Draft 17 October 1997

OCAAS

The comprehensive

Observatory Control and Astronomical Analysis System

Reference Manual for Software Version 2.0

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1. Observatory Control and Astronomical Analysis System

1.1 Introduction

OCAAS is a complete UNIX software package for the local and remote operation of an astronomical observatory. It allows both real-time and unattended scheduled operation. It controls the telescope, CCD camera, filter wheel, focuser, dome and shutter. OCAAS also includes programs for off-line photometric and astrometric image analysis.

1.2 Main Control Features

1.2.1 Supports equatorial and altitude-azimuth mounts

The OCAAS allows the telescope axes to be arbitrarily oriented. Thus, equatorial, altitude-azimuth or any mount situation is acceptable. German equatorial mounts are also supported. Comprehensive automated calibration procedures will compute the orientation to a high precision. Note that if the orientation is other than equatorial, field rotation will occur during exposures. The OCAAS accommodates this by generating commands to operate a field rotation motor (which must be supplied).

1.2.2 Tracks planets, comets, asteroids, and Earth satellites

Ephemerides for all planets and the Moon are built in and match the precision of the *Astronomical Almanac.* Orbital elements for all current comets and all numbered asteroids are included and may be easily extended and updated. Earth satellites may be tracked, assuming very current orbital elements have been retrieved and the mount is capable of tracking rates on the order of degrees per second..

1.2.3 Unattended scheduled observing

A special language is provided for specifying details of an observation, such as filter, duration, object name or RA/Dec, offsets, special calibrations, repeat count and delays. Files of requests may be created using any text editor, with a Web page form, or with a GUI application. Collections of individual observing requests are then combined using a scheduling tool, *telsched,* into an optimum aggregate schedule which will be performed unattended throughout a night. All details of each observation are logged individually, in addition to a continuous log of all engineering data.

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1.2.4 Remote Internet or Phone operation

All control software is fully network-aware. Thus, real-time or batch scheduled operation can be performed and monitored using any viable network connection. Ethernet is preferable, but ISDN and PPP connections via modem are also supported. Note that dissemination of data via modem is not usually practical due to the very large data sets generated in a typical session.

1.2.5 Automated powerup and axes calibration sequencing

When power is first applied to the OCAAS, it automatically initiates a self-test and calibration sequence. Power-on self-tests include CPU, memory and all peripheral controllers. Then each axis is sent to find its home position to calibrate the motor step and encoder positions. When the procedures compete, in typically less than two minutes, the system is fully operational and, if batch observations are pending, observing resumes automatically.

1.2.6 Simple Basic-Alignment procedure

When the OCAAS is first installed at a new site, the telescope mount orientation must be determined. This is a simple procedure which requires only that three known stars be located in sequence. The operator is prompted during each step of this procedure which takes about 15 minutes to perform. This procedure need only be repeated if the telescope mount is disturbed.

1.2.7 Automated Fine-alignment procedure

Once Basic-Alignment has been completed, the telescope is quite capable of acquiring targets within a few arc minutes of accuracy. If this is acceptable no further alignment is necessary.

However, if acquisition accuracy approaching a few arc seconds is required a fine-alignment procedure may be performed. This procedure compensates for several systematic errors including mount flexure, axis misalignment, incorrect location and drive train eccentricity. The procedure schedules several hundred images to be taken which cover the sky in a fine mesh. This procedure can be scheduled using a single menu selection from the *telsched* batch preparation tool. Once these images have been acquired, they are calibrated to sub-arcsecond accuracy and are combined into a map of pointing errors which is then automatically utilized for all subsequent pointing operations. It usually

1.2.9 All images automatically corrected and WCS calibrated

As the OCAAS acquires each raw image from CCD camera, they are automatically corrected with the appropriate bias, thermal and flat frames. Cataloged reference frames may be used, or new bias and thermal frames may be generated specifically for each image. The details of this procedure are recorded in the FITS header. After corrections have been applied, stars throughout the field are identified and matched to the Hubble Guide Star Catalog to compute a best coordinate solution. The resulting coordinate system is recorded in the FITS header using the standard World Coordinate System FITS header keywords.

1.2.10 Field rotation control (required only for non-equatorial mounts)

Field rotation will occur during any extended exposure for any telescope mount whose polar axis is not aligned very well with the celestial pole. Once at least the basic-alignment procedure has been performed to determine the polar axis orientation, the OCAAS control software can compute the field rotation in real-time during each exposure. This operates a stepper motor attached to the camera to counter rotate and effectively removes the rotation effect from the exposure.

1.2.11 Dome, shutter and roof control

The OCAAS can read an incremental encoder attached to a dome, and use the information to control a bi-directional A/C motor to automatically maintain dome slit alignment with the current telescope pointing position. The OCAAS can also operate a motor to open and close a shutter curtain on the dome, and pre-rotate the dome to a fixed position each time if necessary to align power take-off wipers for the shutter motor power. Or, the shutter control can be used to activate a motor for roll off roof.

1.2.12 Lossless or Optimized image compression

As images are acquired, they can be automatically compressed to reduce data storage requirements. The compression can be lossless and will achieve approximately a 2:1 savings in space. Or a compression algorithm which is optimized for astronomical images can be specified which can achieve compression factors of 10:1 or more while preserving all quantitative photometric and astrometric characteristics of the images. The type and degree of compression can be specified separately for each observation.

1.2.13 Continuous Weather monitoring and logging

OCAAS will monitor local meteorological data on a continuous basis and automatically terminate further image acquisition and initiate shutter or roof closing immediately if preconfigured limits are reached. When these conditions no longer exist operation will automatically resume.
The OCAAS logs all meteorological data on a periodic basis. The meteorological conditions under which each image was taken are also stored in the FITS header.

1.3 Requirements

1.3.1 Pentium IBM-PC, such as Dell XPS 160 or 200

OCAAS software drivers are currently written for controllers which function in any PC hardware platform with at least two ISA slots. For best performance, computation and paging loads require at least a which can achieve compression factors of 10:1 or more while preserving all quantitative photometric and astrometric characteristics of the images. The type and degree of compression can be specified separately for each observation.

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1.3.2 Linux ELF 2.0.31 or newer, Moo-Tiff 2.0.1

All OCAAS software is written in ANSI C. GUI applications are written with the X Windows and Motif API libraries. The software does not use any user process features specific to Linux and should function on any UNIX system, with the exception of the low-level device drivers which have been optimized for Linux.

1.3.3 OMS PC-39-E6 Intelligent Stepper Motor ISA controller

The stepper motors and incremental encoders interface to the PC hardware using an intelligent controller built by Oregon Micro Systems. This controller is a full-width card for the ISA bus interface. This controller provides high level commands for such features as linear and cosine profile accelerations, home and limit switch logic, pulse generation and encoder pulse accumulators, and multiple axis control. The facilities of this controller are important for off-loading the time-critical pulse generation from the PC host.

1.3.4 Stepper motors on all axes

The OCAAS requires stepper motors to control all axes, including RA (or Az), Dec (or Alt), focus, filter wheel and, if necessary, field rotator.

1.3.5 Incremental encoders on major mount axes

OCAAS requires incremental shaft encoders on the RA (or Az) and Dec (or Alt) axes. This assures accurate slewing acquisition should modest drive slippage occur. The encoders are also used during tracking to refine the ideal velocities if small slippage occurs.

1.3.6 Limit switches on all axes

Limit switches are required on all axes. These should be set to protect the mechanical and safety aspects of the equipment and installation. The limit switches are also used during the initial power up sequence if the telescope was not stowed before loss of power. The limit switches should *not* be used to restrain the observing circumstances for the site, such as minimum altitude, as these are defined and enforced by the software system.

1.3.7 Home switches on all axes

1.3.10 Encoder on dome, and/or TTL-level roof/shutter actuators

OCAAS software is capable of controlling either a rotating dome with a motorized shutter, or a roll-off roof observatory configuration. If a rotating dome is used, an incremental encoder and home and limit switches must be attached to provide accurate position information on demand. The dome, shutter and roof motors are controlled by two TTL logic level outputs to activate a suitable motor in one of two directions as needed. The OCAAS software is capable of operating a dome shutter which is supplied power via a power take-off wiper that requires the dome to first be rotated to a particular azimuth.

1.3.11 Peet Bros. Ultimeter 2000 weather station

OCAAS software currently supports the Ultimeter 2000 weather station from Peet Bros. This system provides data on wind speed and direction, temperature, humidity, air pressure and precipitation via an RS-232 interface.

2. Installation and Setup

Thi s section discusses planning and installation issues related to a new or updated telescope configuration. For the most part, these topics do not arise during routine operation. The exception is the necessity to find the Home postion (see § 2.4.1.1) each time the host computer is powered on.

2.1 Observatory Considerations

A fully operational observatory is much more than OCAAS. OCAAS encompasses only the software aspects of an observatory. Issues such as environmental, electrical, safety, site infrastructure, building, personnel, hardware selection and so on are at least equally important but are beyond the scope of this document.

2.1.1 Data Dispensation

One issue which can be discussed is the large amount of data which an automated observatory can generate and the implications that has on storing and retrieving that data.

Consider a 1kx1k CCD camera with 16 bit pixels. Each image will be 2MB. If an average exposure is 60 seconds, one exposure is begun every 2 minutes, and the observing period is 12 hours long, then 360 images will be taken. Assuming the images are compressed by a lossless method by a factor of two, this will require 360MB of disk storage. Each night, night after night. If the observatory is operating at a remote site, this data must be retrieved, either through an electronic transmission or via removable media.

2.1.1.1 Bandwidth Implications

A 33kbit/sec telephone modem operating at 3KB/sec throughput will require 120,000 seconds or more than 33 hours. This is not acceptable because the data is acquired faster than it is dispensed. An ISDN connection operating at 100kbit/sec throughput will require 10 hours. At least this will keep up. A 10mbit/sec ethernet operating at a typical 200KB/sec throughput will require one half hour. This is very reasonable.

