands of so many enthusiastic individuals can only advance the state of astronomical knowledge,

and enable organized observing programs heretofore impossible. This product has only become possible in recent years, due to the freefall in the price of computers and CCD imaging devices. We intend to upgrade our software often to take advantage of the rapid improvement in computer graphics taking place. Enjoy using the ST-4, and appreciate that you are using equipment superior to anything available when man first went to the moon.



## *Problem Solving with the ST-4*

This section discusses common problems you may experience while using the ST-4 and discusses possible solutions to those problems.

### **PROBLEM:** Can't find the star!

This problem is usually due to the telescope being badly out of focus. Remove the CCD and put a piece of ground glass or strip of Scotch Tape over the end of the telescope eyepiece tube. Point the telescope at a bright object such as the moon or a planet and focus the image on the diffuse screen (this is easiest if you look at the screen as if you were sighting down the eyepiece, but from 12 inches away. (The CCD optical position is actually about 1/8th inch in from the end of the tube). Move to a bright star. Center the image in the tube and then insert a high power eyepiece.

Without changing the focus, adjust the telescope to center the image in the eyepiece. Then insert the CCD and the star should be readily apparent in the display values. It is very handy to boresight another telescope to the guide telescope during initial use of the CCD. This allows the CCD to be rapidly moved to a variety of stars of different brightness.

**PROBLEM:** Error message appears after the drive calibration step.

### **MESSAGE:** E1 1 (or 2, 3 or 4)

This message appears when the instrument did not 'see' the star move at all in one or more of the four directions (+X, -X, +Y, -Y) during calibration. Re-check the drive controls using the four drive adjustment buttons on the box.

### **MESSAGE:** E2 1 to 4

This message appears when the ST-4 did not see an adequate correction in one of the four correction directions. A correction of at least 5 pixels (2 units) must be seen in all four directions. If this is not the case, the instrument assumes there is no correction equipment for that direction and ignores corrections in that axis in the future. This feature is helpful, for example, when no Declination motor is installed on the

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telescope mount.

would cause each star to form a streak about 2.6 arcseconds long.

**PROBLEM:** Star images in photos are not round!

First, check to see in what direction the images are smeared. If it is in Right Ascension, which is most likely, consider the following possible problems.

1. The guide telescope focal length is so short that adequate tracking is not possible. The guide telescope should have a focal length of at least 1/4 that of the primary telescope doing the photography.
2. The telescope drive is very poor quality or ST-4 exposure times are too long. Some telescope drives produce rather abrupt hops in their position which create motion too rapid for the ST-4 to follow. Also, some drives drift so badly that they can not go uncorrected for even five seconds. In these cases, the tracker exposure time (which controls the time between corrections) must be reduced. This may limit the ability of the ST-4 to track faint guide stars.

If the error is not only in Right Ascension, it is possible that differential deflection is occurring between the guide telescope and the primary telescope. The simplest solution in this case is to use an off-axis guider, or the on-axis guider offered by SBIG.

Note that the ST-4 tracker is capable of better correction than a human because it averages the position of the star over a period of seconds, while a human sees the star dance about an ambiguous central position due to atmospheric turbulence. Also the ST-4 makes precise drive adjustments in response to a guiding error, while a human stabs away at the pushbuttons until the star is again centered.

Another error can occur when guiding on a star some distance off-axis with an improperly adjusted mount. The guide star is tracked accurately, but stars within the camera field of view will rotate slightly about the guide star. This effect is small, but significant in careful work. A one half degree error in correctly positioning Polaris could produce an image rotation in the telescope of 5 minutes of arc per hour. If you were to take a 0.5 hour exposure using a guide star centered 1 degree away from the field of view of your camera this effect

## Appendix A

The tables below show the pin-outs of the four connectors on the ST-4 and the colors of the wires on the cables supplied with the unit.

Pin Number	Function	Color
11	+X, Common	Gray
3	+X, Normally Closed (NC)	Pink
10	+X, Normally Open (NO)	Tan
5	-X, Common	Brown
12	-X, Normally Closed (NC)	Yellow
4	-X, Normally Open (NO)	Violet
14	+Y, Common	Green
6	+Y, Normally Closed (NC)	Orange
13	+Y, Normally Open (NO)	Blue
8	-Y, Common	Black
15	-Y, Normally Closed (NC)	Red
7	-Y, Normally Open (NO)	White

*Table A1. Relay Connector/Cable*

Pin Number	Function	Color
5	Chassis Ground	Green
4	+12 VDC, 1 amp, or 12 VAC	Red
9	Other side of 12 VAC, or DC ground	Black
2	Alarm relay <sup>1</sup> , common connection	Orange
6	Alarm relay, normally closed	Blue
1	Alarm relay, normally open	White

*Table A2. Power Connector/Cable*

Pin Number	Function	Color	PC Pin	Mac Pin
2	Transmit data from ST-4	Red	3	9
3	Receive data to ST-4	White	2	5
5	Ground	Black	7	3

*Table A3. RS232C Connector/Cable*

For additional information regarding the operation of the ST-4 Star Tracker / Imaging Camera, please contact the Santa Barbara Instrument Group:

**SANTA BARBARA INSTRUMENT GROUP**  
 1482 East Valley Road, Suite 601  
 Santa Barbara, CA 93108  
 Telephone (805) 969-1851  
 FAX (805) 969-0299

<sup>1</sup> The alarm relay in the ST-4 can activate an external alarm or light (110 volt).



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