Palomar Integral Field Spectrograph Operations Manual

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Contents

1 Before the Run **7**
- 1.1 Scientific Objective . . . 7
- 1.2 Choice of Infrared Camera . . . 7
- 1.3 Object Preparation . . . 8
  - 1.3.1 Object Coordinates . . . 8
  - 1.3.2 Guide Stars . . . 8
  - 1.3.3 Atmospheric Transmission and OH Lines . . . 9
  - 1.3.4 Wavelengths and Position Angles . . . 10
  - 1.3.5 Finder Charts . . . 10
- 1.4 Other Observing Preparations . . . 11
  - 1.4.1 G-stars . . . 11
  - 1.4.2 Standard Stars . . . 12
  - 1.4.3 Gas Lamp Spectral Lines . . . 12
  - 1.4.4 Log Sheets . . . 12

2 A Brief Orientation **13**
- 2.1 Basic Information . . . 13
- 2.2 Facts and Figures . . . 14
- 2.3 PIFS Field Orientation . . . 15
- 2.4 Grating Characteristics . . . 17
  - 2.4.1 High Resolution Grating . . . 17
  - 2.4.2 Low Resolution Grating . . . 19

3 The PIFS Instrument **21**
- 3.1 The Optical Layout . . . 21
  - 3.1.1 The Optical Path . . . 21
  - 3.1.2 Design Rationale . . . 23
- 3.2 Observer Controls . . . 24
  - 3.2.1 Offset Guider . . . 24
  - 3.2.2 Tertiary Mirror . . . 24
  - 3.2.3 PIFS Gratings . . . 24
  - 3.2.4 PIFS Flip-in Mirrors . . . 25
  - 3.2.5 Camera Motions . . . 25
  - 3.2.6 Other Mechanical Motions . . . 25

4 Starting Up **27**
4.1 Booting Up . . . 27
4.2 Checking Camera Status . . . 28
4.3 Verifying Operation . . . 29
4.4 Restarting After a Crash . . . 32
4.4.1 Software Restart . . . 32
4.4.2 Hardware Restart . . . 33

5 Commands **35**
5.1 A Word About FORTH . . . 35
5.2 PIFS Commands . . . 36
5.3 Camera Commands . . . 37
5.4 Telescope Commands . . . 39
5.5 Display Commands and Other Miscellany . . . 41
5.6 User-Defined Commands . . . 43
5.7 $f/70$ Tip-Tilt Guider Commands . . . 44
5.7.1 Basic Setup and Operation . . . 44
5.7.2 The Commands . . . 45
5.7.3 Normal Operation . . . 46
5.7.4 That Wacky Stripchart . . . 47
5.7.5 Abnormal Operation . . . 47

6 Other Hardware **49**
6.1 The Guider Quantex . . . 49
6.2 The Function Generator . . . 50
6.3 The Secondary Angle Control . . . 51
6.4 The Crosshair Machine . . . 51
6.5 The Center Field Display . . . 52

7 Observing Cookbook **53**
7.1 Dark Frames . . . 53
7.2 Dome Flats . . . 54
7.2.1 Getting Set Up . . . 57
7.2.2 Taking Dome Spectra . . . 57
7.2.3 Cleaning Up . . . 58
7.3 Imaging Sky Flats . . . 59
7.3.1 Setting Up for Flats . . . 59
7.3.2 Doing K and K_s Flats . . . 59
7.3.3 Doing J and H Flats . . . 60
7.3.4 Cleaning Up . . . 61
7.4 Typical Object Observation . . . 61
7.4.1 Getting There . . . 61
7.4.2 Start Guiding . . . 61
7.4.2.1 No Guide Star . . . 62
7.4.2.2 Faint Guide Star . . . 62
7.4.3 Find and Center Object . . . 63

7.4.3.1 Take the First Image . . . 63
7.4.3.2 Interpreting the Sliced Image . . . 63
7.4.3.3 Positioning the Object . . . 65
7.4.3.4 Faint Objects . . . 65
7.4.4 Spectra . . . 67
7.4.4.1 Dither Patterns . . . 67
7.4.4.2 Integration Time . . . 68
7.4.4.3 A Sample Series . . . 69
7.4.4.4 All Done? . . . 73
7.4.4.5 Additional Notes . . . 73
7.4.4.6 The Final Product . . . 73
7.5 Obtaining the PSF . . . 75
7.5.1 Setting Up for PSF image . . . 75
7.5.2 Guided PSF Image . . . 75
7.5.2.1 Using Current Guide Star . . . 75
7.5.2.2 Switching Guide Stars . . . 76
7.5.3 Unguided PSF Image . . . 77
7.5.4 Using PSF to Focus . . . 78
7.6 Standard Stars . . . 79
7.7 G-star Calibration . . . 80
7.7.1 Preparation . . . 81
7.7.2 General Procedure . . . 81
7.7.3 Putting it into Action . . . 82
7.7.4 Now Go Get a "Stake" . . . 85
7.7.5 Moving On . . . 85
7.7.5.1 To Another G-star . . . 85
7.7.5.2 Not Another G-star . . . 85
7.7.5.3 To the Monastery . . . 87
7.8 Now What? . . . 87

8 Saving the Precious Data 89
8.1 Hooking up the Machines . . . 89
8.2 Transferring the Data . . . 89
8.3 Converting to FITS . . . 90
8.4 Writing to Tape . . . 91
8.5 Delete the Files . . . 91

A Finder Charts 93

B Atmospheric Calibrator Stars 97

C Photometric Standard Stars 103

D LaTeX Log Sheet 105

E Automatic Transfer to SPARC 107

Preface

The Palomar Integral Field Spectrograph[1] is a cryogenic, image slicing spectrograph designed for use in the near-infrared, and operating on the Palomar 200-inch Telescope. Its modular nature allows one to choose from two[2] infrared cameras. The PIFS field of view is $5.4'' \times 9.6''$, with two spectral modes and an imaging mode available. The high resolution spectral mode delivers a resolution of $R \approx 1300$, while the low resolution mode has $R \approx 600$. The spectral coverage in these modes are $\sim$5,000 km s^{-1} and $\sim$12,000 km s^{-1}, respectively. The $5.4'' \times 9.6''$ field of view is sliced up into eight slits, each $0.67'' \times 9.6''$ in size. The eight slits are then arranged into a pair of effective long-slits. These two effective slits each feed their own spectrograph, in the end producing a 4×2 array of spectra on the detector array. Data reduction is relatively straightforward in the sense that all one really has is a set of eight longslit spectra to deal with. The PIFS has proven thus far to be a robust, predictable instrument. Coupled with the high quality instrumentation comprising the Cassegrain IR setup, the PIFS is a sound and versatile instrument well suited to scientific research.

This document is accessible at `http://www.its.caltech.edu/~tmurphy/pifs/pifs.html` in PostScript form.

[1] Or PIFS. Also affectionately known as D83.

[2] As of this writing, D80 and D78 are available for use with the PIFS.

Chapter 1

Before the Run

1.1 Scientific Objective

The most important first step of any successful observing run is to have a clear understanding of the scientific goal of the observation. This knowledge lies at the base of every decision that must be made during an observing session. How important is continuum shape to you? How important is two-dimensional spatial information? How important are velocity gradients? Are you simply after line fluxes, line images, continuum images, or a full-blown three-dimensional datacube with high resolution spatial and spectral information? The overall goals of the research will guide the manner in which the observations are carried out.

Therefore the best preparation consists of both knowing what you want to see, and knowing what it is you *expect* to see. Are the lines strong enough? What velocity range is expected? Will the object fit into the field? How long of an integration will be necessary to get adequate signal-to-noise?

1.2 Choice of Infrared Camera

Currently two infrared cameras, called D80 and D78, are available for use with the PIFS. D80 is the preferred camera in that the PIFS output is designed to match the D80 focal plane. D80 contains a 256×256 HgCdTe array, operating from 1–2.5μm, with a pixel scale of 0.167″ per pixel. D78 uses a 256×256 InSb array, with an accessible wavelength range of 1–5μm and a pixel scale of 0.125″ per pixel. The physically smaller detector in D78 will not accommodate the entire PIFS field of view, only passing the central four slits unimpeded. The outer four slits will have a checkerboard-type coverage, which is of little use. Another drawback of D78 is slightly reduced spectral coverage due to the smaller array. The only reason one would elect to use D78 in lieu of D80 is if the range from 2.5–5μm is of interest.

One additional bit of relevant information is that the cameras are not interchangeable with zero effort. This is due to the fact that matching the optical

output of the PIFS to the input of the cameras requires adjusting the gimbal holding the camera. While not terribly hard to do, this does take some effort. Most importantly, D78 has never been operated on the PIFS, so there may be unrecognized problems with this regime. D78 *has* successfully operated on the HNA spectrograph[1], providing a proof of concept, at least.

1.3 Object Preparation

Prior to arriving at the telescope, one should have the following information about the various objects to be observed:

- reasonably good coordinates (1–2 arcsecond accuracy)
- a list of guide stars
- atmospheric transmission and OH lines
- wavelengths to be observed
- preferred position angles
- optional finder chart

For general observation preparations, see Section 1.4.

1.3.1 Object Coordinates

Object coordinates can be expressed in any equinox, but due to the small field of the PIFS, one desires coordinates good to 1–2″. Pointing just a few arcseconds off in the narrow dimension of the field will miss the object, perhaps with no clue of its direction—especially for compact objects in good seeing. On the plus side, coordinates don't need to be any better than this. Even for faint objects where blind offsets from a brighter star are required, the "slit" is huge! So there is no need to worry about precise placement of the object. It isn't necessary to see the object to have some confidence that it is *somewhere* in the field.

1.3.2 Guide Stars

The offset guider for the Cassegrain IR setup is capable of moving out to a radius of 190–200″. Any visible star with $V < 14$ within this range may be used for guiding. However, if the star is closer than about 30″ to the object, it is likely that the offset guide head will vignette or totally obscure the PIFS field of view. Therefore the useful range is about 30–190″. It is also worth noting that if the guide star is directly north, south, east, or west from the object, light from the star may be partially occulted by one of four vanes located in the telescope baffle tube.

[1] The HNA spectrograph, which Has No Acronym, also known as D81, is the longslit predecessor to the PIFS, and shares many properties with the PIFS.

The magnitude limit of the guider varies with the conditions, as can be expected. On the best of nights, with 0.5″ seeing, and photometric skies, stars down to $V = 15.5$ are useful for guiding. However, crummy nights impose limits more like $V = 11$–12.

A recommended source for generating guide star lists is the Hubble Guide Star Catalog (GSC), which is often encountered as a two-CD set. Gerry Neugebauer wrote a nice routine called `guide` to search the GSC and dig up all stars within a specified radius of a point on the sky. The output gives the star magnitude, radial offset, offsets east and north, and position angle from the object. This is a handy format for both selecting the guide star, and entering the information into the guider controller. The input file used by `guide` requires the following fields separated by spaces (*not* tabs): object name, R.A. (in hh mm ss.ss), and dec. (in dd mm ss.s). One warning: if the object name contains a "+" or a "−", a positive or negative declination will be assumed accordingly. The program looks for any plus or minus sign in the input line to signal the sign of the declination. So be careful. If I'm still at CIT, I'll be happy to run the program for you, given an input list. I'll go out on a limb and say that any member of the IR group will be helpful in providing guide stars given a formatted input list.

The GSC stars are not complete down to the limiting magnitude of the guider, so under good conditions it is likely that a suitable star is within range of the guide head even though nothing shows up on the GSC output. See Section 1.3.5 for how to cope with this situation.

1.3.3 Atmospheric Transmission and OH Lines

Though the PIFS itself will operate anywhere between 0.5μm–5μm, and the usable cameras span the 1–2.5μm and 1–5μm ranges (see Section 1.2), the atmosphere is not so flexible. Various absorptions, mainly due to CO_2 and H_2O limit the useful wavelengths to discrete bands. Information on atmospheric transmission as a function of wavelength can be found at: `http://www.jach.hawaii.edu/UKIRT/astronomy/`. The online data is for Mauna Kea, and should be raised to a factor of ∼1.6 for Palomar. A glimpse of what this transmission looks like can be seen in Figures 2.4 and 2.5. One definitely wants to take the atmosphere into consideration when planning object observations.

A second consideration is the atmospheric airglow spectrum of OH. These lines are relatively abundant throughout the J, H, and the first half of the K bands, and are useful for wavelength calibration (see Section 1.4.3). For the most part, these lines are a minor hindrance to the observation. They are resolved out quite well in the high resolution mode, and hardly interfere with observations of moderately bright objects. However, if observing faint objects, one may want to verify that the expected emission line feature lies between OH lines. Otherwise the line emission may be swamped in the high background of the OH line. See Oliva & Origlia, A&A **254**, 466 for wavelengths and relative strengths. Also see the `http://www.jach.hawaii.edu/UKIRT/astronomy/` web page for online graphs and line lists.

1.3.4 Wavelengths and Position Angles

I highly recommend arriving at the telescope with wavelength and position angle information prepared for each object on your list. The PIFS is tunable to any wavelength between 1–5μm, so the only limitation comes from the atmosphere. If there are multiple objects to be observed around the same wavelengths, I recommend standardizing wavelengths, minimizing the number of dome-flats necessary for calibration. After all, two observations with spectra displaced only by a few pixels is somewhat wasteful. In addition to the number of dome-flats required, another disadvantage of close-but-not-equal wavelength tunings is that should one forget lamp spectra or some other calibration (i.e. G-star observation) for one object, the calibration from the similar wavelength observation cannot be used as a backup. In general, if $\Delta\lambda/\lambda < 0.002$ for the high resolution mode (0.004 for low resolution), it is pretty safe to standardize to a single wavelength.

In terms of position angle, it might seem at first blush that this information doesn't matter with an integral field spectrograph, as long as the object or region of interest fits within the field of view. But the nature of the image slicer is not symmetric. There is still a cross-slit direction and a direction along the slit. Spatial information along the slit direction is seeing limited, with a pixel size of $0.167''$. Spatial information in the cross-slit direction is somewhat crudely sliced into $0.67''$ (4 pixel wide) slits, making for an effective pixel scale in that direction of $0.67''$, which means that the Nyquist resolution limit is $1.33''$ for a single exposure. In this limit, it makes sense to choose the spatial direction of greatest importance along the slit direction, since full seeing-limited spatial information will be immediately obtained along this axis. Before despairing, let me point out that a judicious dither pattern in your observation sequence allows one to recover seeing-limited cross-slit spatial information, provided the seeing conditions are moderately stable. This is discussed at greater length in Section 7.4.4.1.

1.3.5 Finder Charts

Finder charts are very helpful for verifying the positions of both object and guide stars (or reference stars as aids to pointing). In addition, finder charts may enable one to locate guide stars in the absence of suitable candidates in the list generated by the method discussed in Section 1.3.2. If the guide star list is produced from the Hubble GSC, then unless the seeing is good and conditions are photometric it is unlikely that "unlisted" stars picked off the finder chart will be sufficiently bright for guiding. But don't completely write it off until you've tried.

I generally make finder charts using the "Advanced" interface to the SkyView Virtual Observatory at `http://skyview.gsfc.nasa.gov/skyview.html`. Here, I create a field that is $500''$ on a side (0.138889°) using the Digitized Sky Survey as a grayscale image. Saving this as `fits`, I then use IDL to normalize the image (subtract median and divide by sky noise level) and display from -5σ to $+15\sigma$. Then I put crosshairs on the image and draw a circle of radius $200''$—

the maximum offset guider range. Plotting the 300×300 pixel image on paper at 5.875 inches on a side seems to work well for producing a scale of 0.3mm per arcsecond. If interested in the IDL code used to generate these finders, see Appendix A.

1.4 Other Observing Preparations

There are other useful items to have at the telescope for the purpose of observing. These mostly deal with calibration. They include:

- a list of bright Gv stars
- a list of standard stars
- a list (or plot) of the noble gas infrared emission lines
- log sheets

1.4.1 G-stars

G-stars are used primarily to calibrate the spectral throughput of the atmosphere, but are also used to generate flat-fields for spectral observations. Main sequence G-stars (and late F-stars) have only minor absorption lines, making them a good choice for spectral calibration, as their spectral shape is very well approximated by a blackbody. I have prepared a list of F8–G9 stars, of luminosity class V, with apparent magnitudes ranging from 3.5-6.5. This makes for about 270 stars, spread throughout the entire sky. Appendix B has this entire list.

Because the atmospheric transmission function varies with airmass, it is desirable to match the airmass of the calibrator star with that of the observed object. Matching the airmass within 5% results in a faithful atmospheric profile, but in a pinch a 10% match is probably acceptable. To minimize potential complications from instrument flexure, it is most desirable to find a calibrator star in the same part of the sky as the object was during observation. So for instance, the ideal G-star for a one-hour long observation would be positioned at the same declination, and approximately 30–40 minutes to the east in right ascension. Sometimes it is necessary to observe more than one G-star in order to accommodate the full range of airmass encountered during the object observation. For this reason, it is often best to obtain the G-star calibration after the observation, so that the observation's airmass range is known. Keep in mind that careful G-star calibration will have the most significant impact on precise continuum shape. If this is not at all important, a less careful G-star calibration will suffice.

To aid in finding G-stars at the appropriate airmass and sky positions, I have made a handy little analog computer. This is nothing more than a plot of all the G-star positions on the sky, and an overlay with lines of constant airmass drawn on. By setting the meridian axis of the overlay at the right ascension

corresponding to the LST at the anticipated time of G-star observation, one immediately sees the airmasses of all the stars contained in the list. In general, there will be several stars of appropriate airmass. The one with a position closest to the observed object is the best choice. The analog computer may be obtained in PostScript form from `http://www.its.caltech.edu/~tmurphy/pifs/pifs.html`.

1.4.2 Standard Stars

Standard stars are used to tie the spectral observations to a photometric reference. For this purpose, I have taken to using the HST standards, the photometry of which was provided by S. E. Persson. These stars have near-infrared magnitudes in the 10–12 range. See Appendix C for a list of standard stars.

1.4.3 Gas Lamp Spectral Lines

The PIFS uses two types of sources for spectral calibration. The first is the atmospheric airglow spectrum of OH. These lines are relatively abundant throughout the J, H, and the first half of the K bands, and come for free with the observation. See Oliva & Origlia, A&A **254**, 466 for a good treatment of the use of OH airglow lines as a means of spectral calibration. But because the OH lines are never exactly where they are needed (especially for the narrow wavelength coverage offered by the high-resolution mode), gas lamp spectra are used to supplement (or supplant) the OH spectrum for wavelength calibration. Four different lamps are available for the PIFS: neon, argon, krypton, and xenon.

In order to know which of these lamps are appropriate for the wavelength range of interest, it is good to have a plot of the spectrum for each lamp. In this way, not only can one choose which lamps to turn on, but also determine which lamps are either void of lines, or conflict with one another. In cases where two different lamps have emission lines at nearly the same wavelength, it would be best to take two exclusive exposures so that useless superpositions may be avoided. I will try to make these available to observers in advance of their run.

1.4.4 Log Sheets

I can't say enough for the value of log sheets. Log sheets help guide the observation, and act as a reminder of the current instrument state. The status of the gratings and flip mirrors is not displayed on the observer's terminal, making the log sheet the primary source for this information. The form I have adopted has the following fields: frame number, object name, integration time, filter, grating setting, flip mirror status, tertiary mirror status, Universal Time, airmass, telescope offset, and a roomy comment field. Appendix D has a LaTeX file that generates one of these lovely log sheets. The PIFS logsheet may also be acquired from: `http:/www.its.caltech.edu/~tmurphy/pifs/pifs.html`.

Chapter 2

A Brief Orientation

The intent of this chapter is to provide a brief overview of what observing with the PIFS is all about. In addition to such an orientation, things such as the orientation of the field and other tidbits will be covered here. Thus the chapter title. But don't take this idea too far. This chapter has absolutely nothing to do with underwears.

2.1 Basic Information

The PIFS instrument may be thought of as eight spectrographs in one, with contiguously located slits. Though designed to have capabilities beyond 2.5μm, the primary design considerations favor use of the HgCdTe 1–2.5μm camera.

The PIFS instrument itself is simple to use. User controls enable selection of wavelength center, spectral resolution mode (high or low), and selection between imaging and spectral modes. The PIFS-specific commands can be found in Section 5.2. Other commands for controlling the camera, moving the telescope, displaying images, and configuring the $f/70$ tip-tilt guider are treated in Chapter 5.

The more difficult aspect of using the PIFS instrument has to do more with observing strategy, and having a mental picture of the current state of the instrumental setup. Getting used to telescope control, using the guider to maximal advantage, and obtaining G-star calibration will be the most taxing activities for the newcomer. The observer's cookbook in Chapter 7 is a good resource for learning how to conduct an observing session.

The status of the PIFS optics is not reflected anywhere in a direct manner. Therefore it is good to keep track of where the grating is, where the flip mirror is, where the tertiary mirror is, etc. The motor positions are recorded in the header, so this information is not lost, but nonetheless not easily accessed by the observer. It is my belief that a familiarization with the instrument layout, as presented in Section 3.1 will help develop this mental picture of where things are.

2.2 Facts and Figures

This section simply provides a random assortment of pertinent information about the PIFS instrument, and the observing environment in general.

