Operating Manual
for the ST-237
Advanced CCD Camera

Santa Barbara Instrument Group

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Note: This equipment has been tested and found to comply with the limits for a Class B digital device pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the receiver and the equipment.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

Also note that user must use shielded interface cables in order to maintain product within FCC compliance.

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Introduction

Congratulations and thank you for buying the SBIG ST-237 Advanced CCD Camera. This camera offers incredible performance in a small package for a moderate cost. Using the camera will expand your astronomical experience by allowing you to easily take images like the ones you've seen in books and magazines, but never seen when peeking through the eyepiece. CCD cameras offer convenience, high sensitivity (a typical deep-sky image is several minutes), and advanced image processing techniques that film just can't match. While CCDs will probably never replace film in its large format, CCDs offer ease of use and allow a wide range of scientific measurements. Their use has established a whole new field of Astronomy. Some of the features you'll discover about your camera include:

- Based on the Texas Instrument TC37 CCD with 640 x 480 pixels that are 7.4 microns square.
- Double Correlated Sampling readout with 12 Bit A/D for the lowest possible noise.
- Convenient and fast parallel interface offers full frame download times under 4 seconds.
- Thermoelectric cooling and vibrationless fan give sky background limited performance.
- Integral Shutter Wheel that can be replaced with a Color Filter Wheel for Tricolor imaging.
- Telescope port for use as an Autoguider.
- Advanced CCDOPS software for data acquisition, display and processing.
- Track and Accumulate[1] for hassle-free long duration exposures.
- 12 VDC wall transformer or use with battery in the field.
- Standard T-Thread allows use with a variety of telescope adapters including the standard 1.25 inch nosepiece and eyepiece projection units.

This manual is organized for two types of use. Some sections have been designed to be read through from the start while you're learning about the camera and the software whereas other sections are to be used for reference. Briefly the manual consists of the following sections:

- Section 1 describes CCD cameras and how they work. While it is the first section of the manual, it is a bit technical, and some users may wish to skip ahead to the second section then come back to this section once they have had a little hand's on experience.
- Section 2 tells you how to install the camera and camera software and takes you step by step through the process of taking your first images. Even if you have experience with other cameras you should browse through this section and read any sections that are new to you.
- Section 3 describes the CCDOPS imaging software that comes with your camera. It presents the software from the standpoint: "What commands do I use to take

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[1]   Track and Accumulate covered by SBIG US Patent 5,365,269.

images?", etc. While it doesn't discuss every nuance of each command (that's reserved for Section 4) it will give you a good feel for the flow of the software.

- Section 4 presents some more detailed information about how you use the camera for some slightly more advanced tasks. The discussion of even more advanced topics is continued in Appendix D. Once you have become familiar with the basic operations of the camera you will want to read these sections.

- A separate manual describes each and every command in the CCDOPS software and is meant more as a reference section than a narrative one. If you're wondering what the "Dark interval" setting in the Track and Accumulate command does this section is for you.

- Sections 5 and 6 provide a Glossary of common CCD imaging terms, a Question and Answer section on the most common questions you'll have and a section of useful hints and tips for using the camera. Again, this is a good section to read once you have had a little time with the camera.

- Finally, the Appendices provide a wealth of technical information about the camera.

1.   Introduction to CCD Cameras

The CCD (charge coupled device) is very good at the most difficult astronomical imaging problem: imaging small, faint objects. For such scenes, long film 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 without tedious dark room operations, wider spectral range, and instant examination of the images at the telescope for quality. Film has the advantages of a much larger format, one-step color, and independence of the wall plug (the ST-237 camera can be battery operated in conjunction with a laptop computer, though). After some use, you will find that film is best for producing sensational large area 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 camera to support both efforts, as an imaging camera and as an auto-guider to aid astrophotography.

1.1.   How CCDs Work

The CCD is a solid-state imaging detector that is quite commonly used in video tape cameras and is starting to find acceptance in still frame cameras. It has been used for Astronomical Imaging for over twenty years. The CCD is arranged as a rectangular array of imaging elements called pixels. An image is formed by reading the intensity of these pixels.
        The basic function of the CCD detector is to convert an incoming photon of light to an electron which is stored in the detector array until it is read out, thus producing data which your computer can display as an image. How this is accomplished is eloquently described in a paper by James Janesick and Tom Elliott of the Jet Propulsion Laboratory:

> "Imagine an array of buckets covering a field. After a rainstorm, the buckets are sent by conveyor belts to a metering station where the amount of water in each bucket is measured. Then a computer would take these data and display a picture of how much rain fell on each part of the field.   In a CCD the "raindrops" are photons, the "buckets" the pixels, the "conveyor belts" the CCD shift registers and the "metering system" an on-chip amplifier.

> Technically speaking the CCD must perform four tasks in generating an image. These functions are:

> > 1) charge generation
> > 2) charge collection
> > 3) charge transfer
> > 4) charge detection

> The first operation relies on a physical process known as the photoelectric effect - when photons or particles strike certain materials free electrons are liberated. In the second step the photoelectrons are collected in the nearest discrete collecting sites or pixels. The collection sites are defined by an array of electrodes, called gates, formed on the CCD. The third operation, charge transfer, is accomplished by manipulating the voltage on the gates in a systematic way so the signal electrons move down the vertical registers from one pixel to the next in a conveyor-belt like fashion. At the end of each column is a horizontal register of

pixels. This register collects a line at a time and then transports the charge packets in a serial manner to an on-chip amplifier. The final operating step, charge detection, is when individual charge packets are converted to an output voltage. The voltage for each pixel can be amplified off-chip and digitally encoded and stored in a computer to be reconstructed and displayed on a television monitor."[2]
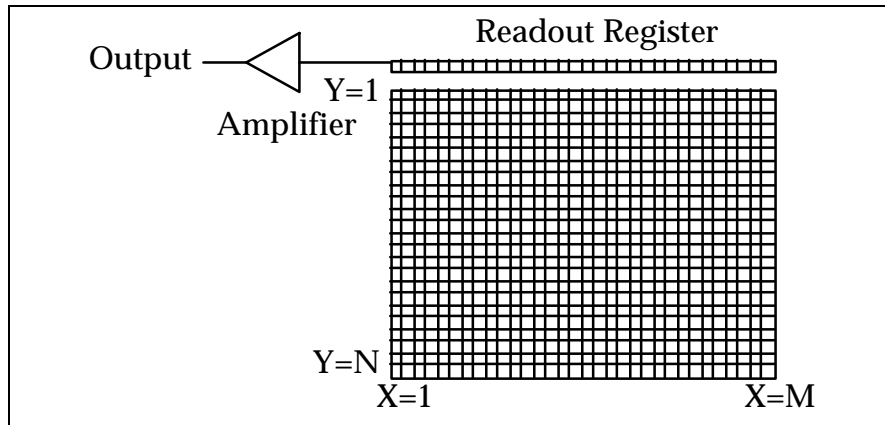
Figure 1.1 - CCD Structure

1.2.   CCDs Applied to Astronomical Imaging

When CCDs are applied to astronomy, with the relatively long exposure times (compared to the 30 frames per second used in video camera), special considerations need to be applied to the system design to achieve the best performance. This section discusses the cooling and dark frame requirements of astronomical imaging.

1.2.1. Cooling

Random noise and dark current combine to place a lower limit on the ability of the CCD to detect faint light sources. If the CCD is producing more electrons from its own internal processes than is produced by photons from a distant object, the signal from the object is said to be "lost in the noise", and will be impossible to display without sophisticated image processing software. Noise here refers to the "gritty" look of short exposure images.

Internally, the CCD generates thermal noise and readout noise caused by the operation of the electronics on the chip. The goal is to eliminate unwanted sources of electron production in the chip and thus make the detector more sensitive to the remaining source of electron production by incoming photons. As you can imagine, the reduction of unwanted noise is important for the best performance of the CCD.

Dark current is thermally generated electrons in the device itself. All CCDs have dark current which can cause each pixel to fill with electrons in only a few seconds at room temperature even in the absence of light. By cooling the CCD, this source of noise is reduced,

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[2]   "History and Advancements of Large Area Array Scientific CCD Imagers", James Janesick, Tom Elliott. Jet Propulsion Laboratory, California Institute of Technology, CCD Advanced Development Group.

the sensitivity increased, and longer exposures are possible. In fact, for every 8°C of additional cooling, the dark current in the CCD is reduced to half. In your camera for example, cooling the CCD from room temperature (25°C) down to 0°C results in an eight-fold reduction in dark current.

The ST-237 uses a thermoelectric (TE) cooler to cool the CCD. The TE cooler is a solid-state device that acts like a heat pump. By running electrical current through the TE cooler, heat is pumped out of the CCD through the TE cooler. The camera also has a temperature sensing thermistor attached to the CCD to monitor the temperature, and the camera electronics control the temperature at a user determined value for long periods.   As a result, exposures up to an hour long are possible, and saturation of the CCD by the sky background typically limits the exposure time.

The sky background conditions also increase the noise in images, and in fact, as far as the CCD is concerned, there is no difference between the noise caused by dark current and that from sky background. If your sky conditions are causing photoelectrons to be generated at the rate of 100 e⁻/pixel/sec for example, increasing the cooling beyond the point where the dark current is roughly half that amount will not improve the quality of the image. This very reason is why deep sky filters are so popular with astrophotography. They reduce the sky background level, increasing the contrast of dim objects, and can be used to advantage with the CCD camera.

1.2.2. Dark Frames

No matter how much care is taken to reduce all sources of unwanted noise, some will remain. Fortunately, however, due to the nature of electronic imaging and the use of computers for storing and manipulating data, this remaining noise can be drastically reduced by the subtraction of a dark frame from the raw light image. A dark frame is simply an image taken at the same temperature and for the same duration as the light frame with the source of light to the CCD blocked so that you get an "image" of the dark. This dark frame will contain an image of the noise caused by dark current (thermal noise) and other fixed pattern noise When the dark frame is subtracted from the light frame, this pattern noise is removed from the resulting image. The CCDOPS software can automatically perform this.

1.3.   The Various CCD Parameters and How they Affect Imaging

If you scan the CCD related literature you will see a slew of new terms describing CCDs and their performance. In this section we will discuss the more common CCD parameters and their effects in an imaging application.

1.3.1. Pixel Size

Every CCD, independent of the manufacturer, is divided into a relatively large number of small pixels. In your CCD camera the imaging area of the CCD is 4.7 mm x 3.6 mm and the pixels are 7.4 microns square (1 micron is one thousandth of a millimeter or roughly 0.0004"). If you looked at the CCDs available from the various manufacturers you would see that their pixels typically vary from 7 microns on the small end to 25 microns on the large end. There are advantages and disadvantages associated with the size of pixels in a CCD.

While having small pixels may seem advantageous in terms of offering "higher resolution", large pixels gather more light and are thus "more sensitive". You can also adjust your telescope configuration to accommodate various size pixels, using faster telescopes to increase the speed of small pixel CCDs or longer focal lengths to increase the resolution of larger pixel CCDs.

Often times the basic goal is to match the CCD resolution to the telescope resolution and to the overall seeing. It would be a waste to use a pixel size of 7 microns on a telescope with a spot size of 25 microns or to configure the CCD/telescope to produce an image scale of 10 arc-seconds per pixel when you're looking for fine planetary detail.

1.3.2. Full Well Capacity

The full well capacity of a CCD is the number of electrons each pixel can hold before the pixels are full. While this may seem like an important consideration in choosing a camera, you need to think about how the camera is used.

The typical CCD astronomer is taking images of faint galaxies and nebulae. While exposures are long, you very rarely will expose the CCD to more than a small fraction of its full well capacity on these dim objects. Some stars in the image will expose to the full well capacity, but not much of the nebulosity. So even though small pixel size CCDs have lower full well capacities than large pixel CCDs, most applications do not stress this CCD parameter.

1.3.3. Dark Current

Every CCD, independent of manufacturer, will suffer from dark current. One manufacturer's CCD may have lower dark current than another manufacturer's, but they all have dark current. The only way to reduce dark current in a CCD is by cooling it, and in general the more cooling, the better. But there is a limit.

In astronomical imaging, you're looking at objects against the sky background, and that sky background isn't perfectly dark. City light and sky glow itself cause the sky to actually have some brightness. As far as the CCD is concerned from a noise standpoint, it can't tell the difference between electrons generated by dark current and those generated by sky background. Because of this, cooling the CCD beyond the point where the dark current is less than the sky background will not result in any further improvement in image quality.

As a matter of interest, your CCD camera produces roughly 1 e⁻/p/s (electron/pixel/second) of dark current when cooled to -5°C and a typical dark sky through an F/10 telescope produces 2 e⁻/p/s. Sky background scales inversely with the square of the telescope's F-Ratio and for example is 25 times higher at F/2 than it is at F/10.

1.3.4. Read Noise

The read noise of a CCD is the noise inherent in the CCD's amplifier and charge detection circuitry. This read noise forms a noise floor below which the CCD will not detect weak signals. Something you're imaging must rise above the read noise level before you'll be able to see it.

Since the read noise is the noise floor, it is really only important for very short exposures of dim objects. As the signal from your target or the signal from the sky background builds up, it will cross the noise floor and the noise in the image will be determined only by the brightness

of the target and the exposure time, not the CCD's read noise. For example, the read noise in your CCD camera is 15 electrons RMS, and when your signal has built up to 225 electrons (15 electrons RMS squared) the read noise is no longer the dominant noise in the final image. At F/10 the sky background alone achieves this level in 2 minutes and at F/2 it occurs in 4 seconds!

There are techniques CCD manufacturers can use to reduce the read noise. One of the techniques is Double Correlated Sampling where some of the noise in the amplifier is subtracted out by making two measurements per pixel rather than one. Your Advanced CCD camera uses such a technique.

1.3.5. Frame Transfer

There are two basic types of CCDs available: Frame Transfer CCDs like the one used in your camera and Full Frame CCDs. A Frame Transfer CCD is divided into 2 separate areas on the CCD. One area, called the image area, is sensitive to light and that is where the image builds up when exposed to light. But CCDs can't be "turned off" and they continue to build up signal, even throughout the readout phase. Remember that during readout, the rows of charge are shifted up to the readout register. It's sort of like advancing the film in a camera with the shutter open. Unless the CCD is covered with a shutter during the readout, the continued buildup of signal throughout the readout phase will cause streaking.

The second area in the Frame Transfer CCD, called the storage area, is shielded from light by an aluminum layer on the CCD. This storage area is used as an "electronic shutter" whereby data from the image area, after completing the exposure, is rapidly shifted into the storage area where it is then digitized. A fast shift from the imaging area to the storage area insures minimal streaking. Once the image is in the storage area, it can read out by the camera electronics without causing streaking.

The simple answer to streaking you might say is to use a mechanical shutter, and in fact your camera does have a shutter but the accurate timing of exposures is not limited by the speed of that shutter but by how rapidly the imaging area can be moved into the storage area. In this way the mechanical shutter is used to cover the CCD chip for taking dark frames while short exposure images can be achieved electronically, without the limitations of mechanical shutters.

1.3.6. Antiblooming Protection

As described above, the individual pixels in the CCD have a limited full well capacity. When a pixel fills up with charge, the excess charge generated has to go somewhere. Again, there are two basic types of CCDs available.

Standard CCDs, when reaching the saturation point, will spill the charge into neighboring pixels, typically up and down the column in a line that is called blooming. If for example you had a pixel that was exposed to 10 times its full well capacity, it would bloom until a column of ten pixels was saturated, causing streaks in the image. The second type of CCD offers Antiblooming protection.

In an Antiblooming protected CCD, when the charge in the pixel gets above some threshold, typically one-half the full well capacity, the majority of the excess charge gets bled off into a drain on the CCD. For example, a CCD with a 100X Antiblooming protection will

drain off 99% of the excess charge, allowing a pixel to overexpose to 100-fold before blooming occurs.

There is a price to pay however with Antiblooming protection and that's why manufacturers produce both protected and unprotected CCDs. First off, the process of Antiblooming protection causes a nonlinearity in the response of a CCD. If you were trying to make accurate Photometric measurements, you would want the integrated star brightness kept below the knee where the Antiblooming kicks in. The second detriment to some Antiblooming protected CCDs is that at the integrated circuit level, the Antiblooming structures can reduce the sensitive area of the individual pixels, causing a slight reduction in overall sensitivity.

The Texas Instruments (TI) TC237 CCD used in your camera has Antiblooming protection and, according to TI, the structures required to implement the Antiblooming protection do not cause any reduction in sensitivity

1.3.7. A/D Bits and Digitization Rate

If you browse through the literature on specifications of the various CCD cameras, you see some of them are 8 bits, some are 12 bits and some are 16 bits. While in general an A/D (Analog to Digital) converter with greater precision is desired, there is a point where the extra precision doesn't get you any increased performance. In most CCD cameras it's actually the CCD that limits the performance, not the A/D converter.

As a starting point, you can take the CCD's full well capacity and divide by the CCD's read noise to come up with a figure for the CCD's dynamic range. In this way the dynamic range is the ratio of the brightest object you could image without saturating to the dimmest object you could detect. You could see that a 16 bit A/D with a dynamic range of 65,000 is overkill for a CCD with a dynamic range of 4000 for example. Let's look at your camera. The CCD has a full well capacity of 30,000 electrons and a read noise of 15 electrons RMS giving a dynamic range of roughly 2000. A 12 bit A/D offers a dynamic range of 4096 and covers the CCD fairly well.

