

CTIO 4-M TELESCOPE PRIME FOCUS CCD DIRECT User Manual

***** INSTRUMENT NO LONGER AVAILABLE!!!!!!

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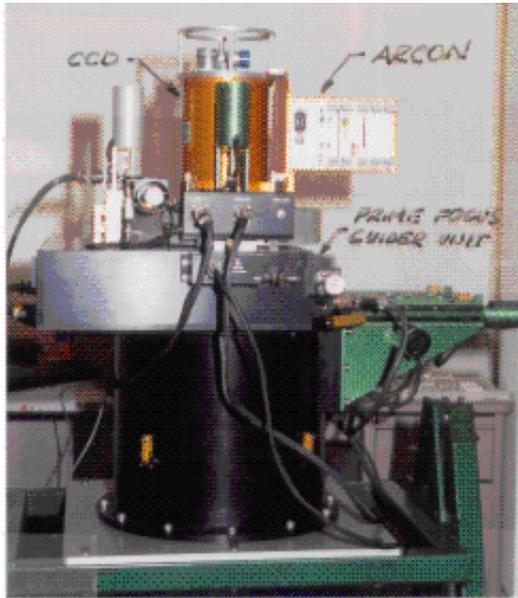


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1. INTRODUCTION

At CTIO all CCDs are now operated using ARCON controllers. These controllers consist of a small box bolted to the dewar, which contains all the electronics needed to operate that particular CCD, followed by a fiber-optic link to a TRAM BOX "Silicon City" which sits beside a SUN 10/41 computer to which it is connected. A real-time display is attached to the TRAM box. Apart from gains in reliability (compared to our old VEB controllers) expected to follow from the affixing of the CCD dewar to its electronics, the use of fiber-optics, and the great attention that has been paid to mechanical and electronic construction, there are a number of performance gains:

- quad channel readout for CCD's with multi-amplifiers
- unsigned 16 bit data (0-65535) allows greater dynamic range
- dc coupled preamp means no memory of image in overscan
- real time display with saturated pixels in red, any orientation is possible
- direct data interface to SUN/IRAF
- faster readout in single channel mode for most CCD's

The conversion to Arcon's is an unfortunately rather slow process, due to the need to schedule the CCD's we have, implement new CCD's, and also to convert instruments to operate in the new (SUN, Arcon, IRAF) environment. We are taking the opportunity to simultaneously update the motor controllers on some instruments, using STD Bus controllers, and where possible, DC and DC servo motors. At present we have the following ARCON's:

- Arcon 3.2, Tektronix 1024 #2 CCD
- Arcon 3.3, Tektronix 2048 #3 CCD (Dedicated to the 0.9m telescope)
- Arcon 3.5, Loral 3K CCD (4-m spectroscopy: Argus, RC, Echelle)
- Arcon 3.6, SITe 2048 #6 CCD
- Arcon 3.7, STIS 2048 #5 (Spare)
- Arcon 3.9, Loral 1K CCD (1.5m spectrograph)
- Arcon 3.17, SITe 2048 #5 CCD

Many of these CCDs are have four working amplifiers thus ensuring rapid readout. Detector characteristics (for direct-imaging CCDs) are summarized in section IV below. We will schedule the CCD that we think is the optimum one for your program, taking into consideration the device specifically requested on the Visitor Support Questionnaire and the proviso that in cases of conflict the larger telescope has priority. As indicated above, some CCDs (eg both Lorals) are in specialized dewars, while others are dedicated to a particular telescope (0.9m, Schmidt).

2. INSTRUMENT AND COMPUTER CONFIGURATION

2.1 SUN computers

Manuel Hernandez and Mauricio Navarrete (Tololo) are the computer specialists, and will be available for assistance with the Tololo computer systems. They will assign you a visitor account number on the SUN computer network. You will be the sole user of this account while you are at CTIO. The telescope has two SUN computers in the control room. The present configuration is that a SUN 10/41 (ctioa1) operates the Arcon and the PFCCD, but the data ends up on the disk of a fast Ultrasparc (ctioa7.) Due to the very large amounts of data generated by the larger CCDs, all data still on disk will only be keep until noon of the day following the completion of your observing run. You should also not fall behind in writing your data to tape. We have installed the KPNO "save-the-bits" scheme which will automatically save your raw data. The second SUN computer has peripherals (exabyte, dat drive, laser printer, mag tape drive, etc) attached. Both

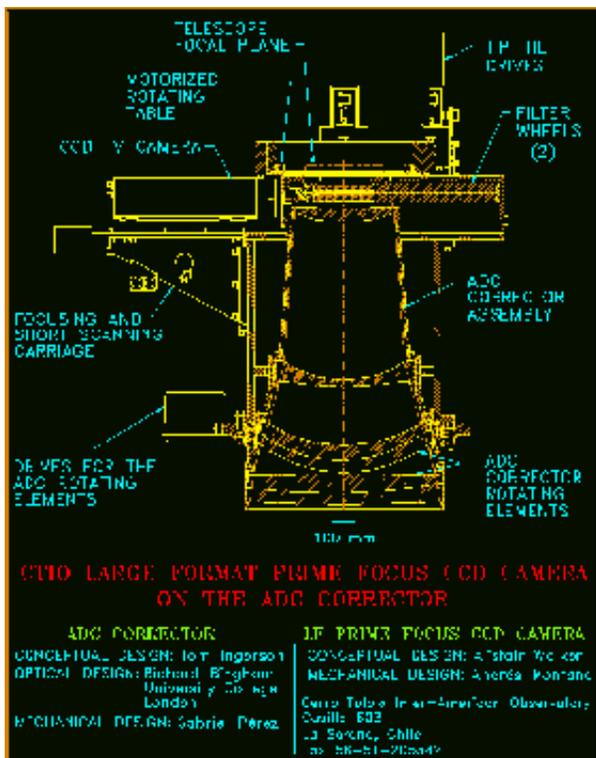
are on the mountain Ethernet. You will find in the control room a full set of IRAF manuals, and COOKBOOKS containing advice and directions for reducing your data. Refer also to the manual: "[The Arcon-IRAF Interface, A Preliminary User's Guide for Direct Imaging](#)".