- The PIFS field of view is $5.4'' \times 9.6''$, sliced into eight slits. The field of view can be rotated to any position angle on the sky.
- The PIFS high resolution grating delivers $R \approx 1300$ spectra, with ~5,000 km s^{-1} of coverage in velocity space, or roughly 22 resolution elements. Velocity centroids for bright lines may be accurate to ~20 km s^{-1}. This mode is typically enabled with the `hires` command.
- The PIFS low resolution grating delivers $R \approx 550$ spectra, with ~12,000 km s^{-1} of coverage in velocity space. This mode is typically accessed with the `lowres` command.
- When using D80, the pixel scale is $0.167''$ per pixel, with each slit being 4 pixels wide and 58 pixels long.
- The PIFS has an imaging mode that enables quick assessment of what is in the field. This imaging mode is accessed via the "flip mirror in" command, `fmi`.
- Flexure of PIFS is minimal, with measured focal plane shifts on the order of one pixel for large motions of the telescope. Most observations will be unaffected. However, this may be a factor in the mismatched fringing of dome flats (see Section 7.2).
- The total PIFS system throughput, including D80 is 20–25%, from the top of the atmosphere to total electron counts.
- The calculated sensitivity of the PIFS estimates the ability to detect 5×10^{-16} erg s^{-1} cm^{-2} at 3σ in 30 minutes for a spatially and spectrally unresolved line emission source under 1 arcsecond seeing. With the most optimistic seeing conditions (0.5–$0.7''$), one should be able to see a $K = 18$ continuum source (0.04 mJy) in something like one hour of on-source integration.
- The PIFS cryogen hold time (25 liters of LN_2) is approximately three days, sitting still.
- In the spirit of numerics, construction of the PIFS required over 150 engineering drawings, 350 machined parts, hundreds of precision mechanical parts (pins, bearings, springs, Belleville washers, gears, etc.), and over 500 machine screws. It was built for about $70k in less than two years[1].
- The array characteristics of D80, with MPARM2 set to 16 are: 17 electron read noise, 8 electrons per dN. Saturation for D80 is at about 20,000dN, provided CSCALE is appropriately set.

- Minimum exposure time is 0.375 seconds, and the minimum with 16 reads is 6.0 seconds.
- The chopping $f/70$ secondary is undersized to permit chopping without losing light from the secondary. The net effect is an effective primary mirror area of 15.5 m^2.
- The offset guider is a fiber bundle with a hexagonal shape, measuring $15''$ across the flats (as opposed to a corner-to-corner measurement).
- The offset guider can access guide stars as far out as $200''$, and as close in as $20–30''$ without vignetting. Guide stars on crummy nights need to be brighter than V =11–13, but can be as faint as $V \sim 16$ on the best of nights.
- The center-field camera has a circular field measuring $70''$ across. The field is oriented with north up and east to the left for a ring angle of 90°.
- The telescope focus should be somewhere in the range of 63-65mm.

2.3 PIFS Field Orientation

The PIFS field is sliced up before it ever appears on the detector. How then does one make sense of the chopped up image on the array? The first important point is that every slit has the same orientation on the sky. Therefore the integral field is achieved through simple translations of the slits. The second important point is that the vertical ordering on the array is the same as the vertical ordering in the integral field. This means that reconstructing the integral field is a simple matter of horizontal displacements. Not only do the slits not rotate, but they do not cross each other. The third important thing to know is that the "left" direction on the array points in the direction of the ring angle on the sky. For example, if the ring angle is 90°, East is to the left in the image. However, North will point down, as there are an odd number of number of reflections overall. If the ring angle is 0°, North is to the left, and East is up.

Figure 2.1 will shed some light on the arrangement. Figure 2.2 is then a reconstructed field from the 8 slits. Notice that to get the final integral arrangement all that one must do is slide each slit to the left or right, consolidating into a single column, then ignoring the space between the top and bottom portions. The orientation of the rectangular field portrayed in Figure 2.2 is shown for the four cardinal ring angles in Figure 2.3.

The images that accompany Chapter 7 will likely be of great help in orienting the PIFS newcomer to the appearance of the data as it is acquired at the telescope. In particular, Section 7.4.4.6 offers an example of the kind of data one may expect from the PIFS.

[1] By none other than me.

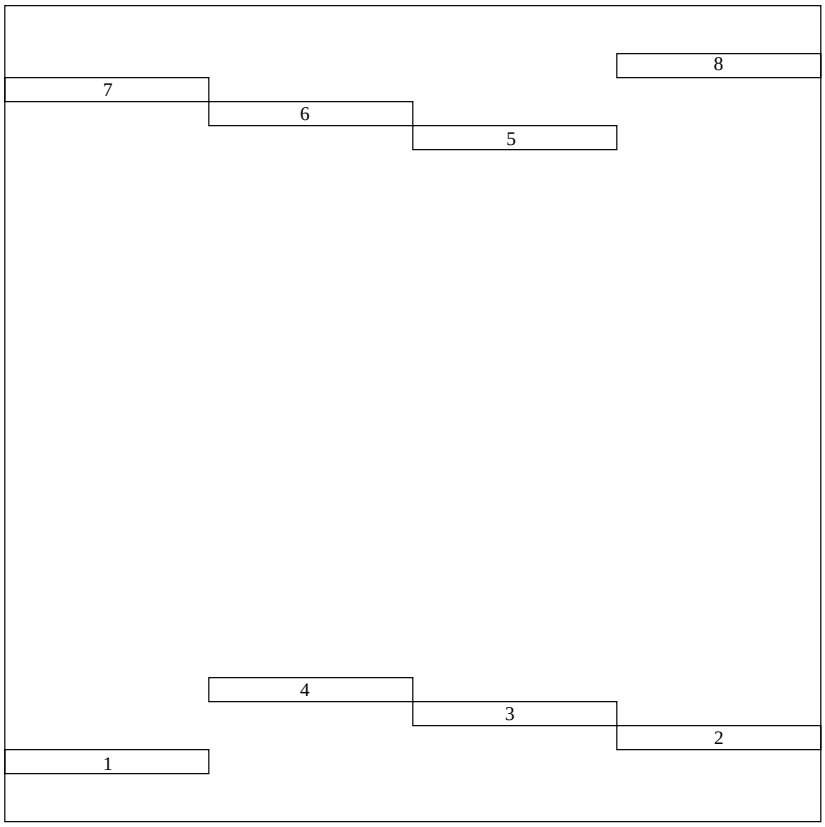

Figure 2.1: The arrangement of the slits on the detector array.

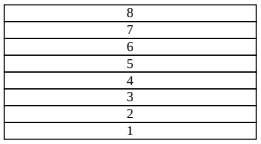

Figure 2.2: The arrangement of the slits in the integral field.

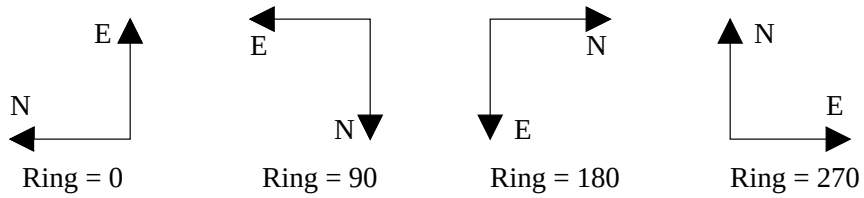

Figure 2.3: Orientation of the rectangular PIFS field for the four cardinal ring angles. Note that left always corresponds to the ring angle. Also note that there is an overall reflection, such that when North is up, East is to the right instead of the familiar left.

2.4 Grating Characteristics

The PIFS uses two replication gratings for the two resolution modes. The replicas are from off-the-shelf master gratings, which greatly reduced cost and time to delivery. However, the chosen gratings are not optimized for maximum efficiency across the near-infrared bands. However, they are reasonably well matched to the intended science goal of the PIFS. In particular, the Paα, Paβ, H_2, and [Fe II] lines are well placed with respect to the grating peak efficiencies.

2.4.1 High Resolution Grating

The high resolution grating has a blaze angle of 36.8°, with 300 grooves per mm. This puts the first order blaze peak at 4.0μm, with higher order peaks at 2.0μm, 1.33μm, and 1.0μm. Figure 2.4 shows the general characteristics of this grating, including the blaze function, wavelength coverage, input grating angle, and effective spectral resolution, all as a function of wavelength.

Obvious from Figure 2.4 is that performance is worst in the H band, with best performance in the blue end of the K band and in the red end of the J band. In the lower portion of the uppermost panel in Figure 2.4 is an indication of the simultaneous wavelength coverage as a function of wavelength. The scale for this function is the wavelength scale itself, such that the coverage at 4μm, for instance, is about 0.1μm, and about 0.05μm at 2μm. The input angle, discussed more in Section 5.2 is computed using a value for $\alpha - \beta$ of 4.0°, as is appropriate for the PIFS geometry. The lower panel in Figure 2.4 shows that effective spectral resolutions can vary by a factor of two across the J, H, and K bands, from $\sim$ 900 to $\sim$ 1800.

There are roughly 25 spectral resolution elements presented for all slits on the array, so one may compute the wavelength or velocity coverage at any point as $\Delta\lambda = 25\lambda/R$, or $\Delta v = 25c/R$. Caution must be taken about pushing these numbers to their limits. Though grating repeatability is superb (< 0.2 pixels), absolute placement has a complicated, wandering pattern, such that exact coverages cannot be guessed. Moreover, as the two gratings are independently moving mechanisms, the exact coverage will differ between the top half of the PIFS field

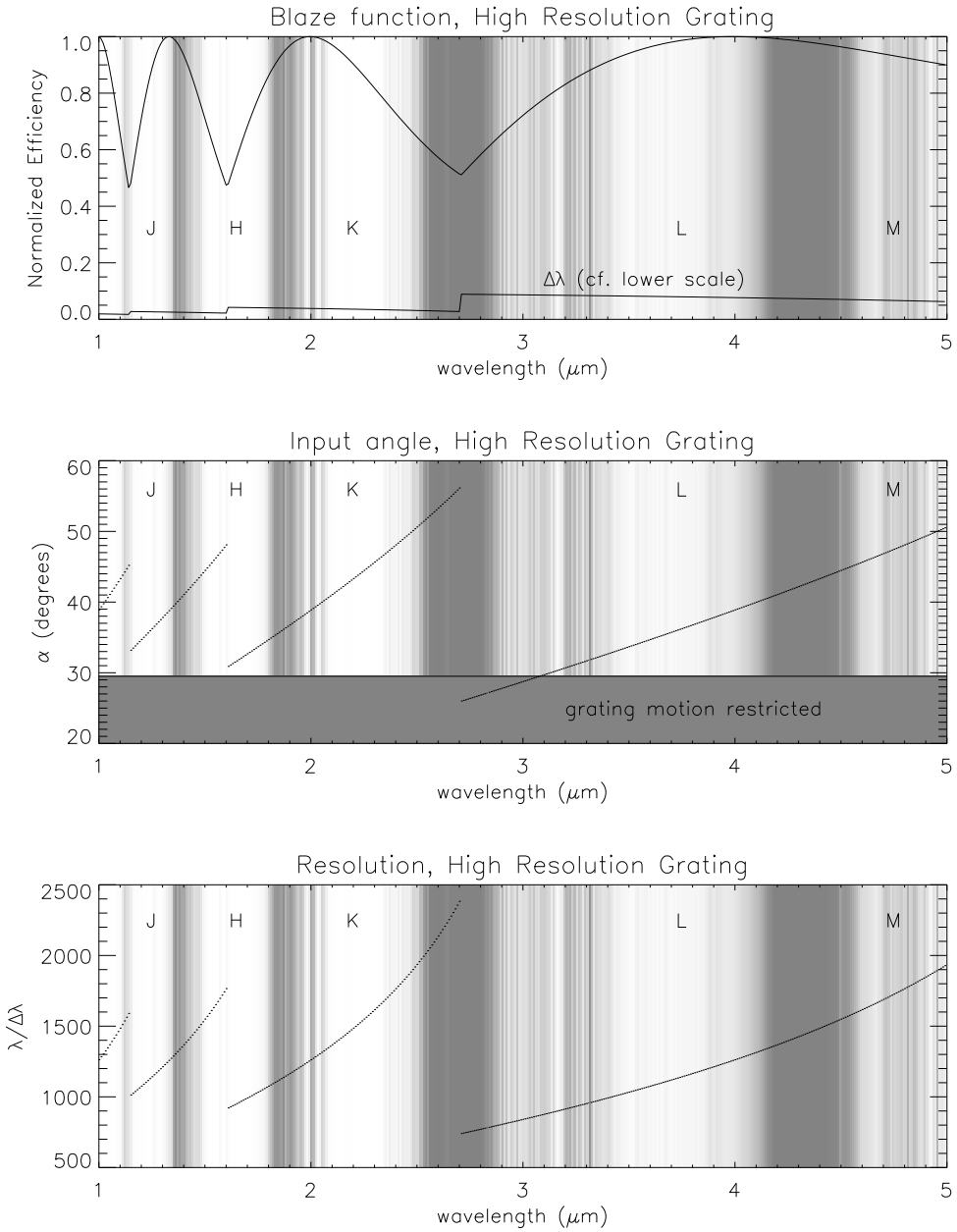

Figure 2.4: High resolution grating characteristics as a function of wavelength. The grayscale represents atmospheric transmission, with dark bands signifying high opacity. The $\Delta\lambda$ plot in the uppermost panel represents wavelength coverage as a function of wavelength, the scale for which is represented by the lower wavelength scale. The coverage at 4μm, for instance, is 0.1μm.

and the bottom. In other words, the $\Delta\lambda$ will be the same between the two, and is predictable, but the central wavelength of top and bottom each have uncertainties in the 4-pixel range (roughly one resolution element), such that top and bottom may differ by two full resolution elements. Don't plan to put important features at the edge of the range!

2.4.2 Low Resolution Grating

The low resolution grating has a blaze angle of 17.45°, with 150 grooves per mm. This puts the first order blaze peak at 4.0μm, with higher order peaks at 2.0μm, 1.33μm, and 1.0μm. In this way, it is exactly like the high resolution grating. Figure 2.5 shows the general characteristics of this grating, including the blaze function, wavelength coverage, input grating angle, and effective spectral resolution, all as a function of wavelength.

The comments that are made above for the high resolution grating apply here as well, though the figures offered in the second paragraph of the preceding section are not to be taken literally for this section.

One other comment is worth mentioning here. The PIFS was designed for best performance in the high resolution spectral mode. When the low resolution grating surface is moved into the beam, the pupil image is slightly out of focus. While the resulting light loss is insignificant, the spectral separation at the array center between top and bottom spectra is not as sharp. Though as far as I can tell, this poses no problem. Also it will be noticed that the spectra are shifted left-right in the low resolution mode. This is normal, and results from a wedged epoxy layer into which the grating surface is replicated. Again, this is a cosmetic issue with no detriment to the data.

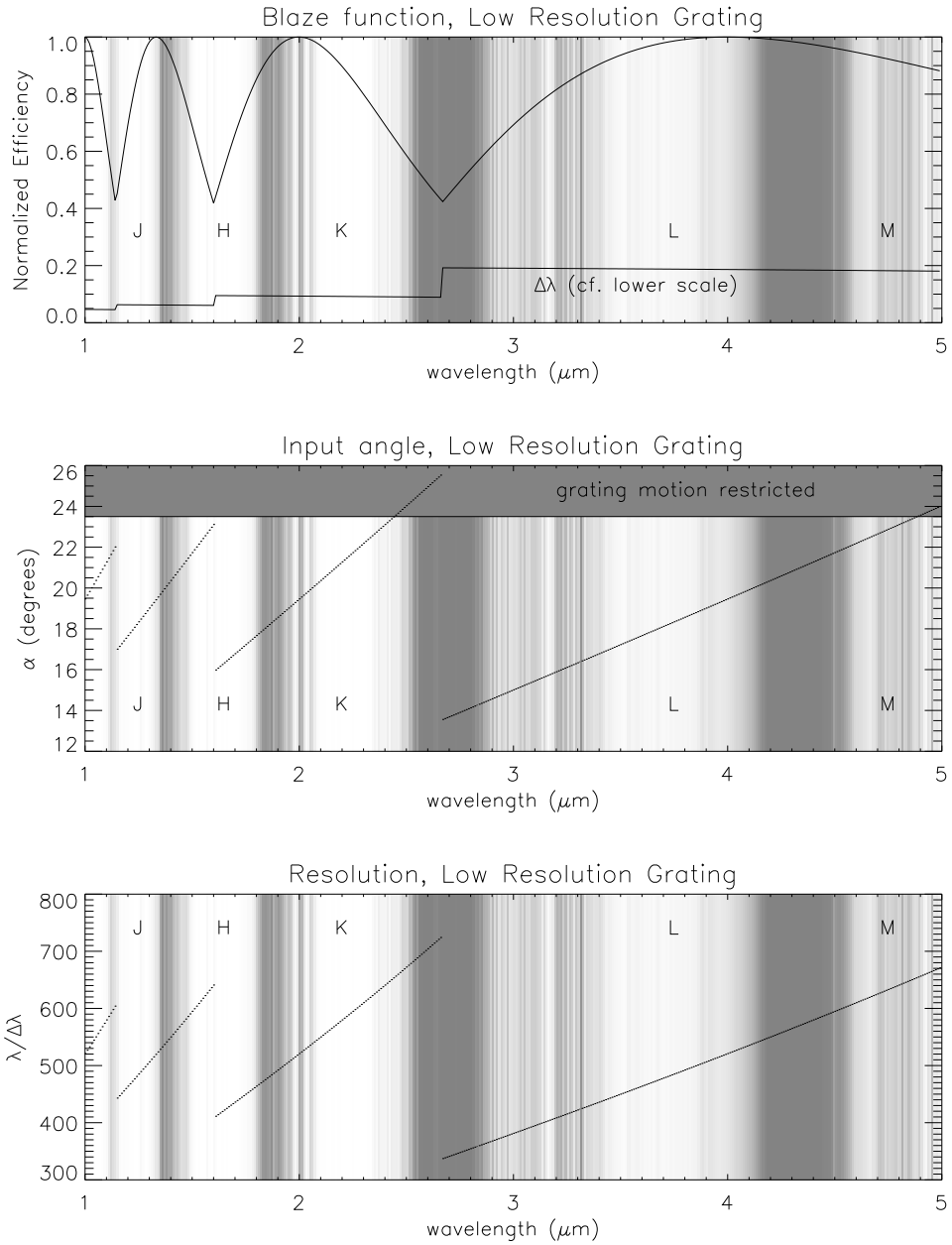

Figure 2.5: Low resolution grating characteristics as a function of wavelength. The grayscale represents atmospheric transmission, with dark bands signifying high opacity. The $\Delta\lambda$ plot in the uppermost panel represents wavelength coverage as a function of wavelength, the scale for which is represented by the lower wavelength scale. The coverage at 2μm, for instance, is 0.12μm.

Chapter 3

The PIFS Instrument

The Palomar Integral Field Spectrograph is a simple device to use. The hard part has already been done. In brief, it takes a contiguous two-dimensional patch of sky, $5.4'' \times 9.6''$ in size, and slices it up into eight slits. The user is left with the option of either producing an image of these eight slits, or a spectrum in one of two resolution modes. That's it. It's hard to mess that up. The following sections describe in a little more detail the control the user has over the instrument, from the instrument's point of view.

3.1 The Optical Layout

No good instrument manual can go without a figure of the instrument layout, though probably only the builder ever looks closely at it. The layout is therefore presented in Figure 3.1.

3.1.1 The Optical Path

The optical path through the PIFS is somewhat complicated, but here's a walk-through of the beam. The $f/70$ cone of light comes down from the secondary mirror, flying past the offset guider (which is not shown here, but exists near the top-plane of the drawing), then hits the small tertiary mirror, sitting in the warm environment of the "coffin". The still-converging beam enters the PIFS through a small sapphire window, with a 90° fold at the top of the dewar. From this point until exiting the dewar, all optical surfaces are at $\sim 77°$K. The beam comes to a focus to find a jumble of thin planar mirrors contained in the image slicer. The beam is sent from this jumble in eight different directions, now slowly expanding en-route to the second set of reflectors in the image slicer. These mirrors, also flat, are arranged in two sets of four in end-to-end configurations. Each set of four outlines a staggered effective long slit pattern. Each "long slit", in turn, feeds its own spectrograph within the dewar—thus the symmetrical layout of the optics within the PIFS. Following only one of the "long slits" (group of four),

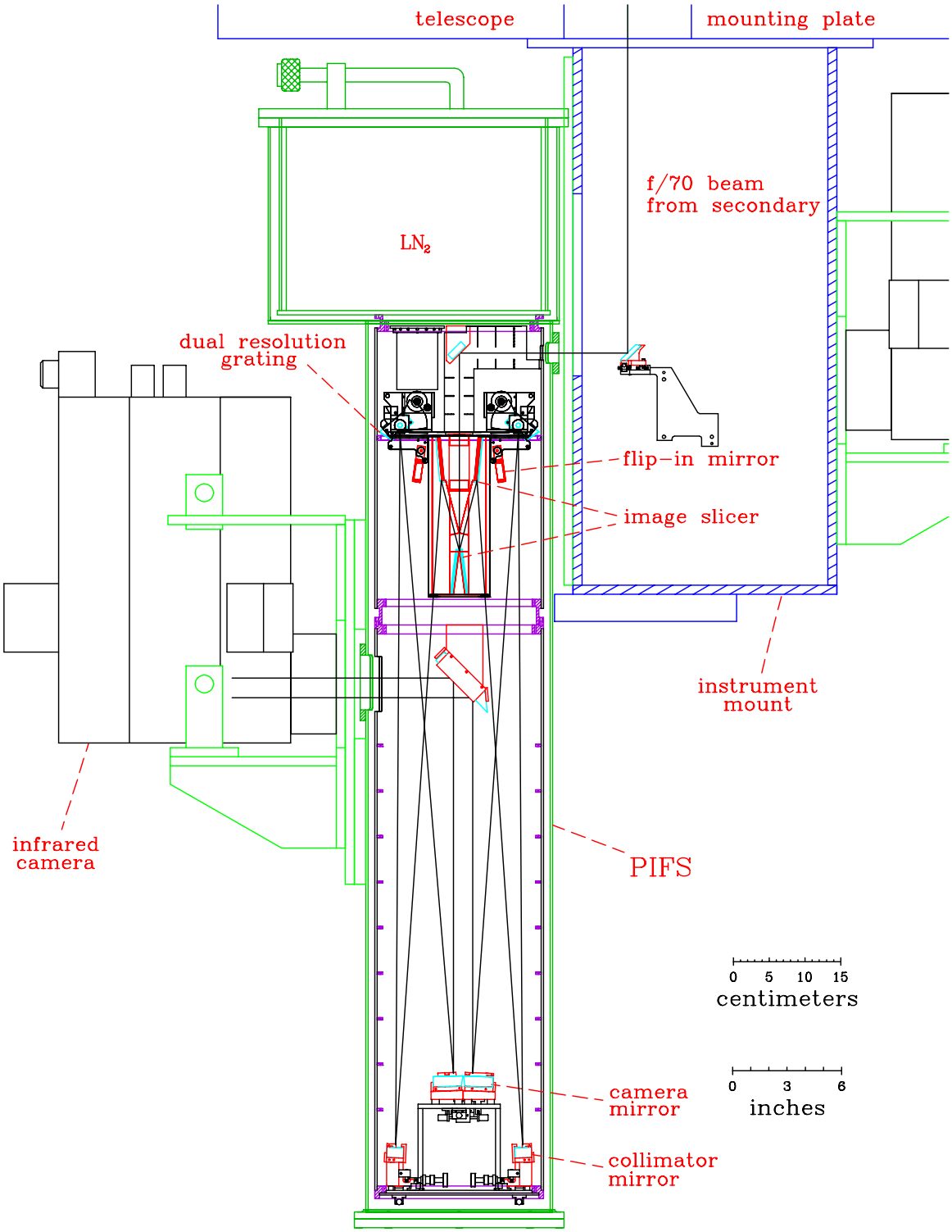

Figure 3.1: The Palomar Integral Field Spectrograph.

the beam leaves the image slicer for a collimator mirror, near the bottom. This spherical mirror stops the beam divergence, sending cylinders of light converging onto the grating. The grating is able to rotate through a little more than 65°, and has two different grating surfaces that can access the beam. This is what provides the two resolution modes. As shown in Figure 3.1, the beam is hitting the larger high-resolution surface. The low-resolution surface is pointing down and outward. Note also in this vicinity the flip-in mirror. This mirror can be moved into the beam in front of the grating, interrupting spectral service to bring instead an imaging service. Note that the image will still be sliced up, but is easily rearranged back into the original field. Leaving the grating, the cylinders of light have acquired a variety of angles in the plane of the page corresponding to various wavelengths. These cylinders are collected near the bottom of the PIFS dewar by a spherical mirror sharing the same focal length as that of the collimator mirror. The effect is to produce a converging $f/70$ beam which folds off of the large diagonal mirror and out through a CaF_2 window, coming to focus within the infrared camera. Therefore the infrared camera, designed to image the $f/70$ field of the 200-inch, is being fed a seemingly identical $f/70$ beam that has been sliced and dispersed. The mirrors in PIFS are all overcoated gold on Fused Silica substrates, except for the image slicer optics, which are overcoated silver on Al 6061-T651 substrates.

