The NIRC User's Manual

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Please note that the HTML version of this document may not be formatted optimally. In particular Greek symbols use the Symbol font, which most UNIX-based systems call something else. Equations also are not translated correctly into image files in some cases. Images themselves may look worse on the lower-resolution screens of the Web than they will on printed output.

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NIRC Overview

The Keck Observatory Near Infrared Camera (NIRC) is an instrument designed to produce both infrared images and low resolution spectra from 1 to 5 µm. It includes a 256 x 256 pixel InSb detector produced by Hughes-SBRC, and is located at the f/25 Forward Cassegrain focus of the 10 meter Keck I telescope. It shares the Forward Cassegrain Module with LWS and LWIRC, two mid-IR instruments. More information about the instrument can be found in Matthews & Soifer (1994; in *Infrared Astronomy with Arrays*, ed. I. McLean, Kluwer, p. 239–246).

Light from the secondary mirror first encounters NIRC's tertiary mirror (not to be confused with the telescope's tertiary mirror, used at Nasmyth and bent Cassegrain focal stations). The tertiary mirror has a cover or lid that can be controlled from the computer. The mirror can also be tilted in order to align the pupil onto the instrument's pupil mask; this however is an engineering task that rarely needs to be performed. The one case in which the tertiary mirror is not encountered first is when the image converter is installed; this "add-on" is located just outside the tertiary mirror box, and converts the f/25 telescope beam into an f/180 beam.

The dewar window is encountered next, followed by the focal plane, which contains two movable slides. The top slide contains an occulting finger and several slits. The bottom slide contains a mask that masks off the other slits when one of them is selected.

Further down the optical path is a field mirror, then a folding flat and a cold, circular pupil stop. Note that the pupil stop is optimized for the f/25 mode of operation; the f/180 beam from the image converter underfills the pupil, allowing significant f/25 background light into the system.

Just past the pupil stop are two filter wheels (inner and outer), each with 20 positions. After the filter wheels is the camera lens, followed finally by the detector, a 256 x 256 pixel InSb detector produced by Hughes-SBRC. The detector has a QE of 89.5% at 1.7 microns. The detector is attached to a cold block that provides both cooling through the liquid helium (LHe) dewar, and thermal regulation through a small heater attached to the block. The 30 µm pixels project onto the sky as 0.15 arcsec/pixel, for a total field of view of 38 arcsec. (The scale is 0.0206 arcsec/pixel, and the field 5.3 arcsec with the image converter in the optical path.) Detector read-out noise is ~75 electrons in the best timing pattern. Fowler and correlated double-sampling (CDS) readout modes are not available at this time, but work is progressing to implement them. Fowler mode improves the signal-to-noise of read-noise dominated imaging and spectroscopy, while CDS improves bias removal from all images.

NIRC not only produces 1–5 micron images, using two filter wheels with 20 slots each, but also has low resolution (R ~ 60–120) grisms available for spectroscopy. The occulting finger may be used for coronographic imaging, but not for coronographic spectroscopy, as the finger is on the same slide as the slits.

Output from the NIRC detector is sent to the IRE (InfraRed Electronics) rack. A four-channel readout is provided, along with coadders, filter banks, and user-selectable gains. The analog-to-digital conversion can also be toggled between 12-bit or 16-bit ADCs. The 12-bit ADCs are generally used only with the fastest timing patterns. The analog to digital converters (ADCs) will produce numbers in the range 0 to $2^{16} - 1 = 65535$ for the 16 bit converters and 0 to $2^{12} - 1 = 4095$ for the 12 bit converters. Note that *saturation may occur before these ADC limits are encountered*! The coadders can coadd up to $2^{19} = 524{,}288$ frames of the 16 bit converters and up to $2^{23} = 8{,}388{,}608$ frames of the 12 bit converters.

Guiding is done via an optical Photometrics CCD guide camera, which is centered some 305.5 arcsec away from the NIRC detector center. The guide camera has a 45 x 60 arcsec field (long axis more or less pointing towards NIRC), with 0.157 arcsec pixels. It is fixed to the same base optical bench surface as NIRC and the other IR cameras. It does not rotate separately nor travel on a stage independently from NIRC. Guide star's are acquired by rotating the entire instrument.

The OA controls the guiding software. Guide stars of 8th to 18th magnitude are usable. Brighter stars will show a diffraction pattern of rays but can still be useful for verifying pointing. Observers who come without preidentified guide stars can still ask the OA to find one. They will generally use the *SKY* program, but optionally may rotate the instrument in search of guide stars. SKY can also be used to download and overlay picture files from the Digital Sky Survey, although the facilities for doing this are currently somewhat primitive.

The OA can also save frames from the guide camera as well as move the telescope in guider x, y, az, el, north, and east in pixel or arcsec units. The geometric relationship between NIRC and the guider is discussed in (*KSD 40: DCS Coordinate Systems*).

The rest of this manual is organized roughly along the lines you would expect to follow in preparing for a run and then observing. The first couple of sections discuss preparations for your run, followed by observing sections, and then a couple of sections on backing up and analyzing your data. Also note that throughout this manual the computer's messages will be shown in `typewriter font` and your commands will be shown in **`boldface`**, even though they may look different on the actual computer screen.

Preparations for Observing

Available Filters

Following is a list of filters available in the NIRC filter wheels. In general the filters have been crossed with appropriate blocking filters, either within an individual filter cell, or by using a blocking filter such as a uv22 short-pass filter in the other filter wheel.

The last two columns of the table show the background rate, in electrons/sec, and the sensitivity of the filter, given as 2.5 times the log of the count rate (in electrons/sec) of a zeroth magnitude star. *Note that these are estimates only!* The background rate depends on the sky conditions at the time, whether the Moon is up (for shorter wavelengths), and the airmass. Likewise the sensitivity depends on the sky conditions and the airmass. In converting these values to DN, recall that the inverse gain of the detector is roughly 6 electrons/DN.

NOTE: It was at one point thought that the L_S filter was poorly blocked. However, recent (1999 March) tests showed that it is well blocked, and observers can feel free to use it without worry of blue or red leaks.

Table 1. Available Filters

Command	Central wavelength	FWHM	FWI pos	FWO pos	Background	Sensi-tivity
Broad-Band Filters						
z	1.03225	0.1565	2	19		
j	1.251	0.292	3	10	2000	28.13
jh	1.30	0.60	1	10		
h	1.6575	0.333	4	10	6400	27.80
hk	1.967	1.13	9	19		
kp	2.1235	0.337	6	19	3800	*26.92*

Command	Central wavelength	FWHM	FWI pos	FWO pos	Background	Sensi-tivity
ks	2.155	0.33	7	19	3600	26.78
k	2.2135	0.427	8	19	7200	27.16
kw	2.249	0.594	10	19	30,000	*27.50*
ch4	2.269	0.155	5	10		
ls	2.9785	1.023	12	19	3,200,000*	26.62
kl	3.1475	2.003	14	19		
lw	3.492	1.490	15	19	24,800,000*	26.94
lp	3.831	0.620	13	19	9,700,000*	26.24
lm	3.945	2.002	17	19		
m	4.718	0.628	16	19	95,000,000	*24.87*
mw	5.022	1.356	18	19		
Thermal Blocking Filters						
uv22i	1.45	2.5	11	19		
uv22o	1.45	2.5	19	10		
Narrow-Band Filters						
hei	1.0829	0.0136	19	0	49	*24.70*
pgamma	1.0930	0.0104	11	1	47	*24.62*
oii	1.23605	0.0105	19	2	86	*24.31*
pbeta	1.2823	0.0146	11	3	350	*24.72*
feii	1.6471	0.0176	11	4	330	*24.12*
h210	2.12495	0.0235	11	11	150	*22.98*
brgamma	2.1647	0.0224	11	12	200	*23.21*
h221	2.24855	0.0239	11	13	138	*22.95*
kcont	2.25965	0.0531	19	15	570	*24.43*
co20	2.2973	0.0274	19	14	240	*23.41*
pahcs	3.0825	0.1007	19	16	285,000	*24.25*
pah	3.3100	0.063	19	17	540,000	*23.53*
pahl	3.4128	0.0734	19	18	490,000	*23.92*
bralphacont	3.9923	0.0483	19	5	930,000	*23.51*
bralpha	4.0455	0.0524	19	6	1,320,000	*23.40*

* Empirical fits of the background rate as a function of airmass, AM:

Background rate in L_S = (1.8 * AM + 1.4) x 10^6 electrons/sec
Background rate in L' = (2.8 * AM + 6.9) x 10^6 electrons/sec
Background rate in L_W = (2.4 * AM + 22.4) x 10^6 electrons/sec

Remember in these formulae that AM is always greater than or equal to 1!

These formulae can be interpreted as a sky background rate, which depends on AM, and a telescope + instrument background rate, which is independent of AM.

Note that while the previous software cleared the slits every time a filter was selected, the current behavior is more in keeping with what most observers seem to expect; the slits are *not* cleared automatically. Most filter moves now also move both motors in parallel, saving some time.

Exposure Time Estimation

To estimate a total exposure time from the table in the last section is relatively straightforward. The two values you need to supply are the brightness of the target and the size of the area in pixels in which you are interested. For point sources the latter is usually the PSF. For a seeing of 0.6 arcsec you might assume that N=16 pixels will contain the bulk of the flux. For extended targets you may have a surface brightness in mag/sq. arcsec, hence N=44 (= $1/0.15^2$).

Let's assume that you have a target of magnitude M, spread over N pixels, and you want to take n exposures each of integration time t. Using the photometric zeropoints, M_0, and the background rates, B, given in the table, together with the read noise, R, allow you to calculate the signal-to-noise ratio, S/N:

$$\frac{S}{N} = \frac{nt10^{0.4(M_0-M)}}{\sqrt{nR^2N + BntN + nt10^{0.4(M_0-M)}}}$$

The three terms in the denominator represent the read noise, the background noise, and the noise from the object itself. Note that if you are doing broadband imaging the read noise is probably insignificant, hence you can approximate R=0 above.

I order to determine how many integration you will require, recall that you will generally be constrained by a minimum integration time and a maximum integration time. The minimum time is dependent on the timing pattern. For patslow, the usual broadband timing pattern, it is 0.41 sec/frame. The faster pat4xa allows 0.137 sec/frame. (Subarrays of course can use shorter integrations times. See "Fast Pictures for Longer Wavelengths and Speckle" below.)

The maximum integration time is generally set by either the rate at which the background or your target fills the detector wells, or the rate at which the atmosphere changes. The detector wells are linear to ~162,000 electrons, so you can use the table above to estimate the maximum exposure time for a particular filter. For example, the background in K is produces 7200 electrons/sec/pixel, hence the background will saturate in ~20 sec. A bright target in the field will naturally saturate some pixels faster.

Another example can be taken from the thermal IR. The highest background is from the M filter, which has a rate of 95,000,000 electrons/sec. This implies a maximum tint of only 1.7 msec! Even with the faster pat4xa timing pattern, this requires a subarray of 16 x 16 pixels *or less*! The max12ur timing pattern can be used with subarrays of 32 x 32 pixels or slightly larger. Fortunately this is the worst case scenario (except for M band at high airmass).

The following table summarizes the maximum exposure times for the sky background in a number of broadband filters.

Table 2. Maximum integration times

Filter	electrons/sec	Max. Int. (sec)	Filter	electrons/sec	Max. Int. (sec)

Filter	electrons/sec	Max. Int. (sec)	Filter	electrons/sec	Max. Int. (sec)
j	2000	80	kw	30,000	5
h	6400	25	ls	3,200,000	0.05
kp	3800	40	lw	45,000,000	0.004
ks	3600	45	lp	9,700,000	0.017
k	7200	20	m	95,000,000	0.0017

Overheads

When estimating the time it takes to perform a series of observations one must always be aware of the overheads involved. We estimate some of them here. They include: (a) slewing to and centering on a new target, (b) finding a guide star and turning guiding on, (c) taking an image, (d) offsetting the telescope to a new dither position, and (d) reconfiguring the instrument.

The time it takes to acquire a brand new target depends somewhat on the distance from the old target. Remember that the Keck telescopes have alt-az mounts, which means that two targets near zenith but on different sides of declination 19° may be quite close together in the sky but may still require large azimuth moves of the telescope. The telescope typically moves about 1°/sec (at the time of writing the numbers are 1.3°/sec in azimuth, 0.5°/sec in elevation). Including a typical slew, identifying the field, centering, and sending to the science detector, a round number to use is 5 minutes for an acquisition. Note that during the slew time the rotator can be rotated into position to find a guide star, and the observer can reconfigure the instrument if necessary.

Finding a guide star naturally goes much faster if you already know where a good guide star is. This is discussed in Finding Charts & Guide Stars below. Good preparation will make this time insignificant, but if the OA has to hunt for a guide star it could take minutes.

A specific formula is used by the facility scripts to calculate the total time to take an image, but a good set of estimates are:

1. An overhead of 8.5 sec for each normal frame.
2. No overhead for coadding. (But multiply the integration time by the number of coadds!)
3. An overhead of 0.6 sec for each full-frame speckle slice.
4. A single frame overhead for chopped frames, but remembering in the end to multiply by two for the two chop positions. A frame overhead here is equal to the minimum integration time for that timing pattern (not the total integration time selected using **`tint`**).
5. Remember to multiply by the number of chop coadds (set using **`nchop`** and shown by the keyword `CHPCOADD`).

Offsetting the telescope includes the actual move plus the time it takes for the guiding to settle. This is typically 6 sec.

Reconfiguring the instrument is generally pretty quick, except for filter and slit moves. A good number is 7 sec for either type of move. These can be done while the OA is slewing to a new target, of course, but during integration on a single target it is trickier to combine, say, filter moves and simultaneous telescope offsets. Current facility scripts do not support this.

Starlists

The target list for observing can be converted into a "starlist," which can then be read directly into the "SKY" program used to operate the telescope. The *SKY* format for the object list is:

- Name in columns 1–16 (no tabs); *this is very important, and the most common cause of errors in the star list!*
- Next three space-separated tokens are RA hh, mm, and ss.s (ss.s may be variable precision ss.sss),
- Next three space-separated tokens are Dec. dd, mm, and ss.s (if the Dec is between 0 and –1, the "dd" field *must* be "–00."
- Next token is equinox (not in parentheses), with 1950 or less meaning FK4 and > 1950 meaning FK5. "APP" means apparent position.
- Optional next two tokens (both must be present and valid numbers in order to be used) are proper motion in sec/yr, arcsec/yr. Use "pmra=" and "pmdec=." Epoch is always the same as equinox.
- *SKY* can also deal with nonsidereal tracking rates for Solar System objects. In this case the equinox *must* be "APP," and "pmra=" and "pmdec=" are used to specify the differential rates.
- *No blank lines!* This is the second most common cause of errors in the star list!
- At the end of each line one can also include notes—spectral types, magnitudes, etc.—as long as they don't confuse other functions like "pmra=". This is also a good place to record the p.a. of a good guide star, although the OAs cannot see this information.

