WHIRCAM User's Guide v1.0

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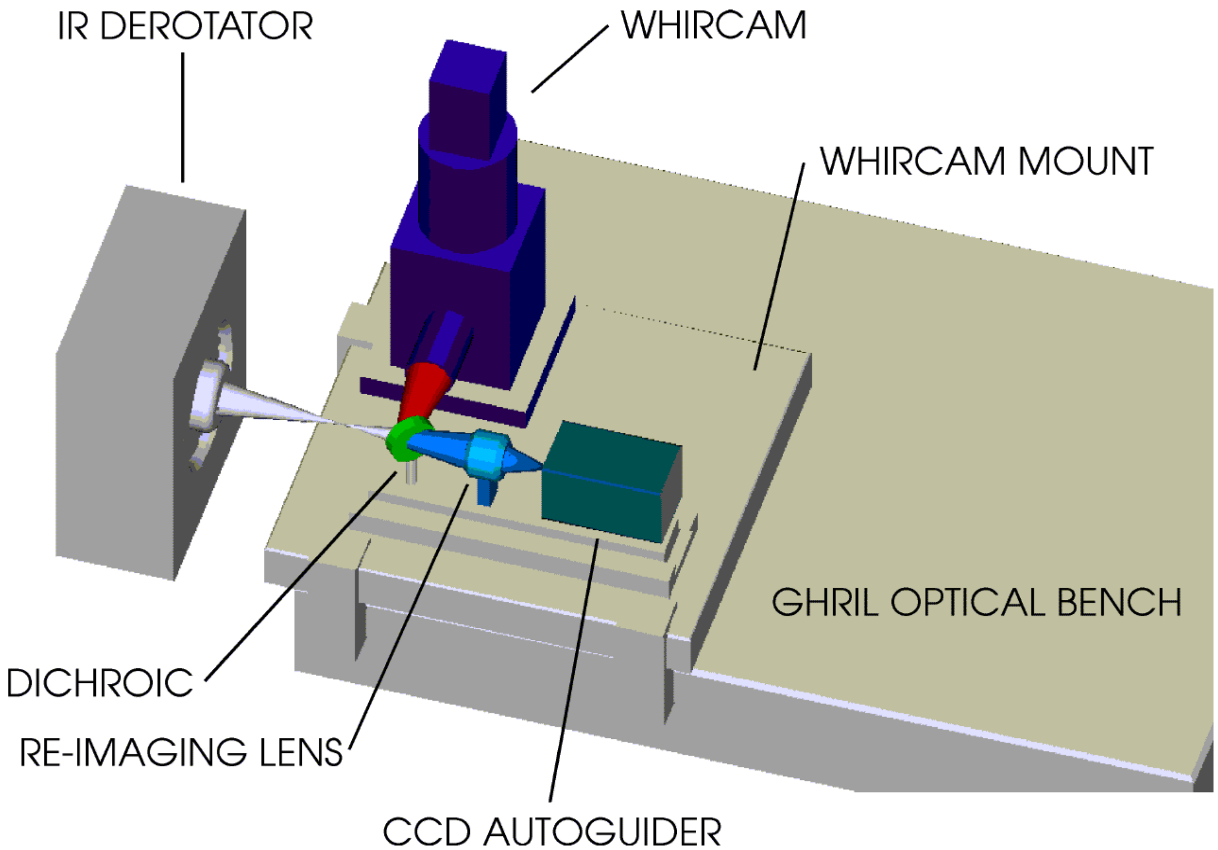

Figure 1: WHIRCAM at GHRIL

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Contents

This manual is intended to give enough detail for astronomers to take IR images with WHIRCAM on the WHT. Many thanks are due to Colin Aspin (JAC) for supplying a preliminary version of the IRCAM3 manual, upon which much of these notes are based, especially Appendices A and B. A more detailed document describing WHIRCAM's optics, ALICE, mounting and alignment, etc, has been produced by P.F.Roche, and is available on request (a copy is also held in the WHT control room).

WHIRCAM is an infrared imaging camera built for the WHT (the 4.2 m William Herschel Telescope on La Palma) by Pat Roche (Oxford) in collaboration with Joel Sylvester, Magnus Patterson, David Laird and Phil Puxley (ROE).

1 Observing in the IR

If you haven't observed in the infrared with arrays before, then there a few extra problems (and techniques for overcoming these), compared to visible CCD observing, that you should know about! Further details can be found in the article *Observing with IR arrays* by Richard R. Joyce in *Astronomical CCD Observing and Reduction Techniques* (1992, ASP Conference Series, Vol. 23, p 258, ed. Steve. B. Howell). A copy of this article is held in the WHT control room.

1.1 Obtaining Optimum Images

There are three particular 'features' of the WHIRCAM array, that differentiates it from modern optical CCDs in terms of observing procedure. These are *residual imaging* where a recent high count in any pixel causes a larger count than normal in a subsequent exposure, a *high DARK current*, and a *large number of hot pixels*, some of which are unstable and come and go on very short timescales (seconds). The residual imaging effect means that observing a bright object will result in a 'ghost' in the subsequent image, and the high DARK current means that if the array is idle for a time, most of the pixels will have a high count, so that a subsequent exposure will have a spurious higher count level. Hence each exposure sequence should be preceded by at least two DARKs, to ensure that the pixel response returns to nominal for the OBJECT exposures. And the large number of hot pixels means that it is essential that each of these OBJECT exposures consists of at least three (preferably more) dithered images, such that median or other suitable filtering can be employed to remove the hot pixels. *This applies to standards as well as objects!* Dithering also enables accurate sky subtraction for point sources, removes cosmic rays, ensures good temporal and spatial correlation between object and sky, and removes detector dark current automatically. All at no additional cost in observing time.

Fortunately this observing sequence is easily achieved by the use of EXEC files (see § 3.5.1) that specify a dithered pattern of exposures per filter, preceded by two DARKs. Make sure that the dither pattern is not exactly square, otherwise the bad column ($\sim$# 55, see Figure 2) will create a residual series of streaks in the final montage.

You will also need to obtain good estimates of the sky, which is very much brighter in the IR compared to the optical. For example, at K, the sky is typically 12 mag/arcsec^2, compared to $\sim$22 mag/arcsec^2 in V. This means that most broad band imaging will be sky limited, and the maximum exposure times to avoid saturation will be determined by the sky brightness in most observations. Also, if your aim is to measure surface brightnesses and your source is extended, or the background is not uniform (eg a gradient on a galactic field) and covers a large fraction of the WHIRCAM FOV, then you'll need to take offset skies (ie offset the telescope to a patch of true sky), of comparable exposure time, similar airmass and UT as your object exposures.

Such offset sky exposures should also be taken in a dithered pattern, to remove faint stars, hot pixels and the occasional cosmic ray.

1.2 Calibration Frames: Darks and Flatfields

The pixels on IR arrays are produced by generating voltages across the substrate applied to individual electrodes. Captured photons are converted to an effective charge, which changes the voltage in a given pixel, and it is this voltage which is read out. Thus the output counts consist of a reset level produced by the initial bias voltage,[1] dark current produced within the substrate, and (normally) a signal generated by the source and sky photons. Thus from an observed count at any pixel ($N_{obs}(i,j)$), to recover the source signal from the object ($N_{obj}(i,j)$), the reset level ($N_R(i,j)$), dark current ($N_D(i,j)$), and sky ($N_S(i,j)$) must all be measured, as well as a flatfield which measures the variations in pixel-to-pixel response and vignetting from optical components ($F(i,j)$):

$N_{obs}(i,j) = N_R(i,j) + N_D(i,j) + N_S(i,j)F(i,j) + N_{obj}(i,j)F(i,j)$

A DARK exposure will give $N_R(i,j) + N_D(i,j)$ (but make sure it has the same exposure time as your object exposure, as the dark current isn't linear with integration time). In IR observing, the flatfield often varies on timescales of hours, due to changes in thermal emission from various components, hence the best flatfield is generated from sky frames (N_{sky}) obtained with the object exposures, thus:

$F(i,j) = \frac{N_{sky}(i,j) - N_R(i,j) - N_D(i,j)}{N_S(i,j)}$

Because the sky is so bright in the IR, and because the flatfield can vary, it is important to subtract the sky from object before flatfielding. This also has the advantage of not needing to explicitly subtract a DARK from the OBJECT, as the dark current is already in the sky exposure (but a DARK is still needed to generate the flatfield). Thus the object signal is then obtained from:

$N_{obj}(i,j) = \frac{N_{obs}(i,j) - N_{sky}(i,j)}{F(i,j)}$

WHIRCAM has two main observing modes: STARE and ND_STARE. In STARE, one readout at the end of the exposure is made, giving N_{obs}, while in ND_STARE, an initial readout is made immediately after the initial reset is applied, and this reset level is subtracted from another readout at the end of the exposure, giving $N_{obs} - N_R$. Thus it is important not to mix DARKs taken in STARE mode (ie $N_R + N_D$) with DARKs taken in ND_STARE mode (ie just N_D).

In the WHIRCAM array, Well depths, and hence saturation, vary across the chip, and in particular the odd column pixels have a lower well depth than the even column pixels. To reduce the problems of different saturation levels on the odd and even columns (which would be difficult to measure in real time), different reset levels have been applied to the odd and even columns, such that at 80% of saturation the odd and even column counts are approximately the same (see Figure 5). A side effect of this is that the flatfields are dominated by an odd-even column fixed pattern noise. Consequently, most faint images will not be seen on the raw image display. To confirm the presence of a faint image while observing, you'll need to subtract off sky and divide by a flatfield (eg. using IRCAM_CLRED – see Appendices A and B).

The sky counts in narrow band images may not give enough signal to noise to generate an accurate flatfield. In this case, use either the bright twilight sky, or dome flates obtained during the afternoon from the halogen flatfield lamp (ask your TO or SA where this is stored).

[1] The initial voltage is called the bias, which is thus different to the bias in optical CCDs (a signal added at readout), but has a similar effect in the raw frame (ie an extra 'constant' level added to the image which must be removed).

2 WHIRCAM Characteristics

The detector is a Santa Barbara Research Corporation (SBRC) InSb array enclosed in the old UKIRT IRCAM-1 cryostat. The internal optics were designed by Eli Atad (ROE), and consists of a doublet (the fore-optics), which collimates an expanding f/11 beam, two filter wheels, and an f/6.2 triplet that re-images the collimated beam onto the array.

The detector is cooled to 30K by a closed-cycle high pressure He cooling system, consisting of a vibrationally isolated heat pump mounted on top of the cryostat, connected to a compressor in the oil pump room on the ground floor by $\sim$ 60 m of high pressure stainless steel piping. The triplet lense and filters are also cooled, to $\sim$70 K, with the doublet probably a little warmer, as it sits in an extended snout.

The InSb detector currently installed is serial number FPA40348, and has the following characteristics:

- Array size = 256×256 of 30 μm pixels
- Image scale (direct) = 0.24″/pix, giving a full FOV = 61″×61″
- Image scale (Martini ×3) = 0.08″/pix, giving a full FOV = 20″×20″
- Image scale (Martini ×5) = 0.05″/pix, giving a full FOV = 13″×13″
- Quantum efficiency $\sim$ 80% over 1 – 4 μm (includes *J, H, K*)
- Dark current = 1 e^-/s, but is effectively $\sim$10 e^-/s due to thermal emission leaks within the cryostat
- Gain $\sim$ 6 e^-/DN
- Readout noise $\sim$ 40 e^- for ND_STARE, 55 e^- in STARE
- Reset level (STARE mode) $\sim$22,000 DN (even columns), $\sim$30,000 DN (odd columns).
- Non-linearity: like most IR arrays, WHIRCAM's response is non-linear, as a function of well depth, and the well depth varies with bias voltage. 1% non-linearity sets in at about 3000 counts, and reaches 10% at counts of 17000 for odd columns and 20000 for even columns, in ND_STARE mode with a bias voltage of 0.68 V. If this proves to be stable, then corrections up to the 10% level can be applied afterwards.
- Saturation $\sim$ 10,000 DN for ND_STARE, and 37,500 DN for STARE (both 80% full well capacity), for a bias of 0.68 V (see § 5.2).
- Readout times of: 120 ms (256×256 full array)
36 ms (128×128 subarray)
12 ms (64×64 subarray).

Although the detector is sensitive over the wavelength range 0.8–5.5 μm, the WHT is not optimised for the IR (in particular, it doesn't have a chopping secondary, the secondary is oversized with respect to the primary beam, plus the central obstruction and the baffles on the chimney and secondary are seen by the beam), so that most imaging will be restricted to 0.8 – 2.3 μm (i.e. *J* to *Ks*).

The total throughputs (includes sky absorption, all optical surfaces, lens and filter absorption, and detector quantum efficiency) are $\sim$16% for *J*, 17% for *H* and 17% for *Ks* (this is

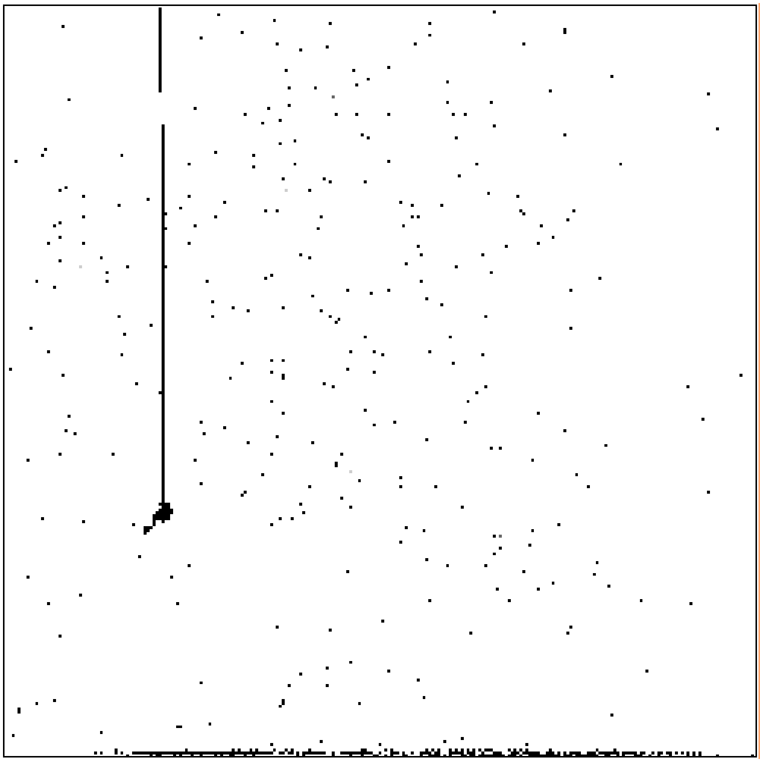


Figure 2: The location of the main hot pixels.

for GHRIL, which has an all-reflecting image de-rotator, thus adding an extra 3 reflections. There are plans to mount WHIRCAM at Cassegrain Auxiliary Port, which should give higher throughput, plus the use of the offset guider, but this probably won't be ready until after semester 96B).

There are a number of known bad (i.e. dead and permanently hot) pixels on the array (see Figure 2), the main feature being a few bad columns between pixel positions (55, 81) and (54, 256). The brightest of these are recorded in a bad pixel map, and are masked off for display purposes (see § 3.5.1), but the frames are written to disk unmasked.

The readout/detector control is a virtual copy of the Array Limited Infrared Control Environment (ALICE) rack built for UKIRT's IRCAM-3 and CGS-4, which is controlled by a DEC VAXstation 4000 via Ethernet. The chip can also be continuously displayed via 3 coax cables to an RGB monitor. Control software is a copy of UKIRT's IRCAM-3, except for the stepping motor controllers (two filter wheels and one focus) and the telescope interface (for writing coords, etc to the headers).

Normally WHIRCAM sits on its own optical breadboard at the GHRIL Nasmyth focus (Figure 1). At GHRIL, the beam passes through an all-reflecting (silver plus MgF coated) image de-rotator to an optically flat dichroic, which reflects most of the light longward of 0.9 μm, and transmits the optical light (Figure 3) to an optical CCD autoguider, via an f/6 re-imaging lens. The CCD autoguider has a field of view of 52″(NS)×70″(EW) (but is vignetted beyond a diameter of 40″), a scale of 0.2″/pix, and a limiting magnitude of ∼17 mag in V for an integration time of ∼4 sec (this is for a typical full moon sky brightness and 0.8″ seeing, but it will of course vary depending on the sky brightness and seeing). The centre of the WHIRCAM field lies at a position (230, 180) on the Autoguider CCD (ie is not centred).