Within the camera are mirrors, filters and lenses, in addition to its own CaF_2 entrance window. The total efficiency of the camera, from window to electron counts is about 47%, while for PIFS, the window-to-window throughput is in the neighborhood of 58%.

3.1.2 Design Rationale

The dual-spectrograph design of the PIFS was done simply to double the field of view. Using the approach of outputting a focal plane matched to an existing camera meant that the pixel scale was predetermined. So the total field of view available was 38″ times the slit width. To double that, two effective slits were used instead of just one. Real estate on the detector is limited, and one must not let the spectrum from one slit overrun that from the other slit. Narrow band interference filters are inadequate for this task, as the variety of angles passing through such a filter in the camera is quite large, ranging over about 18°. This variety of angles (different angle for each pixel) results in a wavelength coverage that is far from uniform across the array. The measured variation of the 1.3% CVF across the field was roughly equal to the bandpass, which severely limits such a filter's ability to cleanly separate spectra. The design shown in Figure 3.1 physically splits the two slits apart, using different spectrographs for each. One may think of the selection between the two spectra as happening at the compound camera mirror at bottom center. Light from the left-hand grating hitting the left-hand camera mirror makes it successfully into the camera. Light from that same grating hitting the right-hand mirror fails to make it into the camera. Not shown in Figure 3.1 are the nine baffle planes in the lower canister that discourage departures from the intended light path.

Another point worth mentioning is that the two-dewar approach used here has a few disadvantages. The main disadvantage doesn't rear its head until the thermal infrared regime is reached, out past 2.2μm. It doesn't become formidable until somewhere past the K band, where few dare tread. If observations past 2.5μm are desired, the warm window interface will present a serious barrier, perhaps limiting the type of science that can be done to very bright objects. A less serious disadvantage of this approach is the 8% transmission loss of each window.

3.2 Observer Controls

The observer is able to move various elements within the spectrograph, the camera, the coffin, and the IR baseplate. These motions are accomplished via stepper motors through a computer interface. The available motions pertain to the offset guider (2 motors), the tertiary mirror (1 motor), the PIFS gratings (2 motors), the PIFS flip-in mirrors (2 motors), the camera slit and slit mask (unused for PIFS—2 motors), and the camera filter wheels (2 motors).

3.2.1 Offset Guider

The offset guider is moved via two motors (#15, #16)[1], moving the guide head in θ and r, respectively. As mentioned in Section 1.3.2, the offset guider has a range out to a radius of 190–200″. The `og` and `og/r` commands will be used to move the guide head.

3.2.2 Tertiary Mirror

The tertiary mirror moves on a slide, propelled by a screw turned by motor #8. In practice, one only needs to move the tertiary mirror either *in* or *out*. The "in" position is used for observing through the PIFS, and the "out" position is used to clear the tertiary mirror from the center field camera's view. When the mirror is moved out of the way, a cover moves in front of the mirror. This protects the mirror from dust and dewar condensation. Thus when not using the spectrograph, *please* remember to move the tertiary mirror *out* to its protected position. The commands `mspect` and `/o` are used to move the mirror in and out, respectively.

3.2.3 PIFS Gratings

The gratings on the PIFS can be moved through about 65°, in order to tune wavelength and select the high- or low-resolution modes. Motors #5 and #9 control the two gratings. The top of the image display corresponds to grating

[1]For this and other paragraphs in this section, keep in mind that it is almost never necessary to know which motor does what, as direct motor commands are generally not needed. Macros to perform the sensible motor motions are described in Chapter 5. This information is presented here for the sake of completeness.

#5 (right side in Figure 3.1), and the lower portion to grating #9 (left side in Figure 3.1). While the two gratings can, in fact, move independently, there is almost no reason why anyone would want to do so. The macros, therefore, move both gratings in tandem. The existing macros are simply called `hires` and `lowres`. For the real gear-head, grating angles (α in the grating equation) can be controlled directly via `hiangle` and `lowangle`. The `hires` and `lowres` commands are really just front-ends to these two macros. See Section 5.2 for details.

3.2.4 PIFS Flip-in Mirrors

The flip-in mirrors (or just flip mirrors), are moved by motors #6 and #10. The upper half of the image display corresponds to flip mirror #10 (right side in Figure 3.1), and the lower portion to flip mirror #6 (left side in Figure 3.1). Again, these two *can* be moved independently, but the macros move them together. Being two-state in nature, only two commands are needed: `fmi` and `fmo`, for flip mirror in, and flip mirror out.

3.2.5 Camera Motions

For most intents and purposes, the slits and slit mask in the camera do not need to be moved, and will therefore not be discussed here. What will be moved without doubt are the filter wheels inside the camera. There are two filter wheels in each of the two IR cameras. Each has 5–10 holes for filters, plus a semi-circular hole for a CVF (Circularly Variable Filter). D80 has two CVFs, one covering the K band at 1.3% bandpass, and the other going from 1.5–3μm with a 5% bandpass. There are broadband filters for Z, J, H, K_s, and K. There is also a smattering of narrow-band fixed-λ filters. In addition to filters, there exists in the D80 filter wheel a Si lens that images the pupil (secondary mirror). This lens makes alignment of the camera in its gimbal quite easy. Macros are used to access the various filters, which are covered in Section 5.3.

3.2.6 Other Mechanical Motions

Besides the controls described above, there are a few other motions of importance that are not motorized. But these motions are for alignment purposes and should not be attempted by anyone not already familiar with the process. Some of these motions are relevant to the interchange of D80 and D78. These cameras are held in a gimbal mount attached to the PIFS dewar. The gimbal mount provides the camera with four degrees of freedom, namely two translational motions and two rotational motions. The translational motions can be exercised to optimize the position of the focal plane[2]. The rotational motions allow the camera to be "tipped-up", aligning the cold-stop in the camera to the pupil image of the

[2]This position is currently optimized for D80.

secondary mirror. The tipping will be different for each of the cameras[3]. Each camera has a pupil-imaging lens that greatly facilitates the tipping process.

[3]The current values for D80 (as read on the micrometers) are: tip: 0.400, rotation: 0.295.

Chapter 4

Starting Up

This chapter describes the process of starting up from scratch, as well as how to restart in the event of a crash of some form. Some of the computer commands mentioned in this chapter are explained in greater detail in Chapter 5.

4.1 Booting Up

After the spectrograph and camera are in place at the Cassegrain focus, with all the cables attached and microVAX in the cage up and running, the system is ready to start. Log into SAM at the observer station:

```
Username: IRCASS3                                    (if using D80)
Password:          (look at terminal border for current password)
$ SET PROC/PRIV=OPER
$ RMIRELLA
```

The last command runs the Mirella program, which is the primary camera control environment. From here on, a `M>` prompt represents the Mirella environment, and a `$` prompt indicates the VAX prompt. As Mirella starts, you will need to enter a few tidbits of information:

```
Choose target camera: D78 or D80 > d80
Valid array sizes are (64,64) (128,128) (256,256)
Enter array size: x,y > 256,256
USE OLD MOTOR SETTINGS FILE? (Y/N)   Y
USE OLD OFFSET GUIDER SETTINGS FILE? (Y/N)   Y
RESTORE MACROS TO MEMORY FROM SAVE FILE? (Y/N)   N
```

You will then be asked to enter the observers, or accept the current list. The IRA tradition is to input initials here.

```
M> ready                        (sets a target task for the camera)
Starting target network task...
```

```
M> gosby                          (go standby—awaiting commands)
M> spawn                                    (start a VAX shell)
$ copy appl:[ircass3.userdir]d83.m userdir:
$ copy appl:[ircass3.userdir]d83ze.p1m userdir:
```

Hint: use the up arrow to edit the first command, saving typing.

```
$ eoj                                                  (end-of-job)
M> load d83.m        (load the macros, or words really, for PIFS)
M> rmacf camst                  (read macro file for camera start)
M> // camst   (run the camera start macros, homing motors, etc.)
M> damac                                        (delete all macros)
M> rmacf d83ze                   (read macro file for PIFS start)
M> // d83ze                (run the PIFS motor homing macros)
M> damac                                        (delete all macros)
M> rmacf cam          (read the macro file for camera commands)
M> 0. 0. og/o                  (set the guider origin to (0,0))
M> agon                                  (turn the auto-guider on)
M> 0.6 d(set differential refraction term for K band; use 0.4 for J)
```

Now everything is ready to roll. If the process doesn't go smoothly, I suggest trying again. If things seem to hang up for several minutes when running the motor-homing macros, then something is probably wrong with the motor controller or associated connections. Go into the Cassegrain cage and check that all motor cables are properly seated. If failure persists, there is a motor controller reset switch tie-wrapped to the inside of the rack containing the motor controller. It is a little pushbutton device. It is rare that such action is necessary, but it has been known to happen.

4.2 Checking Camera Status

After booting up, verify that the camera is in the correct mode. This is done by looking at the top of the Mirella screen at the various numbers characterizing the camera status. An example for D80 appears below.

MODE	10308	F7OP	0.0	PICT	1	F7ODISP	1
MPARM1	0	OGAUTO	0	FRAMES	1	SING_POS	1
MPARM2	16	DELAY	0.0	PIXRATE	16.5	F7ON	1
AMPGAIN	25	DETBIAS		TINT	120.0	EXP_TIME	126.75
CYCLE	1	COADDCYC	1	DETGATE		CSCALE	16
NEXTFILE	1	OBJECT	IR0831	FILTER	CVF2	NOD-E	100.0
LASTFILE		IMAGETYP	OBJ	WAVELEN	2.360	NOD-N	0.0

Many of the numbers in the lower display will change with observing mode, as will numbers referring to exposure time, etc.

4.3 Verifying Operation

Upon starting up, the first thing to do is verify that everything is working properly and there are no apparent problems. First and foremost, see that the camera is delivering images.

```
M> /77k
M> 10. tint
M> goi dcp
M> goi wait odiff
```

This series takes a pair of 10 second dark frames, first displaying the raw dark, then a difference between two. The raw dark should look mostly flat, with a few blotches and hot corners. The difference should look pretty flat.

Next, check that light is making its way into the camera. This can be done by simply looking at the warm tertiary mirror cover using the K band filter.

```
M> /k
M> 10. tint                              (if not already set to this)
M> fmi    (flips the mirrors in front of the gratings for a slit image)
M> goi dcp
```

Don't worry too much about the commands and their meanings at this point. This will all be covered in Chapter 5. The current display should show the thermal emission of the tertiary mirror cover in the form of eight slits. Don't worry about the fact that the upper right slit falls off the edge of the array. It is normal, and doesn't affect the spectral mode. If you want the full story of why this is the way it is, I'd be happy to entertain you. The important thing at this point is that you see light screaming through the instrument.

Now it would be good to check the spectral mode and make sure all is working there. To do this, send the tertiary mirror out (should already be there) and turn on a lamp:

```
M> /o
M> argon
M> 10. tint
M> 2.099 hires                                (or use lowres)
M> goi dcp
M> lampoff
```

You should be staring at an emission line, roughly centered in the wavelength range. I should note that as the two spectral regions come together in the middle of the array, they are vignetted slowly out of existence. So near the center, the throughput is steadily dropping to nil. Therefore the center of the usable spectral range is not at the geometrical halfway point between array center and edge. You may also notice that part of the array is vignetted, at the sides and bottom. This vignetting is due to the fact that D80 is a copy of D78, which was designed

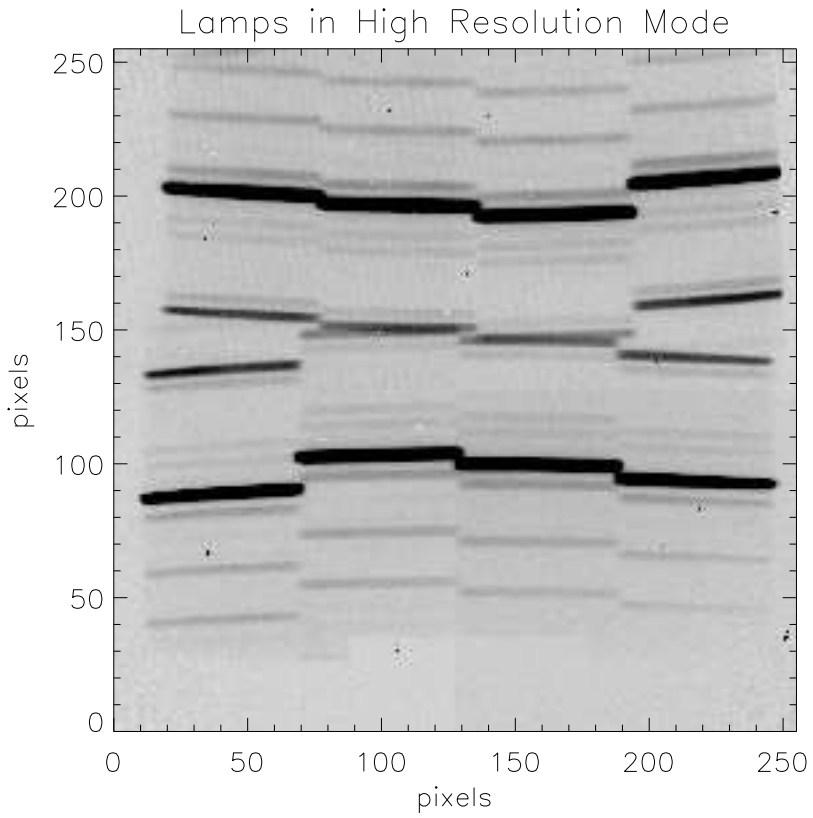

Figure 4.1: A combination spectrum of all four lamps with the high resolution grating set to 2.062μm.

for a 256×256 array of 30μm pixels. But D80 has an array using 40μm pixels, so it's a bit oversized. If reducing data from D80, you will come to appreciate this vignetted region as a tool for adjusting floating quadrant levels. With the vignetting as it is, the center y-value of the usable space is at pixel 148, not 128. And with the central vignetting of the spectra, the central wavelength pixels are roughly at $y = 87$ and $y = 199$. Try other lamps as well, but just remember to issue the `lampoff` command when you are done. It is also possible to turn on any combination of lamps, using the more generic `lamp` command (see Section 5.2). Example appearances of the lamp lines in both high resolution mode and low resolution mode are seen in Figures 4.1 and 4.2, respectively.

If you feel that seeing is believing, then it may be worth turning on all the lamps with the `1 1 1 1 lamp` command and then walking out to the cage, and peering into the coffin (from the side opposite PIFS, if an imaging camera is not in place there) to see that each tube is glowing. The neon tube will dominate in the visible regime. Remember to turn the lamps off with `lampoff` when done.

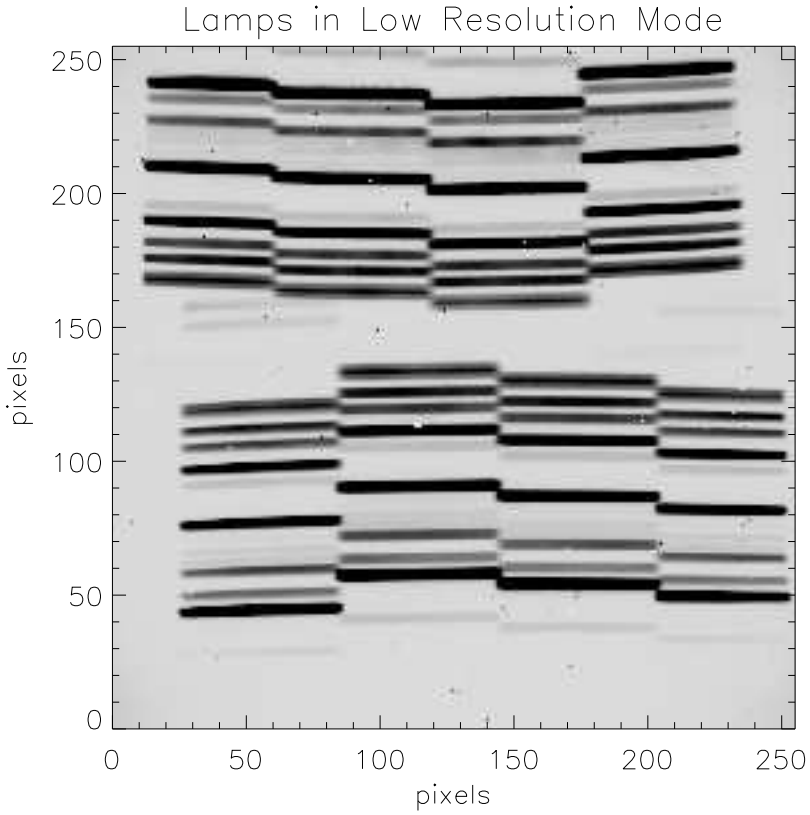

Figure 4.2: Argon lamp spectrum with the low resolution grating set to 1.33μm.

With the imaging and spectral modes checked out, all systems are go for the night sky. There are, however, darks and dome flats that can be taken during daytime hours. See Sections 7.1 and 7.2 for more on this.

4.4 Restarting After a Crash

Sometimes things just go wrong. It may not be your fault, but it probably is. Most of the time there is no need to panic. By panic, I mean start over from scratch. If the problem is software, there is no need to re-home the motors, for instance. If the problem is hardware, then maybe this step will be necessary after all.

4.4.1 Software Restart

Should the software become confused, it may be desirable to restart the Mirella program. To do this, first type:

```
M> bye
```

to exit Mirella. It may be the case that you were dumped out already, in which case you will see the $ (VAX) prompt. Occasionally I've encountered an anomalous problem with Mirella kicking me out in the process of entering an object name. It's a bizarre bug, and is certainly not your fault. I have developed a superstition that it only happens when shortening the `object` command to `obj`. This theory may be completely insane, however.

In any case, once out of Mirella, restart the program:

```
$ RMIRELLA
```

Now answer the usual questions again:

```
Choose target camera: D78 or D80 > d80
Valid array sizes are (64,64) (128,128) (256,256)
Enter array size: x,y > 256,256
USE OLD MOTOR SETTINGS FILE? (Y/N)   Y
USE OLD OFFSET GUIDER SETTINGS FILE? (Y/N)   Y
RESTORE MACROS TO MEMORY FROM SAVE FILE? (Y/N)   N
```

At this point, just hit return to keep the same observer list (or change list if desired).

```
M> ready                    (sets a target task for the camera)
M> gosby                    (go standby—awaiting commands)
M> load d83.m       (load the macros, or words really, for PIFS)
M> rmacf cam         (read the macro file for camera commands)
M> 0. 0. og/o                (set the guider origin to (0,0))
M> agon                              (turn the auto-guider on)
M> 0.6 d(set differential refraction term for K band; use 0.4 for J)
```

Now the system is ready to go again.

4.4.2 Hardware Restart

In the event that the motors become confused, or you become confused about the motors, or the motor controller goes belly-up, you may need to re-home the motors. First, exit Mirella:

```
M> bye
```

Then go through the following startup procedure:

```
$ RMIRELLA
Choose target camera: D78 or D80 > d80
Valid array sizes are (64,64) (128,128) (256,256)
Enter array size: x,y > 256,256
USE OLD MOTOR SETTINGS FILE? (Y/N)   Y
USE OLD OFFSET GUIDER SETTINGS FILE? (Y/N)   Y
RESTORE MACROS TO MEMORY FROM SAVE FILE? (Y/N)   N
```

At this point, just hit return to keep the same observer list (or change list if desired).

```
M> ready                        (sets a target task for the camera)
M> gosby                       (go standby—awaiting commands)
M> load d83.m          (load the macros, or words really, for PIFS)
M> rmacf camst                  (read macro file for camera start)
M> // camst    (run the camera start macros, homing motors, etc.)
M> damac                                          (delete all macros)
M> rmacf d83ze                   (read macro file for PIFS start)
M> // d83ze                (run the PIFS motor homing macros)
M> damac                                          (delete all macros)
M> rmacf cam           (read the macro file for camera commands)
M> 0. 0. og/o                  (set the guider origin to (0,0))
M> agon                                    (turn the auto-guider on)
M> 0.6 d(set differential refraction term for K band; use 0.4 for J)
```

Now everything is ready to roll. If the process doesn't go smoothly, I suggest trying again. If things seem to hang up for several minutes when running the motor-homing macros, then something is probably wrong with the motor controller or associated connections. Go into the Cassegrain cage and check that all motor cables are properly seated. If failure persists, there is a motor controller reset switch tie-wrapped to the inside of the rack containing the motor controller. It is a little pushbutton device. It is rare that such action is necessary, but it has been known to happen.