2.2 Telescope

The 4m telescope will be operated by an Observing Assistant, who is familiar with the operation of both the telescope and the CCD system. The Observer Support section will have helped in the setup and will have checked out the instrument, and they will respond to any problems that might arise. The telescope should point to better than 10 arc sec rms, assuming accurate input co-ordinates. If the pointing is much worse than this then you should complain. The telescope control computer (TCS) is a VME bus computer with a program written in C, operating under VxWorks. The TCS computer will be operated by your Observing Assistant.

2.3 PFCCD

All CTIO CCDs that are available for direct use can be installed at the f/2.8 prime focus imager of the CTIO 4-m telescope, which is shown below.



[Click on the image for a more detailed view.](#)

The CCD that has been used for all 4-m PF direct imaging is a Tektronix 2048, in recent times #6. This had a powered dewar window to compensate for the curvature of the CCD. See [section 4](#) for details.

The PFCCD imager must be used with a corrector. The only corrector currently used is the new four-element ADC (Atmospheric Dispersion Corrector). This corrector can compensate for atmospheric dispersion up to a zenith distance of 70 degrees, and by design can produce 0.25 arcsec images over most of a one degree diameter field. The corrector contains PSK3 and LLF1 glasses that have low UV transmission, while four of

the eight surface have an AR coating that cuts off sharply below 3400Å. Transmission of the corrector is nominally 74% at 3650Å, 54% at 3500Å, 31% at 3400Å, 11% at 3350Å and near-zero at 3300Å. Thus, with a suitably blue-sensitive CCD such as the Tektronix 2048, Johnson U band photometry should be possible but Strömgren u photometry will be marginal.

Behind the corrector are two filter wheels and an off-axis pick-off mirror for the CCDTV camera, followed by the CCD dewar. Each filter wheel can hold up to five 4-inch square filters, which must be less than 1 cm thick. Inserts are available for holding 4-inch round, 3-inch square and 2-inch square filters. The Tek 2048 is normally used with 4-inch filters although 3-inch filters used in the upper filter wheel will not vignette. See [Appendix I](#) for filter information.

The CCD is placed on-axis. The tilt and rotation of the CCD can be adjusted so that the CCD is accurately perpendicular to the optic axis, and aligned NSEW. The scale is 18.00 arcsec/mm. The CCD is focused by moving the entire PFCCD camera head (including filters and TV camera).

A field approx 26 arc min North of the optical axis is viewed by a Peltier cooled CCDTV camera with leaky memory for acquisition and guiding. The TV is on a scan table which can be moved to acquire a guide star, and in the future will be used to implement short-scanning. The TV has its own filter bolt with 4 positions - the TV does not image through the CCD filter bolts. On moonless nights stars as faint as $V = 21$ can easily be seen in a few-second exposure.

All hardware functions in the CCD camera head (with the exception of the CCD shutter and preflash) are controlled by a STD bus computer (actually a small stand-alone PC with non-volatile RAM disk). The operation of this computer should be transparent to the user, and all motor commands are initiated from the Arcon-IRAF user interface. The dewar tilt and rotation will have been adjusted at the start of the run and should not need to be altered. The telescope focus control and readout are available to the data acquisition program. This means that when a filter is changed the telescope and TV camera will automatically refocus according to tables of offsets entered in the **wheel1** and **wheel2** parameter sets. Focussing, either by the classical method of moving the telescope between positions, or by moving the charge on the CCD (preferred), is an automatic procedure.

2.4 HELP!

Observers needing further information should consult the following persons, in the first instance contacting people who are actually on Tololo at the time:

- General help on the mountain: Ricardo Venegas, Daniel Maturana (4.0-m, 1.5- m), Arturo Gomez, Eduardo Cosgrove (1.0-m, 0.9-m, Schmidt).
- General questions regarding observing procedures: Your staff contact or Alistair Walker - Specifics concerning CCDs: Alistair Walker
- Arcon hardware: Tololo electronics, Roger Smith
- Arcon software: Manuel Hernandez, Mauricio Navarrete, Jim Hughes
- Arcon user interface: Manuel Hernandez, Mauricio Navarrete, Nelson Saavedra, Steve Heathcote
- PFCCD Motor Control: Tololo Electronics, Tom Ingerson
- Reduction and IRAF Procedures: Mauricio Navarrete, Manuel Hernandez
- Errors and omissions in this manual: Alistair Walker

3. DATA-TAKING PROCEDURES.

3.1 Introduction

The IRAF-based user interface allows observing commands to be sent to Arcon from within the IRAF cl. This results in a single uniform user interface for data taking and data reduction and allows the Arcon user to employ features of the cl such as the parameter mechanism and the history editor. It also allows advanced users to write cl scripts which freely mix data acquisition and data reduction operations. We have tried hard to make the user interface look very similar to "ICE" as used at KPNO. However, users should be aware that it is NOT identical and parameter lists, etc. will differ.

Below we describe recommended observing procedures. You are recommended to use IRAF for reducing your data, and for writing your frames to dat tape or exabyte. Information on the use of CCDRED, and IRAF in general, is given in the manuals and cookbooks kept near the SUN terminal. Observer Support personnel and the Data Reductions Specialists can assist you with IRAF. But you should not go to the telescope and expect to learn IRAF at the same time as you observe!

THE MANUAL "["THE ARCON-IRAF INTERFACE"](#) DESCRIBES OBSERVING SOFTWARE AND PROCEDURES. YOU SHOULD REFER TO THIS MANUAL FOR THE MECHANICS OF HOW TO TAKE DATA. Only a brief outline is given below.

3.2 Starting Up, and Some Miscellaneous Advice

1. You should login on the data acquisition computer using your assigned username as password. You will use the OPENWINDOWS environment, with XIMTOOL as the default display. Several windows will open automatically, including a (blue-colored) IRAF ARCON user-interface window via which you interact with the CCD. There is also a (brick red-colored) IRAF reduction window, an ARCON console window, an ARCON status window with countdown timer, and an XImtool display window. The transputer boot-up is automatic (watch the ARCON console window). See the Observing Software Manual for procedures. IRAF should automatically start in the two IRAF windows. In the IRAF Acquisition window the **arcon** and the **astronomer** packages load automatically, correctly configured for the PFCCD. You will be asked whether you wish to synchronize parameters (ie force the controller to the parameters that are set in the User Interface. Normally, the answer is "yes". In the IRAF Reduction window load the **arcon** and **quad** packages, and anything else you want. Back in the acquisition window, the **astronomer** package contains all the commands needed for observing. Some of these are:

1. **setdetector** initializes the CCD controller according to the parameters set in **detpars**. There are four other parameter files that control data-taking. They are **instrpars**, **obspars**, **rtdpars**, and **telpars**. You should review these parameter files and check whether they are set to your requirements. It is likely that only a few (if any) of the parameters will need to be altered. Do not change items at random!
2. **ccdinfo** lists the **detpars** pset, including the gain/read noise table, and the gain actually set.
3. **setdewar**, **settv**, **setscantable** interactively adjust specific PFCCD motors (if you say **setdewar inter+** for example, otherwise you are just prompted for the settings required).
4. **observe** this command controls data-taking. You can also use **zero**, **comp**, **dark**, **pflat**, **dflat**, **sflat**.
5. **abort**, **stop**, **pause**, **resume**, **tchange** interrupt an exposure (temporarily or permanently) (**** **abort** should not be used yet, use **stop** instead).
6. **preview**, **movie** read out the CCD without storing the data, once (**preview**) or continuously (**movie**).
7. **motorstat**, **motorinit** [note1](#), **motormove** read status, initialize, and move the PFCCD motors.
8. **wheel1**, **wheel2** set up filters, and differential focus.

2. You should check you know where your home directory is (**show home**) and where your pixel files are

going (**show imdir**). Check that you have lots of disk space (**disks**). Make sure that when you do an **observe** that an IRAF image ends up where you expect it do be. Display an IRAF image, using **display**. See below for instructions on how to check whether your CCD system is functioning correctly.

3. Some of the CCDs operated by Arcon have more than one (either two or four) output amplifiers available. The CCD is read out through each amplifier in parallel, the data is then digitized through (1,2,4) 16-bit analog-to-digital converters and then transmitted on a single serial fiber-optic line to the SUN computer. A raw bi- or quad-amplifier picture looks a little unusual. Each quadrant has a slightly different electrical offset (ie overscan level), and the four overscan segments are in the center of the picture. A CCD read out through two amplifiers can either have two overscan strips at the side of the picture (parallel split) or two parallel strips in the center of the picture (serial split). The real time display automatically removes the overscan and applies an offset to each quadrant to normalize the DC level. In addition, the real time display colors any saturated (ie 65535) pixel in red. 4. "Quad" CCD pictures are trimmed and overscan-subtracted in a separate pre- processing task called **quadproc** (in the **quad** package). Note that even after the pictures are trimmed and overscan subtracted the sky levels in each quadrant will not be identical (unless sky level is zero). This is because each of the four CCD amplifiers has a slightly different gain. This can be measured using **gfind** (**contributed** package). Gain variations between different amplifiers are removed when the object frames are divided by a flat field frame.

5. There should be an exabyte drive, a 9-track drive and maybe even a DAT drive available in your dome. The Arcon produces 16 bit data of type 'unsigned short integer' with valid data ranging from 0 to 65535. Thus the unprocessed frame from a 2K CCD requires about 8.8 Mbytes.

3.3 Instrument Setup and Checkout

At the start of your observing run, Observer Support personnel will check that the CCD is operating correctly, and that all the hardware functions. They will fit your selected filters into the filter wheels. They will also have set the CCD gain and binning, via **setdetector**. See what they have done by typing **ccdinfo**. The gain and read noise are calculated using the **gfind** task which is in the **contributed** package. You will first need to do two low level (bias) exposures, and two high level exposures (both at the same light level).

It is your responsibility to check that the instrument is operating to your satisfaction. A few tests are suggested below which should aid you in this evaluation. You should also be on the lookout for any changes in the CCD characteristics during the run, which may signal the onset of CCD or dewar problems. Count rates from dome flat field (white spot) exposures should be the same from day to day, to better than 10 percent. You should also divide the night's flats by the previous night's and check to see that the division is quite flat, with perhaps only the addition of one or two "rings" due to specks of dust falling on the filters (ask for the filters to be cleaned if these seem excessive, but don't try to use your old flats later on). Examine zero (bias) exposures, they should not show horizontal or diagonally slanting noise "stripes", which move position from frame to frame. Sometimes very low level noise features are seen on zero frames, before complaining check whether these are at a significant level to affect your data. Use of the IRAF **imhist** command is also recommended. Histograms should exclude bad columns, edges etc., and should be smooth with no missing codes.

It is worthwhile making a few test exposures before proceeding further. These tests can be repeated as desired throughout your run. All can be done during the daytime.

3.3.1 Zero (Bias) exposures.

These zero illumination exposures should show no noise patterns down to about the 1 adu level. They should be approx. flat although bright columns will show up (Tek 2048 #3). Now do an exposure (dome flat) that adds a small signal. Any exposure with some illumination should show the overscan strip. Don't forget that the Real Time Display automatically clips out the overscan so you will need to display the image within IRAF. The overscan strip may appear down the left side, right side, or center of the picture depending on the number and position of the CCD amplifiers in use (note that, to avoid confusion, the orientation of the CCD frame on the Real Time Display (RTD) and in IRAF does NOT change when a different readout amplifier(s) is selected. The overscan is on the right hand side of the picture (single channel readout, right-side amplifier), or down the left hand side of the picture, or down the center (quad readout). If you are reading through more than one amplifier the overscan strip will be made up of sub-strips, one for each amplifier.

3.3.2 White Spot exposures.

Ask for the telescope to be pointed at the white spot on the dome, and turn on the quartz halogen lamps. Make sure the telescope focus is approximately correct for the filters you will be using during the night. Put the color balance filter in the beam. This filter makes the 3000 C quartz lamps look more like the 5500 C night sky. Take a trial exposure, typically a few seconds through a broadband (B,V,R,I) filter. Display the frame, and do a row plot across it. The response should be reasonably flat (say ± 10 percent in general). After trimming and subtracting off the zero (bias) exposure (use **quadproc**) you can try dividing frames at two different count levels whereupon all the structure seen in the dome exposures should disappear to better than a few 0.1%. For CCDs with more than one amplifier in use, the "quadrant" edges should all disappear, to better than ~ 0.2 percent. Note that in general comparisons between parts of the CCD read out via different amplifiers is a powerful test for correct functioning of your CCD system. ARCON has separate data paths from the CCD until after the ADC, and it is very unlikely that a controller fault would affect each data path in the same way. In the above case we are testing for differential non-linearity, and can detect it far easier than we can measure absolute linearity, which for our CCDs is also at the 0.1-0.2 percent level.