2.1.1.2 Media Implications

An alternative to transmitting the data is to store it on mass media. This will require a small amount of time from a local site operator to attend media changes and arrange for the media to be mailed back to the home facility. This involves operational expenses for several sets of media to be in constant rotation, postage, and operator compensation.

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As an example of current media technology using the scenario defined above, 360MB of data could be stored on four 100MB Iomega Zip disks. Or, almost three nights of data could be stored on one 1GB Iomega Jaz disk.

2.2 Mount Installation

The mechanical issues involved in properly mounting a telescope are many. But once it is firmly mounted, cables are securely positioned and the scope is ready for operation OCAAS includes methods to calibrate the axes of a newly positioned telescope and focus the camera. If the telescope is an Alt-Az mount with an image rotator, the reference rotation is also calibrated.There are effectively three methods each of which progressively refine the alignment, but even the initial procedure is often entirely sufficient for nominal tracking accuracy.

The exciting implication of easy axis alignment is the possibility of a portable telescope. Mounted on a suitable trailer or other mobile facility, such an instrument would be well suited for rendezvousing with transient phenomena including eclipses, occultation and grazing events.

2.3 Editing Configuration Files

Several text files exist which define local observing circumstances and specifications of the observatory hardware. These files may be edited using any text editor. When OCAAS is delivered as part of total system, these files will already be set and little or editing will be required. The following sections describe the fields in each file and how to determine their correct values. All config files reside in the directory /usr/local/telescope/archive/config.

The overall structure of each configuration file is the same. There is one parameter per line. The name of the parameter is followed by an optional equals sign (=) then the value then an optional comment which begins at the first exclamation point (!) and continues to the end of the line. For example:

HSTEP 31176565 ! number of motor steps per full revolution

It must be emphasized that these files are critical to proper operation. Errors in the configuration files can render the entire system inoperable. Once properly set, it is seldom if ever necessary to edit these files.

2.3.1 Using *xedit*

An easy to use text editor for editing configuration files called *xedit* is included with the OCAAS system. To use this editor, position the mouse over the root window. Use the right mouse button to navigate the pop up menu and release over the entry named *xedit*. A new application will appear. Enter the name of the file to be edited in the space to the right along the top and press ENTER. The file will be displayed. Edit the file as desired, using arrow keys to navigate and the Backspace key to delete. When changes are complete, save the file by positioning the mouse over the Save option along the top and pressing the left button.

2.3.2 telescoped.cfg

This file contains information about the configuration of the telescope mount. The file contains the following fields. Throughout the list, the "H" axis refers to the longitudinal axis; on an equatorial scope this is the Hour Angle or Polar axis and on an alt-az scope this is the azimuth axis. Similarly, the "D" axis refers to the latitudinal axis or Declination or Altitude axes respectively.

HSTEP Number of H-axis motor steps per full revolution.
HSIGN 1 if H-axis motor steps increase ccw looking down from North, 0 if cw
HMAXVEL maximum H-axis motor velocity, in rads/sec
HMAXACC maximum H-axis motor acceleration, in rads/sec/sec
HESTEP Number of H-axis encoder steps per full revolution
HESIGN 1 if H-axis encoder steps increase ccw looking down from North, 0 if cw
HLIMMARG H-axis limit switch margin, rads
DSTEP Number of D-axis motor steps per full revolution.
DSIGN 1 if D-axis motor steps increase with latitude Northwards, 0 if Southwards
DMAXVEL maximum D-axis motor velocity, in rads/sec
DMAXACC maximum D-axis motor acceleration, in rads/sec/sec
DESTEP Number of D-axis encoder steps per full revolution
DESIGN 1 if D-axis encoder steps increase with latitude Northwards, 0 if Southwards
DLIMMARG D-axis limit switch margin, rads
ACCERR acquisition error per axis, rads; must not be smaller than encoder resolution

2.3.3 focus.cfg

This file contains information about the focus hardware and contains the log of focus positions and temperatures.

2.3.4 dome.cfg

This file contains information about the dome or roof configuration.

2.3.5 filter.cfg

This file contains information about the filter hardware, including the number and names of each filter wheel position. The file contains the following parameters.

FILSTEP number of motor steps per full revolution (or total tray travel)

2.4 Telescope Alignment Procedure

A new installation, or following any activity which may have disturbed the telescope, requires the telescope axes to be calibrated with respect to the celestial coordinate system. Use the following procedure to calibrate the telescope axes anytime its orientation is in doubt. The *Basic* alignment procedure calibrates the telescope as well as possible assuming ideal mechanical operation. This procedure is often adequate in practice with a high quality mount. The *Fine* alignment procedure allows for imperfections by creating and installing an error map over the entire sky.

2.4.1 Basic alignment

This section describes initial and basic alignment of the telescope axes.

2.4.1.1 Find Homes

Using *xtelescope*, activate the *Find Homes* option in the *Setup* menu. This will cause OCAAS to move all axes and find the location of the home switch on each. This will establish the origin of the encoder coordinate system on each axis. This procedure must be activated each time the OCAAS host computer power is turned on. (OCAAS can also be setup to perform this procedure automatically each time the power is turned on.)

2.4.1.2 Find Limits

Once the home positions are known, then activate the *Find Limits* option in the *Setup* menu. This will cause OCAAS to explore the maximum range of motion of each axis equiped with limit switches. The encoder value of each limit position, minus a small safety margin, will be recorded in the *home.cfg* config file. This procedure need only be repeated if the limit switches are physically moved on the telescope.

2.4.1.3 Calibrate Axes

Once the home and limit positions are known, activate the *Calibrate axes* option in the *Setup* menu. This will bring up a dialog box which contains step-by-step instructions for using three stars to establish the celestial orientation of the telescope, and also to measure any nonperpendicularity ini the mount between the polar and declination axes (or altitude and azimuth axes).

The first step asks you to confirm that the computer time is correct and that the geographic location of the telescope is correct. If you are using the GPS option, these should be accurate already but it would be wise to double check them at this time.

If you do not have the GPS option but have an Internet connection, you may use the program *udp_time_update* to connect to the National Institute of Standards and Technology and set the computer clock. You must do this from an *xterm* window. Or, again from an *xterm* window, use the *date* command to type the date and time and hit RETURN when it is correct. You can get an accurate voice time from the US Naval Observatory Master Clock by calling 1-900-410-TIME or tune a shortwave receiver to 10 Mhz and listen to radio station WWV operated by the National Institute for Standards and Technology. As for latitude and longitude, you can work out your location from a topographic map for your area available from the US Geogical Survey at most public libraries. Edit the values into the *telescoped.cfg* config file.

When the time and location are correct, press the button to indicate *Step 1* is complete.

The next step asks you to choose a method of calibration. The choices are to use a finder (or eyepiece) visually at the telescope, or to use existing ccd images. The first time this procedure is run, use the visual method. This will allow you to establish an initial coordinate system which is sufficiently accurate for tracking and thus take useful images. Tracking is also necessary in order to focus the ccd camera. This is, in fact,

a basic chicken-and-egg problem: in order to focus the camera and take images tracked long enough to contain sufficiently many stars to be solved for an accurate position, the telescope axes must be accurately aligned; but best alignment can only be achieved by analysing well focused and tracked CCD images. Thus, one begins using the visual technique which does not require images then repeats using the images method.
At this point, choose *Use finder scope* then press the button to indicate *Step 2* is complete.
The next three steps requires three stars to be chosen and the telescope maneuvered so they are each in turn well centered in the finder scope (or eyepiece). Choose stars which are widely separated in both altitude and azimuth and bright enough to be easily seen in the finder. Avoid stars near the celestial pole, or the pole of the telescope if it is an alt-az mount.
Use the *Sky View* from *xephem* to Indicate each choice. There, the option *Enable Telescope Control* should be turned on in the *Telescope* menu. Then, using the mouse, position the cursor over the first star to be used; press the right mouse button to bring up the popup menu and select *Set telescope*. You will see that the name of your star choice appears in the *Calibrate axes* dialog at step 3.
Now the first star must be centered in the finder. To move the telescope, use the *Software paddle* available from the *Telescope* menu of *xtelescope*. Because the axes are not yet calibrated, use only the *Raw* controls at this time to move the telescope. When the first star is centered in the finder, press the button to indicate *Step 3* is complete. Repeat for steps 4 and 5 for two more stars, again using *xephem* as before to first indicate your choice of stars then locate them in the finder.
When *Step 5* is complete, OCAAS will attempt to use the information gathered about the known celestial positions of the three stars and the time and encoder values of each observation to compute several quantities. These characterize the orientation and scale of the axis encoders and their relationship to the home switches on each. The resulting values are shown near the bottom of the dialog. The meaning of the numbers presented is as follows.

HT Hour angle of the North pole of the telescope, in H:M:S
DT Declination of the North pole of the telescope, in D:M:S
XP Angle from the home switch on the longitudinal axis to the North celestial pole, moving ccw as looking down from the North end of the telescope, in D:M:S
YC Angle from the equatorial plane of the telescope to the home switch on the latitudinal axis, moving from the plane Northwards, in D:M:S
NP Non-perpendicularity angle of the latitudinal axis from ideal right angle with the telescope polar axis, in D:M:S
FIT The largest of the angles between the pole solutions derived from of each of the three pairs of combinations of stars, in D:M:S. This number is effectively a figure of merit for the solution. The smaller this angle, the better.

HESTEP This is the total number of raw encoder steps to make one full revolution of the polar axis (or azimuth axis in the case of an alt-az mount).
DESTEP This is the total number of raw encoder steps to make one full revolution of the declination axis (or altitude axis in the case of an alt-az mount).
R0 The offset for the image rotator, in D:M:S. This value is zero if no rotator is installed.