Chapter 5

Commands

The Mirella commands you will be using can be divided into four groups:

- PIFS commands
- camera commands
- telescope control commands
- display commands & other miscellany

In addition, if using the $f/70$ tip-tilt guider, there are commands for the guider. The guider commands are entered on the MINC terminal usually to the left of the VAX terminal.

5.1 A Word About FORTH

The Mirella program is written in FORTH, which is a stack-thinking language, much like good old RPN on HP calculators. The Mirella command structure inherits this stack mentality, and as such, most of the commands take arguments previously placed into the stack. Thus arguments precede commands on the command line, e.g., `10. tint`; `2.2 hires`.

Now before assuming all is understood, be aware that there are *two* stacks: an *integer* stack and a *float* stack. These are not the same stack. The input sequence: `1.0 3 5.2 80 command` puts two arguments into the float stack (the first and third), and two entries into the integer stack (the second and fourth). If `command` takes two floats, then it first grabs the value `5.2` off the stack, followed by the value `1.0`.

Also worth mentioning is that any number of commands may be placed on the command line, with spaces between. Examples might look like:

```
M> 10. tint 16 mparm2 1 frames 16 cscale
M> goi dcp -10. 0. 90. mvpix goi wait odiff
```

Most of the forth commands presented in the following sections are technically not macros, but FORTH "words". There is limited room ("dictionary space") for words, though there is usually enough room left over for a few user words, which is the subject of Section 5.6.

5.2 PIFS Commands

The following words (commands) are located in the `d83.m` file, loaded during the startup process.

`fmi`	Flip mirrors in front of the gratings. Used for imaging mode.
`fmo`	Flip mirrors out of the way, exposing grating to beam. Used for spectral mode.
`mspect`	Moves the tertiary mirror into the PIFS spectrograph position.
`/o`	Moves the tertiary clear out of the way, allowing the center field camera an unobstructed view. Also puts cover in front of mirror for protection, and provides diffuse surface for scattering calibration lamp-light.
λ `hires`	Rotates high-resolution grating to center λ μm on the array, where λ is a *floating-point* number. This routine also selects the appropriate order-sorting filter and performs a `fmo` command, removing the flip mirror from the beam.
λ `lowres`	Rotates low-resolution grating to center λ μm on the array, where λ is a *floating-point* number. This routine also selects the appropriate order-sorting filter and performs a `fmo` command, removing the flip mirror from the beam.
`neon`	Turns off all lamps, then turns on the neon tube.
`argon`	Turns off all lamps, then turns on the argon tube.
`krypton`	Turns off all lamps, then turns on the krypton tube.
`xenon`	Turns off all lamps, then turns on the xenon tube.
`lampoff`	Turns off all lamps.
. . . . `lamp`	Takes four *integer* arguments (`0` or `1`), separated by spaces, and turns on/off combinations of lamps. A `1` means "on", and a `0` means "off". The least significant bit (rightmost) represents neon, while the most significant bit (leftmost) represents xenon (in order of atomic weight). Therefore the command: `0 1 0 0 lamp` turns on only krypton, `1 1 1 0 lamp` turns on all lamps but neon, and `0 0 0 0 lamp` is effectively a `lampoff` command.

α `hiangle` Takes the *floating-point* argument, α, and moves the face of the high-resolution grating in such a way that the input light strikes the grating at angle, α, in degrees. This is a low-level command that is actually the back-end to `hires`.

α `lowangle` Takes the *floating-point* argument, α, and moves the face of the low-resolution grating in such a way that the input light strikes the grating at angle, α, in degrees. This is a low-level command that is actually the back-end to `lowres`, and operationally just adds 72.75 to α and calls `hiangle`, since the relative angle between the two grating surfaces is rigidly fixed.

The last two commands will probably never be used, but I realize that their inclusion here is pointless without the following information about the two grating surfaces. The high-resolution surface has a blaze angle of 36.8°, with 300 grooves/mm. The low resolution face has a blaze angle of 17.5°, with 150 grooves/mm. The average value of $\alpha - \beta$ is about 4.0°, using the standard convention in the grating equation:

$$\sin\alpha + \sin\beta = \frac{m\lambda}{a}$$

with α as the input angle, β as the exit angle, m as the order, and a as the groove spacing, This should enable one to calculate desired grating angles for certain wavelengths. At present, the `hires` and `lowres` commands do not support grating tunings beyond 2.5μm. Working in this long-wavelength regime will necessitate using the lower level `hiangle` and `lowangle` routines, or using a higher order setting then manually selscting the appropriate filter.

5.3 Camera Commands

The following words (commands) are read in when the `rmacf cam` command is entered upon startup. Refer to the standard IR camera user manual for more detailed descriptions and additional commands.

t `tint` Integration time for each frame. Can take *float* or *integer* arguments for t. The integration time can range upwards from 0.375 seconds, but see the discussion of `mparm2` below.

i `mparm2` Number of non-destructive reads at beginning and end of integration. For integration times less than 6.0 seconds, use a value of $i = 1$ for MPARM2. For longer integrations, use $i = 16$ for MPARM2. The value, i, should be an *integer*.

i `frames` Set this to co-add i frames (an *integer*) into a single data file. This command also issues a i `cscale` command.

i `cscale` Should set *i* equal to (the number of frames)×(the number of reads), or to (FRAMES)×(MPARM2). All this does is sets the display to a consistent scale, such that saturation is always at the same display value (20,000 for D80). Note that the `frames` command automatically sets CSCALE to the same thing. This is okay if MPARM2 is 1, but is wrong otherwise. The stored data is independent of the value of CSCALE.

`goi` Go immediately. This command sends a request to the camera to take the specified number of frames of the specified integration time. In other words, this command is the "take a picture" command. The `go` command does essentially the same thing, but prompts for object name, etc.

`snapi` Similar to `goi`, but this command also grabs a sky image after the object image. For the sky image, a telescope move command is issued, the image type changes to "SKY", and an equal-length exposure is taken of the sky, after which the telescope returns to the original position, with the image type field restored to its original value. The sky position is determined by the NOD-E and NOD-N values (see Section 5.4). Like `go`, there is also a plain `snap` command that first prompts the user for information.

`/77k` Moves the 77° blocker in front of the array.

`/z` Moves the *Z* band filter into place.

`/j` Moves the *J* band filter into place.

`/h` Moves the *H* band filter into place.

`/ks` Moves the K_s band filter into place.

`/k` Moves the *K* band filter into place.

λ `cvf1` Moves the narrow (1.3%) bandpass CVF into place, centered at wavelength λ μm, which is a *floating-point* value. This filter (in D80) runs from 2.0–2.5μm.

λ `cvf2` Moves the medium (5%) bandpass CVF into place, centered at wavelength λ μm, which is a *floating-point* value. This filter (in D80) runs from 1.5–3.0μm, and is the primary order-sorting filter used throughout this wavelength range for both the high-resolution and low-resolution spectral modes.

`/lens` Places the filter-wheel lens in front of the array, allowing one to image the pupil (secondary mirror) for the purpose of assessing the camera alignment within the gimbal.

`lo` Open secondary lid, so that light around the edge of the secondary comes from beyond the telescope. This action reduces thermal background, as the warm lid is replaced by cold sky. The `/ks` and `/k` filter commands automatically open the lid, unless it has been locked with `ll`. A sustained beep sounds when the lid is in motion.

`lc` Closes secondary lid, so that light around the edge of the secondary comes from the dome-temperature lid itself. This action reduces non-thermal background, and should be implemented shortward of 2μm. The `/77k`, `/z`, `/j`, and `/h` filter commands automatically close the lid, unless it has been locked with `ll`. A sustained beep sounds when the lid is in motion.

`ll` Locks the secondary lid so no action is taken when the `lo` or `lc` commands are issued, which also holds for filter changes.

`lu` Unlocks the secondary lid, such that the `lo`, `lc`, and filter commands will affect a motion of the lid. This is the normal lock state of the lid.

5.4 Telescope Commands

The following commands pertain to moving the telescope and the guider, or both at once. Except where noted, these commands are read in with the `rmacf cam` command as entered upon startup. Refer to the standard IR camera user manual for more detailed descriptions and additional commands.

$\Delta\alpha$ $\Delta\delta$ `mt` Move telescope $\Delta\alpha$ arcseconds East, and $\Delta\delta$ arcseconds North. $\Delta\alpha$ and $\Delta\delta$ are *floating-point* numbers, and negative signs affect motions West and South, respectively.

$\Delta\alpha$ $\Delta\delta$ `mtg` Same as the `mt` command, but move the guide head in the opposite direction by the same amount thus leaving the guider looking at the same spot on the sky. In other words, keep the guide star. Obviously this command only makes sense for small moves within reach of the guide head.

$\Delta\alpha$ `e` Move telescope $\Delta\alpha$ arcseconds East, where $\Delta\alpha$ is a *floating-point* number.

$\Delta\alpha$ `w` Move telescope $\Delta\alpha$ arcseconds West, where $\Delta\alpha$ is a *floating-point* number.

$\Delta\delta$ `n` Move telescope $\Delta\delta$ arcseconds North, where $\Delta\delta$ is a *floating-point* number.

$\Delta\delta$ `s` Move telescope $\Delta\delta$ arcseconds South, where $\Delta\delta$ is a *floating-point* number.

x y θ `mvpix` This command comes from `d83.m`, and moves the object around on the field of view, keeping the guide star in the guider. This is opposite the philosophy of moving the telescope. In essence, this is simply an `mtg` command with a coordinate transformation. All arguments are *floating-point* values, with x representing the number of $0.167''$ pixels to move to the right, and y representing the number of $0.167''$ pixels to move in the up direction. The third value, θ, is the Cassegrain Ring Angle, in degrees. For instance, the command: `10. -6. 75. mvpix` moves the *object* 10 pixels to the right and 6 pixels down if the ring angle is currently 75°. Do not be alarmed by the message on the screen that the guider is locked off, no action. This simply means that during the move, the guider is turned off.

`sweep` This is a special PIFS command, loaded from `d83.m`. It is used to drag a chopped G-star across the PIFS field in a uniform way. The sweep routine is actually rather simple, moving motor #15 (angular motion of guide head) in $0.1''$ steps $8''$ one way, then $8''$ back (this assumes a radius of $30''$). By guiding on the end of the triangle-wave chop, the star is pulled across the field and back. More on this technique in Section 7.7.

`gsky` This is really just the latter part of a `snapi` command, from `d83.m`. It changes the image type to "SKY", moves to the designated nod position, takes an exposure, then returns both the telescope and the image type to their original fields. Useful for G-stars after a `sweep` command, or for a quick sky-grab.

$\Delta\alpha$ `node` Set the nod to $\Delta\alpha$ arcseconds East. $\Delta\alpha$ is a *floating-point* value. This nod is used by `snap` and `gsky` to determine the sky offset.

$\Delta\delta$ `nodn` Set the nod to $\Delta\delta$ arcseconds North. $\Delta\delta$ is a *floating-point* value. This nod is used by `snap` and `gsky` to determine the sky offset.

$\Delta\alpha$ $\Delta\delta$ `nod` Set the nod to $\Delta\alpha$ arcseconds East and $\Delta\delta$ arcseconds North. Both $\Delta\alpha$ and $\Delta\delta$ are *floating-point* numbers. This nod is used by `snap` and `gsky` to determine the sky offset.

$\Delta\alpha$ $\Delta\delta$ `og/o` Set the offset guide head origin to $\Delta\alpha$ arcseconds East and $\Delta\delta$ arcseconds North. $\Delta\alpha$ and $\Delta\delta$ are both *floating-point* values. Should only have to set once per run, and usually then it's set by: `0. 0. og/o`.

$\Delta\alpha$ $\Delta\delta$ `og/r` Send the offset guide head to $\Delta\alpha$ arcseconds East and $\Delta\delta$ arcseconds North of the guider origin. $\Delta\alpha$ and $\Delta\delta$ are both *floating-point* values, and are recorded in the header variables OGX and OGY, respectively. The `/r` stands for rectangular coordinates.

`og` This updates the guide head position, and is used to verify that the guider is where it thinks it should be. Most commonly, this is used if the Cassegrain ring angle has changed after the last `og` command was issued.

`agon` This turns the auto-guider on, such that Mirella has control of the MINC computer. It is necessary that the auto-guider is on for many operations to work correctly.

`agoff` Not surprisingly, this turns the auto-guider off.

5.5 Display Commands and Other Miscellany

The following commands are read in with the `rmacf cam` command as entered upon startup. Refer to the standard IR camera user manual for more detailed descriptions and additional commands.

`wait` Wait for current exposure to finish before processing the next command.

`lastfile` Returns *integer* corresponding to frame number of last *complete* exposure. This is often used to feed `pdiff`, as in `lastfile 102 pdiff`.

i `nextfile` Sets the frame number in which to place the next exposure. If you set this to overwrite previously taken frames, the old frames must first be deleted.

i `dp` Display Picture with frame number *i*, an *integer*.

`dcp` Wait, then Display Current Picture. If no exposure is in progress, this displays the last picture, like the `dlp` command listed below. This command is essentially a `wait lastfile dp` command.

`dlp` Display Last Picture, as referenced by LASTFILE.

`odiff` Subtract (LASTFILE−1) from LASTFILE and display. The command means "object difference", and is used when the sky frame is taken *before* the object frame. No `wait` is built in, so `goi wait odiff` is frequently seen.

`sdiff` Subtract LASTFILE from (LASTFILE−1) and display. The command means "sky difference", and is used when the sky frame is taken after the object frame. No `wait` is built in. The `snap` command does have a wait, so `snapi sdiff` is a frequently used command.

i j `pdiff` Subtract frame *j* from frame *i* and display. Both *i* and *j* are *integers*.

i j `lindisp` Change the display stretch to a linear ramp from value *i* at the low end to value *j* at the high end. Both *i* and *j* are *integers*.

`cu` Enter cursor mode. This offers a means to explore the currently displayed image, allowing multiple cursors to move across the display as both markers and probes. Cursors #0 and #1 display their *x* and *y* positions, as well as their data value at the bottom of the display screen. Cursors #0–3 have distinct shapes, going plus, diamond, box, x-shape, respectively. Cursors are moved around using the numeric keypad on the right side of the keyboard. The eight keys surrounding the "5" key move the cursor in eight corresponding directions. The `cu` command enters its own environment with the following commands:

`+`	Increment to next cursor.
`-`	Decrement to previous cursor.
`x`	Print cursor position and data value on terminal.
`f`	Speed up cursor (FAST) one notch.
`s`	Slow down cursor (SLOW) one notch.
`c`	Change cursor color (`0`=black, `1`=white, `2`=blink)
`q`	Quit cursor mode, returning `M>` prompt.

`box` Statistics in a box. Enters cursor mode and provides two cursors (usually pop up at screen center) to move around, ultimately defining opposite corners of a box. The cursors are toggled in the usual way, with the (`+`/`-`) keys, and otherwise manipulated in the same ways as normal cursors in cursor mode. When the box is defined, quitting cursor mode (with `q`) draws the box on the display, and prints statistics information to the terminal.

i `photometric` Specify the photometric conditions (for inclusion in the header). The *integer*, *i*, can be `1` (photometric), `0` (not photometric), or `-1` (unknown).

`poff` Turn off requests for photometric status updates.

`object` Prompts for object name.

`typ` Prompts for image type (out of a list, e.g., Dark, Flat, Object, Sky, etc.).

`abort` Abort the exposure currently being taken. Do not write to file, and reset NEXTFILE to the aborted frame number.

`^C` CONTROL-C interrupts the current action, sending a prompt saying that you are impatient, and asking if you want to return to the interpreter (do you want a prompt back?). Unless the

CTRL-C was a mistake, you'll want to answer yes (`Y`). You'll then get a prompt, and will most likely `abort` the exposure, if that's why you hit CTRL-C in the first place. It is also useful for getting a prompt back after a `goi dcp` command, or the like. In this case, the exposure will continue unless aborted, but the `dcp` is prevented. The virtue of this is that you get a prompt back in case there is something you want to do.

`spawn` This temporarily leaves Mirella, providing a VAX prompt. This is often used to delete files, edit word files, or check file headers. When finished with the task, type `eoj` at the `$` prompt to return to Mirella.

`/end_night` This command should be performed whenever there is about to be a significant downtime. It pulls the tertiary out (`/o`), protecting it from junk, puts the 77°K filter in (`/77k`), protecting the array, and closes the secondary lid (`lc`). It doesn't have to be the end of the night for this command to be sensible.

`bye` Exits Mirella, leaving a VAX prompt.

5.6 User-Defined Commands

Sometimes frequently repeated command sequences are most efficiently placed into a user-defined FORTH word (command). Any name can be assigned to a word, though if the chosen name is already associated with a previously defined word, Mirella will complain that the word is not unique, and the old function will be replaced by the new function—sort-of. The caveat is that any other word that uses the doubly-defined word still uses the definition that was in place at the time of its own definition. There is a `forget` command to un-define a word, but *every* word defined *after* the erased word will also be erased. So use `forget` only if familiar with its operation, and *use with caution* even then.

That said, the best way to explain word definition is by example. In the following examples, the `]` symbol is the prompt Mirella uses during word definition. Any number of carriage returns are acceptable, being treated much like spaces. The definition is started with a colon command, and terminated with a semi-colon.

```
M> : dolamp
] /o 10. tint 1 1 1 1 lamp goi dcp  (dcp has a wait built in)
] lampoff goi wait sdiff mspect
];
M>
```

This example defines the word `dolamp`, which, when executed, will move the tertiary mirror out of the way, set the integration time to 10 seconds, then take two exposures, with lamps on and lamps off. The lamp-on raw image is

displayed, as is the final difference. When all is done, the tertiary mirror is moved back in place[1]. The next examples abbreviate the process of switching back and forth between long and short exposure regimes.

```
M> : short
] 1 mparm2 10 frames 0.375 tint
];
M> : long
] 10. tint 16 mparm2 1 frames 16 cscale
];
M>
```

The `short` command sets up the shortest possible exposure, 0.375 seconds. Ten frames are used to better average atmospheric fluctuations. The `long` command leaves this regime for the more normal long exposure setup. In the `short` example, note that the `tint` command comes last. This is to prevent Mirella from complaining that the integration time chosen is too short for the current value of MPARM2. It would still do the right thing if the `tint` command came first, but would issue a warning. In the `long` example, the `tint` command could go anywhere, as all exposure times greater than 0.375 seconds are valid with MPARM2 set to 1. Note also that the `short` command does not include a `cscale` command. Recall that `frames` automatically changes CSCALE to the same value. So in this case all is well. It is for this reason that `cscale` comes *after* `frames` in the `long` example.

5.7 $f/70$ Tip-Tilt Guider Commands

If using the $f/70$ tip-tilt guider controller (the MINC) rather than the Palomar facility guider, the guiding workload is higher, but with potentially sharper images/spectra. This section is by no means complete, and may be the only documentation ever attempted for this system. Bear in mind that this subject has some nebulous regions in my head. Only Keith[2] knows this system cold.

Not discussed in this chapter is the operation of the Quantex DS-12, which is a key element in the guider system. The operation of the Quantex is briefly discussed in Section 6.1.

5.7.1 Basic Setup and Operation

If you know nothing else about the guider, at least know the `GO` command. This activates guiding. How is guiding stopped? By hitting <RETURN>. The `GO` command has three bits to toggle. `GO 7` runs the guider with all three options

[1] Ordinarily, I would not include the tertiary commands. I prefer to do this manually because if two `dolamp` commands were executed in a row (i.e. for two grating settings), the mirror would move back and forth unnecessarily, wasting time and effort.

[2] I refer to the illustrious (wacky?) Keith Matthews, or KYM. He built the $f/70$ tip-tilt secondary, and wrote the control software. He knows it.

on: (1) Basic guiding (called auto-guiding), (2) Tip-tilt guiding, and (4) the graphical stripchart. Simply multiply the numbers in parentheses above by 1 (on) or 0 (off) and add for functionality. Thus `GO 5` runs the guider without tip-tilt.

Aside from the `GO` command, there are a number of parameters to set. This is not done in stack-style, but in a more conventional `command` *argument* syntax. Entering the command with no argument returns the current value, with no change made. This is a convenient way[3] of checking the current parameter values.

Be aware that this system was created without concern for robustness or user-friendliness. Therefore if the wrong thing is typed, "The whole world may blow up and you'll be left with nothing"[4].

5.7.2 The Commands

`GO` i — i is a bitmask, with 1=guiding, 2=tip-tilt, and 4=stripchart. See explanation at the beginning of this section if confused. To stop guiding, hit <RETURN>.
Examples:

- `GO 1` Guide without stripchart and without tip-tilt.
- `GO 5` Guide with stripchart, but without tip-tilt.
- `GO 7` Guide with tip-tilt and stripchart

`GO` — If no number is provided, the last used value is assumed.

`HEAD` $[\theta]$ — Angle of guide head. Must match actual angle of guide head within 10° for proper guiding. To get correct value, type `og` in Mirella to find out.

`F70A` $[\theta]$ — Angle of the current secondary chop direction. Should match the actual angle within 10° for proper guiding. Look at numeric LED display near bottom of $f/70$ rack for appropriate angle. Remember to change this parameter if the secondary is moved.

