The UCT CCD Photometer

User & Technical Guide

Version 2.0

November 17, 1999

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Chapter 1

Introduction

1.1 System Overview

The UCT CCD is a Wright Instruments Peltier-cooled Camera with a 576x420 thinned, back-illuminated EEV CCD. It can be used on the SAAO 74", 40" and 30" telescopes. The two larger telescopes have SAAO autoguiders. The 30" only has an SBIG ST-4 guider and no movable 45° mirror so that acquisition must be off the optical axis. 30" users should consult with Darragh O'Donoghue about the additional complexity involved.

A schematic of the instrument is shown below:

```
                    -------------------
                    |                  |  X-Y Slides
    Acquisition     |      \           |-|
        Box         |     o \          | |___--|      SAAO
                    |   45             | |___  |   Autoguider CCD
                    |   flat  \        |-|   --|  (40" & 74" only)
                    |   mirror \       |
                    |__________________|
     Filter Box        |  .......  |
    (2/1 wheels)       |___________|
                           |___|      Turntable
     UCT CCD Camera Head    |_|
```

Although it can be used conventionally, it is primarily intended as a rapid exposure device. In this mode, a mask is placed over half the chip and at the end of an exposure, the image formed in the unmasked half is shifted to the masked half, whence it is read out during the next exposure of the unmasked half. This mode of operation, called frame transfer mode, allows exposure times as short as 10 sec with no deadtime for readout (exposure times can be even shorter if the chip is windowed or prebinned).

The camera is driven by a 486 PC (running DOS) which collects the data, displays images as they are read out, and permits simple image manipulation. The PC is linked to a Unix workstation which is connected to the Sutherland Ethernet. The workstation's disk is used as the principal data storage medium (as the PC has very little disk storage available). The workstation's DAT drive is used for data archiving. The workstation is also used for on-line reduction and plotting of the data.

1.2 The Workstation: SUNs and Pentium PCs

The first workstations used with the UCT were SUNs. In the first half of 1998, Pentium PCs running Linux with speeds much faster than the SUNs were installed in three domes at Sutherland. These are now the normal data storage and reduction machines. The SUNs have essentially become obsolete.
The term “workstation” will be used to denote either a Pentium PC or a SUN. The term PC in the remainder of this manual refers to the Data Acquisition PC. The manual is primarily written for users using Pentium workstations.

1.3 How To Avoid Reading This Manual

The more urbane manuals are aware of how little they are relished by their readership. Accordingly, here is how to get the information you want by reading the barest minimum. There are 3 levels of information: (i) a pedantic guide to data acquisition for novices; (ii) a more advanced and faster-paced guide to data acquisition for experienced users and (iii) a summary sheet for Wizards. The Wizard Summary Sheet is a $\sim$ 7 page minimal summary of the entire system for quick reminders. Separate copies are available. Data reduction is described at a level intermediate between (i) and (ii), as well as very succinctly in the Wizard Sheet. So:

If you are a **novice** knowing nothing, continue to chapter 2 (data acquisition) and then 4 (data reduction).

If you are a **previous user** of the system, jump to chapter 3 (data acquisition) and then 4 (data reduction).

For information on how to **write data to DAT**, jump to chapter 5.

For **reference info**, jump to chapter 6.

If you are looking for **technical information**, jump to chapter 7.

The **Wizard Summary Sheet** appears in chapter 8.

It would be very helpful if you could email/phone/see Darragh O’Donoghue concerning corrections, suggestions, comments: dod@da.saao.ac.za

Chapter 2

Novice User's Guide To Data Acquisition

2.1 Arriving At The Telescope

You MUST visit the telescope on Tuesday afternoon and check things out. The technicians will have attached the instrument to the telescope and probably started the data acquisition program running. Here's a couple of things that you need to verify with the technicians about the setup on the telescope:

1. **Ensure you know what's in the filter wheels.**

   On the 40" and 74", the filter box has 2 wheels (A and B). On the 30", there's only 1 wheel (**wheel B**). Each wheel has 8 positions. Usually the 40" has the same set of filters. The filters in the 74" and 30" wheels are unpredictable. Please ask the support astronomer or mechanical technician to tell you, or show you, what filters are loaded. **If there are two wheels, make sure you know which wheel contains which filters.** Through no fault of his own, a visiting astronomer recently wasted a night by performing all filter operations on wheel A (which was empty) while the filters he wanted to use were in wheel B. Through no fault of her own, a local astronomer believed she was using a V filter because she thought UBVRI filters were loaded in positions 1-5; instead, BVRI filters were loaded so she was using an R filter. Filter screw-ups are Equal Opportunity activities, and are open to all people, irrespective of gender, status or ethnic origin.

   At the time of writing (1999 November), an apparently stable filter setup appears to be working. A specific set of UBVRI filters, plus BG38 and BG39, occupy the first 7 positions of a wheel of type B (Wheel A and B are wired slightly differently). This wheel is moved between the 74" and 30" as needed. When the system is on the 40", the standard 40" set up is used. **This information should NOT be taken for granted - the onus is on the observer to check.**

2. **Ensure that the frame transfer mask is installed for frame transfer mode.**

   The support astronomer or technician should be able to tell you this. You can check for yourself when you get the first image (see below).

3. **Select the orientation of the CCD.**

   The long axis of the chip (including the masked off half), is collinear with the camera head connector. Thus the short axis of the imaging half of the chip runs in this direction too. The camera head can be rotated by unclamping the brass knob on the turntable, rotating the camera head and reclamping. You can, of course, rotate the camera head as much as you like but if you are using filters, separate flat field calibration will, in principle, be required.

2.2 Getting To Know The Two Computers

There are 2 computers associated with the instrument. A workstation and a 486 Data Acquisition PC.

At the time of writing, the 40" and 74" have permanently resident SUNs belonging to SAAO called sun40 and sun74. These machines used to be called saao2 (40") and saao1 (74"). For use of the UCT CCD on the 30", the UCT Astronomy Dept's SUN, called astrosun, used to be shipped to Sutherland. As mentioned earlier, these SUNs are now obsolete and not used any more, but mention is still made of them for historical continuity. The three larger telescopes now all have fast Pentium PCs. These are called s30, s40 and s74. The rest of this manual will usually assume that the Pentium is the machine used for data storage and reduction, although mention of SUNs may be made from time to time, just to save the trouble of stripping out all references to the SUNs.

2.2.1 Logging On To The Workstation

Make sure the workstation is up and running and that's its screen is on (wiggle the mouse). If not, call a technician.

It is best to log out the previous user. This should be done if the console login prompt on the monitor is not visible, but instead the windows system is up and running. To log off the previous user:

- for the Pentiums, press **Cntrl-Alt-Bkspce** to halt the windows system. Then type **exit** to log off.
- for a SUN, **put the mouse into the background (i.e. not in a window), hold the right button down, slide down to choose `Exit` and let go the button**. Confirm you want to exit the windows system and wait for the console login to appear.

Now enter the username:

- **ccd** (for any of the Pentiums, password **Saaoccd**).

  Start the X-Windows system by typing startx and pressing return.

- **user1** (for the 74" and 40" SAAO SUNs, password **abcdef1**)

  For the SUNs, the X-Windows system should start up automatically.

2.2.2 Logging On To The Data Acquisition PC

Reboot the PC by pressing the Reset button on the front panel gently. After several minutes of gobbledegook, you will then be asked to indicate which workstation the PC is to connect to. Enter the appropriate number for your workstation: **s30** (30"), **s40** (40") or **s74** (74"). *Do NOT choose option 4 for Pentium dod as the data will then end up on my desk in Cape Town!*. Watch carefully. The network software XFS should start up and make contact with the appropriate workstation. If a long pause ensues (during which it's trying) and it then says "arp timeout", check that the two machines are connected to the Sutherland network. This connection is at a little "hub" in each dome to which machines are connected by cables with modern telephone-type connectors on them. Call the electronics technician to help you if necessary. Be careful to enter the correct name of the machine. For example, a common error is to enter the name of a workstation that is connected to the network in another dome, in which case the data will end up elsewhere.

Turn the `Num Lock` light on the keyboard off by pressing the `Num Lock` button.

Now make a directory for yourself on the PC by entering

mkdir xxx

where xxx are your name or your initials (<= 8 alphanumeric characters). Change to this directory with

cd xxx

Start the data acquisition program by typing

wrmwind

Various diagnostics of the PC's health will start to appear but after a while, the program will prompt you for a run number. Enter

999

This is a "messing about" run number for use while you play with the system. The program will then make two files: **disk999.log** and **set999.up**. **disk999.log** will initially be empty but will eventually contain a log of all ccd images that get saved on disk. **set999.up** will contain information about the telescope and CCD in use, the filters in the wheels etc. As the program doesn't know this information, it asks you to supply it. Thus answer all the questions accurately. The UCT CCD contains the WRT1 ccd. Pay careful attention to the specification of filters for each wheel. If the 30" box (with only a single wheel) is in use, or wheel A in the 74" has nothing in it and the 30" box's wheel is in wheel B's position, enter blanks for the filters of wheel A. The filter names that you enter and filter numbers are entered into the FITS header associated with all data files - hence the need for care in supplying correct information. **Do NOT believe the defaults offered by the program**.

After reviewing the filters you've entered, press **Enter**, the screen will clear and the menu and information boxes of the program in its normal mode of operation will appear. This will be followed by an attempt to initialize the filter wheels. Each wheel is initialized in turn by first moving it to its "reference" position and then moving it to the startup position you chose. On the 30", only filter wheel B exists so filter wheel A will be permanently disabled (the program will continue with disabled filter wheels).

In subsequent starting up of the program, if you select run 999, the program will detect the existence of **disk999.log** and **set999.up** (provided you start the program from the same directory) and will not ask you to enter the setup information again. The **disk999.log** file is read and the next file number to be recorded is calculated from the disk file number of the last file in **disk999.log**.

2.3 A Tutorial On The PC Data Acquisition Program

2.3.1 The Main Menu

The top box on the PC screen is a menu with a number of choices. The menu items can be selected by positioning the highlight with the arrow keys and pressing Enter, or by typing the first letter of the menu item. The result is usually the appearance of a sub-menu which is manipulated in the same way. The main menu choices are:

Filter

to initialise and move filter wheels

Program

to execute a range of observing programs (including bias and dark)

CCD

for low-level control of the CCD (gain, pre-binning, frame transfer, HSP mode and snapshots)

ImageDisp

to control the image display monitor, do quick photometry, fit a gaussian to stellar profiles

Disk

to save and get images from disk, change next file number, select storage on Data Acquisition PC, or workstation

Utilities

to change Run number or exposure time

Exit

N.B. all menu items can be selected by positioning cursor with the arrow keys or by typing the highlighted keys.

2.3.2 Prepare: Clearing The CCD

You are now ready to try your first CCD operation. Press

C

and the CCD sub-menu will appear. Alongside item 5 is **prepare**. This sweeps the CCD clean of any accumulated charge (dark current, cosmic rays) since it was last read out. Press

5

and the Prepare status will be highlighted in the bottom right hand status box. After completion of the operation, the highlight disappears as does the CCD sub-menu. Try pressing **C5** several times for practice. Apart from wasting time, no harm can ever be done by pressing **C5**. Note how the keystrokes **C** and **5** are now concatenated (for brevity) to **C5**.

2.3.3 Expose: Starting An Exposure

Now press

C and then **8**, i.e. **C8**

and you will be prompted for an object name. Just press **Enter**. When prompted for the exposure time, enter **5** for 5 sec. The exposure will begin and a countdown will start in the top right hand box (note: sometimes you may get the message `Warning: Viewing Mirror In Beam   Press Enter To Continue`. This alerts you to the fact that the 45^{o} flat mirror in the acquisition box is not centred and is preventing starlight reaching the CCD. Ignore this when “messing about” and simply press Enter, but obviously don’t ignore it when observing!).