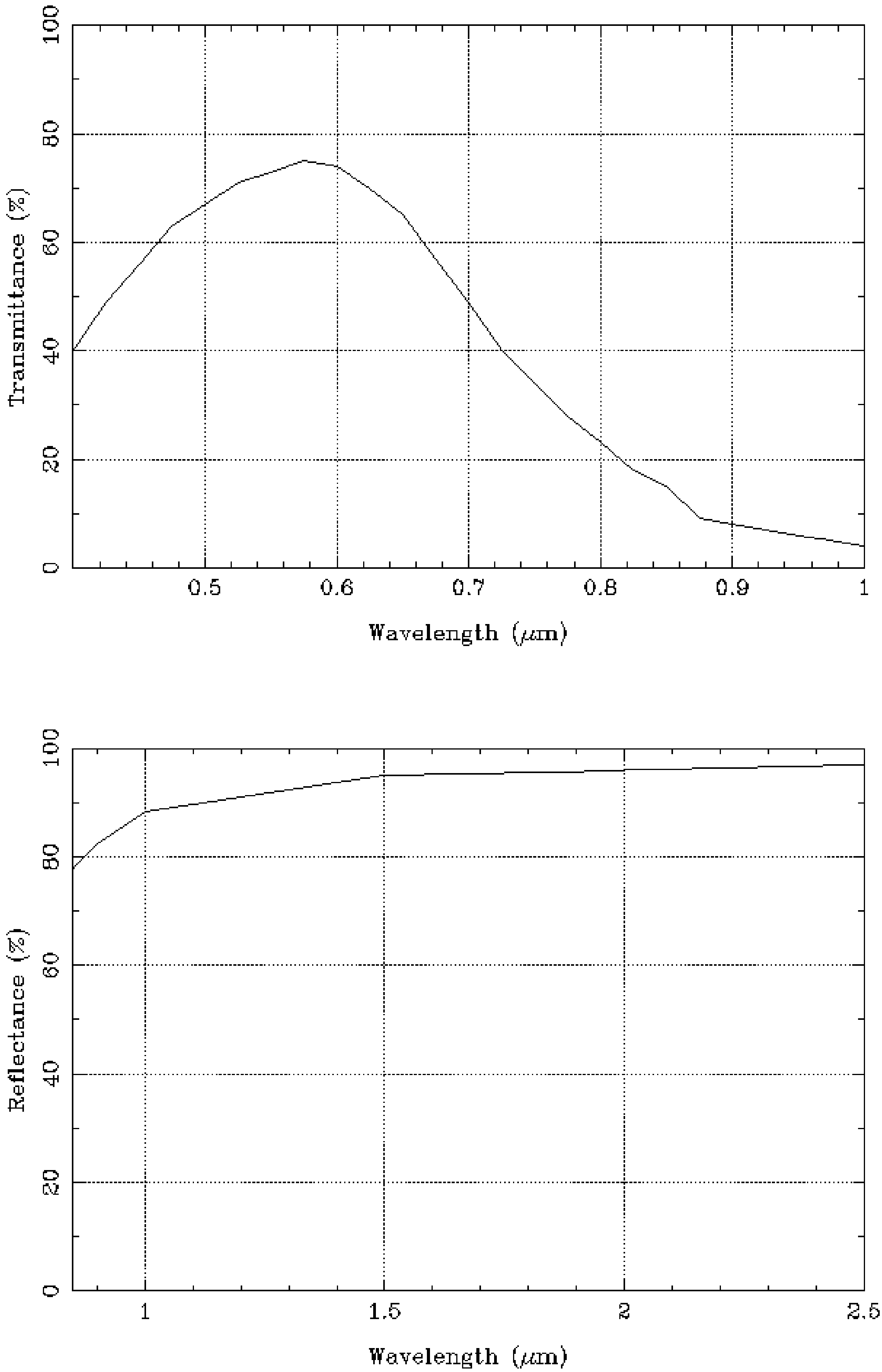


Figure 3: Dichroic's transmission (upper) and reflectance (bottom) curves.

3 Observing with WHIRCAM

3.1 Introduction

WHIRCAM is controlled by a Vaxstation 4000 running a slightly modified version of the UKIRT IRCAM package, which employs Screen Management System (SMS) screens running under Adam. Status screens display the instrument configuration and the transputer activity while an SMS menu is used to control the instrument and initiate data taking sequences. Instrument configurations can be retrieved from the Vaxstation disk and combined in observing sequences within EXEC files. The telescope can be controlled from within the EXECs; for example it can be stepped in a grid pattern to form a mosaic and/or a dither pattern (for median filtering of hot pixels, etc from frames). Alternatively, a sequence of measurements in different filters with a number of different telescope offsets can be initiated. The data are stored on a 2 Gbyte disk in SDF format.

3.2 Starting up

If you are intending to observe with WHIRCAM (as opposed to simply starting it to familiarise yourself with the commands and create EXEC and CONFIG files), then you need to ensure the Telescope Control System (TCS) is up so that WHIRCAM's SLIDE commands etc will communicate with the telescope. First, verify that an ICL session is running on the computer specified on the whiteboard (lpvf or lpvg). Ask your Support Astronomer (SA) or Telescope Operator (TO) if you are unsure. You should also make sure you start WHIRCAM after 10:00 am, as the directory and filename nomenclature (see § 7) incorporates the current date, and this is incremented at 10:00 am so that an entire night's observations will be written with the same prefix in the same directory.

If ICL isn't running, then log onto LPVS3 or LPVS2 as OBSERVER, select the correct system (lpvf or lpvg), type 'ICL', and accept all the defaults.

Your TO should also ensure that TCS is running with the following:

- Select *GHRIL Derotator*
- Select *GHRIL Autoguider*
- Select *Own* instrument
- Select a SKY PA of 0
- Enter the correct temperature and humidity
- Enter the correct wavelength for observations

Also, at the autoguider terminal, select the *GHRIL Autoguider* application.

Once ICL is running, log on to the WHIRCAM Vaxstation (IRCMVX) (or telnet from the LPVS3 terminal next to the ALICE screen if you want to be near the camera display) as user WHIRCAM (get the current password from your SA or TO). In the DECterm window type:

```
whircam_start
```

which will start up the WHIRCAM control software.

At this point you'll be asked to enter a unique ID (usually the observer's initials). This will then either direct the ALICE software to your own unique directory where your personal

CONFIG and EXEC files are stored (there are also several standard example files in the system directory), or else create one to store any such files you may create during your run.

The colour monitor (ALICE Graphics Display) and ALICE Transputer/Occam control software will be initialized, and three windows will be created:

- A large DECterm window, the *instrument status* screen, containing current values for detector, array size, bias voltage, observing mode, filters, exposure time, number of integrations, observation number, and current and planned CONFIG and EXEC files.
- A small DECterm window, the *ALICE occam status* screen, showing current status of ALICE communications with WHIRCAM.
- Another DECterm window, the *IRCAM3 Instrument Control* screen, where you can load and edit CONFIG and EXEC files, and execute them, or take exposures directly.

During initialization, check that one of the status messages scrolling up the *IRCAM3 Instrument Control* screen reads:

```
connected to Telescope Control Task.
```

This means the ICL system was running, and that the ICL tasks and WHIRCAM can talk to each other. Initialisation should take about 4 minutes.

Before you start taking exposures, you should start AUTOFITS running (see § 7) to record your frames to tape as they are taken.

If you wish to analyse your data as they are taken, it is usually easier (and less messy) to do this from the RODIR directory (see § 7), in which case you should also start up an ACVT session which automatically copies frames from IDIR to RODIR as they are taken. To do so, open another DECterm window, and simply type:

```
ircam_setup
ACVT
```

You can then iconise this window and it will run in the background.

3.2.1 Menu Control

The WHIRCAM instrument control and data acquisition system is currently run from a Starlink supported menu system called SMS, in the *IRCAM3 Instrument Control* screen. This menu system makes extensive use of the keyboard keypad (to the right of the main section of the keyboard) and particularly the PF (Programmable Function) keys.

The main features to be aware of are:

You DO NOT use the mouse at all under the SMS menu system!! (apart from defining which window is currently active)

Use the Enter key to go down into the menus.

Use the PF1 key (top left of the keypad) to Exit menus and execute options.

Use the arrow keys (left, right, up, down) to move between menu items.

Hit the dot key the keypad and you can then use the prev screen or next screen buttons to scroll the message display.

The optimum usage of the PF keys is always noted on the bottom line of the SMS menu screen.

Use the Select key (usually above the arrow keys) to run an ICL command. This tends to be most useful in running DCL commands, for which you must prefix each command with DCL. For example, if your user ID is XYZ, and you'd like to list the contents of your personal EXEC directory, hit the Select key, which will produce a 'Command:' prompt at the bottom of the screen, at which you type:

```
DCL DIR DISK$USERSPACE:[XYZ.IRCAMEXEC]
```

To refresh the screen, use cntrl^ R.

Alternatively, you can create a new DECterm session using the same screen by typing SPAWN at the command prompt. When you have finished your DCL session, simply LOGOUT and the *Instrument Control* screen will reappear.

3.2.2 Startup Menu

Go into the *'Startup'* menu. This menu should contain the following:

```
Observer_name   ?
PATT_reference  ?
Instrument      WHIRCAM
Detector        FP40348
```

Enter the relevant information in the spaces provided. Your PATT reference number can be found on the WHT schedule. Use the PF1 key to exit this menu and go back to the top level menu.

3.2.3 Defining Telescope Pointing Model

At the start of every WHIRCAM run, and whenever the telescope structure is changed (eg if another instrument is changed during the day, which will cause a slight shift in the telecope balance), a pointing calibration must be performed on a set of astrometric stars. This is done by your TO, but it must be done with respect to the WHIRCAM ALICE display. Therefore, go into *Movie* mode (see § 3.5.4), choose the filter you'll be using most of the night, set the integration time to 0.3 sec, and aquire the first of the position standards (ask for the faint set, as the normal set saturate on WHIRCAM). You now need to define the the telescope rotation centre:

- (1) Position the telescope such that the star is near the top edge of the ALICE display, and mark this with a whiteboard marker pen.
- (2) Ask your TO to change the SKY PA to 180, and you'll see the star describe a half circle on the ALICE display, and mark this new position (If it looks like it will move off screen, mark the approximate centre of rotation, go back to SKY PA 0, move the star closer to the rotation centre, and start again.)

- (3) The telescope rotation centre will be the point halfway between your two marks.

The TO should then centre each of the position standard stars on this centre. You can find out where this centre is with respect to the WHIRCAM array by going into the *'Set_graphics'*, *'statistics_window'* menus, and changing the X and Y position of the statistics box until it is centred on the rotation centre.

3.3 Initial Engineering Tests

Once the instrument control software has finished running up, the default *'Set_observation'* option is:

```
Object = Array Tests
Obs_type = EXEC (ie highlighted)
EXEC_name = ARRAY_TESTS
```

which will run the EXEC called ARRAY_TESTS. This takes a standard set of 8 dark images which, when analysed, give an indication of how the array is currently performing (ie. dark current and readout noise). If these are not the defaults, enter them yourself. Hit PF1 to exit this menu. Upon exit, the contents of the EXEC ARRAY_TESTS will be loaded into the execution stack and displayed on the *IRCAM parameter status* screen. Move to the *'Run'* item to execute the EXEC ARRAY_TESTS by hitting Enter. Note down the start observation number of the ARRAY_TESTS EXEC. Let's call this start observation number N.

Once the EXEC has finished (a message will appear in the scroll region of the IRCAM instrument control SMS screen), the user should process the images acquired. (The very first ARRAY_TESTS almost always produces a larger than real dark current, so take two sets of ARRAY_TESTS, and only analyse the second.)

Within the IRCAM_CLRED window (see § 10 for how to start this up), type ARRAY_TESTS. Enter the start observation (N) of the ARRAY_TESTS data. The current STARE and ND_STARE readout noises and the current dark current will be estimated from the dataset and the values printed at the end of the analysis. Also given is an evaluation as to whether these values are in the valid operational range. An example of output expected is:

```
STARE    mode readout noise (e-) =  55.474
ND_STARE mode readout noise (e-) =  36.892
DARK CURRENT (e-/sec)            =  2.231

** STARE readout noise is nominal **
** ND_STARE readout noise is nominal **
** Dark current is nominal **
```

If these values are not nominal, then you need to check if the temperatures are too warm or if the chip is being properly read out (see §9).

3.4 Observing Modes

There are currently four observing modes with WHIRCAM. These are:

- STARE – the array is reset, read after the user-defined on-chip exposure times, and reset again.
- ND_STARE – the array is reset and read immediately and read again after the user-defined on-chip exposure time. The difference between the post-exposure and pre-exposure images is taken and stored.
- S+A – In Shift-and-Add mode, images are pre-processed in ALICE. The peak pixel in a user-definable area is found and the image is shifted (by integer pixels) so the peak pixel falls onto a fiducial mark on the array. N images are co-added in this manner. S+A mode works in STARE mode only and is used to sharpen images and reduce seeing/tracking effects. The user is referred to § 8 for more details.
- Atmospheric Monitoring imaging – intended to allow monitoring of such things as seeing and image stability, but not yet implemented.

The two advantages of ND_STARE over STARE is that (1) the direct read-out architecture of the detector means that the integrated charge may be sampled non-destructively and an improvement in read-noise is thus obtained by making multiple reads, and (2) the reset level can vary, so you automatically subtract the latest reset in ND_STARE. However, there is also an extra time overhead in each readout, so for very short exposures (as in S+A) STARE is better. The shortest integration where ND_STARE is likely to be beneficial is about 1 sec.

3.5 Taking an Exposure

3.5.1 Imaging menu

Imaging parameters (filter, exposure time, number of exposures per integration) are controlled by CONFIG files. These in turn can either be recalled, or loaded via EXEC files. EXEC files specify a small program of observations and telescope operations, such as executing DARK, SKY, or OBJECT exposures, and using a series of SLIDE commands to perform a mosaic and/or dither pattern of exposures. Both of these are accessed (and executed) from within the *'Imaging'* menu:

- *'Set_instrument'* : The instrument parameters are defined by loading an *instrument configuration* (CONFIG) file. For example, the observer chooses the filter from a list in the *instrument configuration* screen and the appropriate filter combination and focus offset is automatically loaded. The exposure time must be short enough to avoid saturation (see § 5.2) and long enough to ensure that the observation is background limited for maximum sensitivity (see § 5.4); it can vary from 120ms at nb$L$ (or as short as 12 ms if you read out a 64×64 subarray) to tens of seconds in narrow band filters. With short integration times, many exposures may be coadded by selecting a number of exposures per integration, before the data are written to disk. This saves on disk space and readout time overheads. The final image written to disk is divided by the number of exposures, thus giving an *average* exposure. This may be confusing as the exposure time in the header gives the total integration time (ie $N\times$exposure time). The log produced at the end of the night keeps a record of the number of exposures per integration.

- *'Set_EXECs'* : Telescope offsets (for mosaics, etc) and sequences of different filter exposures can be specified with *execution* (EXEC) files. These are text files containing a list of commands to be executed in sequence by the software. A list of valid EXEC commands is given below (Table 3.5.2 in § 3.5.2). An EXEC controls how data are taken with WHIRCAM (e.g. which CONFIG to use, where the telescope points relative to the slew coordinates, whether to take an OBJECT, SKY or DARK exposure etc). This menu allows the user to define and/or edit operational EXECs. The editor for the EXEC files is EDT, so the PF1 and Enter keys become redefined as part of the EDT keypad during an EXEC edit. To exit the editor, type cntrlˆ Z.

- *'Set_observation'* : This menu allows the user to define the type of observation being made (e.g. whether to execute an EXEC or a direct observation of the OBJECT, SKY, DARK etc.

- *'Run'* : Entering this item runs the currently defined setup (by Set_observation). Data are actually taken and stored on disk. To avoid writing rubbish to disk (and to tape), it is a good idea to add a BREAK at the beginning of every EXEC (see § 3.5.4) so that you have an oportunity to review a proposed EXEC, and to ensure that the telescope is tracking properly (especially if you are autoguiding).

- *'Movies'* : This menu allows you to take data in movie mode. Movie mode takes images of a pre-defined on-chip exposure time and displays them on the ALICE display without storing data to disk.

- *'Set_ALICE'* : This menu allows the user to define ALICE Transputer setup parameters, such as varying the size of the array being read out.

- *'Set_graphics'* : This menu allows the user to change the ALICE on-line display setup. The user can change, for example, the plotting range for image display (don't attempt to change the colour table (LUT), as this can often hang), or the position and size of the statistics window on the ALICE image display. You can also specify the bad pixel mask to be applied to the display. Choose either 'BPM_FPA40348_DEAD', which locates the brightest hot pixels, or 'BPM_FPA40348_SAA' which locates most hot pixels, and should be used whenever taking frames in Shift+Add mode.

(Don't be too concerned if the above menu titles don't appear exactly as described, as they may change under a new release of the IRCAM3 software.)

3.5.2 Valid EXEC Commands

Table 3.5.2: Valid EXEC Commands

EXEC Command	Description
CONFIG NGC1333_J	loads and executes CONFIG named NGC1333_J
BREAK	breaks current EXEC until Resume_EXEC is hit Normally put after a CONFIG, to allow the observer to check correct configuration. You can also append a label that will appear as a comment on the screen, to remind you what the BREAK is for (eg 'check autoguider')
DARK	takes a dark observation with dark setup (it is good practice to have two DARKs before an OBJECT or SKY – the first removes any residual counts, the second is the proper DARK)
OBJECT	takes an object observation with object setup
SKY	takes a sky observation with object setup
SLIDE -20 +50	slides telescope to offset -20,+50 in arcsec SLIDE can be used when autoguiding or not, but must be done with the telescope tracking at SKY PA 0
TOFF -20 +50	moves telescope (alone) to offset -20,+50 TOFF can only be used when NOT autoguiding

3.5.3 Initial Setup

The following procedure describes taking data in STARE and ND_STARE modes, which are the normal modes for WHIRCAM. See § 8 for taking exposures in Shift+Add mode.