`BOX` $[n]$ — Set guide box to n pixels across. Usually $n = 4$ is good, though bad seeing calls for a bigger box ($n = 5$) and good seeing will benefit from a smaller box ($n = 3$). I have seen conditions good enough to use a 2-pixel box, but that's very rare. BE AWARE that the smaller the box, the faster the computation, therefore the faster the guiding feedback. The rate-controllers below (or "gains") are therefore affected by the box size, and are not invariant in their feedback rate.

`TVLL` $[x]$ — TV Low Level control. Default is 0.1. Keith Likes 0.05–0.07. This sets the sky background level above which to look for the guide star.

[3] Heck. It's the only way!
[4] A quote from Keith Matthews.

`AGG` [i] Auto-Guiding Gain. This sets how fast the system issues telescope move commands in response to excursions from the box center. High number is fast, low number is slow. Good conditions are suited by a value for i (an *integer*) of 5–10. If the star is faint, lower this number to the 1–4 range. Keep in mind that box size also affects the response time (see `BOX` entry).

`F70G` [i] The $f/70$ Gain. This sets how fast the secondary tries to track image wander in response to excursions. For faint stars or poor seeing, use a low value for i (an *integer*), from 1–4. For decent conditions with a reasonable guide star, set this to 5–10. For the best of conditions (i.e. 9^{th} magnitude guide star, $0.5''$ seeing) this value may go up to 15 or so. Keep in mind that box size also affects the response time (see `BOX` entry). When changing `F70G`, also adjust `F70D` accordingly.

`F70D` [i] The $f/70$ Damping. For low values of `F70G` (< 5), this parameter doesn't do much. For these cases, use a value of $i = 0$. For higher values of `F70G`, use a value for i that is maybe 70% of the `F70G` value. Or set i to be smaller than `F70G` by about 3–4. Only Keith will get it right.

5.7.3 Normal Operation

Normally, when going to a new guide star, do the following things in roughly the suggested order. Remember that to check values of parameters, simply type in the parameter name with no argument.

- Retrieve `HEAD` angle for guide head (from Mirella `og` command) and set.
- Check that `F70A` is properly set. Only changes when secondary chop angle is adjusted.
- Verify (visually on guider TV) that box size is reasonable for the current seeing.
- Check the values of `AGG`, `F70G`, and `F70D` for reasonable settings.

Now type `GO`, or some variant thereof, to start guiding.

Be aware that if issuing a large `mtg` command, the guide star's position angle relative to the new field may significantly differ from the old position angle. This means that the `HEAD` angle has changed. Be sure to check the head angle after large moves, and reset if necessary.

When moving the telescope with `mvpix` or `mtg`, a message will appear on the screen that the autoguider is locked off, with no action taken. This message simply means that during the move, the guider is turned off. Operation will return to normal once the move is complete. The stripchart will verify that the guider resumes guiding.

5.7.4 That Wacky Stripchart

The graphical stripchart displayed on the guide computer screen is actually a helpful tool. To first order it signals whether or not guiding is going on. If points are being added to the right, and the dots are scrolling by, the guider is doing its thing (at least it thinks it is).

The shape of the strip chart can indicate at a glance the stability of the atmospheric conditions. A level stripchart chugging along indicates a stable sky—quite possibly photometric. There are two points plotted for each time step. The top point is the total flux inside the box, with some weighting unbeknownst to me. The lower point is the sum of the flux in the central four pixels. So under photometric conditions with variable seeing, the spacing between these two points will reflect the seeing fluctuations. Under less than ideal conditions, or with a faint guide star, the chart may be all over the place to the point that distinguishing two separate stripcharts is impossible.

5.7.5 Abnormal Operation

If the guide star is pushed out of the box, or appears to orbit the box, the angle information is wrong (by $\sim 180°$ in the first case, and $\sim 90°$ in the second case). Check the `HEAD` and `F70A` values.

If you accidentally hit the BREAK key, as I have done plenty of times, the familiar `$` prompt will disappear, and a scary `@` prompt appears. Hit `P`, then <RETURN> to get back to the `$` prompt (of course!).

If the system goes totally haywire, go over to the MINC computer (far left), and follow the instructions taped to the top of the box. The few times I've had to do this, it has worked well.

Chapter 6

Other Hardware

Chapter 5 focused on computer operations, which encompasses the majority of observing tasks. There are, however, some pieces of hardware that need to be manipulated during the course of observation. The devices covered here are (roughly right-to-left from computer):

- The guider TV's Quantex DS-12 image processor
- The function generator
- The secondary angle control
- The crosshair machine
- The center field TV's Quantex DS-12 image processor

6.1 The Guider Quantex

The guider Quantex sits just below the guider TV, and above the oscilloscope on top of the $f/70$ tip-tilt rack. The most important control on the guider Quantex is the gain knob at lower left. Adjust this to bring the star up to a reasonable brightness level (all the way up for faint stars). The optimal gain level will have the star's central pixel saturating (rolling the color map over for this pixel, turning it dark[1]) a small fraction of the time. Remember to turn the gain all the way down before a telescope move (and hit <RETURN> on the guider computer to cease guiding). The guider Quantex should have the following nominal settings:

Mode:	Average (1 frame count for bright objects)
Source:	Memory
Gain:	Manual

[1] Known to us as "brown-capping".

Video Gain: 4×

Bit Level: 6 bits

White Level: roughly 9 o'clock position

Black Level: roughly 12 o'clock position

The white- and black-levels can be tweaked to suit.

For faint stars, one can `average` 2 or more frames, but adjust the guider `AGG` to a lower value accordingly. If the star is still not bright enough, try the `integrate` mode. If you resort to this, turn `F70G` and `F70D` to zero (or use `GO 5`), as tip-tilt corrections in this regime are meaningless.

Just a note: the guider is extremely good at picking up faint stars. It can guide on stars that are barely visible to the eye on the screen. Motion of the strip chart will indicate when guiding is taking place.

When the sky is bright (i.e. twilight, moonlit, etc.), the sky background will be visible in the guider monitor. The offset guider is a hexagonal fiber bundle, whose shape will become apparent under these conditions. The size of the hexagon is 15″ across the flats (not corner-to-corner).

6.2 The Function Generator

The function generator is a beige box below the oscilloscope, which is just below the guider Quantex. The output of this generator is sent to the chopping secondary, forcing the secondary to wobble in the manner dictated by the function generator. In normal operations, the generator function knob is set to DC, but can be set to sine, triangle, or square waveforms.

The angle on the sky that the secondary moves is determined by the secondary angle control, discussed in Section 6.3.

The amplitude and frequency of the chop are controlled via the function generator. The secondary is a physical block of material, and has limits about how fast and how far it can be moved. Don't over-do it. There are no safety mechanisms, and anyone is perfectly capable of breaking the darned thing with careless turns of knobs. So know what you're doing when adjusting the function generator.

There is a knob at lower right with a ten-turn potentiometer and a turn counter (100 units per turn). This knob controls amplitude. There is also a pull-out-to-flip switch located just to the left of the amplitude knob labeled 20dB. Pulling this switch up increases the amplitude by an order of magnitude. Be careful when doing this that the ten-turn pot reads less than about 200. If without the 20dB increase activated there is still not enough throw for your purposes, turn the amplitude *all the way down* before throwing the switch. This will keep the secondary attached to the telescope. Once flipped, you may increase the amplitude to the desired amount.

A word about the 20dB switch. Even after turning the function generator back to DC, some residual noise will cause a sub-arcsecond wiggle in the secondary, which could slightly elongate point source images. To take care of this, simply get into the habit of turning off the 20dB switch whenever turning off the chopper (switching back to DC). If the amplitude was already set to a reasonable value before flipping the 20dB switch off, don't bother turning amplitude down before flipping the switch back on, as suggested above. In this case you already know that the chop amplitude with the 20dB switch on is not going to hurt anything.

As for frequency, there's hardly ever a reason to adjust this. 50 Hz is a reasonable value, but don't go too much higher than this.

6.3 The Secondary Angle Control

Below the function generator in the $f/70$ guider rack is a simple box with a 4-digit LED display in the center, and a double-pole switch underneath. The 4-digit number reads the position angle from North of the secondary chop direction. The range is -90 <`F70A`< 90. The use of `F70A` here is no coincidence. This is the same angle that the guider computer needs in order to know how the secondary is oriented (see Section 5.7).

To change the secondary angle, simply pull the switch to one side (guess which way) and hold it there while the numbers change. Let go of the switch when approximately one degree away from the target angle and wait a second for it to stop. Bumps of the switch can produce the small changes necessary for tuning.

If the angle is equal to the Cassegrain ring angle (modulo 180) then the chop direction will be along the PIFS slit direction.

Tie a mental string around your finger to remind yourself to change `F70A` on the guide computer before guiding again (assuming you're using the tip-tilt system). Better yet, change it now.

6.4 The Crosshair Machine

This beautiful piece of work sits below the center field camera monitor. There is a 6-position switch labeled 1-2-3-4-1&2-3&4, a toggle for white/black, and eight locking potentiometers.

The crosshair generator displays one of four crosshairs on the center field display, or certain combinations of two at a time. The crosshair number is selected with the 6-position switch, and made white or black with a toggle switch. The crosshair positions are manipulated with the locking pots. The top row of four controls the x-position of cursors 1–4 (left to right), and the bottom row of pots controls the y-positions. Use these to mark the central position, the position of the guide head for G-star sweeps, or whatever makes sense. The locking pots

operate by sliding the tab to one side (thus unlocking), dialing the knob, then sliding the tab back into the lock position.

To locate the appropriate central position, move the guider to the origin and guide on it. Then move the guider out of the way and place the crosshair on the star position. This ties the guider origin (also the center of the PIFS field) to the crosshair. This sequence will look like:

Place a star in the center of the field.
`M> 0. 0. og/r`
`minc$ HEAD` θ (get θ from `og` output)
`minc$ GO`
`minc$ <RETURN>` (once guider has locked on)
`M> 50. 50. og/r` (move guider out of the way)
Now adjust crosshair to star position.

6.5 The Center Field Display

The center field camera display is controlled with a Quantex image processor, just like the guider camera. Therefore I won't repeat the basics of operation or default settings, as these are virtually identical to the guider Quantex setting. Refer to Section 6.1 for the general operations and settings. The only difference is that you'll probably be better off with a bit level setting of 7 bits for increased dynamic range. I'll also repeat the request to turn the gain all the way down before a telescope move. This will save the Xybion camera from getting zapped by the moon or some other bright source during the move.

The center field F.O.V. is 70″ across, and is very useful for the following:

- Initial pointing, centering up on SAO star
- Focusing on star
- Finding guide star
- Verifying position of tertiary mirror
- Verifying chop angle

One other caution here regards the calibration lamps. If the gain is not down when the lamps are turned on, the camera will be overloaded with light. Turn the gain down before doing calibration lamps.

The field orientation is in the conventional sense when the ring angle is 90°. In general, the left side of the display points towards the position angle equal to the ring angle. In comparison to the PIFS field, the left-right direction is identical, while the vertical direction is flipped. Flipping the arrows in Figure 2.3 about the horizontal yields the center field orientation.

Chapter 7

Observing Cookbook

This chapter is divided into 7 sections covering different operations, roughly in order of complexity. Examples offered are for typical scenarios, and will vary depending on the observation. Explanations abound, so it should be easy to understand what is happening. In all the examples, a `M>` prompt represents a Mirella prompt, a `$` represents a VAX prompt, and a `minc$` represents the prompt on the guide computer (if using the $f/70$ tip-tilt system). Refer to Chapter 5 for a full description of the commands encountered in this chapter.

The following observing operations are covered in this chapter:

- Dark frames
- Dome Flats
- Imaging Sky Flats
- Typical object observation
- Obtaining a PSF
- Standard Star
- G-star for atmospheric calibration & flat field

7.1 Dark Frames

Often times, it is good to take dark frames at the beginning of the run, in the daytime, after everything is set up but there is time before dinner. I usually take a whole suite of darks, many different integration times, and usually 5 exposures per integration time (enough to perform a meaningful median). Since this is usually the first data I care to keep, I reset the `nextfile` to 1 to start anew. I try to get darks for every exposure time I'm likely to use.

```
M> 1 nextfile                (do this only if starting out fresh)
M> spawn
$ del *.hdr.*          (CAUTION! will wipe out everything!)
$ del *.img.*          (CAUTION! will wipe out everything!)
$ eoj
```

The preceding chunk should be used only if starting fresh with no useful data taken as yet.

```
M> /77k                                  (puts in 77 Kelvin blocker)
M> object                          (will prompt me for object name)
   dark
M> typ                               (will prompt me for image type)
   d                                     (will select Dark out of list)
M> 10. tint
M> goi dcp goi dcp goi dcp goi dcp goi wait odiff
```

This command takes five darks in a row, displaying each as it goes, and displaying a difference of the last two when done. This serves as a signal to when all is done, since the difference looks different from the raw dark. You can tell from across the room when it's done. See Figure 7.1 for the appearance of a raw dark frame. Figure 7.2 shows a subtracted dark frame, which is read-noise dominated. Sometimes the four quadrants subtract differently, which is no cause for alarm. This can easily be remedied in software. The vignetted edge of the array is your friend here.

```
M> 20. tint
M> goi dcp goi dcp goi dcp goi dcp goi wait odiff
M> 30. tint
M> goi dcp goi dcp goi dcp goi dcp goi wait odiff
M> 60. tint
M> goi dcp goi dcp goi dcp goi dcp goi wait odiff
M> 180. tint
M> goi dcp goi dcp goi dcp goi dcp goi wait odiff
M> 300. tint
M> goi dcp goi dcp goi dcp goi dcp goi wait odiff
```

This last sequence takes 30 minutes, and is a good dinner-time project. Leave it running while enjoying the yummy vittles at the Monastery.

If there are other exposure times you expect to use, you probably want to get a few darks at these integration times as well.

7.2 Dome Flats

Dome flats are used in the spectral flat-fielding process, but not directly. The G-stars are used for the real flat-fields, but the dome flats help tie the G-star

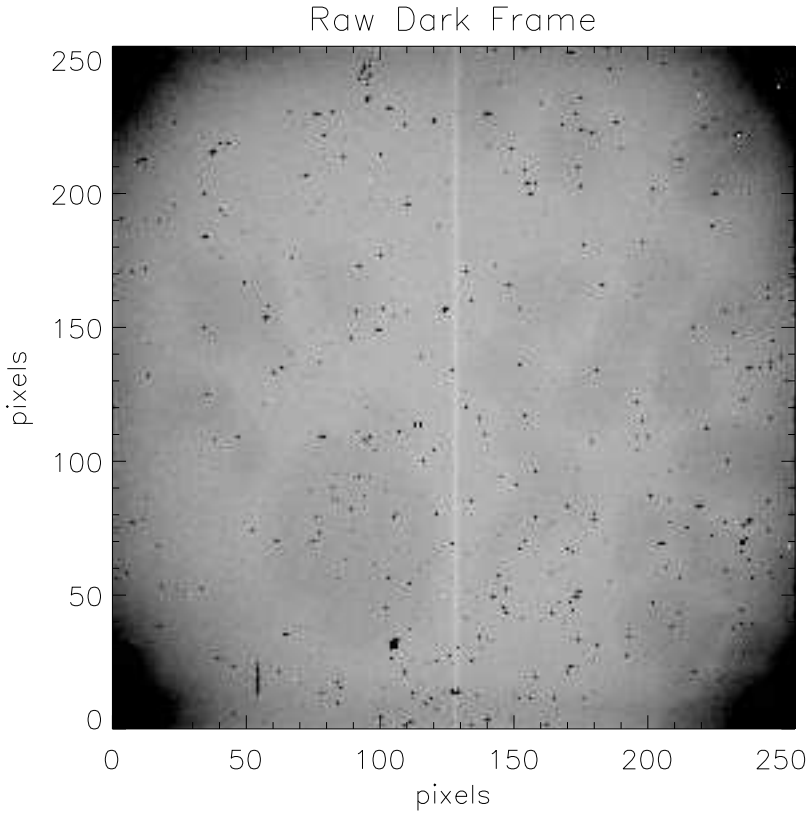

Figure 7.1: A raw 20 second dark frame with D80.

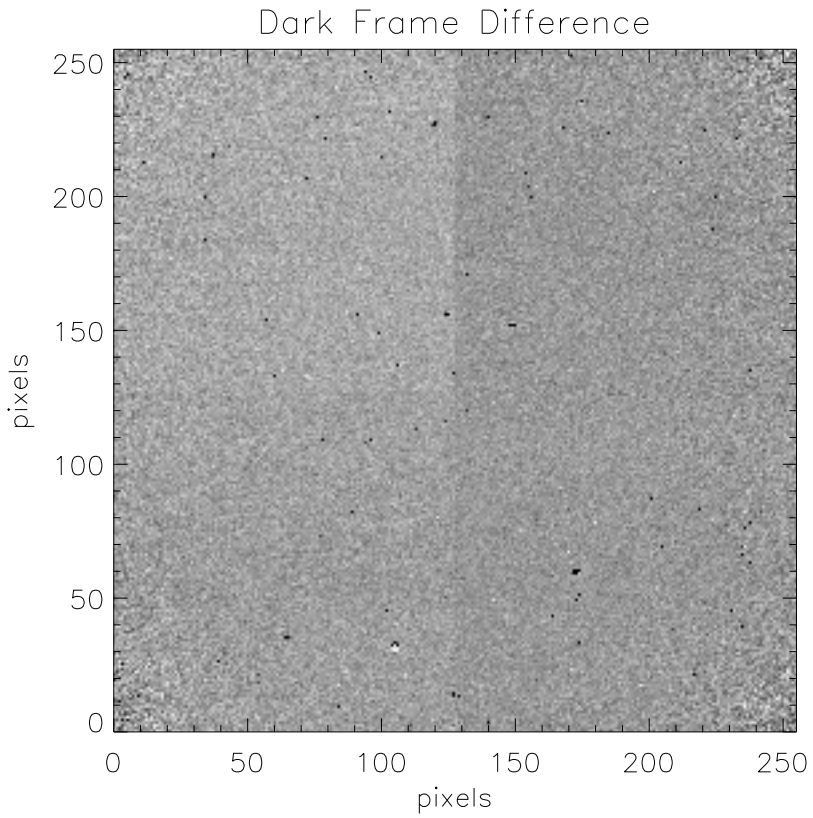

Figure 7.2: Differenced 20 second dark frames from D80.

flats down, and ensure they are flat. The chief reason for using G-star flats as opposed to dome flats is the fringing problem. The HgCdTe array in D80 has a sapphire coating on it that acts as a Fabry-Perot device. It is never noticed in broad-band imaging, as the fringes are averaged over. But the fringes show up in spectral frames. It is found that the fringing isn't rock-solid repeatable. It may be flexure, but whatever the reason, the best cure seems to be to get the flat-field as close in time and telescope orientation as possible to the object observation. Thus the G-star flats. Because it is hard to ensure uniform illumination of the PIFS field of view with G-star photons, the dome flats provide this uniform reference.

Dome flats are performed with the dome "hi-lamps" turned on and off. The Hi-lamp switch is at the telescope control panel, at the bottom of the diagonal panel. It is a three-position switch: up is hi-lamp on, down is low-lamp on, and center is both off.

The dome flats (and other flats) should also be done with the secondary lid closed. I won't go into details about the lid here, but having the lid closed ensures that light will not be coming through around the secondary mirror.

I find that dome flats are most efficiently done near the end of the run, because until then it may not be known which grating settings need calibration.

One last note: It may be desirable to obtain lamp spectra at each grating setting along with the dome flat to wavelength-calibrate the dome flat. In practice, I have never used such calibration, assuming it to be similar enough to the observation calibration. Because of the minor role of dome flats (given G-flats), this step is really unnecessary. If spectral shape calibration is important, however, you may want lamp spectra with every G-star flat you take.

7.2.1 Getting Set Up

First open the primary mirror cover. If you've never done this, find help.

```
M> mspect                          (put tertiary into place)
M> lc ll                      (close secondary lid and lock it)
M> 60. tint
M> object                           (prompts for object name)
   dome_flat
M> typ                              (prompts for image type)
   f                                      (chooses Flat from list)
M> 9001 nextfile              (sets flats apart from other data)
```

7.2.2 Taking Dome Spectra

```
M> 2.121 hires                 (set grating, filter, flip-mirror)
Turn Hi-lamp on (manually)
M> goi dcp
After exposure, turn Hi-lamp off
M> goi
```

```
M> wait sdiff 2.143 lowres        (type while exposure is going
                                  wait command holds action until end)
```

This action is a way to streamline the process, preparing the next grating setting immediately after the exposure is done. These commands can, of course be separated onto their own lines, which you may want to do at first. The above method is a little more efficient. Now to continue:

```
Turn Hi-lamp on
M> goi dcp
After exposure, turn Hi-lamp off
M> goi
M> wait sdiff 2.033 hires          (set up for next calibration)
After exposure, turn Hi-lamp on
M> goi dcp
M> goi
M> wait sdiff 2.35 hires
```

OH NO! forgot to turn off hi-lamp, and exposure is underway. Now there is no prompt available (due to the `wait` command). Here's what you do:

```
^C                (CTRL-C interrupts and asks if you are serious)
You are very impatient. Blah Blah Blah.
Do you want to return to the interpreter (Y/N)?   Y
```

Answer yes, and you'll get the prompt back. All commands following the `wait` command will not be executed as a result of the interrupt. Now you want to quickly abort the exposure:

```
M> abort                    (stops exposure, sets nextfile back)
Now turn off hi-lamp
M> goi
M> wait sdiff 2.35 hires
```

Continue going on in this manner until all the desired wavelength settings have "on-off" dome pairs. Once finished, perform the configuration clean-up described in the next section.

7.2.3 Cleaning Up

First, close the primary mirror before you forget.

```
M> n nextfile      (set file counter back to the next empty frame)
M> lu                                (restores lid to unlocked status)
M> /o          (moves tertiary mirror out into protected position)
M> /77k                               (puts blocker in front of array)
```

The log sheet should indicate the appropriate value for n to feed to `nextfile`.

7.3 Imaging Sky Flats

Imaging flats can be helpful things to have. Try to get at least something during the run. For the K band flats, the sun practically has to be up for the sky to be brighter then the thermal environment of the dome. I find that night assistants would rather arrive early enough to get sky flats at the beginning of the night than sit around waiting for the sky to get bright at the end of a long night. If you start within 10 minutes after sunset, you'll probably be fine.