One thing you do want to do with the A/D is make sure that the A/D's noise (typically a fraction of a count) is lower than the CCD's noise so that you are truly CCD limited. Setting the A/D to have a fraction of the noise of the CCD allows averaging several images to improve noise.

Finally, the CCDs can be used in a mode where the pixels are combined in a process called binning which is described in detail below. Binning reduces the CCD's spatial resolution like increasing grain size in film, but increases the CCD's sensitivity and dynamic range. With your camera you can bin the CCD 2 by 2 or 3 by 3 resulting in increased dynamic range.

The final consideration regarding the A/D is how fast the data is digitized and downloaded from the CCD to the computer. The A/D is not the only contributor to that time. The actual transmission of the data to the computer is a significant portion of it. In your camera an entire image can be digitized by the A/D converter and sent to the PC in under 15 seconds. This is done using the PC's standard Parallel port without requiring the addition of expensive (and difficult to configure) SCSI adapter cards.

1.3.8. Binning

Binning is a process where multiple pixels in the CCD are combined to form a single larger pixel. This reduces the CCD's resolution but increases the sensitivity. Different CCDs from various manufacturers support different types of binning.

Some CCDs support on-chip binning, where all the pixels in the group are combined in the CCD itself. This has the advantages of lower noise (a single read noise is generated for the group of pixels) and higher speed digitization since fewer pixels are involved. In imaging applications you tend to bin the images in both directions to preserve a "square" aspect ratio. The one final advantage of binning is that it increases the overall image throughput, reducing the digitize and download times due to the reduced number of pixels involved.

The camera software allows you to select a High resolution 7.4 micron square mode where the pixels are unbinned, a Medium resolution mode resulting in 14.8 micron square pixels and a Low resolution mode with 22.2 micron pixels. The latter is useful for fast acquisition of faint objects.

1.3.9. Spectral Response

Like film, CCDs have a varying response to differing wavelengths. The basic fabrication techniques used in manufacturing the CCDs greatly affect their spectral response. At the extreme Red end of the spectrum, the CCDs loose their sensitivity because the photons simply do not have enough energy to generate electrons in the CCD wells. At the Blue end of the spectrum, the photons do not penetrate deep enough into the CCDs to get into the wells and are stopped by the top layers of the CCD. Between the Red and the Blue, interference effects in the top layers of the CCD can also cause peaks and valleys in the response.

This affects you in several ways. The most obvious is the overall effect that causes you to take longer exposures with CCDs for various colors. For example, when taking color images, your Blue exposure is typically several times longer than the Red exposure to give an image with similar quality or Signal/Noise. One last interesting note about CCD's spectral response is that they have much more response in the near infrared than film.

The TC237 CCD used in your camera is made using Texas Instrument's Virtual Phase technology that gives excellent Blue response compared to other CCDs. This is achieved by reducing the number of photon-absorbing clocking gates in the CCD.
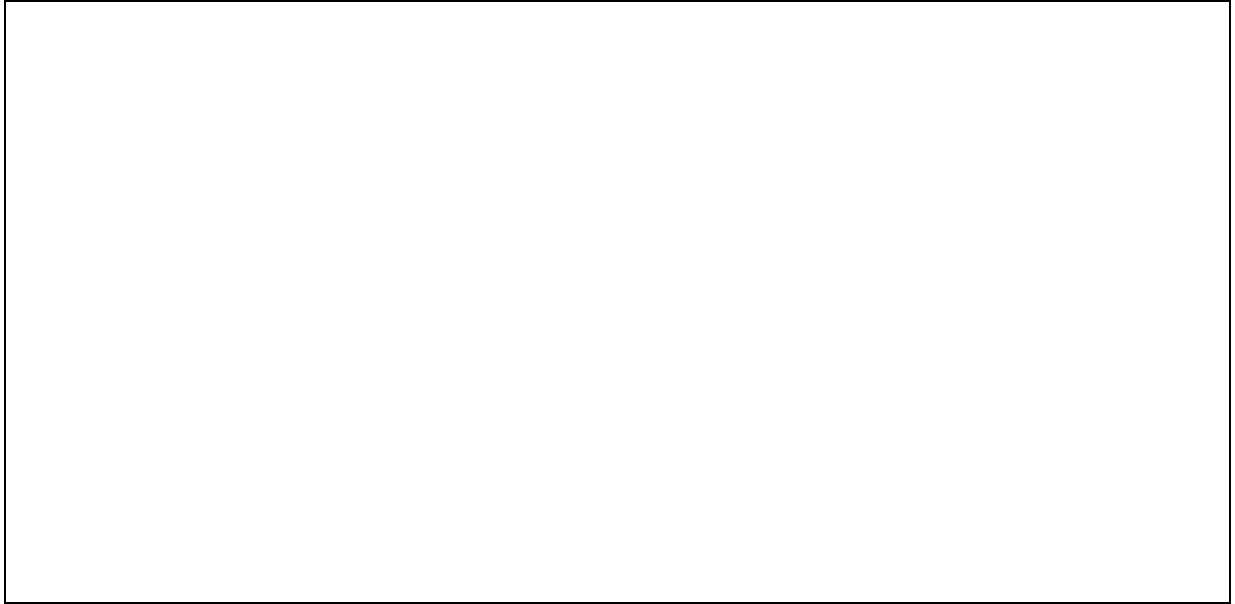
Figure 1.2 - CCD Quantum Efficiency

1.4.   Camera Hardware Architecture

This section describes the ST-237 Advanced CCD Camera from a systems standpoint. It describes the elements that comprise a CCD camera and the functions they provide. Please refer to the figure below as you read through this section.
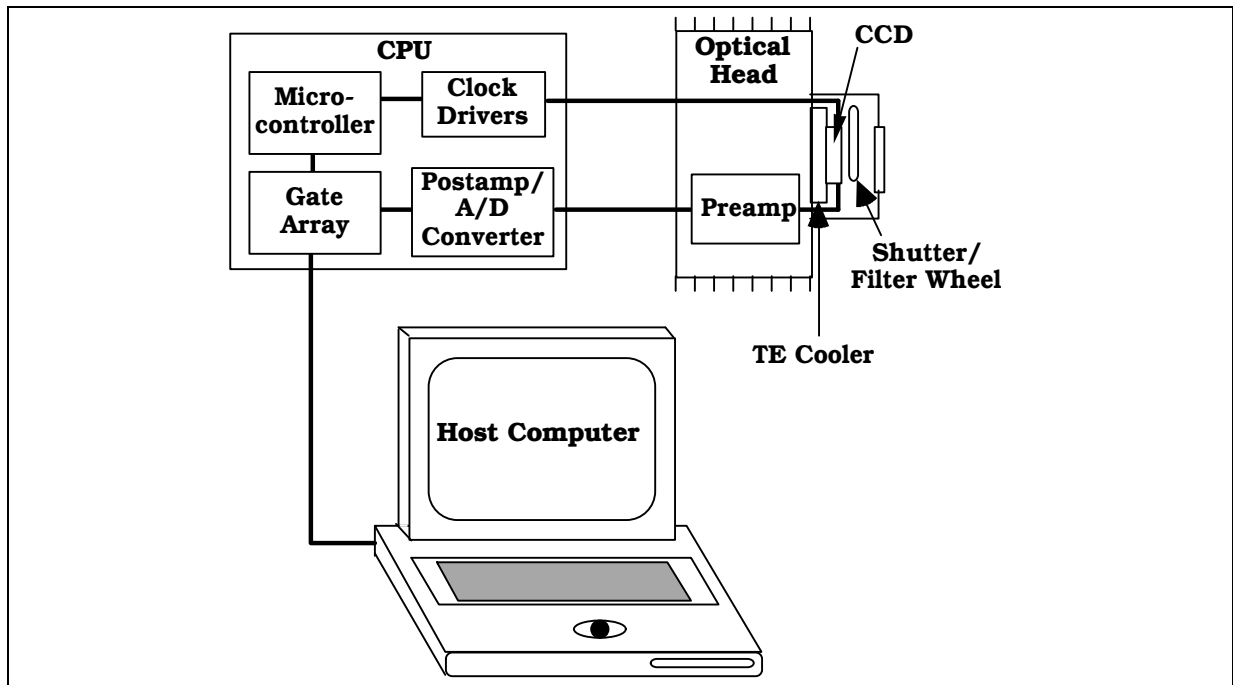
Figure 1.3 - CCD System Block Diagram

The ST-237 camera is a two piece system consisting of an Optical Head and a CPU. The Optical Head houses the CCD and Preamplifier and the CPU contains the Readout and Control

Electronics. The CPU is powered by an external 12 VDC wall transformer and can be easily run off a 12 volt battery in the field. Finally, the CPU interfaces to the PC through the Parallel Port and is controlled by the software.

Examining the Optical Head in more detail shows the "front end" of any CCD camera which is the CCD sensor itself. In this case the CCD is the Texas Instruments TC237. The CCD is cooled by mounting it on a thermoelectric (TE) cooler. The TE cooler pumps heat out of the CCD and dissipates it into the camera body where it is removed by a small fan in the rear of the Optical Head.

Since the CCD is cooled below 0°C (32 °F), some provision must be made to prevent frost from forming on the CCD. The camera has the CCD/TE Cooler mounted in a windowed hermetic chamber sealed with an O-Ring. The hermetic chamber does not need to be a vacuum, and contains a desiccant packet to absorb the small amount of moisture that might condense.

Other elements contained in the optical head include the preamplifier and a rotating shutter wheel. The shutter wheel makes taking dark frames a simple matter of pushing a button on the computer. Remember that the shutter wheel does not perform the task of timing the exposure, it merely blocks the light from the CCD to facilitate taking dark images. Timing of exposures is based upon the electronic clocking scheme applied to the CCD. Also, the shutter wheel can be replaced by a Color Filter Wheel which allows taking Tricolor images and dark shuttering.

The Microcontroller acts as the "brains" of the camera electronics. It is responsible for starting and stopping exposures in the CCD, clearing the CCD at the start of the exposure and transferring the image into the CCD's storage area at the end of the exposure. The microcontroller also regulates the CCD's temperature by monitoring the temperature sensor and adjusting the power to the TE cooler. Finally, the microcontroller provides control of the Shutter/Filter Wheel and the Telescope Port that is used when Autoguiding.

The final element of the camera system is the host computer and operating software. The CCDOPS software runs under MS-DOS and is used to acquire, display and process images from the camera. As you will learn, CCDOPS is a powerful package with a user-friendly interface. It is unequaled in the industry. Also, third party software packages such as Software Bisque's SkyPro for Windows will support the ST-237 Advanced CCD Camera and open up a whole realm of capabilities including integrated Telescope and Camera control.

2.   The First Day with the Camera

This section takes you step-by-step through your first use of the software and camera.

2.1.   Setting up the System

This section tells you how to install the CCDOPS software and establish a communications link with the camera.

2.1.1   Installing the CCDOPS Software

The CCDOPS software is provided on floppy diskette, and should be copied to your system's hard disk prior to use. SBIG's CCDOPS software which supports all cameras except the original ST-4 is available for Windows, DOS and the Macintosh (Mac users need the optional Mac/SCSI Adapter). Follow the instructions below to install your software:

> Windows - The software comes as a 2 diskette set. Insert the first floppy disk and run the Setup.exe program to install the software.

> DOS, Macintosh - Create a CCDOPS directory on your hard disk and copy the contents of the floppy disk to your hard drive.

After you have finished installing the software, place the floppy disk in a safe place in case you need to reinstall it later.

2.1.2.   Getting Acquainted with CCDOPS Software

Upon entering CCDOPS a warning (referred to as an Alert) states no camera is hooked up yet. To proceed, hit any key and you are presented with our user friendly menu based interface shown in the figure below:

Section 2 - The First Day with the Camera

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┌──────────────────────────────────────────────────────────────────────┐
│  *   │Fi le   Camera   Display   Utility   Misc   Track   Fi lter      │
│      ┌─────────────────┐                                               │
│      │ Open    Alt-O   │                              ┌───────────┐    │
│      │ Save    Alt-s   │                              │ Menu Bar  │    │
│      └─────────────────┘   ┌─ Display ──────────────┐ └───────────┘    │
│           ┌──────┐         │                        │                  │
│           │ Menu │         │  Display mode: Analysis  Photo            │
│           └──────┘         │  Auto contrast: Yes  No                   │
│                            │     Background: 100                       │
│                            │                                           │
│                            │    [ Enter ]    [  Esc  ]                 │
│                            └──────────────────────────┘  ┌────────┐    │
│      ┌─ Status ────────────────────────────────────────│ Dialog │    │
│      │ Welcome to the CCDOPS Software          └────────┘         │    │
│      │                                                            │    │
│      │                              ┌────────────┐                │    │
│      │                              │ Status Box │                │    │
│      │                              └────────────┘                │    │
│      │                                                            │    │
│      └─ Data Buffer ──────────────────────────────────────────────    │
│       Name:M27.237                                                     │
│      ─ Camera ────────────────────────────────────────────────────    │
│       Link:              ┌───────────────┐                            │
│        Res:              │ Camera Status │                            │
│                          └───────────────┘                            │
└──────────────────────────────────────────────────────────────────────┘
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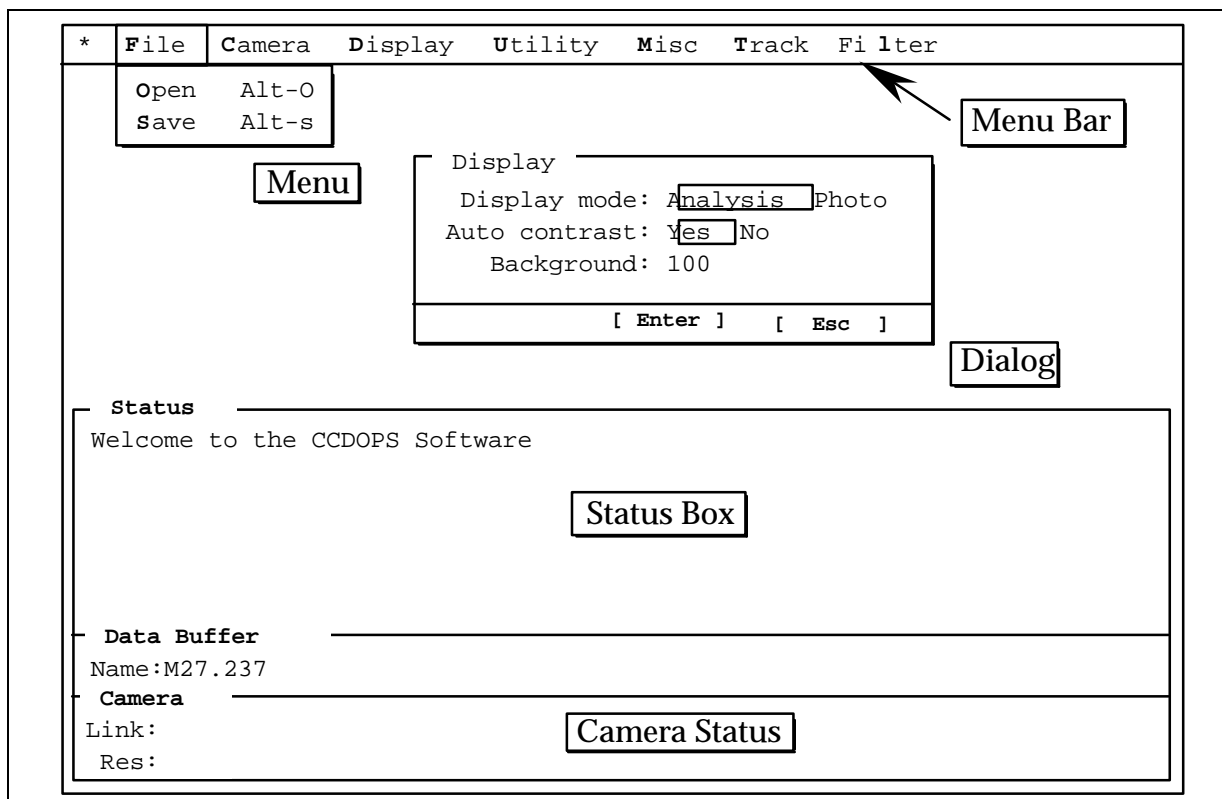
Figure 2.1 - The CCDOPS User Interface

The menu bar starts with an * at the top left and extends horizontally to the Filter menu item on the right. Navigating between these menus can be accomplished with a mouse or left/right cursor arrows on your keyboard. Go ahead now and move between these items.

The File menu is the most frequently used since it navigates you toward image retrieval (Open command) and the image Save command. It also is the way to the off switch, via the Exit command. To pull down the File menu, highlight it and simply hit Enter or click on it when highlighted. To leave it, hit Esc key or click on another menu.

Camera Menu

Move to the right and Camera menu is highlighted. Pull it down to see the 3 sections making 7 commands. None of these function yet since a camera is not hooked up or powered. Notice that you are alerted to this fact by the software when you hit Enter on a highlighted command.