3.3.3 Dark Exposure.

A five minute dark exposure (lights off in dome) should only show the hot columns (Tek 2048 #3) and a few cosmic rays and hot pixels. The general background should be at the same level as the overscan. For all our CCDs, the dark rate is so low in comparison to sky background rates as not to warrant doing long dark exposures, however if you insist, you should do several dark exposures at least as long as your longest object exposure. Hot pixels tend to be non-linear in their dark rate as a function of time so may not subtract out perfectly.

3.3.4 Shutter Timing.

The shutter unit has a 100mm clear aperture. The effective "open" time is always longer than the nominal number of seconds requested for your exposure time. This is a delay prior to opening and closing. The speed of the shutter blades is high and the corner-center exposure difference is only a few ms for the smaller CCDs. For the Tek 2048 the center-to-corner difference is some 60 ms (ie exposures are 60 ms longer than nominal at the center, and 0 ms longer at the corners). So beware when doing short exposures for flat fields and standards. Sometime during your run, it is a good idea to determine this correction. The easiest way of doing this is to compare (for example) a 20 second dome flat with the sum of 20 1s dome flats. The latter can be

done extremely quickly using the focus procedure but not bothering to move the focus (or the telescope), whereupon you can avoid reading the CCD out 20 times but the shutter will have opened and closed 20 times. Bracket this exposure with normal 20s exposures (just choose a filter and exposure time to give several thousand adu total counts), the bracketed exposures can be averaged to take out any drifts in the lamp output, but in any case it is wise not to begin this test until several minutes have elapsed after turning on the lamps. Subtract bias off the two frames, then if the counts are C1 for the sum of the 20 1s exposures, and C2 for the single 20s exposure, then to first order we have

$$\text{shutter delay time (s)} = (C1/C2) - 1.$$

You can easily do a contour plot which is probably the best way of displaying the result. You could also in principle correct all your data (see Stetson, in "Highlights in Astronomy, 8, 635, 1988).

Shutter times less than one second are possible, but below about 0.1s shutter operation is unreliable. However these very short shutter times are useful when checking the telescope pointing using a very bright star, for instance. Non integral shutter times are possible, and are correctly recorded in the image header. They will most likely be seen when using **pause** and **resume**.

3.4 Calibration Frames.

The following calibration exposures are essential so that your data can be properly reduced. Consult the CTIO IRAF manual for full details.

Most of the calibration frames can be taken during the afternoon. Almost all observers prefer to take calibration frames each day, and we also recommend this, but it is not absolutely essential. Observer Support personnel will help you to get set up if required. **If you have special requirements (dome flats in the morning etc) please consult with Observer Support in advance so that arrangements can be made. In general, it is assumed that astronomers will not wish to use the telescope for calibrations etc from approx 08h00 until at least 14h00.** Note that in order to ventilate the domes so as to minimize "dome seeing" it is normal for the shutters to be opened approximately one hour before sunset. Please try to finish your calibration frames prior to this time.

3.4.1 Zero (Bias) Exposures. These zero exposures can be started using the commands **zero** or **observe**. You should obtain between 5 and 25 exposures, if you are doing really low S/N photometry through narrow band filters then you should aim for the higher number. These can be combined into a single frame with an "average sigma clipping" algorithm (IRAF), the idea being to produce a "zero level" frame from which any cosmic ray events have been removed. You will get plenty of cosmic rays on the Tek 2048 frames due to the long readout time, so make sure you have at least 5 zero frames for this CCD. Combine these using **zerocombine** which you will find in the **quad** package.

3.4.2 Dome (white spot) Flat Fields. These exposures map the sensitivity variations of the CCD, and since the response alters as a function of wavelength it is necessary to prepare a flat field for each filter. Ultimately, the quality of your data will depend on how well you prepare your flat fields. You can use the **dflat** or **observe** commands to take dome flats. Broad band (eg BVRI) dome flats require use of a color balance filter. Do not use the color balance filter for U, or for medium band (eg Strömgren, DDO) or narrow band filters. You should aim for flat levels of several thousand (say 5000 - 40000) counts. Take a sequence of several exposures per filter.

The resulting frames can then be averaged to produce a single dome flat field frame for each filter. Data frames should successfully be flattened with dome flats to 1-2 %, perhaps a little better for redder passbands such as V,R,I. To do better than this there are two alternatives -either to use twilight flats alone, or to correct

the low spatial frequencies in the dome flats by using a dark sky exposure(s) or with the twilight flats. However you are advised to take dome flats anyway, just in case the twilight or dark sky flats are unsuccessful. You may find the dome flats are good enough for your purposes. NOTE - You can get excellent pixel to pixel statistics with dome flats, and in some cases this may be more important than low spatial frequency errors.

3.4.3 Twilight Sky Flat Fields. Broadband B and U (especially) twilight sky flat fields appear to flatten data frames better than do dome flats. However they will not have particularly good pixel to pixel statistics, particularly if you are working near 1 e-/adu. You can either use a smoothed twilight sky flat to take the low spatial frequencies out of your dome flats, thus preserving the good high spatial frequency S/N of the dome flats, or else dispense with dome flats and use the sky flats directly. Consider taking 2x2 or 4x4 binned frames and later use them as smoothed corrections to your dome flats in order to correct the low spatial frequency errors in the latter.

You will need to point the telescope towards the east (HA -3 hrs) in order to lessen polarization effects (or just leave it at the zenith, polarization effects seem to be minimal). Do not use color balance filters. As the sky darkens after sunset, take one second exposures (with U if you are using it) until the sky is dark enough so that an exposure of a few seconds gives about 20000-50000 counts. Use the **preview** command, and look at the counts in the ARCON STATUS window.

You should have time to take several flats in each filter, and if so these can be combined later (IRAF **flatcombine** in the **quad** package). To make it easier to remove star images from your flats, take the flats with the TELESCOPE DRIVE ON, and jog the telescope a little after each exposure. If you wait until it's too dark, then your exposures will be longer and the chances of getting significant contamination by stars is greater, particularly in R and I. These will be removed in the combining process as long as you have 4-5 de-registered frames. Twilight flats should be done in the order UBVRI and exposures should be at least 5-6 seconds long in order to reduce the center- corner variation due to the shutter to negligible proportions. Start the test U exposures at sunset or just a few minutes after. **DON'T ZAP THE THOMSON CCD BY DOING (FOR INSTANCE) I FLATS JUST AFTER SUNSET-** this CCD suffers from after- images!.