The tricky thing about sky flats is that the sky is bright and rapidly changing. Short integrations are called for.

Keep the secondary lid closed for the sky flats. This will better approximate the illumination pattern of the night sky under operating conditions.

7.3.1 Setting Up for Flats

Once the dome is open and mirror cover open, it's show time:

```
M> lc ll                          (close and lock secondary lid)
M> 1 mparm2 5 frames 1.0 tint
M> fmi                                        (flip mirror in)
M> mspect                                  (tertiary mirror in)
M> object                            (prompts for object name)
   sky_flat
M> typ                                    (prompts for image type)
   f                                        (chooses Flat from list)
```

7.3.2 Doing K and K_s Flats

Once the setup from Section 7.3.1 is done, perform the following steps.

```
M> /k                        (do K first, for sky brightness reasons)
M> goi dcp goi dcp goi dcp          (3 makes for good combine)
M> cu                  (enter cursor mode, and check level of slit)
```

If the slit level reads more than about 15,000, there may be saturation problems. Saturation is at 20,000[1]. Try cutting the integration time to 0.500 or 0.375 if saturation is a problem. Saturated sky flats will do you no good.

```
   Leave cursors #0 and #1 on different slits.
q                                              (to quit cursor mode)
M> /ks
M> goi dcp goi dcp goi dcp                (another series for K_s)
```

Check that level is good (5,000–10,000 is optimum). If the two cursors are already on slits, you can read off values from each image as it is displayed. Adjust the integration time if necessary.

[1] The saturation value of 20,000 is for D80, with CSCALE set correctly

Now close the mirror cover for the "off" images.
`M> goi dcp goi dcp goi dcp` (off series for K_s)
Note the level of the "off" slits and compare to "on" value.
Set `tint` to the value used for the K flats.
`M> /k`
`M> goi dcp goi dcp goi dcp` (off series for K)
Again, check levels and compare to "on" values.

If the levels of the "on" slits (mirror cover open) are lower than the "off" slits (mirror cover closed), then the sky wasn't bright enough thermally in comparison to the mirror cover. Try again the next night (or morning). Unless going on to do J and H flats, perform the clean-up activities in Section 7.3.4.

7.3.3 Doing J and H Flats

Imaging flats for J and H are easier in the sense that the mirror cover is never brighter than the sky, especially during twilight. But it may be necessary to wait 10 minutes or so for the sky to get dark enough to image without saturating. First, be sure that the steps in Section 7.3.1 have been done.

Open primary mirror cover
`M> /h`
`M> 0.375 tint` (as short as it gets)
`M> goi dcp goi dcp goi dcp` (3 makes for good combine)
`M> cu` (enter cursor mode, and check level of slit)

If the slit level reads more than about 15,000, there may be saturation problems. Saturation is at 20,000[2]. If saturation is a problem, wait a few minutes for the sky to darken (evening twilight). If the counts are low, increase the tint accordingly. A good target level is 5,000–10,000 dN.

Leave cursors #0 and #1 on different slits.
`q` (to quit cursor mode)
`M> /j`
`M> goi dcp goi dcp goi dcp` (another series for J)

Check that level is good (5,000–10,000 is optimum). If the two cursors are already on slits, you can read off values from each image as it is displayed. Adjust the integration time if necessary.

Now close the mirror cover for the "off" images.
`M> goi dcp goi dcp goi dcp` (off series for J)
Note the level of the "off" slits and compare to "on" value.
Set `tint` to the value used for the H flats.
`M> /h`
`M> goi dcp goi dcp goi dcp` (off series for H)
Again, check levels and compare to "on" values.

[2]The saturation value of 20,000 is for D80, with CSCALE set correctly

Once done with flats, clean up the configuration as suggested in Section 7.3.4.

7.3.4 Cleaning Up

After finishing with the flats, here are a few items that will put the camera back into an orderly state:

```
M> 1 frames                          (be sure to remember this!)
M> 10. tint                          (a reasonable default value)
M> 16 mparm2 16 cscale
M> lu lc                        (Unlock and close secondary lid)
M> /77k                                          (put in blocker)
M> /o                  (move tertiary out to protected position)
```

The last three command lines can be accomplished more expediently with the `/end_night` command.

7.4 Typical Object Observation

This is what you're at the telescope for—not for dome flats and dark frames. Calibration techniques are covered in subsequent sections. Several mock observations are spelled out below, with an attempt to cover most likely scenarios. What follows is at least a fair portrayal of my typical observing sessions.

7.4.1 Getting There

Much of the time, the object to be observed is faint, and will not show up prominently in the center field camera. If this is the case, it helps tremendously to first point at a nearby SAO star. If your object is bright, this step may be skipped.

Provide the object coordinates and desired ring angle to the night assistant. For faint objects, ask to go to a nearby SAO star first. The star can be used both to fine-tune the pointing, and to check and adjust telescope focus.

While the telescope moves, it is a good time to enter guide star information. See Section 7.4.2 for more on this.

At the SAO star, center up on the crosshair (use the correct crosshair; see Section 6.4), and ask the night assistant to "TX", or issue a "temporary X" command. Focus if necessary, writing down the new value when done.

Now make the short hop over to the object.

7.4.2 Start Guiding

Enter the guide star information into Mirella. If our guide star has offsets from the object of 63.7″ West and 120.2″ North, then enter:

```
M> -63.7 120.2 og/r                  (put in guide star offsets)
```

This moves the guider into position, and prints guide head information to the terminal screen. Get the `HEAD` angle from this information and put it into the MINC guider computer. Also enter the secondary angle into `F70A`.

```
minc$ HEAD 332
minc$ F70A 0
```

After the telescope move is complete, if the Cassegrain ring angle has changed, update the guider with:

```
M> og                                    (update guider position)
```

It's not a bad idea to do this anyway, as it ensures that the guider is where you told it to be. Turn up the gain on the guider Quantex and behold your guide star.

Adjust gains and other guider parameters (Section 5.7), then start guiding:

```
minc$ GO                                 (or some variant thereof)
```

7.4.2.1 No Guide Star

If the guide star does not appear, first do an `og` command, and check the output to verify that the input coordinates are what you intended.

Next try finding the guide star in the center field camera, by "sending" the star over, centering up, then "sending it back".

```
M> /o                                    (if the tertiary mirror is in)
M> -63.7 120.2 mt (move telescope to alleged guide star position)
```

Now turn up the gain on the center field camera, and look for the star. Sometimes it helps to already be looking at the TV when the telescope motion is executed, by virtue of the fact that sometimes the motion makes it easier to see. If the star is visible, center it on the crosshair. If not, check coordinates, etc. or pick another guide star if available. In any case, you'll want to send the telescope back to the starting position.

```
M> 63.7 -120.2 mt   (up arrow to last mt and negate arguments)
```

If the guide star was centered in the center field (and the crosshairs are a fair representation of the guider origin—see Section 6.4), then it should now appear in the guider camera. Of course it may be too faint, in which case refer to the next section.

7.4.2.2 Faint Guide Star

In the case of a faint guide star, the first thing to realize is that if you can see it on the screen, the guider can guide on it. Turn the Quantex gain all the way up. If more is needed, try messing with averaging or integrating on the Quantex (see Section 6.1).

If the guide star is very faint, but visible, turn off tip-tilt (either with gains or with `GO 5`—see Section 5.7) and adjust `AGG` to a low value.

7.4.3 Find and Center Object

7.4.3.1 Take the First Image

If the guide star offsets are correct, and the guider is guiding on the star, then the object should be squarely within the PIFS field. So let's find out.

```
M> object                          (prompts for object name)
   IR1019
M> typ                             (prompts for image type)
   obj                             (selects Object from list)
M> mspect[3]                       (put tertiary in)
M> fmi                             (flip mirror in for imaging)
M> /ks                             (choose K_s for imaging)
M> 10. tint
M> 100. node                       (100'' East nod)
M> snapi sdiff                     (get object/sky pair and display)
```

What is displayed on the screen is the sliced-up image of the current field of view. Figure 7.3 shows the appearance of the slit image for the initial pointing position. Refer to Chapter 2 for a description of the slit pattern. The display convention for Mirella is black=positive flux, white=negative flux. If the object is reasonably bright, the slits should show some black patterns within them. Figure 7.4 displays the reconstructed field of the slit image portrayed in Figure 7.3.

7.4.3.2 Interpreting the Sliced Image

A mental re-assembly of the slit may seem a hopeless task, but it is really not so bad. Left is always left, and up is always up. All that is required is simple left-right translation of the sub-slits to align them into a single column. Doing so will put the lower-far-left on the bottom, the lower-far-right directly above it, the lower-middle-right above that, and so on. The pattern ends when the upper-far-right is placed on top of the stack. See Section 2.3 for more information on this, and Figures 2.1 and 2.2.

For centering, it is most important to recognize that the two central slits appear at lower-middle-left and upper-middle-right. If a compact source is seen equally in these two, and centered left-right within these slits, then the object is well centered in the PIFS field.

But this approach is not always good enough to really tell where things are within the field, and a reconstruction algorithm is sought. For this purpose, I usually have a SPARC station set up to the right of the observing station that slurps over data frames as they become accessible. Then I run the IDL program `deslice.pro` or `redo.pro` to reconstruct the two-dimensional image. See Appendix E for more on this procedure.

[3] You are bound to forget this step at least once during the run. If you can't seem to find *anything* in the sky, check this mirror. Let the log sheet guide you.

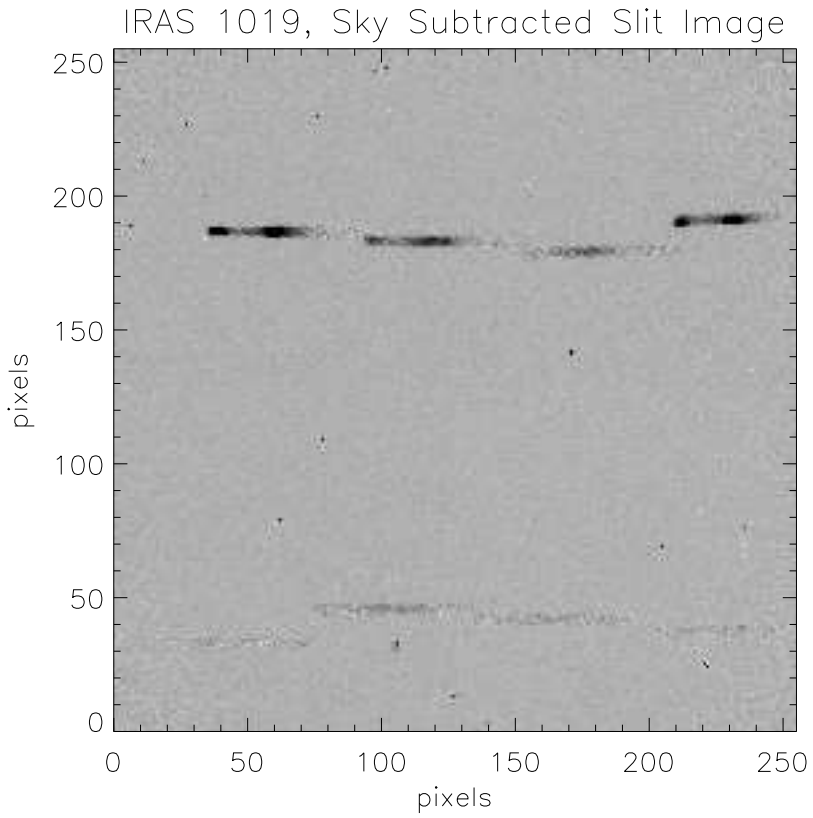

Figure 7.3: A sky-subtracted slit image revealing the initial position of the object within the PIFS field.

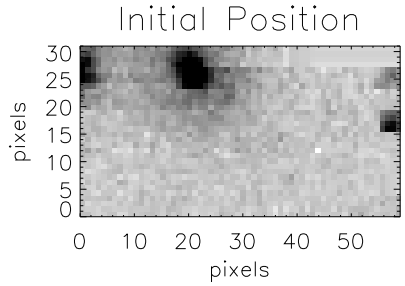

Figure 7.4: Reconstructed field from Figure 7.3. The object needs to be moved to the right and down to be centered.

7.4.3.3 Positioning the Object

For most purposes, you will want the object centered within the PIFS field for maximal coverage. This strategy, however, will require separate sky integrations for sky subtraction, doubling the observing time and introducing the effects of fluctuating sky (i.e. OH line) levels. But for many objects there is no way around this, given the field of view. In these cases, centering the object is simple.

Compact objects may be dithered around the field, with a suggested two-position diagonal pattern. I recommend upper-left to lower-right dithering, as field coverage is best here.

Determine how many pixels the object is away from its desired position, keeping in mind that slits are approximately 60 pixels long and 4 pixels wide. For instance, if the object appears to be approximately 2/3 of the way along the slit from left-to-right, and sitting squarely in the third slit up (lower-middle-right), then the object needs to move about 10 pixels to the left and 6 pixels up to be centered. For the example shown in Figures 7.3 and 7.4, the appropriate motion is about 20 pixels to the right, and 14 pixels down.

```
M> 20. -14. 65. mvpix    (20 pixels right, 14 down for 65° ring)
M> goi wait odiff              (using previous sky from snap)
```

Don't be alarmed by the appearance of a message that the guider is locked off, and no action is taken. This simply means that the guider is shut off during the move. As long as the stripchart resumes operation, guiding is functioning normally. Do this moving around until satisfied with how the object is framed, sometimes using snaps to get new sky images. Figure 7.5 shows the centered slit image, and Figure 7.6 is a reconstruction of the centered object within the PIFS field.

Once satisfied with the position, type `og` and *write down* the OGX and OGY coordinates of the offset guider. These appear on the screen as `Guider X =` OGX and `Guider Y =` OGY entries. This information becomes be invaluable if you loose track of your motions.

7.4.3.4 Faint Objects

Faint objects may not be visible in a 10 second exposure. Try longer exposures, but be careful not to saturate. Look at the 10 second raw image (`dlp` or `dp` commands) and use cursor mode to measure data values on the slit. This will guide your decision regarding how long it will take to saturate. If CSCALE is set correctly (see Section 5.3), then saturation is at 20,000 dN, so aiming for 10,000 dN is not a bad idea.

If longer integration is not revealing the object, and if this object has an emission line feature, it may be possible to see using the narrow bandpass (1.3%) CVF, which operates from 2.0–2.5μm. Even the 5% CVF, running from 1.5–3.0μm may help.

```
M> 90. tint
```

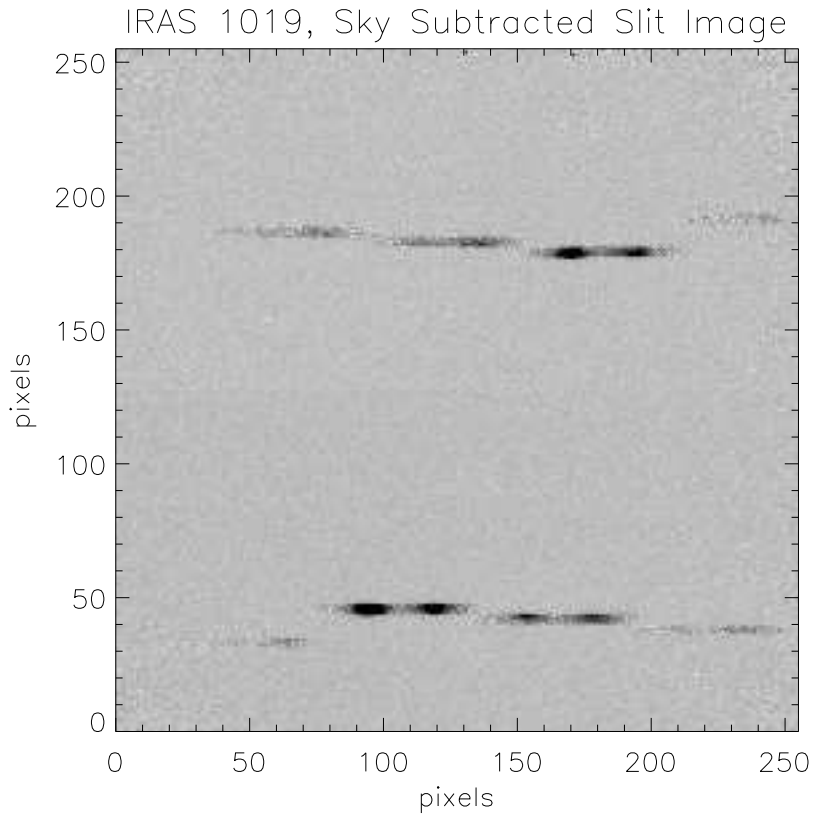

Figure 7.5: Slit image of centered object. Note the left-right "centeredness" within each slit, and the equal distribution between the upper and lower fields.

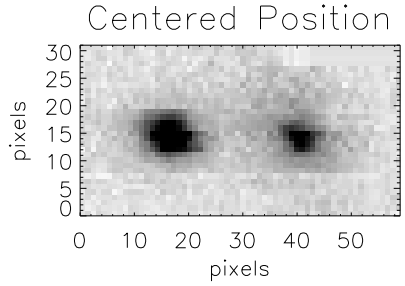

Figure 7.6: Reconstruction of slit image from Figure 7.5. Note that the object is now well centered in the field.

```
M> 2.345 cvf1                    (1.3% CVF tuned to 2.345μm)
M> goi dcp
Check level of slit to verify no saturation
M> gsky sdiff      (performs second half of a snap and displays)
```

Integration times can be much longer with the narrow CVF (`cvf1`), perhaps up to 300 seconds.

The other approach is to use a blind offset from a reference star. The PIFS field is large enough that this technique is virtually guaranteed to get the object into the PIFS field. Assuming that the reference star is close enough that the same guide star is accessible, here's what you do:

```
M> 10. -15. mtg          (reference star 10″ East, 15″ South)
M> 10. tint                                (longer if necessary)
M> /ks                                        (or other filter)
M> snapi sdiff
If you see the star, center it:
M> 13. -3. 90. mvpix                                (for example)
M> goi wait odiff                              (verify position)
M> -10. 15. mtg                                (offset to object)
```

Now if the reference star offsets are worth their salt, the science target should be comfortably within the PIFS field. If the reference star never was visible, check coordinates, equinox, etc.

7.4.4 Spectra

Satisfied with the object position, it is time to take some spectra. In this example, we will get a set of high-resolution data around 2.018μm, another high-resolution set around 2.283μm, and a low-resolution set at 2.099μm. Let's say the Cassegrain ring angle is set to 32°.

7.4.4.1 Dither Patterns

The PIFS field has an inherent asymmetry in its spatial resolution properties. Along the slit direction, one recovers the seeing-limited spatial resolution with each integration. The cross-slit direction, however, is coarsely chopped into eight 0.67″ chunks. These chunks act like coarse pixels in the cross-slit direction. Therefore the Nyquist spatial resolution for a single integration is 1.33″ in the cross-slit direction. The seeing is often better than this, and one would like to recover this spatial resolution.

Each slit is four pixels across. Two pixels is the minimum requirement for Nyquist sampling in the spectral direction. The choice to use D80 in a modular way resulted in a fixed pixel scale, and a two-pixel wide slit would have been needlessly narrow, and would have restricted the field of view to half its present value. In either case, the asymmetry is unavoidable. A one-pixel wide slit would

avoid spatial asymmetry, but would have lead to under-sampled spectra, and an even smaller field of view.

If seeing conditions are moderately stable, then a careful dither pattern allows recovery of the cross-slit spatial information. A four-step dither pattern is needed to fully recover the pixel scale in the cross-slit direction, as each slit (crude pixel) is four pixels across on the array. Rather than do a 1-2-3-4-1- pattern, patterns such as 1-3-2-4-1- or 1-2-4-3-1- are preferable, as adjacent integrations are maximally separated from neighbors in the base-4 system (1 is next to 4). Such a pattern offers the greatest immunity to seeing variations, as the coarse scales get priority attention.

Since objects typically start out centered, it is probably best to dither *around* this position rather than away from it. Therefore shifts in the y-pixel direction ought to be positive and negative. The best strategy to avoid confusion is to pick something and go with it. As such, I'll go with the 1-3-2-4 pattern, starting at the "2" position, thus the moves will go like: (0)-(+2)-(−1)-(+1), etc. The zero position (or first position) will refer to the start position.

Dithering in the x-direction could also be advantageous from the perspective that bad pixels have less of an effect on the final product if the pixel pattern is moved around with respect to the object. Here, a 3-cycle pattern may be recommended to be somewhat incommensurate with the cross-slit dither pattern. I will carry this convention through this section, but it is not a necessary part of the process[4]. The full 2-d dither sequence, done in this manner, will have the following (x,y) pairs: (0,0); (2,2); (−2,−1); (0,1); (2,0); (−2,2); (0,−1); (2,1); (−2,0); (0,2); (2,−1); (−2,1); (0,0); etc.

7.4.4.2 Integration Time

I almost always use a 300 second integration time for spectra. Sometimes I'll go to 450 seconds. While I can't rigorously justify my choice, I think it offers a reasonable balance between factors such as: read noise, cosmic rays, atmospheric transparency variation timescale, seeing variation timescale, and OH skyline variation timescale. All but read noise argue for shorter times. In the K band, especially beyond 2.2μm, a 300 second integration time definitely is in the background-limited regime. I'll more often opt for 450 seconds in the H or J bands. Keep in mind that if trying to carefully reconstruct two-dimensional spatial information, the longer the time between successive integrations, the more susceptible you are to problematic variation. Also remember that often there is a lengthy sky integration sandwiched between adjacent object integrations as well. Of course if the conditions are completely stable, many of these factors wane in importance—so integrate for however long you want.

[4] As of the first writing (March 1999), I had only used PIFS for a sum total of 8–9 hours, under unfavorable conditions. I had not been dithering in x, yet had no problems reconstructing images.