First, load a CONFIG appropriate to your planned observing. If you don't do this you may be in an incorrect filter or have an incorrect observing mode selected in the setup phase.

- Start from the *'Imaging'* menu and go into the *'Set_instrument'* menu.

- Select the *'Recall_configuration'* menu and enter the name of the pre-defined CONFIG to be used and select YES for *'Apply_now'* option. PF1 twice to exit back to the *'Imaging'* menu. The named CONFIG will load into the system and will be executed (i.e. filters will move, the exposure time set, etc).

3.5.4 Setup on Source

- Go into *'Movies'* menu. Go into the *'Set_movie'* menu and select a movie exposure time (which is independent of the observing exposure time in your CONFIG), say, 0.5 sec, and a number of movie exposures per integration, say, 1 exposure/integration. PF1 to exit.
- If you are using ND_STARE mode, go to next item below. If you are using basic STARE mode you may need to subtract a recent DARK or SKY exposure before you can see your source in movie mode. If you need to subtract a DARK or SKY, go into the *'Set_graphics'* menu, then go into the *Background_subtraction* menu. Use either the *Subtract last integration* or *Subtract specified integration* items to define the DARK or SKY to be downloaded into ALICE and subtracted prior to movie display. Definition of a background to be subtracted automatically enables background subtraction. Remember to disable background subtraction once you are finished with it. (By the way, don't try and load a different LUT within *'Set_graphics'* as it causes the system to crash).
- Select the *'Run_movie'* item. You will need to *'Abort_movie'* before you can exit from this item. In movie mode, images of the defined exposure time are taken and displayed automatically on the ALICE movie screen. Note: *No data are stored to disk in this mode.*
- Ask the TO to centre the object at the position you require on the array. Check that the object is not saturated by inspecting the statistics displayed (see § 5.2 on saturation levels). If necessary, *'Abort_movie'* and reduce the movie exposure time and repeat the above. Because of the hot pixels, you must be careful about checking for saturation from sky. Rather than looking at the peak count, try and choose an area of the array relatively free of hot pixels, and divide the sum total by the number of pixels in the statistics box, to obtain a mean count. You can also change the display stretch from 'nsigma' to 'zero-to-saturation' within *'Set_graphics'*.
- When you are happy with the source positioning and exposure time, end the movie with *'Abort_movie'* option. PF1 twice to return to *'Imaging'* menu.

3.5.5 Taking Data On-source

- Go into *'Set_observation'* menu and type in name of object, set EXEC mode (move through the options with the left/right arrow key until EXEC is highlighted), and enter the name of the EXEC to be run. PF1 to exit. Doing this will load the EXEC into the stack displayed on the IRCAM parameter status screen. Check that the values selected are OK.
- Execute the *'Run'* item. Generally, an EXEC will have a BREAK command in it like CGS4. This serves the purpose in WHIRCAM of allowing a final check of the EXEC to be run (rather than allowing peakup as in CGS4). Once you have checked the EXEC, select *'Resume_EXEC'* and the EXEC will run to either termination or until the *'Break_EXEC'* item is selected in the *'IRCAM3_running'* menu.
- Once the system is running you will see messages on the Instrument control (menu) window of the the form:

  ```
  OBJECT configuration achieved OK
  Starting observation 5
  Started   IDIR:I960229_5_1
  Completed IDIR:I960229_5_1
  ```

```
Starting observation 6
Started   IDIR:I960229_6_1
Filed     IDIR:I960229_5_1
Completed IDIR:I960229_6_1
Filed     IDIR:I960229_6_1
```

The three messages can appear asynchronously since the software works in that manner.

- Once the message starting with 'Filed' has been issued by the system, the image of that number will soon be available for plotting/processing.
- On the IRCAM_CLRED window, a message of the form:

  ```
  Observation file RODIR:RO960229_7 available!
  ```

  will appear when the image (Observation 7 in this example) is available to the reduction software.

3.6 Focussing

The breadboard on which WHIRCAM sits has a series of permanent mounts that should ensure WHIRCAM is properly aligned with the optical axis and at a reasonable focus, and your support astronomer will check to make sure that this is the case in the evening twilight of the first WHIRCAM night (see §9 in case alignment is lost). Acquire a 5-8 mag star, and ask your TO to focus it on WHIRCAM (not the autoguider!). Once focussed, the temperature monitors, coupled to the WHT focus drive, should ensure that focus is maintained throughout the night. However, if the seeing does seem to deteriorate, it is always good procedure to re-check the focus.

The internal lenses are made from combinations of LiF and BaF elements, which apart from optimising IR transmission, also ensure very good image quality and only a small shift in focus position over the range 1 – 5 μm. To compensate for this wavelength-dependent focus shift, the detector is attached to a movable mount, whose position is automatically controlled by the Vaxstation software, using a lookup table of internal focus positions for each filter. The offset positions, in mm, are $J = -1.4$, $H = -1.1$, $K = -0.9$, and $L = -1.0$.

3.7 Shutting Down

At the end of the night, when all exposures have been taken, simply hit the PF1 key until you reach the top of the Instrument Control's menu tree. You'll then be asked to verify that you want to shut down, so answer 'yes'. When ALICE has finished shutting down, all but the ALICE occam screen and the original DECterm window should have closed. If you logout of the DECterm window, the ALICE occam screen should also close, but if it doesn't, simply select its 'Files' button and choose 'Exit'.

4 Filters

Two filter wheels, each with 10 positions are available inside the cryostat. An extensive set of filters is installed currently, but there is room for more in the current configuration. Changing filters requires the cryostat to be opened up, so ANYONE WHO WANTS TO USE A FILTER NOT LISTED IN TABLE 4 MUST GIVE SUFFICIENT NOTICE FOR THE FILTER TO BE OBTAINED AND INSTALLED (6 Months).

In general, broad band filters are placed in the front wheel, while pupil apertures and any narrow band filters that require the broad band filters as blockers are installed in the second wheel. The Filters and apertures currently installed in WHIRCAM are listed in Table 4.

Table 4: WHIRCAM Filters

Position	Wheel 1		Wheel 2	
	Element	λ (μm)	Element	λ (μm)
1	Blank	opaque	2.10 K_{Cont}	2.10 ± 0.01
2	J	1.28 ± 0.15	20 mm aperture	open
3	H	1.67 ± 0.14	16 mm aperture	spider
4	K	2.20 ± 0.20	H_2 (v=1-0 S(1))	2.12 ± 0.01
5	$K_{\rm sh}$	2.16 ± 0.16	Brγ	2.16 ± 0.01
6	nb$L$	3.42 ± 0.03	7 mm aperture	open
7	*L'*	3.80 ± 0.30	5 mm aperture	open
8	Blank	opaque	2.25 K_{cont}	2.25 ± 0.02
9	Spare H_2	2.12 ± 0.01	3 mm aperture	open
10	Blank	opaque	JOSE array	lenslets+prisms

The transmission profiles for the main filters are plotted in Figure 4.

The *Ks* filter ($\equiv K_{sh}$) is mounted with a PK-50 long wavelength blocker, which unfortunately also cuts transmission by a further 20%. *Ks* is a relatively new filter from Barr Optical, without a fully characterised transformation to *K*. However, as Pahre & Mould (1994 ApJ 433, 567) point out, its bandpass is intermediate between *K* and *K'* (2.10 ± 0.18 μm), and rough corrections of *Ks* to *K* can be obtained by taking half those for *K'* to *K*. This transformation is well defined by Wainscoat & Cowie (1992 AJ 103, 332):

$K' - K = (0.22 \pm 0.03)(H - K)$, for $0 < H - K < 0.4$

(For stars redder than $H - K = 0.4$, the relation flattens off to $K' - K \sim 0.07$ mag.)

The *K* and *L'* filters are tilted by about 5° to measure any ghosting effects, but no serious ghosting is apparent. This means there may be a slight shift in an object's position when you change to/from these filters.

A fixed 17 mm diameter stop is fixed at the pupil (cold stop) near the filter wheels. This is slightly oversized with respect to the pupil image to ensure that all the light from the telescope aperture is used at J and H. The open apertures produce a restricted cold stop (this is not strictly correct as the rear filter wheel is a few mm from the true cold stop, but is close enough to be effective), which should block most of the thermal emission from the perimeter of the secondary baffle, and should be automatically selected by WHIRCAM only with filters longward of 2 μm, as the penalty for reduced thermal emission is slightly higher vignetting. The different sizes correspond to the different magnifications used with Martini (see §12). For direct imaging the calculated telescope pupil diameter is 16.35 mm. The apertures with spiders are designed to also block thermal emission from the central obstruction.

Each of the filter options available in the CONFIG files will automatically load the appropriate combination of wheel 1 and 2 options. Thus selecting *Ks* will move wheel 1 to position 5 (the filter), and wheel 2 to position 3 (the 16 mm aperture to block thermal emission). Note that the CONFIG filters under OTHERS (ie J2, H2, K2 etc) are mostly for MARTINI. In particular, don't confuse H2 (which is the *H* filter plus a 16 mm aperture) with the H_2 filter, which is the narrow band filter centred on the v=1-0 S(1) transition, called s1 in the CONFIG file. The 2 μm narrow band filters are used with a broad band filter to block out of band leaks. DARKs are taken with a blank + Brγ to block both reflected and thermal emission. The combinations associated with each filter definition are defined in UKIRT_SCT:IRCAM.SCT, and while they must be ammended if a filter is changed (along with the UKIRT_CONFIG:WHIRCAM.DATA file), this should only be done by your SA or one of the telescope software engineers!

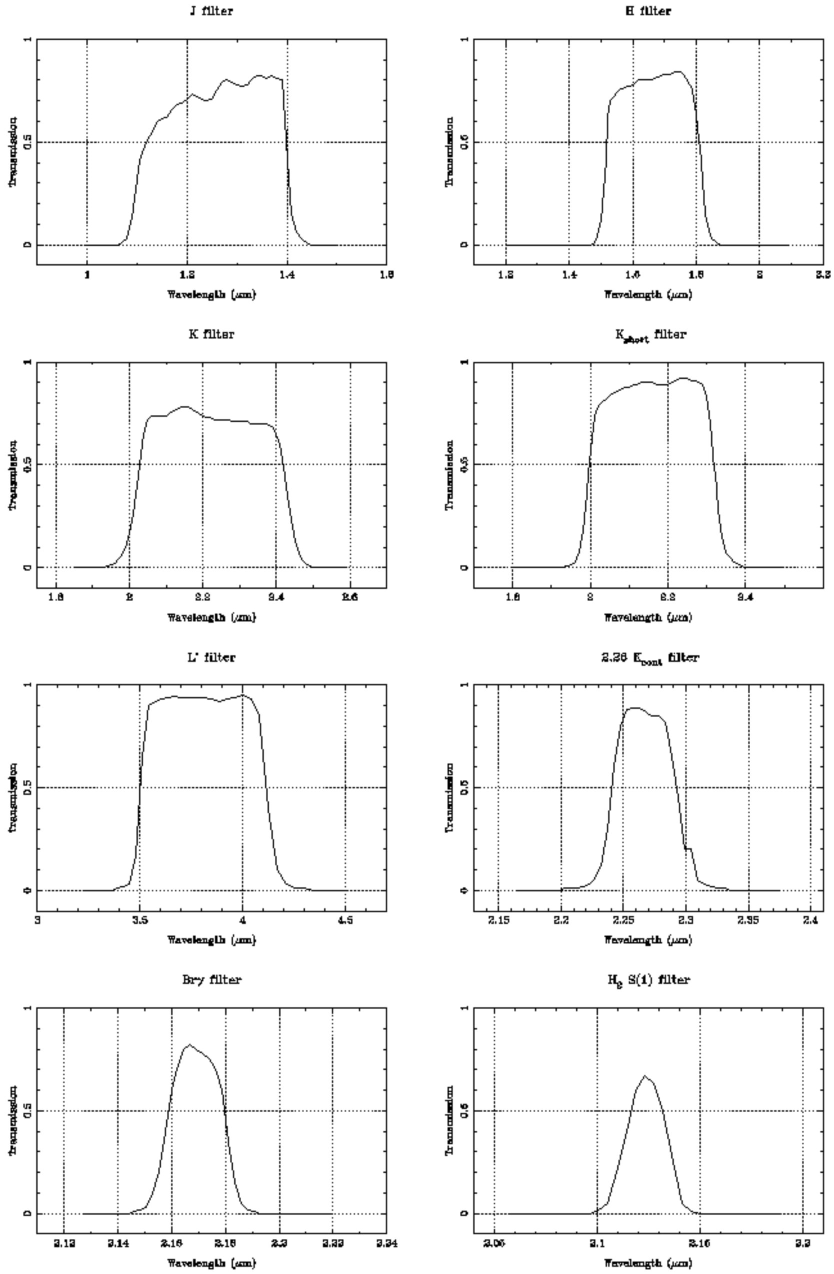


Figure 4: Filter transmission profiles.

5 Exposure Times

5.1 Array Linearity

Like all detectors, the relationship between input photons and output counts for WHIRCAM is not exactly linear. But as can be seen in Figure 5, it is almost linear over most of the dynamic range, up to about 80% of well capacity. While it is possible to correct for the deviations from exact linearity over this range, via a linearity correction table, this is currently not available. Hence if you require very precise photometry, you would be advised to create a linearity map, by exposing the detector to a reasonably flat, but constant, light source, over a range of exposure times, to accurately measure the non-linearities of every pixel.

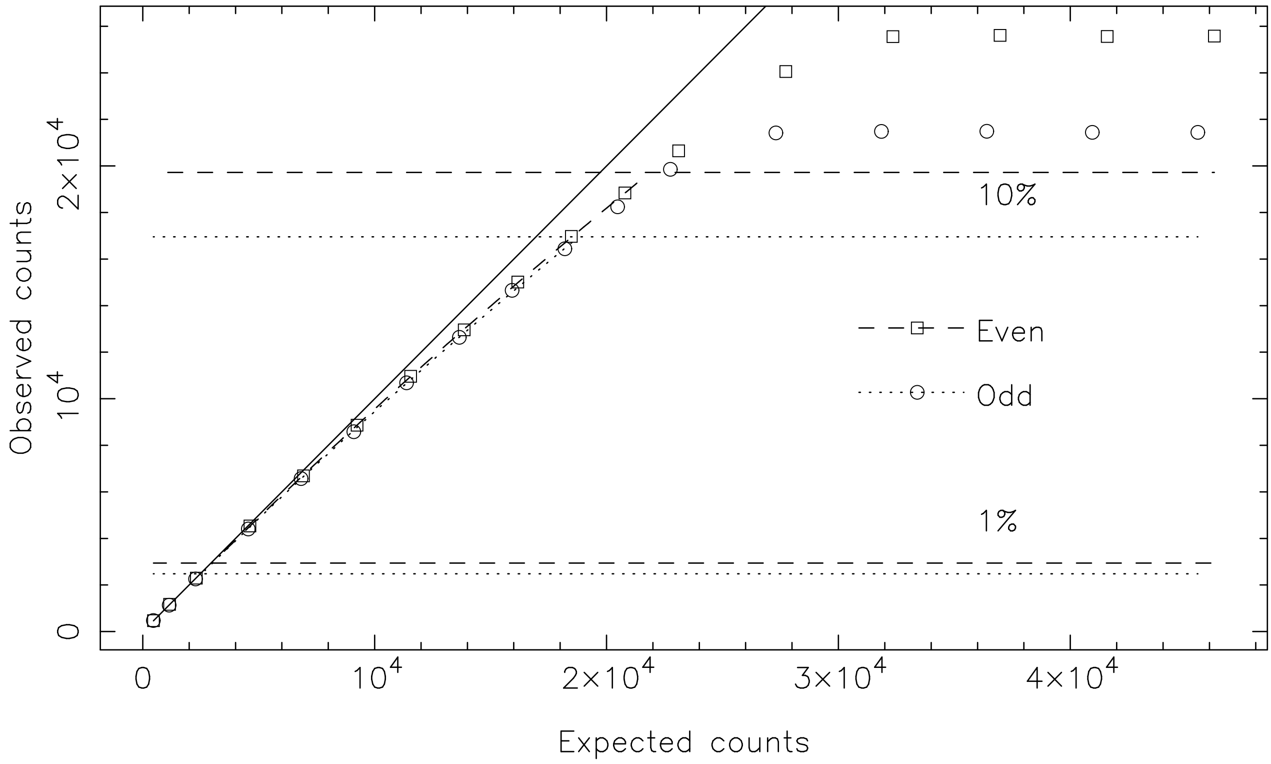


Figure 5: Accumulation of counts in odd and even columns, showing offset for odd columns in the reset level, the degree of linearity, and the onset of saturation.