Note that the values for HT and DT indicate the direction of the telescope's polar axis. For an equatorial telescope, this indicates directly the deviation from perfect polar alignment. Looking at the North celestial pole with the unaided eye, 0 hours Hour Angle is upward from the pole, -6 hours is to the right (east), +6 is to the left (west) and +/- 12 hours is straight down. Thus, the HT value indicates the direction of the telescope pole from the celestial pole. DT is the declination of the telescope's pole and so the value subtracted from 90 degrees is the angular distance of the telescope pole from the celestial pole. A perfect alignment is indicated with a value for DT of exactly 90:0:0. If this is achieved, the value for HT is meaningless. So, for example, if HA is 6:0:0 and DT is 89:0;0, the telescope is pointing 1 degree to the left (west) of the celestial pole and so should be nudged to 1 degree towards the right (east) and the basic alignment procedure repeated. Higher accuracy polar alignment is required to eliminate drift during longer duration image exposures.
Since the nature of this computation is iterative and not closed form it is occasionally possible for the solution to be entirely nonsensical. It is important to inspect the values presented to make sure they are reasonable. The value of the FIT parameter is a particularly good indication of he solution quality. It should be on the order of the accuracy with which stars were centered in the finder (or eyepiece). If it is and the other numbers compare with what one would expect from the basic physical situation of the telescope, then these values may be saved and *Installed* using the last step, *Step 6.* If they do not seem reasonable, repeat the procedure by selecting *Restart* at the bottom of the dialog. The next time through, choose three different stars.
Once a new solution has been installed, this completes the initial phase of the Basic calibration procedure. The telescope should now be capable of centering objects in the finder and tracking them for short periods of time.
Now that the telescope is capable of tracking, calibration can be improved further by using images from the CCD camera. First, focus the camera as described by Auto focus (§ 3.1.1.2.2). Then choose three widely separated points in the sky again. They need not be the same locations as used before and indeed should *not* be near very bright stars. Using *xephem, xtelescope and* th *Camera* application, track each chosen location and take and save an image. Before saving the image, inspect it to insure it contains at least, say, 20 stars. Then using the *Options* menu in *camera,* choose to *(Re)compute WCS.* In the same menu, also turn on *Show GSC stars.* Check that each solution agrees with the image and save each image. Then *Restart* the *Calibrate axes* dialog in *xtelescope..* Repeat the procedure but

Include these images in a schedule run in the usual fashion and proceed with running the schedule.
The next day, inspect a representative sample of the images using *Camera* to confirm they have good WCS solutions. Then, from an *xterm* window, run the *pterrors* program on all the files. This will generate a pointing errors map file. Place this file in the directory /usr/local/telescope/archive/config/telescoped.mesh. An example session might go as follows:

```
% cd ~/user/images
% pterrors pt*.fts >
/usr/local/telescope/archive/config/telescoped.mesh
```

Install the new mesh file using *xtelescope* by selecting the *Reread Config files* option in the *Setup* menu. The mesh will now be used automatically for all subsequent telescope operation. This completes the fine alignment procedure.

3. On-line Controls

3.1 Real-time Operation

3.1.1 xtelescope

This program is used to make direct commands to the telescope, focus, filter wheel, dome and dome shutter. This program can also command several setup procedures, including finding *Home* and *Limit* switches; calibrating telescope axis orientation; performing an automated focusing procedure and reloading configuration files. This program also controls whether the unattended batch observing sequencer program, *telrun* is engaged. Direct control operations are inhibited as long as *telrun* is active.

3.1.1.1 File

3.1.1.1.1 Batch

This command allows you to choose whether the system will run automatically under the control of the *telrun* batch scheduler daemon, or be operated under direct manual control. *Telrun* will expect to find a file of scheduled operations in /usr/local/telescope/archive/telrun/telrun.sls as prepared ahead of time by the telescope batch scheduling program, *telsched.*

3.1.1.1.2 Quit

This command will terminate the *xtelescope* program, after asking for a confirmation. If any direct commands are in progress, they will stop. If batch operation has been enabled, it will continue.

3.1.1.2 Setup Options

This menu contains commands which are performed to setup the telescope for basic operation. For the most part, the list is in reverse order of frequency of use; that is, the items at the top are generally more frequently used in day-to-day operation than those near the bottom.

3.1.1.2.1 Calibrate Axes

This command will bring up a dialog which walks you through the steps to perform a basic alignment procedure. This should only be necessary when the telescope is initially installed or if the mount has been disturbed. See the description in section XXX for complete details.

3.1.1.2.2 Auto focus

This command will initiate an automatic focusing procedure. The procedure will drive the telescope to a location at high elevation and take several images at various focusing positions. The sky conditions must be sufficiently clear for distinct star images to appear. Basic axis alignment and a Home sequence must have been performed so that the images will not contain star trails. The images are examined and used to compute an optimal focuser position. The stepper motor value and ambient temperature of the resulting focus position as stored in a file, *focu.cfg.*

3.1.1.2.3 Find Limits

This commands the telescope to sweep through each axis in each direction until it encounters each extreme limit switch. The encoder value of each limit switch is stored in the config file *home.cfg.* Once the system knows where the limit switches are located, it will prevent any command which would encounter them from beginning.

3.1.1.2.4 Find Home

This commands the telescope to sweep through each axis to locate the position of each home switch. This procedure must be performed before any other telescope command can be issued. Some systems perform this operation automatically when the computer is powered on.

3.1.1.3 Telescope

The follow sections describe how the telescope may be controlled in real-time by several methods. These options are all in the *Telescope* pulldown menu of the *xtelescope* program.

3.1.1.3.1 Move to Stow position

This is a convenience command to drive the telescope to its stow position. The location of the stow position is stored in the configuration file /usr/local/telescope/archive/config/telsched.cfg. The altitude and azimuth of the stow position are stored in the configuration parameters STOWALT and STOWAZ, respectively. The value may be set to anything desired. However, if they are set beyond the soft limits (also specified in *telsched.cfg)* then in order for the Stow command to function, the *Ignore limits* option in the *Options* pulldown menu must be turned on. As odd as this might seem at first, it is quite typical to stow the telescope in an orientation which is beyond what would be acceptable for quality observing. For example, it is considered good practice to stow a telescope such that the front surfaces of all the mirrors are vertical. This would require the stow altitude to be set to 0 degrees, or directly at the horizon. However, this generally is a very poor position for observing objects, hence will likely be below the soft altitude limit.

3.1.1.3.2 Move to Service Position

altitude and azimuth of the stow position are stored in the configuration parameters STOWALT and STOWAZ, respectively. The value may be set to anything desired. However, if they are set beyond the soft limits (also specified in *telsched.cfg)* then in order for the Stow command to function, the *Ignore limits* option in the *Options* pulldown menu must be turned on. As odd as this might seem at first, it is quite typical to stow the telescope in an orientation which is beyond what would be acceptable for quality observing. For example, it is considered good practice to stow a telescope such that the front surfaces of all the mirrors are vertical. This would require the stow altitude to be set to 0 degrees, or directly at the horizon. However, this generally is a very poor position for observing objects, hence will likely be below the soft altitude limit.

3.1.1.3.2 Move to Service Position

This is a convenience command to drive the telescope to its service position. The location of the stow position is stored in the configuration file /usr/local/telescope/archive/config/telsched.cfg. The altitude and azimuth of the service position are stored in the configuration parameters SERVALT and SERVAZ, respectively. The discussion accompanying Move to Stow Position regarding the interaction with the soft limits also applies to the Service Position.

3.1.1.3.3 Enter object to track from catalog

This command brings up a new dialog. At the bottom of the dialog is a list of catalogs. Select one of these catalogs with the mouse and click. Then at the top of the dialog will appear a list of each object within that catalog. If you double-click on one of these objects, the telescope will immediately slew to the object and begin tracking if it is within the soft limits. The telescope will continue to track the object until it is manually stopped or until a limit is encountered.

3.1.1.3.4 Enter RA/Dec to track

This command brings up a dialog in which you may type a Right Ascension and Declination, at epoch 2000. The format of the RA value is H:M:S; that of the Dec value is D:M:S. Any subfield left vacant will be considered as zero. Once values have been typed in and if they are within the constraints defined by the soft limits, then pressing the Enter key or selecting the Ok button with the mouse will cause the telescope to immediately slew to the coordinates and begin tracking. The telescope will continue to track the object until it is manually stopped or until a limit is encountered.

3.1.1.3.5 Enter HA/Dec to slew

This command brings up a dialog box in which you may type an Hour Angle and Declination. The format of the HA value is H:M:S; that of the Dec value is D:M:S. Any subfield left vacant will be considered as zero. If the position is within the soft limits, pressing Enter or

STOPPED, the telescope will move the corresponding distance and direction and stop. If the state is SLEWING, the amount will be added to the current total offset and will cause the telescope to continue to move to the new net total offset before stopping. If the state is HUNTING, the amount will be added to the current offset and the hunt will continue. If the state is TRACKING, the amount will be added to the current offset and the state will become HUNTING until the new location is acquired at which time it will return to TRACKING.

The interpretation of the arrow buttons may be specified using the toggle buttons and scales in the bottom portion of the dialog. At any one time, the arrow buttons may be set to adjust the telescope in terms of Altitude and Azimuth; Hour Angle and Declination; or the raw telescope axes directly. The amount of offset for each press of an arrow may be controlled by moving the scales before the button is pressed. Note that the scale offers a very wide range of offset, from 1 arc second at the left to many degrees at the right. The left third of the travel for each scale makes changes in arc seconds; the central third makes changes to arcminutes; and the right third to whole degrees. Note that for convenience, the HA/Dec mode may also be set to use Hours instead of Degrees for Hour Angle.

Each press of an arrow button adds to a total accumulated offset for that mode. The current total offsets for the current mode is displayed near the bottom of the dialog. The total offsets for all modes may be reset to zero using the *Zero Offsets* button at any time. The offsets are also automatically reset to zero at the completion of any Slew command.

3.1.1.3.8 xephem Sky View

The telescope may also be pointed at any object and begin tracking by using the *Sky View* within the *xephem* program. Bring up the Sky View and select the *Telescope* pulldown menu. To turn on marking the current location of the telescope on the Sky View, enable the option titled *Enable telescope marker.* As long as this option is on, and *xtelescope* is running, a circle-X marker will be displayed on the Sky View to indicate the location on the sky at which the telescope is currently pointing. The location is updated approximately every two seconds. If the center and field of view of the Sky View does not contain this location, the center will automatically be moved so the telescope marker will be visible.