Once you have created a starlist, you can copy it to the directory /kroot/starlists/*observer_name*; type **`cd /kroot/starlists`** (from *any* computer) and then search for your own directory if you forget the exact name. Often the OAs have to change these starlists, either to fix typos or add stars at the request of the observers, so please give them write privileges to your starlists by typing (in your starlist subdirectory) **`chmod oug+rw *`**; this will allow them both read and write access.

Finding Charts & Guide Stars

Finding charts are used for identifying your targets as well as identifying guide stars. There are a number of sources for producing finding charts, often involving the Digitized Sky Survey (DSS). A simple interface for downloading such charts is the STScI Digitized Sky Survey Web page. This interface allows users to download either FITS or GIF format images from the STScI's copy of the DSS. An alternative is being developed here at Keck, but is still in the nascent stages.

Finding charts for objects, standards, and guide stars are very useful and should be provided by the astronomer. The *SKY* program, described in *KD 118: SKY 9.0*, is available from the Keck-menu pull down, and can be used to find guide stars within a specified radius and brightness range. It currently uses a culled list of SAO stars as well as the full HST *Guide Star Catalog*, the latter extending down to about mag. 14. It is often useful to have *SKY* at your home institution; the source code and instructions for installation can be obtained from Keck Observatory. Useful guide star information includes the position angle, radius, and brightness. The position angle should be given verbally to the O.A.

Apart from reading your starlists, *SKY* is also valuable for identifying guide stars. Use "options" then "set defaults" in the *SKY* pull down menu to search for stars within an inner radius of 0.077 degrees. Select "report P.A." Set the outer radius to 0.093 and brightness range from 5 to 18. For long integrations, it is impossible to work without a guide star and you may want to offset your object on the NIRC detector in order to get to a guide star on the guider.

To use SKY to find PSF stars at the same position angle as the object and guide star, use "options" then "set defaults" in the SKY pull down menu. Select "PSF mode? Yes". Select "Rotator PA mode 2det". Select "Report radius/PA and restrict inner radius? Yes". Set the PSF search radius. Select "OK". In the main SKY window set degrees on the sky to 0.1. Set the *V* brightness min and max. Select "list".

Other options for locating likely guide stars are available. For example, one can download Digitized Sky Survey images of a field from one of various *Web sites*, and create a finding chart for your object. Then, a transparent overlay of the NIRC guide annulus, extending 276 to 335 arcsec from the target, can be placed atop the finding chart. Guide stars should lie within this annulus; choose brighter guide stars if possible, and also ones nearer the center of the annulus if possible. This technique allows guide stars fainter than the stars in the HST *Guide Star Catalog* to be identified and used.

Telescope Pointing Limits

In planning for observing it is always good to keep in mind the pointing limitations of the Keck I telescope. In most of the sky the lower shutter begins to vignette the telescope below 18° elevation. The telescope will point below this level, albeit with part of its aperture blocked. Note that this can be particularly devastating for 3–5 micron work, where the extra thermal emission from the dome could drive up the background flux.

In the eastern part of the sky the telescope can see only above 33.3° elevation, below which the Nasmyth deck interferes with it. The following diagram demonstrates this graphically. Note the small "dots" on each declination curve; these represent hours of H.A.

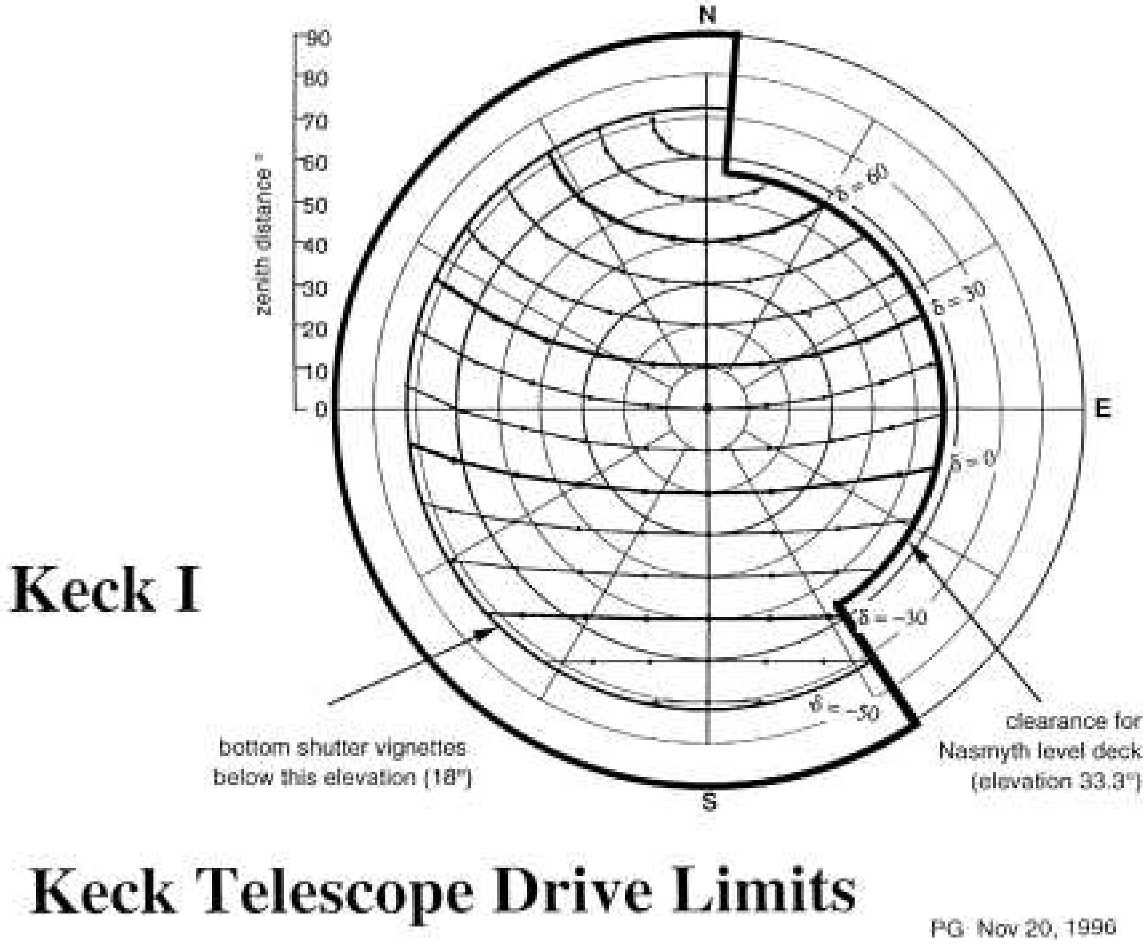

Figure 1. Keck I Telescope Limits

Another useful plot is the airmass as a function of hour angle and declination:

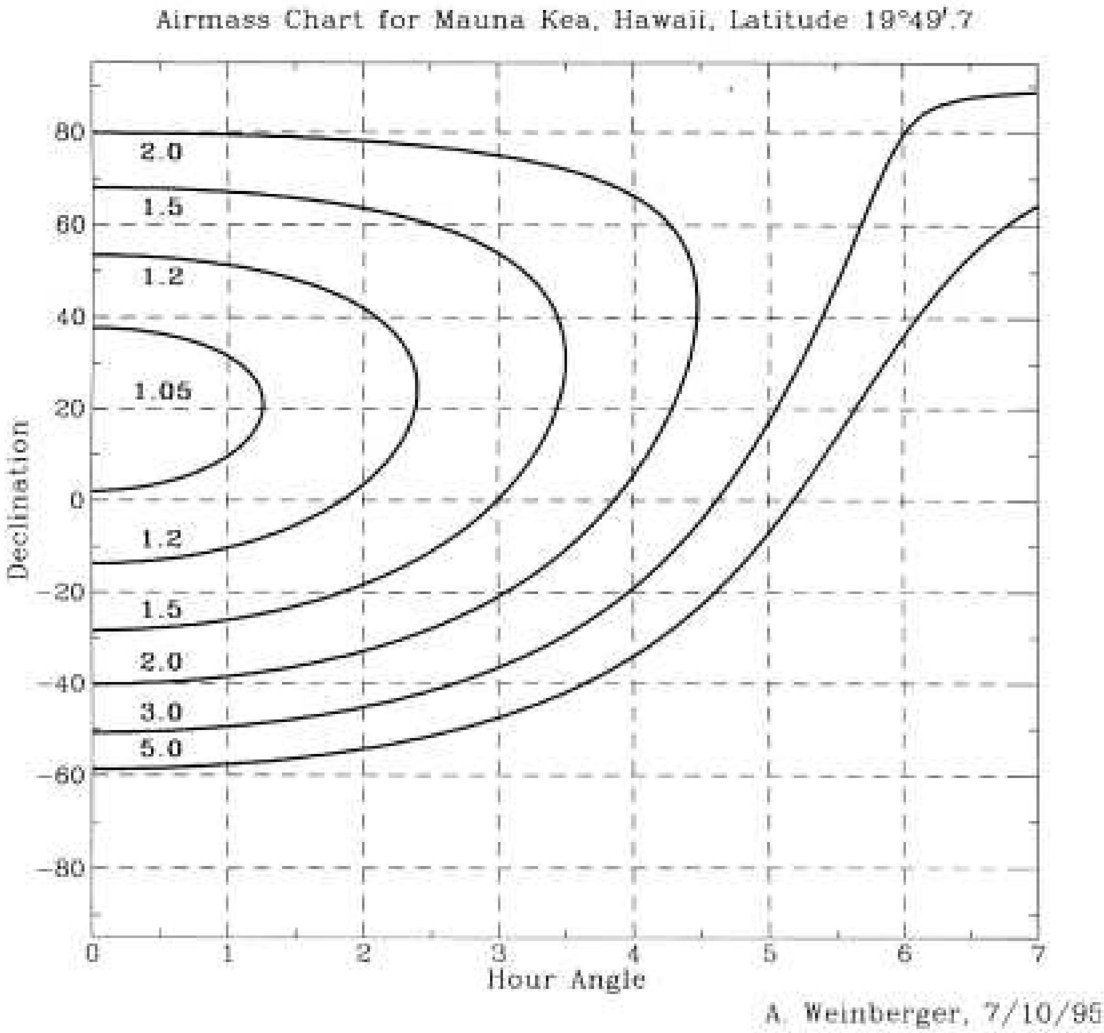

Figure 2. Airmass vs. Declination and Hour Angle

Summit vs. Remote Observing

Another decision facing the observer is whether to observe from the summit or remotely from Waimea headquarters. It is possible to remotely observe from Hale Pohaku (HP), the dorm level on the mountain, but this option combines the worst of the other two options.

Most observing is now done remotely, from Waimea HQ. The Keck I Remote Observing room is outfitted with a closed circuit television system which shows the observing room on the summit. This allows close communication with the OA. In some cases the OA might even be in Waimea, if some reason prevents them from working at the summit. In such a case, a technician or the night attendant will be available on the summit for “hands-on” problems.

To experienced Mauna Kea observers, remote observing has some clear advantages. Observing is generally not as strenuous from 2000 feet as it is from 14,000 feet. Sleeping facilities are just a brief walk across the lawn at HQ, rather than a bumpy, 30-minute drive down the mountainside. Most people seem to sleep better at lower altitudes, too, and the Waimea Visiting Scientist Quarters

(VSQ) are nicer rooms than the HP dorms. This extra rest, combined with the ability to think more clearly at lower elevations often makes for more efficient observing from Waimea.

Advantages of observing from the summit include close contact with the state of the sky. There is also a certain psychological advantage in being closer to the telescope itself, and indeed on those rare occasions when the computer link from Waimea to the summit goes down, summit observing (or HP observing) is the best way to observe. (We have observed remotely by having the astronomers tell the OA how to run the instrument, either over the PictureTel closed circuit TV or the phone, but this is clearly a very inefficient technique, and has only been used in emergencies!) It should be stressed that the link from Waimea to the summit has been extremely reliable in the past, though.

All in all, most observers currently choose to observe remotely.

Observing Plan

A good observing plan consists of more than the target list from the proposal. The following is a sort of checklist of items which you may or may not want to consider:

- Target list
- Finding charts
- Guide star position angles
- Observing strategy
    - Filters
    - Exposure times
    - Dithering patterns
    - Timing patterns
- Calibrations
    - Flux standards
    - Bias frames
    - Dark frames
    - Dome flats
    - Twilight flats
    - Linearity measurements

Observing

The following sections are mostly to aid you once you are at Keck for your observing run. There will be some differences depending on whether you are observing from the summit or from Waimea.

Starting an Observing Session

Most observing these days is done remotely, from the Remote Ops I room in Waimea. There should be little operational difference between observing from there and from the summit, other than using different computers: haleiwa in Waimea and honolii at the summit. These are 2- or 3-headed monitors, to allow more screen real estate for observing. Below we will use haleiwa as an example; replace that computer name with "honolii" if you are at the summit.

Log into the data-taking computer as "nirc." At the password prompt, type the password supplied by the CARA Instrument Specialist or Observing Assistant (O.A.). Visiting scientists will be given temporary use of one of the login accounts nirc1, nirc2, nirc3, nirc4, or nirc5 for data reduction. These accounts are recycled after each observing run, and any files you wish to keep should be backed up to your tape, or transferred over to your home institution (but be wary of large file transfers!) as soon as possible.

Windows

The X window display manager will start up followed by the virtual desktop manager on all monitors. An xterm window logged onto maili should automatically appear upon login. Note that there is generally a message printed at the top of every newly created maili xterm; read this for recent changes and for a quick reminder of the setup steps.

The first step is to find a data disk with enough space for your data, and create a subdirectory to hold the data. The easiest way to do this is to type the **`newdir`** command. This command searches for the disk with the most space available, goes to the **`nirc`** subdirectory on that disk, and creates a new subdirectory consisting of the UT date for that night. If such a directory already exists you will be told. One can also add a specific disk name to the **`newdir`** command to force it to use that particular disk: **`newdir /sdata300`**, for example.

Alternatively, one can create a subdirectory by hand. We will use fictitious numbers in the following example, but this should give you the idea. To create a unique subdirectory name, we encourage you to use the UT date (not HST date!) of your night of observing. *Note that use of a very generic name like "nite1" will make it difficult to retrieve your data off the Keck archive tapes, if you need to do this.* To check disk space, type:

```
maili% disks
```

which will give you an ordered list of data disks and the amount of space available on each. Choose one, usually the top of the list, with enough space for your data. We will use "/sdata300" as an example. Go to the nirc directory on that disk and create your subdirectory:

```
maili% cd /sdata300/nirc
maili% ls
maili% mkdir 21apr97
```

Here **`ls`** lists the directory contents, just to make sure there is not already a subdirectory with the name you intend to use. The new NIRC software *will* write over existing files!