5.2 Saturation

An important thing to be aware of is array saturation. With WHIRCAM, saturation is defined by the full well capacity of the pixels, NOT by the dynamic range of the A-D converter (65,535 DN). The full well capacity is controlled by the substrate voltage (called the bias voltage), but as this also affects the number of hot pixels, a larger well capacity is paid for by a larger number of hot pixels. The default voltage setting (0.68 V) provides a reasonable well depth and a bearable number of hot pixels. If fewer hot pixels are required, then you can select a lower bias voltage by selecting *Imaging*, *set_ALICE*, *recall_setup*, then change *recall_input* to FPA40348_SHALLOW, followed by *select_enable* = YES. This will change the bias voltage to 0.60 V. The default is FPA40348_DEEP, with a bias voltage of 0.68 V.

To make life interesting, the well depths, and hence saturation, vary across the chip, and vary with wavelength. And because of the non-linearity above 80% of full well capacity, the effective saturation level is even lower. In the following, all saturation figures are defined as 80% of full well capacity.

For ND_STARE mode with a bias of 0.68 V, the minimum saturation in *Ks* is 9,500 DN (along the lower edge of the chip), and the minimum saturation within the central 128×128 pixels is 12,000 DN. There is also an odd/even column effect, giving rise to two peaks in the saturation levels, at 13,500 and 17,500 DN. At *J*, these figures tend to increase, with the minimum saturation being 11,000 DN, the minimum within the central 128×128 being 14,000 DN, and the two odd/even column peaks being at 15,500 and 17,500 DN. Figure 5, plots the non-linearity for the even and odd columns, but shows simply the means of these columns. **Users should be very careful to estimate exposure times such that the maximum counts will not saturate on the chip in the area of interest. As most observations will be taken as combinations of dithers, then the best practice would be to aim to have final counts always below 10,000 DN in ND_STARE.** For STARE mode, the fixed pattern noise, dominated by the reset values, has a range of 20,500 to 28,000 DN, making a comparison with ND_STARE difficult. With a bias of 0.68 V and a *Ks* filter, STARE mode has a minimum 80% full well saturation above reset level (ie 100% of reset level plus 80% from there to saturation) is ∼37,500 DN, with less well-resolved peaks at 38,000 DN and 40,000 DN.

The approximate 80% well depths and number of hot pixels for each Bias voltage are given in Table 5.2.

Table 5.2: Bias Voltage

Bias Voltage	Min Saturation DN (STARE)	Min Saturation DN (ND_STARE)	Number of Hot Pixels
0.68	37500	10000	1500
0.60	34500	7000	200

A problem with this array is that the odd columns tend to have a lower well depth than the even columns. So that both sets of columns will have 80% saturation at similar DN values, the reset level has been set up such that it is higher for the odd columns (see Figure 5).

In the thermal near-IR (3–5μm), the background level is always high and dominates any astronomical signal. Short on-chip integrations are always required.

Although the detector is a direct readout device with 4 readouts which each address every fourth column, the minimum exposure time for full frame readout is 120 ms, limited by the multiplexer performance, and it is this minimum exposure time and finite well depth that defines lower magnitude limits below which stars will saturate the chip. Table 5.2 gives the minimum magnitudes of stars which will saturate at this minimum exposure time (in 0.5″ seeing and a scale of 0.24″/pix): Faster exposures can be made (of brighter stars) if subarrays are employed.

Table 5.2: Brightest observable stars

J	∼8.6
H	∼8.4
K	∼7.8

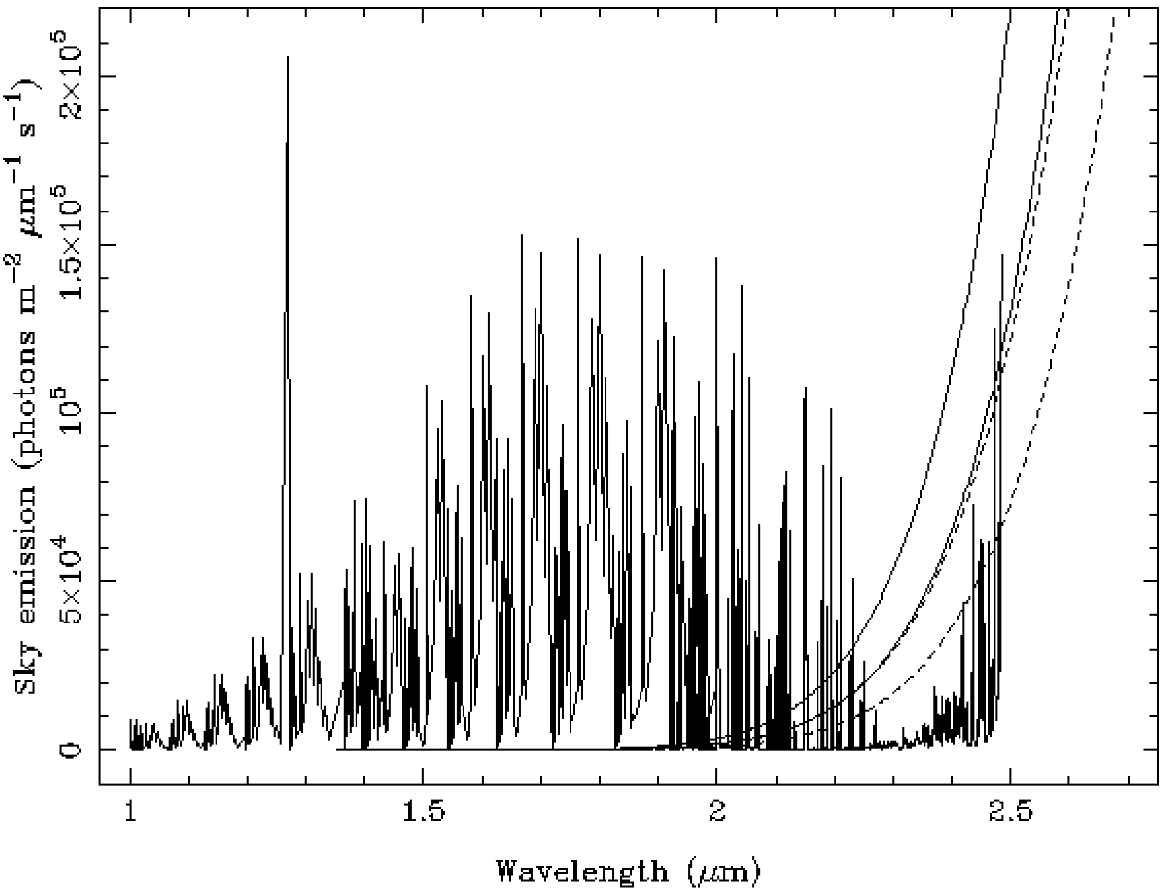


Figure 6: Calculated sky emission for winter (T = 278 K) under dry conditions between 1 and 2.5 μm. The strong airglow emission lines dominate the spectrum shortwards of 2.3 μm, where thermal emission from the sky starts to become apparent. However, emission from the telescope increases rapidly beyond 2.2 μm and dominates the background. The dotted and dashed curves represent the emission from a 20% emissive telescope at 285 and 275 K respectively.

5.3 Extinction and Sky Brightness

The extinction at *J*, *H* and *K* was estimated from observations of standard stars at about 0.10, 0.11 and 0.07 mag/airmass, respectively, but these values are likely to vary from night to night, and the best solution is to monitor a few standards throughout the night, over the same range in air mass as your objects. A model of the sky emission together with a representation of telescope emission is shown in Figure 6, while an atmospheric transmission spectrum is shown in Figure 7. The winter and summer sky brightnesses are given in Table 5.3.

5.4 Background-Limited Operation (BLIP)

Minimum exposure times needed for noise due to sky to dominate the readout noise (RN $\sim 40e^-$), assuming gain of 6 e$^-$/DN and a pixel scale of 0.24″/pix are given in Table 5.4.

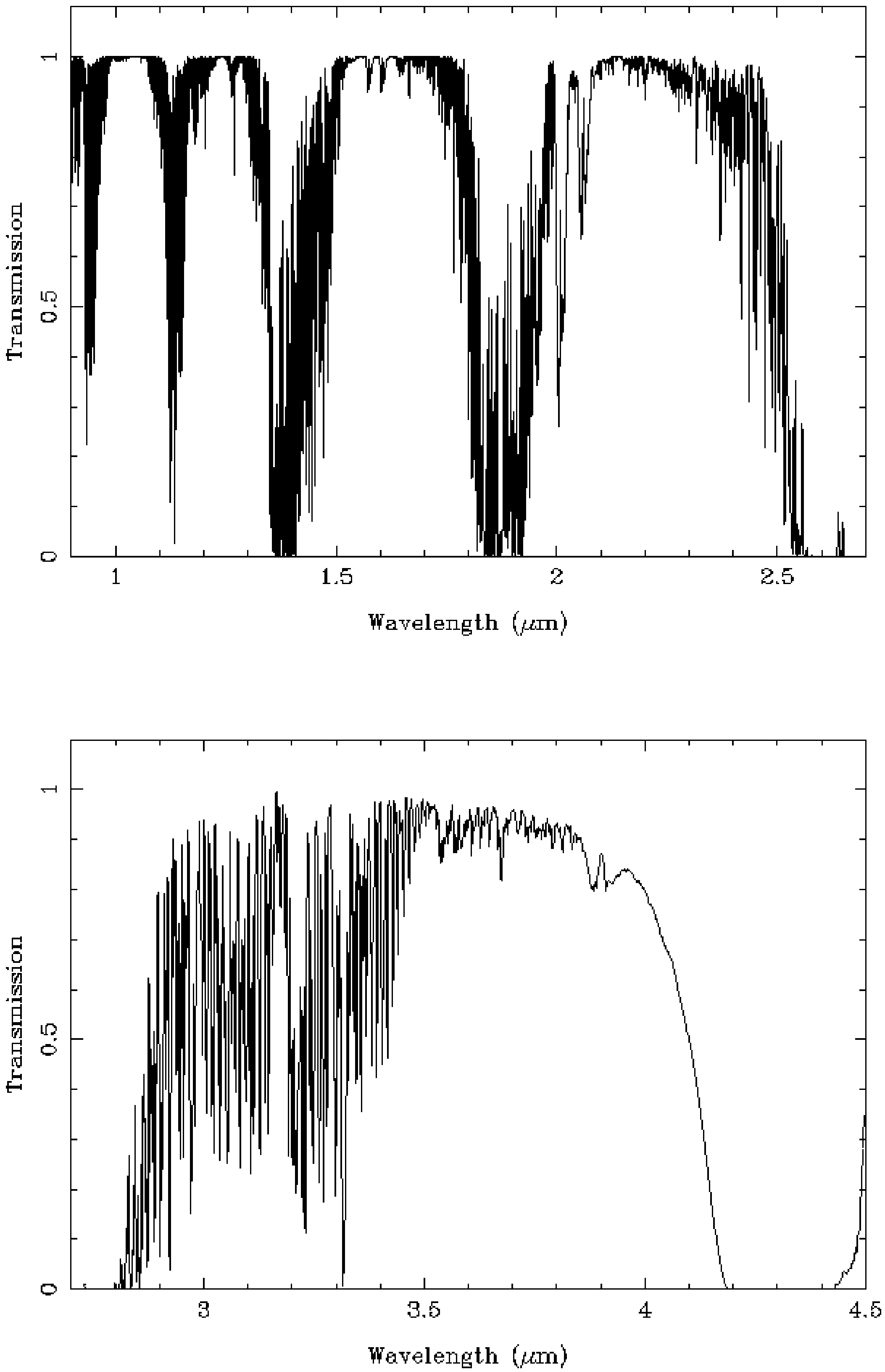


Figure 7: Calculated sky transmission spectrum for La Palma.

Table 5.3: Measured Sky Brightness - Mag/arcsec^2

	February 95	June 95 Full Moon
J	16.6	15.6
H	14.4	13.9
K	11.0	11.4
Ks	12.0	12.0
L	2.9	3.4

Table 5.4: BLIP Times

Band	Sky Noise/RN 1.0	3.0
J	~3s	~9s
H	~1s	~3s
K	~0.5s	~1.5s

5.5 Limiting Magnitudes

Figure 8 plots the log(Exposure time (secs)) needed to reach a given magnitude at a S/N of 5 and 20, for seeing conditions of 0.564$''$ (ie 1 $\square''$, ie for surface brightness), 0.8$''$ and 1.2$''$, and for apertures of radius 2.5×seeing, observing in ND_STARE mode.

5.6 Throughput

The total instrument + telescope + atmosphere throughput was measured in June 1995 at about 15%. This value is lower than expected, compared to the estimated total system throughput of about 22%, based on the figures in Table 5.6.

Table 5.6: Estimated Throughput

Sky	0.95
3 x Al Telescope mirrors	0.9^3
3 x Ag Derotator mirrors	0.95^3
dichroic (wavelength dependent)	0.95
Window	0.95
5 x lenses	0.95^5
Filter	0.75
Detector	0.8
Stop Vignetting at $\lambda > 2\mu$m	0.9
Total	0.22

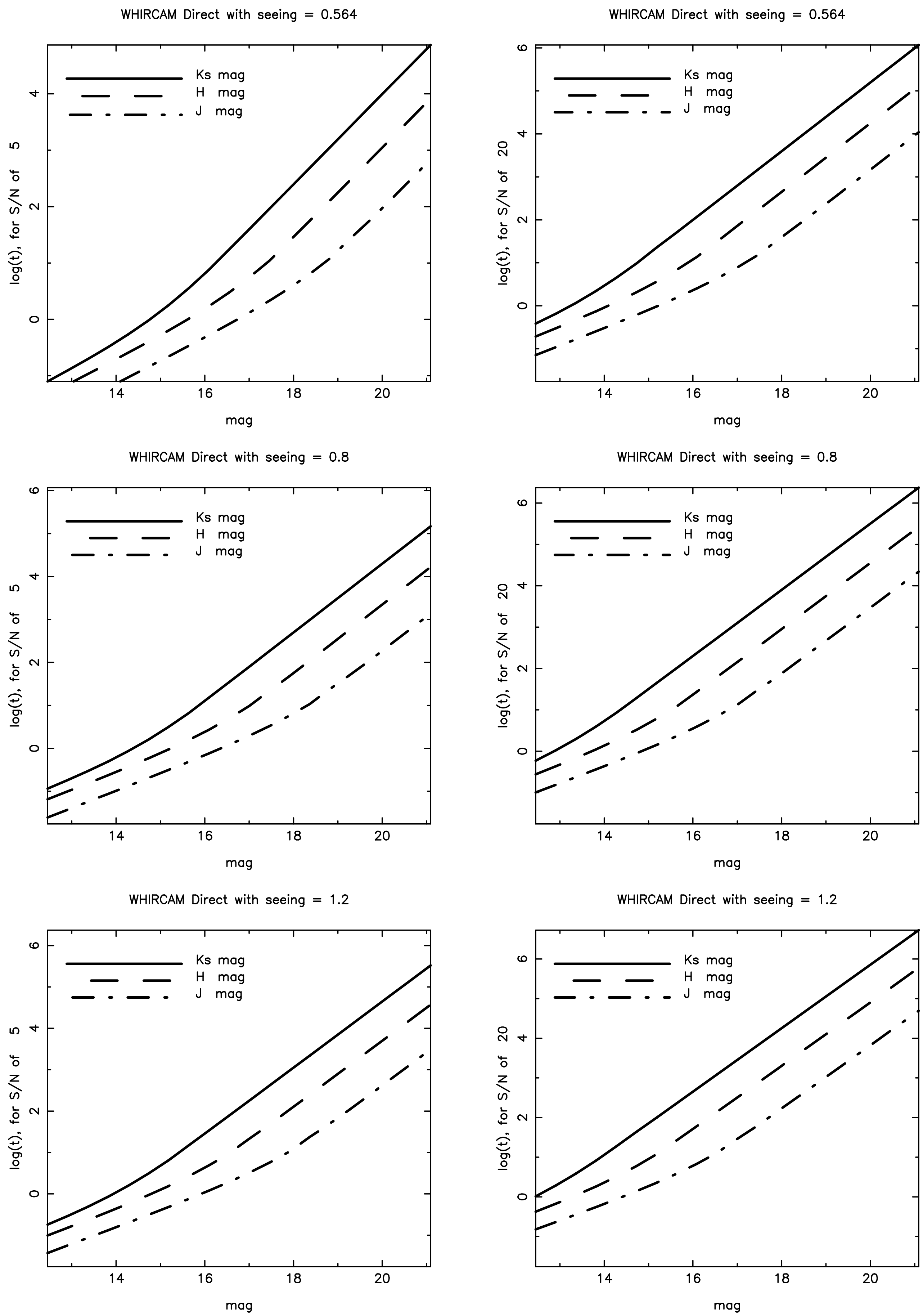


Figure 8: Calculated exposure times for various conditions.

6 Standards

A list of Faint and Bright (for 3 μm) IR UKIRT standards can be found in Appendix D. The positions of these standards are also loaded into the default WHT standards catalogue. Typical exposure times for most of these will be 1-3 secs, and you should of course take each standard exposure through each filter used on your programme objects. At the very minimum you should take 3-4 standards at the beginning and end of the night and 2-3 in the middle, and it is always a good idea to take 1-2 throughout the night, every 1-3 hours, to monitor the sky conditions (especially true if there is any dust around, or the possibility of cirrus). You should also aim to observe at least one standard over as large a range of airmass as possible, so you can derive extinction coefficients for each night, as these may change depending on how much dust is around.