To turn on the ability to point the telescope from the Sky View, enable the option titled *Enable telescope control.* This will cause a new option to become available in the popup menu which comes up whenever the right mouse button is pressed over the Sky View. This option is labeled *Set Telescope*. Releasing the mouse over this option will cause the telescope to slew to that location and begin tracking. The telescope will track the location until a limit is encountered.

3.1.1.4 Auxiliary

The following sections describe how the supporting systems, such as filter, focus wheel, and dome, may be directly controlled from *xtelescope.* The options are available from the *Auxiliary* pulldown menu.

3.1.1.4.1 Enter Filter selection

This command allows you to choose a filter from an option menu. The filter wheel will rotate to center the indicated filter in the light path. Valid filter codes and their wheel positions are as defined in the *filter.cfg* configuration file. Note that the current filter selection is always displayed in the right-most column of the *xtelescope* status display area.

3.1.1.4.2 Enter Focus movement

This command allows you to command the focus motor to move the mirror a given number of microns (micrometers) and stop. The mapping between microns and motor microsteps is defined in the *telescoped.cfg* configuration file.

3.1.1.4.3 Rotate Dome

This command allows you to command the dome to rotate to a desired azimuth. If the value is valid, the dome will rotate to the commanded azimuth and stop.

3.1.1.4.4 Open or Close Dome shutter

This command allows the dome shutter to be opened or closed. If the dome must be at a particular azimuth to apply power to the shutter motor, the dome will rotate to the required azimuth; stay there until the shutter operation competes; then rotate back to its original position.

3.1.1.5 Options

This menu contains several options which effect the operation of *xtelescope* as a whole.

3.1.1.5.1 Beep while slewing

This command will toggle whether the computer automatically issues a regular series of beeps while the telescope is slewing to acquire a commanded position. Once the position has been reached and the telescope stops or begins tracking (depending on how the command was initiated) one more beep is issued at a different pitch and the beeping stops. The pitch, loudness and duration may be set in the configuration file *telsched.cfg.*

3.1.1.5.2 Ignore Soft Limits

This command toggles whether software limits are to be enforced or ignored. The limits are defined in the *telsched.cfg* configuration file. This toggle only effects manual commands issued from *xtelescope;* limits are always imposed during automated batch operation. Limits should only be ignored during unusual engineering situations.

3.2 Batch Scheduled Operation

This command will toggle whether the computer automatically issues a regular series of beeps while the telescope is slewing to acquire a commanded position. Once the position has been reached and the telescope stops or begins tracking (depending on how the command was initiated) one more beep is issued at a different pitch and the beeping stops. The pitch, loudness and duration may be set in the configuration file *telsched.cfg.*

3.1.1.5.2 Ignore Soft Limits

This command toggles whether software limits are to be enforced or ignored. The limits are defined in the *telsched.cfg* configuration file. This toggle only effects manual commands issued from *xtelescope;* limits are always imposed during automated batch operation. Limits should only be ignored during unusual engineering situations.

3.2 Batch Scheduled Operation

The OCAAS allows the telescope to carry out a series of observations completely unattended. The series is built from a sorted collection of individual observing requests. Each request is defined in a separate file with the extension *.sls.* The format of this file is defined in the next section.

Once the collection of individual observing requests is defined, they are read into an interactive sorting program called *telsched.* This program allows you to read combine many individual requests to form an optimized schedule for the telescope in advance. Scheduled may be prepared days in advance and left standing by in a run file known as *telrun.sls.* The *telrun* program serves as the basic automated sequencer for the system when running automatically.

3.2.1 Creating Individual Observing Requests in *.sls* Files

Each observing request is defined in its own file. The format of the file consists of collections of *Keyword= Value* pairs. The equal sign (=) is optional. Any number of pairs may be present, although some pairs interact and so must be used correctly. Keywords retain their values until changed. Case is ignored in all keywords, and for those values which are predefined. Values which contain whitespace must be surrounded by single quotes ('). Comments may occur anywhere and consist of are all characters from any occurrence of the pound sign (#) or bang (!) to the end of the same line. Blank lines may appear anywhere and are ignored. Once the desired keywords have been defined the observation is marked as completely defined by a slash (/). Since the keywords support creating repeated observations in a loop, the slash often appear as the last entry in each loop.

These files may be created manually using any text editor such as *vi* or *xedit.* Or they may be created using a GUI application named *obsrequest* or using an Internet Web form interface. They are then combined into an overall aggregate batch sequence for an entire night using the *telsched* program.

Follows is a description of each keyword recognized in the *.sls* file format.

BINNING The number of CCD pixels which are to be combined within the camera to form one pixel in the resulting file. The format is the number of pixels to bin in the X and Y dimensions, separated by a comma (,). For example, 2,4 means to combine 2 pixels in the X dimension to form one in the file, and 4 in the Y dimension. If this keyword is not specified, the default value is 2,2.

COMPRESS	The amount of compression to be applied to the image. A value of 0 will disable any compression. A value of 1 will apply a lossless compression which will usually reduce the size of the file by approximately a factor of two. Larger compression values will result in larger reductions in file size but the at the expense of not being able to exactly recreate the original pixels. The compression uses is the H-Compression algorithm developed at the Space Telescope Science Institute. Values up to about 100 allow the file to be restored with suitable accuracy to leave quantitative photometric and astrometric largely unaffected, although at progressively significant loss in esthetic value for visual usage. If this keyword is not specified the default value is 1.

DEC	Declination of the image center. The format is DD:MM:SS.S, optionally preceded by a minus sign (-) to indicate the southern hemisphere. Setting this keyword cancels any pending SOURCE value, and also requires that RA and EPOCH be set before the current observation definition is closed.

DECOFFSET	Value to be added to DEC. This keyword is intended to be used when the target is specified using the SOURCE keyword and the target moves, such as comets, asteroids or planets. The format is DD:MM:SS.S, optionally preceded by a minus sign (-).

DURATION	The length of the exposure, in seconds. The format permits any number of values to be specified, each separated by a comma. If more than one FILTER is specified, the durations are paired with the corresponding FILTER. If there are more FILTERs than DURATIONs the last DURATION is assigned to all subsequent FILTERs. If there are more DURATION values specified than FILTERs, the last FILTER is assigned to all subsequent DURATIONs.

EPOCH	The reference frame for the RA and DEC keywords, in decimal years.

FILTER The code designating the filter. Valid codes are as listed in the *filter.cfg* configuration file. The format allows any number of codes to be specified, each separated by a comma. Generally speaking, there should be as many FILTERs specified as DURATIONS. See the DURATION keyword for what happens when the number of each does not match.

HASTART	Requests that the observation be scheduled so that the SOURCE, or RA/DEC, is located at the given local Hour Angle when the observation begins. The format is HH:MM:SS.SS. The LSTSTART keyword specifies the allowed tolerance. If this keyword and LSTSTART are not specified, the SOURCE will scheduled as near transit as possible.

IMAGEDIR	The directory in which the final image file will be stored.

LSTDELTA	The allowed tolerance for a specified HASTART or LSTSTART. The format is HH:MM:SS.S. If the observation can not be scheduled within this tolerance, it will not be performed at all.

LSTSTART	Requests that the observation be scheduled to begin at the given Local Sidereal Time. The format is HH:MM:SS.SS. The LSTSTART keyword specifies the allowed tolerance. If this keyword and LSTSTART are not specified, the SOURCE will scheduled as near transit as possible.

OBSERVER	Specifies the value of the OBSERVER string keyword to be added to the FITS header.

PRIORITY	An integer which influences the scheduling algorithm. The scheduler sorting algorithm satisfies observing requests in

keyword specifies the allowed tolerance. If this keyword and LSTSTART are not specified, the SOURCE will scheduled as near transit as possible.
IMAGEDIR The directory in which the final image file will be stored.
LSTDELTA The allowed tolerance for a specified HASTART or LSTSTART. The format is HH:MM:SS.S. If the observation can not be scheduled within this tolerance, it will not be performed at all.
LSTSTART Requests that the observation be scheduled to begin at the given Local Sidereal Time. The format is HH:MM:SS.SS. The LSTSTART keyword specifies the allowed tolerance. If this keyword and LSTSTART are not specified, the SOURCE will scheduled as near transit as possible.
OBSERVER Specifies the value of the OBSERVER string keyword to be added to the FITS header.
PRIORITY An integer which influences the scheduling algorithm. The scheduler sorting algorithm satisfies observing requests in increasing order of PRIORITY, that is, lower values are more likely to be satisfied. If this keyword is not specified, the default value is 100.
RA Right Ascension of the image center. The format is HH:MM:SS.S. Setting this keyword cancels any pending SOURCE value, and also requires that Dec and EPOCH be set before the current observation definition is closed.
RAOFFSET Value to be added to RA. This keyword is intended to be used when the target is specified using the SOURCE keyword and the target moves, such as comets, asteroids or planets. The format is HH:MM:SS.S, optionally preceded by a minus sign (-).
REPEAT
REPEATDELAY
SOURCE The name of the object to be imaged. The name must occur within the catalog specified by the CATALOG keyword.
SUBIMAGE The number of CCD pixels which are to be combined within the camera to form one pixel in the resulting file. The format is the number of pixels to bin in the X and Y dimensions, separated by a comma (,). For example, 2,4 means to combine 2 pixels in the X dimension to form one in the file, and 4 in the Y dimension. If this keyword is not specified, the default value is 2,2.
SUBIMAGE The number of CCD pixels to use for the image. The format of this value is four integers separated by commas. The numbers are the X and Y coordinates of the upper left corner of the image and the width and height of the image.
TITLE Specifies the value of the TITLE string keyword to be added to the FITS header.
UTDATE The UTC date at which the observation will be scheduled. The format is MM/DD/YYYY.