Now that you have created the directory, select the "Start NIRC Software" from the pull-down menu. This will bring up a number of windows…

6. **NIRC P3 Control—**where you will type all of your commands.
7. **rabbit tip—**the "console" of rabbit, the diskless computer actually controlling NIRC.
8. **log tail—**the log of low level NIRC communications.
9. **NIRC P3 Auxiliary—**a second window from which you can access a subset of NIRC commands. This window is mostly used for interacting with the display while the P3 Control window is busy running observing scripts.
10. **FIGDISP—**the image display window, together with its GUI.
11. **NIRC_Status**.**—**a text-based, self-updating window showing the status of various NIRC parameters

The NIRC software will automatically initialize in the "NIRC P3 Control" window. Watch for a question asking which directory you will use. You can always change this later in your session if you wish, using the **`runname`** command.

The NIRC software attempts to be relatively smart when it starts up. For example it will try to talk to the necessary programs on rabbit. If it cannot, it will try to start those programs. If, after waiting a certain length of time, it still cannot contact the rabbit programs, it will print out some suggested further courses of action and quit.

The startup script will also try to determine whether the motors have been homed. If they have not, or if the daemon running on rabbit has been killed off by a software reset, it will ask you whether you want to home the motors or not. If you answer **`n`**, it will remind you to run the **`homemot`** command at some point in the future. (For those doing engineering, if the tertiary mirror pitch and yaw controls are connected, you will have to also type **`enabletm`** to enable the appropriate motors. There is no homing mechanism on the tertiary mirror motors.)

Another thing the startup software tries to do is tell whether the NIRC DSPs are ready. If it cannot find a legitimate timing pattern name it will assume that the DSPs need to be rebooted. It will then automatically load the "patslow" timing pattern.

If all of the software successfully comes up, you should see "NIRC/P3 should now be ready to go."

Several lines should scroll up on the "log tail" window right away and system log messages appear there as they are written. In the unlikely event that you need to reboot rabbit when restarting NIRC, type **`~#`** in the "rabbit tip" window.

You should at this point check to see whether you are talking to the DCS simulator, or to the real DCS (telescope *D*rive *C*ontrol *S*ystem). During the day, when accidentally moving the telescope could be hazardous to the day crew, NIRC often is set up to talk to the DCS simulator. To find out, type **`check_dcs_mode`**. To initiate the DCS simulator, if you are for example trying to test dither procedures for typos during the day, type **`make_dcs_sim`**. If the simulator is not running, this command will also tell you how to start it. If you are talking to the simulator, but want to change to the real DCS after the OAs have got it up and running, type **`make_dcs_real`**. Unlike the previous software, this can be done at any point during data-taking. Subsequent commands will use the real DCS.

Additional "NIRC tools" are available on pulldown menus after the telescope is initialized:

- "**Reset NIRC Software**" is an automated method of trying to recover from crashes. It works fairly well, and should be your first choice if there seems to be a software problem.
- "**Restart NIRC Status**" brings up a new version of the xshow window. It will kill off any existing copies it can find first. This might be useful if you prefer the xshow window on a different monitor, for example.
- "**Restart Auxiliary NIRC Window**" brings up another auxiliary window, which will have access to a restricted set of NIRC commands.
- "**Help**" brings up Netscape and the NIRC home page. This contains the latest information on instrument configuration and startup and supercedes the startup information in this manual. In particular, note the "Latest News" page for current problems/workarounds, tips, upcoming events, etc.
- "**Telescope—graphical version (FACSUM)**" shows where the telescope is pointing, the time, the rotator angle and status, etc. This is the "Facilities Summary" or Facsum screen.
- "**Telescope—text version (xshow)**" shows the telescope parameters in a text format.
- "**Guider Eavesdrop**" is generally used in remote observing to create a copy of the master guider display used by the OAs. *When you want to kill the eavesdrop, use the "Guider Eavesdrop Stop" menu item, rather than choosing "Quit" from the title bar's pull-down menu!* This is because there are two processes involved in the eavesdrop, and choosing "Quit" will kill only one of them, leaving the other around to possibly cause problems later on.
- "**Chopper Status**" displays various chopper parameters.

- "**Compass rose...**" will bring up either an Azimuth/Elevation or an RA/Dec directional indicator, depending upon which option is selected. This applies to both NIRC and the guider, which are rotated with respect to each other by only 0.52°.
- "**Weather**" brings up the XMET weather display for Keck I. This shows current temperatures of the outside air, the dome air, the secondary, and primary mirrors. It also shows the dew point depression for the mirrors and the outside air, relative humidity, and information on the wind. Web sites at UKIRT, CSO, and other summit observatories often have other useful information.
- **Close Windows—**This will close the windows on your computer that were brought up by the startup script. Use this, for example, if you do not want to shut down the NIRC software, but want to move from the computer you are on to a different one.
- **End Night and Close Windows—**At the bottom of the NIRC Tools sub menu, this will do an "endnight, " which closes the tertiary mirror cover, places the cold plug and slit mask into the beam, and turns off power. The command then does a "close_windows, " which will close the windows opened by the startup script.

Next, you may want to open the lid on the tertiary mirror so the dewar can see the light from the secondary. (If you want to take dark frames, keep the lid closed but type **`f77k`** to insert the cold aluminum plug.) To open the tertiary mirror cover, type:

```
p3maili% tmopen
```

`tmo` is an alias for `tmopen`. The commands **`tmclose`** or **`tmc`** will close the lid. It is good practice to close the lid during long idle periods in order to keep dust off the mirror.

If you did not clear the slit and slit mask from the optical path earlier, type:

```
p3maili% sltclr
```

Facility and User Scripts

You are now working in the normal UNIX shell ("tcsh" to be specific). You can type any UNIX commands, as well as any NIRC commands; the latter are generally UNIX scripts. If you are using some scripts of your own, you will need to put them on maili into a directory of the form ~nirc/p3/vis/xyz, where xyz are your initials. (Your full name can be used, too.) To access your scripts, type **`user xyz`** and the subdirectory will be added to the UNIX path variable, which tells UNIX where to look for scripts and commands. Note that your user directory will be added to the *start* of the path, meaning that if you have your own version of **`goi`** it will be used rather than the facility version.

The NIRC commands also have some new built-in smarts. One problem with running within the UNIX shell is that there may be UNIX commands with the same name as NIRC commands. One example is "`finger`," which in UNIX will list current users of the system, but which in NIRC is used to place the occulting finger into the light path. In many cases the NIRC script intercepts such and checks for an appropriate argument. In the case of "`finger`," if the command is followed by a number the script interprets it as a NIRC command; otherwise it runs the UNIX finger command for you.

Some commands are also more versatile than before. For example, the "`goi`" command can now take an optional argument specifying the number of frames to take. Hence "`goi 10`" will take 10 frames using the current parameters. This replaces the functionality of "`ngoi`," although "`ngoi`" remains behind, for backward compatibility. (If you are not familiar with "`ngoi`," don't worry; it's easier to ignore it and use "`goi`" instead.) Other commands that normally take an argument, such as "`coadd`," now return the current value of a parameter if the argument is left off. Hence "`coadd`" by itself will report the number of coadds currently set.

Finally, the "`help`" command, with no arguments, prints out a brief command list, as it did before. However, "`help` *command*" will print out information on *command*; specifically it will print out all comment lines in the script (those lines beginning with the "#" character.)

Taking Data

Before you start an exposure, you probably want to set up the exposure parameters. First you will need to select a timing pattern. There are three timing patterns in general use: patslow for normal JHK and narrow-band imaging and for spectroscopy is the workhorse, and is loaded during the normal startup of the NIRC software. It has a minimum integration time of 0.43 seconds. For speckle work and some longer wavelength work (especially with narrow-band filters in the 3–4 micron range), the pat4xa timing pattern provides a minimum integration time of 0.143 secs. For broad-band 3–5 micron imaging use the max12ur pattern (minimum integration of 0.030 seconds). The faster patterns tend to have higher readout noise, and in fact the max12ur pattern must use the 12-bit ADCs to achieve their speed.

The command **`tint 5`** will set the integration time to five seconds. Tint may be set to any number greater than the minimum time which is shown when a timing pattern is loaded. Also, you need to select how many frames you wish to coadd together. The command `coadd` followed by an integer will allow you to do this:

```
p3maili% tint 2.5
p3maili% coadd 4
```

This sequence of commands will coadd 4 frames, each of 2.5 seconds duration, and output one coadded image to disk. The maximum number of frames which can be coadded is 2^{19} = 524,288 with the 16 bit ADC and 2^{23} = 8,388,608 with the 12 bit ADC.

The most common variables have been set, and you may take a picture by typing **`goi`**. There are essentially three flavors of image-taking: **`goi`**, **`snapi`**, and chopping mode. The first two are by far the most common with NIRC. `Goi` takes a single frame, without moving the telescope. `Snapi` takes a pair of frames, moving the telescope by the "nod" distance in between. (Basically it does two "`goi`" commands with a telescope move in between.) After the picture has been taken, you can display it in the Figdisp window by typing the command `dlp`. This "display last picture" command shows the most recent picture taken.

```
p3maili% goi
p3maili% dlp
```

Note: If you wish to name the object before taking a picture, you can use the `obj` command. You may need to put the name inside *double* quotes, if there are any special shell characters (*&/`?.). Similarly, you can specify an image type via the `typ` command:

```
p3maili% obj "My Target"
p3maili% typ "data"
```

These actions will cause two keywords, OBJECT and IMAGETYP, respectively, to be set.

The file is saved in the directory specified by the `runname` command. For example, the first file will be called /sdata300/nirc/21apr97/s00001.fits. The runname is usually set during the startup script, although it can be changed at any time, for example:

```
p3maili% runname /sdata300/nirc/23apr97
```

This will put data into /sdata300/nirc/23apr97/s00001.fits. The program also looks for the highest numbered FITS file in that directory, and adjusts the frame number (FRAMENO) to write new data in sequence with the old data. If you get an error message when you try to write a file, check that the directory exists, that you have write permission, and that the disk is not full.

If you do not want to start with file number 1, the **`frame`** command may be used. Note that, unlike the old NIRC software, you *can* now silently write over existing data files.

Display

FIGDISP is the display used with NIRC and most other Keck instruments. It is fairly versatile, but there are a number of features that you will likely want to take advantage of immediately. For example, you may want to click on the "Pan/colors" button; this will allow you to pan across the image with the left mouse button, or (more useful) change the contrast and zero level of the grayscale mapping of the display, by clicking and dragging with the right mouse button. A single click with the right mouse button will reset the color mapping to the original default values. Clicking and dragging with the middle mouse button will create a line plot across the drag, useful for looking at PSF shapes.

Note that the "Pan/colors" and "Stat" buttons are mutually exclusive. To use the latter, click on that button. Then the left mouse button will define the upper left corner of a box, and the right mouse button will define the lower right corner. The statistics of all pixels within that box are displayed in a pop-up window. Note that often the corners don't get defined properly; you might have to adjust your box selection.

Another feature of FIGDISP is that it allows three different types of scaling of the data onto the display. These correspond to buttons labeled "Linear," "Hist. Eq.," and "Auto." Often FIGDISP will choose the one that allows you to see the *least* detail in your image. Judicious switching between these three options usually finds one that will show what you need to see. The "Pan/colors" button can then be used to further fine-tune the color mapping if needed.

There are also keyboard commands for many of the FIGDISP functions. The following keystrokes are available. "F" refers to keys in a row at the top of the keyboard, "L" to keys on the left-hand side of the keyboard, and "R" to keys on the right-hand side.

Table 3. FIGDISP Buttons

Key	Function
F2	Zoom in
F3	Normal zoom
F4	Zoom out
F5	Help (display this help message)
F6	Toggle cursor display
F7	Recenter image
F8	Toggle display of window showing location of main window in image
F9	Quit
F10	Show a window containing the color map
L1	Toggle display of window showing the pixel values around the cursor
L2	Produce a row plot in the line graphics window
L3	Print the image

Key	Function
L4	Print the visible portion of the image
L5	Move another window to the front
L6	Inhibit interpretation of all other keys until this key is pressed again
L8	Toggle color map inversion
L9	Toggle display of window showing centroid and FWHM of star near cursor
L10	Produce a column plot in the line graphics window
,	Decrease number of pixels averaged for a line plot
.	Increase number of pixels averaged for a line plot
/	Reset number of pixels averaged for a line plot
R1	Cycle between: histogram equalization, autodisp, and normal ("Pause" key)
R2	Toggle mouse: box ul, slit, box lr, or center, slit, color ("Print Screen" key)
R3	Print image statistics within box ("Scroll Lock" key)

Of course observers familiar with other displays may wish to use those to look at their images. IDL, IRAF, and VISTA are all available at Keck.

Locating Your Object

If you have prepared a "starlist" containing your targets, let the OA know which file you are using, and the target name within that file. At this point it is also good to let them know at what position angle you need the rotator, and whether this p.a. corresponds to a guide star, an angle along the y-axis, or an angle along the slit. It is important to understand that the definition of the angle is as important as the value, as there are subtle (or not so subtle) differences between the angles.

The IR rotator is used in two basic modes with NIRC. PAMODE removes the field rotation inherent in tracking an object with an alt-az mount. This is the mode generally used for everything except speckle observations and other special types of observations requiring that the telescope pupil remain fixed during an integration. PAMODE also allows guiding the telescope by keeping a guide star stationary on the guide camera.

STATIONARY mode basically turns the rotator off, allowing the field to rotate during an integration. This mode is used for speckle and some other observations because it keeps the telescope pupil stationary. In this case the center of field rotation should be around the "pointing origin," which we describe next.

NIRC has three or more "pointing origins," which are special positions within the telescope's focal plane. They have two important functions: they specify where in the focal plane the current RA and Dec. represent, and they specify the center of field rotation in STATIONARY mode. The REF pointing origin corresponds to the center of the guider camera. The NIRC pointing origin corresponds to the center of the detector. When the OA acquires a target, he or she will first center the star in the guide camera using REF, then send the star to the NIRC pointing origin. (This is the OA's jargon; in reality, of course, the OA is first centering the point in the telescope's focal plane corresponding to the guider center on the star, then recentering the telescope so that the star falls on the center of the NIRC detector.) There is also a NIRCIC pointing origin that corresponds to the center of the NIRC image converter (offset about 2.5 arcsec from NIRC). There are also pointing origins for various commonly used subarrays, such as the lower left 128 x 128 array, the lower left 64 x 64 array, etc.