Display Menu

Moving right again to the Display menu, you see 2 sections of 5 items. You can use your up/down cursors or mouse to navigate between these. Similarly, when selected, error messages come up in all but the Slide Show command. Select it. Now you are prompted by a new window (referred to as a Dialog) to select a slide show script. Move the highlighted box to the DEMO.SLD script which we created for you and hit Enter. Now you are presented with more choices. Temporarily ignore these and hit Enter again. When in doubt, just hit Enter to use the

standard defaults. You are now viewing a library of images created with the TC-237 chip in your camera. These will run until you hit Esc.

You can adjust your monitor's brightness or contrast for best view. If you find an image you wish to freeze, hit the Space bar. Hit the R key to resume slide show or hit any other key to fast forward through the images.

File Menu

To call up specific images stored in image files, Esc the Slide Show command. In order to display an image, it is necessary to first select its image file. Move the cursor to the File menu, hit Enter, select the Open command and again hit Enter. Now you see the File Open dialog presenting you with many choices. First are file directories shown in <>. These are created by the software and later by you to organize and store images. The current directory you are in is noted at the top center of list of files. Move the highlighted cursor to the MOON.237 file and click on it twice in short succession (double-click) or hit Enter.

You are first shown with the image header data pertaining to that image. After viewing the data, hit Enter. Highlight the Display menu and hit Enter to bring it down. Execute the Image command and the software brings up the Display Settings dialog. Use the mouse or the cursor keys to select the Photo display mode and then hit Enter one last time and your selected image is now displayed.

If you have a VESA based SVGA display adapter, depress the up/down arrows to adjust the image brightness and right/left arrows to adjust its contrast. This feature allows real time display optimizing. If you are not getting a satisfactory image display, refer to the Graphics Setup command in Section 5, the Software Reference section for help. Note that images will almost always look better on a video monitor than from a laptop LCD. If you wish to increase image size, again refer to Graphics Setup command in Section 5 and change the graphics card to VGA or MCGA. Your selected image will still be held in the image buffer, ready for redisplay when selected. When you're done with looking at the image hit Esc to return to main menu.

Utility Menu

The next menu to the right, Utility, allows you to modify an image. Pull down the Utility menu. These commands can be used without permanently modifying the selected image until you save it. Move back to File menu.

Open and display the Jupiter image using the File Open and Display Image commands and study the image briefly. Esc back to the main menu. Under the Misc menu use the Graphics Setup command and make sure the graphics card is set to Auto. Press Enter and then redisplay the image. Adjust the image with arrow keys for the best detail. Hit Esc and move to Utility menu and execute the Sharpen command.   In the Sharpen dialog select Lunar/Planetary and Medium settings. Hit Enter. A sharpened image of Jupiter comes up and notice how the red spot (light oval) now shows on Jupiter's right side by one of its moons. Also, cloud band detail has been enhanced. At this point, you could save this image, but be cautious and make sure you have read the manual and understand what the save function can do to the original unsharpened Jupiter image. You are only a few Enter keystrokes away from modifying your original data permanently unless you heed the warning box displayed while

executing the Save command. No problem, just hit Esc or be sure to rename the modified Jupiter file before saving it so as not to modify the original file.

Display the sharpened Jupiter image again using the Display Image command and hit Esc. We will go to the Utility menu and do something else to this image. Select the Depixelize Image command and hit Enter. You have magnified the number of pixels in this image four-fold. Be aware that this would increase the size of the image on disk four-fold as well if you saved it. Notice that even more detail becomes visible. Vary the contrast and brightness with cursor arrow keys for the best view.

You have just successfully retrieved an image and optimized it for viewing. Since this is any easily repeated example, let's get rid of the modified image by hitting Esc and moving to Misc menu on the main menu bar.

Misc Menu

The Misc menu contains one section with 3 commands. You previously used this to verify the graphics setup. These commands are covered in detail in Section 5 if you want to refer to it, otherwise let's move right over to the Track Menu.

Track Menu

In the Track menu you see 3 sections containing 6 commands. Except for the Track and Accumulate command, these all pertain to using your CCD camera as a separate auto guider for astrophotography with accessories such as a Radial Guider, guide scope or to guide a separate piggyback camera from your main scope. It is for advanced users with appropriate equatorial tracking mounting systems.

Filter Menu

The last menu on the top right is the Filter menu. The commands in this menu are used for controlling the Color Filter Wheel accessory and are discussed in Section 5 and in the manual that comes with the Color Filter Wheel.

This basic preview should make you comfortable with the ease of moving around in CCDOPS and what it entails. You can exit through the File menu now. Notice how a warning box still alerts you that you are leaving an unsaved image that will be lost when you exit. Specify "Quit:Yes" and hit Enter to leave CCDOPS and exit back to a DOS command. You can now shut down your computer or type in WIN and hit Enter to go back into your Windows software.

2.1.3. Connecting the Camera to the Computer

Place the camera's CPU midway between the computer and the telescope or some other convenient place. With the power to the CPU disconnected, plug the Optical Head into the CPU at the marked location and plug the beige parallel cable provided with the system into the CPU. Connect the other end of the parallel cable into your computer's Parallel port (printer port). Finally plug the power supply into the CPU and turn on the power switch. The CPU's power switch should light up and the small fan on the back of the optical head will begin to spin.

> **Important Note**: *Never connect or disconnect the CCD head from the CPU box unless the power switch on the rear side of the CPU box is turned OFF. Damage to the CCD head, or the CPU could occur.*

2.1.4. Establishing a Communications Link with the Camera

Run the CCDOPS software and when it starts up, it will automatically attempt to establish a link to the camera. If the camera installation is successful, the "Link" field in the Status Window is updated to show the Link status. If the camera is not connected or the LPT port setting has not yet been properly set, a message will be displayed indicating that the software failed to establish a link. If this happens, use the Communications Setup command in the Misc menu to configure the CCDOPS software for the parallel port you are using. Then use the Establish COM Link command in the Camera menu to re-link.

2.1.5. Operating your Camera with CCDOPS - a Daytime Orientation

With the Camera menu highlighted, select the Setup command. Notice the choices for temperature regulation, etc. Ignore these for the time being and hit Esc to get rid of the dialog. Again select the Camera menu and then execute the Grab command. Note the exposure time, etc. Verify that the exposure time is set to :1.00 second and other settings are Dark frame:Only, Auto display:Analysis, Exposure delay:0 and Special processing:None. With the CCD camera nosepiece uncovered, hit Enter. A sequence of events occurs and you will notice a spotted image. This represents a 1 second exposure dark frame at your room temperature with the CCD chip still covered by the internal mechanical shutter wheel to keep out light. At the upper left on your current screen is a menu named Display. Under the image is a box with information pertaining to this image. Of interest is Back (background) and Range. These are pixel values that can theoretically go from a low of 0 to a high of 4,095. These will register numbers in the low thousand range. Using your mouse or Enter key, pull down the Display menu. Notice 8 choices. Select the X-Hairs command.

You are presented with a lot of data pertaining to the small crosshair cursor (+) now located in your dark frame image. The cross placement is now in your control and is used to obtain pixel information. Move it around with the arrow cursors or rapidly by mouse point and click. Notice 9 lines of data in the X-Hair box that are updated with each pixel position movement. A convenient zoomed box located below and left of the entire main image magnifies the immediate area surrounding the crosshair cursor. The very center of this zoomed box represents the cursor position. Move the crosshair toward the top of the frame. Now slowly move it, an arrow stroke at a time, to find a dark pixel (low value). A reading of 400 to 1400 is typical. Now move it to the bottom of the image and note the brightest pixel value. It might be in the range 1200-1300. A single very hot pixel could give a value of 3000. Hitting Enter again brings up more advanced crosshair commands. Hit Esc twice to view just the image. This is what you will typically view after you capture an image.

Next, Esc back to the main menu and hit the Grab command again. Select Dark frame:None. With the camera nosepiece uncovered, hit Enter to begin another exposure. This time you are taking a light frame. Notice how smooth the image looks. Repeat the above steps used in evaluating pixels in the dark frame. Notice that they all saturated with 4,095 counts. This is the maximum amount of light entering as photons and converted to electrons that the CCD can read.

Next, cover the nosepiece of the camera and use the Grab command again, only this time select Dark frame:Also and hit Enter. This image has a much lower background and range, and represents a dark subtracted image. Still, pixel intensity variations fall between 50 and 250. Some individual hot and cold pixels may show at 30 to 900 counts, but their Average Value is 100 or so. This "Avg" value (displayed in the crosshairs data) represents the low end intensity of your pixel image data, while 4,095 represents the maximum intensity value. All your CCD image data is represented as shades of grey between 100 and 4,095 counts. This is a very large range, far beyond the photographic process capability.

Let's Esc to the main menu and use the Setup command in the Camera menu. We will cool the camera to 0 degrees C. with a new Setpoint setting of 0. Also, set Temperature regulation to Active. Nothing happens yet until you hit enter. Notice the lower corner of the Camera Status that shows Temperature and that it is rapidly dropping.   When it stabilizes at around 0, you can see the percentage cooler capacity you are using shown in parentheses. Grab another dark subtracted image(Dark frame:Also) and study the display. First notice the much more uniform look the pixels show. The benefits of CCD cooling are very evident. Notice that the average count remains consistently around 100 but that the pixels are much more closely clustered around 100 counts.[3]

If your room temperature is about 70 degrees F., try further cooling to -8 degrees C. Nearly 100% cooler capacity may be indicated. For good astroimages, don't run above 90%. Grab an image once the temperature stabilizes in the -8 degree range. Notice that the image is even more uniform appearing now. The average pixel count is still around 100, but "hot" pixels have greatly diminished except for an errant few that may always read high. No amount of cooling can help these. They are inherent in the manufacture of most CCDs and typical.

Summary

Even at a 1 second exposure, the value of cooling is demonstrated to be important as well as the dark taking and subtraction procedure. These steps are absolutely necessary to get the most from your CCD camera. If you were at the telescope, all that would be left to do is to save this image. Let's do that now but first we will need to use the Create Directory command in the File menu to make a new directory for our images. Execute the command and when it asks you for a directory name type CCD.[4] Hit Enter to create the directory.

Finally, get back to the main menu and use the Save command in the File menu. Type a name for the image (that follows standard DOS naming convention) with 8 legal characters, e.g., the first eight letters of your name and hit Enter (don't put spaces in the file name). Then use the Open command in the File menu and look for your name there. Highlight it and hit Enter to open it. Notice the displayed header data has the file name you gave it, the date and time setting of your computer as well as exposure time and temperature, etc. Some other parameters were not yet set by you and may be incorrect. See Section 5 and the Telescope Setup and Edit Parameters commands for more on this. This data will always be connected with the

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[3]   You might think the pixel values would be clustered around 0 counts but instead they are clustered around 100. That's because the CCDOPS software adds 100 counts to the dark subtracted image to stop pixels from going below zero when the two images are subtracted. Just remember that 100 counts represents zero signal.

[4]   As a convenience the software makes up directory names for you by adding the current month and day to DATA. You can use this name or type in your own name.

saved image as long as it is viewed by any CCDOPS software such as a friend's or a magazine's.[5]

Repeat the above procedures to capture, display and save images until you are confident enough to take the next step of coupling your CCD camera to a telescope at night. This time, before you exit the software, use the Shutdown command in the camera menu. You want to do this before you turn off power to the CPU so that it has a chance to let the cooler warm up a bit before the power is turned off. After using the Shutdown command give the CPU 30 seconds or so before turning off the power. If you try to exit the software with the cooling on, the software will prompt you to shut it down first.

2.2. The First Night with the Camera

Focusing a CCD camera can be a tedious operation, so a few hints should be followed. Before using the software to focus the camera the first time, you should place a diffuser (such as scotch tape, wax paper or ground glass) at the approximate location of the CCD's sensitive surface behind the eyepiece tube and focus the telescope on the moon, a bright planet , star, or a distant street lamp. This preliminary step will save you much time in initially finding focus. The approximate distance behind the eyepiece tube for your CCD camera is 0.660 inches as shown in the figure below.
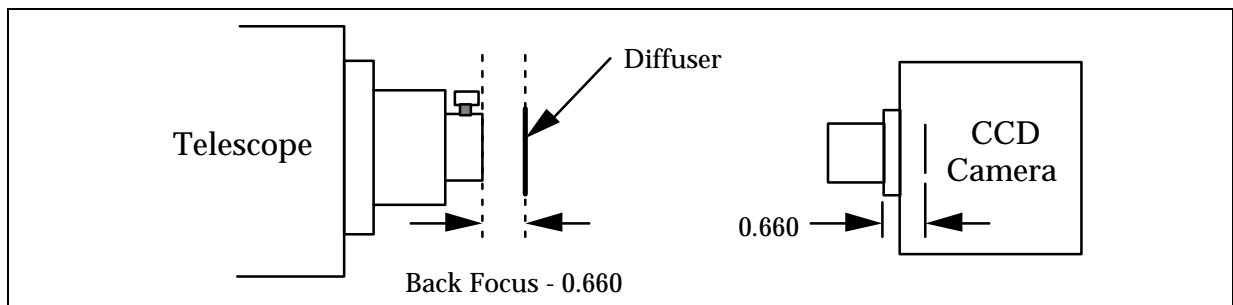

Figure 2.2 - Camera Back Focus

Your CCD camera has a T-Thread on the front and is supplied with a screw-in 1.25 inch nosepiece. Most users will find simply inserting the nosepiece into the telescope focuser in place of the eyepiece the most convenient. Using the camera with other T-Thread accessories like eyepiece projection adapters is also possible. At first, just use the nosepiece.

Orient the camera as shown in the figure below and drape the optical head's cable over the telescope fork so that it is not hanging free and being dragged by the telescope which could cause the telescope to have erratic RA (Right Ascension) motion. The orientation shown below has the CCD's wide axis (X) aligned with RA and the narrow axis (Y) aligned with Declination. Re-balance the telescope as required.

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[5]   Note that it's always a good idea to display the image and adjust the background and range parameters to your liking before you save the image. That way the CCDOPS software will remember the settings and use them the next time you load and display the image.
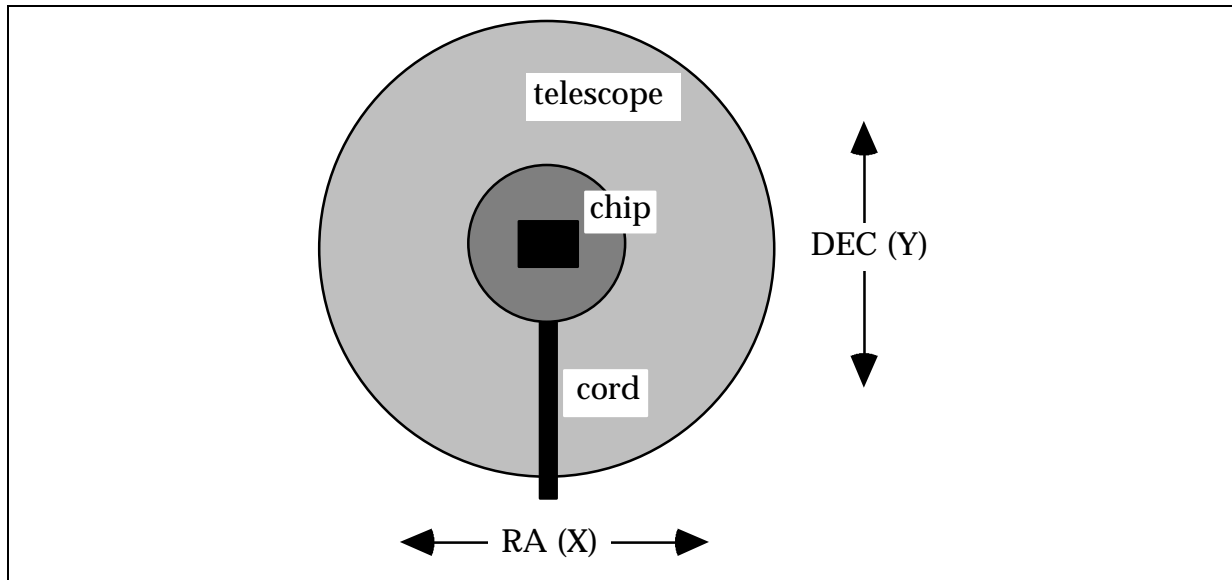
Figure 2.3 - Camera Orientation

If you haven't done so already, power up the CCD camera and computer. Under the Misc menu use the Telescope Setup command to enter your telescope information. For the Aperture item enter the clear aperture in square inches (for example an 8" SCT is 43 square inches). The focal length will be close to the product of the telescope diameter and the f-ratio (for example an 8" f/10 has an 80" focal length). Finally enter your name in the User item. These parameters are saved with each image in the image header.[6]

2.2.1. Focusing the Camera

The telescope should be polar aligned and tracking. Since at this point you can be fairly far out of focus, we recommend you start with a relatively bright star (2nd Magnitude or brighter). Visually center the telescope on the star using your finder/guide scope or by sliding an eyepiece in and out of the telescope without readjusting the telescope focus knob.

Use the Focus command in the Camera menu and set up for a 1 second exposure, Full frame, Automatic update, Zero delay and Auto grab disabled. When you hit the Enter button, the software will switch into graphics mode and start taking images, displaying them on the screen one after another.