3.2.2 *obsrequest* -- creating an observing request

This interactive program is used to create one observing request file. It presents the user with a simple form in which the various options and values may be easily entered and selected. When the form has been filled out as desired, it can be checked for self-consistency and saved to disk for later inclusion in a plan for an entire night.

3.2.3 *telsched* -- planning the night in advance

This interactive program is used to read many individual observing request files and form one overall schedule of events for an entire night. The program sorts the requests and tries to satisfy as many as possible while at the same time minimizing the amount of slewing required by the telescope. A graphical timeline can be displayed which shows the utilization of the night at a glance and marks conflicts. The user may add, delete and edit requests to resolve conflicts manually or let the sorting algorithm satisfy requests automatically according to priority. Once a final overall schedule has been produced, it is saved as an schedule list file in *.sls* format for use by the *telrun* program. Schedule lists may be produced for individual days arbitrarily in advance.

3.2.4 *telrun* -- executing the plan

The *telrun* process is a daemon process which reads a schedule file in *.sls* format and carries out the directions in detail. This process is not controlled directly by the operator. This process is controlled via the *Batch* control from within the *xtelescope* program.

Telrun takes all of its directions from one file, /usr/local/telescope/archive/telrun/telrun.sls. This is the file which was prepared using the *telsched* program. This file is updated in real-time as *telrun* works through it. In particular, the Status line is marked N if the associated scan is New and has not yet been attempted; D if the scan is completed; and F if the scan failed for any reason. *Telrun* allows this file to be changed out from under it. If the file disappears, *telrun* will simply stop performing any actions. If the file suddenly reappears, *telrun* will begin to work through it from the top. When *telrun* begins, it always looks for this file and begins to consider the scans it contains immediately. Since the scans are time and date stamped, *telrun* knows when it may process each scan. *Telrun* waits for the appropriate time begin each scan. If not scans are appropriate, *telrun* does not command the telescope to perform any actions.

As *telrun* operates, it generates detailed log files of all of its activities. One file contains all operations and is located in /usr/local/telescope/archive/logs/telrun.log. It also generates a separate log for each observing code encountered within the .sls file it is working on. These contain only those operations which were a result of actions requested by a given observing code. These files are located in /usr/local/telescope/user/logs.

4. Off-line Tools

The following programs are available to perform image analysis and various scientific analysis functions. All programs operate on 16-bit FITS images.

4.1 *Camera:* Interactive Image Acquisition, Display and Measurement

The *camera* program serves two rather distinct roles in OCAAS. One role is direct real-time control of the CCD camera. In this role, it can command the camera to take an image and display it immediately and it can take Bias, Thermal and Flat image calibration frames for use immediately or later during batch scheduled operation. Used in this way, the *camera* program is using the CCD camera and so batch scheduled operation should not be active (batch operation is turned on and off using the *xtelescope* program). However, if one closely monitors the activity of the batch system and knows that it is not in fact using the CCD camera at the moment, it is Ok to use the CCD camera from *camera* during this idle period (the current activity and time of the next scan can be monitored using the *shm* system status display). If one is not sure, attempting to use *camera* while the CCD camera is in use by the batch system will simply result in the message that the camera is currently in use result in no harm done. However, if *camera* is using the CCD camera when the batch system wants it, the batch control process will get the in-use error and the scan will be marked as Failed and skipped.

The other role of *camera* is to analyze image files. Used in this way, *camera* is not using the CCD camera and so may be used at any time, whether or not scheduled batch operation is active.

4.1.1 Image Acquisition

Taking an image using the CCD camera with *camera* involves first defining the exposure parameters, then taking the image. Images may be taken one at a time or continuously until stopped.

Note that continuously taking images is not often necessary with OCAAS because focusing is done automatically and axis alignment does not require target stars to be within the image frame. It is included for completeness however.

4.1.1.1 Exposure setup

Set the exposure parameters by selecting the *Setup...* option from the *Expose* menu. This will being up a dialog in which you may set image size, binning, location, duration and choose to flip rows or columns. The dialog will only permit settings which are valid for the installed CCD camera.

The dialog also displays the current state of the thermoelectric cooler and allows it to be turned on or off and to set its target temperature. Note that it is far preferable to operate a CCD camera at a temperature it can hold AtTarget rather than just setting it to drive to a temperature lower than it can possibly reach. This is because just as important as a low temperature is a constant temperature.

Once the desired parameters have been set, the CCD camera may be operated directly from the button along the bottom of the dialog or from the items in the *Expose* menu in the main *camera* menubar. If the parameters are not likely to change, it is more conservative of precious screen space to *Close* the setup dialog and use the menu.

4.1.1.2 Taking an image

Once the exposure parameters are set as desired, pressing *Take 1* from either the exposure setup dialog or directly from the *Exposure* menu will command the CCD camera to begin the exposure. The shutter is opened for the specified time and a countdown is begun. The seconds remaining is displayed in the message line at the top of *camera*. When the time has elapsed, the shutter is closed and pixels are read from the CCD camera into computer memory. If the exposure duration was for 30 seconds or longer, the computer will beep when the pixels are completed being read. If the option has been set to automatically calibrate each acquired image, then the most recent Bias, Thermal and Flat which match the image binning are applied. Once the image is complete, *camera* immediately displays the image. The contrast, magnification and other initial settings depend on options discussed in subsequent sections.

To take images continuously, use the Continuous option from either the exposure setup dialog or the *Expose* menu. Once begun, each image will be taken, corrected and displayed forever until the Stop option is pressed.

Note that at least for all brands of CCD cameras currently supported by OCAAS, the time to read the pixels is proportional only to on the net number of rows after binning, not the number of columns.

4.1.2 Taking Calibration Images

The following sections describe how each type of calibration image is taken and saved. All types of calibration images are taken using *camera* by using the dialog which is brought up by choosing the *Calibration...* option within the *Expose* menu from the main menubar.
A separate set of calibration frames must be created for each combination of row and column binning. This is because changing binning makes a significant difference in the behavior of the camera. Calibration frames should be taken at full frame with no subimaging. In this way, OCAAS can pull out the relevant portion when calibrating images taken with any values of subimaging.

4.1.2.1 Bias

A Bias calibration image is designed to measure the signal which appears from the CCD camera even when no light has hit the CCD. It is a result of the readout noise associated with the electronics within the camera circuitry. To measure this effect, the idea is take an image of zero seconds duration with the camera shutter closed. In this way, the CCD chip supposedly contributes nothing and the entire signal is that of the electronics alone. For statistical reasons, it is best to take several such images and average them together to get a mean value for the readout noise. The bias level is likely to change somewhat, often on time scales of hours to days. For this reason, it is wise to take new bias frames often. (When using the batch scheduling system, it is possible to specify that a new bias frame be taken using the CCDCALIB keyword when preparing the schedule request).
To take a bias frame, specify the number of images to take and average together in the text field provided. Numbers like 5 or 10 are reasonable. Enter a file name for the resulting averaged bias frame or choose Auto to let OCAAS create a file name. The latter is recommended for most situations to insure the name adheres to the proper conventions and is in the proper directory for use by the batch scheduling subsystem. Pressing Take will then take the given number of images, average them and store a new bias calibration image.

4.1.2.2 Thermal

A CCD chip will accumulate values from heat as well as light. Even a CCD cooled to a very low temperature will not be immune. OCAAS assumes that this accumulation is proportional to the exposure time of the image.
Some systems refer to a Dark calibration image. These images are created by taking an exposure of finite period but with the shutter closed. OCAAS does take Thermal images this way too, but then subtracts the Bias frame. OCAAS also stores in the FITS header of the Thermal image the exposure time of the image. When OCAAS then uses the Thermal image in later calibration, it scales the values according to the ratio of the exposure time of the calibration image to that of the new image being calibrated. By removing the bias from the Thermal, this scaling is more accurate because it does not also scale the inherent bias as well.
To take a thermal frame, specify the number of images to take and average together in the text field provided. Numbers like 5 or 10 are reasonable. Also specify an exposure time. Experiment with your camera to find a time which results in pixel

values roughly midway from saturation, that is, about 30,000. (This is not critical; mean values from, say, 10,000 to 40,000 are fine). Enter a file name for the resulting averaged thermal frame or choose Auto to let OCAAS create a file name. Also specify the name of a bias frame to use or choose Auto to let OCAAS choose a suitable existing bias file. Using Auto for each step is recommended for most situations to insure the name adheres to the proper conventions and is in the proper directory for use by the batch scheduling subsystem. Pressing Take will then take the given number of images, subtract the bias and average them, and store a new thermal calibration image.

4.1.2.3 Flat

A Flat is intended to capture the irregularities in the optics of a camera system including scratches, dust and bubbles in the glass. Flats are actually just normal exposures but taken while the camera is aimed at a field which is very evenly illuminated. This allows any deviations from a perfectly "flat" image to be attributed to the optical path irregularities and not the scene. OCAAS subtracts bias and thermal effects from images to be used as flat fields.

How to obtain an evenly illuminated reference is a matter of convenience and preference. Some people use the sky at dusk or dawn. Others build a light source which carefully diffuses the light onto a panel. Others put a white panel on the wall of their observatory and depend on ambient light to illuminate it evenly.

To take a flat frame, specify the number of images to take and average together in the text field provided. Numbers like 5 or 10 are reasonable. Also specify an exposure time. Experiment with your camera to find a time which results in pixel values roughly midway from saturation, that is, about 30,000. (This is not critical; mean values from, say, 10,000 to 40,000 are fine). Enter a file name for the resulting averaged flat frame or choose Auto to let OCAAS create a file name. Also specify the name of a thermal frame to use or choose Auto to let OCAAS choose a suitable existing thermal file. Using Auto for each step is recommended for most situations to insure the name adheres to the proper conventions and is in the proper directory for use by the batch scheduling subsystem. Pressing Take will then take the given number of images, subtract the thermal and average them, and store a new flat calibration image.