These are of the form NIRC128, NIRC64, etc. Note that centered subarrays will of course still use the NIRC pointing origin.

The position angle of the instrument is naturally of interest. In stationary mode the "PA" corresponds to the physical rotation angle of the rotator mechanism itself. The translation of this angle onto the sky (what astronomers normally call "position angle") depends on the telescope's position, and of course will rotate with time as the telescope moves across the sky. The physical rotator p.a. is represented by the keyword ROTPPOSN, written to the FITS header of each image. In PAMODE, the "position angle" corresponds to the normal astronomical definition of the vector from the NIRC detector center to the guide camera center. This is the most commonly used definition, as finding a guide star is the most common reason for choosing one particular PA. It is represented by the keyword ROTPOSN, also in each FITS header.

Other definitions are important: the "up" direction on the NIRC detector, for example, or the p.a. of the slit. The OA will require the "SKYPA," while ROTPOSN is the appropriate FITS keyword written to the file headers. They are related by SKYPA = ROTPOSN + 100°. Useful angles can be calculated as follows:

- detector to guider vector
  = SKYPA
  = ROTPOSN + 100°

- "up" along slit
  = SKYPA + 80.05°
  = SKYPA + 90° – arctan$((Y_N - Y_g)/(X_N - X_g))$ – 0.52° + 1.3°
  = ROTPOSN + 180.05°

- "up" on detector
  = SKYPA + 78.75°
  = SKYPA + 90° – arctan$((Y_N - Y_g)/(X_N - X_g))$ – 0.52°
  = ROTPOSN + 178.75°

where the NIRC pointing origin is (X_N, Y_N) and the guider pointing origin is (X_g, Y_g). The current pointing origins are available from the DCS GUI or by asking the OA. The value –0.52° accounts for a slight misalignment between the rotator axes and the NIRC axes, and 1.3° is the tilt of the slit relative to the NIRC axes (in imaging mode; in spectroscopic mode the slit images will then lie parallel to NIRC columns.

Some useful conversion formulae; to convert from guider (*x,y*) coordinates to rotator (*XIM, YIM*) coordinates:

$$\begin{bmatrix} XIM \\ YIM \end{bmatrix} = S\begin{bmatrix} 192 - x \\ y - 144 \end{bmatrix} + \begin{bmatrix} X_g \\ Y_g \end{bmatrix} = 0.19\ \mathrm{mm/pixel}\begin{bmatrix} 192 - C \\ R - 144 \end{bmatrix} - \begin{bmatrix} 366.4 \\ 10.2 \end{bmatrix}$$

To convert from NIRC (x,y) coordinates:

$$\begin{aligned} \begin{bmatrix} XIM \\ YIM \end{bmatrix} &= S\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} x - 128 \\ y - 128 \end{bmatrix} + \begin{bmatrix} X_N \\ Y_N \end{bmatrix} \\ &= 0.19\ \mathrm{mm/pixel}\begin{bmatrix} \cos\theta & \sin\theta \\ \text{-}\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} x - 128 \\ y - 128 \end{bmatrix} + \begin{bmatrix} -2.4 \\ 58.8 \end{bmatrix} \end{aligned}$$

where $\theta = 179.48°$.

The precise definitions of all angles and keywords are contained in *KSD 40: DCS Coordinate Systems*. This document is the definitive one, but is rather difficult reading the first time.

Telescope Status

Telescope status is usually viewed from a window called "FACSUM" which stands for Facility Summary. The O.A. has this display in front of them, and remote observers can bring up a copy on one of their screens. There is also a simpler test version of this display, which contains a slightly different subset of the DCS keywords.

The IR module rotator angle and telescope compass roses may be displayed by selecting "compass rose (az/el)", or "compass rose (ra/dec)", under the "NIRC Tools" submenu.

To see a list of DCS or chopper keywords:

```
p3maili% show -s dcs keywords
p3maili% show -s chp keywords
```

To show the chopper status use the "chopper status" selection under the "NIRC Tools" submenu.

To check that the telescope is in simulate mode:

```
p3maili% check_dcs_mode
```

The user should check that the telescope is being simulated before doing any daytime testing with NIRC commands that may move the telescope (such as **snapi**).

Focusing the Telescope (malign and foc8)

The best way to focus the telescope is to run MAlign because it is seeing-independent, unlike techniques that try to minimize the FWHM of stellar images. MAlign will compute a tilt and *z* position for the secondary, as well as restack the 36 mirror segments if needed. The secondary tilt adjustment is used to remove any residual coma in the image, something else standard techniques cannot do. Six images are taken with a NIRC procedure which automatically takes a sky frame, then takes two images at one primary mirror focus mode (PMFM) position with all segments spread out, and then takes two images at the opposite PMFM. The OA will run the MAlign analysis tool. The sequence of steps is:

The OA should first center an 11th or 12th mag star on the guider and then send it to NIRC. Since the *HST Photometric Standards* are all about the right brightness, it is often convenient to start by looking at one of them. A fairly sparse field is chosen because any stars within ~30 arcsec will have segment patterns overlapping that of the focus star, confusing the data reduction.

The observer will then type:

- **k**
  Any filter is fine to use, although the integration time given below is for the K filter. A table containing relative throughputs for other filters is in the works.
- **tint 2 ; coadd 10**
  Set tint to about 2 sec (depending on seeing conditions and spectral type), and coadds high enough to bring the total integration time to 20 sec (to average over seeing variations).
- **malign**
  Run malign at the `p3maili%` prompt to take the frames. The computer will beep after each frame is taken. First it will go off to the nod position to take a sky frame, then come back to begin taking the malign data. Only the first object – sky pair is displayed. The observer will be told what frame number to relay to the OA, who can then begin the analysis. This entire process takes 5 to 10 minutes.

> Malign checks the currently set nod parameters, set with the "nod" command, and uses them if they are more than 25 arcsec away from zero. If they are not (commonly they are not used, hence are set to zero throughout a run), the telescope will nod 40 arcsec north to get sky. Malign also automatically stores your runname, changes to another directory where the malign data is stored, takes its data, and then restores your original runname. Ctrl-C will short circuit this process, but should restore your runname.

In addition, the Offset Guider has an autofocus routine that may be requested by verbally asking the OA to run "autofoc"on the guider. This will not adjust tilt or primary stack. After this procedure, fine focusing can be done on the NIRC detector itself using `foc8`, `foc5`, `foc3`, or `focus`.

To change the secondary focus, type:

`p3maili%` **`foc`** *n*

where *n* is the new focus.

To take a series of frames at different focii, type:

`p3maili%` **`focus`** *fmin fmax*

where *fmin* is the starting minimun focus, and *fmax* is the ending focus. The step size used is 0.05. Positive focus moves the secondary away from the primary. The best focus is found by subtracting a sky frame from each of the focus series frames and using Kfigdisp to measure FWHM (the "FIND" key) to find the frame that has the smallest FWHM. Other data analysis tools such as IRAF or IDL can also be used.

`foc8` *start step* does 8 focus positions of a focus star centered on the NIRC detector and mosaics these 8 stars on a single frame. It moves the telescope 40 arcsecs north, takes a sky frame, moves back to the centered object, takes a strip in the middle of the frame at the `start` focus, subtracts the corresponding sky, mosaics the strip into the bottom of buf4, changes the focus by *step* mm, takes the next frame at the new focus, mosaics the sky subtracted strip to the next strip of buf4. The resultant buf4 frame of 8 focus stars is written out to the next FITS file number on the disk and displayed, with the *first* focus position at the bottom of the image. Pick the best focus using the Figdisp fwhm key or send the frame to IRAF for analysis.

`foc5` does 5 focus positions and **`foc3`** does only 3 focus positions. Throughout the night, telescope focus will be compensated automatically for temperature and elevation changes. For the best results, however, focus should be checked when moving to a new object.

Offsetting the Telescope

There are several useful commands for offsetting the telescope, in either detector or guider coordinates, or relative to the telescope azimuth and elevation axes, or in R.A. and Dec. Remember that positive y moves the telescope up and therefore the image on the detector display moves down and similarly with the other moves. All moves are in arcseconds. Parameters *x* and *y* may be positive or negative numbers and they may be entered as integers or as real numbers with decimal points and trailing digit(s).

Table 4. Offsetting Commands

Procedure	Units	Description
x *x*	arcsec	Moves the telescope *x* arcsecs horizontally on NIRC relative to the current position.
y *y*	arcsec	Moves the telescope *y* arcsecs vertically on NIRC.

Procedure	Units	Description
mxy *x y*	arcsec	Moves the telescope in both *x* and *y* (arcsecs) on NIRC.
az *x*	arcsec	Moves the telescope *x* arcsecs in azimuth.
el *x*	arcsec	Moves the telescope *x* arcsecs in elevation.
gxy *x y*	arcsec	Moves the telescope(*x*,*y*) arcsecs in guider coordinates.
e *e*	arcsec	Moves the telescope *e* arcsecs east.
n *n*	arcsec	Moves the telescope *n* arcsecs north.
s *s*	arcsec	Moves the telescope *s* arcsecs south.
w *w*	arcsec	Moves the telescope *w* arcsecs west.
en *e n*	arcsec	Moves the telescope *e* arcsecs east, *n* arcsecs north.
cent *x y*	pixels	Centers an object on NIRC coordinates (*x*,*y*) to (128,128).
scent *x y*	pixels	Centers an object on NIRC coordinates (*x*,*y*) to (180,128), the default grism center.
iccent *x y*	pixels	Centers an object on NIRC coordinates (*x*,*y*), without the image converter to the middle of the image converter field.
mov *x1 y1 x2 y2*	pixels	Moves an object on NIRC coordinates (*x1*,*y1*) to (*x2*,*y2*).
sltmov *x*	arcsec	Moves the telescope along the slit *x* arcsecs. +*x* moves the object up the slit.

Notes on Offsetting in Azimuth or Elevation

Offsetting to sky and back can be done using detector (x,y) coordinates, or changes in (α,δ), or changes in azimuth and elevation. The latter might be desirable when you want to avoid the diffraction spikes of your target (in case it is very bright). (The diffraction spikes rotate with time in celestial coordinates, but not in (az,el) coordinates.) Using azel offsets to go to sky and back can, however, cause drifting of the image.

An example:

When in stationary mode, the field will appear to rotate around the pointing origin, which is generally either the NIRC center or the image converter center (which is close to the NIRC center). When the telescope offsets in elevation to the sky position, it continues to rotate around the sky position (not the target position). This causes the target to rotate around the sky position. If the telescope is then commanded to move the opposite distance in elevation, the target ends up off-center.

Another way of looking at this, which is perhaps more appropriate to the rotator's P.A. mode, is that a change in elevation at one point in time is not the same (Δα, Δδ) as at other times. Hence the second move does not bring the telescope back to the same position as the first move.

How can image drift be avoided if you must use azel offsets? One technique is to record the DCS keywords RAOFF and DECOFF before moving to sky. Then move in elevation or azimuth to the sky position. When ready to return to the target, rather than use the azel move opposite to the original, reset the telescope RAOFF and DECOFF keywords to their original values:

```
modify -s dcs raoff=$oldraoff decoff=$olddecoff rel2base=t
```

This will return the telescope to the target position regardless of the original sky move.

Dithering

Infrared imaging very commonly uses “pair subtraction,” in which two images of identical exposure times and coadds and taken close in time to each other are subtracted. The image pair sometimes consists of a target field and a widely separated “sky field.” Generally you would use `snapi` and the nod parameters to control this type of data-taking. Recall that `snapi` takes an exposure, then moves the telescope by the nod parameters, takes another “sky” exposure, and then returns the telescope to its original position.

Moving the target all the way off the detector, however, cuts your on-source integration time in half. Many projects use smaller moves, in which the target is moved from one part of the detector to another. This technique is called “dithering,” and is most often controlled by one of various procs which use the `goi` command:

Table 5. Dither Commands

Procedure	Description
box5	Moves the telescope in a 5-position box pattern using the **nod** distances.
box9	Moves the telescope in a 3x3 box pattern using the **nod** distances.
bxy5 *x y*	A 5-position pattern specified by *x* and *y* arcsecs in NIRC coordinates.
bxy5q *x y*	Same as **bxy5**, but does not display differences.
bxy9 *x y*	A 3x3 pattern specified by *x* and *y* arcsecs in NIRC coordinates.
bxy9q *x y*	Same as **bxy9**, but does not display differences.
mosaic *nx ny dx dy*	An *nx* by *ny* mosaic of *dx* and *dy* increments in NIRC coordinates
thinxy *x y n*	A 5-position pattern in either *x* or *y* arcsecs (the other direction should be set to zero), useful for when the guide star is on the edge of the field. *n* is the number of times to repeat the 5 positions.
thinxyq *x y n*	Same as **thinxy**, but does not display differences.
Spectral Dithers	
s5 *n*	A 5-position pattern along the slit, repeated n times.
sp2 *n*	Switch between 2 positions along the slit, separated by 12.8 arcsecs. Repeat n times.
sp55 *n*	A 5-position dither along the slit, repeated *n* times. The sequence is (+10, –5, +5, –10, 0) arcsecs.
sp56 *n*	A 5-position dither along the slit, repeated *n* times. The sequence is (+12, –6, +6, –12, and 0) arcsecs from the initial position.
sp74 *n*	A 7-position dither along the slit, repeated *n* times. The separation is 4 arcsec.

More Capabilities

NIRC has more capability than simple IR imaging. In the following sections we discuss some of this versatility.

Fast Pictures for Longer Wavelengths and Speckle

To acquire data at longer wavelengths such as L' or M, or to take speckle frames more rapidly, the NIRC detector must be clocked faster than the default 423 ms per frame. Faster timing patterns such as `nircfast` (61ms), `pat4xa` (149 ms), `speckpat` (98 ms), `maxur` (42 ms) , or `max12ur` (29 ms) may be used. `max12ur` will automatically set to the faster 12-bit A-to-D converter. Faster timing patterns are noisier but allow data acquisition at longer wavelengths.

In addition, total readout time may be decreased by reading only a portion of the array. The fastest subarrays are in the lower left corner of the image; these are accessed by the subll command. Central subarrays can be chosen using the subc command. Follow the command by the subarray size: **`subll 128`** will choose the lower left 128x128 subarray, for example, while **`subc 256 32`** will choose a centered strip 32 pixels high and the full chip wide (potentially useful for spectroscopy). If only one parameter is specified, the missing one is assumed to be the same (i.e. the subarray will be square). Note that the number of horizontal pixels must be divisible by 8, and the number of vertical pixels by 2. These constraints will be forced upon the subarray sizes if the input parameters are not divisible by these values. To return to full chip readout, use **`initsub256`**.