What you will typically see is a huge, out of focus star image. On an SCT if the focus is off enough, you'll see an image of a donut with the telescope's central obstruction showing in the middle of the star. On refractors there won't be any central obstruction. At this point you adjust the telescope's focus, causing the star's image to shrink until it is a fairly small, bright spot. When you get close to focus, you will see the star starts to bloom, with streaks protruding above and below the core of the star. In fact, the signs of a really good focus is when the blooming tails are their longest. For now don't worry about getting a perfect focus, just get close. When you think you are focused hit the ESC key to exit from focus mode.

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[6] Refer to Section 5, the Software Reference section for a more detailed description of the Telescope Setup command.

Now, reposition the telescope on a dimmer star, 5th or 6th Magnitude should work well. We want to do the critical focus on a star that won't saturate the camera. Reenter the Focus command using a 3 second exposure and the Planet frame mode. The 3 second exposure allows the camera to average out some of the atmospheric effects. The Planet frame mode takes a full frame image and then allows you to position a box around the star using the mouse or keyboard in order to reduce download time. You can also resize the default box as desired.

To position the planet frame with the mouse, click and drag the upper-left and lower-right corners of the box or click and drag the center. To position it with the keyboard, you use the arrow keys in combination with the T key. The T key toggles whether you are moving the Center, the Upper-Left or the Lower-Right corner of the box. You can see which is currently selected in the upper-left corner of the display adjacent to the Hot label. Once you have placed or redrawn the box, proceed with the Focus command by hitting the L key (for located).[7]

You achieve critical focus by watching the Peak value displayed in the upper-left corner of the display and adjusting the telescope focus until the highest peak value reading is achieved. We recommend you start on one side of focus and adjust the telescope a little at a time. On the first pass just get a feel for what sort of peak reading you'll be able to achieve and don't worry if you go past the peak. In fact, make sure you have gone through the peak and the peak values are dropping off or the star image is deteriorating. Then back up the focus and go through it again, this time stopping when you get close to the peak readings from the first pass. For SCT's always enter exact focus with a counter-clockwise focus knob movement.

2.2.2.   Finding and Centering the Object

Once best focus is achieved, we suggest changing the Focus command to the "Dim" mode to help center objects. This mode gives a full field of view, increased sensitivity, but reduces resolution in order to increase the digitization and download time. If you have difficulty finding an object after obtaining good focus, you can remove the head and insert a medium or low power eyepiece. Being careful not to adjust the focus knob on the telescope, slide the eyepiece in until the image appears in good focus. Then visually find and center the object, if it is visible to the eye. If not, use your setting circles carefully. Then, re-insert the CCD head and set an exposure time of about ten seconds. Center the object using the telescope hand controls. Remember, your CCD chip is only 4.7 x 3.6 mm or the size of a match head. This field of view is like using a 4-6 mm focal length ocular!

Note: *With a 10 second exposure, objects like M51 or the ring nebula are easily detected with modest amateur telescopes.*

2.2.3.   Taking an Image

Take a CCD image of the object by selecting the Grab command and setting the exposure time to 60 seconds. Set the Dark Frame option to Also so the software does an Auto-Dark subtraction, set with Image size to full and enable Auto Display. The camera will expose the CCD for the correct time, download and then display the image. You can then save it or keep

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[7]   You don't have to remember all the key names. The CCDOPS software has a pull down menu in the upper-left corner of the display (named Focus in this case) that you an click on with the mouse or pull down with the Enter key. You can then make choices from that pull-down menu.

trying your acquisition and focusing technique. Refer to section 3.2.2 for the "dated directory" saving short cut. If you now have questions, read on through section 3.

When you are through for the night don't forget to use the Shutdown command in the Camera Menu before you power down the CPU.

3.   Software Flow

This section describes the CCDOPS software from a work flow standpoint. Rather than discuss each command in every detail which is done in the separate Software Manual, this section lets you see the forest through the trees, describing at a high level what each command does and why you would use it. Read this section after your first night with the camera system and it will help chart your course for future use.

3.1.   Image Acquisition Routines

Probably the most important part of any CCD camera system is the acquisition of image data. This section describes the various commands that can be used to take images.

3.1.1   Grab

The **Grab** command is the most straight forward way to take images with the camera. It's just like pressing the button on your SLR to take a snapshot. You use the Grab command once the camera system is all set up and focussed. In its simplest form it takes a single image of a programmed duration and downloads it to the PC.

There are several options associated with the Grab command that expand its use. First off, you can choose to take an **auto Dark-Subtracted image** or a single **Dark Frame** or **Light Frame**. At the start you'll want to take auto Dark-Subtracted images and later, as your experience grows, you may want to take Dark frames separately and store them on disk for later manual subtraction from Light frames.

Another aspect of the Grab command is that you don't have to take full frame images. You can choose to take **Half Frame** or **Quarter Frame** images where only the central half or quarter of the field of view is captured. This has the benefit of reducing storage requirements for images of objects such as Planets that don't fill the field of view. Along this vein, note that you can also use the **Camera Setup** command described below to reduce the camera's resolution through binning which also reduces storage requirements while preserving the field of view.

Finally, the Grab command can be programmed to **automatically display** the image after it has been acquired, or **delay** a number of seconds prior to starting an exposure to allow you time to get back to the telescope and start hand guiding when desired.

3.1.2   Focus

The **Focus** command works like a continuous version of the Grab command. It takes images and displays them on the computer, one after another. In its most simple form it is used to focus the telescope and to find and center objects in the field of view.

As each image is downloaded and displayed on the screen, the Focus command searches through the image and reports the brightness and location of the **brightest pixel** in the image. Critical focus of the telescope/camera system is easily achieved by adjusting the telescope focus until this peak value is maximized.

The Focus command can be programmed to take a partial frame image to help speed up the image display in the **Planet mode**. In Planet mode you select a small region of the full frame with the mouse and on subsequent images only that region of interest is digitized and downloaded. For focusing on stars, this can dramatically increase the frame rate when used with short exposures.

You can also program the Focus command for the **Dim mode** where the camera is switched into low resolution mode. With the use of binning, the image resolution is reduced and pixel size increased to 22.2 x 22.2 microns. This is handy for finding faint objects, as larger pixels gather more light, or for generally improving the image throughput (if binning is selected from setup mode, don't forget to change resolution prior to imaging at Hi-Res).

3.1.3   Track and Accumulate

Track and Accumulate is a patented process invented by SBIG that allows you to take long duration images through the telescope without having to hand guide. It greatly simplifies digital astrophotography.

First, a little background is required. It's obvious that the clock drive in your telescope counteracts the earth's rotation, but what may not be so obvious is that even the most precise drives, with periodic error correction and an excellent polar alignment eventually drift, causing streaking of your images. What Track and Accumulate does is divide the long exposure into several shorter duration **snapshots** which are automatically co-registered and co-added. The final result is an image that is nearly identical to a single longer image except that there is no tracking induced streaking!

There are a few limitations of this process though. First of all, this couldn't be applied to a bunch of 0.01 second images to remove the effects of atmospheric turbulence, as desirable as it may seem. To get the benefits of co-adding several images to equal a single longer image, the noise in each of the snapshots must be above the camera's read noise floor. What this implies is that you still need to get a relatively good mount and have a fairly good polar alignment. The good news is that today's modern mounts can track fairly well over a minute to several minutes. Also faster f/# telescopes and larger pixels help. A second limitation is that over a long exposure time, the effects of accumulated telescope drift reduces the size of your final image due to misregistration of shifted frame edges. For example, if over the duration of the acquisition the telescope had drifted 15 pixels in RA and 10 pixels in DEC, the final image would be smaller by that amount.

When using the Track and Accumulate command you choose the **snapshot time** and the **number of snapshots**. You can also program it to take a partial frame, selecting the **Half-Frame** or **Quarter-Frame** mode. The Track and Accumulate command always takes auto Dark-Subtracted images but you can program how often it takes a dark frame by setting the **dark interval**.

3.1.4   Eyepiece Mode

The **Eyepiece** feature turns your camera into an electronic eyepiece. You select the exposure time (and the resolution) and the camera tkes image after image, displaying the image on the screen. Point you telescope at the heavens and watch the galaxies fly by.

3.1.5   Auto Grab

The **Auto Grab** feature allows taking a sequence of images at some periodic interval and saving them to disk. It isn't a command in itself but rather an extension of the **Grab** and **Focus** commands. It's most useful for monitoring type programs or for selecting the best images out of a series of images (planets).

With the Auto Grab feature you must pick a **file name** for the series of images and the software automatically adds an index to the name for you as the images are being logged. In addition to the file name, you also specify whether to save the images in the **SBIG**, **TIFF** or **FITS** formats discussed below. Finally you select the **number of images** to acquire and the **interval** from the start of one image to the start of the next.

When used in conjunction with **Grab** command, the Auto Grab can further be programmed to refresh the dark frames for auto Dark-Subtracted images at a specified **dark interval**. The software then proceeds through the program, taking images at the periodic rate and logging them to disk. Again, this feature is quite handy for variable star monitoring or other related tasks.

When used in conjunction with the **Focus** command, the Auto Grab feature can be used to see the images while they are being acquired or to manually select the best image from a series of images for example. If the Focus command is programmed for the **manual update** mode then after inspecting each image you can choose to skip the image or save it to disk. In the **auto update** mode the Focus command automatically logs each image to disk.

3.1.6   Color Grab

The **Color Grab** feature works in conjunction with the Color Filter Wheel accessory and takes a series of three images with dark frames through the red, green and blue filters and logs them to disk. Color Grab isn't a command in itself but rather an extension of the **Grab** and **Track and Accumulate** commands.

With the Color Grab feature you must pick a **file name** for the series of images and the software automatically adds an extension (.R, .G or .B) to the name for you as the images are being logged (example M51.R). In addition to the file name you also specify whether to save the images in the **SBIG**, **TIFF** or **FITS** formats discussed below.

For programming the exposure time, you set the **Red exposure** in seconds as part of the **Grab** or **Track and Accumulate** commands and then with the **Color Grab** extension you set the **Green** and **Blue** exposures as a ratio of the Red. We do it as a ratio so you can easily compensate in exposure time for the decreased CCD sensitivity in those color bands. This need only be set once.

3.2.   File Operations

Just as important as acquisition of image data, is saving and retrieving images on the disk. This section describes the various commands that are used for image storage and retrieval.

3.2.1   Naming Conventions

Although you can choose most any name when saving your images you are restricted by MS-DOS's naming convention of an eight character **name** followed by a three character **extension** **(example 8INCHM51._ _ _)**. Beyond that, we have a few recommendations that may simplify your image naming.

We recommend that you use the eight character name as you wish but try to leave the three character extension up to the CCDOPS software. For everyday images the CCDOPS software will attach the .237 extension to the file name when you save it. For **Auto Grab**

images the CCDOPS software will attach a .001, .002, etc. to mark the image sequence. Finally, for **Color Grab** images the CCDOPS software will attach the .R, .G and .B extensions etc.

3.2.2   File Path and Filter

For convenience MS-DOS allows you to divide your hard disk into different **sub-directories**. To get the maximum flexibility out of the CCDOPS software, you should be quite familiar with how sub-directories work, remembering that your hard disk is C: and your floppy disk is A:. For example, you might have your CCDOPS software installed in the C:\CCDOPS directory and save your images in the C:\IMAGES\CCD directory.

CCDOPS software always works in one directory at a time and you tell it which directory to use by setting the **path** parameter. You can set the path in two ways. If you know the name of the directory, you can use the **Set Path/Filter** command to type in the path. If however you would like to browse through the directories, searching for files in some forgotten spot, the software allows you to navigate through the file structure within the **Open** and **Save** commands.

When searching through directories looking for images to load, the software also allows you to restrict the files displayed to match a certain pattern by setting the **filter** parameter. For example, if you set the path to C:\IMAGES\CCD and the filter to *.237, only files with the .237 extension show up in the directory. To display all files you would set the filter to *.*. The filter is changed using the Set Path/Filter command.

The simplest way to create a directory in which to store an evening's images is to use the Create Directory command in the File menu. This adds that evening's date after DATA. Now any image saved to it will be in a directory with that date. After midnight, images are still saved in the previous day's directory since you didn't change it. Each night of image taking, you can perform this "/dated data directory" shortcut and the next day save images in more appropriate directories that you may wish to create.

3.2.3   Saving Images

Saving images on the disk is accomplished using the **Save** command. You can choose to save the images in one of two **SBIG formats** or in the **TIFF** or **FITS** formats. Which format you choose will depend on what you plan to do with the image in the future.

Images saved in the SBIG **compressed** and **uncompressed** formats can later be read back into CCDOPS which is a very important consideration. Compressed images take up about one-half the space of the uncompressed format with no loss of information and we recommend you always save your images in this format.

The **TIFF** format is popular with desktop image processing software packages such as Adobe's Photoshop. The **FITS** format is a scientific image format that is popular with professional astronomical image processing packages. Be forewarned that *if you only save your images in TIFF or FITS format, you will not be able to read the data back into CCDOPS* and could limit 3rd party software image processing capability.

Also, the TIFF and FITS formats support 8 or 16 bit data. While 16 bit mode is preferable from a standpoint that there is no reduction in image dynamic range (remember the camera is 12 bits), many TIFF programs for example do not know how to handle 16 bit data so you have to use the 8 bit format. When saving the image in the 8 bit format, you should first

display the image to get a suitable display and then save the 8 bit data. In that way you have told CCDOPS how to reduce the 16 bit data to 8 bits.

3.2.4   Loading Images

You use the **Open** command to load SBIG **compressed** and **uncompressed** images from the disk into CCDOPS. When the software presents the Open dialog, you can select files or move through the directory structure by opening other directory or disk entries. Also note that you can point to an image file and click on the **Info** button to view the image parameters without having to load the image.

3.3.   Image Display Routines

Image data wouldn't be very valuable if you didn't have some way to look at it. This section describes the various commands and parameters that affect the image display.

3.3.1   Photo vs. Analysis Mode

There are basically two ways to view and image: **Analysis** and **Photo** mode. In either mode you can choose to display the image as a **Negative** or with a soft **Smoothing**. Also if your computer has a **VESA** extended VGA display adapter, you can use the **arrow keys** to adjust the image brightness and contrast in real time.

In **Analysis mode** the image is displayed and several tools are available to analyze or modify the image. You can use a **Crosshair** to inspect individual pixels and to make **Photometric** and **Astrometric** measurements or verify focus of individual stars. You can perform a **Horizontal** or **Vertical Flip** of the image to match other published results or to compensate for varying optical configurations such as refractor, Cassegrain, Newtonian, or diagonal use. You can **Crop** the image to remove something from the field of view or you can **Zoom** the image 4:1, taking a small portion of the image and expanding it to full scale.

In **Photo mode** the image is displayed in the center of the screen free of any other information. This is handy for taking photographs of the screen and visual presentation.

3.3.2   Image Parameters

The CCDOPS software saves an **image header** with every SBIG format image. The header contains various parameters affecting the image such as the exposure time, the date and time the image was acquired, etc. Several commands utilize this header information.

The **Display Parameters** command shows the image header in a tabular form. The **Modification History** command shows which CCDOPS operations have been performed on the image, such as dark subtraction, etc. The **Edit Parameters** command allows you to change some of the parameters after an image has been acquired (if they had been set incorrectly for example) and the **Telescope Setup** command allows you to tell CCDOPS about the type of telescope you are using. This information also gets saved in the header.

3.3.3   Slide Shows

The CCDOPS software allows you to create **Slide Shows** of images you have acquired. A slide show is just what it sound like: a series of images is displayed in **photo mode** at a periodic interval. You'll have to provide the narration though!

You use the **Create Slide Show** command to build the slide show, selecting the images and the sequence. The script gets saved on disk and is later played back with the **Display Slide Show** command. When playing back the slide show you can program the **interval** between slides, whether the slide show **loops** at the end and whether the images are shown as **negatives** or with a soft **smoothing**.

3.3.4   Printing Images

The **Print** command allows you to make a hard copy print of the image. It supports **Postscript** and **HP compatible** laser printers and the FotoFun dye sublimation printer. The image is printed along with the **header**. You can print the image as a **negative** or save it on **disk**[8].

3.3.5   Background and Range

The **Background** and **Range** parameters are used throughout the display software and affect the displayed image's brightness and contrast. While the image data has a relatively large dynamic range, computer displays and the human eye only work over a limited range. For example while the CCD may be able to distinguish 4,096[9] shades of grey, your eye would have a hard time distinguishing more than 100 and the computer displaying more than 64 shades.

Using the background and range parameters you select which portion of the image's intensity values you wish to display. On dim objects you can increase the contrast for example. You can get the CCDOPS software to analyze the image with the **Auto Contrast** setting and have it set the background and range for you or you can set them yourself. Usually Auto Contrast results in the best display.

The background parameter sets the black level in the image or the overall image brightness. Any pixels with intensity below the background are completely black on the display. Lowering the background increases the image brightness by displaying dimmer pixels.

The range parameter is relative to the background level and sets the white level in the image or the overall image contrast. Any pixels with intensity above the level equal to *the background plus the range* are displayed as completely white. Again, decreasing the range parameter increases the image contrast as dimmer pixels begin to saturate on the display.