After completion of the exposure, readout begins and on the image display attached to the PC (the awkward looking screen next to the PC monitor), you should see a rather dark but still distinct image sweeping down the screen. If not, you need to get more ambient light from the dome on to the CCD so try one or more of the following steps: (i) ensure that no filter is in the beam; (ii) centre the Viewing Mirror using the autoguider program (see AAGS manual); (iii) put more light on in the dome; (iv) open mirror. If the frame transfer mask is in place, the bottom half of the image (which will disappear below the bottom edge of the display) will be much brighter than the top half. (NB: if the chip is saturated, the bottom half will appear black so check the signal level with the Image Measure command described two sub-sections further on. If it reports negative pixels, the image is saturated so reduce the exposure time.)

2.3.4 Frame Transfer Mode

Press

C3

and frame transfer mode will be selected. If you now press

C8

and repeat the 5-sec exposure of the last section, the top (darker) half of the screen will not appear as this is the masked off half. Instead, what was formerly the bottom (brighter) half will appear where the top dark half was. This is because the bottom brighter half is frame-transferred from the bottom image section of the chip to the top store section before readout begins. The chip is now in frame transfer mode and should stay in this mode while the mask is on the chip.

Check the alignment of the mask: the ccd chip has a thick insensitive border. Apart from a slight wobble in the inside edge of this border, there should be no sign of the mask cutting across the image.

Frame transfer mode can be toggled on and off by repeated **C3**.

2.3.5 Checking The Health Of The CCD

Press

C5

to clear the chip a few times. Now press

C1

and the chip should be read out without opening the shutter. It should therefore have only the “bias” signal with superimposed readout noise. Now press

I

and the Image Display sub-menu will appear. Press

M

to make measurements. A crosshairs will come up on the image display. Move the crosshairs on to the middle of the CCD chip and press **Ins** (**did you remember to turn off Num Lock? If you didn't, Ins will not work properly**). A green circle will appear on the display and statistics on all the pixels in the circle will be listed in the scrolling box. Note the standard deviation. This should be ~2.5-4.0 and represents the noise, in ADU, of the pixels in the circle. As the gain, when the system starts up, is 2.5 e^{-}/ADU (this gain is called Gain 4 in the Wright Camera status box), the range 2.5-4.0 corresponds to a noise of 6.3-10.0 e^{-}/pix. Substantially larger values means there is something wrong.

Move the crosshairs to other parts of the chip and press **Enter**. Note the noise. Finish these measurements by pressing **q**.

Now press

P

to select the program sub-menu. Select the Dark Frame item and provide the integration time: choose at least 1000 sec but 3000 sec would be better. The program will clear the chip and start timing *without opening the shutter.* At the end of the chosen integration time, the chip will be read out. Use the same procedure as before to measure the statistics inside the circle. The **mean** level, after bias subtraction, should be ~ 20 ADU corresponding, with a gain of 2.5 e^{-}/ADU, to a dark current of 50 e^{-}/pix per 1000 sec exposure. Substantially larger mean values means that the dark current is excessively high. (Note, though, that there will be several "hot" pixels with much higher dark current. These, though undesirable, are "normal").

With these two tests completed, the health of the CCD is checked out.

2.3.6 The Filter Sub-Menu: Testing The Filter Wheel

Another test of the hardware of the UCT CCD you need to make is exercising the filter wheel.
Press

F

to bring up the filter sub-menu. You can try re-initialising the filter wheels or moving wheels A and B to different positions. (Recall that on the 30", only filter wheel B exists so filter wheel A is permanently disabled.)

Each filter has a number which is recorded in the FITS header of data images: filter 7 in wheel A and 2 in wheel B is recorded as filter 72. The filter number of a disabled filter wheel is 0.

2.3.7 The Disk Sub-Menu: Disk Storage

All images are stored in FITS format in disk files with the following kind of name:

annnmmmm.fts

where nnn is the 3-digit run number and mmmm is the 4-digit image number. Thus the first image of run 999 is stored in a file called a9990001.fts . This file is stored in the directory c:\image on the PC's hard disk. However, this disk is very small and can store only 20 or 30 images before filling up. Thus, the normal place to store data is on the workstation's disk. This is possible because the PC runs the PC-NFS (NFS is the Network File System of Unix) software which enables the PC to gain access to the workstation's disk (which is 2 Gbytes or more in capacity). This disk is known to the PC as the e: or f: disk (depending on the way the PC linked to the workstation when you rebooted it). Thus you need to change the disk on which the data are written from c: to e: or f: and this can be achieved by pressing

D

and then

H (**DH** for short)

from the disk sub-menu. The program will then ask you to enter the new disk which must be specified as c:, e: or f:. The data will now be stored in e:\image or f:\image as appropriate.

Now try obtaining and storing an image. Start an exposure as described in a previous section. When it is finished and read out is completed, press

DS

and the image will be written to file a9990001.fts on the workstation's disk. You can check this by exiting the program and typing the DOS command

dir e:\image

Other items on the Disk sub-menu allow you to type the disk log file (disk999.log) (**DT**), clean up the disk (**DC**) retrieve a previous image from disk (**DG**) and, most importantly, change the disk frame number (**DF**). This latter is important because of the irritating feature of DOS that if the system crashes with a file open for writing, the contents of the file are lost. You will discover that the PC does crash at various times (in non-repeatable and thus essentially unfixable ways) which will result in the contents of the disk log file being lost. When the PC is restarted, it will find an empty disk log file and set the frame number to 1. **It will then, if unchecked, overwrite all the data already stored under that frame number**. This option on the Disk sub-menu allows you, once you have looked on the workstation to see which was the last file written before the PC crashed, to reset the frame number to be one larger than this last stored file.

2.3.8 Controlling The CCD To Get Data

The process of acquiring and storing CCD images can be summarized as follows:

- Move the filters to their desired positions.
- Clear the CCD by doing a **Prepare** using **C5**.
- Start an exposure using **C8**.
  (These two steps, **C5** + **C8**, can be achieved with **C6**)
- Store the data on disk with **DS** when exposure is over and readout is completed.

Automating these steps as far as possible is needed to maximize observing efficiency, and there are two distinct ways of doing this.

Using Programs For Conventional CCD Photometry

The Program sub-menu allows you to enter, delete, edit and tweak programs which are then executed (the Program sub-menu also allows you to obtain Bias and Dark Frames).

A program is a defined sequence of steps of the kind listed immediately above. To enter a program, press

PE

and you will be asked to give a program number. Choose **1**. The PC will then ask you to:

- Specify the filter in Wheel A
- Specify the filter in Wheel B
- Indicate if the chip should be Prepared before exposure (usually yes)
- Give the exposure time
- Indicate if the data is to be stored on disk
- Indicate if the program should continue with another filter
  in which case go back to the first step
- Indicate if the whole sequence up to now should be repeated

You can enter the default answers in angle brackets `< >` by simply pressing `Enter`. Some of the questions may be answered y/n/a. The 'a' stands for "ask" which means that when that line of the program is executed, the user is prompted, as opposed to 'y' or 'n' which indicate yes or no without consulting the user.

An entered program can be inspected by **PT** and executed by **PR**. A program which is not in "repeat mode" will run until the exposure of the last filter in the sequence is finished, the chip read out and the data stored (if requested). On the other hand, a program in repeat mode will then begin again at the beginning and will continue indefinitely until stopped with **PS**.

A convenient feature is the tWeak option **PW**. This allows you to change quickly one of two attributes of an already existing program: (i) the exposure times or (ii) saving to disk. The exposure time can be scaled (by the same factor if the program has more than one filter) or turning on/off saving to disk can be flip-flopped with this command. Exposure time scaling is especially useful for obtaining flat fields and saving to disk can be turned off while a program is tested.

High Speed CCD Photometry

If your observing program requires continuous monitoring of a single target through a single filter (or no filter), especially with short integration times, acquiring data in high speed photometry mode is the best option.

Once begun, high speed photometry mode essentially locks out the user from the program until the `Esc` key is pressed to stop the sequence. The one exception is the user is still able to change the lookup table for the display. Thus, it is essential to check that the CCD gain and prebinning are correct before beginning. In addition, the CCD *must* be operated in frame transfer mode (**C3**).

Assuming these are all set up correctly, high speed photometry is initiated with **C4**. Enter the target name (and its RA and Dec if this is the first time the target has been observed), the exposure time (should not be shorter than 8 sec if no prebinning is used) and the disk for writing the data to (e: or f:). Press a key to start the run. The sequence is stopped with the `Esc` key. Try this now (without storing data on disk) and terminate it after a few frames have been acquired.

2.3.9 The Image Sub-Menu

You have already worked with the **IM** command which measures statistics of that part of the CCD image inside the circle produced when the cursor is moved to a specific place and `Ins` is pressed (with `Num Lock` off, of course!). Other useful commands in this sub-menu are **IF** to fit a Gaussian to the star image indicated by the cursor, and **IT** (Image Transect) which requires you to position the cursor in two different places, each time pressing `Ins` to specify the place. A plot of the pixel values along the line joining the two points is then produced. All these commands require cursor input which is controlled by the arrow keys. Cursor speed can be changed with `F1` and `F2`. These commands will continue expecting further cursor input until q is pressed. The size of the circle used in the Measure command (as well as specifying the sub-image used in the Gaussian fitting) can be changed with the **IC** command.

Perhaps the most frequent use of this menu is to control the appearance of the image display. The CCD digitizes the data using 16 bits; the display, however, uses 8 bits per pixel. This is done by transferring the 16-bit image in the PC's memory onto a 512x512x8 bit memory residing on a frame grabber board in one of the PC's expansion slots. The display is a continuous display of the frame grabber memory. 8 bits of the original 16 are discarded in the transfer process and the exact way this is done is controlled by the choice of the Look-Up Table (LUT). There are two LUTs, the Image LUT and the Display LUT, the former being the most important. The first Image LUT retains the least significant 8 bits of the original data and the effect of this is that pixel value 0 is displayed black, pixel value 255 is displayed white: bright stars are saturated (often "wrapping" the LUT several times with alternating dark and bright rings) while faint features are given maximum contrast. The second LUT retains significant bits 2-9, the third 3-10 etc. The higher the LUT, the less saturated are bright parts of the image while the contrast of the fainter parts decreases. Image LUT 7 is a logarithmic scale while Image LUT 8 requires the user to specify the minimum and maximum in the original data onto which the range 0–255 (black–white) is mapped in the Image display. Experiment with a range of LUTs to appreciate this discussion.

In high speed photometry mode, Image LUT 1-6 can be selected by pressing F1–F6.

2.3.10 The CCD Sub-Menu

We have already looked at

- **C1** Readout the CCD
- **C3** Turn on/off frame transfer mode
- **C4** Start a high speed photometry run
- **C5** Prepare the CCD (clear it of charge)
- **C6** C5+C8
- **C8** Start an exposure

Of the remainder, the two most important are:

- **C7** Change the Gain
- **CC** Change the prebinning

It is desirable to match as closely as possible the Full Width At Half Maximum (FWHM) to 2.2 CCD pixels. This simultaneously means that the images are adequately sampled and, as each CCD pixel has associated readout noise, measured with the minimum number of pixels. Thus in bad seeing, it is important to use prebinning. In addition, because the plate scales of the 40" and 74" are rather large compared to the pixel size in the UCT CCD (22 micron), if the seeing is 1 arcsec (FWHM) on both telescopes (80 and 166 microns respectively), 2x2 (40") and 3x3 (74") prebinning should be used. 2x2 prebinning results in all the light falling into a group of 4 pixels with a common vertex being combined into one pixel before read out, thus incurring the readout noise of only 1 pixel instead of 4. Prebinning also reduces data storage and speeds up readout. Prebinning is selected with **CC** and the allowable range is 2x2 to 6x6. Prebinning can be turned off simply by pressing **CC** again. Prebinning must be turned on *before* frame transfer mode.