And don't forget to take your standards in a series of dithered exposures, to allow accurate removal of sky and cosmic rays, and to remove all the hot pixels!

7 Data Storage

The exposures are written to an external hard disk as .SDF files, which should have up to 2 Gb (3.9 M blocks) free space at the start of your run. Each 256×256 frames is 270 kb (530 blocks) large, hence you should be able to store up to ~7000 full sized images on disk, although the amount of free space will often be less than as WHIRCAM data from previous runs are generally not deleted until after the D-tape has been varified. If your exposure times are short, you should consider using a number of exposures per integration to save disk space (see § 3.5.1).

The disk name, directory structure and filename nomenclature are:

```
DISK$IRCAM:[WHIRCAM.DATA.IRCAM_DATA.YYYYMMDD.IDIR]IYYMMDD_N_1.SDF
DISK$IRCAM:[WHIRCAM.DATA.IRCAM_DATA.YYYYMMDD.ODIR]OYYMMDD_N.SDF
DISK$IRCAM:[WHIRCAM.DATA.IRCAM_DATA.YYYYMMDD.RODIR]ROYYMMDD_N.SDF
```

where YYYYMMDD is the directory date (eg. 1996 Feb 29 = 19960229), YYMMDD is the filename date (eg. 1996 Feb 29 = 960229), and N is the run number. The IDIR directory contains the array+header data, and it is these files which are written to tape by AUTOFITS (see below). The files in the ODIR directory are just the header information for each frame, and the RODIR directory is where frames read in and/or produced by IRCAM_CLRED are stored (ie Reduced Observations).

At the beginning of each night's observing start AUTOFITS running, which will automatically back-up your data to a DAT D-tape and a C-tape (DAT or exabyte) as each frame is written to disk. AUTOFITS converts the .SDF files to FITS format as it writes them to tape. The C-tape is the observer's copy which you can take home with you.

To use AUTOFITS with WHIRCAM, log onto one of the VAXcluster machines (LPVE, LPVF or LPVG, usually from one of the VT220 terminals in the computer terminal room) as TPCOPY (no password required), type AUTOFITS, and answer all the questions. You can currently write up to four tape copies simultaneously (one D tape and up to 3 C tapes, but remember that more than one C tape must be paid for), and append files to previous nights' data tapes. AUTOFITS will write every file stored in the current IDIR directory, including vector maps (created in Shift+Add integrations) and any reduced data frames you may create there (if you don't want these written to your archive tape, then reduce your data in the RODIR directory).

If you wish to reduce your data at site using IRAF on the unix cluster, you can either re-read your C-tape copy using rfits in IRAF, or else create diskFITS copies using WDFITS in Figaro, and copy these to a unix disk using ftp, followed by rfits in IRAF.

8 Shift + Add Mode

Although S+A may sound like a good way to obtain sharper images, in practice it suffers from a number of problems, making its use limited to bright compact sources, not faint extended structure. In order to benefit from S+A, the exposure times need to be shorter than the typical variations in seeing (ie as short as possible), for which the readout noise will dominate the background noise. And because there are a large number of readouts per stored frame, the summed readout noise will be quite large. The effective noise will be even larger if the number of transient hot pixels confuses the shift algorithm to occasionally shift to the hot pixel rather than the source, hence the limiting magnitude of the guide star needs to be lower than just a shorter exposure time might imply. As well, to obtain very good images, a magnified pixel scale is required, but there isn't enough room at GHRIL (in direct mode with the dichroic) to insert the pair of magnifying mirrors. S+A also requires an offset sky frame to be taken beforehand, which is then subtracted from all the object frames before they are shifted and added. And the number of exposures per integration must, for some peculiar reason, be a prime number.

You would only ever want to use S+A to sharpen your images, hence you need exposure times shorter than the seeing variation timescale. A reasonably bright star (brighter than ~12 mag) is therefore needed for the S+A centring algorithm to determine the correct shifts. Because of the extra readout overhead with an ND_STARE, S+A is taken in STARE mode. This means a SKY frame must be taken before a S+A sequence, so it can be subtracted from the subsequent OBJECT frames within ALICE, in order remove most of the hot pixels (but alas not all – see § 3.4) and the fixed pattern of the bias pedestal and flat field, so that centroiding can be done efficiently. SKY subtraction also minimises the extra noise created by dithering the fixed pattern noise. So before running S+A, offset to a clear patch of sky, and take a sky frame of the same exposure as your object.

The sequence of commands to get S+A going is:

- Go into the *'Imaging'* menu, then the *'Set_ALICE'* menu, and then the *'Set_read_area_&_speed'* menu. Set *'Readout_area'* to 128×128 or 64×64, depending on the FOV required and the frequency of corrections (see readout times in §2). Also set *'Readout_speed'* to STANDARD.
- Move telescope to an offset SKY position.
- Go into *'Set_Instrument'* menu, then into *'Direct_config'* menu, and set Filter, Magnifier (2X or 5X if using Martini – this tells WHIRCAM to select the appropriate cold stop), Aquisition_mode (to STARE), Object_exposure_secs (something short, like 0.07 sec), and Object_exp_per_integ (enough integrations to give a decent S/N. NOTE this number MUST BE A PRIME!).
- Take a SKY exposure: Go into *'Set_observation'*, set to SKY, then go into *'Run'*. Make sure this exposure time is the same as for your object.
- Move telescope to OBJECT and acquire object.
- Tell WHIRCAM to subtract the SKY image: go into *'Set_graphics'*, then into *'Background_subtraction'* and set *'Subtract_last_integration'*.

- Now select S+A: go into *'Set_ALICE'*, then into *'S+A'*, and set Enable_shift_&_add to TRUE, Bid_area_dimensions to 32×32 or 64×64 (to define the size of array ALICE searches for a peak), and Bid_area_centre_X to 128 and Bid_area_centre_Y to 128, if search area is in centre of chip. Note that the X and Y coords for the search area are with respect to the whole chip, not any subarray that may have been selected to decrease the readout time.
- Now tell WHIRCAM to ignore bad pixels in its search for the peak: go into *'Specify_bad_pixel_mask'*, and set _for_shift_&_add_observations to 'bpm_fpa40348_saa', and set Force_download_of_newmask to TRUE.
- Finally, go into *'Set_observation'*, set to OBJECT, then go into *'Run'*.

Once the OBJECT integration is finished, a normal (but hopefully better resolved) WHIRCAM image file will be created, plus a vector map of all the centroids determined by ALICE, in an image filename suffixed with 'V'.

9 Trouble Shooting

It is possible as with all complex instruments and electronic systems, that a time will come when the user encounters a problem, a hangup or a crash. This section details known problems and how to recover from them cleanly. Please seek the help of your SA or TO when a problem occurs! It is likely they have 'seen it all before'.

WHIRCAM REFUSES TO STARTUP

- The PROBLEM: After typing whircam_startup, at some point you get an obscure error message and the startup task exits before all windows are created.
- The SOLUTION: Check to ensure that the ADAMNET task is running on both the WHIRCAM Vaxstation and on the VAX cluster by typing SH SYS on the WHIRCAM terminal, and on LPVS3 or LPVS2, and make sure the ADAMNET task is running on both. If it isn't, then type @UKIRT_DIR:ADAMNET
If ADAMNET was running, or if one of the error messages is "nonsense SP request," then shutting down WHIRCAM and logging out, then logging in and re-starting should solve the problem. If it still gets stuck, reboot IRCMVX (the WHIRCAM Vaxstation) (ask your SA or Duty Engineer).

THE ALICE OCCAM/TRANSPUTER SYSTEM HANGS/DIES

- PROBLEM: At some point, the Occam/Transputer system will crash/die with one of the following error messages appearing on the IRCAM3_DEV SMS menu window.

```
BDS_ERRCHK> Error while getting ackn from CORE of GO completion
- BDS_CORE_SERVER> ERROR: Channel comms timed out on tag receive
WFG_OBEYW> Error completing action COMPLETE in 4^^1 task.
BDS_CORE_SERVER> ERROR: Channel comms timed out on tag receive
!! AIM> After INTEGRATE TASK_DONE SAI-I-ERROR, Error
%SAI-I-ERROR, Error
148013867
```

or

```
BDS_ERRCHK> Error while sending parameter block
- BDS_CORE_SERVER> ERROR: Channel comms timed out on tag send
WFG_CONFIGURE> Action SEND_PARAMETERS in BDS task failed.
- BDS_CORE_SERVER> ERROR: Channel comms timed out on tag send
!! ALICE_DONE> Action failed to complete in WFG : STATUS =
SAI-I-ERROR, Error
!  ALICE_DONE> Returned OUTVAL =BDS_CORE_SERVER> ERROR: Channel
comms timed out
! on tag send
!! AIM> After CONFIGURE TASK_DONE SAI-I-ERROR, Error
%SAI-I-ERROR, Error
148013867
```

What is happening is that the BDS gets a command (to say, GO) and sends this onto the CORE transputer system. This should be, and is, acknowledged. When the observation completes, the CORE has to send an acknowledgement to the BDS that the (GO) completed successfully - it is this acknowledgement that the BDS never receives (e.g. ackn from CORE of GO completion). This is a sure sign that the Occam is hanging for some reason - the subsequent error:
(starting BDS_ERRCHK> Error while sending parameter block ...)
is a further indication that the Occam side cannot communicate with anything else.

- The SOLUTION: Try the following first:
  1. Click on small ALICE parameter display window to re-activate it.
  2. Do cntrlˆ C three times. The result of this will be to re-gain the DCL $ prompt.
  3. Open a new DECterm window under the Applications menu of the Session Manager.
  4. In the new DECterm type:

     ```
     ALICE_CONFIG <CR>
     ALICE_OCCAM <CR>
     ```

     This will re-load the Occam/Transputer side.
  5. Click on IRCAM3_DEV window to re-activate it again.
  6. Go up to the top level IRCAM3 menu.
  7. Go into the *'Engineering'* menu.
  8. Go into the *'ALICE_engineering'* menu.
  9. Go into the *'Reinitialise_occam'* item. This will re-establish communication with the Occam/Transputer system.

  Unfortunately, this appears not to be successful ALL the time. If this procedure does not work then run down the whole WHIRCAM system, logout and start again! This process will take about 5 minutes.

THE ALICE/TELESCOPE LINK HANGS/DIES DURING A SLIDE

- The PROBLEM: If your EXEC calls for a series of SLIDES (eg for a dithered pattern), and the telescope is also autoguiding, then occasionally the link between WHIRCAM and the telescope control software (TCS) dies and the EXEC is suspended. This is because the TCS was waiting for a handshake from the autoguider, telling it that the guide star has been re-acquired after the SLIDE, but it didn't get it within the default response time.
- The SOLUTION: On the ICL terminal, type 'SEND AUTO CANCEL GUIWIND', which should cancel the hung state of the TCS. Then get your TO to re-aquire the guide star with the autoguider, then on the *IRCAM3 Instrument Control* screen select *'Resume_EXEC'* and the EXEC should resume where it left off.

ETHERNET FAILS

- The PROBLEM: Communications fail.
- The SOLUTION: First, check for a flashing light on the ethernet box in the WHT computer room. WHIRCAM is connected to port 4. If its flashing, reset the box.

  If no flashing light, then type SET PROC/PRIV=ALL in WHIRCAM's SMS window, then type UCX. At the UCX prompt, type 'ping cgs' which checks for a response from ALICE. If no response, then something is likely wrong with either the ethernet, the B300, or IRCMVX ethernet. Call a duty tech.

THE WHIRCAM MOTOR DRIVES FAIL

- The PROBLEM: Being a mechanical part, the motor drives that position WHIRCAM's filter wheels are the one part that may fail at some time (usually about 3 am). As the filter wheels are positioned according to indents on the wheels tripping a microswitch, ALICE should tell you if it can't move the filter wheels, such as when a drive motor fails.
- The SOLUTION: First, check that it is a problem, and select the *'datum_motors'* menu in *'ircam_engineering'* (via the *'engineering'* and *'set_instrument'* menus). If this fails, then reload the motor drive software, as described in the WHIRCAM DUTY ENGINEER CHANGE MANUAL (in the WHT control room or the WHT manager's office). If this fails, then the motor(s) is/are probably stuffed.

  Replacing the failed motor drive is the obvious solution, but so as to avoid losing a large fraction of the night, there is an option of running WHIRCAM without motor control, in which all the other functions will continue as normal, but filter changes will have to be done by hand. In this case, close down WHIRCAM, and restart with 'whircam_manual' instead of 'whircam_start'. The motor drives sit on the back of the WHIRCAM cryostat, and when not powered (switch off the drives in the GHRIL console area), can be rotated by hand. The datum position (position 1) is marked on the drive wheel, and each new position (in the direction of the arrow) can be felt by hand as you rotate the wheel. While this may be time consuming and laborious, real astronomers prefer this than to going to bed early.

HIGH DARK CURRENT

- The PROBLEM: The results from an array_tests (see §3.3) gave non-nominal results for the dark current.
- The SOLUTION: Repeat array_tests to make sure it wasn't a fluke. If it still persists, check that the cold head temperatures on the temperature displays in the GHRIL room are nominal (Table 9).

  If any temperatures aren't nominal, then the He in the closed cycle cooler may be low, and needs to be topped up. Call the Duty Tech.

Table 9: Nominal Temperatures

Temp Probe	Nom Temp
Optics	~70-80
Detector	30
Cold head 1	~60
Cold head 2	~20

HIGH READOUT NOISE

- The PROBLEM: The results from an array_tests (see §3.3) gave non-nominal results for the readout noise.
- The SOLUTION: If your ALICE display shows a lot of diagonal streaks, then ALICE probably isn't switched on. The enable switch is a key in the upper middle part of the ALICE rack up in the GHRIL control room, and should be fully turned CLOCKWISE (a green LED to the right of the key will be on if enabled).
  If the display looks flat (apart from hot/dead pixels), then repeat array_tests to make sure it wasn't a fluke. If it still persists, then check if the chip is being properly read out. To achieve fast readout times, ALICE uses 4 ADCs, each reading out every 4th column. Check to make sure all readout channels are reading out similarly, by plotting a histogram of each readout output. To do this, open another DECterm window, type 'set def DISK$IRCAM:[WHIRCAM.DATA.IRCAM_DATA.19960229.RODIR]', then 'ircam_setup', then type 'cgs4dr' (the Data Redustion System for UKIRT's CGS4 IR spectrograph). This will create another SMS window session. Within this, select the *'engineer'* menu, then *'graphics'*, then *'plot_histogram'*. Within this menu set Data to the 4th image in the array_tests sequence (this is a DARK), and the following:

  ```
  Display_port = 1
  Data_area = DATA
  Number_of_bins = 50
  X_step = 4
  Y_step = 1
  Smooth_size = 0
  Soft_or_hard_copy = SOFT
  Display_whole_area = FALSE
  _xstart_if_not_whole = 1
  _ystart_if_not_whole = 1
  ```

  This should plot a histogram of the first transputer readout in the upper left quadrant of the image display. To display the second transputer readout, reset Display_port to 2 (shifts to the next display quadrant in upper right) and _xstart_if_not_whole to 2. Repeat for the third and fourth transputer readout. You should then end up with 4 histograms, one per display quadrant. They should be all about the same mean, with widths of typically a few counts. If one is noticeably wider, then check the cable for that transputer (in the ALICE rack in the GHRIL control room) to make sure it isn't loose. If the SA doesn't know which cable belongs to which transputer (eg the brown cable is channel 4), you'll have to disconnect each in turn, repeat array_tests and re-plot the histograms to see which one changes.

If all cables seem to be OK, then it may be that one of the ADC cards is broken. Spare cards exist, so call your Duty Engineer.

MISALIGNMENT OF WHIRCAM AND/OR DICHROIC

- The PROBLEM: Normally, WHIRCAM should be properly aligned with respect to the rotation and optical axes by the SA at the start of a run. However, if some clod happens to later bump into either WHIRCAM or the dichroic, then you'll need to call your SA (or the site SA) to re-align the optics.
- The SOLUTION: This is the method your SA should use to realign. If only the optical breadboard was bumped, then use the alignment jigs to re-position it back to its nominal position and orientation. Stand next to the optical table, facing WHIRCAM's snout (ie looking over the dichroic box towards WHIRCAM, with the telescope and de-rotator to your left). Get someone else to face you, on the other side of the table (the breadboard is heavy and won't slide very easily, so you'll need someone else to push/pull while you pull/push). There are two metal alignment tabs attached to your side of the breadboard, and one tab on your left side of the breadboard, near the re-rotator. Slide the breadboard such that all 3 tabs touch the sides of the optical table. Make sure that the various location clamps on the breadboard are still tight.