4.1.3 File Control

4.1.3.1 Opening a FITS file

This brings up a file selection dialog box from which a FITS file may be selected and displayed. Both uncompressed files, with an extension of .fts, and compressed files, with an extension of .fth, are supported. For convenience, a list of the most recent several files successfully opened appears at the bottom of the pulldown menu, and one of these may be reopened just by selecting the desired line.

4.1.3.2 Deleting a FITS file

This option permanently deletes the file currently being displayed from disk.

4.1.3.3 Saving a FITS file

This option allows saving the current image to disk in FITS file format. This option exists in order to save images which have

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This option permanently deletes the file currently being displayed from disk.

4.1.3.3 Saving a FITS file

This option allows saving the current image to disk in FITS file format. This option exists in order to save images which have just been taken directly with the CCD camera, a file to which additional COMMENT fields have been added, or to save an image in different location or as a different name.

A dialog box is presented in which the directory and file name may be entered. You will see that as each new image is acquired, *camera* assigns it a new potential file name. The name of the new file is the current date, hour, minute and second, each as two digits, plus the conventional .fts extension. The Save dialog also includes an option called Auto Save. When this is active, each new image acquired will be saved to disk automatically.

4.1.4 Basic image display

Certain basic image control features are always active in *camera*. See the other sections for features which have their own controls.

The overall window size used by *camera* may be adjusted in the usual way by manipulating the resize handles surrounding the main application window. Images which are larger than the current window may be panned by using the scroll bars which will appear to the right and bottom edges of the image.

Near the top of the main *camera* window is a status line with basic information about the image being displayed. This includes the file name; the value of the OBJECT header field; the value of the EXPTIME exposure time header field, expressed in seconds; and the value of the ELEVATION header field, expressed in terms of airmass (labeled Z).

Moving the mouse over the image with the left button depressed will display the row and column of the cursor and the raw numeric value of the pixel in the message line near the top of *camera's* main window. If the image header includes World Coordinate System fields, the Right Ascension and Declination of the center of the pixel are also displayed in this line.

A yellow Area of Interest, or "AOI", is always present as an overlay to the image. This AOI may be redefined by using the mouse. Begin by moving to the desired upper left corner of the box and pressing the middle button. Keep the button pressed and move to the desired location of the lower right corner of the AOI and let go. As described in the *Tools* section, the AOI can be used to define a subset of the image for computing various statistics and determining a brightness and contrast level. Whether this is true at any point in time is defined by the settings of these tools.

an height. Also on this dialog is an option to Crop. When option is active, only that portion of the image which lies within the AOI will be displayed. When the option is off, the entire image will again be shown (clipped to the size of the *camera* window of course).

4.1.5.3 Magnifying Glass and FWHM

This option brings up a complex dialog box. At the top are statistics about the pixels which currently lie within the magnifying glass. These include mean, median, standard deviation, and the value and pixel coordinates of the brightest pixel within the glass.

Below the statistics are controls for setting the magnification factor and the size of the box. The size refers to the number of pixels in the original image, not the size after magnification.

Next below is an option *Snap to Max.* When this is on, the center of the magnifying glass is always over the brightest pixel in the neighborhood of the cursor, that is, within a box the size of the glass centered on the cursor. Note that this effect stays in force even when this dialog is closed; this can be rather perplexing if one forgets later.

Next below is an option to display horizontal and vertical cross sections of pixels in red. When active, the dialog box is made larger to hold these two graphs. The top graph is along a vertical line centered at the cursor location for the length of the glass box. The bottom graph is along a similar horizontal line. The gray background lines are a relative indication of numerical pixel value and use the same scale on both graphs, although they change dynamically such that the minimum and maximum values along the current cross sections fill the available space in order to show maximum detail.

The last option is to *Overlay Gaussian.* When this is active, the horizontal and vertical cross sections are overlaid with a best-fit Gaussian curve in green. In addition, the center, height and Full-Width-Half-Max values of the Gaussian are displayed in units of pixels. If WCS coordinates are in the image header, the center is also displayed in units if RA and Dec and the FWHM is displayed in arc seconds.

4.1.5.4 Contrast and Histogram

This option brings up a complex dialog which offers insight and control over the display of the image.

Across the top are statistics about the pixels within the image. These include mean, median, minimum, maximum, standard deviation.

Next down are several controls which effect how the image is displayed. If the *Auto Window* option is active then the contrast and brightness of the image are automatically set according to either one of two methods which may be selected. One method is to assign black to all pixel values which are less than or equal to the median pixel value minus one standard deviation and white to all pixel values which are equal to or greater than the median plus two standard deviations. The other method is to assign black to the smallest pixel value and white to the brightest pixel.

The purview of the above statistics and rules may be set using the next set of controls. The calculations may be performed on

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The purview of the above statistics and rules may be set using the next set of controls. The calculations may be performed on all pixels within the entire image, just those pixels within the current AOI, or just those pixels which lie outside the current AOI.

Next below are controls which determine the color map to use. Choices include a conventional gray scale, and three different pseudo-color mappings. In addition, any of the color maps may be inverted by using the *Invert* control.

At the bottom of this dialog is a graph of the histogram of the pixel values of the image. As before, the pixels may be from within or without the AOI or the entire image. The abscissa is the pixel value, and the ordinate is the relative count of pixels with that value. If the *Auto Window* option is active, then the lowest and highest pixels in the graph correspond to the method being used to set the black and white colors. Normally, the vertical scale of the histogram is linear, but there is an option just about the histogram which may be set to a logarithmic scale to show more detail in areas of the graph with lower counts. Also above the histogram are places which display the exact pixel values at each end of the graph. These may be changed by typing in a new value and pressing RETURN on the keyboard. The end values may also be changed by moving the mouse onto the histogram and pressing the left button; the location of the mouse will determine a new value for the minimum or maximum value to be displayed, depending on whether the mouse is in the left or right half of the graph, respectively. Whenever the histogram limits are changed in either of these ways, they determine a new contrast setting as well and the *Auto Window* option is automatically turned off.

4.1.5.5 Relative and Absolute Photometry

This option brings up a relatively complex dialog which may be used to perform either relative or absolute sparse-field aperture photometry. Relative photometry allows the magnitudes of stellar objects to be compared within one image or among several images. This method uses an arbitrary star and reference magnitude which may be selected and specified. Absolute photometry utilizes a corresponding set of reference images containing stars of known magnitude which were taken at nearly the same time as the image being investigated. The *telsched* batch preparation program may be used to easily display the information about the star. A red circle is drawn around the star over the image to show its relative magnitude and center for confirmation.

The top of the dialog is common to both modes. At the very top are two fields. The first controls how far to hunt from the cursor to find the brightest pixel which defines a nominal center for the star. This is useful to avoid having to place the cursor precisely on a star. Larger values are handy for sparse fields; smaller values are necessary for more crowded fields Below that is an aperture field and a control to lock it. When starting to perform photometry, leave the field unlocked. *Camera* will compute an optimum aperture radius; that is, one which maximizes the signal-to-noise ratio. Or one may enter a desired radius in the text field. Once a radius is selected, it should be locked for all subsequent comparisons.

Next below is information about the most recent star clicked on. Information includes the location of the center of the star and its maximum value. These values are based on best-fit horizontal and vertical Gaussian profiles and hence are accurate to sub-pixel resolutions. If the image header includes WCS fields, the star location is also displayed in RA and Dec, epoch 2000.

Next below is the main choice of whether to perform relative or absolute photometry. The remainder of the dialog depends on which choice is selected.

If the choice is relative, then fields are presented which allow choosing a star as a reference and a text field to assign it a magnitude value. As new stars are selected, their magnitude, and an error estimate, are shown with respect to the star chosen as a reference.

If the choice is absolute, then fields are presented which display the true magnitude of the star through Blue, Visible (yellow), Red and Infrared filters. Selecting the *Setup* button brings up additional dialogs which are used to locate and calibrate the system using the standard Landolt fields.

4.1.5.6 Rubber band

This option brings up a measurement dialog. The top half indicates the location of a reference position and the cardinal and straight-line distances and angle to the current cursor position. These values are given in units of pixels. If the image header contains valid WCS fields, these value are also given in RA and Dec, epoch 2000. The bottom half of the dialog displays a cross-section between the reference position and he cursor position.

To use this feature, move the mouse to a location to be used as a reference and press the left mouse button. If this is the first time this dialog has been up, this location will automatically be made the reference. Otherwise, use the *Set Ref* button to make this location the new reference. Once a reference position has been set, roaming the mouse over he image with the left button down will cause the distance, angle and cross section to be displayed on a continual basis.

The dialog can also compute a curvilinear velocity. To use this feature, set the reference to a location of, say, an asteroid on one image. Then open an image which contains the same asteroid but taken at a different epoch. Leaving the reference position. These values are given in units of pixels. If the image header contains valid WCS fields, these value are also given in RA and Dec, epoch 2000. The bottom half of the dialog displays a cross-section between the reference position and he cursor position.

To use this feature, move the mouse to a location to be used as a reference and press the left mouse button. If this is the first time this dialog has been up, this location will automatically be made the reference. Otherwise, use the *Set Ref* button to make this location the new reference. Once a reference position has been set, roaming the mouse over he image with the left button down will cause the distance, angle and cross section to be displayed on a continual basis.

The dialog can also compute a curvilinear velocity. To use this feature, set the reference to a location of, say, an asteroid on one image. Then open an image which contains the same asteroid but taken at a different epoch. Leaving the reference set from the first image, click on the asteroid in the second image and *Camera* will display its velocity on the celestial sphere in arc seconds per second. An implementation which will allow using three images taken at different epochs to compute the orbital elements of the asteroid is under consideration.

4.1.5.7 Display FITS Header

This option brings up a dialog, the top portion of which displays the FITS header for the current image. The header may be scrolled as necessary both vertically and horizontally.

The bottom portion allows new COMMENT fields to be added to the image header. This only changes the header in memory; be sure to *Save* the image again to make these changes permanent on disk.

The proportion of room taken by these two portions may be adjusted by moving the sash which appears between them in the dialog layout.