3.4.4 Dark Sky Flats. Exposures of "star-less" high galactic latitude fields can be used to provide an "illumination correction" to flat fields. There are several options. One is to take several stepped (e.g. 20 arc sec) exposures of the field then combine the exposures in such a way (e.g. median filtering) that faint stars are removed. Since the final frame will be heavily smoothed a sky level of 200-300 ADU over bias is sufficient. Be sure to remove any bad pixels before smoothing. The resulting smoothed frame can then be combined with the corresponding dome flat to form a master flat. That is, the sky flat removes low spatial frequency errors in the dome flat. The advantage of this procedure over using twilight sky flats is that you retain the good pixel to pixel statistics of the dome flats, and the color match is improved. In practice the latter advantage does not seem to be very important. The disadvantage of using a combination of dome flat + smoothed sky flat is that any high spatial frequency errors in the dome flats will not be removed, however in general these are few. A second option is to use the combined, star-less flats directly. You need lots of counts in the sky level to get good statistics, so this is really only feasible in the R and I bands. A third option is to prepare flat fields from combinations of your object frames. This is generally only possible if they contain few bright stars, and even then it may be necessary to "patch" out the brighter objects prior to combining the frames. But if you have lots of relatively long-exposure object frames then this is a very efficient method.

Note that dark sky flats are recommended so as to allow removal of any fringes due to night sky emission lines causing interference in the thinned CCDs (Tekes). None of these CCDs fringe excessively (<1% in the I band is typical) and so you may not need to de-fringe.

With care, you should be able to reduce systematics in your flat fields to below 0.1 percent, and better over

smaller areas. It is possible to determine sky to maybe 0.01 percent, in sparse fields. To reach this degree of accuracy requires considerable care, and if you are unfamiliar with these rather specialized techniques you are encouraged to consult with your CTIO support astronomer prior to your observing run. (See J.A. Tyson, J. Opt. Soc. Am. A 3, 2131, 1986).

Positions where there are a few less stars than usual:

RA 01 20 22.4 DEC -30 49 04 (1986.5)

RA 12 56 07.7 DEC -76 56 39 (1950)

RA 16 49 42 DEC -15 21 00 (1982)

3.5 Night Time Procedures.

3.5.1 Start of the night procedures. About an hour before sunset the dome shutters will be opened unless calibration frames are still being taken. All doors should be closed and lights turned off. During twilight, your Observing Assistant will fill the dewar with liquid nitrogen, open the ventilation doors, and check the telescope pointing on a bright star near the zenith. If it is the first night that the CCD has been installed then the offset between the CCD and the acquisition TV camera will also be determined, and the focus of the TV camera checked.

Your Observing Assistant is familiar with focussing methods, offset determinations, operation of the TV and Guider, and will help if required.

3.5.2 Focussing the Telescope. On the first night set the telescope focus to the "nominal" value. Ask your Observing assistant or look amongst old Observing Record Sheets to ascertain the relevant value. Try pedestal (telescope) focus = 27000.

Accurate focus is found by taking several snapshots of the star, each at a different focus position. Use the **focus** command, with the relevant **obspar**s and **instrpar**s parameters set. At the 4-m, the focus mode should be set to "auto". This will allow multiple exposures on a single CCD frame. Please save your focus frames and write a note on the night report sheet saying where they are, they will be written to tape and kept as a database for seeing and optics improvements. For broadband filters at the 4m you can just point the telescope at any random field, a 10 second exposure in V will give you several stars suitable for determining the focus. Offsets for the standard UBVRI sets are known (ask Observer Support) so you need only focus one filter.

When focusing, always focus against gravity: move out (to larger readings of the pedestal). The procedure is as follows:

Once rough focus is known, a focus sequence can be done automatically. You specify the middle = approx focus, plus focus step size, plus number of measurements to make. Choose either telescope or detector (recommended) method. A step size of 50-100 units is suggested, use the smaller number if the seeing is good. The CCD will be read out after the last exposure. The sequence will automatically do a double space in offset **AFTER THE FIRST** exposure (be careful with multi-amplifier CCDs, the orientation of the sequence may be reversed when comparing the upper and lower halves of the CCD).

The quickest way to examine your images is to use **imexam** to plot profiles. Best focus will be that with highest peak intensity and minimum distortion in the wings. This last criterion is perhaps the most stringent one. **Make sure you check the focus for several stars on the CCD frame, and best over-all focus is achieved by using a star some ~ 1/3 of the way center -> corner of the CCD.** The focus will change during the night, as it is a function of temperature and telescope position. In good seeing (FWHM <1.5") frequent focus checks are recommended especially if you move the telescope more than 10 or 20 degrees, thus you

should re-focus at your fields for best results.

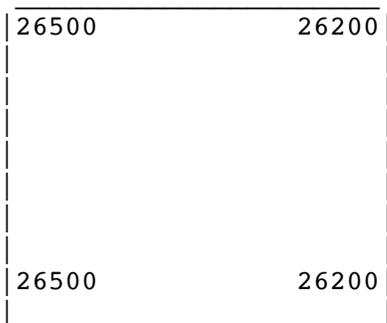
3.5.3 Checking the dewar tilts and rotation. Do this (on your first night) using a focus frame. Compare the focus position (ie the value of the focus for best image quality) for stars near the four corners of the CCD. It is best to average results for 2-3 stars at each position. You should find that the focus variation corner-corner is no more than ± 100 microns. Since the Tek 2048 CCDs are not flat you should not waste time striving for perfection! At the time of writing, and with the Tek 2048 #4 CCD (Arcon 3.6) the tilts are set to

$x_{dewarti} = 600$

$y_{dewarti} = -400$

for best results. The rotation is set at its nominal value (zero). You can adjust the tilts and the rotation using **setdewar**. You can review all the motor positions including tilts and rotation with **motorstat**. The diagrams below represent three different examples of what you might find when you do a focus run. The numbers on the diagrams correspond to the focus at that position on the CCD. Beside each diagram is the prescription for returning the CCD to a position normal to the focal plane.