  If the dichroic was moved, then you must tweak the micrometers to re-align it:

  - In the GHRIL control room, disconnect the graphics monitor cable, and connect up a PC monitor (which if not in the GHRIL control room will have to be 'borrowed' from someones desk), and place it on the optical table.
  - Run MOVIE with 0.5 sec integration, in ND_STARE mode, the nbL filter, and 0.68V BIAS. Put the statistics window on a dead-pixel-clear part of the chip (select *set_graphics, statistics_window* menus, then set centre_column to 145, centre_row to 120, width to 10, height to 10). Take a DARK and set graphics to subtract it from subsequent exposures.
  - Point telescope to near zenith, make sure dome and mirror covers are open, and that you are pointing at blank sky and not a bright star, and make sure the telescope is tracking.
  - Adjust first one micrometer so as to minimise the total counts from sky (the night sky at L should always be less emissive than the secondary baffle!). Make sure stray fingers don't touch the dichroic, and are well away from WHIRCAM's FOV when you take the measurements. Now do the same for the other micrometer (ie the other axis). Finally, repeat for the first micrometer.
  - You should now be re-aligned. Take note of the micrometer readings. (In January 1996 these were twist (azimuth) = 5.810 mm, shout (altitude) = 5.135 mm.)
  - To be sure, you can repeat the above, but first set up on a bright star, set the filter to J, and now try to maximise the total counts (check to make sure the peak pixel isn't saturated, and keep the whole of the stellar image within the statistics box on the monitor).

- The final micrometer readings should be the same as those obtained on sky in NBL. If not, repeat on sky with the NBL filter.

You may need to re-determine the rotation centre (your TO should know how), but make sure it is for SKY PA 0. (In Jan 1996 the rotation centre was at WHIRCAM pixel position 103, 195).

10 Appendix A. Data Reduction with IRCAM_CLRED

These notes are taken from UKIRT's IRCAM3 manual by Colin Aspin (see http://www.jach.hawaii.edu/~caa/caa_ircam3.html), and modified for WHIRCAM. A UNIX version of IRCAM_CLRED has also been recently written, called IRCAMDR (see http://www.jach.hawaii.edu/ukirt_sw/ircamdr/sun41.html).

Either log onto any of the Vaxstation terminals (LPVS3 or LPVS5) as user OBSERVER (get current password from SA or TO), or open another DECterm window on the WHIRCAM terminal, then type (where YYYYMMDD is the current year, month and date, eg 19960229):

```
ircam_setup
set def DISK$IRCAM:[WHIRCAM.DATA.IRCAM_DATA.YYYYMMDD.RODIR]
ircam_clred
```

You will be asked to supply the same ID as you entered under IRCAM_DEV, a workstation number (always choose 18), the data format ('NEW' for WHIRCAM data), the UT date relevant for the frames taken (eg 960229), a filename suffix (choose 'none') and the plate scale (0.24 ″/pix for WHIRCAM direct).

The IRCAM Command Line REDuction system will now run up and present you with the IRCAM logo (on the graphics window) and the prompt:

```
Ircam-Clred >
```

You can, if you like, reduce the size of the DECterm windows to see the whole of the GKS graphics window by clicking on 'Options' and selecting 'Window' and clicking on 'Condensed Font' then 'Apply' and finally 'OK'.

Once in IRCAM_CLRED, the system is setup to access the reduced observation files (prefixed by RO) in the current directory by their observation number alone.

- To display an RO image (eg observation 42) type:

  ```
  NS 42 <CR>
  ```

- To display the difference between two images (say, an OBJECT and a SKY or two OBJECTs at different spatial positions) type:

  ```
  DISP 42 41 <CR>
  ```

  to subtract 41 from 42 and plot the difference.

- To define a zeropoint use the command:

  ```
  STDPHO 41 42 <CR>
  ```

  where observations 41 and 42 are the first two images of a faint standard (FS) 5-point mosaic (see § 6). The difference between the two images will be plotted and you will be asked to select the standard star with the cursor. The system will calculate a zeropoint and load it into the system.

- To reduce STARE and ND_STARE mosaics type:

```
STRED <CR>
```

Below is an example of the input required by STRED.

```
Ircam-Clred > stred
Current IRCAM file prefix =  RO960229_
Current IRCAM file suffix =  NONE
Enter a PREFIX for the output image(s)
Prefix    |IMAGE_| ? field22_
Enter start observation number ?
Start           |1| ? 21
Enter number of images to be reduced ?
Number of Images |1| ? 5
Enter the DARK image number :
Dark number    |1| ? 2
    Observation specified as DARK is truly a DARK!
    CONGRATULATIONS, you did good!!!
Do you want to MEDIAN FILTER the objects for a flat or
use a SEPARATE pre-prepared (normalized) SKY image ?
Median or Separate Sky (M,S) |M| ?
Do you want the images airmass corrected ?
Airmass Correction (Yes or No) |N| : y
Do you want the images auto-mosaiced ?
Mosaicing (Yes or No) |Y| : y
Getting RA,DEC offsets from input images...
  Image  RO960229_21
  Image  RO960229_22
  Image  RO960229_23
  Image  RO960229_24
  Image  RO960229_25
RA,DEC (modified) offsets in image sequence are :
     0.000     0.000
     0.656    -5.297
     6.178    -5.124
     6.268     0.379
     5.633     5.411
Use these offsets or use user-defined telescope  offset (ASCII) file ?
File Offsets or User-defined (F,U) |F| ?
Give name for FINAL mosaiced image :
Final Image |X| ? field22_final
```

STRED then reduces the specified images and, if requested, puts together the final mosaic. Output images will be, as in the e.g. above,

```
FIELD22_21DFGA
FIELD22_22DFGA
FIELD22_23DFGA
FIELD22_24DFGA
FIELD22_25DFGA
FIELD22_FINAL
```

Other useful IRCAM_CLRED commands include:

- CSTATS gives statistics (max,min,mean,median,1-sigma std) on cursor defined box on image.
- LIMAG gives 1-,5-,10-,100- sigma limiting magnitudes of images/mosaics once zeropoint has been defined.
- PHO to get photometry of sources - 4″ aperture is good for faint standards, 2″ is good for faint sources (e.g. asteroids, QSOs etc).
- EXIT to exit.

11 Appendix B. IRCAM_CLRED Commands

Image Analysis commands

Name	Description
ANNSTATS	Statistics in annulus in an image.
APERADD	Statistics in aperture in an image.
APERPHOT	Aperture photometry in an image.
APERPOL	Aperture polarimetry in 4 pol images.
BINUP	Compressed image in size by averaging pixels.
BLOCK	Block smooths an image.
CALCOL	Calculates colours from magnitude images.
CALEXP	Calculates optimum exposure time for image.
CALMAG	Calculates magnitude image from flux image.
CALZER	Calculates zeropoint from flux/inst. mag.
CENT2	From two cursor positions, calculates source distance and p.a.
CENTROID	Calculates centroid position of stellar image.
COMPADD	Compresses size of image by adding numbers in NxM box.
COMPAVE	Compresses size of image by averaging numbers in NxM box.
COMPICK	Compresses size of image by picking every Nth, Mth pixel.
COMPRESS	Compresses size of image.
CREFRAME	Creates an test image with different output options.
CSGEN	Generates a centro-symmetric polarization pattern THETA image.
DAOCEN	DAOPHOT utility for ...
DAOFIND	DAOPHOT utility for ...
DAOGID	DAOPHOT utility for ...
DAOGID2	DAOPHOT utility for ...
DEVFCS	Calculates deviation from centro-symmetry in polarization THETA image.
FINDPEAK	Finds a peak (??)
HISTEQ	Histogram equalizes an image.
HISTGEN	Generates a histogram of an image.
IMCOMB	Combines images by scaling and insertion.
LAPLACE	Applies a Laplacian filter to an image.
LIMAG	Calculates limiting magnitudes using zeropoints set by SETVAR.
LOOK	Shows on terminal sub-array values in an image.
MANIC	Changes size of an image busing cubic-spline interpolation.
MEDIAN	Applies a median filter to an image.

MOFF	Mosaic tiles auto DC and spatial offset matching.
MOFFLOT	Applies MOFF to a sequence of images.
OLOOK	Shows on terminal sub-array of image referred to by observation number.
PHO	Aperture photometry on image using separate sky aperture.
PHO2	Aperture photometry on image using concentric sky annulus.
PHO3	Ap phot on image using concentric sky annulus displaced from object aperture.
RADIM	Produces a radial profile image from given image and user-defined position.
SEE	Interactive star selection then (KAPPA) PSF fitting for FWHM.
SHADOW	Shadow enhances an image.
STDPHO	Performs photometry on images and defines zeropoint.
STEPIM	Steps an image (pseudo-contours) between user-defined flux levels.
STREHL	Calculates the Strehl ratio of an image.

Image Display commands

Name	Description
ABLOCK	Plots colour block at at user-defined location.
AGAIN	Re-displays last image plotted.
ANNCOL	Sets colour of displayed annotation.
BORDER	Draws a simple box border around an image.
BOX	Plots a rectangular box on an image.
CABLOCK	Plots a colour block at cursor selected position.
CBOX	Plots a rectangular box at cursor position on image.
CCIRCLE	Plots a circle at cursor position on image.
CCROSS	Plots a cross at cursor position on image.
CCUT	Plots a cross-cut through an image from x1,y1 to x2,y2.
CELLIPSE	Plots an ellipse at cursor position on image.
CIRCLE	Plots a circle at user-defined position on image.
CLEAR	Clears the plotting window of all images/line graphics.
CLEARIT	Clears a user-defined area of images/line graphics.
CLINE	Plots a line between cursor defined positions on image.
CNSIGMA	Plots an image with NSIGMA scaling at cursor position.
COLCYCLE	Cycles a pre-defined colour table (LUT) N times.
COLINV	Inverts the colour table (LUT) colours.
COLTAB	Write a pre-defined colour table (LUT) to plotting window.
CONTOFF	Defines offsets on screen (in pixels) for contour map plot.
CONTOUR	Plots a contour map of image defined in SETCONT.
CONT_TITLE	Defines the title for a contour map plot.
CPLOT	Plots an image with X to Y scaling at cursor position.
CRANPLOT	Plots an image with +-X on mean scaling at cursor position.
CRECOLT	Creates a colour table (LUT) with user-defined colours.
CROSS	Plots a cross at user-defined position on image.
CROSSCUT	Plots cross-cuts through user-defined point in image.
CROSSCUT_PEAK	Plots cross-cuts through peak closest to user-defined images.
CURSOR	Puts up cursor and returns value a selected position.
CUT	Plots cut/slice through user-defined points in image.
CUT2FF	Allows/disallows writing of CUT values to ASCII file.
CUT_TITLE	Sets title of CUT plot.
CVARGREY	Plots image with dual-slope scaling at cursor position.

CXWIN	Increase or decreases plotting window size by 10%
DISP	Subtracts two images, displays the result and allows simple photometry.
DISP2	Plots two images side by side with annotation.
DISP4	Plots four images in quadrants with annotation.
ELLIPSE	Draws ellipse at user-defined on image.
FPSTRIPLOT	Plots an FP strip chart.
GETCM	Returns current calculated plot limits.
GETRAST	Gets size of workstation in raster coordinates.
GRID	Draws a grid of user-defined width on image.
HARDCOPY	Makes a hardcopy of image or line graphics.
HARDLOT	Makes a hardcopy of a sequence of images.
LAGAIN	Plots last line graphics (CUT,CONTOUR,VEC) again.
LINE	Plots a line between user specified points on image.
LINECOL	Sets colour of lines plotted on images.
LINE_WIDTH	Sets line width of lines plotted on images (useful for HARDCOPYs).
LOGO	Plots IRCAM3 logo image.
MANYCOL	Plots all available colour tables (LUTs) in sequence.
MCURSOR	Displays cursor N times and returns values in image.
MORENSIGMA	Re-plots last NSIGMA plot with different stretch.
MOREPLOT	Re-plots last PLOT with different limits.
MORERANPLOT	Re-plots last RANPLOT with different range on mean.
MOREVARGREY	Re-plots last VARGREY with different parameters.
NSIGMA	Plots an image with $\pm$N-sigma on mean scaling.
PCLOSE	Closes plotting on current device.
PENCOL	Sets user-defined pen to user-defined colour.
PENINT	Sets user-defined pen to user-defined RGB intensities.
PLOT	Plots an image using user-defined scaling limits.
PLOTGLITCH	Plots an image (NSIGMA) and removes user-selected bad pixels.
PLOTLOT	Plots a sequence of images with user-defined scaling limit.
POPEN	Opens plotting on a user-specified device.
RANPLOT	Plots an image using user-defined range on mean for scaling limits.
SETCEN	Defines centre point for image display.
SETCOMORI	Sets orientation of comments written to display.
SETCONT	Setup definition for CONTOUR.
SETCONTIC	Sets contour tick mark ...
SETCUR	...
SETCURMARK	Defines whether cross is drawn on cursor selected points.
SETCUT	Setup definition for CUT, CCUT.
SETCUTAXRAT	Defines cut axis ratio on display.
SETFONT	Defines font used for comments.
SETHARD	Defines hardcopy device used in HARDCOPY.
SETMAG	Defines magnification factor used in image display.
SETMAX	Defines maximum value for limit scaling of image display using PLOT.
SETMIN	Defines minimum value for limit scaling of image display using PLOT.
SETMM	Runs both SETMAX and SETMIN above.
SETNUM	Defines axis annotation in terms of RA,DEC or offsets.
SETNUMORI	Defines number orientation on image axes.
SETNUMSCA	Allows user to scale numbers on axes.

SETPOLCOL	Sets colour of polarization vectors on display.
SETPRE	Sets file prefix for old style container file reduction.
SETPS	Defines current pixel scale in images.
SETQUAD	Defines which is 5 quadrants (incl. centre) images are displayed in.
SETRADEC	Defines RA,Dec of fiducial mark in image for axis annotation.
SETVAR	Defines various parameters for image analysis (eg scale, ap sizes, zp's).
SETVARGREY	Defines parameters for a VARGREY image display.
SETVEC	Defines polarization vector map setup.
STRIPLOT	Plots a stripchart data set obtained with STRIPCHART.
SURROUND	Displays axis annotation around an image and defined by SETNUM.
TICKIO	Defines whether plot ticks are plotted inside or outside the border box.
TICKLEN	Defines the length of the tick marks plotted.
VANS	Displays a S+A vector array image.
VARGREY	Displays an image using variable grey scaling.
VEC	Plots a polarization vector map defined by SETVEC.
VEC_TITLE	Defines the title plotted on a polarization vector map produced by VEC.
WRCCOM	Writes a comment on the display device using cursor selection.
WRCOM	Writes a comment on the display device at user-defined positions.
WRITELUT	Writes a colour table (LUT) to device using numeric code of COL LUTs.

Image Mathematics commands

Name	Description
ADD	Adds two images.
CMULT	Multiplies image by a constant.
CSTATS	Returns statistics in cursor selected area in image.
CSUB	Subtracts a constant from an image.
DIV	Divides two images.
EXP10	Raises image to power 10.
EXPE	Raises image to power e.
EXPON	Raises image to arbitrary power.
HISTO	Calculates statistics on an image.
LOG10	Takes Log10 of an image.
LOGAR	Takes LogX of image where X is user-defined.
LOGE	Takes LogE of image.
MULT	Multiplies two images together.
OADD	Adds two images referred to by observation number.
OCADD	Adds a constant to an image referred to by observation number
OCDIV	Divides an image referred to by observation number by a constant.
OCMULT	Multiplies an image referred to by observation number by a constant.
OCSTATS	Statistics on sub-array of image referred to by observation number.
OCSUB	Subtracts a constant to an image referred to by observation number
ODIV	Divides two images referred to by observation number.
OHISTO	Calculates statistics on an image referred to by observation number.
OMULT	Multiplies two images referred to by observation number.
OSTATS	Calculates statistics on image referred to by observation number.
OSUB	Adds a constant to an image referred to by observation number
POW	raises image to arbitrary power.
ROOT	Takes the square root of an image.

STATS	Returns statistics on an image.
TRIG	Takes trig function of image cos(image) etc.

Image Reduction commands

Name	Description
ACCOFF	Calculates accurate offsets between mosaic tiles.
AMCORR	Airmass corrects an image.
AMCORRLOT	Airmass corrects a sequence of images.
APPLYMASK	Applies bad pixel mask to an image.
APPLYMASKLOT	Applies bad pixel mask to sequence of images.
ARRAY_TESTS	Reduces array test data.
AUTOMOS	Corrects mosaic tiles for DC offsets.
CADD	Adds a constant to an image.
CDIV	Divides an image by a constant.
CHPIX	Changes a pixel value in an image.
CHRED	Reduces CHOP mode observations.
COFF	Calculates/stores accurate offsets between mosaic tiles.
COLMED	Median filters down image columns and creates 1D slice.
CREQUILT	Creates QUILT format mosaic file from image/offset lists.
CURHOT	Auto-removed hot pixels in cursor defined area of image.
DARKLOT	Dark subtracts a sequence of old format container file images.
DEFGRAD	Defines a gradient across image from edge-to-edge.
DEGLOT	Removes bad pixels from sequence of images.
DISPICK	Extracts sub-image from image using cursor definition.
FCOADD	Sums a sequence of images.
FLAT2	Flat-fields two images, A with B and B with A.
FLATLOT	Flat-fields a sequence of images.
FLIP	Flips an image horizontally or vertically.
GAUSS	Applies a gaussian filter to image.
GAUSSTH	Applies a gaussian filter to pixels > threshold.
GETOFF	Gets spatial offsets from RO data files of mosaic.
GLITCH	Removes glitches from image.
GLITCHMARK	Interactive bad pixel definition from image.
HOTSHOT	Auto-removal of hot pixels in image.
INDEX	Indexes through a old-style IRCAm container file.
INSETB	Sets pixels inside box to user value.
INSETC	Sets pixels inside circle to user value.
INTLK	Creates an integer representation of sub-array of image.
IO2RO	Converts I/O (archival) files to RO files.
JITREG	Calculates accurate mosaic offsets using request offsets as template.
MAKEBAD	Makes a bad list from N-sigma cut on an image.
MAKEGLITCH	Makes a bad pixel mask from glitch file (eg created by GLITCHMARK).
MAKEMASK	Makes a bad pixel mask from glitch file (eg created by GLITCHMARK).
MED3D	Median filters scaled image stack for flat-field creation.
MEDLOT	Calculates median in image and subtracts it for sequence of images.
MOS2	Mosaics and displays 2 images with calculated spatial offsets.
MOSAIC	Mosaics N images in spatial mosaic.
MOSAIC2	Mosaics 2 images with user-defined spatial offsets.