The user should also appreciate the significance of the Gain. The Gain specifies the ratio of photo-electrons in each pixel to Analog-To-Digital (ADU) Numbers in the readout and digitization process. With the UCT CCD two gains are possible: Gain 1 corresponds to 10 e^-/ADU and Gain 4 corresponds to 2.5 e^-/ADU. The Gain can be toggled between these two possibilities with the **C7** command. Which Gain to select in a given circumstance is dictated by the brightness of the brightest object in the field to be imaged. The Analog-To-Digital (A/D) converter saturates at 32768 while the CCD itself saturates at $\sim$ 250000 e^-. Thus with a Gain of 1, you should be aware that pixel values of 25000 and above are near the saturation limit of the CCD. With a Gain of 4, a pixel value of 25000 corresponds to only 62500 e^-. It should be clear, then, that a Gain of 1 is useful for bright objects and a Gain of 4 should be used for faint objects.

2.3.11 The Utilities Sub-Menu

For now, there are only two items on the Utilities sub-menu of interest to you: changing the integration time (**UI**) and changing the run number (**UC**). The integration time can be changed from its value when you started the exposure. If you inserted a value of zero then, the exposure will continue indefinitely until an integration time is specified by this command.

The run number can be changed by pressing **UC**. When this is done, you will be asked to enter a new run number. The setnnn.up file will then be copied to setmmm.up, where nnn is the old run number and mmm is the new run number. In addition, an empty file diskmmm.log will be created. The procedure thus avoids the specification of the filters and CCD chip that had to be followed the first time you started up the data acquisition program.

This completes the tutorial on how to manage the PC Data Acquisition Program.

2.4 Observing Procedures

2.4.1 Obtaining Flat Fields

The first task you have to perform is to obtain flat field images. These are images of the twilight sky and **must be taken in photometric conditions**. The sky is presumed to be of uniform brightness and thus any departures from uniformity in the flat field images are presumed to be due to variations in the instrument. These arise from pixel to pixel sensitivity variations in the CCD chip. Dust on the filters and CCD dewar window also contributes significantly.

2.4.2 Planning The Sequence Of Flat Fields

There is a window of opportunity of approximately 10-20 min during which flat fields may be obtained. This window opens when the sky is sufficiently dark that the CCD does not saturate in exposure times of $\sim$ 1 sec but sufficiently bright that exposures of a few sec will give reasonable count rates (and are free of bright stars, of course!). You should be driving up to the telescope at sunset in order to be ready when the sky is appropriately bright.

The sky falls by a factor of 2 every 3 minutes. The recommended range for flat fields is 100000–250000 e^-/pixel. The upper limit is set by nonlinearities/saturation of the CCD pixels. The lower limit is somewhat arbitrary; however, flat fields must have sufficient exposure that photon noise is essentially negligible. This is achieved by summing many flat fields; weakly exposed flat fields add little to the summation.

Two further points need to be considered in planning flat fields: (i) Filter sequence. If you are intending to obtain images in several filters, a flat field must be available for each filter; (ii) Prebinning. If you use prebinning, it is best to obtain flat fields in the prebinned mode. 2x2 prebinning concentrates 4 times as much light into 1 pixel so prebinned flat fields can be obtained after those without prebinning if you are prompt.

The exposure times (very rough) to obtain equal counts in each of the Johnson $UBVRI$ filters are in the ratio:

Table 1: Sky Flat Count Rate Ratios

U	B	V	R	I
15	1.3	1	1	2

Because the U filter requires so much longer exposure times, it is best to obtain a number of U flat field frames while the sky is still very bright, then switch to $BVRI$ flats when the sky has dimmed. It is best to obtain the latter in sequence by defining a program to cycle amongst the $BVRI$ filters. Use the tWeak option to scale up the exposure times when the sky has fallen.

2.4.3 A Recipe For Flat Fields

Having planned how to obtain the flat fields, you should:

- Enter a program to obtain repeated flat fields (in a single filter or multiple filters as appropriate)
- Set the Gain to 1 (10 e^-/pix) (there is no point in obtaining flat fields with Gain 4)
- Ensure that disk writing will go on to the e: or f: drives (command **DH**)
- Move the filter wheel so the filter you want is in the beam (or the first filter of the sequence)
- Take test exposures of 1 sec (never use less than 1 sec for flats - shutter opening and closing may affect the results). Measure the count rate. Saturated flats have negative count rates and the display is black.
- When the sky is dim enough, start the program.
- **It is essential that the name of flat field images has `fl` or `FL` in it (e.g. vflat, vfl, flatv etc.) so that the FITS header will indicate this is a flat field.**
- After $\sim$ 3 min, the sky will have fallen, so stop the program using **PS**; if further flats are desired, use **PW** to tWeak the exposure times and restart.

2.4.4 Focussing The Telescope

The next task is to focus the telescope. There is a focus routine in the CCD sub-menu. This involves taking a number of exposures with different telescope focus settings and slightly different star positions, but *without* reading out the CCD . The CCD is then read out and the FWHM of each of the multiple images measured. It is probably faster, though, to read out individual exposures. Thus:

- Acquire an E-Region standard star (a list should be in the warmroom) of about 9-10th mag. A fainter field star on the 74" may be needed.
- Get the telescope roughly focussed by adjusting the focus control on the warmroom handset until the star image size on the autoguider is minimized. This assumes, reasonably, that the autoguider and CCD are at nearly the same focus.
- Select a filter (or no filter if that is the way you plan to work - there is a small focus difference between unfiltered imaging and filtered imaging, but the focus difference among different filters is probably negligible).
- Take a test exposure of about 3-5 sec (to smooth the seeing); make sure the star is not saturated.
- Measure the FWHM of the star by fitting a gaussian using the **IF** command. Note the focus and the FWHM in x and y.
- Move the focus (by typically 2-4 units), and repeat so that you have a table of focus readout and FWHM in x and y. Select the focus which minimizes the image.

It is possible that the FWHM will have a minimum at a different place in x and y. This is because of astigmatism in the optics and is especially noticeable on the 40". Also, in poor seeing the focus test is not sensitive so expect a less certain result in such circumstances.

If the FWHM exceeds 4.5 pix, it is advisable to use prebinning. Focus changes in the night are common. Repeated checking is also advisable.

You should now be ready to obtain data.

2.4.5 Run Numbers And Data Management

As mentioned already, disk files are store with the name

annnmmmm.fts

where nnn is the run number and mmmm the frame number. It's a good idea to keep a unique run number for each high speed photometry time series. Possible schemes are either to keep a running number starting from 1, or use 101 for run 1 on night 1, 102 for run 2 on night 1, 201 for run 1 on night 2 etc. It might also be useful to use run 0 for flat fields, standard star observations and run 999 for tests.

Each run number has an associated setup file (`setnnn.up`) and a disk log file (`disknnn.log`).

The run number can be changed in the Utilities sub-menu. The current setup file will be copied to the new run's setup file and an empty disk log file will be created for the new run.

Chapter 3

Experienced User's Guide To Data Acquisition

This chapter is a succinct version of the Novice User's Guide. Refer to chapter 2 for an expanded description.

3.1 Arriving At The Telescope

1. **Ensure you know what's in the filter wheels.**

   On the 40" and 74", the filter box has 2 wheels (A and B). On the 30", there's only 1 wheel (**wheel B**). Each wheel has 8 positions. Usually the 40" has the same set of filters. The filters in the 74" and 30" wheels are unpredictable. **If there are two wheels, make sure you know which wheel contains which filters.**

2. **Ensure that the frame transfer mask is installed for frame transfer mode.**

3. **Select the orientation of the CCD.**

   The long axis of the chip (including the masked off half), is collinear with the camera head connector. Thus the short axis of the imaging half of the chip runs in this direction too. The camera can be rotated by releasing the brass knob of the turntable, rotating the camera and tightening the knob.

3.2 Workstation Preliminaries

At the time of writing (1999 November), the 30", 40" and 74" have permanently resident Pentium PCs (which are called workstations in this manual to avoid confusion with the Data Acquisition PC). These machines are named s30, s40 and s74 respectively. Before these machines arrived, the 40" and 74" workstations were SUNs belonging to SAAO named sun40 (also named saao2!) and sun74 (also named saao1!). The UCT Astronomy Dept's SUN, named astrosun, was sent to Sutherland and back for use in the 30"; this is never done any more. Instead, as mentioned earlier, the standard workstation is either s30, s40 or s74.

3.2.1 Logging On To The Workstation

- **Log out the previous user**.

  For the Pentiums, press Cntrl-Alt-Bkspce to halt the windows system. Then type exit to log off.

  For the SUNs, place the mouse in the background, hold the right button down, choose `Exit` and let go. Confirm you want to exit the Windows system.

- **Log on** with:

  username **ccd**, password **Saaoccd** (Pentiums).

  username **user1**, password **abcdef1** (74" and 40" SAAO SUNs) or

  For the Pentiums, start the X-Windows system with **startx**. The X-Windows system should start automatically on the SUNs.

- **cd** to the `/image` **subdirectory**:

  /data/image on the Pentiums.

  /usr1/user1/image on the 74" and 40" SAAO SUNs.

  Clean out old data files and directories to maximize space.

3.2.2 Logging On To The Data Acquisition PC

- **Connect the PC and Workstation to the Sutherland network.**
- **Reboot the PC** by pressing the Reset button on the front panel gently.
- Enter the number corresponding to the workstation you will use:

  1: saao2 in 40"

  2: saao1 in 74"

  3: astrosun in 30"

  4: s30 in 30"

  5: s40 in 40"

  6: s74 in 74"

- Turn the `Num Lock` light on the keyboard off by pressing the `Num Lock` button.
- Make a directory for yourself on the PC: **mkdir xxx**, xxx is your name/initials (<= 8 alphanumeric characters). (This directory may still be there from your last run)
- **cd xxx** to change to this directory
- **wrmwind** to start the data acquisition program
- **Enter run number** (e.g 999). Enter the filter names that you **know** to be correct. **Do not assume the defaults are correct**.

The PC initialises filter wheels and presents screen with range of menus which control:-

- **F**ilter

  to initialise and move filter wheels

- **P**rogram

  to execute a range of observing programs (including bias and dark)

- **C**CD

  for low-level control of the CCD (gain, pre-binning, frame transfer,
  HSP mode, and snapshots)

- **I**mageDisp

  to control the image display monitor, do quick photometry, fit a
  gaussian to stellar profiles

- **D**isk

  to save and get images from disk, change next file number, select storage on Data Acquisition PC, or Pentium workstation

- **U**tilities

  to change Run number or exposure time

- **E**xit

N.B. all menu items can be selected by positioning cursor with the arrow keys or by typing the highlighted keys.

3.2.3 PC Operations

Here's a summary of the most useful PC commands:

- **CCD Sub-menu**

  C5 Prepares or sweeps chip clean

  C8 Starts an exposure

  C6 = C5 + C8

  C3 turns on frame transfer

  C4 Starts a high speed photometry run

  C7 sets gain (choose 4)

  CC prebin (2x2 to 6x6)

  CA sets read-out speed (choose **Lo**)

  CE puts CCD into rapid readout, "video" mode

  C1 Simply reads out the CCD in its current state

- **Program Sub-menu**

  PR to execute a program

  PE to enter a program for 1st time (must choose *yes* for **prepare**)

  PA to alter existing program

  PW to tweak existing program (multiply exp. times by factor, toggle disk writing)

  PS to stop a repeating program

  PB to execute BIAS frame

  PD to execute DARK frame

Use one program (e.g. 2) for single test exposures for checking levels, focus, etc

Use one program for $BVRI$ flat fields (do U separately)

Use one program for complete set of filters for standard star observations

- **Filter Sub-menu**

  FI Initialises filter wheel

  FD Disable filter operations

  F Wheel A Move filter wheel A

  F Wheel B Move filter wheel B

- **Image Sub-menu**

  II to set LUT

  IM to measure counts in circle (position cursor and press INS)

  to get sky subtracted counts, position cursor on sky

  and press s, position cursor on star and press INS

  IF to fit gaussian to star (position cursor and press INS)

  NB: INS key will NOT work if `Num Lock` is on

  F1 and F2 will change the speed of cursor movement

  press q/Q to exit **IM** or **IF** (before end of current integration!)