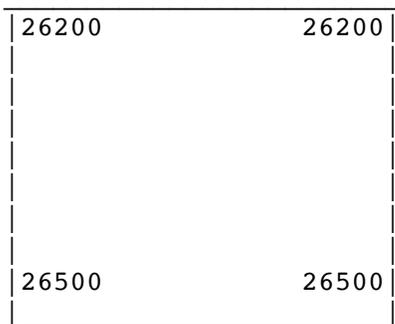
E



Problem 1: tilted about E-W axis

Solution: increase X by 1000 microns

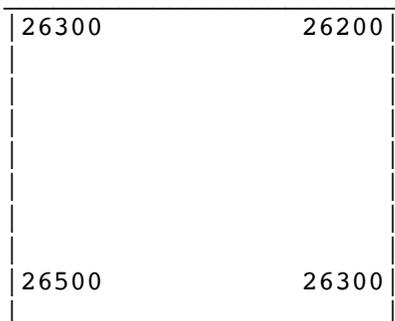
E



Problem 2: tilted about N-S axis

Solution: decrease Y by 1000 microns

E



Problem 3: tilted about both axes

Solution: increase X, decrease Y,
each by 1000 microns

You are cautioned that if the PFCCD motor-controller has its power cycled, or is manually reset, or the commands **motorinit** or **motorreset** are executed, then the tilts will be set back to their nominal (ie zero) positions. You will then need to reset the tilts using **setdewar**. The same is true for the other PFCCD motors, but their positions are generally rather more obvious and not so damaging to the data. Positions for all motors can be displayed by the command **motorstat**. If the Arcon software needs to be re-loaded, then answering "yes" to the question re synchronizing the controller will force both controller and the instrument to the configuration set by the User Interface parameter files (obspar, instrpar).

3.5.4 TV Camera.

A Peltier-cooled CCDTV camera serves both for field acquisition and for guiding. Field of view is approximately 4 by 3 arc minutes. On the CCDTV control panel integration time can be switch selected and gain/offset controls are available. Try integration time of 1-2 seconds, gain = 2 and offset so that you see star images. On the Leaky Guider (0.9m, 1.5m), hardware windowing allows the user to select the contrast and brightness of the displayed image optimum for detection and/or guiding. The autoguider does real time centroiding of a designated star in the TV field.

At the 4m PF, there is a TV filter bolt with four positions, directly in front of the CCD camera. It contains V,B,R and clear(fused silica) filters (positions 1-4) of identical thickness. Focus the TV after focusing the CCD. Watch for smallest images, preferably with the Leaky Guider switched to "digital". This focus is not that critical, as the guider will work fine on slightly out of focus images.

Normally the determination of the TV-CCD position offset will be carried out entirely by Observer Support personnel on the first night only. In any case, in these days of large CCDs it is more efficient to find objects and center up using the CCD in **preview** mode. But if you want to determine the offset, see the Software Manual.

3.5.5 Guider Operation. At the 4m, the CCDTV camera digital frame is fed directly into a PC running a guiding program written by Steve Shectman (Carnegie). This has a very nice display showing guide errors, etc. At the other telescopes the CCDTV signal is fed into a leaky guider. Best results are with a fairly contrasty image, and with the leak time set to 1/2 or 1 second leak. Longer times will not correct for rapid telescope motion, while no leak results in trying to guide too fast and may result in oscillation.

Set window first and identify a guide star on the TV monitor. Then enable only the "rectangular box" cursor. Do NOT try to adjust windowing while guider is enabled. The guide box always remains in view on the TV screen.

The guider, if it gets confused, can confuse you even more. Never try to move the telescope with the guider enabled. If the guide star vanishes for any reason (clouds, TV turned down, telescope moving, cursor A turned off), then the guider will try to center on noise. This could cause very large guide corrections resulting in unpredictable telescope motion.

3.6 Observing.

3.6.1 Finding Your Object: The quickest procedure is to point the telescope at the correct position and take a **preview** or **movie**. Alternatively the telescope can be positioned such that the object is on the TV, and then offset back to the CCD. Then find a guide star. If need-be, move the TV scan table (**setscantable**) and refocus (**settv**).

3.6.2 Exposure times: All the CCDs bleed charge down columns, and to a lesser extent across rows, when an integration is long enough for a star image to become saturated. All recover well from over-exposure,

however excessively bright stars should be avoided. All the CCDs have very low readout noise so there is an advantage in dynamic range by splitting a long exposure up into a number of shorter ones. You should also beware of bright stars just outside the CCD field. These can easily scatter light onto the CCD frame and make photometry difficult.

Cosmic rays tend to be either single or double hot pixel events. The standard way to remove them is to do at least 3 exposures (4 or more give better statistical results) of the same field and median (or use `avsigclip` option in the IRAF `combine` command) filter to remove transient events. The IRAF `cosmicray` and `imedit` commands can be effectively used to remove cosmic rays from single frames.

You should be careful not to over-exposure your object(s) of interest. Saturated pixels are colored RED on the real-time display.

3.6.3 Bad pixels: There are two types: 1) hot (above local background) and 2) cold (less than local background). Sometimes hot pixels tend to be found at the beginning of a column of cold pixels - it appears that most of the charge finds its way into just one pixel. Neither type are transient events: they are both permanent defects in the CCD. However, the number of bad pixels is a function of intensity: there are many more at low light levels. The Tek 2048 #3 CCD has hot columns and large charge traps. These are obvious, and should be avoided. The Thomson CCDs have about 20 short traps visible only at low background levels; at higher backgrounds almost all of these shorten to a single low pixel.

3.6.4 Standard Stars: In broadband UBVRI work excellent results have been achieved by using standards from Landolt (AJ 104, 340, 1992). There are several fields (eg T Phe, SA 98, SA 110) which contain several stars in a 3-4 arcmin diameter field with a wide range in color, and so are invaluable for use with large CCDs. John Graham's uncrowded E region standards (PASP, 94, 244, 1982) in the magnitude range of 10 to 16, the older Landolt standards (AJ, 78, 959, 1973; AJ, 88, 439, 1983) and some of the fainter (10-11 mag) Cousin's stars (J.W. Menzies et al., SAAO Circ., 13, 1) are useful. Copies of these lists are kept in each of the console rooms. Look carefully at the quoted errors on the standards before observing them. Residuals in the photometric solutions are a few percent at worst, and standard stars (properly done) repeat to 0.005 mag or better from night to night. It is preferable not to mix Landolt standards with those of Cousins/Graham if you are interested in getting systematics much below the 0.02 mag level, particularly for stars of extreme colors, and for U-B.