MOSCOR	Calculates DC offset between two images.
NUMB	Informs user of number of pixels above user specified DN value in image.
OBSEXT	Extracts a sequence of images from an old style IRCAM container file.
OBSLIST	Lists items from an old style IRCAM container file.
OUTSETB	Sets values outside box to user-defined value.
OUTSETC	Sets values outside circle to user-defined value.
PICKIM	Extracts sub-array with user-defined position,size from image.
PICKLOT	Same as PICKIM, but from sequence of images.
PIXDUPE	Increases size of image by pixel duplication.
POLCAL	Calculates polarization images from 4 polarization flux images.
POLLY	Calculates polarization values from 4 polarization flux values.
POLREG	Registers 4 polarization flux images to average position.
POLSHOT	Corrects polarization p image for shot-noise bias.
POLTHRESH	Thresholds 4 polarization images.
QUILT	Mosaics tiles of mosaic together with specified spatial offsets.
REMOS	Re-mosaics a sequence of mosaic tile images using user-specified offset file.
RFLOT	...
RODARKLOT	Dark subtracts a sequence of new format RO images.
ROINDEX	Give list of observation with parameters.
ROMED	Median filters a stack sequence of images.
ROTATE	Rotates an image by an arbitrary amount.
ROTLOT	Rotates a sequence of images by an arbitrary amount.
ROWMED	Median filters along image rows.
SCALEDARK	Scales an old format container file dark by exposure time/coadd number.
SCALELOT	Scales a sequence of images.
SETFILE	Defines input data file type (old or new format).
SETVAL	...
SHIFT	Shifts an image by ractional pixel amounts.
SHIFT2	Shifts 2 images to average position.
SHIFT3	Shifts 3 images to average position.
SHSIZE	Shows size of an image in pixels.
SKYSUB4	Sky subtracts 4 (polarization) images using user-defined sky area.
SPLITLOT	Creates N small images from a sequence of images into large images.
SQORST	Changes image size by bi-linear interpolation.
STCOADD	...
STRED	Reduces a mosaic sequence of images.
SUB	Subtracts two images.
THETAFIX	Corrects polarization position angle to be 0-180 degrees.
THRESH	Thresholds an image both below and above user-defined values.
THRESH0	Thresholds an image below user-defined value to zero.
TOMAG	Converts a flux image to magnitude images using input zeropoint.
TRACE	Lists complete data file structure elements.
TRANDAT	ASCII lists of offsets,fluxes to SDF image.
TSLOT	Thresholds and scales a sequence of images.
WMOSAIC	Produces a weighted mosaic from mosaic tile images.
WQUILT	Produces a weighted mosaic from mosaic tile images using ASCII file input.
WRAPCOR	Corrects images for wraparound.
WRAPLOT	Corrects a sequence of images for wraparound.

X2MAG	Defines the pixel scale when using the 2x magnifier.
X5MAG	Defines the pixel scale when using the 5x magnifier.
YADD	Averages an image along the Y-axis producing a linear image.
YGROW	Expands the linear image produced by YADD to a 2D image.
ZAPLIN	Removes bad rows and columns from an image by interpolation.
ZAPLOT	Removes bad rows and columns from a sequence of images.

On-line image reduction/display

Name	Description
NOMAG	Informs system there is no external magnifier and plate scale is 0.286″/pixel.
SEE	Interactive star selection then (KAPPA) PSF fitting for FWHM.
SETFILE	Defines input data file type (old or new format).
X2MAG	Defines the pixel scale when using the 2x magnifier.
X5MAG	Defines the pixel scale when using the 5x magnifier.

12 Appendix C. WHIRCAM with Martini

Martini-III is an interim adaptive optics imaging instrument developed by the University of Durham, which uses WHIRCAM as the IR detector. For more information than is provided here, contact Peter Doel (A.P.Doel@durham.ac.uk) or Richard Myers (R.M.Myers@durham.ac.uk) at Durham, or Vik Dhillon (vsd@ing.iac.es) at La Palma.

Overview

In order to sample the high resolution images delivered by the Martini Adaptive Optics system, a reflective f-converter can be inserted upstream of the telescope focal plane to produce image scales of 0.08 or 0.05 ″/pixel in WHIRCAM. The f-converter consists of two 25 mm diameter gold-coated mirrors (M1 and M2, see Figure 9) which are used off-axis to convert the f/11 beam to f/33 or f/55 before entering the WHIRCAM cryostat. Cold stops matched to the size of the telescope pupil image formed inside the cryostat are installed in the rear filter wheel and are automatically rotated into position when the f-converter is used to limit the background emission, by choosing the relevant magnifier option in the CONFIG file. The FWHM diffraction limit of the WHT at 2.2 μm is 0.13″, and the 0.05 arcsec/pixel scale is designed to sample the diffraction-limited core of well-corrected K-band images. The instrument field of view in this mode is 13×13″ at 0.05 ″/pixel. (Due to space contraints, the f-converter can't be used in direct imaging mode.)

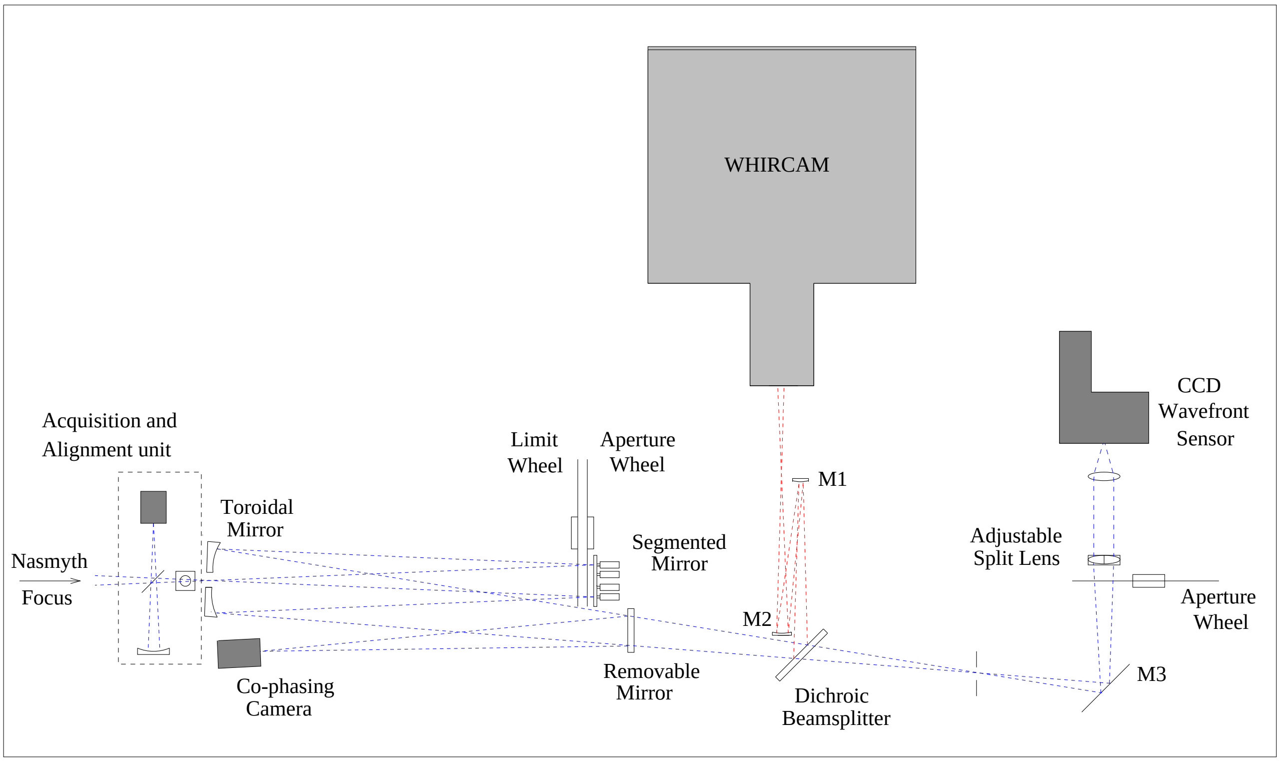


Figure 9: Martini and WHIRCAM setup at GHRIL (courtesy of Peter Doel).

Imaging with Martini

In Martini a 6-segment adaptive mirror is placed downstream of the telescope focus at a conjugate of the turbulent layer. An off-axis toroid mirror reimages the telescope focal plane further down the GHRIL table. A dichroic placed about 300 mm upstream of the reimaged Martini focus diverts the infrared light to WHIRCAM via the f-converter. The visible light is transmitted to the CCD wavefront sensor where the corrections to be applied to the adaptive mirror segments are measured. The converging f/11 beam reflected by the dichroic falls on a convex mirror (M1: 100 mm radius of curvature) mounted 50 mm upstream of the reimaged focus and tilted at 5° to the axis. This mirror collimates the beam and reflects it onto a concave mirror (M2: 500 mm radius of curvature) which is mounted 200 mm from M1 and tilted so that it sends the beam to WHIRCAM parallel with the beam from the dichroic. The concave mirror converts the beam to f/55 and forms a focus 250 mm from its front surface, which is in the same plane as the reimaged focus from Martini but translated across by 25 mm.

The 100 mm r_c convex mirror gives an image scale on WHIRCAM of 0.05 ″/pixel. It can be substituted by a 160 mm r_c mirror (M1a) placed 175 mm from the dichroic to give an image scale of 0.08 ″/pixel. The pupil images formed inside the cryostat by these f-converters have diameters of 3.3 mm and 5.2 mm respectively, and for maximum sensitivity, these should be matched by cold stops. The rear filter wheel currently contains stops with diameters of 7, 5 and 3 mm which can be rotated into position just ahead of the fixed cold stop. The stops do not lie precisely at the position of the pupil images and it has not yet been possible to evaluate which stops give the best performance. Furthermore, the small pupil image sizes make the alignment of the instrument very critical and it is probably wise to use oversized stops until the alignment accuracy has been assessed.

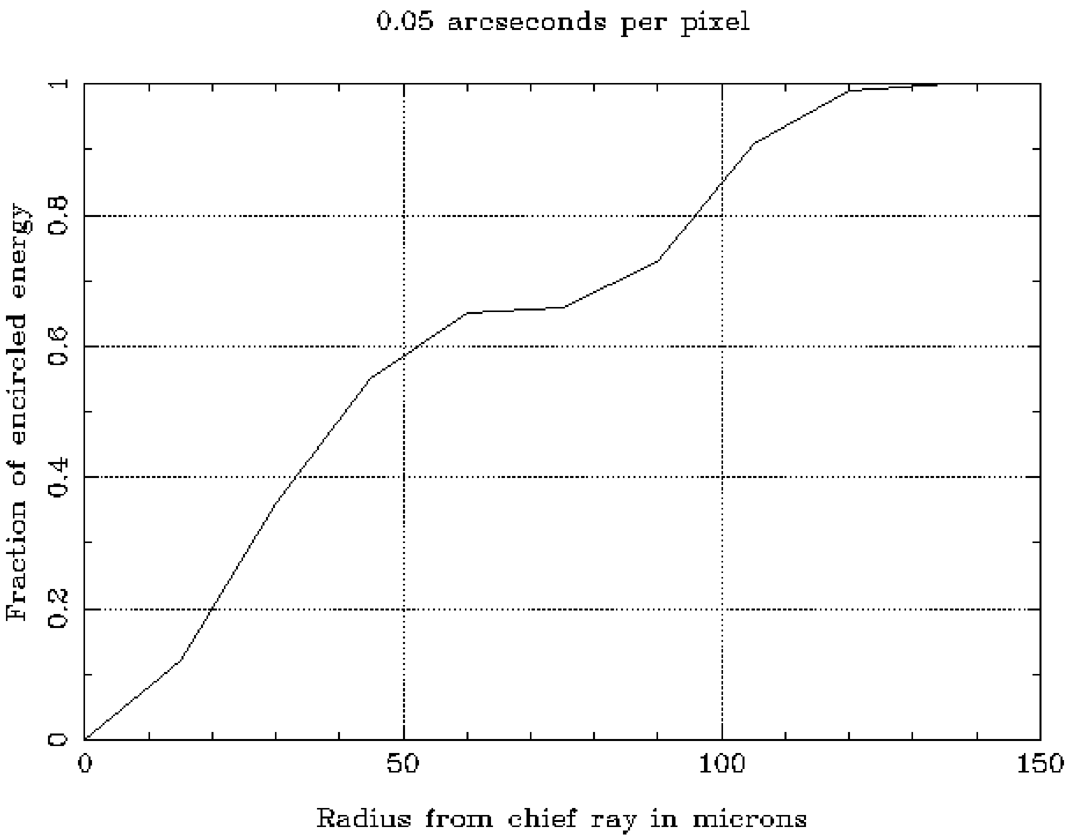
The concave f-converter mirror can be aligned to the optical axis of WHIRCAM by positioning the mirror 250 mm in front of the WHIRCAM focal plane (which is 125mm from the front of the snout) and running movie mode after selecting the nbL filter with one of the small stops (say 5 mm for the 0.05 ″/pixel option). The mirror can then be tipped so that it reflects back into the cryostat and adjusted so that it is centred by altering its height (which should be very close to 150 mm above the GHRIL table) and translation so that the signal is minimised. When it is aligned, out-of-focus images of the corners of the mirror may be faintly visible.

The Martini beam from the dichroic can be aligned using the Martini laser beam injected into the telescope focal plane. The beam from the dichroic is centred onto M1 by tipping and tilting the dichroic with the micrometer adjusters. From M1, the beam is directed to the centre of M2 by tilting the M1 kinematic mirror mount with hex wrenches. Finally, the beam from M2 is aligned with the WHIRCAM optical axis by pointing it at the dimple in the centre of the cryostat window cover; this is achieved by tilting M2 with the hex wrench adjusters.

The mirrors are glued into holders which are held in kinematic mirror mounts supported on posts and bases (Thorlabs). The f-converter mirrors were supplied by Technical Optics (Isle of Man). Their surface accuracy is $\lambda/10$ and they are coated with a protected gold coating.

Performance

Although the off-axis mirrors introduce significant aberrations, the images are still diffraction-limited at 2 μm across the entire 12″ field at 0.05 ″/pixel. The aberrations are more significant with the 0.08 ″/pixel image scale particularly in the J band, but as a diffraction-limited image cannot be fully sampled with this pixel scale, the images are completely adequate. Encircled energy plots are shown in Figure 10.



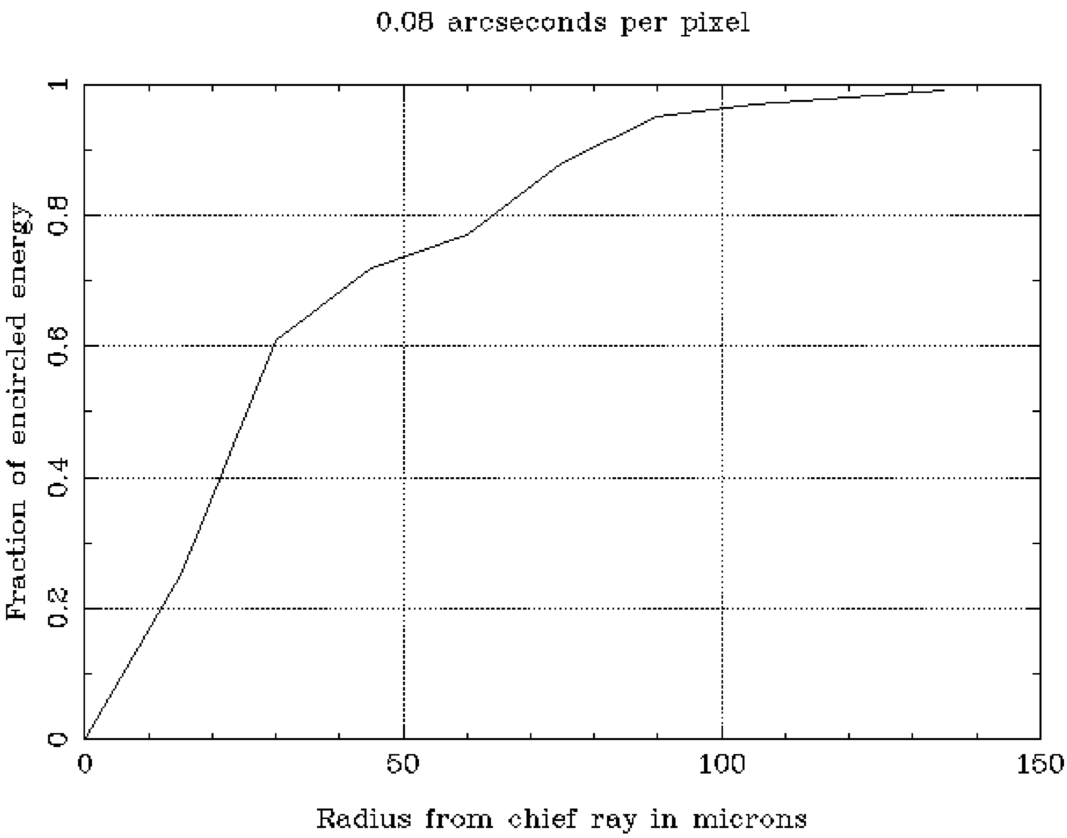


Figure 10: Encircled Energy diagrams for Martini

13 Appendix D. UKIRT Standards

Faint Standards

Standards are on the UKIRT system as defined by the UKIRT bright standards. 1 sigma errors are shown in parentheses.