  IC to change radius of measurement circle

  IS to display the image (after getting an image back from disk)

- **Disk Sub-menu**

  DS Stores current image to disk

  DH cHanges disk drive to e:, f: (or back to c:)

  DF Change the number of the next disk file to be stored

  DG Get an image back from disk

  Use **IS** to display it

  DT Type the disk file log

  DC Cleanup the disk by deleting files

- **Utilities Sub-menu**

  UC Change the run number

  UE Change or set the exposure time

3.2.4 Checking The CCD, Filter Wheels And Data Storage

Now check out the CCD's noise and dark current, the filter wheels and verify data storage on the workstation is working:

- Get BIAS frame to check readout noise

  PB to clear chip and readout

  IM to measure statistics

  std dev should be ~ 10 e^-/pix

- Get DARK frame to check dark current

  PD to obtain a dark frame. Expose for at least 1000 s

  IM to measure statistics

  mean should be ~ 0.05 e^-/pix/sec

- Exercise filter wheels (while you are waiting for the dark frame)

  FI to initialise the wheels

  F and choose Wheel A or B to move the wheel

- Check PC link to workstation by saving a test image

  DH and choose drive e: or f: as appropriate

  DS then look on the workstation to verify the file is there

3.3 Observing Cookbook

3.3.1 Data Storage And The Run Number

Ensure data will be stored on Pentium workstation. Use **DH** command.

Individual images are saved in files with a run number and frame number component:
annnmmmm.fts where nnn is the run number and mmmm the frame number. The first image in run 302 on the workstation disc would be a3020001.fts.

The choice of run number is arbitrary. The Oxford group usually

- Use run number `n` for night `n` general purpose files (e.g. BIAS, FF, standard stars, normal single CCD images of targets).
- Use run number `n0m` for the `m`th HSP target of that night (e.g. 2nd HSP target on 3rd night would be run number 302).

DOD usually

- Uses run number 0 for general purpose files (e.g. BIAS, FF, standard stars, normal single CCD images of targets.
- Uses run number 999 for tests.
- Uses a different run number for each different HSP time series in a simple sequence (i.e. not subdivided on a nightly basis).

The run number can be changed in the Utilities sub-menu. A copy of the current setup file will be made and an empty disk log file will be created for each new run.

3.3.2 Flat Fields

- Approx 15-30 mins after sunset (drive up at sunset)
- Do in order BVRI wl (sunset), wl IRVB (sunrise) (wl=white light)
- Enter a program for repeated flat fields (in one or more filters)

- Move the filter wheel if necessary
- Set the Gain to 1 (10 e^-/pix) with **C7**
- Take test exposures of 1 sec or longer with **C6**. Aim for 20,000-25,000 ADU/pix - check level with **IM**
- When the sky is dim enough, start the program (**PR**).
- **It is essential that the name of flat field images has `fl` or `FL` in it (e.g. vflat, vfl, flatv etc.) so that the FITS header will indicate this is a flat field.**
- Repeat key FFs (e.g. clear) to reduce photon noise ($> 10^6$ e^-/pix in summed flat field is desirable) and ease cosmic ray removal
- Remember, sky decreases (increases) by factor 2 in 3 mins.
- As sky dims, use **PS** to stop, **PW** to tWeak the exposure times, **PR** to restart.

3.3.3 Focus

- It is possible to do a "focus run" (option **CB**), but single exposure readouts are probably faster (**C6**).
- Acquire an E-Region standard star (a list should be in the warmroom) of about 9-10th mag (30 or 40"), or a fainter field star (74").
- Get the telescope roughly focussed by adjusting the focus control on the warmroom handset until the star image size on the autoguider is minimized. This assumes, reasonably, that the autoguider and CCD are at nearly the same focus.
- Select a filter if desired (there is a small focus difference between unfiltered and filtered imaging: 1-2 units).
- Take a test exposure of about 3-5 sec (to smooth out seeing) with **C6**.
- Measure the FWHM of the star by fitting a gaussian using the **IF** command. Make sure the star is not saturated. Note the focus and the FWHM in x and y.
- Move the focus (by typically 2-4 units), and repeat so that you have a table of focus readout and FWHM in x and y. Select the focus which minimizes the image.
- Always set focus drive in same direction (to avoid backlash).
- Check regularly through night. Especially if temperature changes. There is NO focus tracking!

3.3.4 Bias

- Take at beginning and end of night (**PB**)
- Check level with **IM**, which also gives readout noise
- Discard biases with cosmic rays in them

3.3.5 Standard Stars

- Use E-region standards (Menzies et al list in Warm Room).
- Choose 10th mag stars if possible, otherwise defocus to prevent saturation.
- Use standard star to mark position of CCD centre on A&G TV. Note position wrt CCD bad column.

3.3.6 Normal Observing

- Check level and position of target with 5-10 sec snapshot (**C6**)
- Alter program 2 with **PA** to desired settings
- Start with **P rtn 2**
- Don't forget to enter target name (prompted before exposure starts)

3.3.7 HSP Observing

- Choose desired filter and prebin for run (cannot be changed in HSP mode).
- Optimise target position wrt reference stars.
- Ensure frame transfer mode is on (**C3**).
- Enter HSP mode with **C4**.
- Choose exposure time (usually 8-15 sec) and disk e: or f: for data. Shorter integration times can be chosen if prebinning is used. Exposure times as short as 3 sec can be used with 3x3 prebinning.
- Can adjust LUT in HSP mode using keys F1-F4. **All other options are locked out during an HSP run!**
- Press ESC to finish HSP run.

Chapter 4

Data Reduction

Data is transferred from the PC into directory:

> **/data/image** on the Pentiums.
>
> **/usr1/user1/image** on the 74" and 40" SAAO SUNs.

Data reduction comprises two steps:

- Flat fielding and cleaning of the images
- Extracting the brightness of stars on the frame using `DuPHOT` (an adaptation of DoPHOT).

Data reduction can be done "offline" (i.e. after acquisition is finished) or "online" (i.e. as soon after each image is acquired as possible).

In the following, user inputs will appear in **bold** print. The various programs ask questions and may list the acceptable replies. If a possible reply appears in `[]` or `<>` brackets, pressing `Enter` will cause that default to be assumed.

4.1 Data Reduction Program Name Changes

Because of clashes with Luis Balona's programs of the same name, data reduction program name changes took place in 1998 April. These name changes are only relevant to the Pentiums. Thus on the Pentiums, and for the remainder of this manual, the programs to scan FITS files and clean them, and the photometry program are now called:

- **scanfits**
- **cleen**
- **duphot**

4.2 Offline Data Reduction

4.2.1 Flat Fielding And Cleaning

Flat-fielding and cleaning involves: (i) subtracting from the image the bias measured from the overscan strip; (ii) trimming off this overscan strip and any other unwanted edges of the CCD; (iii) interpolating bad pixels; (iv) multiplying the image by a normalized flat field to remove pixel to pixel sensitivity variations.

Because an individual flat field will have significant photon noise, flat fielding must be done with normalized files which are the sum or median of a number of individual files. The first step is to assemble all the flat fields to be combined in one directory. Some believe it is wise to use only flats from a given night for data from that night; others believe that combination of all flats is acceptable. DOD believes that, provided the equipment configuration has not been tampered with (filters not moved, CCD orientation the same etc.) the second option is ok. Make your own decision and copy the necessary files into a separate sub-directory (called `flats` or `night1` or some such).

The first program to run is `scanfits`. It scans the current directory for all files called *.fts or *.fits. Those called *.fts it renames to *.fits. It examines the FITS header and classifies an image either as FLAT or OBJECT. The list of flats is written to flt.tmp and the list of objects is written to obj.tmp.

Type:

scanfits

Enter the CCD no: **4** (for Wright frame transfer CCD)

After `scanfits` has finished, you can inspect flt.tmp and obj.tmp. The next program to run is `cleen`. This first prepares normalized flat fields from the list of flats, one for each filter, and for each prebinning. These normalized flat field files are called `flatp01.fg` where `p`=prebinning (range 1-6), `f`=number of wheel A filter, `g`=number of wheel B filter. For example, flat301.67 is formed from flats taken with 3x3 prebinning, filter 6 in wheel A, filter 7 in wheel B. `Clean` then trims the edges, interpolates bad pixels, applies the flat field correction and writes the data out. Each object file, annnmmmm.fts, is written out to a file called cnnnmmmm.fits.

To invoke `cleen`, type:

cleen

Enter the CCD no: **4**

Delete the raw data files? (y/[n]) **n**

Jump straight to cleaning object frames? (y/[n]) **n**

If normalized flats are produced by `cleen`, which then subsequently crashes because of a problem with an object file, the last question may be answered y, in which case the normalized flat field construction step will be skipped.

The data are now cleaned, flat-fielded and ready for photometry.

4.2.2 Saoimage: Inspecting Images And Normalized Flats

Images may be inspected with saoimage. They must be in FITS format and be stored in files called *.fits (*.fts files will not be recognized).

startsaoimage to start saoimage

click on `etc` **&** `new` to load image

click on `Color` & ↖ / ↘ to alter brightness and contrast (hold down left button and move mouse around over the image)

click on `etc` **&** `QUIT` to stop saoimage

Exiting from saoimage gracefully is very important (trust me!).

Try not to kill it by Ctrl-C or destroying the window.

Normalized flats are *not* in FITS format but may be converted to FITS by

flt2fits

Binary filename? **flat301.67**

->Fits filename? **FF301.67.fits**

and then inspected with saoimage.

4.2.3 Creating The `windows` File

This is the file which tells `DuPHOT` where to search for objects of interest for photometry. It is quite possible, of course, to run `DuPHOT` without being in windowed mode. However, the Wright CCD has a thick, insensitive border which is not completely trimmed and/or flat-fielded satisfactorily. `DuPHOT` has a tendency to spend ages hunting for stars along the border. In addition, if the field is very crowded, `DuPHOT` can waste a lot of time measuring very faint stars which sometimes have enough signal, sometimes don't. It is best to ignore stars this faint. It is thus best to use a windows file. It *must* be called `windows`

Use saoimage to display a good quality, *cleaned* image. There are 2 options for the `windows` file:

- A single window which excludes a 5 pixel border around the edge
  (to prevent `DuPHOT` hunting endlessly for stars near the edges)
- Multiple windows containing positions of program and comparison stars

Use a text editor (e.g. `pico`, vi (see section 6.3)) to make the `windows` file. For the first option, enter a single line:

```
-1 5 5 0
```

This tells `DuPHOT` to ignore 5 pixels around the edges and search for objects in the rest of the field and perform photometry. Generally only OK for sparse fields, otherwise if there are many stars, particularly faint ones, these will be found and much cpu time spent on unnecessary computation. Note: stars whose "skirts" extend into the 5-pixel "no person's land" will not be adversely affected. These pixels *will* be included in the computations. The "no person's land" is excluded only from star searching.

For the second option, measure the coordinates with the saoimage mouse of all objects of interest, i.e. the program star itself plus comparisons star(s). Also estimate a suitable size for the window around each star. Typically, 10 pixels is a good size. However, this may need adjustment if there are nearby faint neighbours that you don't want `DuPHOT` to find. Because of differential flexure between autoguider and science CCD, stars can drift over a few hr so be generous with the window sizes if possible.