Finally, pixels with values between the background and the background plus the range are displayed using shades of grey.

3.4.   Image Processing Routines

The third part of any imaging system, after image acquisition and storage, is image processing. This section describes the commands found in the **Utility** menu that are used to process

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[8]   Saving printed images on disk allows you to take the print file to other laser printers if you don't have one of your own.

[9]   In the binned Medium and Low Res modes the CCD has 8,192 and 12,228 shades of grey.

images. Note that the image processing commands that are part of the **Analysis display mode** (Horizontal and Vertical Flip and Crop/Zoom) have already been discussed as part of the Display Commands.

3.4.1 Depixelize and Reduce

The **Depixelize Image** command enlarges the image 2 times and fills in the missing pixels using pixel interpolation. This rounds out square looking star images when taken through short focal lengths and increases the size of the image four fold. It is also handy when sending TIFF images to photo labs for prints to reduce the "blocky" pixel appearance of enlargements and increases the file size to one they are accustomed to handling.

       The Reduce command does just the opposite. It reduces the size of the image four-fold by combining groups of 2 by 2 pixels into a single pixel. This is analogous to running the camera in the binned Medium resolution mode.

3.4.2 Filtering

The commands in this section are used to filter the images, typically comparing pixels to their neighbors and enhancing or reducing the differences.

Smoothing

The **Smooth** command softens the image by replacing each pixel by a weighted average of itself and its eight neighbors. Three settings of smoothing are available: **soft**, **medium** and **hard**. This can be used to advantage in images that are underexposed and have an objectionable amount of graininess, but it will reduce the sharpness of the image.

Sharpening

The **Sharpen** command enhances image detail and is available in three strengths (**soft**, **medium** and **hard**) and in two forms: **Nebulae** and **Lunar/Planetary**. The Lunar/Planetary option provides the most sharpening but can leave rings around stars that are buried in nebulosity.

Warm/Cool Pixel Removal

The **Remove Cool Pixels** and **Kill Warm Pixels** commands ferret out single pixel blemishes in the image and replace them with a weighted sum of their neighboring pixels. The commands are available in three strengths: **soft**, **medium** and **hard**. Warm pixels are generally caused by hot dark current pixels in the CCD that saturate in the exposure and thus don't subtract out correctly. Cool pixels are often caused by using poor quality dark frame or one taken at a slightly different temperature.

Co-Adding and Averaging

You can reduce the noise in images by co-adding or averaging several images. The **Average Dark Frames** command is most useful for dark frames. Both commands allow registering one image relative to the other after you had used the crosshairs to note the required displacements.

3.4.3   Image Corrections

The commands in this section are generally used to correct the images for one type of artifact or another, whether they be from the camera or the telescope.

Dark Subtract

The **Dark Subtract** command is used when you are manually taking and storing **light frames** and **dark frames** as opposed to **auto Dark-Subtracted** images. This can be handy in situations where you know you are going to be taking a group of exposures of equal length. You could take a dark frame first, save it on disk, and then take several light frames. using this command to subtract the dark frame before saving the result.

Flat Field

The **Flat Field** command is used to correct an image for the effects of vignetting and/or small pixel-to-pixel variations in response. To correct an image for these effects you first need to make a **flat field image**. That is done by imaging the inside of the dome or a nearby wall or card held in front of the telescope that is uniformly illuminated. The purpose of the flat field image is to record what happens to a uniformly illuminated target, and then apply those intensity variations in reverse to your images. See page 31.

3.4.4   General Purpose

The commands discussed in this section are general purpose image processing commands.

Log Scaling

The **Log Scaling** command compresses the image's dynamic range through a non-linear logarithmic scaling function. It essentially highlights the dim portions of the image and attenuates the bright portions, much like a photographic dodging & burning effect. This is useful for compressing the incredible dynamic range of objects like the Orion Nebula where bright stars and nebulosity are surrounded by faint nebular detail and useful for well exposed galaxies.

Build Track/Accum Flat

The **Build Track/Accum Flat** command is used to prepare a special **flat field** image for correcting **Track and Accumulate** images. In the process of capturing a Track and Accumulate image, the CCDOPS software co-adds several images together, shifting them relative to one another to compensate for the telescope drift. To properly correct for the pixel-to-pixel variations and any vignetting, the flat field file must have the same shift and add operations applied to it. This is accomplished with the this command in conjunction with a **Track List** file that is created as part of the Track and Accumulate command.

3.5.   Image Analysis Routines

The commands discussed in this section are general purpose image analysis commands.

3.5.1   Histogram

The **Histogram** command displays the image histogram in a graphical format. The histogram is an analysis of the image on a pixel-by-pixel basis where an accounting of the number of pixels at a given intensity is made. It's sort of like a census count of the pixels. How many pixels have intensities between 1 and 10? How many between 10 and 20? Simply stated it is a graph of the number of pixels having a given intensity (this is also referred to as the frequency) vs. pixel intensity. But what good is it, you ask?

One of the ways the CCDOPS software uses the histogram is in setting the background and range parameters as part of the **Auto Contrast** feature. The software looks for the portion in the histogram where pixels start to have a non-zero frequency and sets the background to that value. It then looks at the top end of the histogram and again looks where the pixel frequencies drop to zero, setting the range accordingly. In that way, the background and range have been adjusted to show the bulk of the image's dynamic range.

3.5.2   Cross Hairs

Using the **Cross Hairs** as part of the **Analysis** display mode allows you to examine the image on a pixel-by-pixel basis. As you move the crosshairs around with the mouse or arrow keys, the **coordinates** and brightness **value** of the pixel under the crosshair are shown. The software also shows the **average** pixel value and the deviation (**noise**) of the pixels in a selectable box of pixels surrounding the crosshair.

As explained in detail later, you can also make Photometric (stellar and nebular brightness) measurements and Astrometric (separation) measurements. Finally when positioned over a star, the software will make an estimate of the **seeing** in arcseconds (this counts on you having good focus and tracking).

3.6.   Setup Functions

This section describes the various commands that are used to customize the CCDOPS software to your PC and Telescope.

3.6.1   Camera Setup

The **Camera Setup** command is used to set/enable various options in the camera. You can enable **temperature regulation** and choose a **setpoint**. The camera then regulates the CCD temperature to that setpoint. Choosing a setpoint is usually a fairly simple matter. You want to choose as cold a setpoint as possible without having the power supplied to the TE cooler hold at 100% (as shown in the lower-right hand corner of the main menu display). If you pick a setpoint roughly 30°C below the ambient temperature, you should be safe. You can monitor the CPU temperature with the **Camera Info** command or the ambient temperature by means of an external thermometer. You don't have to pick the exact right setpoint, as long as the power to the TE cooler is running between 80 and 95 percent.

You can also program the camera's **resolution** , choosing **Hi**, Medium, **Low** or **Auto** res modes. In Hi res mode the camera is configured for 640 x 480 pixels of 7.4 micron square. In the Medium res mode the camera is binned 2 by 2 and in the Low res mode the camera is binned 3 by 3. Finally the Auto mode configures the camera for Hi res mode in all cases *except*

the Full Frame Focus mode, where it uses Low res mode. This is handy for speeding up finding objects and focusing the camera.

You can also configure the CCDOPS software to **reuse** dark frames. With that option enabled, the software will remember when you take a dark frame of equal duration to light frame and try to reuse that dark frame for future exposures rather than taking a new one.

3.6.2   Graphics Setup

The **Graphics Setup** command allows you to configure the CCDOPS software for your computer graphics hardware. You can select the type of **graphics card** you have, but in general the **Auto** setting should work well. You can configure CCDOPS display for a **Color** monitor, **Monochrome** LCD or for color display of a **NiteVision** mode where every thing turns red. Finally you can configure the mouse and enable an annunciator that beeps at the start and end of an exposure to tell you when you need to be guiding and when the image is fully downloaded.

3.6.3   Communications Setup

You use the **Communications Setup** command to tell CCDOPS which port you are using to communicate with the camera. You will want to select the **Parallel** interface and the appropriate parallel **port**. LPT1 is the default.

3.7.   General Purpose Camera Functions

The commands discussed in this section are general purpose camera control commands.

3.7.1   Establish Link

You use the **Establish Link** command to tell the CCDOPS software to look for a camera and to establish a communications link with it. The software does this automatically when you run the software so you will typically only need to use this command after you have changed parallel ports or turned off the camera and then turned it back on again.

3.7.2   Information

The **Camera Information** command interrogates the camera and shows you information about your camera's capabilities including the version of firmware. This information may be useful should you have problems with the camera and are in need of technical support.

3.7.3   Shutdown

The **Shutdown** command should be used when you are ready to put the camera away for the night. It turns off the camera's cooling and otherwise prepares it for being powered down. It's a good idea to wait 30 seconds or so after shutting down the camera before turning off the CPU power because that gives the TE cooler time to warm up.

3.7.4   Autoguiding

The commands in the **Track menu** allow you to use your camera as an autoguider. The **Calibrate** command is used first and it lets the CCDOPS software measure your drive's correction speeds so that it can make calibrated corrections. The **Autoguide** command is then used to do the autoguiding. For a more in depth control of the autoguiding operation, the **Autoguide Parameters** command allows you to fine tune tracking and the **Convert Track Log File** command allows you to diagnose tracking problems. More on this later in section 4.4.

3.7.5   Filter Wheel

The commands in the **Filter Menu** are used to position the filter wheel in cameras that have been upgraded for tricolor operation. There is one command to select each possible filter position.

4.   Advanced Imaging Techniques

The following sections describe some of the advanced uses of CCD cameras. While you may not use these features the first night, they are available and a brief description of them is in order for your future reference.

4.1.   Taking a Good Flat Field

If you find that flat field corrections are desired due to vignetting effects or for more accurate measurements of star magnitudes, try either taking an image of the sky devoid of stars or take an image of a blank wall or neutral grey card that is evenly illuminated.

      Finding areas of the sky devoid of stars is very difficult after twilight. Therefore, you should take flat field images of the night sky after sunset, but long before you can see any stars. If this is not possible, take an image of a featureless wall or card held in front of the telescope. However, if using this second method, be sure that the wall or card is evenly illuminated. Do not use a flashlight to directly illuminate a card, but rather allow the light to bounce off of another card or the wall of your observatory opposite the one you are imaging. Use a diffuse light source.

      If you plan on flat fielding Track and Accumulate images, you should also refer to section 4.6. Since the same flat field is added to itself a number of times, be sure that you do not saturate the flat field image by starting with pixel values too high. Typically try to keep the pixel values between 10% to 20% of saturation for this purpose. For single flat field images, try to keep the values to approximately 50% of saturation. That is a value of roughly 2,000 counts for the TC-237 in Hi-Res.

4.2.   Track and Accumulate

An automatic Track and Accumulate mode is available in CCDOPS which simplifies image acquisition for the typical amateur with a good telescope drive. Drives employing PEC or PPEC technology and accurate gears, only need adjustment every 30 to 120 seconds. With Track and Accumulate the software takes multiple exposures and automatically co-registers and co-adds them. The individual exposures are short enough such that drive errors don't show up and the accumulated image has enough integrated exposure to yield a good signal to noise ratio.

      Procedurally, the camera will take an exposure, determine the position of a preselected star, co-register and co-add the image to the previous image in the CPU, and then start the cycle over again. Up to 64 images can be co-added. The resulting exposure is almost as good as a single long exposure, depending on the exposure used and sky conditions. The great sensitivity of the CCD virtually guarantees that there will be a usable reference star within the field of view. This new patented feature provides dramatic performance for the amateur, enabling unattended hour long exposures!

4.3.   Color Imaging

The field of CCD color imaging is relatively new but expanding rapidly. Since your CCD camera is equipped with a monochromatic CCD, discriminating only light intensity, not color, some provision must be made in order to acquire color images. Your camera has been

designed with color imaging in mind with the ability to easily upgrade the camera with an internal color filter wheel in place of the standard shutter wheel.

The color filter wheel allows conveniently placing colored interference filters in front of the CCD in order to take multiple images in different color bands. These narrow band images are then combined by software to form a color image. The Red, Green and Blue pass filters are used to acquire three separate color images of the object. The resulting images are combined to form a tri-color image using the CCDCOLOR software.

Color imaging places some interesting requirements on the user that bear mentioning. First, many color filters have strong light transmission in the infrared (IR) region of the spectrum, a region where CCDs have very good response. If the IR light is not filtered out, then combining the three images into a color image can give erroneous results. If your Blue filter has a strong IR leak (quite common), then your color images will look Blue. For this reason, you place an IR blocking filter in front of the three color filters.

Second, since you have narrowed the CCD's wavelength response with the interference filters, longer exposures are required to achieve a similar signal to noise compared to what one would get in a monochrome image with wide spectral response. This is added to the fact that tri-color images require a higher signal to noise overall to produce pleasing images. In black and white images your eye is capable of pulling large area detail out of random noise quite well, whereas with color images your eye seems to get distracted by the color variations in the noisy areas of the image. The moral of the story is that while you can achieve stunning results with CCD color images, it is quite a bit more work. Fast optical systems, f/2 through f/6.3, work best. Focal reducers also help.

4.4. Autoguiding

The CCDOPS software allows the CCD camera to be used as an autoguider through the commands in the Track menu.

When used as an autoguider, the CCD camera repeatedly takes images of a guide star, measures the star's position to a fraction of a pixel accuracy, and corrects the telescope's position through the hand controller input. While autoguiding alleviates the user of the tedious task of staring through an eyepiece for hours at a time, it is by no means an end-all cure to telescope drive corrector performance. All the things that were important for good manually guided exposures still exist including a good polar alignment. Use of an auto guider is to correct for the small drive errors and long term drift, not to slew the telescope or compensate for a poor drive.

One of the reasons that autoguiders are often better than human guiding is that rather than just stabbing the hand controller to bump the guide star back to the reticule, it gives a correction that is the precise duration necessary to move the guide star back to its intended position. It knows how much correction is necessary for a given guiding error from the Calibrate Track command. The Calibrate command, which is used prior to autoguiding, exercises the telescope's drive corrections in each of the four directions, measuring the displacement of a calibration star after each move. Knowing the displacement and the duration of each move calibrates the drive's correction speed.

To autoguide you need to connect the camera's Telescope port to your telescope's CCD input. On Celestron Ultima, Losmandy and LX-200 mounts this is accomplished with the small 6 conductor "telephone" cable provided with the camera. Simply plug one end into the Telescope port on the camera's CPU and the other end into the telescope. On Ultima and

Losmandy mounts you will need to unplug the hand controller and plug the auto guiding cable in its place. On the LX-200 you plug the cable into the CCD jack. Finally if you have an older telescope that does not support the 6 pin CCD port contact SBIG Technical support and inquire about custom hand controller modifications and whether you need an external Relay Adapter box.

4.5.   Field Operation

The ST-237 Advanced CCD Camera is supplied with a wall transformer for operation off 110 VAC that provides 12 VDC output to the camera. You can run the camera off of a car battery when operated in the field. If you are interested in this please contact SBIG or refer to Appendix A for the power jack pinouts.

5.   Glossary

Antiblooming Gate - When a CCD pixel has reached its full well capacity, electrons can effectively spill over into an adjoining pixel. This is referred to as blooming. The Antiblooming gate can be used to help stop or at least reduce blooming when the brighter parts of the image saturate.

Astrometry - Astrometry is the study of stellar positions with respect to a given coordinate system.

Autoguider - All SBIG CCD cameras have auto guiding or "Star Tracker" functions. This is accomplished by using the telescope drive motors to force a guide star to stay precisely centered on a single pixel of the CCD array. The camera has four relays to control the drive corrector system of the telescope. The CCD camera head is installed at the guide scope or off axis guider in place of a guiding eyepiece.

CCD - The CCD (Charged Coupled Device) is a flat, two dimensional array of very small light detectors referred to as pixels. Each pixel acts like a bucket for electrons. The electrons are created by photons (light) absorbed in the pixel. During an exposure, each pixel fills up with electrons in proportion to the amount of light entering the pixel. After the exposure is complete, the electron charge buildup in each pixel is measured. When a pixel is displayed at the computer screen, its displayed brightness is proportional to the number of electrons that had accumulated in the pixel during the exposure.

Dark Frame - The user will need to routinely create image files called Dark Frames. A Dark Frame is an image taken completely in the dark. Dark Frames are subtracted from normal exposures (light frames) to eliminate fixed pattern and dark current noise from the image. Dark Frames must be of the same integration time and temperature as the light frame being processed or numerous hot and cold occur.

Dark Noise - Dark Noise or Dark Current is the result of thermally generated electrons building up in the CCD pixels during an exposure. The number of electrons due to Dark Noise is related to just two parameters; integration time and temperature of the CCD. The longer the integration time, the greater the dark current buildup. Conversely, the lower the operating temperature, the lower the dark current. This is why the CCD is cooled for long integration times. Dark noise is a mostly repeatable noise source, therefore it can be subtracted from the image by taking a "Dark Frame" exposure and subtracting it from the light image. This can usually be done with very little loss of dynamic range.

Double Correlated Sampling - Double Correlated Sampling (DCS) is employed to lower the digitization errors due to residual charge in the readout capacitors. This feature results in lower readout noise.