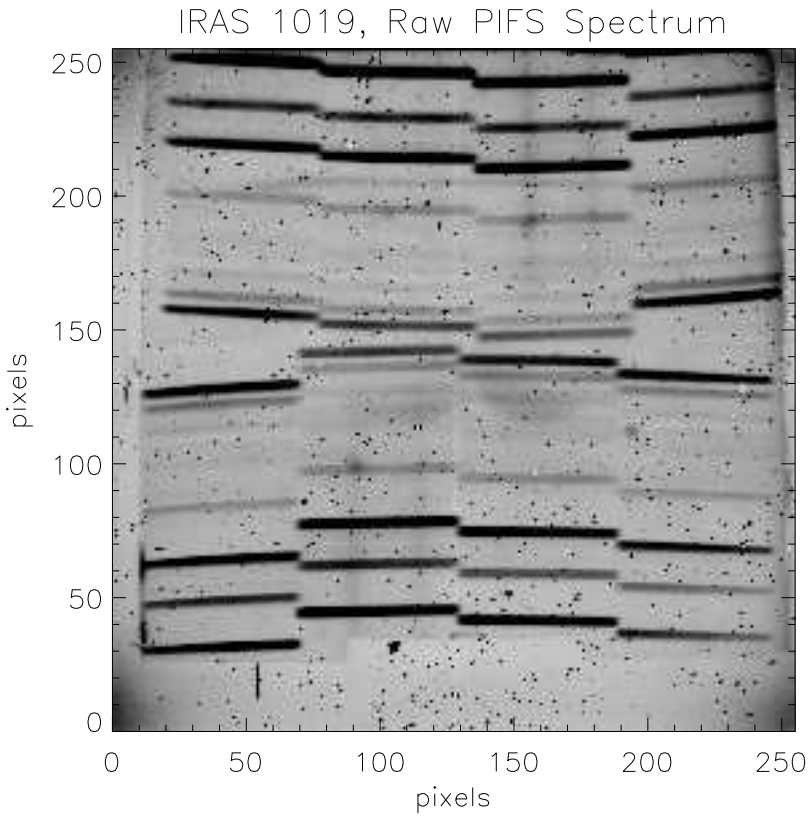

Figure 7.7: A raw spectrum. The faint continuum can be seen as vertical stripes in slits 4 and 5, but the spectrum is dominated by sky emission—note the very strong OH emission lines in every slit.

7.4.4.3 A Sample Series

```
M> object                          (prompts for object name)
   IR1019
M> typ                             (prompts for image type)
   obj                             (selects Object type from list)
M> 300. tint
M> 2.018 hires                     (sets grating, filter, flip mirror)
M> goi dcp
```

Now you're off and running. If you want to regain a prompt, hit CTRL-C and answer yes to the insulting question. If you do interrupt, `dcp` will not be executed. Otherwise, the raw spectrum will be displayed as soon as available, looking like the image seen in Figure 7.7. In what follows, it is extremely helpful to record all motions (or offsets) so that a reconstruction of events can be made

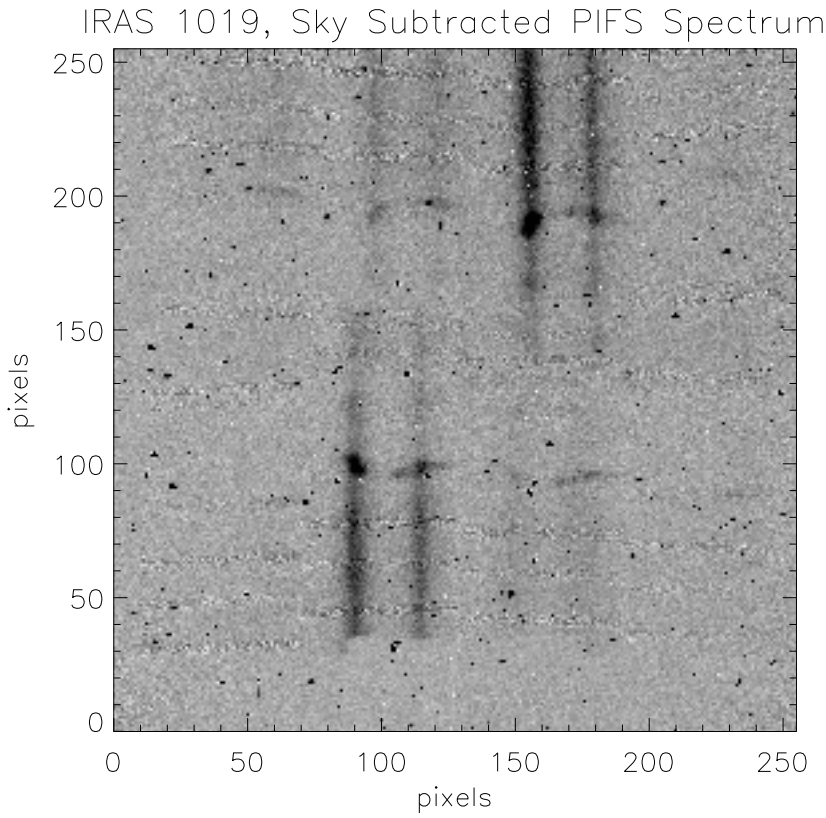

Figure 7.8: The sky-subtracted spectrum shows clearly the continua of the two nuclei, and the spatially extended Paα line is also prominently seen. Note the interesting velocity information present in the Paα emission as well.

later. The "Offset" column in the log sheet is for this purpose, and greatly aids data reduction.

```
M> gsky sdiff    (grab sky at nod position and display difference)
```

Figure 7.8 displays the much improved sky-subtracted spectrum, with the Paα line blazing through, appearing in every slit. Note the fine velocity information seen here as well.

```
M> 2. 2. 32. mvpix              (at position (2,2) → record this)
M> goi wait odiff             (expose and subtract previous sky)
M> 120. 0. 32. mvpix        (manually moving to a sky position)
M> goi wait sdiff -120. 0. 32. mvpix     (expose and return)
M> -4. -3. 32. mvpix        (at position (-2,-1) → record in log)
M> goi                                          (expose object)
```

```
M> wait odiff 50. 0. mtg          (manually move with mtg)
M> goi                                          (expose sky)
M>                      (no wait or dcp → got prompt back)
M> wait sdiff -50. 0. mtg             (difference and return)
M> 2. -1. 32. mvpix              (at position (0,1) → record)
M> goi wait odiff          (expose and subtract previous sky)
M> gsky sdiff    (get sky at nod position and display difference)
M> 0. -1. 32. mvpix                   (back to (0,0) position)
```

This sequence took 4 object/sky pairs, taking about 45–50 minutes with overhead. The object is back in its original position and ready for another round at a different wavelength. Before changing the grating, we'll get lamps. It is also advisable at this time to obtain a measure of the PSF (see Section 7.5 for how to do this).

```
M> /o        (take mirror out, using mirror cover as lamp diffuser)
M> 10. tint
M> 1 1 1 1 lamp            (all lamps on, watch Quantex gain)
M> goi dcp
M> lampoff                        (remember to turn lamps off)
M> goi wait sdiff
M> mspect                                          (don't forget!)
```

That's it for lamps. Looking at the plot of lamp lines, there were no obvious overlaps in this wavelength range, so all lamps come on.

Now let's do the next sequence of spectra. This time, sky frames will be taken via the **gsky** routine. Comments will be much more sparse for the next sequence.

```
M> 300. tint
M> 2.283 hires
M> goi
M> dcp
M> gsky sdiff
M> 2. 2. 32. mvpix                                    (at (2,2))
M> goi wait odiff
M> gsky sdiff
M> -4. -3. 32. mvpix                                 (at (-2,-1))
M> goi
M> wait odiff
M> gsky sdiff
M> 2. 2. 32. mvpix                                    (at (0,1))
M> goi wait odiff
M> gsky sdiff
M> 0. -1. 32. mvpix                                (back to (0,0))
M> /o
M> 10. tint
```

Make sure Quantex gain is down.

```
M> 1 0 1 1 lamp     (possible conflict between neon and krypton)
M> goi dcp
M> krypton
M> goi dcp
M> lampoff
M> goi wait sdiff
M> mspect                                          (don't forget!)
```

With that observation done, you may want to get a PSF now. See Section 7.5 for how. Now let's do the final sequence, using the low-resolution grating, and using `mtg` this time for sky positions.

```
M> 300. tint
M> 2.099 lowres
M> goi
M> dcp 60. 0. mtg
M> goi wait sdiff -60. 0. mtg
M> 2. 2. 32. mvpix                                    (at (2,2))
M> goi wait odiff 60. 0. mtg
M> goi
M> wait sdiff -60. 0. mtg
M> -4. -3. 32. mvpix                                  (at (-2,-1))
M> goi
M> wait odiff 60. 0. mtg
M> goi
M> wait sdiff -60. 0. mtg
M> 2. 2. 32. mvpix                                    (at (0,1))
M> goi wait odiff 60. 0. mtg
M> goi wait sdiff -60. 0. mtg
M> 0. -1. 32. mvpix                                   (back to (0,0))
M> /o
M> 10. tint
M> 1 1 1 1 lamp (no obvious lamp conflicts, watch Quantex gain)
M> goi dcp
M> krypton
M> goi dcp
M> lampoff
M> goi wait sdiff
M> mspect                                          (don't forget!)
```

Again, this would be a good time to grab a PSF measurement. The disadvantage of the previous sky technique using `mtg` is that arbitrary moves might not be possible given the location of the guide star.

7.4.4.4 All Done?

If you're done with this object, you'll need to obtain a G-star calibration. See Section 7.7. It may also be a good time to grab a photometric standard, as described in Section 7.6.

If done for the night, don't forget to type `/end_night` to protect various hardware.

7.4.4.5 Additional Notes

Alternate sky methods include `mvpix` (as illustrated in first sequence), and `snapi` (for the pair at once). If using the `snap` method, be prepared to wait a while before seeing anything, as intermediate results are not displayed.

Lamps are always a good idea, because even if there are OH lines in the raw spectrum, not all those lines are reliable wavelength calibrators on account of being blends of two nearby lines. Lamps will provide backup calibration, and are quick and easy to do. Just remember to move the tertiary mirror back in after the lamp spectrum.

The science integration times are often very long, and quite often there are things you want to do while integrating—such as display previous images, or change the stretch of the display (see `lindisp` in Section 5.5). Therefore it is nice to have a prompt available for these tasks. For this reason, I prefer a plain `goi` command to a `goi dcp` or `goi wait odiff`, or the like. When there are only 30–60 seconds left in the integration, I'll type the display and move command, such as `wait odiff -60. 0. 90. mvpix`, then hit return. The `wait` command keeps the `odiff` and `mvpix` commands from being processed until the exposure is finished. If you wait until the exposure is finished before typing the display and move commands, photons are hitting the floor while you type. Sure, it's only a 5–10% effect, but I for one like to leave the telescope thinking I wasted no time and got as much data as I could have in the available time.

7.4.4.6 The Final Product

To illustrate the kind of data that the PIFS delivers, the example galaxy used throughout this cookbook section is shown in its reduced form. Figure 7.8, which represents a single object-sky pair, is fraught with cosmic rays, and lacks the signal to really see the structure of the Paα emission line gas. Figure 7.9, however, has been cleaned, straightened, and represents 40 minutes of on-source integration time. In this figure, the eight spectra have been arranged side-by-side in sequence. Wavelength increases upwards, and clear spatial extent and velocity structure of the Paα emission are seen in the two-dimensional spectra.

As an example of what can be extracted from PIFS datacubes, Figure 7.10 shows the same galaxy that appears in Figure 7.9 in various wavelength slices of the datacube. Shown in the figure is a pure continuum image, a pure Paα line image, plus two velocity cuts of the same line emission data.

The velocity bins chosen for Figure 7.10 are coarser than the 230 km s^{-1} resolution element of the PIFS in high resolution mode. And it is obvious from

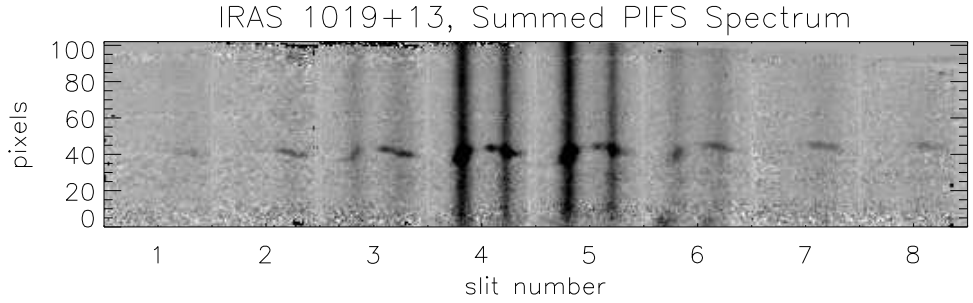

Figure 7.9: Two-dimensional spectra of the ultraluminous infrared galaxy IRAS 1019+13, showing the eight longslit spectra reorganized into a sequential strip. Wavelength increases upwards. The central two slits (4 & 5) each show strongly the double-nucleus continuum. Note that Paα shows up in all eight slits on the right-hand source.

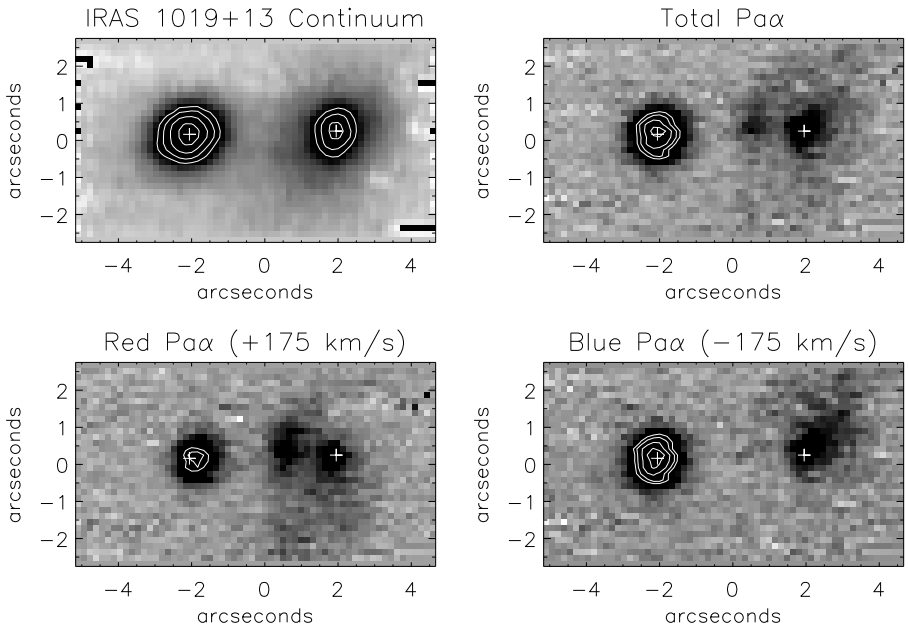

Figure 7.10: PIFS data of the double-nucleus ultraluminous infrared galaxy IRAS 1019+13, shown in pure continuum and continuum-free Paα. Note the isolated clump of line emission in the red Paα image, with no continuum counterpart. Note also the very diffuse velocity-differentiated gas surrounding the source at right. Crosses mark the continuum peak positions. The velocity-binned images are each 350 km s^{-1} apart and 350 km s^{-1} wide.

Figure 7.9 that far more information is present in the datacube than is presented in Figure 7.10. Beware that the images in Figure 7.10 have been flipped about the vertical axis such that east lies 90° *counter-clockwise* of north—the conventional orientation. As such the ordering of slits is opposite that depicted in Figure 2.2. For the present figure, slit one is at top, and slit eight at bottom.

7.5 Obtaining the PSF

A PSF image is the best way to get a measure for the local current seeing condition. I try to get a new measure every 30–45 minutes. In addition to seeing variability, telescope focus changes as a function of temperature. PSF images therefore facilitate the assessment and adjustment of focus.

7.5.1 Setting Up for PSF image

I'm assuming here that the camera and spectrograph are set up in the spectral configuration. If set up in imaging mode, much of the following will already be configured.

```
M> 10. tint      (at least 10 sec. to average short time variations)
M> fmi
M> /ks           (or filter best covering current wavelength tuning)
```

7.5.2 Guided PSF Image

The most desirable scenario is to have a PSF star within 200″ of the current guide star such that the same guide star can be used, and an `mtg` command is all that is needed to get to the PSF star. Look at the list of guide stars, and see if there are any other stars near the guide star. A good first indication is position angle to the guide star (from the main object). This information is one of the items in Gerry's `guide` program output (see Section 1.3.2). Potential guide stars with similar position angles are almost sure to be accessible. If nothing turns up in the list, look at the finder chart that you have hopefully made (Section 1.3.5) for a star within 200″ of the guide star. If the scale of the plot is some convenient fraction (e.g., 0.3 mm/arcsecond), then obtaining offsets (from the main object) is a simple task.

If both methods fail to turn up a PSF within range of the current guide star, there are two options available: either switch to a different guide star within reach of another star, or move the telescope to the current position of the guide star and take an unguided image of the thing.

7.5.2.1 Using Current Guide Star

This is the best of situations, requiring the minimum effort and having the best chance of not getting off track.

Before moving anywhere, type the `og` command, and write down the OGX and OGY coordinates of the offset guider in the current (home) position. Should you loose track of moves, this info will help guide you back home. This information is reported on the screen as `Guider X =` OGX, for example.

For this example, we pretend that the guide star OGX and OGY (offsets from home) are (42.7, 145.2), and the PSF star has offsets of (−23.1,125.4). One note: comparing the guide star offsets with the list values may indicate a coordinate offset that, if applied to all stars on the list will give improved pointing accuracy.

Stop the guider (hit <RETURN> on the MINC), then type in the move command.

```
M> -23.1 125.4 mtg
Note the HEAD angle reported on the screen
minc$ HEAD 73                          (73° for this example)
minc$ GO                           (once guide star is visible)
M> snapi sdiff
M> 2.018 hires          (current λ setting should not actually
                        move grating, just filter and flip mirror)
M> snapi sdiff
minc$ <RETURN>                                  (to stop guiding)
M> 23.1 -125.4 mtg      (can up-arrow then edit previous mtg)
Check reported guider position with home position (OGX,OGY)
minc$ HEAD 16              (set back to original HEAD angle)
M> 300. tint
```

In this example, and the ones that follow, a spectral PSF is also illustrated. I have not had much experience with this, but this is an imaging spectrograph. One might as well measure the PSF in the primary observing mode. You could even get fancy and dither several such exposures, but it's not clear this is really necessary, unless the seeing is fantastic and the star only appears in one slit!

If additional moves were made in the process of finding the PSF star, be sure to reverse each of those motions. In the end, verify guider position with that recorded prior to the moves.

7.5.2.2 Switching Guide Stars

This is the second-choice scenario, but is sometimes necessary. It is similar to the previous example, but with a few extra bits at beginning and end.

Before moving anywhere, type the `og` command, and write down the OGX and OGY coordinates of the offset guider in the current (home) position. Should you loose track of moves, this info will help guide you back home. This information is reported on the screen as `Guider X =` OGX, for example.

For this example, we pretend that the guide star OGX and OGY (offsets from home) are (165.2,-16.9), and the PSF star has offsets of (220.6,40.7). Note that the PSF star is too far out to be used as a guide star for the object, but is within reach of the chosen guide star—on the other side of it. This often happens.

Stop the guider (hit <RETURN> on the MINC), then type in the move command.

```
M> 165.2 -16.9 og/r                    (move guider to new star)
```
Adjust gain on guider Quantex.
```
minc$ HEAD 96
minc$ GO                               (once guide star is visible)
minc$ <RETURN>        (now with star locked in, shut off for move)
M> 220.6 40.7 mtg
minc$ HEAD 224
minc$ GO                               (once guide star is visible)
M> snapi sdiff                                    (get PSF image)
M> 2.018 hires              (current λ setting should not actually
                          move grating, just filter and flip mirror)
M> 30. tint
M> snapi sdiff                                (get PSF spectrum)
minc$ <RETURN>                                  (to stop guiding)
M> -220.6 -40.7 mtg                           (reverse ALL moves)
M> 42.7 145.2 og/r           (move guider back to original star)
```
Adjust gain on guider Quantex.
```
minc$ HEAD 16
minc$ GO                               (once guide star is visible)
M> 43.2 144.8 og/r          (revise position as per OGX, OGY
                           recorded previously for home position)
```
Check that guider update did not loose guide star.
```
M> 300. tint
```

Again, reverse any and all motions performed in search of the PSF. This will ensure that you get back to your home position with minimum fuss. The importance of recording the home position's OGX and OGY values cannot be stressed enough. This saves the effort of re-finding the object and re-centering it. Once guiding at the same-old OGX and OGY, you can be assured that the object is right where you left it.

7.5.3 Unguided PSF Image

In the unfortunate situation that no PSF stars are available from nearby guide stars, You'll have to go-it unguided. Though the integrations are short and tracking errors are non-existent, you are more vulnerable to wind shake and image wander. These are really only concerns if using the tip-tilt guider. Otherwise the main spectroscopic observations are subject to the same influences. The bottom line is that you want the PSF measure to be as representative as possible of the science observation PSF. Thus try as much as possible to use the same guiding method for both.

And yet again, before moving anywhere, type the `og` command, and write down the OGX and OGY coordinates of the offset guider in the current (home)

position. Should you loose track of moves, this info will help guide you back home. This information is reported on the screen as `Guider X =` OGX, for example.

Probably the lowest brain-power approach is to offset the telescope to the guide star. At least you know this star exists, and that it is indeed a star (not just some unidentified entry in the guide star list—which can cause problems occasionally).

Stop the guider, then type in the move command:

```
minc$ <RETURN>                          (stop guider before move)
M> 43.2 144.8 mt    (use the actual recorded OGX, OGY offsets)
M> snapi sdiff
M> 2.018 hires            (current λ setting should not actually
                          move grating, just filter and flip mirror)
M> snapi sdiff
M> -43.2 -144.8 mt                        (reverse ALL moves)
minc$ GO                                     (resume guiding)
M> 300. tint
```

In this case, the guider was never moved, so no adjustment is necessary. Once guiding again, the object is assured to be right where you left it.