4.2 Image Manipulation Tools

The following programs are available from a UNIX command line, such as from an *xterm* window. All programs print usage summaries and exit if executed with the -help option or with any unidentified option.

These programs are written in this form primarily so they may be used in higher level specialized batch scripts to perform automated extensive processing on large numbers of files. Indeed, OCAAS uses several of them in just this way during batch scheduled processing. GUI wrappers around these programs may be available in later releases, depending on demand.

4.2.1 *calimage* -- calibrate a raw image file

This program takes one or more raw images on the command line and applies appropriate Bias, Thermal and Flat calibration fields. The results are stored over the original file *in place* so copy the files first if you want to keep the raw images.

4.2.2 *crop* -- reduce image sizes

Crop is a program which crops a set of FITS images to the largest common AOI. Or, crop can be given a file which lists OBJECT names and AOIs and it will crop each image to that AOI. Or, crop can be given an AOI on its command line and it will crop all images to that.

N.B. It creates the new cropped images *in place*. Copy the images first if you want them preserved.

Usage:

WCS is a program which takes one or more FITS images and sets the C* fields by matching star patterns in the GSC catalog.

```
wcs: usage: [options] [file.fts ...]
  -r dir:  alternate cdrom directory (default is /cdrom)
  -c dir:  alternate cache directory (default is
/home1/ccdoper/archive/gsc)
  -s sep:alternate directory separator(default is /)
  -v:      verbose
  -o:      allow overwriting any existing WCS fields
  -w:      write header (default is read-only)
  -d:      delete any WCS header fields (requires -w)
  -u rad:hunt radius, degrees (default is 1)
  -f file: name of file containing filenames.
```

4.3 Research Tools

The following programs are available from a UNIX command line, such as from an *xterm* window. All programs print usage summaries and exit if executed with the -help option or with any unidentified option.

These programs are written in this form primarily so they may be used in higher level specialized batch scripts to perform automated extensive processing on large numbers of files. GUI wrappers around these programs may be available in later releases, depending on demand.

4.3.1 *fphotom* -- absolute field photometry

Fphotom is a program for producing true photometric magnitudes for all stars in a color field, that is, all stars that are found in common among a set of four images taken through B, V, R and I filters. Photometric calibration constants for the night of the image set are read from the file photcal.out, or from a set of standard defaults in photcal.def if no date matches. The output is a table, one star per line, of star positions, their B, V, R and I values, with error estimates, and the geometric mean and ratio (Y to X) of their full-width-half-max values.

```
Usage:
fphotom: [options] config_file
Options:
  -c file: photometric constants file. default is photcal.out
  -d file: default file to use when date not found. default is photcal.def.
  -p file: directory of out/def files; default is
/home1/ccdoper/archive/photcal
  -v:      verbose.
Required:
  config_file
```

The config_file is required and must consist of exactly either 2 or 5 lines. In either case, the first line contains two fields, separated by whitespace, to define the photometry parameters, as follows:

```
   rsrch:      max radius to search for brightest pixel
   rap:  aperture radius, pixels.
```

The file may then have four additional lines which are the names of images of the same field through B, V, R, and I filters. The filenames may be given in any order.

Or, the file may have one additional line which begins with a * and is the name of a file which contains the names of the four BVRI filter images, exactly as though they appeared directly in the config file as above.

4.3.2 *photcal* -- produce calibration constants for absolute photometry

Photcal scans a directory of images of Landolt photometric standard fields and, along with standard field name information in photcal.ref and default k" values from photcal.def, determines a set of 8 photometric parameters: V0 and k' for each of 4 colors, BVRI, which best-fits the image data. These values are written in a form suitable for use with fphotom and so, by default, photcal appends the new set of values with a date header to the file photcal.cal. The values of k" are held constant and may be read from photcal.def or changed on the command line. Run the program with no arguments to display the built-in defaults.
The photometric model is from Simon et al 1994 and can be summarized as follows:

$$V = Vobs + V0 + k'Z + k''(B-V)$$

where:

Symbol	Meaning	Role/Source
V	true apparent magnitude	per star, from photcal.ref
Vobs	observed magnitude	per star, from pixels
V0	instrumental correction	to be solved
Z	air mass	per field, from header
B-V	color index	per star, derived from photcal.ref
k'	airmass dependency	to be solved
k"	color index dependency	to be solved

This equation is repeated for each color B, V, R and I. Thus, the total solution consists of 8 numbers: V0 and k' for each color. (Be careful not to confuse the color V with the V in the equation).
Stars with SNR < 4.0 are rejected.
Usage summary;
photcal: [options] mm/dd/yyyy
Options:
-i dir: directory of images; default is .
-p file: directory for def/ref/out files; default is /home1/ccdoper/archive/photcal
-d file: default k" values filename; default is photcal.def
-r file: field ids filename; default is photcal.ref
-c file: calibration filename to append to (- means stdout); default is photcal.out
-k B V R I: values of k" for each color; may be set from file using -d or built-in defaults are: -0.46 -0.15 -0.02 -0.06
-t days: +/- days image's JD may vary from given date; default is 0.5
-v: verbose: generates additional output
-m: print name, Z, filter, observed mag and err for each star.
Required:
mm/dd/yyyy: date for which constants are to be determined d may be a real number; y is full year, e.g., 1995.
The program prints error messages to stderr if trouble but usually tries to keep going. The resulting values are appended to the output file in the following format. No output is generated if there are not sufficient data to solve for all four sets of values.
JD (M/D/Y)
B: V0 k' k"
V: V0 k' k"
R: V0 k' k"

I: V0 k' k"

4.3.3 *photom* -- relative photometry of specified stars and asteroids

Photom is a program which performs aperture photometry on sparse-field star images. It is driven by a configuration file, described below. The config file lists several .fts image files and the locations of several fixed stars. The first image is a reference image and its last star is a reference star. The config file may also specify the location of a "wanderer" on two images and the location will be interpolated on all other images. The locations of stars are given by their RA and Dec. The images must have WCS header fields.

Photom produces one line of output per image with the following columns:

file number
file name
airmass
pixel displacements from previous image
value to be subtracted from JD to get heliocentric time
Heliocentric JD (minus a bias of 2449000.0)
Median sky value around reference star on this image
RMS of sky value

Subsequent columns are in sets per star. Each set consists of:

magnitude difference
error estimate
geometric mean of horizontal and vertical full-width-half-max values, pixels
ratio of horizontal and vertical full-width-half-max “FWHM” values, if -f
X image location of brightest pixel in star, if -x
Y image location of brightest pixel in star, if -x

In a given row, the magnitudes are relative to the star in the last column. The magnitude reported in the last column is relative that star on the first image. Estimates of the error of each brightness calculation are also given.

Usage:

Follows is a description of the command line options photom recognizes:

-c Crop: Find a bounding box that contains just the given stars and replace each image file with a version cropped to this size (plus a border of 20 pixels). The box is adjusted for the aligned location of the stars in each image so the location of the box will differ for each image but they will all have the same size box. Photom does this IN PLACE forever destroying the original image files. To record the cropping action that photom has performed it adds two INTEGER fields to the FITS header of each such cropped image: CROPX and CROPY. The effective bounding box size is just the size of the image, of course.

-f Include the two FWHM columns; they are not printed by default.

-x Include the two X and Y columns; they are not printed by default.

-v Verbose: Generate extra output. One line per star per image consisting of:

star number
x= X location of star
y= Y location of star
max= maximum pixel value of star

r= radius where star ends and noise begins
sum= sum of all pixels within r
n= number of pixels within r
nmed= median pixel value in noise annulus
nmean= mean pixel value in the noise annulus
nsd= sd within the noise annulus

Follows is a description of the photom configuration file format:
All blank lines and lines which begin with # are ignored. Names which appear in BOLD FACE are keywords that should appear in the file; case is ignored.
The first line consists of two integer parameters, separated by one or more spaces:
rsearch: max radius to search for brightest pixel from given coordinate
apradius: the aperture radius to use, in pixels. If set to 0, the aperture will be automatically determined using the reference star on the reference image, based on that radius which maximizes the SNR. Use 0 if unsure.
The next section names the files to use:
FILES:
<file>
<file>
<file>
...
where:
<file> can be any of:
a simple file name;
a range; ranges must be of the form Xaa-bb.fts, where:
X is anything;
aa-bb is a starting and ending hex range, such as 10-a0.
or the name of a file containing file names or ranges. Must be preceded with a * to mark it as a file of files.
There is no fixed limit to the number of files which may be given.
The next section defines the locations of stars and asteroids to measure:
FIXED:
<RA Dec>
<RA Dec>
<RA Dec>
...
where:
<RA Dec> are star coordinates. These may be in H:M:S and D:M:S format;
or decimal degrees (yes, even RA is given in decimal degrees).
WANDERER: file1 RA Dec file2 RA Dec
This line is optional. If present, it specifies the location of an object assumed to move linearly in time and space between its location on the two files indicated. The format of the RA and Dec fields are as for fixed objects, above. Its position on all other files will be interpolated from these known positions and times.
No more than 100 stars may be specified, including the wanderer if present.
Sample:
```
# Sample photom config file
10 10 .1
# the files
FILES:
gabb2114.fts
```

```
gabb2216.fts
gabb2218.fts
gabb2220-3f.fts

# the fixed stars
FIXED:
0:39:09.6 -0:26:37
0:39:45.2 -0:19:18
0:39:44.0 -0:32:00

# an asteroid
WANDERER: gabb2114.fts 0:39:22.7 -0:24.57 gabb2236.fts 0:39:15.0 -
0:23:09
```

4.3.4 *predict* -- date and times of variable minima

Predict prints out a list of times when eclipsing binary stars will be at a minima. Only minima which occur during local night with the star above the horizon and within abs(HA) < 6 are shown, unless the -a switch is used.

The program requires two environment variables: LATITUDE, in rads +N, and LONGITUDE, rads +W.