The following commands are used with subarraying:

Table 6. Subarray Commands

Command	Description
initsub256	resets to full-chip readout.
subc *nx* [*ny*]	selects the central *nx* x *nx* or *nx* x *ny* readout.
subll *nx* [*ny*]	selects the lower left *nx* x *nx* or *nx* x *ny* readout.
initsub64bar	selects the central 256 x 64 readout.
initsub32bar	selects the central 256 x 32 readout.

The following minimum times are available with various timing patterns where "C" indicates a centered subarray and "LL" indicates a lower left subarray closest to readout register:

Table 7. Minimum Times for Subarrays

			Minimum Frame Time (msec)		
Cols (x)	Rows (y)	Position	patslow	pat4xa	max12ur
256	256	full	409.52	137.01	25.02
128	128	C	106.28	38.15	9.73
128	128	LL	102.94	34.81	6.84
64	64	C	28.89	11.86	4.21
64	64	LL	26.06	9.02	2.04

Cols (x)	Rows (y)	Position	Minimum Frame Time (msec) patslow	pat4xa	max12ur
32	32	C	8.76	4.50	1.99
32	32	LL	6.71	2.46	0.72
256	128	C	205.26	69.00	13.01
256	64	C	103.13	35.00	7.01
256	32	C	52.07	18.00	4.01
256	16	C	26.53	9.50	2.51

Using the Image Converter

- **`homeic`** homes the image converter. Normally this is done as part of the home motor sequence at startup, and does not need to be done again.
- Put the image converter in by typing: **`icin.`**
- Remove the image converter by typing: **`icout`**.
- **`iccent`** *x y* moves the telescope so that the object at *x y* comes near the center of the detector when the image converter is in place. Alternatively, the OA can point from the REF pointing origin on the guider straight to the NIRCIC pointing origin representing the center of the image converter field.
- **`gois [nslice [n]]`** takes *nslice* speckle frames and puts it in one file. The default for *nslice* is 100. A second optional argument (*n*) will specify how many of these data cubes will be taken (producing *n* files, each with *nslice* frames. Currently the number of frames that can be taken per file is limited to 196, so please adhere to this limit or risk crashes!
- **`ldbuf8`** *n* loads buf8 from a stored file on disk
- **`ibuf8`** *n* puts the *n*th frame of buf8 into buf1
- **`display buf1`** shows the extracted *n*th frame now

Using the Grisms for Spectroscopy

NIRC is furnished with a set of slits and a slit mask in the cold focal plane, grisms in the outer filter wheel, and blocking filters in the inner filter wheel for obtaining low resolution spectra. There are three grisms, gr150 (blazed at 1.7 microns in the first order), gr120 (blazed at 2.1 microns in first order), and gr60 (blazed at 4.2 microns in first order). There is also a choice of blocking filters for use with the grisms. If you are observing in the range 3–5 microns then would typically use gr60 and the LM blocker. Similarly for 1.4–2.5 microns use gr120 + HK, and for 1.0–1.6 micron spectra use gr150 + JH.

Apart from choosing a grism and a blocking filter, you also need to choose one of six slits widths: `slt1`, `slt2`, `slt3`, `slt4`, `slt8`, or `slt16` correspond to 1.5, 2.5, 3.5, 4.5, 8.5, or 16.5 pixel-wide slits, respectively. These commands take as an argument the column number in which you want the slit image to appear. Column 180 is the standard choice, which places the spectra in a convenient place on the detector, but observers may want to adjust this. Refer to the wavelength calibrations below.

It is best to have a good idea where the slit will end up in imaging mode before you point to your spectroscopic target. This can be done in daytime by looking at the tertiary mirror cover using the Kw filter. Move the chosen slit into position by typing `slt3 180`, for example. Note the center of the slit in row 128; it should be near 180 in this example, but may not be exactly 180. When observing you will want to put the targets onto (180,128) on the detector. Also note that the slit is at an angle of 1.3 degrees to the *y*-axis. This angle, however, produces a correctly oriented grism spectrum. The commands to move the slit also position the slit mask appropriately.

The observing sequence should go something like the following:

- Have the OA rotate to the appropriate position angle and point to your target.
- Move the telescope using *x* and *y* commands to center the object at pixel position (180,128) or use the **`scent`** *x y* command. Take a picture with **`goi`** using the K filter to verify position.
- Insert the slit and take another image. For bright objects you should be able to see the object in the slit, and possibly determine visually how well centered the target is.
- Alternatively, remeasure the slit center and tweak up the pointing is necessary by using the **`mov`** command.
- Select a grism. For example, **`gr150`**.
- Select a filter. For example, **`blkjh`**. (Note the use of the "blk" prefix, which prevents clearing the slits.)
- Begin your spectral exposure. For the example configuration, the first order will span pixels 32 to 157. For the blocker jh filter this will mean column 32 corresponds to 1.0 μm and column 157 would be 1.6 μm. Second order would start in column 191. When gr120 and blkhk are used, the first order will span pixels 59 (1.4 μm) to 246 (2.532 μm).

Wavelength Calibration

NIRC does not have any internal calibration source for measuring the wavelength scale. A combination of OH emission lines and various absorption lines from the night sky should give a reasonable scale. Unfortunately, the OH lines are all blended at this resolution, and the resultant calibration is not good. An alternative is to use natural sources (eg. a planetary nebula) to measure the wavelength scale and curvature of spectral lines.

Wavelength increases from left to right on the array. Rough calibrations, courtesy of Gerry Neugebauer, are:

HK + gr120	λ/microns = 2.118 + 0.005916*(x – xslit) – 3.52e–7*(x – xslit)**2
JH + gr150	λ/microns = 1.715 + 0.004912*(x – xslit) – 4.45e–7*(x – xslit)**2
LM + gr60, KL+gr60	λ/microns = 4.220 + 0.01285*(x – xslit).

Moving the slit to higher columns will shift the spectrum in the same direction, bringing shorter wavelengths onto the left hand side of the array.

Throughput and Higher Order Light

Some sample spectra will demonstrate some of the effects shown by various grism/filter combinations. Of particular interest are the effects of higher order spectra, atmospheric absorption, and an absorption feature caused by the resin in the grisms. Below we show some spectra of the Elias standard star HD 106965. This A2 star has broadband magnitudes of J = 7.375, H = 7.335, K = 7.315, and L = 7.295. The spectra that follow are *raw*. They include absorption from the atmosphere, from stellar features, and from the optics. Count rates are given in electrons/sec, integrated over the entire spatial width of the spectrum through the 3.5-pixel wide slit in 0.45 arcsec seeing.

The gr150+JH combination works well to isolate the J and H bands with no contamination. Second order light can be seen starting around 1.9 microns, well separated from the first order spectra. Note in this spectrum that outside the bandpass the flux does not go to zero. This is an artifact of "bleeding" in NIRC, which primarily shows as horizontal stripes associated with bright objects. In this case the spectrum itself causes the bleeding. See "NIRC bleeding" for further details.

Note also that flux is detectable between the J and H bands. The Mauna Kea sky is often dry enough that spectra can be obtained between the bands, albeit at reduced signal.

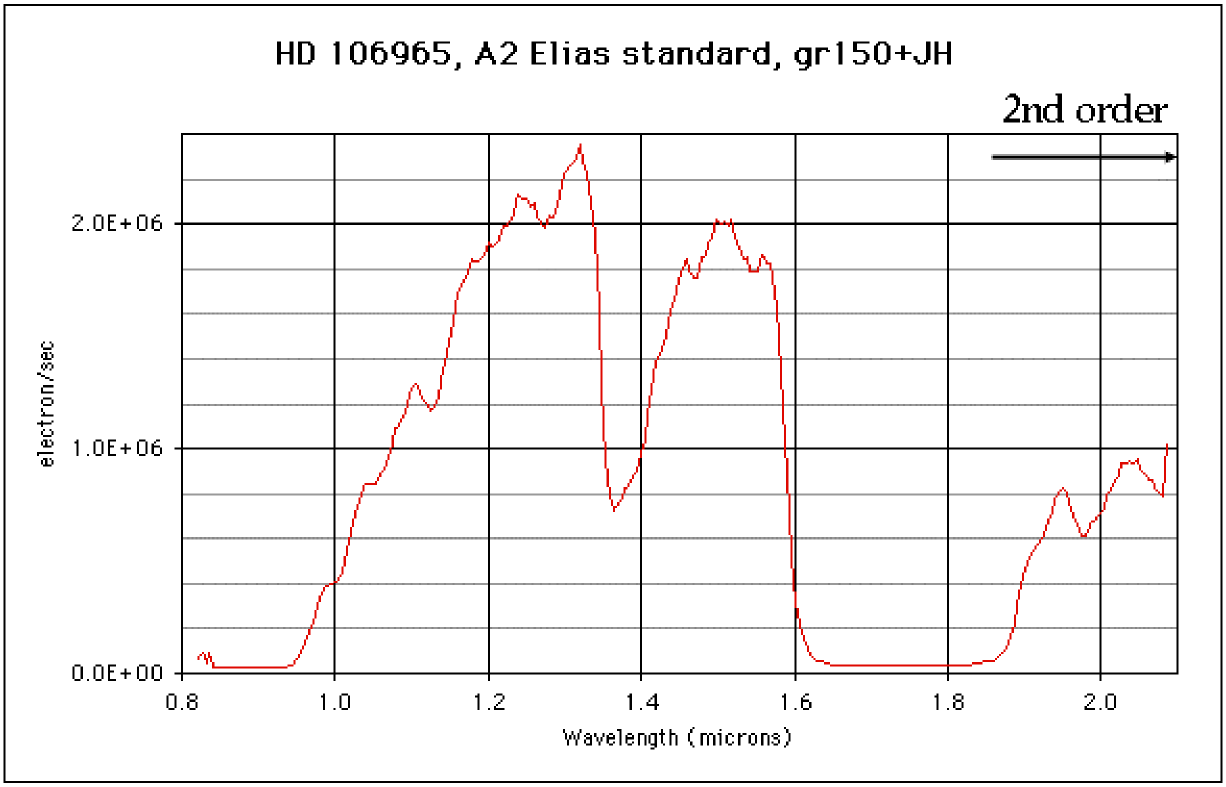

Figure 3. gr150+JH spectrum of the Elias standard HD 106965

The gr120+HK combination is also well blocked, and again it is possible to observe between the bands.

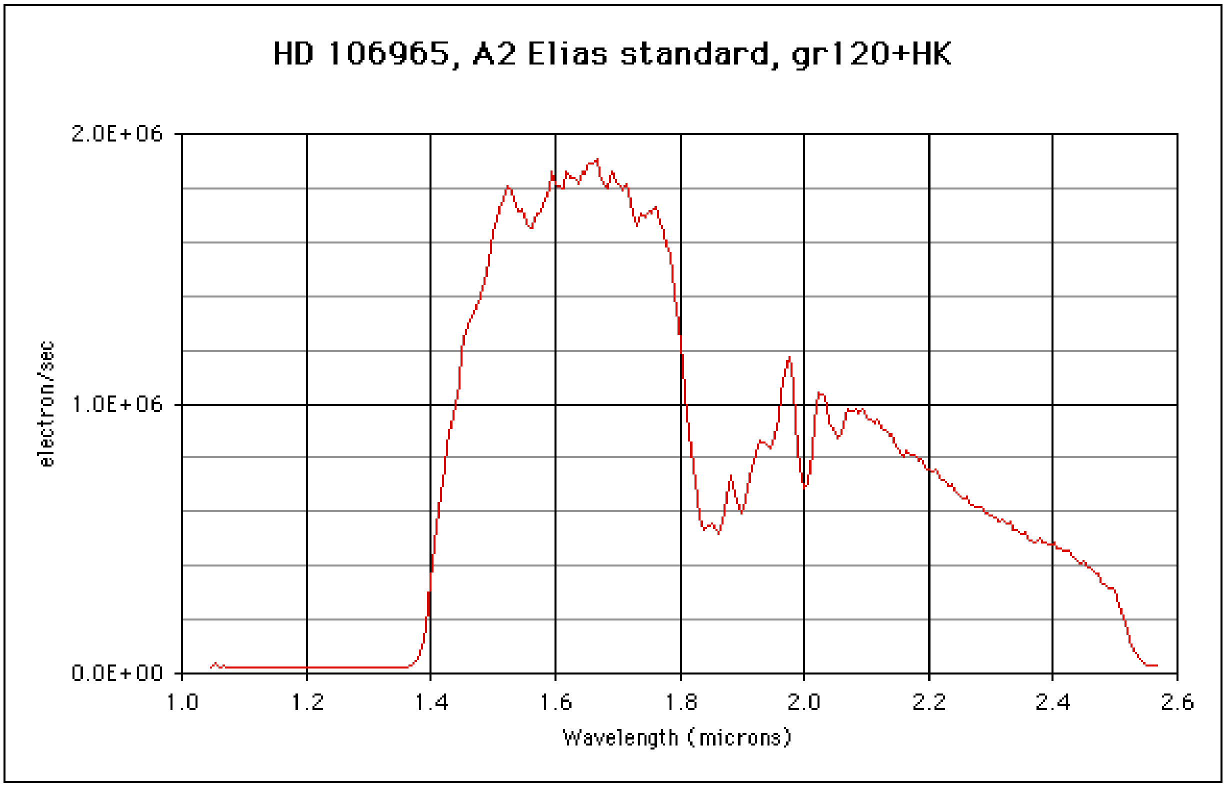

Figure 4. gr120+HK spectrum of HD 106965

The gr60+LM combination is well blocked, although the thermal emission from the sky at these wavelengths is large. You will either need to use a very fast timing pattern such as max12ur, or will have to subarray the detector to avoid saturation. The spectrum below was taken using a 256x20 subarray (**`subc 256 20`**).

Just below 3.6 microns is a broad absorption feature due to the resin used as the transmission grating part of the grism. This causes a drop of up to 50% in the count rate at some wavelengths.