Enter the coordinates into the file windows. The format of coords is as follows:

```
0 x1 y1 b1
0 x2 y2 b2
0 x3 y3 b3
...
```

where

x1 is the x coord of the position of star 1

y1 is the y coord of the position of star 1

b1 is the size of the window around star 1 (full side)

For each star of interest (program and comparison), make a note of its peak brightness above the sky. You will need this information in setting suitable thresholds for `DuPHOT`.

4.2.4 Batchduphot: Preparing To Run `DuPHOT`

`DuPHOT` will be run in batch mode, taking the list of files to process from a file called duphot.bat. Associated with each file are 2 lines of parameters. Setting up the duphot.bat file is done by program batchduphot. A number of questions must be answered, the two most important of which are the specification of the thresholds:

- `Tmin` is the threshold (above sky) that the brightest pixel in a star image must attain to be considered for measurement

    set this too low and `DuPHOT` wastes time measuring faint stars

    set this too high and the stars you want will be omitted

- `Cmin` is the threshold (above sky) that the brightest pixel in a star image must attain to be used for PSF measurement

    set this too low and many faint stars will be used for the PSF,

        thereby degrading all the photometry

    set this too high and there may be no stars used for the PSF

Thus for stars whose peak pixel is brighter than Cmin, a 7-parameter fit is executed: (sky, x-centroid, y-centroid, intensity, σ_{x}^2, σ_{xy} and σ_{y}^2) where the σ's describe the shape of the PSF. These are set to be equal to the average of the parameters derived for all the individual stars with peak pixels brighter than Cmin.

For stars with peak pixels brighter than Tmin, but fainter than Cmin, a 4-parameter fit is executed with the σ's held fixed. The four parameters are: (sky, x-centroid, y-centroid, intensity).

It is thus advisable to give some attention to the specification of Tmin and Cmin. The precise values will depend on the CCD field, so no general recipe can be given.

After determining these values from measurement by saoimage, initiate `batchduphot` by:

batchduphot

and answer the following:

Are the data single filter <0> or multi-colour (1) ?

answer appropriately

Do you want diagnostic star classification info
to be output to file classifications ? (y/[n])

assists with diagnostics. Non-experts answer **n**

Do you want to specify min threshold ? (y/[n])

Tmin is the threshold (above sky) below which no star will be measured

See above discussion

Do you want "windowed" mode ? ([y]/n)

Answer **y** unless you know what you are doing

If you answer y, file windows must exist in current sub-directory

Do you want "crowded field" mode ? ([y]/n)

Answer **y**, even in uncrowded fields (don't ask why!)

Do you want to specify Cmin ? (y/[n])

Cmin is the threshold (above sky) for PSF stars.

See above discussion

Do you want to specify the aperture size ? (y/[n])

Answer **n** unless you want to use fixed-size aperture photometry in specialized circumstances

Batchduphot will scan the directory for *.fits files and make up a duphot.bat file containing this list with 2 parameter records for each file.

4.2.5 Running DuPHOT

Run DuPHOT by

duphot

Number of CCD? **4**	(for Wright CCD)
Screen output (y/[n])? **n**	(minimal screen chatter)
Batch mode ([y]/n)? **y**	(input from duphot.bat)

For each frame, cnnnmmmm.fits, a "sum" file, sum.nnnmmmm, is produced containing the results of DuPHOT's computations.

The sum file contains useful header information (object name, filter, times etc.). More importantly, for each measured star on the frame, records in the following format are written:

N	T	Sky	X	Y	Int	Sig2x	Sigxy	Sig2y	StrAp
1	1	5.15	135.94	59.13	146.82	11.9052	-0.0191	7.0057	1.4965E+04
2	1	5.26	115.93	45.79	82.60	11.9052	-0.0191	7.0057	8.8323E+03
3	4	4.76	93.76	124.17	53.22	11.9052	-0.0191	7.0057	5.2338E+03
4	7	3.89	284.47	233.93	32.93	11.9052	-0.0191	7.0057	3.3360E+03
5	7	4.81	108.53	141.46	14.22	11.9052	-0.0191	7.0057	1.4862E+03
6	7	4.78	56.47	57.87	6.72	11.9052	-0.0191	7.0057	7.0688E+02

Additional parameters appear at the end of each line but these are not significant for the present. The above numbers should be interpreted as follows:

- N is the star number
- T is the type

  1 indicates a PSF star

  7 indicates a non-PSF star

  3 indicates a component of a double star

  2 indicates an extended object

  4 indicates a non-converged fit

  8 indicates a cosmic ray

  Only objects classified type 1, 7 or 3 may be used
- Sky is the sky background used in the PSF fit
- X, Y are the centroids of the PSF
- Int is the height of the PSF (gives PSF mag)
- Sig2x, Sigxy, Sig2y are σ_x^2, σ_{xy} and σ_y^2 describing the PSF
- StrAp is the no. of ADU in the aperture (gives aperture mag)

Check that the program star and comparison stars appear in the *first* sum file. *If they don't, they will never be used in subsequent processing.* The next steps are:

1. Merge the "sum" files to produce a file called `datin.dat`. This will contain a light curve for each star.
2. Plot these light curves to select comparison stars.
3. Perform differential photometry of the program star with respect to the comparison stars.
4. Plot the final light curve.

These steps are described in section 4.4. Skip now to that section.

4.3 Online Data Reduction

Online data reduction evolved from offline data reduction. It is recommended that you read section 4.2 before continuing as repeated reference to the information in it will be made.

4.3.1 Preparing the Flat Fields

The first step is to prepare suitable summed, normalized flat fields. You may choose to use all flats so far accumulated, or make up flats on a night-by-night basis. See the discussion in section 4.2.1. In either case, a separate directory is needed. Thus:

mkdir flat_n# (where # is the night number)

or

mkdir flats

Copy the appropriate flat field frames into this directory. Now run `scanfits` and `cleen` as described in section 4.2.1. The result will be for each filter, and for each prebinning, a summed normalized flat field with name flatp01.`fg` as described in that section.

4.3.2 Setting Up The Reductions Sub-Directory

It is crucial that you do NOT do on-line reductions in the `\image` *sub-directory.* You will erase raw data files if you do. Make a sub-directory of the `\image` sub-directory called night1 (for night 1) or 211 (for run 211) or whatever is suitable. Copy the appropriate prepared flat field(s) into this directory.

Make up a suitable `windows` file as described in section 4.2.3 and ensure it is also in this sub-directory.

4.3.3 Running `reduce`

Check that:

1. the working directory is a subdirectory of `image`, otherwise `reduce` just stalls at the first file (and doesn't tell you!!).
2. the working directory must contain a `windows` file and the appropriate flat field file.

To start the reductions, type

reduce

Questions similar to those asked in section 4.2.4 must be answered:

Enter the directory where the raw data is
The default is: **/data/image/** (correct for Pentiums)

/usr1/user1/image/ (on SAAO SUNs)

NB: the directory name *must be terminated* by a "/" as shown

Enter the run number (1-999)

401 (e.g. for the first object on night 4)

Enter the starting frame number (1-9999) <1>

Press **Enter** if 1 is correct

Number of CCD?

4 (for Wright CCD)

Are the data single filter <0> or multi-colour (1)?

0 (always 0 for HSP)

Enter the filter number (0-88)

67 (e.g. for filter 6 wheel A and filter 7 wheel B)

Enter the flat field file name <flat101.67>

flat301.67 (3x3 prebin). Note: default only applies if no prebinning

Do you want to specify min threshold ? (y/[n])

Tmin is the threshold (above sky) below which no star will be measured.

Default usually produces too many useless faint stars, so should answer y.

See discussion in section 4.2.4 - if answer y, then:

Enter min threshold:

50 (for example)

Do you want "windowed" mode? ([y]/n)

Use default unless you know what you are doing

If you answer y, file windows must exist in current sub-directory

Do you want "crowded field" mode ? ([y]/n)

Answer **y**, even in uncrowded fields (don't ask why!)

Do you want to specify Cmin? (y/[n])

Cmin is the threshold (above sky) for PSF stars.

Consult discussion in section 4.2.4. Should answer y. If so:

Enter Cmin:

100 (for example)

Do you want to specify the aperture size ? (y/[n])

If you have only 1 star on frame, fixed aperture photometry is all you can do.

Otherwise let `DuPHOT` use it's variable aperture scheme so answer n

`reduce` will then begin to process the images, producing, for each file cnnnmmmm.fits, a "sum" file, sum.nnnmmmm, containing the results of the computations. `reduce` performs `scanfits`, `cleen` and `DuPHOT` on the images and gives its current status. Consult section 4.2.5 for information about the contents of the "sum" files. To check that the required stars are being processed properly, examine field T in the sum files. It should be either 1 (a PSF star with peak counts $>$ Cmin), 7 (Tmin $<$ peak counts $<$ Cmin) or, rarely, 3 (a component of a double).

`DuPHOT` gives timing info on the processes it is doing (in file `timing`).

4.3.4 Trouble-shooting

1. If `reduce` stalls at first image, then it can't find it, so check that the directory name was entered correctly.
2. Sometimes, it will spend far too long `DuPHOT`ing a file, so if you want to get it moving again use CTRL-C in the window, and it will move on to the next image.

   (N.B. you **must** then delete the corresponding sum file otherwise

   the merging program will crash!!)
3. `reduce` never terminates of its own accord at the end. i.e. the process continues awaiting the next file for ever. Therefore, terminate manually with CTRL-C once last image has been processed.
4. **Stopping and restarting `reduce` part way through**

   CTRL-C will NOT work, as it only generally kills the current `DuPHOT`

   subprocess, with `reduce` moving on to the next frame. Instead:

   ps -a produces a list of the current processes and PID numbers (e.g. 34278).

   kill -9 34278 i.e. the PID number for `reduce`. Then:

   ps -a again, to identify the zombie `DuPHOT` process left running (e.g. 67253).

   kill -9 67253 completes the job.

   If you hold your finger on CTRL-C, that sometimes works.

   Never use CTRL-Z as that merely suspends the process.

   Note: if you have more than one `reduce` running at a time it is worth making a note at the outset of the PID number so that you know which one to kill if need be. Also to identify the `DuPHOT` process that needs to be killed, just use `ps -a` twice with a good gap, so that the non-changing `DuPHOT` PID can be identified.

4.4 Post-DuPHOT Processing

4.4.1 Mergesum

This program merges all the "sum" files produced by `DuPHOT` so as to create a single file, `datin.dat`, with all the results of the photometry. Type

mergesum

Field name (c/r to ignore)?

Press **Enter**. Otherwise an empty `datin.dat` file is produced

Filter number? (0 to ignore)

Press **Enter** unless multiple filters used

The program then runs through all the sum files, finishing with:

```
Creating datin.dat
```

if all is successful. Notes and problems:

1. mergesum can be run whilst images are being processed. It may crash because:
   (a) During the `DuPHOT` processing, images may have been skipped using the CTRL C option. Fix by deleting the corresponding sum file.

(b) mergesum sometimes crashes right at the end if you are still processing. No fix except to try again.

2. Here is a sample of the `datin.dat`. For each star:

```
star no    xpos        ypos
     HJD     frame no   PSF mag   Ap mag     error      counts   HWHM

    1     97.72      42.00
2450254.21308    1    12.3839   12.4964    0.0024     76107    1.05
2450254.21320    2    12.3711   12.4876    0.0025     76732    1.12
2450254.21331    3    12.3585   12.4889    0.0024     76634    1.17
2450254.21343    4    12.3890   12.4886    0.0028     76659    1.11
2450254.21355    5    12.3752   12.4966    0.0024     76096    1.11
etc.....
```

note: HWHM should not be much less than 1 for the object.