For other systems (Washington, Strömgren, Gunn, etc.) standards are fewer and less conveniently situated. If you are uncertain, consult your CTIO staff contact prior to your observing run.

For narrow band imaging one can try using spectrophotometric standards (R. Stone, J. Baldwin, 1983. MNRAS, 204, 347 and 1984. MNRAS, 206, 241, D. Hayes, 1970. ApJ, 159, 165, M. Hamuy et al., PASP 104, 533, 1992, PASP 106, 566, 1994).

The biggest mistake made in observing standards is to underexpose: try for a peak in the star of at least a few thousand ADU above background (exposure times of 5-20 seconds for $V = 12-14$ at the 4m). Shutter clocking is accurate enough to permit 1 second exposures but, as discussed above, you will need to correct for the shutter delay and for the uneven field illumination.

Use of faint photoelectric sequences (particularly those in crowded fields) requires caution; these often have proven to have systematic errors, and require long exposure times in each filter to reach the desired accuracy in a large measurement aperture.

The care with which one observes standards will be reflected in the accuracy of one's photometric calibration. It is common to observe several standards at the start of a photometric night, several more in the middle, and

still more at the end. If you have fields with only one or two standards, try taking two exposures of a standard field per filter, stepping the telescope by 20 arcseconds between exposures. The extra frame takes very little time, and insures against your star landing on a bad pixel or cosmic ray. For the highest accuracy one should definitely observe enough standards at a range in airmass to solve for the extinction coefficients. Tololo extinction can be as low as $k_V = 0.12$, or > 0.2 if conditions are dusty, so one should not rely on the nominal values (for instance in 1991-2 volcanic dust caused elevated extinctions). The CCD camera has shown itself capable of doing better than 1% photometry: it seems a shame to skimp on the external calibration necessary to achieve this. Furthermore, to make proper use of such an accurate calibration will require the existence in the object frames of uncrowded stars exposed to the same level as the standards.

4. DETECTOR CHARACTERISTICS

4.1. General Principles

CTIO operates several types of CCDs. There is, as yet, no general purpose CCD and a CCD suited to your program will be the one scheduled. Loral CCDs require periodic UV- flooding in order to provide enhanced sensitivity below 5000\AA , and must be kept cold in order to retain the improved response. The output signals from CCDs are extremely small (remember 1 electron = 1.6×10^{-19} Coulomb!) and the electronics must not allow significant extra noise to degrade the performance. In case of problems, electronic components can be replaced (at the board level) and if necessary, the CCD can be changed. If you are dissatisfied with the performance of the CCD system, please consult with Observer Support personnel.

At PFCCD the CCD is mounted in a downward looking liquid nitrogen filled dewar, and is kept at a constant temperature by a small heater. This temperature is displayed in the console room and should remain constant. If the temperature appears to be rising immediately alert either your Observing Assistant or Observer Support personnel. After initial power on and the dewar has been filled with liquid nitrogen for the first time, it requires at least 4 hours for all temperatures and operating voltages to stabilize. The dewar hold time is over 12 hours -filling at the start of the night will generally do for the whole night, except in winter time when, near midnight, the night assistant will ask for permission to return the telescope to the access platform in order to fill the dewar.

The analog signal (which can be considered to be some number of electrons) from each pixel of the CCD is first amplified, then passes through an integrator which discriminates against various noise sources, and is then converted into a digital signal by an analog-digital- converter (ADC). Hence the signal at this stage is measured in "counts" or "adu's" (analog- to-digital-units). The ratio adu/electrons is called the gain, although by convention we usually talk about the inverse gain, electrons/adu. The gain is an adjustable parameter on the CTIO CCD systems. The range of data numbers possible extends from 0 to 65535 (0 to $2^{16}-1$, 16 bits).

4.2 Detector Options

A summary of the characteristics of the detectors normally used for direct imaging is as follows:

	Tek 1024	Tek 2048	STIS 2048
Pixels	1024x1024	2048x2048	2048x2048
Pixel size (microns)	24	24	21
Pixel size (arcsec)	0.3	0.43	0.38
Field size (arcmin)	7.3x7.3	14.7x14.7	12.9x12.9
Readout noise (electrons)	4-6	3-5	3-5

Electrons/ADU (typical)	1-4	1-4	1-2
Cosmic ray rate (per min)	20	100	?
U: Sensitivity at the 4m	10	30	20
B: (U=B=V=R=I)	180	239	90
V: (= 20 mag)	350	348	150
R: (star, in)	380	380	200
I: (electrons/sec)	200	205	130
Read time (quad, secs)	12	30	30

Notes:

1. The full well capacity is the limit above which charge "spills" out of a CCD pixel into adjacent pixels. At some level below full well the response of the CCD becomes non-linear to incident light. Some CCDs retain excellent linearity right up to full well, but for others the departure from linearity becomes severe well below full well. This will define the practical maximum charge capacity per pixel. It may depend on details (slope, amplitude, levels) of the clocking voltages and for some of our devices there is some hope of improving the values given. Typically a factor 20 more charge must be accumulated before noticeable bleeding occurs. This bleeding is stronger in the column direction for our CCDs. With normal gain settings the data system limit of 65535 counts is reached prior to entering the CCD non-linear region. Care should be taken always to operate the CCDs in the linear part of their response.

2. The readout noise is somewhat dependent on gain, larger values of readout noise correspond to larger values of e-/ADU. Similarly, the read time is given for gains of 3-4 e-/adu.

4.3 Detector Notes

4.3.1 The Tek 1024 CCDs

We have two Tek 1024 CCDs, #1 and #2. At the present time only #2 (a quad amp devices) is being scheduled. Read noise is very low. Cosmetics are superb. QE is poor in the UV and U band photometry is not recommended. Note that these CCDs do not have the serial registers and amplifier areas shielded from light, consequently on high light level flat field exposures the overscans show an exponential decay and during reduction should be fitted with high-order splines. See the software manual for more details.

4.3.2 The Tek (SITE) 2048 CCDs

We have three Tek 2048 CCDs (#3, #5, #6). These are thinned, AR coated devices like our Tek 1024s. Read noise is very low, and QE is similar to the Tek 1024's except the U band response is much improved. Tek #3 has several column defects, with bright columns on each side and three blocked columns near the center. These should all be avoided. Tek 2048 #6 is the CCD normally scheduled at the 4-m PF, while #3 is dedicated to the 0.9m., #5 is usually at the Schmidt. #3 & #6 have four low-noise amplifiers and thus have short read time, typically 30 seconds. #5 has one amplifier noisier than the rest, type "ccdinfo" to see the characteristics of the CCD you are using. .