Usage: predict [options]

-a: show all minima, regardless of dusk/dawn/up/HA limits, etc.
-d m/d/y: starting date (y is full year, as in 1996); default is today.
-f starfile: alternate star list; default is /brutus/astrolabs/labimage/varstars/ecl-bin.txt.
-n minima: number of consecutive minima to report; default is 1.
-s starname: name of star; default is all stars in star list file.

The program requires a file of known minima for the stars to be predicted. This file consists of 10 columns, as follows:

Name the name of the star.
RA-h,m,s three columns for RA hour, minute and second (J2000)
Dec-d,m,s three columns for Dec degrees, minutes, seconds; the first of these may be immediately preceded with + or -
P period, days.
JD0 Julian date of a minima, referenced to heliocentric time.
Mag Magnitude range as Brightest-DimmestX, where X is a one-character band code such as B, V, R or I.

The output consists of several columns for each star and minimum in range, as follows.

Name the name of the star.
Date date of minimum, M/D/Y UT.
JD time of minimum, JD.
Dusk time of dusk the night of the minimum, UT.
UT time of minimum, UT.
Dawn time of dawn the night of the minimum, UT.
LST time of minimum, Local Sidereal Time.
HA Hour angle of star at minimum, H:M:S.
Elev Elevation of star at minimum, Degrees.

4.3.5 *snsearch* -- supernovæ search

Snsearch "automatically" searches a list of test images against a list of reference images for stars that have appeared in a test image that are not in the reference image. The search region may be delimited by an area of interest.

Usage:

snsearch arcsec_sep config_file test1.fts ...

or

snsearch -f file_of_files arcsec_sep config_file

arcsec_sep is the maximum separation allowed between object locations, in arc seconds. It is also the amount by which the AOI is reduced for the test image.
config_file is the file containing the list of reference images. The file consists of one or more lines in the following format:

OBJECT ERa NDec WRa SDec reference.fts

...

where:

OBJECT:name of object, as it appears in the OBJECT FITS header field.

ERa:	East RA limit in the form HH:MM:SS (J2000)
NDec:	North Dec limit in the form DDD:MM:SS (J2000)
WRa:	West RA limit in the form HH:MM:SS (J2000)
SDec:	South Dec limit in the form DDD:MM:SS (J2000)

All lines which do not begin with an alphanumeric character are ignored.
The remaining arguments to snsearch are the test image file names. They are matched up with the reference images by matching OBJECT fields and so may be given in any order. A reference object must exist for each test object. The list of test files may also be in a file by using the -f option.
The output generated by snsearch is in two parts. The first part has one line per test image in the following format:

OBJECT rfile tfile date time nref ntest nsuper

where:

OBJECT:name of object, as it appears in the OBJECT FITS header field.

rfile:	name of reference file
tfile:	name of test file
date:	date of test file (same as DATE-OBS FITS field)
time:	time of test file (same as TIME-OBS FITS field)
nref:	number of stars found inside AOI in the reference image
ntest:	number of stars found inside AOI in the test image
nsuper:	number of stars in test with no corresponding star in reference.

The first part is followed by a form-feed character (control-l).
The remainder of the file is a report of the location of each potential supernovae. There will be one line for each supernovae candidate in the following format:

OBJECT tfile RA Dec

where:

OBJECT:name of object, as it appears in the OBJECT FITS header field.

tfile:	name of test file
RA:	RA of candidate (J2000)
Dec:	Dec of candidate (J2000)

A blank line is inserted after each set of objects.

4.3.6 *vsmon* -- variable star monitoring

Vsmon is a program for monitoring a set of variable stars over an extended period. The list of stars to monitor is specified in a catalog file. The format is detailed below. vsmon scans a given directory of fits images and checks each image against the catalog to produce one line of output for each image whose OBJECT field is found in the catalog. The format of the output is detailed below.
Usage:

usage: vsmon [options]
-b: use bright-walk star search method. default is max-in-area.
-c file: alternate catalog file. default is /home1/ccdoper/archive/photcal/vsmon.lst
-i file: alternate image directory. default is /home1/ccdoper/user/images
-o file: alternate output file; use - for stdout. default is /home1/ccdoper/archive/photcal/vsmon.out
-r rmax: max radius to search for star, pixels. default is 12
-v: verbose

The catalog file format consists of three lines per target star, as follows. There is one line for the target star, and one line each for the calibrator and check stars. All fields are separated by blanks. Blank lines and lines which begin with # are ignored.

C name RA Dec V B-V V-R V-I
K name RA Dec V B-V V-R V-I
T name RA Dec V B-V V-R V-I

where:

C/K/T: The first column is one of the characters C, K or T. These serve to mark each entry as the Calibrator, Check, or Target, respectively. They must appear in the first column and always in the order C then K then T for each star group.

name: The second column is the name of the star. Only the name of the Target star is used by vsmon for anything. No spaces are allowed.

RA: The third column is the RA of the star. The format is H:M:S.
Dec: The fourth column is the Dec of the star. The format is D:M:S.
V: The last 4 columns are the magnitudes of the star in several ...
B-V: bands. Column five is the magnitude in the V band; column six ...
V-R: is the B-V magnitude; column seven is the V-R magnitude; and ...
V-I column eighth is the V-I magnitude.

The output file consists of one line per file as follows:

FName OName UD UT HJD Z F Tag TErr TTrig KDiff KErr

where:

FName: name of file
OName: name of object
UD: UT Date of observation, M/D/Y
UT: UT Time of observation, H:M:S
HJD: JD of observation, corrected to Heliocentric time
Z: airmass
F: filter code
TMag: computed true magnitude of target star
Terr: statistical error in TMag, in magnitudes
TTrig: Y if TMag is >= the trigger threshold, else N.
KDiff: measured - expected check star magnitude
Kerr: statistical error in check star, in magnitudes

4.3.7 *vssearch* -- variable star search

Vssearch searches for variable stars in a set of FITS images as follows: Given a set of images taken with a given filter scan each image and build lists of all qualifying stars found in each. Match the stars by position. Find the brightest star that is on the most number of images and use it as a calibrator star. Disregard all images which do not contain the calibrator. Find the magnitudes and errors of each star on each surviving image. Stars which have too much intrinsic error or are not on at least 3 images with the calibrator are discarded. For each remaining star, compute how well the magnitudes fit a straight horizontal line, allowing for their noise estimates, as follows:

Vbar = noise-weighted mean = Sum(Vi/Ei)/Sum(1/Ei)
D = average deviation from mean = Sum(|Vi-Vbar|)/N
Q = figure of merit = sqrt(Sum(((Vi-Vbar)/Ei)**2)/N)

Stars with D below a threshold (set in config file, default is .1) are discarded. Remaining stars are sorted by increasing Q, i.e., increasing likelihood they are variable. Q is based on the mean squared error.

Usage:

vssearch [options] [files...]

Options:

-c file: override internal defaults with a config file (see below)
-f file: file of filenames
-s: product spreadsheet output instead.

Note that filenames may be given as arguments or in a separate file, but not both.

The config file consists of the following nine parameters, one per line; blank lines and lines which begin with # are ignored.

1. max radius to search for brightest pixel, pixels, default is 4
2. photometric aperture, pixels, default is 5
3. max separation between images to be considered the same star, arc secs, default is 5
4. filter code, default is R (all other images will be silently ignored)
5. reject stars with more than this much noise error, default is .1
6. reject stars with more than this much mag estimate error, default is .1
7. reject stars with raw counts greater than this, default is 40000
8. reject stars whose average deviation from the mean is less than this, default is .1
9. reject stars which do not appear on at this many images, default is 3.

Output:

The default output of vssearch is a table with one row for each star that was found on at least 3 images along with the calibrator star. The calibrator star is always the first star shown. The columns are as follows:

I ordinal
Q figure of merit -- higher means more variable.
N Number of images in which the star was found with the calibrator.
RA RA of star (on first image encountered)
Dec Dec of star (on first image encountered)

Then for each image, the following columns are printed:

V The magnitude of the star with respect to the calibrator.
Verr The error in the magnitude.

The format of the Spreadsheet output (-s) is just a huge table, one row per image. The first column is the Heliocentric Julian date of the observation - 2450000, then follows two columns per star: the magnitude relative to the calibrator and the estimated error in the magnitude. If the values are not available for any reason they are printed as 99.99 and 9.99, respectively. Stars that were not on at least three images with the calibrator are not listed at all.

4.4 *XEphem* -- the premier ephemeris planning and mapping tool

XEphem provides a rich set of astrometric calculations and attractive graphical and image displays in an easy-to-use GUI framework. It can also be used within the OCAAS framework to display and directly control the pointing direction of the telescope. *XEphem* includes extensive on-line context-sensitive help. That level of detail is not repeated in this document, but rather we present only the highlights of what is possible.

4.4.1 Primary display capabilities

4.4.1.1 Configurable Data table

4.4.1.2 Earth view

4.4.1.3 Moon view

4.4.1.4 Mars view

4.4.1.5 Jupiter view

4.4.1.6 Saturn view

4.4.1.7 Sky view

4.4.1.8 Solar System view

4.4.2 Research tools

4.4.2.1 Solve user-defined equations of circumstances

4.4.2.2 Create user-defined plots of any data fields

4.4.2.3 Export any data fields to text fields

4.4.2.4 Sort all pairs of objects by increasing angular separation

4.4.2.5 Display FITS and DSS images with catalog overlays

4.4.2.6 Supports all major astronomical catalogs

4.4.2.7 Direct support for PPM, HD, SAO and GSC catalogs

4.4.2.8 Asteroids directly supported by MPC and CAT alerts

4.5 Units

4.5.1 *deghr* -- degrees to hours:minutes:seconds

4.5.2 *hrdeg* -- hours:minutes:seconds to degrees

4.5.3 *lst* -- current local sidereal time

5. Web Access

5.1 Initial Setup

5.2 Accessing Status

5.2.1 Anonymous Report

5.2.2 Privileged Report

5.2.3 Last image acquired

5.2.4 Current meteorological conditions*

5.2.5 Weather trend log*

5.3 Submitting a Schedule Request

5.3.1 Observers Code