4.4.2 Plotting

On Pentiums:

is handled by `PGPLOT`. The DISPLAY variable must be set before any plotting can be done. Enter:

export DISPLAY=192.96.109.219:0 on s30

export DISPLAY=192.96.109.221:0 on s40

export DISPLAY=192.96.109.220:0 on s74

When plotting to a `PGPLOT` window is performed the first time, a graphics window will fill the screen and cause rising panic in you. How do you do anything when this screen filles the entire window? Select an adjacent virtual screen by pointing at the 3x3 "virtual screen icon" and clicking. The graphics window will spill into this adjacent virtual screen. Grab its edge and haul it half into the window. Then reduce its size (using the corner) until manageable. All screen graphics will henceforth appear in this window.

On SUNs:

All plotting *must* originate from an `xterm` window (otherwise gobbledegook appears on the screen). Type:

xterm

and make this the active window.

To plot the light curves in `datin.dat`:

plotmag n

where n = blank or 0: plot PSF mags only

= 1: plot aperture mags only

= 2: plot both PSF and aperture mags

The following information must be provided:

Enter the input file <datin.dat>

Press **Enter**. Output is:

```
Reading star   1   x=  331.6   y=   92.4   Ave      9.4
Reading star   2   x=  272.9   y=   78.4   Ave     11.2
Reading star   3   x=   72.0   y=   69.4   Ave     13.2
...
```

From this listing (which includes coords), the target and comparisons can be identified.

Plot all the stars ([y]/n)?

y if only a few stars in `datin.dat`

n if too many stars in `datin.dat`. If so:

How many stars do you want to plot?

5 (5–10 is a good number)

Enter their numbers

1 2 4 7 9 (for example)

Enter vertical axis range [0.5 mag]

0.5 (0.5-1.0 mag often good for starters)

Plot with nice x-scale <0> or fill x-axis (1)
or allow multiple panels for each star (2)

1 filling x-axis best at this stage

A Tektronix window then opens with the plot. An option to replot with different scale and axis choice appears at end of plotting. To return to xterm, use $\diamond q$ (with cursor in window) to kill it.

4.4.3 Differential Photometry

Having chosen comparison star(s) for differential photometry, type:

diffphot

which will ask for choice of comparisons (how many, and their ID numbers):

How many comparison stars are there ?

2 (for example)

Enter their numbers

1 3

The differential light curve data are written to a file named `answer.dat`. `plotmag` can be used to plot the curves once more, simply by inputting `answer.dat` instead of `datin.dat` when asked for the input file.

Chapter 5

Data Archiving

5.1 Overview

The data are written to Digital Audio Tape (DAT) using the Unix `tar` (tape archive) command. The `tar` command writes all files in the working directory to a "saveset" or tarfile on the DAT. The DAT will be written with an initial end-of-file (EOF) mark so that it is structured as follows:

```
|EOF| Saveset 1 |EOF| Saveset 2 |EOF| Saveset 3 |EOF| ... etc.
```

It is up to you to ensure that you do not overwrite existing data so carry out DAT writing when you are sober, not exhausted and alone (you need to concentrate fully). It should be clear that to write the `n`th saveset to a DAT, you need to skip the previous n-1 savesets. This can be accomplished with the `mt` utility. This will also rewind the DAT, write the initial EOF mark etc.

Unix treats the DAT, as it does with all other peripherals, as a file. The file is actually a device driver. For the Pentiums, the default device driver is fine; you do not need to supply one. For the SUNs, the device driver to use is /dev/nrst4. The n in nrst4 is *very* important as it causes the DAT *not* to be rewound after each operation. Be careful to type this name very accurately. All SUN `mt` and `tar` commands will use this device driver as in the following tables of possible operations:

```
Tape Position Operations With mt:

On Pentiums   On SUNS

mt rewind     mt -f /dev/nrst4 rew      rewinds DAT
mt eof 1      mt -f /dev/nrst4 eof 1    writes an EOF mark to the tape
mt eof n      mt -f /dev/nrst4 eof n    writes n EOF marks to the tape
mt fsf 1      mt -f /dev/nrst4 fsf 1    skips over the next EOF mark on tape
mt fsf n      mt -f /dev/nrst4 fsf n    skips over the next n EOF marks on tape


Pentium Tape Writing Operations With tar:

tar -cv .                  writes current directory and sub-directories
                           to saveset at current tape position

tar -xv                    reads saveset from DAT and writes to current
                           directory

tar -tv                    reads and lists contents of saveset from DAT
                           (but does not write to disk)
```

```
SUN Tape Writing Operations With tar:

tar -cvf /dev/nrst4 .      writes current directory and sub-directories
                           to saveset at current tape position

tar -xvf /dev/nrst4        reads saveset from DAT and writes to current
                           directory

tar -tvf /dev/nrst4        reads and lists contents of saveset from DAT
                           (but does not write to disk)
```

The v option indicates "verbose" so the tar command lists details of what it is doing. The c option indicates write to the DAT. The x option indicates read from the DAT. The t option indicates list table of contents. The f option on the SUN instructions indicates that the next string contains the device driver.

Now study the next section to see how the `mt` and `tar` commands are combined to write, read and list DATs.

5.2 Recipes

- Either write the original .fts files or use `scanfits` to change the file names from *.fts to *.fits.
- Move all files into a single directory and make that the working directory.
- Load tape into the workstation's DAT drive.
- To initialise tape:

```
Pentium version      SUN version

mt rewind            mt -f /dev/nrst4 rew
mt eof 1             mt -f /dev/nrst4 eof 1
```

- To write from the current directory to the tape for the first time:

```
Pentium version      SUN version

mt rewind            mt -f /dev/nrst4 rew
mt fsf 1             mt -f /dev/nrst4 fsf 1
tar -cv .            tar -cvf /dev/nrst4 .
```

- To write from the current directory to the `nth` saveset:

```
Pentium version      SUN version

mt rewind            mt -f /dev/nrst4 rew
mt fsf n             mt -f /dev/nrst4 fsf n
tar -cv .            tar -cvf /dev/nrst4 .
```

- To read back the `nth` saveset to the current directory:

```
Pentium version      SUN version

mt rewind            mt -f /dev/nrst4 rew
mt fsf n             mt -f /dev/nrst4 fsf n
tar -xv              tar -xvf /dev/nrst4    (note: no . or target specification)
```

- To list the contents of the `nth` saveset:

```
Pentium version       SUN version

mt rewind             mt -f /dev/nrst4 rew
mt fsf n              mt -f /dev/nrst4 fsf n
tar -tv               tar -tvf /dev/nrst4
```

- To write the `nth` and `n+1th` savesets:

```
Pentium version       SUN version

mt rewind             mt -f /dev/nrst4 rew
mt fsf n              mt -f /dev/nrst4 fsf n
cd nthdir             cd nthdir
tar -cv .             tar -cvf /dev/nrst4 .
cd n+1thdir           cd n+1thdir
tar -cv .             tar -cvf /dev/nrst4 .

where nthdir and n+1thdir contain data for the respective saveset
```

  i.e. you don't have to rewind between two consecutive savesets

You are urged to list the contents of all (or at least some) of your savesets to check the DAT is written the way you think it is.

Chapter 6

Reference Information

6.1 UCT CCD Performance

The CCD is a thinned, back-illuminated EEV CCD giving good UV sensitivity. The CCD is Peltier-cooled (making for very straightforward operation) to approx -50 Celsius, yielding typical dark count rates of ~ 0.05 e$^-$/pix/sec. With read-out noise of 10 e$^-$/pix this implies total noise of 14 e$^-$/pix for a 1000 sec exposure. Dark count can be ignored for short exposures in frame transfer mode (1-30 s). There are two gain settings:-

- **Gain 1** which gives 10 e$^-$/ADU, useful for bright objects
- **Gain 4** which gives 2.5 e$^-$/ADU, better for faint targets

The Analog-Digital Converter (ADC) saturates at 32,768 ADU and the CCD saturates at $\sim$250,000 e$^-$).

Table 1: CCD Properties

No of pixels	576x420
Pixel size	22μ
Dark current	~ 0.05 e$^-$/pix/sec
Readout noise	10 e$^-$/pix
Gain	1 = 10 e$^-$/ADU
	4 = 2.5 e$^-$/ADU
ADC Max	32768 ADU (16 bit)
CCD saturates	$\sim$ 250000 e$^-$

Table 2: CCD Format

	74"	40"	30"
Plate scale (μ/arcsec)	166	77	59
22μ pixel size (arcsec)	0.13	0.28	0.37
1" Seeing Pre-binning	3x3	2x2	1x1
Number of pixels	127x87	190x130	380x260
Read-out time (sec)	1	2	7
Field of view (arcsec)	50x34	109x74	142x97

Table 3: CCD count rate in phot/sec for star with $V = 18$, $B - V = 0$ on 40"

U	B	V	R	I
7	76	105	91	41

The CCD has 576x420x22 micron pixels. Frame transfer operation requires half of the CCD to be masked (can be removed in daytime if necessary). This, combined with the unthinned and therefore insensitive "bathtub edge", gives a usable data frame of 380x260 pixels (or 127x87 with 3x3 prebinning). The corresponding sky coverage is given in the tables. The minimum read-out times (in frame transfer mode) are also given in the tables. The minimum exposure times in High Speed Photometry mode, where there is *no* dead time between exposures, is just slightly longer than this (add 0.5 sec).

With typical good seeing of 1 arcsec, and with the various plate scales at the different telescopes, you should prebin the CCD by the amounts specified in the tables. In bad seeing, more prebinning is required. The maximum permitted is 6x6.

The sensitivity is given in the last table. For Johnson broadband filters, the count rate in photons/second for a star with $V = 18$ and $B - V = 0$ is given. Scaling by the aperture will yield count rates for the other telescopes. Note that count rates depend on the state of the mirrors, atmospheric extinction etc. and cannot be precisely predicted.

The device is mounted on a simple turntable so the orientation can easily be changed.

6.2 Useful `Unix` Commands

cp file1 file2	Copy file1 to file2
mv file1 file2	Rename file1 to file2
mv ff* dirname	Move files ff* to directory dirname
	(There is no rename *.fts to *.fits, for example)
cd	Change to log in director
cd -	Change to directory you just came from
cd dirname	Change to directory dirname
mkdir dirname	Make a sub-directory of the current directory called dirname
rmdir dirname	Remove sub-directory dirname (only if it's empty)
rm filename	Delete file called filename
rm file*	Delete all files called file* from current diretory
rm *	Delete all files from current directory (dangerous!)
rm -r *	Delete all files in current directory as well as sub-directories (very dangerous!)
ls	Lists files in current directory
ls -l	Long listing
ls dirname	Lists files in directory dirname
ls -a	Shows hidden files too
pwd	Prints current (working) directory name
df -k	Shows system file structure and capacity

NB: The use of `*` in file specifications in `Unix` commands causes the operating system to match the list of files immediately and substitute them on the command line. Where a directory has ~ 1800 files matching the pattern, the command line then becomes too long. Sorry! You'll have to work around it.

6.3 `vi` Quick Summary

If you do not hate vi, you either have had to learn it and grown to like it, or you are weird. Nonetheless, vi is available on every Unix system and you favourite editor may not be. Here's a quick tutorial.

Start vi with:

vi filename	filename=file to be edited

You will then be in "command" mode. Wherever you are, you can return to command mode by pressing `Esc`. Pressing `Esc` while in command mode will just cause a beep. No harm can be done by pressing `Esc`. When in doubt, press `Esc`.