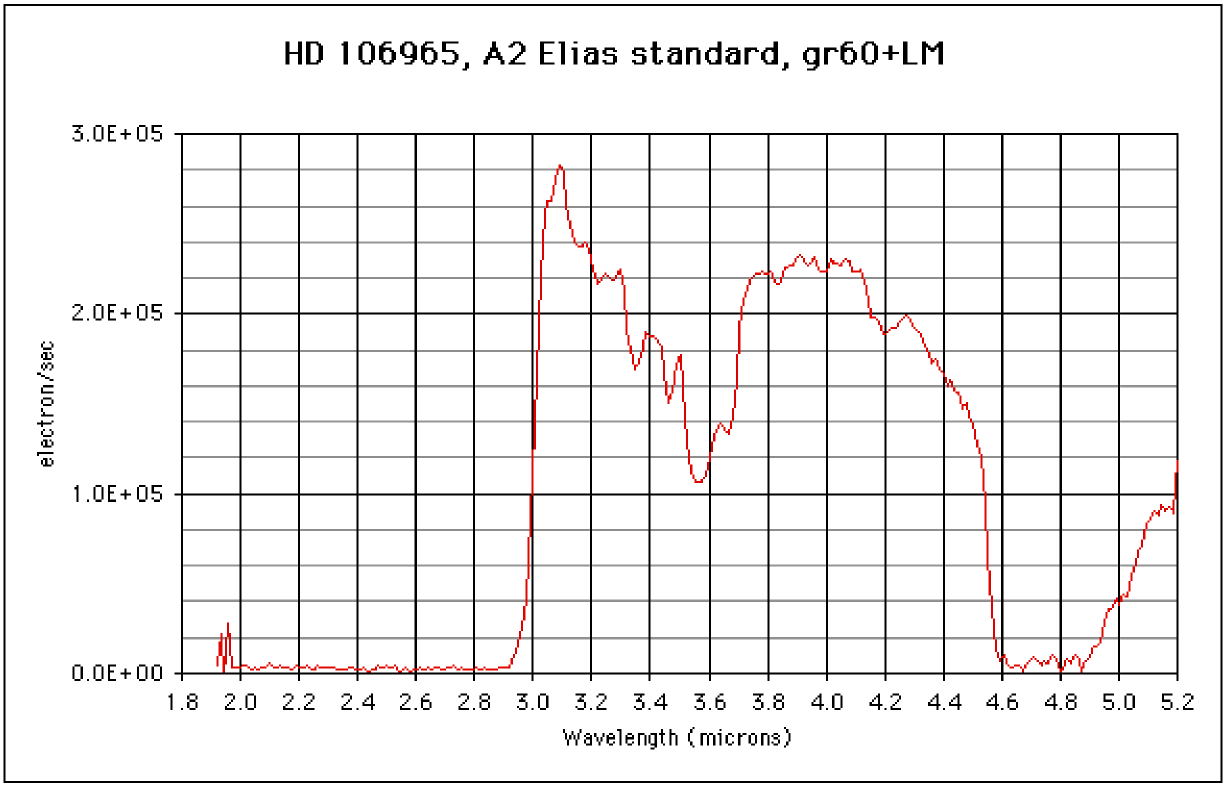

Figure 5. gr60+LM spectrum of HD 106965

The gr60+KL combination is a bit more problematic. This is because the second order light from the K band overlaps the reddest end of the L band, as shown below. As long as this fact is realized, the KL blocker still provides useful, uncontamainated spectra from the K band to 4 microns.

Another effect seen in the spectrum is the very deep atmospheric absorption from 2.6 to 2.9 microns.

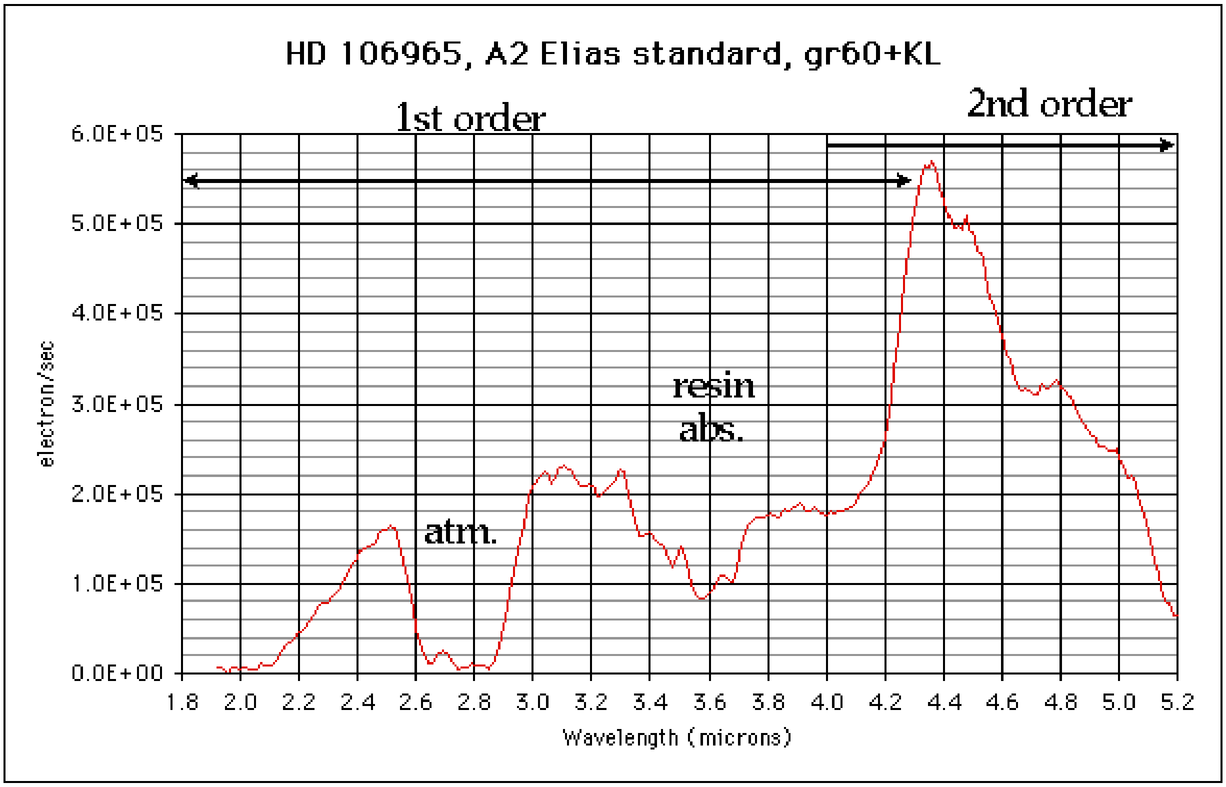

Figure 6. gr60+KL spectrum of HD 106965

Slit Dithering

To do an accurate sky subtraction use one of the observing macros that dithers the star to a fixed number of positions up and down the slit. The macro will move the telescope in rotator coordinates so you do not have to worry about conversion from (R.A., Dec.) to array (x, y) coordinates. A macro such as **s5** is a good choice. You will then use dithered frames to do a first order sky subtraction. This dramatically reduces the need for high accuracy flat fielding.

To dither accurately you *must* have a guide star. If you do not, after a couple of telescope nods the object will no longer be on the slit.

Integration Time

The integration time needed to get background limited performance depends on wavelength and observing conditions. Integration times of 5 minutes and longer are typical for JH and HK. Measure the sky brightness before you start a long sequence and compare the sky shot noise with the read noise of about 16 DN (100 electrons).

Correction for Atmospheric Absorption

The 1–5 micron windows are badly chopped up by H_2O, CO_2, and CH_4 absorption bands. Make sure that your spectral feature does not coincide with a terrestrial absorption line before you start. One way of checking is to look at the KPNO FTS solar atlas.

If you are doing spectrophotometry then you can correct for the atmosphere by observing a star of known spectral type and magnitude. The A0V stars on the Elias list are a good choice. G-dwarfs are also good stars for correcting atmospheric absorption because their spectral features are very weak. When in doubt, you can always take a hot star and a cooler star.

Flat Fielding

Measure flats with the same grism configuration that you used to observe your object. The dome fluorescent lights are not very good because they have Hg lines. Use the old LRIS flat field lamps. The OA can turn them on from a switch in the computer room. Often "superflats" are created by median-filtering observations on the sky to remove stars from the field.

Non-Sidereal Track Rates

Non-sidereal tracking rates can be used for following Solar System targets such as asteroids or comets. The definitive manual is *KSD 43: The Differential Tracking Manual*. Here we describe the use of these nonsidereal rates in your starlists, in the *SKY* program, and on the DCS command line.

The easiest place to put your differential track rates is in the starlist created for use by the OAs. Currently the starlist uses "pmra=" and "pmdec=" to hold the differential tracking rates; you *must* use "APP" as the equinox of your coordinates. This restriction may be relieved at some point in the future. The units for the starlist are sec of time/hour for R.A., and arcsec/hour for Dec.

These rates from the starlist are then read into *SKY* by the OA when they point to your target. Alternatively, the values (same units) can be entered into *SKY* by hand, although again the equinox must be "APP."

A third, rarely used alternative is to type the rates into the DCS by hand. In this case, *the units are different*: sec of RA/sec and arcsec/sec. The commands are `modify -s dcs1 dra =` and `modify -s dcs1 ddec =` . *Note that the text version of the telescope status (xshow) displays these latter units!* The graphical version of the telescope status (FACSUM) does not report differential tracking.

Using the Chopper

See *KSD 4: The Chopper User's Manual* and *KSD 78: The Chopper Keyword Reference Manual*.

The chopper can be commanded to initiate its moves via a square wave signal from NIRC. There is a source select switch on the front panel of the chopper monitor box in the instrument interconnect rack in the computer room at the summit. This switch should be set to NIRC. Chopper status is displayed in an xshow window which is selected by the "NIRC Tools" then "Chopper Status" pull down menu.

Typically to chop you need to set a number of parameters: `chpamp` sets the amplitude of the chop, `chpang` sets the direction relative to some fiducial, `chprelto` defines the fiducial direction. For non-trigger mode, for example **`chpamp 10; chpang 90; chpon`** will start the chopper going at ±10 arcsec offset around the current position at an angle of 90 degrees.

In trigger mode, the chopper amplitude, angle, chptrig enable, and chprelto mode should be set up prior to calling choptrig to take a two frame file. This file will be two frames coadded at each chopper position if coadd is greater than one. **`chopmaster`** prompts the user for these parameters as well as the number of chop positions to be included in each frame. The chopper will then start chopping prior to taking chopper frames with the **`choptrig`** command. This allows reaction masses to settle before real data is taken.

These are chopper commands that can be accessed at the `p3maili%` prompt.

Table 8. Chopper Commands

Command	Description
cdiff	Display the difference between the two beams of a chopped image.
chpen *e n*	Sets the chopper RA and Dec. offsets to *e* and *n* arcsec, respectively.
chpe *e*	Sets the chopper RA offset to *e* arcsec.
chpn *n*	Sets the chopper Dec. offset to *n* arcsec.
chpxy *x y*	Sets the chopper instrument x and y offsets.
chp0	Return the chopper to zero position.
chpinit	Initialize chopper defaults.
chpstart	Start chopping.
chpstop	Stop chopping.
chpfreq *f*	Set the chopper frequency to *f* Hz and start chopping.
chpang *a*	Set the chopper angle.
chpamp *a*	Set the chopper amplitude in arcsec.
chpoffset *o*	Set the chopper offset for the next chop.
chprelto *m*	Set the chopper relative to rotator tracking mode. *posang* = position angle tracking, chop stays fixed relative to stars. *vertical* = vertical angle tracking, chop stays fixed relative to vertical. *fixed* = fixed tracking, chop angle stays mechanically fixed. *rotator* = rotator tracking, chop angle stays fixed relative to rotator angle.
chopmaster	Prompts user for chopping parameters.
chopnod *n*	Chops east and north, then nods telescope by the same distance, repeating *n* times. This takes 4**n* frames.
nircchop	Set the NIRC electronics for chop mode.

The simplest chop-synchronized data taking sequence would be:

- Show chopper status using pull down menu.
- **`choptrigstart`** (start chopping)
- **`choptrig`** (take a 2 frame file)
- **`dpc 1`** (display chopped frame)
- **`n 20`** (move telescope north 20 arcsec)
- **`choptrig`** (take another 2 frame file)
- **`chpstop`** (stop chopping. check chopper status)

You can also chop along the slit. Make sure the rotator is in PA mode. Type **`chprelto rotator`** to define the instrument coordinates as the reference. Then type **`chpang 2.0`** to set the chopper throw along the slit..

Other Useful Telescope Hints

- If stars no longer appear round, use `malign` or `foc5` to check NIRC focus. The Figdisp FWHM (L9 or "FIND" key) may be used to look at image quality.

- If the OA cannot find your object, ask them to read back your coordinates and verify the equinox. The *SKY* program can be used to find guide stars near your object to verify pointing accuracy. Moving the telescope to a nearby star will usually drive through a different PRM (precision reference mark) and reestablish pointing accuracy. There may also be a problem with the observatory clocks. The OA will generally handle most of this.
- If suspicious telescope images or behavior occurs, please remind the OA to note it in the night log with appropriate frame numbers, so it may be investigated at a later time. Accompanying guider frame snapshots are also useful.
- If the images appear to have in-focus ghosts or extraneous segments, then the primary mirror may need to be restacked using `malign` (about 5 minutes) or a previous snapshot might be loaded (about 1 minute). Ask the OA to verify the health of the ACS (Actuator Control System). (See below for some other ghostly notes.)
- Collimation may be checked by taking an out of focus image with NIRC. Change the focus to +4 mm from nominal, take a NIRC picture, then change the focus to nominal –4 mm, and take another picture. A well-collimated system should show a nearly perfectly symmetric image of the (roughly) hexagonal-shaped primary.
- Ghost images on NIRC may occur if there is a very bright source in or near your field or sometimes from glints off the moon or other bright sources in the telescope's field of view. These often appear as 6-sided pinwheels near the upper middle part of the NIRC detector. You may want to change the rotator angle of the Forward Cass module, or come back to the object at a different time, or take sky frames more often for subtraction.

Buffer Manipulation

The new NIRC software does not make extensive use of the buffers needed by the older software. This is because all of the files are written to disk. Many, many commands needed by the old software are now obsolete in part because it is transparent to the new software when you are taking subarrayed images. Nevertheless, the buffers do have an analog in the current software; they are files written to /scratch/buf*.fits, where the “*” can represent anything, but is usually a single digit number. The `go` and `goi` commands no longer write directly to a buffer.

We have tried to retain arithmetic operations on these data buffers such as addition, subtraction, multiplication, and division, are straight forward and fast. (e.g. **`buf3 = buf1 – buf2`**). Further functions:

Table 9. Buffer Commands

`buf2 = buf1`	Copies buf1 into buf2.
`istat buf1` [*xmin ymin xmax ymax*]	Calculates statistics on buf1, or a subsection of buf1.
`display buf1`	Displays buf1.
`wd 1`	Writes buf1 to disk as the next data file.

Data may be separated by each coadder: **`everyn buf1`** where buf1 is now rearranged with four 64 x 256 sections. The unshuffled coadder data can then be displayed.