FITS Image File Format - The FITS image file format (which stands for Flexible Image Transport System) is a common format supported by professional astronomical image processing programs such as IRAF and PC Vista. CCDOPS can save image files in this format but can not read them.

Flat Field - A Flat Field is a image with a uniform distribution of light entering the telescope. An image taken this way is called a flat field image and is used with CCDOPS to correct images for vignetting.

Focal Reducer - A Focal Reducer reduces the effective focal length of an optical system. It consists of a lens mounted in a cell and is usually placed in front of an eyepiece or camera. With the relatively small size of CCDs compared to film, focal reducers are often used in CCD imaging.

Frame Transfer CCDs - Frame Transfer CCDs are CCDs that have a metal mask over some portion (usually half) of the pixel array. The unmasked portion is used to collect the image. After the exposure is complete, the CCD can very quickly shift the image from the unmasked portion of the CCD to the masked portion, thus protecting the image from light which may still be impinging on the CCD. This acts as an electronic shutter.

Full Well Capacity - Full Well Capacity refers to the maximum number of electrons a CCD pixel can hold. This number is usually directly proportional to the area of the pixel.

Histogram - The Histogram is a table of the number of pixels having a given intensity for each of the possible pixel intensities. Remember that, in the end, the image file is nothing more than a list of pixel values, one for each CCD pixel.

Light Frame - The Light Frame is the image of an object before a Dark Frame has been subtracted.

Path/Filter - The Path setting tells CCDOPS which directory and disk drive to find and store the image files. In essence, it defines the current directory. The filter controls which image files are shown in the Open directory. Only files that match the filter are shown. For example, a filter setting of "*.237" will only show files that have an "237" extension.

Photometry - Photometry is the study of stellar magnitudes at a given wavelength or bandpass.

Photons/ADU - This is an indication of the camera's gain in converting incoming light into image counts. This value is used with programs such as Hidden Image. For any image you take the Photons/ADU is shown in the Parameters command from the Image menu.

Pixel Size - The smallest resolution element of a CCD camera is the CCD pixel. The pixel size for your camera is 10 microns square (10 by 10 microns)

Planet Mode - Planet Mode is the most useful way to achieve focus. When you select Planet mode, a full frame is exposed, downloaded, and displayed on the computer monitor. A small window can be placed anywhere in the image area and the size of the window can be changed. Subsequent downloads will be of the area inside the box resulting in a much faster update rate.

Quantum Efficiency - Quantum Efficiency refers to the fractional number of electrons formed in the CCD pixel for a given number of photons. Quantum Efficiency is usually plotted as a function of wavelength.

Readout Noise - Readout noise is associated with errors generated by the actual interrogation and readout of each of the CCD pixels at the end of an exposure. This is the result of fixed pattern noise in the CCD, residual charge in the readout capacitors and to a small extent the noise from the A/D converter and preamplifier.

Readout Streaking - When a bright object is imaged using a short exposure time, readout streaking can occur. Readout streaking can look similar to blooming except it extends across the entire image passing through the bright object. This is a result of image shift

at the beginning and again at the end of an exposure due to frame transfer. The readout streaking is usually very faint with respect to the overall image and can sometimes be eliminated from the display image by slightly raising the background level.

Resolution Mode - The resolution of a CCD camera is determined by pixel size. Pixel size can be increased by combining or binning more than one pixel and displaying it as one pixel. Doing so decreases the effective resolution but speeds up the download time of the image. Maximum resolution is determined by the smallest size of the individual CCD pixel.

Response Factor - Response Factor is a multiplier used by CCDOPS to calibrate a telescope for photometric calculations. The Response Factor multiplied by 1000 is the number of photoelectrons generated in the CCD for a 0th magnitude star per second per square inch of aperture.

Saturation - Saturation refers to the full well capacity of a CCD pixel as well as the maximum counts available in the A/D converter. The pixel is saturated when the number of electrons accumulated in the pixel reaches its full well capacity. The A/D is saturated when the input voltage exceeds the maximum.

Sky Background - The sky background illumination or brightness is the number of counts in the image in areas free of stars or nebulosity and is due to city lights and sky glow. High levels of sky background can increase the noise in images just like dark current. For some deep sky objects, filters can be used to reduce the sky background level.

Seeing - Seeing refers to the steadiness and the transparency of the atmosphere during an observing session.

TE Cooler - The TE Cooler is a Thermal Electric cooling device used to cool the CCD down to operating temperature. The CCD is mounted to the TE Cooler which is mounted to a heat sink, usually the camera head housing.

TIFF Image File Format - The TIFF image file format (which stands for Tagged Interchange File Format) was developed jointly by Microsoft and Aldus Corporations to allow easy interchange of graphics images between programs in areas such as presentation and desktop publishing. CCDOPS can save image files in this format but it can not read them.

Track and Accumulate - The Track and Accumulate function is an patented feature of CCDOPS that allows the user to automatically co-register and co-add (including dark frame subtraction) a series of images of an object. These exposures can be taken unguided as long as the "Snapshot time" does not exceed the length of time before tracking errors of your clock drive become apparent. This allows you to image and track without guiding or the need to connect the CCD Relay port to your drive motors.

Track List - The Track List is a file generated by CCDOPS during a Track and Accumulate session. The Track List logs all the corrections made by CCDOPS for each of the images. Track lists are required when flat fielding Track and Accumulate images.

Tri-Color - Tri-Color refers to color images created using three different colors mixed into a balanced color image using red, green and blue filters. An object is imaged three times,

once with each color filter. The three images are then co-added and color balanced with the appropriate software.

Vignetting - Vignetting is obstruction of the light paths by parts of the instrument. It results in an uneven illumination of the image plane. The effects of vignetting can be corrected using flat field images.

6.   Hints and Tips

This section contains hints and tips to get the most use out of your camera and software. There is a section of Question and Answers to the most common questions followed by several sections of tips.

6.1   Question and Answer

This section contains answers to some of the more common questions we hear in the Technical Support department.

Q. *Is there a short cut to focusing the camera?* A. We find the best method to be using the peak brightness as described in the manual but there are almost as many opinions here as there are people.

Q. *How often do I need to refocus?* A. When there has been a big temperature change (3 °F) or when you have moved to a vastly different position of the sky with an SCT, you should consider refocusing.

Q. What *is the back focus of the camera?* A. Please refer to Figure 2.2.

Q. What *is the extra rectangular bar that came with the camera ?* A. It is a tripod mount that you screw into the side of the camera that allows you to mount the camera on a tripod if you plan to fit it with camera lenses.

Q. *Can I use a camera lens with the camera?* A. Yes, SBIG sells an adapter for the camera that allows you to use C-mount or other lenses with the camera.

Q. *Can I operate the camera off of a car battery?* A. Yes you can. You'll probably want to use a deep cycle marine battery and you'll have to purchase a cable. Please refer to section 4.5.

Q. *How cold should the CCD get?* A. You should be able to work around 30 degrees Celsius below ambient.

Q. *Who should I call when I have questions or problems with the camera?* Call SBIG and ask for PixCel Technical Support.

Q. *How long of a cable can I use between the PC and the CPU?* A. You should be able to use cables up to 100 feet in length but it will vary from PC to PC.

Q. *Where can I get a longer cable?* A. Go to your nearest computer store and ask for a 25 pin male to female extension cable.

Q. *Where can I get a shorter cable?* A. Go to your nearest computer store and ask them to make you a short 25 pin male to female crimp type cable.

Q. *Why does the software say there isn't enough memory?* A. You need to make sure you have at least 1 Megabyte Extended memory and that the HIMEM.SYS driver is loaded into your CONFIG.SYS file. Also check that other entries in the CONFIG.SYS or AUTOEXEC.BAT files are not consuming too much memory.

Q. *I see dark spots in my images, what causes them?* A. If the dark spots are a single pixel they are typically caused by hot pixels in the CCD saturating and can be removed with the Remove Cool Pixels command. If they're several pixels wide you should suspect dust on the window

and that effect can be removed with flat fielding your images or clean the window with an "air duster".

Q. *My images have dark tendrils in the corners. What can I do?* A. These are caused by the CCD frosting and you need to replace the desiccant as described in Appendix C.4.

Q. *Can I write my own software for the camera?* A. Appendix B describes the file format used to save images. You can also request an Application Note from the manufacturer telling how to interface and program to the camera.

Q. *Is there other software available for the camera?* A. You can upgrade your camera with the Color Filter Wheel and CCDCOLOR software. Also there are several third party software packages for image processing, camera control and various printer output.

Q. *Can I run the software under Windows,?* A. While we don't recommend running the CCDOPS software under Windows you should be able to do it. Also Software Bisque's SkyPro software supports the camera under Windows and is fully integrated with their excellent The Sky software. Contact Software Bisque at (303) 278-4478.

Q. *What do I do if my images have elongated stars?* A. If using Track and Accumulate you are probably using a snapshot time that is too long. If the snapshot time is longer than the amount of time your drive can track unguided with acceptable guiding errors, you will see elongated stars in your final images. If your snapshot times are getting down to 30 seconds or less you should improve your drive.
　　If you are using your camera as an autoguider for film photography and are noticing unacceptable guiding errors, please check the following:

1. Can you move the telescope using the Move command? This is an indicator as to whether or not you are properly connected to your drive system via the relay cable from the CPU.

2. Be sure that your calibration time gives at least 10 to 50 pixels of movement for each step of the Calibrate command.

3. Check for flexure between the CCD camera head and your system. Check for flexure between the guide scope or off-axis guider and your telescope system. This is a very common source of guiding errors. A very small movement of the CCD head with respect to the guide scope during an exposure can cause unacceptable streaking.

4. If your mount is stable, try longer exposure times while tracking to average out the atmospheric effects.

Q. *What do I do if my CCD frosts?* A. If your camera starts to frost after a year of use it's time to replace the desiccant as described in Appendix C.

Q. *The moon is too bright, what do I do?* A. Try a full aperture solar filter. Try a variable rotating neutral density filter. Don't use off-axis apertures smaller than 4" or you give up resolution.

Q. *What exposure is best for planets?* A. Use the crosshairs mode to measure the disk's intensity. Make sure that the pixels are about 75% saturated. This should give a good range of brightness. Sometimes moons can also be imaged at the long end of the exposure range.

Q. *Which laptop is best for CCD use?* A. Nearly any laptop will work, however you should take a copy of CCDOPS with images and run it from any units you are considering. Color LCD isn't necessary unless it is your only computer.

Q. *Why are my images grainy looking and not smooth?* A. The grainy look is from low signal to noise. A longer integration time will increase signal and reduce graininess. Try doubling exposure times. This works up to a point where you begin picking up sky background (light pollution) which limits maximum practical integration times. Also make sure your cooler is running at 75% capacity or more.

Q. *What are the advantages of shorter focal lengths and faster F# telescopes?* A. Shorter focal lengths increase the field of view, allowing you to image larger objects. Faster F# telescopes increase the field of view *and* shorten the exposure times. Do not underestimate the benefits of focal reducing your f/10 SCT systems!

6.2. CCDOPS Use Tips

* If you display an image and nothing shows, check that the Auto Contrast was enabled.

* When selecting a Track and Accumulate guide star, it is not necessary to exactly set the cursor on the center of the selected star. It automatically snaps to the brightest pixel, not necessarily the geometric visual center.

* Co-adding images together, whether guided or accumulated, averages out noise and results in a smoother image than one single long exposure. Keep in mind, the longer the individual exposure, the higher the signal to noise until you reach background sky limits. You will find that at f/10, a single 60 second exposure will be grainy for low contrast objects and 5 minutes may be the minimum tolerable, requiring off-axis guiding or a guide scope. At f/6.3, this snapshot time may be 1 minute and at f/2 it may be 10 seconds. Don't be afraid to experiment with poorly guided images of varying exposure times to learn what works best. Co-adding many underexposed images still results in inferior results. This is especially true for tricolor.

* If you are fortunate enough to have access to a full aperture solar filter, daytime use with the CCD camera is possible at f/6.3 to f/10. Distant power poles and power lines silhouetted against the sky work well as a target. Use binning since turbulence will limit resolution. This will allow you to learn the software flow in daylight.

* Dark frames aren't necessary for short exposures of bright objects (Jupiter at f/20 with 2x Barlow projection or the moon).

6.3. Hints and Tips for Laptop Users

* If you mainly use your laptop for field use with CCDOPS, it is possible to modify your AUTOEXEC.BAT file to boot directly into CCDOPS, saving time.

* If your laptop is monochrome, obtain a small piece of red litho stripping film (rubylith) to slip in front of the LCD display. Most print shops have the red plastic. Use it matte side out.

- You can stack your laptop directly on top of the CPU for a compact package. You could make a custom 8" ribbon type cable to couple the CPU to the laptop. The cable is wired pin 1 to pin 1, etc. See Question #11 on page 73.

- Cursor movement through CCDOPS is much faster using the mouse, especially if your laptop has one of the small keyboard based pen-point mice.

- Some LCD displays dim when it is very cold outside. A small heat pad behind the display can help.

- Don't be afraid to adjust display brightness on your computer in the course of viewing an image. Negative views require opposite settings.

- Try to use a laptop with 64 shade gray display capability. Some laptops have a display setup mode in their resident software to optimize. VESA compliant is also useful for real time cursor contrast changes.

- LAPLINK software and cables allow easy next day image file transfer to your main computer. This is very handy.

- Images will always look better when displayed on a video monitor, however, an active matrix LCD display is pretty close except in brightness.

- You may wish to change your display and hard drive sleep cycles (battery conservation) to longer "keep awake" times so as not to interfere with image acquisition (long Track and Accumulate).

- LED flashlights help to see the keyboard when the display is dimmed red.

6.4. Telescope Tips

- Always verify best collimation prior to installing the CCD camera. Because sub-arc second imaging (better than that you can see visually) is possible.

- Always secure the camera head cable to the optical tube assembly. Never let the cable dangle free from the focuser/ocular holder.

- Off-axis guiding is worth it, even on a bunch of 3 minute co-adds of a deep sky object.

- Don't guess on focus. If you're not sure, it is time to refocus.

- Take time to frame your object. Rotate the camera 90 degrees to take advantage of the CCD chip's 3:4 aspect ratio and don't forget to refocus again.

- Focal reduce as much as possible for deep sky objects. Exposure times are then shorter and signal to noise gets better. 2-3 arc-seconds per pixel (30" focal length) is plenty of resolution for deep sky objects, especially nebulae. Good tracking is still critical down to 12" focal lengths in hi-res mode. Always polar align to minimize Dec drift.

- Focusing micrometers really help, especially on SCTs where you want to always enter the best focus position on a counterclockwise knob rotation. This advances the primary mirror forward against gravity and preloads bearings, screw threads and any mirror/baffle rocking. A light knuckle rap prior to exposure or guiding is advisable to settle moving components. It is always possible to ascertain exact focus only after you have passed a peak

intensity and then come back to the peak's setting. You may not see the exact high value, but will see the trend at best focus position. Again, don't guess at focus.

- Focusing on planets is difficult since seeing can uniquely blur each frame. If a planet's moon is present, use the slow motion hand control to move over to it. Readjust exposure time accordingly and refocus on it, then bring the planet back into view and capture it.

- If track problems exist, first check balance in declination and then RA since they interact. Verify the 1 1/4" camera head coupler doesn't rock in the telescope bushing and that it is flush at it's coupler flange with bushing. Check drive clutches or clamps. Check drive rate setting. With guiding ocular visually check PEC setting or reprogram. Trails on only the brightest stars along short axis of the CCD is blooming, not tracking.

- Real dark skies are not necessary for beautiful CCD images of deep sky objects. CCDs are far superior to film with or without filters in this respect. Tricolor CCD will benefit from dark skies, but still works great compared to color film.

- Simple 2 element refractors can show bloated stars due to chromatic aberration since CCDs have a wide spectral response and a very wide dynamic range of signal. Red filters can help or quality multi-element color corrected refractors.

- Always keep an eye on ambient temperature changes. A 3 degree Fahrenheit change can affect SCT focus enough to merit refocusing. Temperature drop = clockwise movement of SCT focus knob (yes, the way you didn't want to move it).

- Closely re-align your finder as needed to the CCD image on the screen to speed up object finding. Don't use a 90 degree diagonal to visually acquire objects and expect them to be in the CCD camera view. The chip is only .1 x .13 inch in size and 90 degree diagonals are never rotationally collimated to optical axis close enough to use for CCD work. Special laser collimated diagonals are available for this purpose as well as CCD framing oculars with exact reticle patterns to match the CCD chip.

- Digital setting circles with hi-res encoders (1/12 degree or better) can get you close to faint objects if you are polar aligned and they are "dialed in" as well.

- Integrating Software Bisque's "The Sky" software into your imaging system is another help in object acquisition, but adds new complexity to the operations until after you are comfortable with CCDOPS and CCD imaging. It is then a very interactive tool.

- Don't bother with deep sky imaging on an Alt/Az configured mount even if it tracks. Image rotation results and precludes co-adding, etc. in most instances. Use a wedge and polar align such systems for best and simplest results.

- Wait for both telescope and CCD camera to thermally settle in before trying for optimal results. Typically wait 1/2 to 1 hour after setting up and running. This is a good time to set up software, balance scope, and polar align, etc.