Name	RA (1950)	Dec	*K*	*J–K*	*H–K*	Other Name	Ref
FS 1	00 31 22.7	−12 24 29	12.967 (0.021)	0.462 (0.011)	0.081 (0.012)	G158-100	2
FS 2	00 52 36.0	00 26 58	10.466 (0.003)	0.247 (0.003)	0.038 (0.003)	SA92-342	1
FS 3	01 01 46.6	03 57 34	12.822 (0.007)	−0.222 (0.011)	−0.097 (0.007)	F11	1,2
FS 4	01 52 03.7	00 28 20	10.264 (0.005)	0.292 (0.003)	0.040 (0.007)	SA93-317	1
FS 5	01 52 04.7	−07 00 47	12.342 (0.006)	−0.007 (0.004)	−0.002 (0.004)	F16	1,2
FS 6	02 27 39.2	05 02 34	13.374 (0.015)	−0.135 (0.014)	−0.069 (0.012)	F22	1,2
FS 7	02 54 47.2	00 06 39	10.940 (0.005)	0.165 (0.012)	0.037 (0.010)	SA94-242	1
FS 8	02 55 12.9	00 04 04	8.313 (0.006)	0.766 (0.002)	0.129 (0.004)	SA94-251	1
FS 9	02 55 38.8	00 58 54	8.266 (0.006)	0.884 (0.003)	0.158 (0.005)	SA94-702	1
FS 10	03 46 17.4	−01 07 38	14.919 (0.072)	−0.170 (0.077)	−0.049 (0.060)	GD50	2
FS 11	04 50 25.4	−00 19 34	11.278 (0.018)	0.076 (0.025)	0.016 (0.019)	SA96-83	1
FS 12	05 49 34.8	15 52 37	13.898 (0.003)	−0.217 (0.014)	−0.091 (0.018)	GD71	1
FS 13	05 54 33.8	00 00 53	10.135 (0.003)	0.382 (0.002)	0.047 (0.005)	SA97-249	1
FS 14	07 21 41.2	−00 27 10	14.261 (0.012)	−0.153 (0.005)	−0.079 (0.020)	Rubin 149	2
FS 15	08 48 21.9	11 55 02	12.360 (0.021)	0.418 (0.008)	0.060 (0.007)	M67-I-48	3
FS 16	08 48 31.0	12 00 36	12.631 (0.008)	0.340 (0.006)	0.038 (0.005)	M67-IV-8	3
FS 17	08 48 35.4	12 03 26	12.270 (0.007)	0.411 (0.007)	0.073 (0.003)	M67-IV-27	3
FS 18	08 51 02.1	−00 25 14	10.522 (0.008)	0.292 (0.003)	0.031 (0.003)	SA100-280	1
FS 19	10 31 14.5	−11 26 08	13.796 (0.025)	−0.231 (0.021)	−0.142 (0.047)	G162-66	1,2
FS 20	11 05 27.6	−04 53 04	13.473 (0.017)	−0.120 (0.015)	−0.069 (0.012)	G163-50	1,2
FS 21	11 34 27.6	30 04 35	13.132 (0.004)	−0.184 (0.033)	−0.101 (0.037)	GD140	4
FS 33	12 54 35.1	22 18 08	14.240 (0.016)	−0.223 (0.010)	−0.078 (0.024)	GD153	4
FS 23	13 39 25.7	28 44 59	12.374 (0.000)	0.623 (0.004)	0.072 (0.018)	M3-193	4
FS 24	14 37 33.3	00 14 36	10.753 (0.008)	0.151 (0.006)	0.019 (0.004)	SA106-1024	1
FS 25	15 35 59.9	00 24 03	9.756 (0.017)	0.475 (0.003)	0.070 (0.005)	SA107-1006	1
FS 26	16 34 26.3	−00 28 39	7.972 (0.009)	0.858 (0.004)	0.155 (0.006)	SA108-475	1
FS 27	16 38 54.2	36 26 56	13.123 (0.018)	0.371 (0.013)	0.058 (0.014)	M13-A14	4
FS 28	17 41 32.5	−00 23 44	10.597 (0.016)	0.148 (0.010)	0.047 (0.005)	SA109-71	1
FS 35	18 24 44.5	04 01 17	11.757 (0.017)	0.474 (0.008)	0.089 (0.005)	G21-15	2
FS 34	20 39 41.9	−20 15 21	12.989 (0.011)	−0.170 (0.008)	−0.070 (0.009)	EG141	4
FS 29	21 49 53.0	02 09 16	13.346 (0.024)	−0.171 (0.011)	−0.075 (0.012)	G93-48	1,2
FS 30	22 39 11.3	00 56 55	12.015 (0.020)	−0.092 (0.013)	−0.036 (0.005)	SA114-750	1
FS 31	23 09 50.4	10 30 46	14.039 (0.010)	−0.241 (0.02)	−0.120 (0.017)	GD246	1,2
FS 32	23 13 38.2	−02 06 58	13.664 (0.012)	−0.205 (0.011)	−0.088 (0.015)	F108	1,2

1. Landolt 1983 A.J. 88,439
2. Turnshek et al 1990 A.J. 99,1243
3. Eggen and Sandage Ap.J. 140,130
4. Priv. Comm.

Bright Standards

The magnitudes in this list have been revised following 1990/91 UKT9 photometry. Asterisks refer to the most frequently re-observed stars. The results define the UKIRT/UKT9 natural photometric system. The K zeropoint is defined as identical to that of the CIT (Elias) system for A0 stars. Transformations to CIT are also given.

	Name	Sp	RA (1950)	Dec	*J*	*H*	*K*	*L*	*L'*
*	HD 225023	A0	0 00 11.8	35 32 14.0	7.082	6.993	6.962	6.94	6.96
	G158-27	M5	0 04 12.0	-7 47 54.0	8.378	7.781	7.447		7.04
	BS 33	F7V	0 08 43.2	-15 44 32.0	3.964	3.689	3.636	3.60	3.60
	HD 1160	A0	0 13 23.1	3 58 24.0	7.060	7.051	7.040	7.05	7.04
	HD 2811	A2	0 28 53.0	-43 52 58.0	7.178	7.093	7.067	7.04	
	HD 3029	A3	0 31 02.3	20 09 30.0	7.263	7.125	7.093		7.06
	BS 337	M0III	1 06 55.5	35 21 22.0	-0.908	-1.703	-1.853	-2.00	-1.98
	BS 696	B2Iae	2 21 43.1	56 23 04.0	5.587	5.499	5.443	5.37	5.33
	BS 718	B9III	2 25 29.8	8 14 13.0	4.374	4.390	4.390	4.40	4.41
	BS 739	gG3	2 29 36.6	-1 15 17.0	3.748	3.218	3.121		3.04
	BS 740	F4IV	2 29 43.0	-15 27 48.0	3.879	3.623	3.585	3.56	3.56
	GL 105.5	M0	2 38 07.6	0 58 57.0	7.305	6.663	6.539	6.47	6.46
	BS 816	gF0	2 42 43.4	4 30 08.0	5.502	5.384	5.353		5.38
	HD 18881	A0	3 00 20.5	38 12 53.0	7.130	7.135	7.140	7.15	7.14
	HD 19904	A2	3 08 49.1	-39 14 24.0	6.727	6.662	6.642	6.62	
	G77-31	M4?	3 10 40.5	4 35 12.0	8.816	8.187	7.857	7.52	
	HD 22686	A0	3 36 18.7	2 36 07.0	7.196	7.190	7.185	7.20	7.19
	BS 1140	B7IV	3 41 49.5	24 08 01.0	5.520	5.500	5.510	5.60	5.64
	BS 1457	K5III	4 33 02.9	16 24 37.0	-1.848	-2.614	-2.783	-2.97	-2.89
	BS 1543	F6V	4 47 07.4	6 52 32.0	2.353	2.117	2.095		2.07
	BS 1552	B2III	4 48 32.4	5 31 16.0	4.029	4.087	4.138	4.18	4.18
	BS 1641	B7V	5 03 00.2	41 10 08.0	3.518	3.646	3.677	3.71	3.74
	BS 1637	F0V	5 06 40.6	51 35 52.0	4.312	4.204	4.153	4.11	4.14
	BS 1713	B8Iae	5 12 08.0	-8 15 29.0	0.240	0.241	0.211	0.13	0.09
	BS 1708	G4III	5 12 59.5	45 56 58.0	-1.334	-1.717	-1.802	-1.87	-1.85
	SAO112626	F8	5 16 41.4	1 39 15.0	8.934	8.670	8.596		8.65
	BS 1869	dF0	5 36 15.9	47 42 56.0	5.532	5.454	5.393	5.36	5.39
	HD 38921	A0	5 45 41.0	-38 14 51.0	7.572	7.551	7.536	7.53	
	HD 40335	A0	5 55 37.6	1 51 09.0	6.555	6.473	6.452	6.43	6.43
	BS 2228	F0V	6 17 34.6	46 25 57.0	6.012	5.943	5.892	5.84	5.88
*	HD 44612	A0	6 21 09.7	43 34 35.0	7.075	7.041	7.041	7.04	7.03
	BS 2491	A1V	6 42 56.7	-16 38 46.0	-1.300	-1.319	-1.320	-1.35	-1.36
	BD+0 1694	?	6 52 07.3	0 00 52.0	5.750	4.857	4.606	4.43	4.43
	BS 2721	G0V	7 12 07.6	47 19 51.0	4.475	4.180	4.126		4.08
	BS 2943	F5IV	7 36 41.1	5 21 16.0	-0.437	-0.564	-0.646	-0.66	
	BS 2990	K0IIIb	7 42 15.6	28 08 55.0	-0.523	-0.975	-1.050	-1.15	-1.17

Bright Standards (continued)

Name	Sp	RA (1950)	Dec	*J*	*H*	*K*	*L*	*L'*
BS 3314	A0V	8 23 09.7	-3 44 31.0	3.920	3.919	3.940	3.94	3.92
HD 75223	A0	8 45 29.8	-39 36 54.0	7.329	7.296	7.281	7.26	
HD 77281	A2	8 59 05.4	-1 16 45.0	7.111	7.052	7.031	7.00	7.06
GL 347A	M3.5	9 26 25.0	-7 08 30.0	8.483	7.881	7.658	7.41	7.36
HD 84800	A2	9 45 35.9	43 53 56.0	7.592	7.549	7.538	7.55	7.54
BS 3888	F2IV	9 47 27.1	59 16 30.0	3.162	3.005	2.983	2.98	2.94
BS 3903	G7III	9 49 04.3	-14 36 40.0	2.617	2.136	2.050	1.98	
V 569	M3	10 09 46.3	-3 29 41.0	5.992	5.310	5.106	4.93	4.89
BS 4069	M0III	10 19 21.5	41 45 06.0	0.132	-0.654	-0.803	-0.94	-0.96
GL 390	M1.5	10 22 44.0	-9 58 36.0	6.939	6.275	6.061	5.87	
GL 406	M6	10 54 06.0	7 19 12.0	7.143	6.469	6.099	5.69	
BS 4358	K3III	11 11 25.9	8 20 05.0	3.879	3.299	3.202		3.14
HD101452	A2	11 37 45.1	-38 52 09.0	7.018	6.890	6.848	6.81	
Y 2730	dM4.5	11 45 08.2	1 05 56.0	6.532	5.935	5.646	5.34	5.26
BS 4550	G8V	11 50 06.2	38 04 39.0	4.957	4.466	4.400	4.35	4.38
HD105601	A2	12 06 56.1	38 54 39.0	6.821	6.719	6.687	6.64	6.65
HD106965	A2	12 15 24.0	1 51 10.0	7.380	7.337	7.316	7.30	7.34
BS 4689	A2IV	12 17 20.8	0 23 21.0	3.810	3.781 3	.781	3.79	3.79
BS 4935	F7V	13 01 05.1	-20 18 55.0	4.604	4.290	4.266		
BS 4983	G0V	13 09 32.5	28 07 52.0	3.194	2.929	2.886	2.88	2.89
BS 5340	K1IIb	14 13 22.8	19 26 31.0	-2.200	-2.878	-2.976	-3.09	-3.05
BS 5447	F2V	14 32 30.2	29 57 41.0	3.723	3.522	3.489	3.48	3.49
HD129653	A2	14 40 38.2	36 58 07.0	6.985	6.942	6.921	6.91	6.93
HD129655	A2	14 41 11.0	-2 17 38.0	6.826	6.724	6.692	6.67	6.68
HD130163	A0	14 44 36.2	-39 43 04.0	6.856	6.846	6.835	6.81	
BD+3 2954	M0	14 52 23.2	3 11 33.0	5.926	5.026	4.825	4.64	
BS 5685	B8V	15 14 18.7	-9 11 59.0	2.759	2.789	2.799		2.85
HD136754	A0	15 19 24.3	24 31 19.0	7.155	7.146	7.135	7.14	7.14
BD+2 2957	K2	15 22 29.0	1 41 06.0	5.280	4.454	4.263	4.08	4.19
BS 6084	B2II+O9V	16 18 08.7	-25 28 29.0	2.491	2.442	2.421	2.43	2.42
* BS 6092	A9III	16 18 14.1	46 25 54.0	4.192	4.257	4.298		4.35
S-R 3	?	16 23 07.7	-24 27 26.0	7.804	7.001	6.543	6.25	
OPH S1	?	16 23 32.8	-24 16 44.0	9.007	7.344	6.378	5.71	
BS 6136	K4III	16 26 00.9	0 46 32.0	2.898	2.184	2.036	1.86	
BS 6147	G8IIIa	16 28 16.4	-16 30 19.0	2.767	2.334	2.269	2.19	2.22
BS 6406	M5Ib	17 12 22.0	14 26 45.0	-2.276	-3.110	-3.351	-3.70	-3.66

Bright Standards (continued)

	Name	Sp	RA (1950)	Dec	*J*	*H*	*K*	*L*	*L'*
	HD161743	A0	17 45 31.8	-38 06 11.0	7.620	7.620	7.615	7.61	
	HD161903	A2	17 45 43.3	-1 47 34.0	7.172	7.059	7.023	6.99	7.01
	HD162208	A0	17 46 20.7	39 59 40.0	7.223	7.141	7.112	7.09	7.14
	BS 6707	F2II	17 56 35.3	30 11 32.0	3.470	3.252	3.210	3.16	3.18
	Y 4338	dM4.5e	18 46 44.1	-23 53 32.0	6.297	5.680	5.416	5.12	5.03
	BS 7120	K3II	18 52 05.8	-22 44 08.0	2.739	2.120	2.033	1.91	
*	GL 748	dM4	19 09 38.0	2 48 36.0	7.105	6.557	6.319	6.05	6.00
	BS 7615	K0III	19 54 25.7	34 56 58.0	2.199	1.716	1.640	1.51	1.56
	BS 7773	B9.5V	20 17 53.5	-12 55 04.0	4.825	4.859	4.859	4.86	4.86
	GL 811.1	dM4	20 54 04.0	-10 37 36.0	7.832	7.185	6.946	6.70	6.69
	HD201941	A2	21 10 13.6	2 26 12.0	6.696	6.657	6.626	6.60	6.61
	BS 8143	B9Iab	21 15 27.0	39 11 04.0	3.886	3.838	3.797	3.73	3.73
	HD203856	A0	21 21 37.1	39 48 12.0	6.926	6.887	6.861	6.84	6.84
	HD205772	A3	21 35 33.6	-41 16 26.0	7.775	7.688	7.657	7.64	
	SAO34401	F0	22 21 47.7	54 57 12.0	7.933	7.766	7.734		7.74
	BS 8541	B9Iab	22 22 29.0	49 13 21.0	4.305	4.267	4.235	4.23	4.22
	BS 8551	K0III	22 25 19.6	4 26 39.0	2.956	2.378	2.312	2.25	2.24
	Y 5546	dM5	22 50 36.2	-14 31 34.0	5.980	5.344	5.066	4.80	4.74