Restarting NIRC

A Control-c in the control window will usually interrupt the NIRC software and gracefully stop an exposure in progress. The P3 software does not suffer from command shell crashes the way the older software did, hence there are in general no elaborate recovery procedures for P3. If a crash does occur, try using the “Reset NIRC Software” item on the pull-down menu; this usually clears up the problem. More severe problems may require rebooting rabbit. This is done by typing **`~#`** in the "rabbit tip" window.

Cleaning Up

Shutting Down NIRC

After a night's observing *please shut down the software*. A proper shutdown assures that various safeties are in place to keep NIRC clean and healthy, as well as releasing the software for either the next observer or daytime engineering tests.

In the **NIRC Tools** pulldown menu, choose **End Night and Close Windows**. This will put in the cold plug, close the tertiary mirror lid, turn off the temperature controller, and turn off level shifter and IRE power. It then closes the windows opened by the startup script. Note that you can shut down the instrument with the command **`endnight`**, if you prefer.

Finally, to exit Openwindows, anywhere in the blue background "root window," press the left mouse button, and select **`exit`**. You will be asked for confirmation that you wish to end the current session. The whole screen should erase suddenly and leave you with a login prompt.

Saving Your Data to Tape

Data grade Exabyte tapes are required for use in all Keck 8mm drives. Although they cost slightly more than video grade tapes, it is well worth the cost if you consider the value of the data being stored on the tapes! Visiting scientists are responsible for bringing their own tapes and copying their files to tape before they leave. CARA can provide observers with tapes in emergencies. Normally data is archived when it is taken, but the archiving software is meant as an emergency backup for observer's data, and it is difficult to retrieve data from the archive tapes on a timely basis.

The following explains how to make a "tar" format tape copy of your files.

On the summit, use the lanikai tape drive located near the GPS clock rack in the computer room. In Waimea, use the drive connected to the data reduction machine papahaku, behind you as you sit at the data-taking computer. Place a tape in the drive. Look for green and yellow flashing leds on the front drive panel as the drive accepts the tape. (If the LEDs are flashing with no tape in the drive, the drive needs cleaning. If there is not a cleaning cassette handy, ask your IS or a computer person to get you one.) If the tape is rejected, you may want to try pushing it in again or try a different tape.

Change to the directory where your data lives, for example, type:

```
papahaku% cd /s/sdata300/nirc
```

where `/sdata300/nirc/21apr97` is your run name. Note that the 21apr97 is not specified; that way that part of the pathname will be written as part of the filenames, making life easier when you write the data back to disk at home. Also note that if you are on maili, where these "sdata" disks reside, you do not have to use `/s` before the disk name, although you can. From all other computers, summit or Waimea, you must specify the `/s` part of the path. It stands for "summit," indicating that the disk resides on the summit. Similarly, to access scratch disks at headquarters you would specify `/h` (for "headquarters"), as in `/h/scratch21/nirc1/21apr97`.

Now you are ready to write to tape. Note that the device names will be different for SunOS machines like lanikai and Solaris machines like papahaku. They will also differ if you write high or low density tapes. The most commonly used options are:

Table 10. Exabyte Device Names

SunOS	Solaris	Description
/dev/nrst0	/dev/rmt/0lbn	Low density (2 Gb; normal mode).
/dev/nrst8	/dev/rmt/0mbn	Medium density (5 Gb; make sure your tape drives at home can read this!)

Note that there is also a high-density, hardware-compression algorithm which can store up to 8 Gb/tape. This requires the *exact same* hardware compression algorithm to read, however, so unless you are sure you have an Andataco 8505 tape drive at home it is best to avoid this format.

To write the tape (we will use low-density and papahaku as an example):

```
papahaku% tar cvf /dev/rmt/0lbn 21apr97
```

where the three flags, `cvf`, in the command tell tar to create a new tarfile, be verbose (provide feedback to the user on the progress of the command), and specify the output device (/dev/rmt/0lbn). The subdirectory (21apr97) tells tar to write everything in that directory and below to tape.

If you have written to a second directory, change to that directory using the cd command, and do another tar command there. A new tarfile will be added to the end of the tape, or more precisely at the point at which the tape is currently located.

Backing up 1000 files can take a half hour or so. To verify that your tape has been written correctly, you will want to rewind it and use tar in its listing mode:

```
papahaku% mt -f /dev/rmt/0lbn rewind
papahaku% tar tvf /dev/rmt/0lbn
```

Finally, to retrieve data from the tape at your home institution, type:

```
my computer% tar xvf /dev/rmt/0bn
```

(or replace the device name with the appropriate name for your system). This will recreate the subdirectory (21apr97) and its contents on your own disk.

Saving Data to CD-R Disks

We currently have a single CD-R/CD-RW drive attached to a Windows PC in one of the pre-/post-observing rooms in Waimea. There are instructions on how to FTP your data over to the PC's scratch disk, how to setup the CD software, and how to write CD-R disks. These disks hold 650 Mb of data, often enough for a number of NIRC runs. Speckle observers, however, may find that CDs hold too little to be efficient. Unfortunately we do not yet have a CD-R drive working on the UNIX side.

Getting Header Summaries

Header summaries will display filenames with pertinent information of object name, coordinates, integration times, and filter names. The command **`header`** will give a one line summary for every FITS file in the current directory. If you want a different set of information, or want to study the full FITS header of a single image, one of the techniques below should serve:

To view a header, type:

```
maili% fold s12345.fits | head -160 | more
```

You can also loop through a number of files using a sequence like:

```
maili% foreach i (s*.fits*)
? fold $i | head -160 | grep TINT
? end
```

which will print the TINT keywords from each files in the directory.

Analyzing your Data

Data reduction should be done on the computers specifically designated for that purpose: lanikai on the summit, and papahaku or pupukea in Waimea. Indeed, any transfers of large files from your home institution (FITS files containing relevant images, large PostScript files containing finding charts or papers, etc.) should be placed on one of the scratch disks, not on the home directory. The home directories do not have much space available to them, and filling up the disk on which they reside could cause headaches in other ways, possibly even crashing the data-taking software! Here are some hints for looking at NIRC data:

- Take dark frames with f77k, the cold plug, of the same integration time and coadds as the object frames.
- Take linearity data by exposing on the tertiary mirror cover for a range of exposure times.
- Subtract a short dark frame from a long dark frame to accentuate bad pixels and create a bad pixel map.
- Subtract a dark frame from both the object frame and reference frames.
- Make a superflat from the median of many dark subtracted sky frames.
- Use the superflat to flatten the dark subtracted object and reference frames.
- Subtract the median sky level from the flattened object frame and flattened reference frames.

Programming Scripts

Many observers like to automate their observing by writing one or more scripts (called "procs" in the old software). In the new software this is generally done by writing a UNIX script, since UNIX is the command shell. The simplest scripts contain a series of NIRC commands typed in just as they would be on the command line. Other scripts contain varying degrees of logic, and may even call other programs, including C or Fortran code. There is a separate, short document on *Programming in NIRC*.

Care and Feeding of the NIRC Detector

Normally the facility scripts—timing patterns, startup scripts, etc.—will set the NIRC detector to appropriate parameters for your observing program. Occasionally, however, you may want to be aware of some of the parameters which can be set, and how they interact with various detector parameters. In this section we discuss some of the details.

Detector Bias

The detector bias can be set using the detbias command. The nominal value is detbias 1; this is a compromise between leakage or dark current, which increases as detbias decreases, and linearity range, which increases as detbias increases. As an example, for different detbias values we have taken linearity data using the patslow timing pattern. Here we show only the curves for detbias 1, the nominal value. A Web page provides more extensive information.

The linearity curve was measured by taking exposures of various lengths through the K filter with the tertiary mirror cover closed. Data were taken during a regular workday, which is not the ideal circumstances, but serves to provide an example. The first plot shows the increase in count rate with exposure.

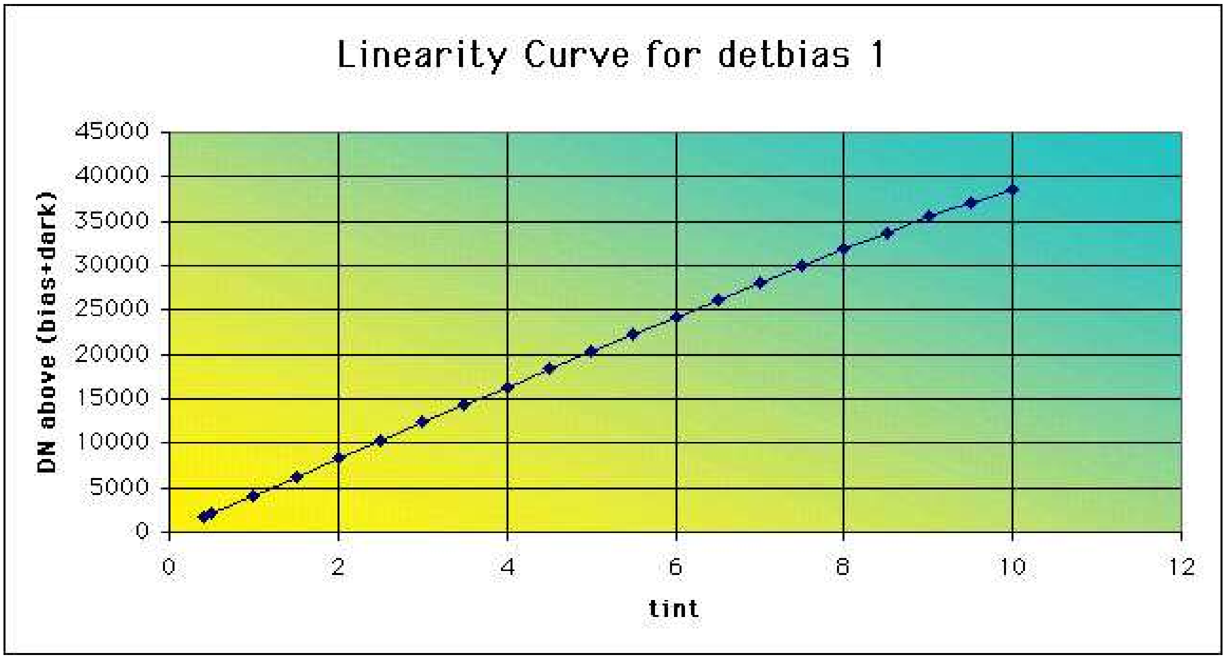

Figure 7. Linearity for patslow, detbias 1.

Note the slight turnover at the highest count rates. In this figure images of the dark plug at each tint were subtracted from the images taken with the K filter, to remove the bias (including slow bias drifts) and dark.

The deviation from linearity can also be quantified. At each integration time we fit a line to all data points with lesser exposure. We then calculate the percent deviation of the point in question from the extrapolation of this line. The following plot demonstrates this for the standard patslow setup.

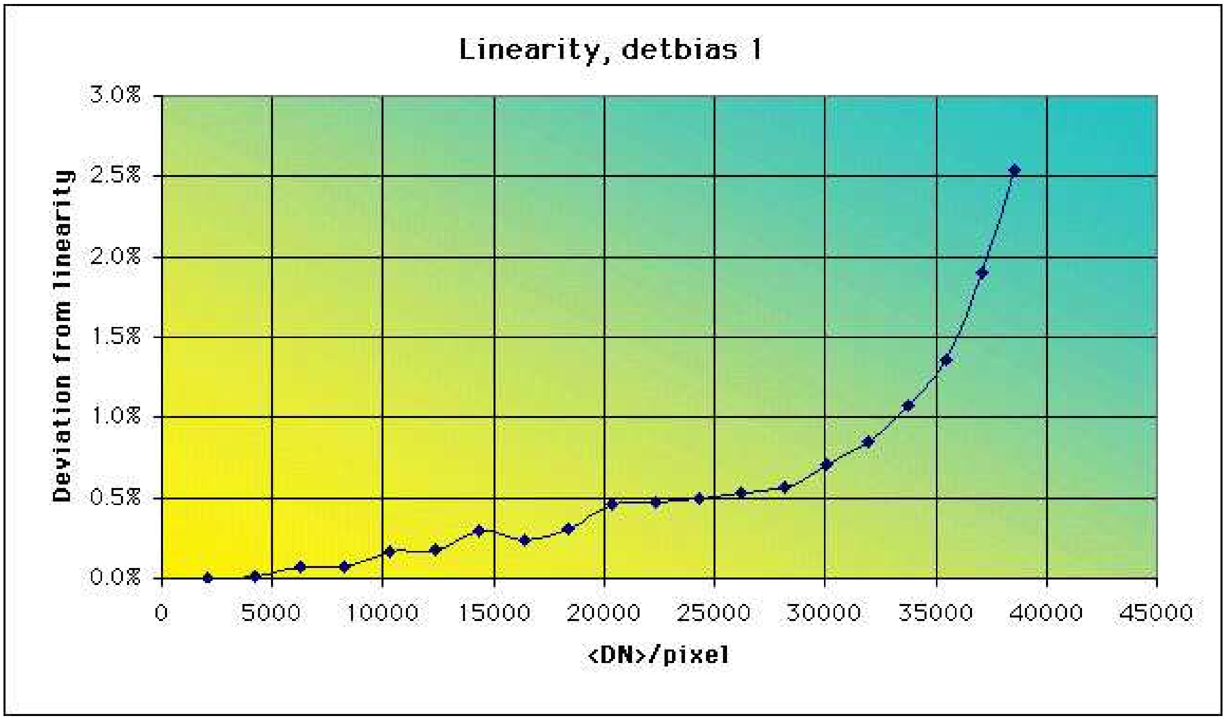

Figure 8. Deviation from linearity for patslow, detbias 1.

From this type of plot we can place the 1% linearity level at 33,000 DN above the bias.

The detector bias changes two important parameters: the dark current and the linearity range. Higher detbias values decrease th dark current but limit the dynamic range available.

Offset DAC

Baseline darks of 0.41 sec are about 23K DN for a detector bias of 0.68 volts and the offset DAC (OSDAC) set to 0 volts. The OSDAC can be set to change the offset of the ADC. With the OSDAC set to 20000, the baseline dark will be about 4K DN. Generally the setting of the OSDAC will not affect the linearity of the detector significantly. However, it might be set to a nonzero value for some of the very fast timing patterns. In order to determine the optimum operating parameters linearity measurements should be performed and interpreted within the context of your scientific goals.

“Bleeding” of heavily exposed images

The NIRC detector shows “bleeding” of bright objects. The main manifestation of this is horizontal “tails” extending towards the right from bright stars, with the tails continuing on in the next lowest row.