- Use a dew shield on SCTs to prevent dewing and minimize stray light. Re-balance as necessary. CCDs have a tremendous dynamic range. Bright stars at edge of field can spray light across nebula, especially Veil, Horsehead, California nebulae. Anti-blooming can't help scattered light. Reposition field slightly and try again.

- Due to small 7.4 micron pixels (.0003") the TC-237 works best at shorter focal lengths of 12" - 80". An 8" aperture is an ideal match for this imager. A bigger scope and larger chip will

just scale results like a larger format 6x7 camera compared to a 35mm camera. A TC-237 and 8" SCT can offer years of imaging capability before plunging into bigger/better with more money. Tricolor should be the next progression before scaling up.

- Fast telescopes with high resolution optics offer remarkable imaging characteristics with CCD cameras, especially tricolor. Exposure times are short, excellent tracking is easier, signal is awesome, therefore contrast of colors in deep sky objects is spectacular enough to warrant color dye sublimation prints that rival photographic color prints done with film through much larger telescopes at a much higher difficulty level. Takahashi Epsilon, Flat Field cameras and specialized SCTs are hard to match in performance.

- Off-axis guiding is necessary to fully exploit the great imaging potential of your CCD camera. Even with an 8" SCT @ f/6.3, the 50" focal length offers 1.6 arc seconds/pixel resolution, much finer than optimum photographic results. Many of the software's sample SCT images were off-axis guided to produce small round high resolution stars. No matter how good your mount is, count on guiding to get the most from your CCD camera.

A.   **Appendix A** - **Specifications**

This appendix lists the specifications for the ST-237 CCD camera.

CCD	Texas Instruments TC237
Active Area	4.7 x 3.6 mm (.186" x .140")
Field of View	8.0 x 6.1 arc minutes at 80 inch focal length (8" F/10)
	2/3° x 1/2° at 16 inch focal length
Pixels/Pixel Size	640 x 480 @ 7.4 microns square
Read Noise	15e- RMS
Dark Current	Typically 1e-/p/s at -5°C
Full Well Capacity	CCD : 30,000 e-
	A/D : 17,000 e- with Photons/ADU set at 4.1
Cooling	Single Stage Thermoelectric, Selectable Setpoint
A/D Converter	12 Bit, 22 KHz Pixel Rate
Power Requirements	12 VDC at 1.2 Amps
Telescope Port	4 Open Drain Outputs
Communications Port	Interfaces to PC Parallel Port
Electronic Shutter	.01 to 3600 seconds
Mechanical Shutter	Rotary Shutter Wheel
Color Filter Wheel	Available as Option
Weight of Optical Head (less cable)	Approximately 1 pound
Size of Optical Head	3.25" diameter by 3" deep
F# throughput of Filter Wheel	f/2 - f/30

A.1   **DC Power Jack**
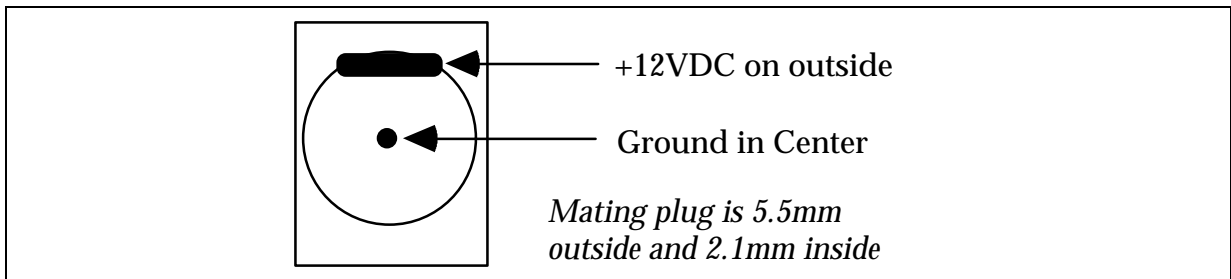
Figure A.2 - DC Power Jack

A.1   **Communications Port**

Pins 2 - 5	Data 0 through Data 3 to Camera
Pins 6,7	Address 0, 1 to Camera
Pin 9	Strobe to Camera
Pins 15,13,12,10,11	Data 0 through Data 4 from Camera
Pins 18 - 25	Data Ground
Shell	Chassis Ground

A.1   Telescope Port

```
1 2 3 4 5 6       1 = +RA (Right)
                  2 = +DEC (Up)
                  3 = -DEC (Down)
                  4 = -RA (Left)
                  5 = Ground
                  6 = No Connect
```

Figure A.3 - Telescope Port

Note that the four outputs are active-low, open-drain outputs without internal pull-ups and are capable of sinking 250 mA DC to ground when activated. They have a breakdown voltage of 45V, a typical on resistance of 1.3 and an avalanche energy of 75 mJ for driving inductive loads.

B.   Appendix B - File Formats

This appendix describes the file format used by the CCDOPS software including the SBIG Compressed and Uncompressed, TIFF and FITS formats.

B.1   SBIG Compressed and Uncompressed Formats

This section describes the file formats used to save SBIG images on both the IBM PC and compatible computers and the Macintosh computers. The files contain the image data as well as header information describing the image in terms of exposure time, telescope, etc. The files come in two varieties: Compressed and Uncompressed. In addition the file format has evolved throughout the development of these CCD cameras and has finally settled down to the "Type 3" format described herein.

<u>Type 3 Format</u>

The Type 3 format starts with a 2048 byte header of ASCII information followed by the image data in one of two varieties: Compressed or Uncompressed. The ASCII information for Type 3 files consists of a line showing the type of camera used to acquire the image and the variety of image data (Compressed or Uncompressed) as shown in the example below:

PixCel237 Compressed Image<lf><cr>
or
PixCel237 Image<lf><cr>

where <lf> and <cr> represent the linefeed (hex 0A) and carriage return (hex 0D) characters. Other camera images replace the "PixCel237" with the camera name ("PixCel255", "ST-4X", ST-5", "ST-6", "ST-7" "ST-8") in the lines above respectively. After the 1st line are several lines of parameters in the format:

Parameter = Value<lf><cr>

where "Parameter = " is a string describing the parameter and "Value" is a string containing the value of the parameter. At the end of all the parameters is the line:

End<lf><cr><ctrl-z>

used to signify the end of the of the image information. The <ctrl-z> is used to tell DOS commands like type to stop and not display any further data. The remainder of the 2048 bytes in the header are unused. The parameters for a Type 3 file are shown below:

Table 1
Type 3 Parameters

PixCel237 Compressed Image
File_version = 1
Data_version = 1
Exposure = xxx
Focal_length = xx.xxx
Aperture = xx.xxx
Response_factor = xx.xxx
Note = xxxxxxxx
Background = xxx
Range = xxx
Height = xxx
Width = xxx
Date = xx/xx/xx
Time = xx:xx:xx
Exposure_state = xx
Temperature = xx.xx
Number_exposures = xx
Each_exposure = xx
History = xxxxxx
Observer = xxxxxxxx
X_pixel_size = xx.xx
Y_pixel_size = xx.xx
Pedestal = xx
E_gain = x.xx

The following parameters are optional and may be present

User_1 = xxxxxxxx
User_2 = xxxxxxxx
User_3 = xxxxxxxx
User_4 = xxxxxxxx
Filter = xxxxxxxx
Readout_mode = xx
Track_time = xxx
Sat_level = xxx
End

Table 2
Parameter Descriptions

??? Compressed Image - This indicates the type of camera used to take the image and the fact that the data is compressed as described below. The ??? will be PixCel237, PixCel255, ST-4X, ST-5, ST-6, ST-7 or ST-8.

??? Image - This indicates the type of camera used to take the image and that the image data is not compressed and is saved as N rows of M pixels where N and M are specified by the Height and Width entries in the header. The pixels are two byte unsigned integers each with the least significant byte before the most significant byte. The pixels are written with pixel (1,1) first, proceeding in left-to-right order to pixel (1,M), followed by the subsequent N-1 rows of pixel data.

File_version - This field should be 3 to indicate the file is Type 3.

Data_version - This field describes the version of the image data and will be 1.

Exposure - This field indicates the exposure time in 1/100ths of a second.

Focal_length - This field indicates the focal length in inches of the telescope used to capture the image.

Aperture - This field indicates the aperture area in square-inches of the telescope used to capture the image.

Response_factor - This field specifies the CCD's response calibration factor.

Note - This field is the annotation attached to the image.

Background - This is the value of the Background parameter used to display the image when it was last saved.

Range - This is the value of the Range parameter used to display the image when it was last saved.

Height - This is the height of the image in pixels.

Width - This is the width of the image in pixels.

Date - This field shows the date the image was captured.

Time - This field shows the time the image was captured.

Exposure_state - This field contains sets of bits indicating whether ABG was active during the exposure, whether Double Correlated Sampling was used and whether DC Restore was used.

Temperature - This field indicates the temperature of the CCD in °C at the end of the exposure.

Number_exposures - This field indicates how many images were co-added to produce a composite image.

Each_exposure - For composite images this field indicates the exposure time of the individual exposures in 1/100ths of a second.

History - This is a string of characters indicating which image processing functions have peen performed on the image. The following is the mapping between individual characters in the string and the operation performed:

@ - Modifications made before history established.

A - Co-addition of image.

B - Image linearly scaled.

D - Image dark subtracted.

E - Cool pixels removed.

F - Flat field corrected.

G - Image smoothed.

H - Image sharpened.

I - Image pseudo flat field corrected.

J - Image quantized or posterized to less than 16 bits precision.

K - Warm pixels removed.

L - Image flipped horizontally.

M - Image flipped vertically.

N - Image zoomed with pixel interpolation.

O - More than 40 operations performed.

P - Image log scaled.

Q - Pixels combined.

R - Image auto dark subtracted.

S - Image zoomed with pixel replication.

T - Image clipped and filled (ST6COLOR)

U - Image converted to 8 bit log format (ST6COLOR).

V - Image merged to color using 2 color merge (ST6COLOR).

W - Image merged to color using 3 color merge (ST6COLOR).

X - Image translated and back filled (ST6COLOR)

Y - Image pixels inverted.

Z - Image sharpened with unipolar algorithm.

[- Image sharpened with one-sided sharpening.

\ - Image modernized by replacing ST6COLOR history characters[10]

] - Image resampled to make square pixels.

^ - Image averaged.

_ - Constant added to or subtracted from image.

` - Constant multiplied by or divided into image.

0 - (Zero) The history string is set to '0' for new images. This is not a C null string, it is actually the '0' character.

a - Image enlarged 2X by pixel interpolation.

b - Image reduced 2X by pixel combining.

c - Column or Row repair.

d - Adaptive dark subtraction.

e - Pseudo 3D

f - Auto HPR dark subtract

g - HPR dark subtract

h - Lucy-Richardson deconvolution

Please note the SBIG reserves the use of the characters '@' through '~' (decimal 64 through 126) for their use, and that any other characters added to the history string by other users should not use those characters.

Observer - This string contains the name of the observer who captured the image.

---

[10]   The ST6COLOR software used history codes 'S', 'T' and 'V' differently than described in this table. Modernizing replaces 'S' with 'T' (clip operation), 'T' with 'U' (compress operation) and 'U' with 'X' (translate operation).

X_pixel_size - This field indicates the width in millimeters of the pixels in the image.

Y_pixel_size - This field indicates the height in millimeters of the pixels in the image.

Pedestal - This field indicates any pedestal (constant value) that has been subtracted from each pixel in the image.[11]

E_gain - This field gives the conversion factor between pixel values and electrons of charge in the CCD. The units are e⁻/count.

The following fields are optional. They may or may not be present. in the header As the CCDOPS software has evolved these fields have been added to the header. a few at a time If present they will be in the order shown.

User_1 through User_4 - These fields are for the use of non-SBIG software packages and can be up to 64 characters in length each, terminated with the <lf><cr> characters. SBIG software will ignore and preserve the settings of these 4 user parameters when reading and writing files. Either all 4 should be present or none of them should be present. If present and any one of them is blank then a single dash character ("-") should be written before the <lf><cr> characters. Finally, SBIG uses the User_1 filed to indicate the version of CCDOPS software used to capture the image.

Filter - This field is a 10 character text string indicating the name of the optical filter used when taking the image.

Readout_mode - This field indicates the readout mode the CCD camera's internal firmware utilized in capturing the image.

Track_time - This field, when non-zero, indicates the exposure used for the Tracking CCD in Self-Guided images.

Sat_level - This field indicates the maximum level you should expect in the pixel data. The ST-4X and ST-5 are 14 bit cameras for example and this setting will be 16383. Note that this level can increase as images are co-added or with Track and Accumulate images.

<u>Image Compression</u>

Type 3 images can be saved using a simple form of image compression. The image compression consists of saving the differences between adjacent pixels and using single bytes for small differences rather than double bytes.

Each line of compressed image data starts with a two-byte integer (least significant byte first) indicating the compressed length of the line in bytes followed by the compressed image

---

[11] All image pixels have a bias of 100 counts added to them to stop underflow due to noise. If you need to flat field correct an image the pixel value that is due to light is:

$$Actual\ Counts = Image\ Counts - 100 + Pedestal$$

where Image Counts is what is read from the file and Actual Counts is the light response. For flat field correcting images you would multiply the Actual Counts by the flat field correction, not the Image Counts.

data. The 1st pixel of the actual image data is written using two-bytes and is the actual pixel value. Subsequent pixels are written as follows depending on the difference between that pixel and the previous pixel (= pixel (m,n) - pixel (m, n-1)):

> If -127   127 then write   as a single byte in 2's complement format, otherwise write hex 80 (-128) followed by the actual pixel value using two-bytes (least significant byte first).

The last caveat to the compressed image data is that if any line after being compressed has as many or more bytes than if it were stored uncompressed then that line is stored uncompressed with the 2 bytes of length followed by the actual pixel values written using 2-bytes per pixel (least significant byte first).

Note also that the compression algorithm described above used in saving images is similar though different than the compression algorithm used in downloading images from the CPU. You can not simply read a compressed image from the CPU and write it to file, adding a header. You must the CPU data and then compress the file data. This unfortunate consequence stems from the desire to have the CPU compression occur on the fly to keep the image throughput up.

B.2.   TIFF Format

The TIFF format (which stands for Tagged Interchange File Format) was developed jointly by Microsoft and Aldus Corporations to allow easy interchange of graphics images between programs in areas such as presentation and desktop publishing. The TIFF format is described in "Tag Image File Format, Revision 5.0, FINAL" by Aldus Corporation, Seattle, Washington.

B.3.   FITS Format

The FITS format (which stands for Flexible Image Transport System) is a common format supported by professional astronomical image processing programs such as IRAF and PC Vista. The format of FITS images is described in "Implementation of the Flexible Image Transport System (FITS)" published by NOST, NASA/OSSA Office of Standards and Technology, NASA Goddard Space Flight Center, Greenbelt, MD.

C.   Appendix C - Maintenance

This appendix describes the maintenance items you should know about with your CCD camera system.

C.1.   Replacing the Fuse

The CPU is internally fused with a 2 amp fast blow fuse. The fuse is located inside the CPU box on the printed circuit board. Remove the four screws on the bottom of the CPU box to access the fuse holder.

C.2.   Disassembling/Reassembling the Optical Head

In order to gain access to the CCD for cleaning or desiccant removal, please follow these instructions or return to the manufacturer for service.

1. Remove the four screws holding the front cover onto the camera and set the cover aside.

2. Remove the shutter/filter wheel from the camera by pulling it straight up out of the camera, lifting it off the axle.

3. Remove the three hex-head screws that hold the inner housing into the camera. The inner housing covers the CCD, making a hermetic chamber for the CCD and desiccant. Lift the inner housing and set it and the O-Ring aside.

At this point you have access to the CCD and all the windows in the system as well as the desiccant pack. To reassemble the camera please do the following:

1. Make sure the desiccant packet is in place below the CCD so that it may be captured by the inner housing. You may find it necessary to take the two outer corners of the desiccant and turn them inwards, making the rectangular packet somewhat conform to the round outline of the inner housing.

2. Seat the O-Ring in the groove in the bottom of the inner housing and gently place the inner housing down into the camera. Place careful attention to not pinching the desiccant packet under the seat of the inner housing. The proper orientation of the inner housing is with the window over the CCD.

3. Tighten each of the three hex-head screws one-half turn at a time until the inner housing is seated completely and flatly into the camera.

4. Place the shutter/filter wheel back into the camera with the side containing the small reference marks and the larger brass bearing towards the CCD. You will have to slightly deform the O-Ring that surrounds the wheel against the shaft of the motor and be careful not to pinch or tear it.

5. Replace the front cover, noting that there is only one orientation that will fit as the four mounting screws are at irregular angles.

C.3.   Cleaning the Optical Windows

The design of the ST-237 allows for cleaning of the CCD. The optical heads are not evacuated and are quite easy to open and clean. Follow the instruction in the section above to gain access to the CCD and clean it using one of the following 3 methods:

1. To remove dust from the windows, a can of dust remover can be used but be careful to hold the can in the proper orientation. If you tilt the cans too far from upright a stream of cold liquid (the propellant) will issue forth rather than the burst of air.