A number of commands cause vi to leave "command" mode and enter "input/replace" mode. Keystrokes will then be interpreted as text to input into the file being edited (or as replacement for existing text). This mode is exited, and command mode resumed, with the `Esc` key.

i	Enter input mode. Subsequent keystrokes entered as text
o	Open a line below the current one and enter input mode
O	Open a line above the current one and enter input mode
a	Append text after the cursor position
A	Append text from end of current line
R	Enter replace mode: keystrokes replace existing text

In command mode, the arrow keys will move you around the file. The most useful commands are:

Cntrl-F	Move down one screen
Cntrl-B	Move up one screen
0	Move to the beginning of the current line
$	Move to the end of the current line
x	Delete the character underneath the cursor
dd	Delete the current line
5dd	Delete 5 lines including the current one
yy	Yank (copy) the current line into a temporary buffer
5yy	Yank 5 lines (incl the current) into the temporary buffer
p	Copy the temporary buffer after the cursor position
P	Copy the temporary buffer before the cursor position
/abcdef	Search forward for string abcdef
?abcdef	Search backward for string abcdef
J	Join next line to current line
u	Undo the last change made in the current line
ZZ	Save and quit
:wq	Write out the file and quit (i.e. same as ZZ)
:q!	Quit (without save)
:n	Go to line n
:0	Go to top of file
:$	Go to bottom of file
:s/str1/str2/	Substitute character string str1 for str2 in current line
:s/str1/str2/g	Substitute all occurrences of str1 for str2 in current line
:%s/str1/str2/	Substitute str1 for str2 in all lines
:%s/str1/str2/g	Substitute all occurrences of str1 for str2 in file
:.,.+3s/str1/str2/	Substitute str1 for str2 in current + next 3 lines
:r file	Read in contents of file to current position

Chapter 7

Technical Information

7.1 Overview

The UCT CCD comprises:

1. A Wright Instruments Pelter-cooled CCD. This is stored in an aluminium case. Individual sub-components are:

   Wright Instruments camera head

   Wright Instruments electronics box (which should be permanently connected to the camera head) to control the camera

   Wright Instruments Interface card for PC expansion slot

2. A Filter Control Unit, designed by D. Carter and built by an SAAO summer student. This can control any of the SAAO filter boxes.

3. A turntable, designed by D. Ellis and built at SAAO.

4. A PC running DOS.

The camera must be attached to its turntable and mounted on one of the SAAO filter boxes (40", 74" or 30"). The electronics box and filter control box are also mounted on the telescope.

The PC controls:

- The CCD, via a coax cable from the Wright interface card to the electronics box. Data and status are sent to the PC via this signal cable.
- The filters, by means of a cable from its printer port to the SAAO filter control unit.

The PC has limited storage capability so it must be connected to a Unix workstation with a large disk on which the data will be dumped, where the data will be reduced and written to DAT. Initially the workstation was the UCT SUN. Connection to SAAO SUNs followed. Now the default is one of the Linux Pentium PC workstations: s30, s40 or s74. SUN support is more or less finished.

The PC may be connected to the Unix workstation via the Sutherland network. Software called XFS runs in the PC to allow it to access directly the workstation disk for remote storage.

7.2 Firing Up The System

After the camera is attached to the telescope and all cables connected, the system may be tested. Thus:

1. Turn the workstation on first as it needs to be operating when the PC starts up. Ensure both are connected to the Sutherland network.

2. Switch on (or reboot) the PC. Select which workstation to connect to:

   saao2 = sun40 (usually in the 40")

   saao1 = sun74 (usually in the 74")

   s30 (30" Pentium)

   s40 (40" Pentium)

   s74 (74" Pentium)

3. XFS should then connect to the workstation. It complains if it doesn't. Disconnect the system from the Sutherland network (or before handing the instrument over to the observer).

4. Make a directory on the PC called, say, `diag` (this may, of course, already exist):

   mkdir diag

   cd diag

5. Start the data acquisition program by typing **wrmwind**. Choose run number 0. If there is no set000.up file, questions will be asked. Accept defaults for filter specifications.

A note about how the PC-workstation linking is done:

The PC connects to the Pentium now (1999 November) using the XFS network file system client software. Before the PC starts the link, it must know which machine to connect to. This is determined when the user answers the question asked by the program datadisk.exe which is run from the autoexec.bat file. Depending on the answer, datadisk.exe (the source code is in datadisk.c in \wrmed) copies either xfs_s30.bat, xfs_s40.bat or xfs_74.bat, which are stored in the \xfs directory, to xfs in the root directory. The last line in the autoexec.bat file executes the file xfs.bat.

You can now perform some simple checks on the system:

- Check that the filter wheel(s) initialized ok. Re-initialize, if necessary, with **F** (to get filter sub-menu) and then **I** to initialize. (Hereafter abbreviated to **FI**). Move the filter wheels by pressing **F**, choosing the wheel and the new position to move it to.

- Take a test exposure (**C6**) and inspect the display to check it looks ok (aligned and not distorted). Put the camera into frame transfer mode (**C3**) and repeat. The illuminated section will be at the top of the display. If the image is too dim, increase the exposure time or the light levels in the dome.

- Test writing to the workstation by selecting the workstation's disk with **DH**. Then simply save what's just been read out with **DS**; while writing is taking place the XFS button in the top right corner of the PC's main (menu) screen will flash. After it has finished, delete any files you wrote with **DC**, answering appropriately.

- When the camera is started, the chip is too hot and `wrmwind` will say so in the top right status box. The camera takes ~10-15 min to cool to operating temperature. The status box is only updated when a menu sequence is completed or `Esc` is pressed. Press `Esc` to check the chip has cooled after the appropriate time.

- Once the CCD is cool, clear (prepare) the chip with **C5** and then immediately read out with **C1**. A Bias frame will be read out. Check that `Num Lock` on the keyboard is off. Then get the cursor displayed with **IM**. Move it into the middle of the image. Press `Ins` (won't work if `Num Lock` is on). The statistics should show the standard deviation of pixels in the green circle. Check this is smaller than 4 (with gain of 2.5 e^-/ADU, 4 ADU = 10 e^-, the nominal readout noise). Finish the **IM** command with q.

- Check the frame transfer mask is reasonably square: put the bright lights on in the dome and take a 1-s exposure. The thick and thus insensitive border of the chip will be obvious. This should not be skew or looking like a parallelogram (though one vertical border is not dead straight). If so, refer to the next subsection on the frame transfer mask.
- If you are really enthusiastic, you can test the dark current. Press **PD** and enter the exposure time. This must be at least 1000 and preferably 2000–3000 sec. At the end of the exposure, use **IM** as you did for the readout noise test. In a 1000 sec exposure, the *mean* value of the counts (with the bias removed) in the circle should be ~20. With gain of 2.5 e^-/ADU, 20 ADU = 50 e^-, or 0.05 e^-/pix/sec, the nominal dark current rate. There will be a few hot pixels around the chip so avoid these when making the measurement.

7.3 Information For The Observer: Filters & Frame Transfer Mask

The UCT CCD can use either the 40" filter box, the 74" filter box (both with 2 wheels each) or a single wheel box for the 30". The single wheel box on the 30" is wired as a filter wheel B.

Earlier in the manual, the observers are asked to check that they know what is in the filter wheels. The 40" usually has a stable filter setup, but at the time of writing (1999 November), only one set of filters is being shared between the 74" and 30" boxes. In the recent past, observers have been in the position of thinking that the filters they wanted were in wheel A (when they were in wheel B), or that the ordering was UBVRI in positions 1-5 (whereas it was BVRIU). The only solution is to show them (or tell them if they will believe you) what is the wheels. Be prepared, therefore, to take the filter wheels out of the filter boxes to show the observers.

Additionally, they may ask whether the frame transfer mask is in position. This is easily determined by taking a test exposure in full frame mode (toggle off frame transfer mode with **C3**) and verifying that half the image is dark, and the other half is much brighter.

The mask is occasionally taken off and may not have been put back on, or it may be slightly skew (as judged from a skew border in bright images). If it is screwed down too tight, the shutter may not open or it may not open fully. You will see something cutting across the image. Another fault that has occurred is that it is orientated the wrong way. In this case you will get very little or no light as the mask is in front of the image section of the chip and the store section is getting all the light. But this section is swept clean by the frame transfer operation.

The mask is like a 50-cent piece with a small rectangle cut out of one half. It screws down the C-mount and sits just above the shutter which is itself just above the window into the ccd chamber. Thus the camera head must be taken off to access it so put the camera head on a table under the telescope. The frame transfer mask has two notches in its edge, into which a simple tool can be inserted to enable you to screw it down into the threaded C-mount socket. The technique is to screw it gently in until you feel it touch the shutter. Then back it off a turn. If you don't back it off, the shutter won't open (fully). There is a locking ring which also screws down in a similar manner.

The orientation of the mask is important: the long axis of the chip intersects the side with the signal cable connector. In addition, the mask must be the correct orientation which, at the time of writing, I don't know. Take a test image in full frame mode before putting it back on the telescope.

7.4 Faults

7.4.1 CCD performance faults

The CCD is housed in an evacuated cryostat that cannot be pumped or otherwise opened up, except by Wright Instruments. In addition, the electronics box has no associated circuit diagrams or other information. Fault finding CCD problems can only be diagnosis of the problem. DOD should be contacted and he will in turn contact Wright to see whether anything can be done here, or whether the camera must be returned for repair.

The first step in diagnosing a CCD problem is to carry out the readout noise and dark current tests listed above. In addition, there is a status word that the electronics box returns. A command in the CCD sub-menu which I can't remember right now (press **C** and look near the bottom of the list) then informs you:

1. If the fan that cools the hot end of the Peltier is on/off
2. If the Peltier cooler is on or off
3. If the CCD temp is > 1 K above or below the set value
4. If the shutter is open/closed
5. If a power supply has had a (momentary) dip

7.4.2 Filter wheel and other faults

Occasionally the filter wheels timeout before they reach their destination. A quick and dirty fix for this is to increase the timeout time. This is usually set to 4 sec (4000 msec) and is contained in the setup file that goes with each run. Thus, ask the observer which directory they are working in, and what their current run number is. Go into that directory and edit a file called setnnn.up. The timeouts will appear as 4000, one for each wheel. Increase this and exercise the filters vigourously.

Chapter 8

Wizard Summary Sheet

This summary is designed only for Pentium workstations. For SUN info, refer to the full manual (which is now containing minimal information for SUNs).

8.1 First Afternoon Procedures And Checks

- Ensure you know what is in filter wheel(s). Don't believe defaults.
- Check with technician that mask is installed for frame transfer mode
- Select CCD orientation. Brass knob on turntable releases.
- Log on to workstation (username **ccd**, password **Saaoccd**).
  Clean up the `/image` sub-directory /data/image
- On PC: **mkdir subdir** (e.g. pac)   **cd subdir**
- **wrmwind**   choose 0 or 999 for RUN number. Answer setup questions. Don't believe filter defaults.
- Check filter wheels working properly
- Check CCD operation (BIAS:**PB**, DARK levels:**PD**)
- Check PC link to workstation by saving test images (**DH** and **DS**)

8.2 PC Operations

Filter	to initialise and move filter wheels
Program	to execute observing programs (including bias and dark)
CCD	for controlling the CCD (snapshots, gain, pre-binning, frame transfer, HSP mode)
Image	to control the image display monitor, do quick photometry, fit gaussian to stellar profiles
Disk	to save and get images from disk, change next file number, select storage on Data Acquisition PC or workstati
Utilities	to change Run number and Exposure time
Exit	

N.B. all menu items can be selected by positioning cursor with the arrow keys or by typing the highlighted keys

8.3 Observing Cookbook

- Controlling CCD

  C5 prepares or sweeps chip clean

  C8 starts an exposure (**C6** = **C5** + **C8**)

  C3 turns on frame transfer

  C4 starts an HSP run

  CC toggles prebinning: (3x3) on 74", (2x2) on 40"

  C7 sets gain (choose 4 for faint stars, 1 for bright stars)

  CA sets read-out speed (choose `Lo` for lowest noise)

- Observing Programs

  P rtn (or **PR**) to execute program

  PE to enter program for 1st time (always choose `yes` for **prepare** question)

  PA to alter existing program

  PW to tweak existing program (multiply exposure times by factor, toggle disk writing on/off)

  PS to stop a repeating program

  PB to execute BIAS frame

  PD to execute DARK frame

  - Recommend creating program for complete set of filters for standard star observations

  - Recommend creating program for BVRI flat fields (do U separately).