Michael Liu and James Graham have an excellent discussion on the Web, and that is probably the most up-to-date analysis available. We can summarize their general results here, however. In their technique they treat the NIRC data as a one dimensional array, in the order in which the pixels are readout (left to right and top to bottom). Within this array, if a given pixel, s0, has flux f(s0), then it contributes to pixel s1

$$f\_bleed(s1) = f(s0) * c0 * \exp[c1 * (s1-s0)], \text{ where } s1 > s0$$

The discussion by Liu and Graham gives details on how they measure this, but they have found that typical parameters are c0 = 0.002655 and -1/c1 = 16.353 pixels/readout. Hence a 20,000 DN pixel will contribute 1 DN to a pixel one row away, and the integrated loss from this bleeding is 4.1% of the original pixel.

Command Summary

Below is a summary of most NIRC commands. The list is always being modified, so some new commands will not appear here. Check the "Latest News" entry on the Web page for updates which may include new commands.

In particular, note the several types of `goi` and `snapi`. These are not too difficult to keep in your mind if you realize the naming convention: add "`buf`" if you want to write only to a memory buffer, not to disk; add "`v`" if you want to display the image (or difference in the case of `snapi`) automatically after it is read out. Hence `goibufv` takes an image and saves it only in a temporary buffer, not to disk, and then displays the image without requiring the observer to type `dlp`.

Table 11. Command Summary

Procedure	Units	Description
help [*command*]	text	Display a brief list of commands, or more detailed information on *command*.
morehelp		Display a longer list of commands, similar to this one.
abs *x*	float	Take the absolute value of *x*.
adc12		Select 12-bit ADCs.
adc16		Select 16-bit ADCs.
ampang *x1 y1 x2 y2*	float	Converts two (x,y) pairs into a distance and an angle. The (x,y) coordinates are assumed to come from NIRC, hence a scale factor of 0.15 arcsec/pixel is used.
autodisp		Switch the FIGDISP mapping to "auto".
az *x*	arcsec	Move telescope *x* arcsecs in azimuth.
azel *a e*	arcsec	Move telescope *a* arcsec in azimuth, *e* arcsec in elevation.
bells *n*	integer	Ring the terminal bell *n* times.
box5		Move telescope in a 5-point box pattern and take frames.
box9		Move telescope in a 9-point box pattern.
bstat [*xlo ylo xhi yhi*]	integer	Show buffer statistics. A subsection of the image can be specified by four additional parameters.
bxy5 *x y*	arcsec	Move telescope in a 5-point pattern aligned with the detector.
bxy5q *x y*	arcsec	Move telescope in a 5-point pattern aligned with the detector; do not display frames.
bxy8 *x y*	arcsec	Move telescope in an 8-point pattern aligned with the detector.
bxy8q *x y*	arcsec	Move telescope in an 8-point pattern aligned with the detector; do not display frames.

Procedure	Units	Description
bxy9 *x y*	arcsec	Move telescope in a 9-point pattern aligned with the detector.
bxy9q *x y*	arcsec	Move telescope in a 9-point pattern aligned with the detector; do not display frames.
cddata		Shows the files in the current data directory.
cent *x y*	pixels	Move an object at (*x,y*) to the center of the detector.
chop		Configures NIRC for using the chopper and sets the chopper's trigger mode to "level."
chpamp *a*	arcsec	Set the chop amplitude to *a*.
chpang *a*	degrees	Set the chop angle to *a*.
chpfreq *f*	Hz	Set the chop frequency to *f*. If *f* = 0, the frequency will be calculated from NIRC parameters.
chpinit		Set the chopper to default parameters.
chpload		Turns chopping off, waits a second, then restarts it. This allows changed chop parameters to become active.
chopmaster *amp ang relto nchop*		Initializes several chopping parameters: chop amplitude and angle, fiducial direction, and the number of chop pairs.
chopnod *nc*	integer	Takes 2**nc* frames, using both chopping and nodding.
chopstat		Shows the status of various chopper keywords, using "xshow"
chpoff		Turns the chopper off.
chpoffset *o*	arcsec	Set the chopperoffset to *o*. This is the distance from the "rest" position to one of the ends of the chop "dogbone."
chpon		Turns the chopper on.
chprelto *m*	text	Selects a coordinate system definition for the chopper throw and amplitude: posang = chop angle relative to sky; vertical = chop angle stays fixed relative to vertical; rotator = chop angle relative to detector.
chpreset		Reset and restore chopper base offsets, using the command "~nirc/bin/reset_chopper."
chpsim *str*	text	Selects the chopper simulator mode ("none" or "full").
chptrig *str*	text	Sets the chop trigger mode on the DCS side to "*str*" ("level" for NIRC).
close		Close the slits and mask.

Procedure	Units	Description
coadd [*n*]	integer	Set the number of frames to coaddto *n*, or report the current number of coadds if *n* is not specified.
contgoi *buf*	integer	Continuously take frames to buffer*buf* without saving.
detbias*v*	volts	Set the detector bias to *v* volts.
dir		List data files.
disablemot		Disable motor power.
dlp		Display last picture.
dp *n*	integer	Display picture *n*.
dpc *n*	integer	Display chop file *n*, showing first frame in upper left, second in upper right, difference in lower left.
dpname *text*	text	Display file *text*.
e *e*	arcsec	Move telescope east *e* arcsec.
el *el*	arcsec	Move telescope in elevation *el* arcsec.
edge *x*	float	Move the edge of the finger mask to column *x*.
en *e n*	arcsec	Move telescope east *e* arcsec, and north *n* arcsec.
enablemot		Enable motor power.
enabletm		Enable power for the tertiary mirror motors.
endnight		Shutdown; does **f77k**, **tmclose**, and turns off electronics.
f77k		Move filter wheels to cold plug.
filt2k		Select 2 kHz low pass filter.
filt20k		Select 20 kHz low pass filter.
filt200k		Select 200 kHz low pass filter.
filt2meg		Select 2 MHz low pass filter.
finger *x*	float	Move the finger pointer to column *x*.
foc *f*	mm	Set telescope focus to *f*.
foc3 *f df*	mm	Take 3-position focus images with telescope focus stepped from *f* by *df*.
foc5 *f df*	mm	Take 5-position focus images with telescope focus stepped from *f* by *df*.
foc8 *f df*	mm	Take 8-position focus images with telescope focus stepped from *f* by *df*.
focus *sf ef*	mm	Take focus images with telescope focus startingat *sf*, ending at *ef*, in 0.1 mm steps.
frame *n*	integer	Set the next frame number to *n*.
fromsky		Offset the negative of the telescope by the nod parameters.
fstretch *x*		Set frame stretch time to *x*.

Procedure	Units	Description
fwi_ *n*	integer	Move inner filter wheel to position *n*.
fwihole		Move inner filter wheel to open hole.
fwo_ *n*	integer	Move outer filter wheel to position *n*.
fwohole		Move outer filter wheel to open hole.
go		Prompt for taking an exposure. .
goi [*n*]	integer	Take an exposure. If *n* is specified, *n* exposures will be taken
goibuf [*n*]	integer	Take a frame (or n frames) but don't save to disk.
goibufv [*n*]	integer	**goibuf** and display the frame(s).
gois [*nslice* [*n*]]	integer	Take *n* data cubes (1 file per cube) which each contain *nslice* frames. If *n* is not specified only one cube is taken, and if *nslice* is not specified it defaults to 100.
goiv		Take exposure and display.
gomark		Return to the previously stored telescope offsets (see **mark**).
grand		Output a random number.
gxy *x y*	arcsec	Move telescope in guider coordinates.
higain		Set preamp to high gain.
histeq		Set the FIGDISP mapping to histogram equalization.
homemot		Home motors.
homeic		Home image converter
iccent *x y*	float	Move object on (*x*,*y*) in full NIRC field to center of image converter
icin		Insert image converter
icout		Remove image converter from beam.
imagetyp *str*	text	Set the "IMTYPE" FITS keyword to *str*.
initcollect		Initialize the collect structure.
initsub128		Initialize offsets for 128x128 centered subarray
initsub256		Initialize offsets for full 256x256 array.
initsub64		Initialize offsets for 64x64 centered subarray
lastfile		Shows the last file number.
lheoff		Turn off relay to read LHe level.
lheon		Turn on relay to read LHe level.
lindisp *min max*	float	Linear stretch display between *min* and *max*.
logain		Set preamp to low gain.
lvloff		Turn off level shifter power.

Procedure	Units	Description
lvlon		Turn on level shifter power.
malign		Take frames for focusing, removing coma, and stacking primary.
mark		Load the current telescope position (used with **gomark**).
math *expr*		Return the mathematical result of the expression. Some examples: math 4 + 5 math $x - 5.43 math $Offset x 6 math \($x + $y\)/2 set result = `math 3 \* 6` Note that "x" can be used for multiplication. If "*" is used, it must be escaped (preceded by a backslash character). Parentheses must also be escaped.
max12ur		Load the fastest, 12-bit timing pattern. Generally used only for broadband 3–5 micron imaging.
mosaic *nx ny dx dy*	arcsec	Move and take **goi** frames in *nx* rows, *ny* cols, with (*dx*,*dy*) offsets.
mot *n x*	integer	Move motor *n* to position *x*.
mov *x1 y1 x2 y2*	pixels	Move an object from (*x1*,*y1*) to (*x2*,*y2*) on the detector.
mskclr		Remove the slit mask from the beam.
mtrwait *[n]*	integer	Wait for motor *n* to stop moving before continuing. If *n* is not specified, all motors must stop before continuing.
mxy *x y*	arcsec	Move the telescope (*x*,*y*) arcsec in instrument coordinates.
n *n*	arcsec	Move the telescope north *n* arcsec.
nchop *nc*	integer	Sets the number of chop coadds (keyword CHPCOADD) to *nc*.
newdir [*disk***]**	text	Creates a new directory on the specified disk (or by default the disk with the most space available—the top of the list produced by the **disks** command). The new directory is of the form /sdata*/nirc/ddMmmyyyy, where ddMmmyyyy represents the UT date, dd being the day, Mmm the month, and yyyy the year.
nextfile *n*	integer	Set the next file number to *n*. If the value is left off, it will set the next file number to one greater than the largest number in the current output directory.
nircfast		Load a fast timing pattern for tint > 68 msec/frame. Not commonly used.

Procedure	Units	Description
nod *e n*	arcsec	Set the telescope nod distance *e* east and *n* north.
node *e*	arcsec	Set the telescope nod distance *e* east.
nodn *n*	arcsec	Set the telescope nod distance *n* north.
obj *str*	text	Set the OBJECT FITS keyword to *str*.
object *str*	text	Same as **obj**.
observer *names*	text	Set observer names.
odiff		Display the difference between the last file and the previous file.
ostat		Show the statistics from the last picture.
pag1		Set preamp second stage gain to 1.
pag2		Set preamp second stage gain to 2.
pag4		Set preamp second stage gain to 4.
pag10		Set preamp second stage gain to 10.
pat4xa		Load the commonly used intermediate speed timing pattern.
patfast		Load the fastest timing pattern for tint > 53 msec/frame. Not commonly used.
patslow		Load the default, low-noise timing pattern for tint > 430 msec/frame.
pause [*text*]	text	Pauses to wait for a carriage return from the keyboard. Optionally *text* can be printed rather than the default message.
pdiff *n m*	integer	Display file *n* - file *m*.
pd *n m*	integer	Display file *n* - file *m*.
peckoff		Turn off Peck cage power.
peckon		Turn on Peck cage power.
pstat *n*	integer	Show statistics from file *n*.
runname *text*	text	Set the data directory to *text*.
s *s*	arcsec	Move telescope *s* arcsec south.
s5		Move object along the slit to 5 positions, taking frames each time.
scent *x y*		Move object at (*x*,*y*) to (180,128), the nominal slit center.
sdiff		Display second to last file - last file.
showfilt		List available filters
showtime		Show the timing generator pattern.
showvolt		Show detector voltages.

Procedure	**Units**	**Description**
skey		Show all instrument keywords.
slt1 *x*		Move the 1.5-pixel wide slit to column *x*.
slt2 *x*		Move the 2.5-pixel wide slit to column *x*.
slt3 *x*		Move the 3.5-pixel wide slit to column *x*.
slt4 *x*		Move the 4.5-pixel wide slit to column *x*.
slt8 *x*		Move the 8.5-pixel wide slit to column *x*.
slt16 *x*		Move the 16.5-pixel wide slit to column *x*.
sltclr		Clear all slits and mask out of the beam.
sltmov *y*	arcsec	Move the object along the slit by *y* arcsec.
sltsclr		Clear all slits out of the beam.
snap		Prompt for information, take an exposure (**go**), nod telescope, take an exposure (**goi**).
snapi [*n*]		Take *n* exposure/nod/exposure/return sequences.
snapiv [*n*]		**snapi** with a display of each object–sky pair.
sp2 *n*	integer	Take *n* exposures, moving 2 positions along slit separated by 12.8 arcsecs.
sp55 *n*	integer	Take *n* exposures, moving between 5 positions along slit separated by 5 arcsecs.
sp56 *n*	integer	Take *n* exposures, moving between 5 positions along slit separated by 6 arcsecs.
sp74 *n*	integer	Take *n* exposures, moving between 7 positions along slit separated by 4 arcsecs.
subc *nx [ny]*	integer	Select a centered *nx* x *nx* or *nx* x *ny* subarray
subll *nx [ny]*	integer	Select a lower left *nx* x *nx* or *nx* x *ny* subarray
tempcntloff		Disables temperature controller.
tempcntlon		Enables temperature controller.
thinxy *dx dy n*	arcsec, integer	Take 5*n* exposures, using a box with (*dx*,*dy*) steps, plus the central position, displaying each.
thinxyq *x y n*	arcsec, integer	Take 5*n* exposures, using a box with (*dx*,*dy*) steps, plus the central position.
tint [*t*]	seconds	Set integration time to *t* seconds. If *t* is not specified, the current integration time is reported.
tmc		Close tertiary mirror cover.
tmclose		Close tertiary mirror cover.
tmo		Open tertiary mirror cover.
tmopen		Open tertiary mirror cover.
tmpitch *r*	radians	Move tertiary mirror pitch to *r* radians.

Procedure	Units	Description
tmyaw *r*	radians	Move tertiary mirror yaw to *r* radians.
tosky		Offset the telescope by the nod parameters.
typ *str*	text	Set "IMAGETYP" FITS keyword to *str*.
unchop		Returns NIRC to normal mode; generally used after setting it to chopping mode using "chop."
w *w*	arcsec	Move telescope *w* arcsec west.
wd [*n*]	integer	Write data in buffer *n* to disk file. If *n* is not specified, buf4 is written.
wide5		
x *x*	arcsec	Move telescope *x* arcsec in instrument coordinates.
xy *x y*	arcsec	Move telescope (*x*,*y*) arcsec in instrument coordinates.
y *y*	arcsec	Move telescope *y* arcsec in instrument coordinates.
zero		
Ctrl-C		Abort a command, return to system prompt.

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