2. In lieu of canned air, a small, soft, camel hair brush can be used to wipe dust from the windows.

3. Finally, for hard to remove particles or water spots, use a Q-Tip lightly dampened in Isopropyl Alcohol to clean the windows.

    Note: The key to cleaning optical surfaces is successive cleanings with a fresh Q-tip each time.

C.4.   Replacing the Desiccant

This section describes the replacement procedure for the desiccant used in your camera. The desiccant absorbs moisture in the CCD chamber, lowering the dew point below the operating temperature of the cooled CCD, thus preventing the formation of frost. The desiccant is contained in a small rectangular package inside the CCD chamber. In normal operation the useful life of the desiccant is over a year. If the CCD chamber is opened often, the desiccant should be replaced when frosting is noticed.

Follow the instructions in the section above to gain access to the CCD chamber and desiccant packet. Discard the old packet and replace it with a fresh one. Note that the desiccant material in the packet can be regenerated by baking it in an oven at 400 degrees Fahrenheit for four hours *but you'll have to remove the desiccant from the packet first* . Otherwise the packet will melt. In a pinch you could snip the end of the packet off, pour out the desiccant beads, bake them out, pour them back into the packet and reseal the packet with scotch tape.

D.   Appendix D - Advanced Image Processing Techniques

This Appendix describes advanced image processing techniques including making Astrometric and Photometric measurements and how to flat field Track and Accumulate images.

D.1.   Astrometry and Photometry

Using the crosshair mode[12] enables examination of images on a pixel by pixel basis for such measurements as Stellar and Diffuse Magnitude, and measurement of stellar positions. The 16 bit accuracy of your camera produces beautiful low-noise images and allows very accurate brightness measurements to be made. With appropriate filters stellar temperature can be measured.

D.1.1 Astrometric Measurements.

The CCDOPS software allows measuring separations between objects in the field of view of an image. Essentially, these measurements involve the user specifying telescope focal length and two points in the image and the software calculating the separation in arcseconds (1 arcsecond $= \frac{1}{3600}$ of a degree). The details of this process follow.

You can specify each of the two points using two methods or algorithms: 1) A point can be selected to be a pixel coordinate in the image; or 2) A point can be calculated by the software to be the centroid or "center of light" of the area near a pixel in the image. The latter works well when measuring separations involving stellar objects, the former should be used in all other cases.

The crosshairs mode of the operating software is used to make the astrometric measurements. Setting the positions of the two points is a five step process: 1) A determination of the background level is made, 2) The cursor is moved to the first point, 3) The position of the first point is recorded and the separation measurement zeroed, 4) The cursor is moved to the second point, 5) The separation is calculated and displayed. These steps are discussed in detail below:

1) If neither of the two points is stellar and measurements from pixel to pixel in the image are desired then you can skip ahead to step 2. If however you want the software to more accurately measure distances based upon stellar objects, then you must let the software know what the background level is. Move the cursor to an area of sky free of stars and nebulosity and hit the 'B' key (for background).

2) Move the cursor to the desired location of the first point using the arrow keys or mouse. If the first location is a star, then position the cursor near the center of the star.

3) If the first point is not a star and you desire to zero the separation on a pixel, then hit the 'S' key (for set position) to set the position of the first point to the pixel coordinate of the crosshair. If however the first object is a star and you wish to zero the separation on the optical center of the star, then hit the 'C' key (for centroid) and the computer will calculate the centroid of the star under the crosshair and zero the separation measurement at that centroid position. The

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12   The Crosshairs mode is accessed through the Display Image command in the Analysis mode.

advantage of using the centroid is that the zero position can be set between pixels resulting in a more accurate measurement.

4) Move the cursor to the desired location of the second point. Each time the cursor is moved, the separation between the 1st point and the current pixel coordinate of the cursor is calculated and displayed.

5) If the second point is not a star then you're done. The separation shown is the separation between the 1st point and the current pixel coordinate of the cursor in seconds of arc. If however the second point is a star and you wish to set the 2nd point to the centroid of the star, then position the cursor near the center of the star and hit the 'P' key (for position). The computer will calculate the centroid of the area under the cursor and use that centroid location for calculating and displaying the separation. You will have to hit the 'P' key each time you move the cursor to a new location because as soon as you move the cursor, the 2nd point is set to the pixel coordinate of the cursor and no new centroid is calculated. Finally note that in both cases, you can make several separation measurements between the 1st point and the different 2nd points without having to re-set the position of the 1st point.

How does the computer calculate the separation, you ask? The separation calculations are discussed in detail at the end of this section but in general, the software does this by measuring the physical separation of the two points in the image and dividing by the focal length of the telescope. For this reason, accurate astrometric measurements depend on the correct setting of the focal length parameter in the Edit Parameters command. This parameter, which is copied from the Telescope Setup command, should be set to the focal length of the telescope in inches.

An object with a known separation, such as a wide double star, can be used to accurately determine the focal length as follows:

1) Set your focal length parameter in the Telescope Setup command approximately correct. For example if you have an 8-inch f/10 telescope, the approximate focal length is 80 inches.

2) Take an image of the known object and measure the separation.

3) Finally adjust the focal length parameter in both the Edit Parameters command and the Telescope Setup command accordingly. For example if the measured separation is 10% lower than the actual value, then you should lower the focal length parameter by 10%.

D.1.2 Photometric Measurements.

The CCDOPS software also lets you make photometric measurements of objects in the field of view. These measurements include stellar magnitude and surface brightness (Diffuse Magnitude). Stellar magnitude measures the total energy in an object . Surface brightness calculates the total energy per unit of area.

These measurements are made in the crosshairs mode and involve three steps: 1) A determination of the sky background is made to zero the calculations, 2) The crosshair is positioned on the star or portion of nebulosity, and 3) An appropriate box-size is determined for accurately measuring the magnitude. These three steps are detailed below:

1) Move the cursor to an area that is representative of the background surrounding the object you wish to measure. For example, if you're trying to determine the magnitude of a star buried in nebulosity, you would select a background area with roughly the same brightness as the nebulosity surrounding the star. If you are trying to measure the surface brightness of a galaxy, then pick a location out in the sky background free of stars and nebulosity. Once the cursor is positioned, hit the 'B' key (for background) to calibrate the magnitude measurements based upon the background level.

2) Position the crosshair over the object of interest. For stellar objects get the crosshair close to the center of the star. For nebular objects place the crosshair over the region of interest.

3) The size of the box used to measure the magnitude is toggled through using the 'T' key (for toggle box size). For stellar objects the box size should be big enough to include all the light from the star but small enough to exclude other objects from the calculations. As you increase the size of the box from 3x3, you will see the calculated magnitude decrease (stellar brightness increase) and plateau out as the box size includes all the star's light. For nebular objects, set the size of the box large enough to get the desired smoothing effects of larger numbers of pixels but small enough to be able to measure any desired spatial variations in the surface brightness.

Accurate measurements of photometric quantities requires attention to several items. First, the CCD's spectral response means it measures light from 4000Å through 9000Å with varying efficiencies. In general the CCD's response peaks near 6750Å and is roughly 50% (relative to the peak) at 4500Å and 7500Å Using the CCD without any optical bandwidth filters is roughly equivalent to measuring photographic magnitudes. Second, the software needs to know the aperture area of the telescope. Larger apertures capture more light. This is set in the Telescope Setup command for images to be taken in the future and in the Edit Parameters command for existing images. This aperture area should be the clear aperture area with any obstruction subtracted. The software also depends on a response or calibration factor to convert pixel counts to magnitudes. This parameter is in both the Camera Setup and Edit Parameters commands. The correct value for your camera is roughly 2000. The reason we say roughly is that the calibration parameter is adjusted to calibrate the magnitude to that of a known star or object. Reasons for the variation include transparencies of optical elements in the telescope, transmission of the atmosphere and manufacturing variations from camera to camera. All this aside, the method you use to determine the correct setting of the CCD response factor is as follows:

1) Select an object in the field of view for which you know the magnitude or take an image of a known object. The former is preferable because it takes into account any variations in atmospheric transmission as a function of altitude in the sky which can be quite substantial. Objects at the zenith go through less air than objects near the horizon.

2) Make a background setting as described in the steps above.

3) Position the cursor over the known object and select the box size as described above. If the magnitude shown is incorrect, use the '+' and '-' keys to adjust the

calculated magnitude. Each press of the '+' and '-' keys adjusts the magnitude by 0.1 or 0.01 depending on whether the Shift key is held down.

4) When the calculated magnitude is correct, note the settings of the response factor parameter in the Edit Parameters command and copy it to the settings in the Camera Setup command so it will be used in future images[13].

If you're interested in the nuts and bolts of the photometric calculations, read on. They're described in full detail below.

D.1.3 Calculation of Centroids

The centroid calculation is directly analogous to a center-of-mass calculation for an object if you represent the local mass density with the pixel intensity values and allow a discrimination level at the average background level. This is shown in the following figures and formulas:
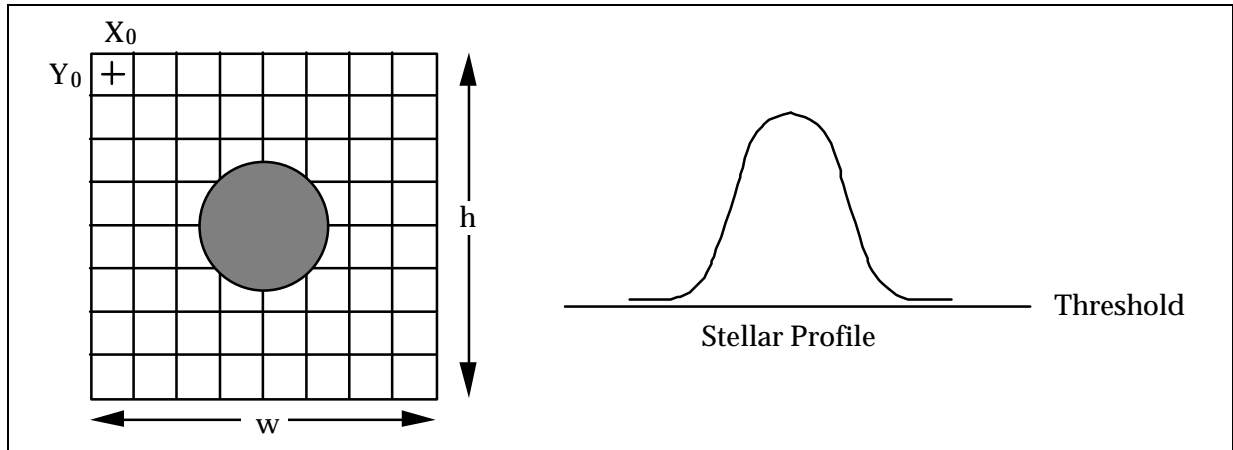
$$Threshold = \frac{\displaystyle\sum_{i=0}^{w-1}\sum_{j=0}^{h-1} P(i, j)}{h \times w}$$

where in the formula above *P(i,j)* represents the intensity value of the pixel at x=X_0+i, y=Y_0+j. Also the *Threshold* value which will be used as a discrimination level in the centroid calculation is taken over the background area and represents the average pixel level in the background area.

$$Xcentroid = X_0 + \frac{\displaystyle\sum_{i=0}^{w-1}\sum_{j=0}^{h-1} i \times (P(i, j) - Threshold)}{\displaystyle\sum_{i=0}^{w-1}\sum_{j=0}^{h-1} P(i, j) - Threshold}$$

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[13] The star's spectral class can produce ±0.5 magnitude errors in this determination. For the greatest accuracy calibrate the response factor on a star with a similar spectral class.

$$Ycentroid = Y_0 + \frac{\sum\limits_{i=0}^{w-1}\sum\limits_{j=0}^{h-1} j \times (P(i, j) - Threshold)}{\sum\limits_{i=0}^{w-1}\sum\limits_{j=0}^{h-1} P(i, j) - Threshold}$$

where in the formulas above should the quantity *P(i,j) - Threshold* be less than zero, zero is substituted on a pixel-by-pixel basis.

D.1.4 Calculation of Separation

The angular separation between two points on the image is determined by calculating the corresponding physical separation between the points on the CCD and dividing by the focal length, keeping track of the units[14]:

$$Separation = \frac{3600 \times 180}{p} \times \frac{\sqrt{(\Delta x \times 0.01)^2 + (\Delta y \times 0.01)^2}}{25.4 \times fl}$$

where *Separation* is in seconds of arc, x and y are the x and y separations between the two points in pixels and fl is the focal length of the telescope in inches.

D.1.5 Calculation of Magnitude

The magnitude calculation involves calculating the total energy in a star, subtracting the background, correcting for the exposure time, aperture area and CCD response factor and taking a scaled logarithm. The calculation is broken down into several steps below:

$$L = \sum_i \sum_j P(i, j)$$

$$B = \sum_i \sum_j P(i, j)$$

where *L* and *B* are the sum of all pixel values in the box centered on the star and background areas respectively.

$$Magnitude = -2.5 \times \log_{10}\left(\frac{L - B}{A \times C \times T}\right)$$

where *A* is the aperture area in square inches, *C* is the magnitude calibration factor and *T* is the exposure duration in seconds. Note that the units of *C* are counts per second per square inch of aperture for a 0th magnitude star. C is proportional to the CCD's response factor from the Camera Setup command. You can calculate C from the CCD's Response factor (R) using the formula below:

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[14]   The pixel sizes shown are for the camera in the High Resolution readout mode (0.01 x 0.01 millimeters). For the other readout modes substitute the appropriate X and Y pixel sizes. This information is shown in the Image Parameters command.

$$C = \frac{1000 \times R}{e^- / AD\ Count}$$

D.1.6 Calculation of Diffuse Magnitude

Diffuse Magnitude is the magnitude per square arcsecond of subtended area. The calculation uses the Magnitude calculated above and the area of the box as shown below[15]:

$$BoxArea = \left(\frac{3600 \times 180}{p} \right)^2 \times \left(\frac{BoxSize^2 \times 0.01 \times 0.01}{(fl \times 25.4)^2} \right)$$

where *BoxArea* is the area of the box over which the Diffuse Magnitude is calculated in square arcseconds, *BoxSize* is the size of the box in pixels and *fl* is the focal length of the telescope in inches. Finally:

$$DiffuseMagnitude = \frac{Magnitude}{BoxArea}$$

D.2.   Flat Fielding Track and Accumulate Images

This section gives the step by step procedure for flat field correcting images taken using the Track and Accumulate command.

Flat field correcting images allow the user to remove the effects of CCD response non-uniformity (typically less than a few percent) and optical vignetting which for some optical systems can be as much as a 50% effect from center to edge. The CCDOPS software allows flat field correcting images using the Flat Field command, but some preparation must be made to use that command with Track and Accumulate images. Essentially you must prepare a special flat field correction image for Track and Accumulate images. This special preparation is necessary to have the same set of alignment and co-addition operations apply to the flat field file that have occurred in acquiring the Track and Accumulate image. In general, the following procedure should be followed when flat field correction of Track and Accumulate images is desired:

1. Take a normal flat field image using the Grab command. Try to adjust the illumination and/or exposure so that the build up of light in the image yields pixel values around 2000 counts or so. You don't want to exceed the antiblooming knee which starts to kick in around 4000 counts.

   Note: *You will have to take a new flat field image anytime you change the optical configuration of your telescope such as removing and replacing the optical head in the eyepiece holder.*

2. Save the flat field image on your disk using the Save command. In the following discussions this flat field file will be referred to as FLAT.

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[15]   Refer to the previous footnote.

3. Take your Track and Accumulate image using the Track and Accumulate command and save it on the disk using the Save command. In the following discussions this Track and Accumulate image file will be referred to as IMAGE.

4. Immediately after saving the IMAGE, use the Save Track List command to save the Track and Accumulate track list. The track list is a file that describes what alignment operations were done to the individual components of IMAGE to achieve the end result. In the following discussions this track list file will be referred to as TRACK.

5. Repeat steps 3 and 4 as many times as desired for all the objects you wish to image, each time choosing a set of corresponding new names for the IMAGE and TRACK files.

6. You will now create a combined flat field image for each Track and Accumulate image you captured. Invoke the Build Track/Accum Flat command. The software will present a file directory box asking you to select the track list saved in step 4 above. Select the TRACK file corresponding to the image you wish to correct. The software will load the TRACK file and present you with another file directory dialog showing all the images. Select the appropriate FLAT image. The software will align and co-add the FLAT image using the same operations it performed on the Track and Accumulate image. Finally save the combined flat field image using the Save command. In the following discussions this combined flat field image will be referred to as COMBINED-FLAT. Repeat this step for each of the TRACK files using a corresponding name for the COMBINED-FLAT image.

7. You will now flat field correct the Track and Accumulate image with the combined flat field image. Use the Open command to load the IMAGE file, then use the Flat Field command. The software will present you with a file directory dialog where you should select the corresponding COMBINED-FLAT image. After the software has finished correcting the image, you can view the results and save the flat field corrected image with the Save command. This image will be referred to as the CORRECTED-IMAGE file. Repeat this step for each of the IMAGE files using the corresponding COMBINED-FLAT image.

D.3. Further Reading

CCD Astronomy by Christian Buil, available through Willmann-Bell Publishing (804) 320-7016.

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