- Image Display and Manipulation

  II to set LUT

  IM to measure counts in circle (position cursor and press INS)

  To get sky subtracted counts, cursor on sky, press s, cursor on star, press INS

  IF to fit gaussian to star (position cursor and press INS)

  press q/Q to exit **IM** or **IF** (must do so before end of current integration!)

  NB: INS key will not work if `Num Lock` on

  F1, F2 change cursor movement speed

  IC to change radius of measurement circle

- Choosing Run Number and Disk

  Use run number 0, or `n` for night `n`, for general purpose files

  (e.g. BIAS, FF, standard stars, single CCD images of targets).

  Select storage of data on workstation (**DH**)

  Use sequential run number, or `n0m` for `m`th HSP target of night `n`, for each separate HSP run

  (e.g. 2nd HSP target on 3rd night would be run number 302)

  Individual images stored in `annnmmmm.fts`, where `nnn` is the run number, `mmmm` is the frame number

  Run number can be changed in Utilities sub-menu

- Flat Fields

  - Approx 30 mins after sunset

  - Set Gain to 1 (**C7**)

  - Do in order BVRI wl (sunset), wl IRVB (sunrise) (wl=no filter)

- Aim for 20,000-25,000ADU (check level with **IM**)
- Repeat key FFs (e.g. wl) to reduce photon noise and ease cosmic ray removal
- Always use the characters `fl` or `FL` in object name (e.g. vflat)
- Remember, sky decreases (increases) by factor 2 in 3 mins.

- Focus
  - 9th-10th mag standard stars on 30” & 40”, fainter field stars on 74”
  - Ignore CCD focus command (**CB**), quicker to do single readouts (**C6**).
  - Use 3-5 sec exposure times (to smooth out seeing). Use **IF** to measure image size.
  - Always set focus drive in same direction (to avoid backlash). Change setting in 3-4 unit steps.
  - There are small differences (1-2 units) between filter and wl focus positions.
  - Check regularly through night. Especially if temperature changes. There is NO focus tracking!

- Bias
  - Take at beginning and end of night (**PB**)
  - Check level with **IM**, which also gives readout noise
  - Discard biases with cosmic rays in them

- Standard Stars
  - Use E-region standards (Menzies et al list in Control Room).
  - Choose 9-10th mag stars if possible, otherwise defocus to prevent saturation.
  - Use standard star to mark position of CCD centre on A&G TV. Note position wrt CCD bad column.

- Normal Observing
  - Check level and position of target with 5-10s snapshot using **C6**
  - Alter program 2 with **PA** to desired settings
  - Start with **P rtn 2**
  - Don’t forget to enter target name (prompted before program starts)

- *HSP* Observing
  - Choose desired filter (and prebin) for run (cannot be changed in HSP mode).
  - Optimise target position wrt reference stars.
  - Enter HSP mode with **C4**.
  - Choose exposure time (usually 5-15s) and disk e: or f: for data.
  - Can adjust LUT in HSP mode using keys F1-F4.

    All other options are locked out during an HSP run!
  - Press ESC to finish HSP run.

8.4 UCT CCD Technical Information

Table 1: CCD Properties

No of pixels	576x420
Pixel size	22μ
Dark current	$\sim$ 0.05 e^-/pix/sec
Readout noise	10 e^-/pix
Gain	1 = 10 e^-/ADU
	4 = 2.5 e^-/ADU
ADC Max	32768 ADU (16 bit)
CCD saturates	$\sim$ 250000 e^-

Table 2: CCD Format

	74"	40"	30"
Plate scale (μ/arcsec)	166	77	59
22μ pixel size (arcsec)	0.13	0.28	0.37
1" Seeing Pre-binning	3x3	2x2	1x1
Number of pixels	127x87	190x130	380x260
Read-out time (sec)	1	2	7
Field of view (arcsec)	50x34	109x74	142x97

8.5 Online Data Reduction on Pentium Workstation (HSP mode)

Data is transferred from the PC into image directory on the Pentium workstation. **NB: Programs that used to be called `fitscan`, `clean` and `dophot` are now called `scanfits`, `cleen` and `duphot`.**

8.5.1 Preparing the Flat Fields

- **mkdir flats** or **mkdir flat_n#** (where # is the night number)
- **cd** to this directory and copy appropriate flat field frames into it
- **scanfits** (changes .fts to .fits, groups flats and objects)

  Enter the CCD no: **4** (for Wright CCD)
- **cleen** (prepares normalized FFs, trims, cleans and flatfields object frames)

  Enter the CCD no: **4**

  Delete the raw data files? (y/[n]) **n**

  Jump straight to cleaning object frames? (y/[n]) **n**
- Normalized flats, flatp01.`fg`, can be examined by:

  flt2fits

  Binary filename? **flat301.67** (for example)

  ->Fits filename? **FF301.67.fits**
- To display this and all other FITS images (which *must* have name *.fits):

  startsaoimage then click on `etc` and `new` to load image

8.5.2 Setting Up The Reductions Sub-Directory

Make sure you do reductions anywhere other than `image` *sub-directory.* Data will be lost if you use `image`.

- Make the `image` directory the working directory
- **mkdir nnn** (where `nnn` is the run number)
- **cd nnn**
- Copy appropriate normalized flats to this directory, e.g. **cp ../flats/flat301.67 .**
- Copy a good quality image from the current run to this directory, run `scanfits` and `cleen` as before, to produce a cleaned version of copied image, cnnnmmmm.fits
- Display the *cleaned* image with saoimage.
- Decide on kind of `windows` file. Section 4.2.3. Use vi, pico or other editor to make windows file:

Either	`-1 5 5 0`	for single window, 5 pixel in from CCD edge
Or	0 x1 y1 ib1	for each star
	0 x2 y2 ib2	etc.
where	xn, yn are star centroids, ibn is box size (on a side)	

8.5.3 Running `reduce`

Check that: (i) the working directory (e.g. /data/image/119) is **not** the `image` directory; (ii) the working directory contains a `windows` file and appropriate normalized FF files. Type

reduce and answer the following questions:

Enter the directory where the raw data is
The default is: **/data/image/**

NB: the directory name *must be terminated* by a "/" as shown

Enter the run number (1-999) **401** (for example)

Enter the starting frame number (1-9999) <1> **1**

Number of CCD? **4**

Are the data single filter <0> or multi-colour (1)? **0**

Enter the filter number (0-88) **67** (for example)

Enter the FF file name <flat101.67> **flat301.67** (for 3x3 pb, filter 67)

Do you want to specify min threshold ? (y/[n]) **y**

Enter min threshold: **50** (for example)

Do you want "windowed" mode? ([y]/n) **y**

Do you want "crowded field" mode? ([y]/n) **y**

Do you want to specify Cmin? (y/[n]) **y**

Enter Cmin: **100** (for example)

Do you want to specify the aperture size ? (y/[n]) **n**

To check that the required stars are being `reduced` properly, examine field T in the `sum` files. This must be either 1 (a PSF star with peak counts > Cmin), 7 (Tmin < peak counts < Cmin), or 3 (a double star).

8.5.4 Trouble-shooting

1. if `reduce` stalls at first image, it can't find it, so check the `image` directory name was entered correctly.
2. sometimes, it will spend far too long `DuPHOT`ing a file, to get it moving again use CTRL-C in the window, and it will skip on to the next image.

   (N.B. you **must** then delete the corresponding `sum` file otherwise the merging program will crash!!)
3. terminate `reduce` manually with CTRL-C once last image has been processed.
4. **Stopping and restarting `reduce` part way through**

   Never use **CTRL-Z** as that puts the process into the background

   CTRL-C will NOT generally work, as it will only skip the current frame. Instead:

ps -a	produces a list of the current processes and their PID numbers (e.g. 34278).
kill -9 34278	i.e. the PID number for `reduce`.
ps -a	to identify the zombie `DuPHOT` process left running (e.g. 67253).
kill -9 67253	completes the job.

   Note: if you have more than one `reduce` running at a time it is worth making a note at the outset of the PID number so that you know which one to kill if need be. Also to identify the `DuPHOT` process that needs to be killed, just use `ps -a` twice with a good gap, so that the non-changing `DuPHOT` PID can be identified.

8.6 Post-DuPHOT Processing

8.6.1 Mergesum

This program merges all the `sum` files to create a single file (`datin.dat`). Type

- **mergesum**

  Field name (c/r to ignore)? (Press Enter)

  Filter number? (0 to ignore) (Press Enter)

Notes and problems:

1. `mergesum` can be run whilst images are being `reduce`d. Occasionally it may crash because `DuPHOT`ing of an image was skipped (with CTRL-C). Delete the corresponding empty `sum` file.
2. `mergesum` sometimes crashes right at the end if you are still `reduce`-ing. Start `mergesum` when `reduce` is cleaning, not `DuPHOT`ing

note: HWHM, listed in last column of `datin.dat` should not be much less than 1. Otherwise reduce prebinning.

8.6.2 Plotting

Plotting is now handled by `PGPLOT`. When first graphics window pops up, go to neighbouring virtual window to resize its edges. The DISPLAY environment variable must be set.

- **export DISPLAY=192.96.109.nnn:0** nnn=219 on s30, 220 on s74, 221 on s40
- **plotmag n**

  where n = blank or 0: plot PSF mags only

  = 1: plot aperture mags only

  = 2: plot both PSF and aperture mags

  Enter the input file <datin.dat> (press Enter).

Plot all the stars ([y]/n)? If no:
How many stars do you want to plot? **5** (5–10 is a good number)
Enter their numbers **1 2 4 7 9** (for example)
Enter vertical axis range [0.2 mag] **0.5** (0.5-1.0 mag often good for starters)
Plot with nice x-scale <0> or fill x-axis (1)
or allow multiple panels for each star (2) **1**

Postscript files are called pgplot.ps

8.6.3 Differential Photometry

Having chosen comparison star(s) for differential photometry from plot, type:

- **diffphot**
  How many comparison stars are there ? **2** (for example)
  Enter their numbers **1 3**

The differential light curve data are written to a file named `answer.dat`. `plotmag` can be used to plot the curves once more, simply by inputting `answer.dat` instead of `datin.dat` when asked for the input file.

8.7 Data Archiving: Pentiums Workstations

- Either write the original .fts files or use `scanfits` to change to name .fits.
- Move all files into a single directory and **cd** to it.
- Load tape into the workstation's DAT drive.
- To initialise tape:

```
mt rewind
mt eof 2
```

- To write on tape first time:

```
mt rewind
mt fsf 1
tar -cv .
```

- To write the `nth` saveset:

```
mt rewind
mt fsf n
tar -cv .
```

- To read back the `nth` saveset to the current directory:

```
mt rewind
mt fsf n
tar -xv                    (note: no . or target specification)
```

- To list the contents of the `nth` saveset:

```
mt rewind
mt fsf n
tar -tv
```

- To write the nth and n+1th savesets:

```
mt rewind
mt fsf n
cd nthdir                   (where nthdir contains data for nth saveset)
tar -cv .
cd n+1thdir                 (where n+1thdir contains data for n+1th saveset)
tar -cv .
```

  i.e. you don't have to rewind between two consecutive savesets

It is *strongly* recommended that you list the contents of all (or at least some) of the savesets on the tape to ensure the DAT is written the way you think it is.