4.3.3 The Thomson 1024 CCDs

RETIRED!!

4.3.4 The STIS 2048 CCD

The STIS CCD was made by Tektronix as part of the development of the CCDs for the Space Telescope Imaging Spectrograph. It has slightly smaller pixels than regular Tek 2048's, and our example is front-illuminated with a metachrome coating, thus its QE is just like the Thomsons (see above). The CCD is very low noise, and reads through all two amplifiers. It has a few column defects. Used as spare.

4.4 Detector Control Options

The observer can control and change several CCD parameters. These are: the CCD readout format, the binning, the preflash time, and the gain. Observers should think carefully whether they need all the field (if not read a ROI) or the resolution (if not, bin 2x2). Even though the CCDs with quad readout have short read times by big-CCD standards, substantial gains in efficiency are possible by reducing the format.

4.4.1 CCD Readout Format

A single region-of-interest can be read out, positioned at an arbitrary place on the CCD. These operate very efficiently, for instance a 1024x1024 ROI centered on a Tek 2048 takes under 10 seconds to read out, while a 256x256 takes just 2 seconds.

4.4.2 Binning

The ARCON controllers are able to bin pixels in various ways. The readout noise per pixel remains the same as in the unbinned case. The gain calibration is unchanged from the unbinned mode. For most direct imaging applications at CTIO the CCDs tend to undersample the images, so there is little advantage in binning. The main advantages of binning are that the readout time is shorter, and less data is created.

4.4.3 Preflash Time

Default is zero. All our CCDs operate without preflash. At the 4-m PFCCD the preflash illumination is rather uneven and thus of little use.

4.4.4 Gain

Generally you will find for direct imaging a gain of about 3-5 e-/adu is a good compromise between sampling the read noise and achieving good dynamic range. Excessively high gain (ie small e-/adu) does little good since digitization noise is soon masked by CCD readout noise and photon statistical fluctuations. Different CCDs are somewhat different in their photon/adu conversion, noise and points at which non-linearities begin to occur. The method used to calculate the gain is described in [Appendix II](#).

4.5 CCD scales at various foci

(1) Pixel sizes (arc sec)

	Tek 1024	Tek 2048	Thomson 1024	STIS 2048
4-m f/2.85	0.43	0.43	0.34	0.37
4-m f/7.5	0.16	0.16	0.13	0.14
1.5-m f/7.5	0.44	0.44	0.34	0.37
1.5-m f/13.5	0.24	0.24	0.19	0.21
0.9-m f/13.5	0.40	0.40	0.32	0.35
Schmidt f/3.5				2.0

(2) Field Sizes (arc min per side)

	Tek 1024	Tek 2048	Thomson 1024	STIS 2048
4-m f/2.85	7.34	14.7	5.81	12.9
4-m f/7.5	2.70	5.40	2.13	4.73
1.5-m f/7.5	7.41	14.8	5.87	13.0
1.5-m f/13.5	4.09	8.18	3.25	7.15
0.9-m f/13.5	6.76	13.5	5.35	11.8
Schmidt f/3.5				68

APPENDIX I: FILTERS FOR CCD IMAGING

A [filter list](#) is available and can also be found in [NOAO Newsletter](#) No. 34. A complete CTIO filter list is also available via ftp. See the WWW home page.

The PFCCD has two filter wheels each holding 5 filters. F1 is the wheel furthest from the CCD and normally contains only a color balance filter for use when doing dome flats. F2 usually contains U,B,V,R,I filters. Other filters can be installed when required. The nominal filter size is 4x4 inches. However 3x3 inch filters in wheel F2 do not vignette CCDs up to a Tek 2048 (49 mm square) in size. We have adaptors to accommodate 3x3 inch filters.

The (4x4 inch) filters we have available for the 4-m PFCCD are as follows:

1. UBVRI set. These are identical to the 3x3 inch filter sets we use at the 0.9-m and 1.5- m telescopes, and similar to the "Harris" implementation of BVR as used elsewhere, except that the prescriptions for B and V have been tweaked slightly. I is an interference filter and U uses a Copper Sulphate solution blocker.
2. Washington set (CMT1). Made according to prescriptions supplied by Doug Geisler. The T2 filter is identical to I (from UBVRI).
3. DDO 51.
4. Gunn griz.
5. Strömgren uvby.
6. Tyson J. A very broad-band filter which approximately matches the photographic J passband.
7. H 6563/75 and 6600/75.
8. [OIII] 5007/50.
9. [SII] 6723/50.
10. HST F-555W and F-814W.

11. Ca H+K
 12. SDSS set (ubvri)
-

APPENDIX II: GAIN AND READOUT NOISE CALCULATION

The gain in electrons/adu is usually accomplished using the **gfind** command (in the **contributed** package). Here is a cookbook recipe for determining the gain in electrons/adu, for anyone who wants to do all the steps one by one.

1. Take a sequence of 2 bias frames. Make sure that the preflash is set to **zero**.
2. Take a sequence of 2 dome flats or, better yet, 2 bias frames with a big preflash value (giving a total signal of approximately 1/2 saturation).
3. Subtract these frames as follows:

BIAS1-2 = BIAS1 - BIAS2 (use **imarith**)
FLASH1-2 = FLASH1 - FLASH2

4. Use the IRAF **imstat** task to determine MEAN(FLASH1), MEAN(FLASH2), MEAN(BIAS1), MEAN(BIAS2), RMS(FLASH1-2), and RMS(BIAS1-2). Note that it is very important that the stats box be positioned on a region of the CCD free from traps, bad columns, or any bad pixels.

5. Calculate the gain,

$$e/adu = (\text{MEAN(FLASH1)+MEAN(FLASH2)}) - (\text{MEAN(BIAS1)-MEAN(BIAS2)}) \text{RMS(FLASH1-2)}^2 - \text{RMS(BIAS1-2)}^2$$

6. The readout noise in electrons is

$$\text{RON}(e) = \text{RMS(BIAS1-2)} * (e/adu) / 1.41$$

Footnote 1

At time of writing, use **smcinit** instead of **motorinit** and **instrument** instead of **motormove**.