7.5.4 Using PSF to Focus

The center field camera is parfocal with the PIFS, so in general focusing via the center field camera is perfectly adequate for getting the array focused. However, in conditions of great seeing, there may be advantage in focusing via the array images. Another scenario that often arises is the recently acquired PSF image shows some obvious shortcoming. In this case, since everything is already set up for PSF imaging, it often makes sense to focus in this mode. This section offers hints pertaining to efficiently performing a focus in this manner.

Firstly, focus adjustments should always be made in the same direction, as there is some backlash in the mechanical device. I usually come up from the bottom (out?), such that the focus number increases. Increments of 0.1 mm seem to be sufficient in practice. Typical values may lie around 64–65 mm.

Being sliced up as it is, direct evaluation of the PSF shape is not easy. If running the SPARC auto-`ftp` process, these images are best evaluated using the reconstructing IDL routine. See Appendix E for more on this.

There isn't too much new to say about imaging here, since this should be relatively familiar by now. But I have a few suggestions for making the process efficient.

Let's say the next frame number is 101. A `snap` command will take an object frame with frame number 101, and frame 102 will be the sky frame. The following one-liner command will take each new data-point in the focus run:

```
M> goi wait lastfile 102 pdiff 0 3000 lindisp
```

The values for lindisp may need adjustment, but you get the idea. A simple up-arrow after each new focus setting recalls this command for immediate re-execution. Makes it fast.

Don't forget to write down each focus setting (i.e. very small in the comment field of the log sheet).

If this concludes the nights activities, remember to enter the `/end_night` command, placing various pieces of hardware into their protected positions.

7.6 Standard Stars

For photometric calibration, it is necessary to obtain an image (or several) of a photometric standard star in each filter band being used. Preferably, several standard stars will be imaged through the course of the night. I have to honestly say that I have not yet performed any real photometric calibration with the PIFS, aside from a simple throughput test. So take the following suggestions with a grain of salt.

For the HNA[5] longslit data, I would simply image these stars in broad-band filters, and tie the flux to the continuum images of the science objects, then assign the continuum flux density to the continuum in the spectrum. This works okay, within the limits of longslit photometry. But PIFS is an imaging spectrograph, so it may make sense to take standards in spectral mode for a more direct comparison with the data. Both imaging and spectral standard methods are covered here. For standard selection, see Section 1.4.2 or Appendix C.

I won't assume anything here about the current configuration, so some of the below steps may not be necessary. We'll start out after the telescope move is complete.

```
M> /o                                   (get tertiary out of the way)
Locate star in center field and center on crosshair
M> mspect
M> object
   std_9155
M> typ
   cal
M> 10. tint
M> 16 mparm2 1 frames 16 cscale                (if necessary)
M> fmi
M> /ks                                         (or other filter)
M> snapi sdiff
```

Center star if necessary. This is easy without focal plane reconstruction for a star. Simply adjust for equal top-bottom contributions, and centered left-right in each slit. Multiple exposures at each filter may be desirable for statistical purposes.

[5] The IR spectrograph built by James Larkin and Rob Knop, which unfortunately Has No Acronym.

```
M> /k
M> snapi sdiff
And so on...
M> 30. tint
M> 2.018 hires                    (previously used setting)
M> snapi sdiff
M> 2.155 hires                    (center of K_s band)
M> snapi sdiff
M> 2.220 hires                    (center of K band)
M> snapi sdiff
M> 2.155 lowres
And so on...
```

If this is the last thing for the night, remember to execute the `/end_night` command, which places the hardware into a protected state.

I'm not yet sure whether or not it is sufficient to get spectra at the center of the bandpass (as this corresponds to the magnitude reference point). So with the idea that once back home, it is impossible to re-do a calibration, one may as well get spectra at each of the used wavelength settings. At 90 seconds a pop (with overhead), this isn't too bad.

To do an accurate spectrophotometric job, it may be necessary to get a G-star spectrum to calibrate the standard spectrum! Calibrating a calibrator! What have we gotten ourselves into? Do this if you like, probably once is enough. The time it takes to do a G-star calibration is large (7 minutes plus about that much overhead for the initial setup).

7.7 G-star Calibration

Perhaps the most difficult procedure encountered while observing with the PIFS is the G-star calibration spectrum. This is hard because the G-star is also used as a spectral flat-field in addition to its primary use as a calibrator for the atmospheric throughput function. For more about this, refer to Section 1.4.1 and Section 7.2.

The first step in this process is G-star selection, which I usually do 10–15 minutes before dropping off of the science object. Look at the current LST, and add the amount of time yet to spend on the object, adding any time for a PSF measurement. Add some time for getting set up on the G-star, about 10 minutes (5 if you're an expert). Figure out which airmass (or airmasses) you will want calibration for, trying to stay within 5% for careful calibration. Anticipate motion of G-stars, and how fast their airmass will change. Sometimes it's better to wait an extra few minutes than to waste time on a missed airmass.

If using the analog computer (iso-airmass overlay on plot of positions, see page 11), set the meridian of the airmass overlay to the projected LST and find the closest star to the present telescope position with the correct airmass. The number next to the star (on my plot) is the star's HR number. The telescope

operator doesn't have this catalog, so look on the G-star list for the corresponding SAO number, which the operator can zip right to.

7.7.1 Preparation

While the telescope is slewing, do the following preparation:

```
M> object
   HR5853
M> typ
   cal
M> 10. tint
M> 2.018 hires                    (substitute with appropriate λ)
M> /o                               (experts may skip this step)
```

If the airmass allows, it is best to calibrate the last used grating setting first. This way, the `hires` (or `lowres`) command does not actually move the grating, and maximum reproducibility is achieved. If the grating has to move, then so be it.

7.7.2 General Procedure

Before doing anything else, get the chopper a-chopin'.

- Set the chop angle to equal the Cassegrain ring angle (Section 6.3).
- With the 20dB switch in the down position, select the triangle wave.
- Slowly turn up gain on center field camera Quantex and verify star in field.
- Unless chop amplitude has been set already, turn pot down to about 100, and flip the 20dB switch on. Verify that chop angle is right (horizontal on TV). Otherwise, simply flip the switch up to 20dB to get previous amplitude.
- Use paddle to move right tip of chopped star onto central crosshair. If the star is double, it may be necessary to resolve the ambiguity of which one is the G or late-F star. In some cases, it may be necessary to change the ring angle by about 90° to split the two. But as this changes the flexure-state, it is not recommended unless near the zenith.

The rest of the procedure is summarized below, and explained in great detail farther down.

- Move offset guider to the origin (0.0,0.0), which strips the guider of the "offset" designation, incidentally.
- Position endpoint of chop (edge-brightened) in guide box, and begin guiding on it.

- Issue a `180. 0.` θ `mvpix` command to move the guider and star to the right. The guider `HEAD` angle will need to be changed (to the ring angle minus 180°, modulo 360°) for this position.
- Adjust chop amplitude (if necessary) so that left end of chop extends 10–15″ past the central position, ensuring full field coverage with no appreciable edge-brightening. Remember that the full circular center field diameter is 70″.
- Put the tertiary mirror in.
- Take a 10 second spectrum to assess vertical position in field, as determined by which slits are illuminated. This step may be eliminated later, if final guider position is noted.
- Adjust vertical placement of star to central position, and then move just beyond *top* of field (24 pixels from center) in preparation for `sweep`.
- Perform the `sweep` and `gsky` routines to get object/sky pair.
- Repeat the last step for each wavelength to be calibrated.
- Change $f/70$ angle to 90° away from ring angle & take a "stake" spectrum.

Sounds like a complicated sequence, and in some ways it is. But a few nights of this and you'll certainly have the hang of it.

7.7.3 Putting it into Action

Having completed the tasks in the top list, here's the lower list in greater detail:

`M> 0. 0. og/r`
`minc$ HEAD` θ (look at `og` output in Mirella to get θ)
`minc$ GO`
Position chop endpoint in box. Should guide in reasonable seeing.
`M> 180.` y`. `θ`. mvpix` ($y = 0$ unless you know better—see below)
`minc$ HEAD` ϕ
Verify guiding properly.
`M> goi dcp` (raw spectrum will show you which slit is getting most flux)
`M> 0. -4.` θ`. mvpix` (for example)
`M> goi dcp` (now centered?)

Once centered, Note the total effective y-move from the initial `180. 0.` θ`. mvpix` command. Next time, stick this into the `180.` y`.` θ`. mvpix` command, and it will not be necessary to check that the position is centered. The guider is very reliable and repeatable. Now you know better (in reference to the `mvpix` comment above).

```
M> 180. tint      (not arbitrary—determined by sweep duration)
M> 0. 24. θ. mvpix                    ("take it from the top")
M> goi sweep dcp gsky sdiff
```

That last command was a mouthful. First, the 180 second exposure is started, then the guider sweep begins, taking $0.1''$ steps about once per second, dragging the chopped star vertically through the field (first down from the top, then back up to the top). The exposure ends shortly after the `sweep` sequence ends. The `dcp` then displays the image, and a `gsky sdiff` obtains and subtracts a sky frame, the position of which is set by the current nod setting. Figure 7.11 shows the appearance of the G-star sweep for a grating setting of 2.018μm, in which one can see the absorption of the atmosphere between 2.00 and 2.02μm (towards center of array), and one also gets a look at the fringing, which is why we bother getting spectral flats in this bizarre manner.

Now get lamps. You know the drill:

```
M> /o
M> 10. tint
M> 1 1 1 1 lamp    (watch Quantex gain, beware of line conflicts)
M> goi dcp lampoff goi wait sdiff
M> mspect
```

Be sure to remember to get the tertiary back in before spending 7 minutes on the next calibration spectrum.

Look for a signal level of $> 1,000$ dN in the bright parts of the array (and between skylines in the raw frame—if you can see them). If your cursors are fortuitously placed, you'll know the level immediately after the first exposure is done. You'll also know if anything is wrong, giving you a chance to CTRL-C out and `abort` the sky exposure to fix any obvious problems. The target of 1,000 dN is somewhat arbitrary, and is based on wanting a 1% noise level in the flat. The D80 array has about 10 e^- per dN, so that 1,000 dN is 10,000 e^-, the noise of which is 1%. If the signal is weak (less than 700 dN, it may be advisable to obtain a second `sweep` exposure.

The `sweep` routine leaves the guider in its starting position, ready for another round. The next round is simple:

```
M> 180. tint
M> 2.283 hires
M> goi sweep dcp gsky sdiff
M> /o
M> 10. tint
M> 1 1 1 1 lamp    (watch Quantex gain, beware of line conflicts)
M> goi dcp lampoff goi wait sdiff
M> mspect
```

You can keep doing this until the cows come home, but watch the airmass and make sure it is not getting away from the target value.

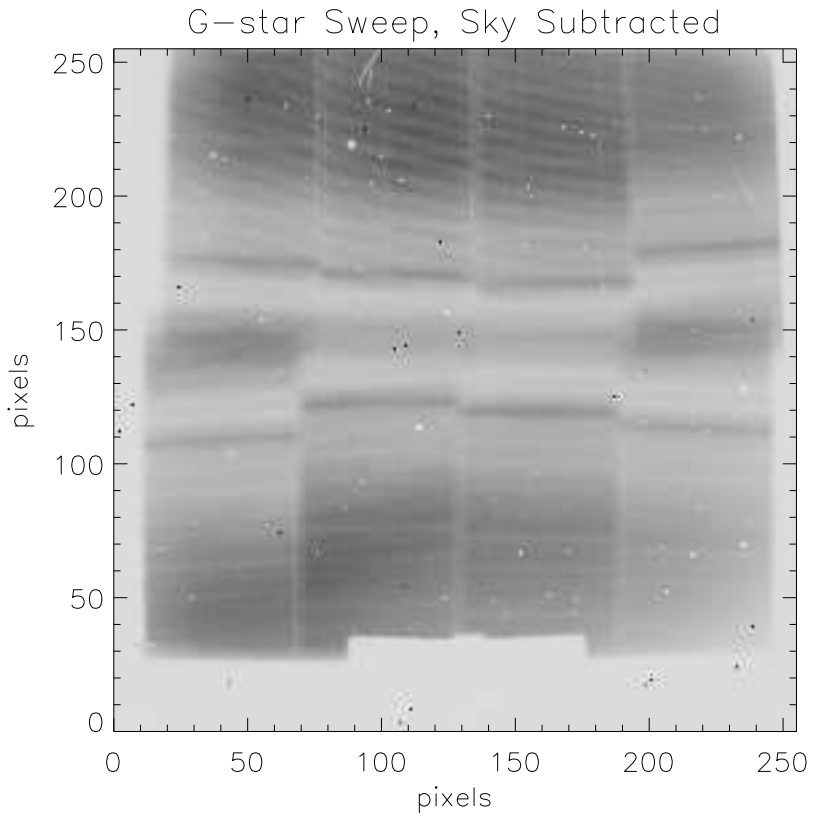

Figure 7.11: G-star sweep, after sky subtraction. The full field of view has been illuminated by the swept star, making this a flat-field in addition to being an atmospheric calibrator. The atmospheric absorption seen here towards the center of the array runs from 2.00–2.02μm. The fringing on the array is also seen here.

7.7.4 Now Go Get a "Stake"

When all the wavelengths are done, there's one more step to do. I call it the "stake" spectrum, which works on two fronts. The basic idea is to chop the G-star vertically, in the cross-slit direction, center the chop left-right (very crudely), and take a short spectrum. The result is a spectrum whose input has the same flux in each slit (thanks to the triangle wave chop action) and the same spatial location in each slit (thanks to the 90° chop angle). The former property helps correct for non-uniform sweeping across the field, and the latter establishes a reference for spatial location along the slit. Both forms stake the data together, in two different ways.

Turn the guider off, then rotate the secondary by 90°, keeping in mind that the secondary range is $-90 < \phi < 90$ (Section 6.3). Do yourself a favor. Enter the new secondary angle into the MINC computer (as `F70A`) *now*, before you forget.

Use the paddle to center the chopped star left-right. You should see the star peeking out from behind the tertiary without having to move it out of the way.

```
M> 10. tint
M> 2.018 hires        (or the current setting, if in spectral mode)
M> snapi sdiff
```

That's it. You have your stake. Do one for each wavelength and you'll be happy later. Figure 7.12 shows the appearance of the stake spectrum for the grating setting of 2.018μm. The atmospheric absorption seen in the G-star sweep can also be seen here.

7.7.5 Moving On

7.7.5.1 To Another G-star

If going to another G-star (for a different airmass, perhaps), you can leave the chopper going during the move. Turn down the Quantex gains before the move, as usual. The chop is already set up across the slits, so once you arrive at the new G-star, you may as well get your stake spectra first. Once done, rotate the secondary for the spectral sequences. You may even see the star in the guider without having to move it, such that you can position the right-hand endpoint in the guider with little fuss. Doing so will put the star in the starting position for the `sweep`. It doesn't get much better than that!

7.7.5.2 Not Another G-star

No, that's not a complaint from the back seat, though perhaps it should be. If going to another object, first turn the Quantex gains down, then turn off the chopper (set to DC, then throw 20dB switch down). Remember to update the MINC with the new value of `F70A`.

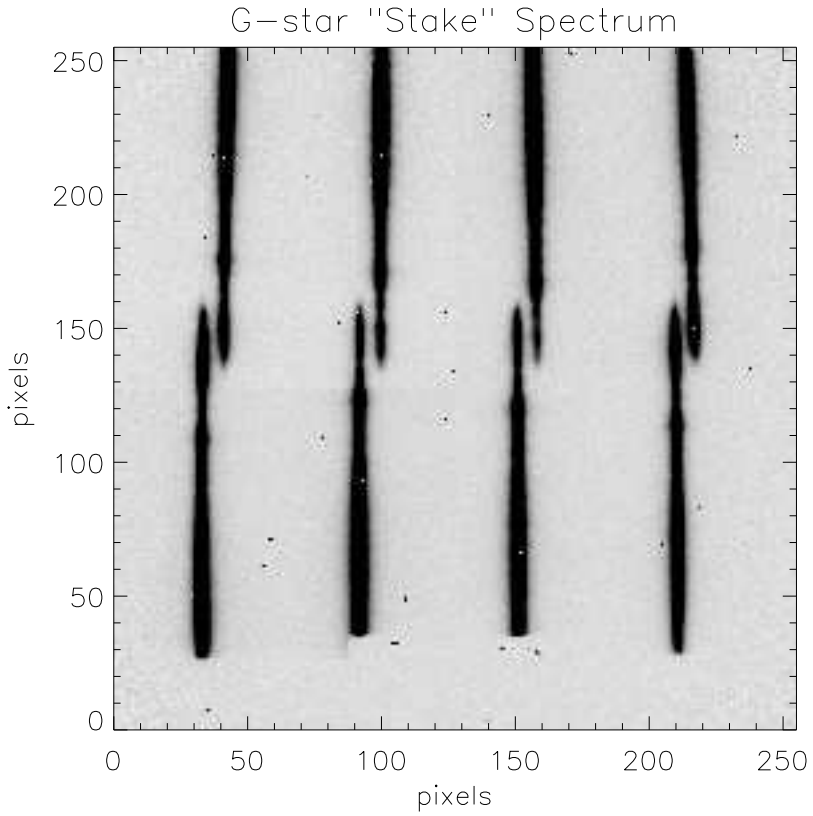

Figure 7.12: The stake spectrum, obtained with the star chopped vertically across all the slits, thus uniformly illuminating each slit. In addition to tying the flux throughputs of each slit, this image can also be used to establish a common left-right spatial position in each slit.

7.7.5.3 To the Monastery

If this concludes your fun-filled night of observing, remember to enter the `/end_night` command before leaving. This command moves out the tertiary mirror, placing the protective cover over it, puts the cold plug in front of the array, and closes the secondary lid.

7.8 Now What?

Well, that does it for the cookbook. I'm hungry.

Chapter 8

Saving the Precious Data

The data taken with the PIFS resides on SAM, the VAX on the Mezzanine level. This is the computer that Mirella is running on, and the computer whose terminal you've been typing on all this time. The data is stored in WFPC format. But astronomers really want FITS files. What follows is a guide to retrieving the data, converting it to FITS, and putting it onto a tape or CD.

If the files are already in place on a SPARC station, as they would be if running the auto-ftp process (see Appendix E), most of these steps can be skipped, and the tape written directly.

8.1 Hooking up the Machines

The sequence that follows is written for the rhea SPARC station, but will be valid for any SPARC station running in the data room.

The first step is to physically connect rhea to SAM, which is done on the wall panel to the right of where the telescope operator sits. Find the BNC jack labeled SAM (ports 1 & 2), and find the one labeled rhea (or replacement). There is very likely a short cable running from the rhea jack to one labeled "repeater", which is the internet connection. Otherwise, if rhea is set up near the observer, the BNC may simply go straight from rhea to the repeater jack. SAM's jack is likely terminated with a 50Ω terminator. Remove the terminator, and take the "repeater" end of rhea's cable, attaching it to SAM (i.e., port 2). Though unnecessary, place the terminator on the repeater jack for safe-keeping. Now rhea is off the internet, and SAM is directly connected to rhea.

8.2 Transferring the Data

What follows may look strange, but `ftp` will only work right in one direction: from SAM to rhea. From the rhea terminal:

```
rhea> telnet sam
```

```
  Username: IRCASS3
  Password:                              (use current password)
$ ftp rhea
  (some prompt): user visitor (actually type these two words)
ftp> cd /scr/visitor/tmurphy/night1          (for example)
ftp> type binary
ftp> mput w*.hdr             (or subset of data if incremental)
ftp> mput w*.img             (or subset of data if incremental)
ftp> quit
$ logout
```

Now disconnect SAM from `rhea`, and replace cables and terminators where you found them. This step is unnecessary if `rhea` is currently set up to auto-ftp new files (as in Appendix E).

It is not a bad idea to do this transfer after every night of successful data-taking. In such a case, modify the `mput` commands above to reflect the partial selection.

8.3 Converting to FITS

With the data now on the SPARC disk, make a list of the files, which will be edited and then executed as a shell script.

```
rhea> ls *.hdr > fitslist
```

Now edit the list with your favorite editor such that each entry reads:

```
wfpc2fit w00001
wfpc2fit w00002
```
etc.

If using `vi`, this can be quickly done with the following sequence:

```
:1,$s/\.hdr//
:1,$s/w/wfpc2fit w/
:wq
```

With `emacs`, first move the cursor to the very first character in the file, and do the following commands, where a `M-` command is interpreted as an <ALT>-command, and a `C-` is interpreted as a <CONTROL>- command:

```
M-x replace-string
Replace string: w
Replace string w with: wfpc2fit w
```
Now move cursor back to beginning of first line
```
M-x replace-string
Replace string: .hdr
Replace string .hdr with:                    (just hit return)
C-x C-s C-x C-c                               (save and exit)
```

This sequence (in `vi` or `emacs`) will properly format the file for shell execution.

Now execute this file in one of the two following ways:

```
rhea> csh < fitsfile
—OR—
rhea> chmod +x fitsfile
rhea> fitsfile
```

Perform this process in each of your data directories, if you have more than one. If skeptical about this `wfpc2fit` program, first do an `ls -l` command to check that the file size is about right (roughly the sum of a `.hdr` file and a `.img` file). Still not convinced? Run `saoimage` and look at the files directly. Seeing is truly believing, but hopefully one or two will convince you that all is fine, and you won't be compelled to visually inspect each file.

If you have trouble with `wfpc2fit`, or can't find it, try another SPARC station. But it should be on all of them, and have execute permissions for all users. If all else fails, issue the following command: `find -name wfpc2fit.c -print` and compile the program in your own directory using a `gcc wfpc2fit.c -o wfpc2fit` sequence.

8.4 Writing to Tape

With the various fits files in their various directories (or single directory as the case may be), insert a tape into the drive and follow the pattern shown below[1].

```
rhea> cd /scr/visitor/tmurphy/night1
rhea> tar -cv *.fit
rhea> ../night2
rhea> tar -cv *.fit
rhea> ../flats
rhea> tar -cv *.fit
```

It is also possible to write your data files onto a CD. There is an instruction manual at Palomar on how to do this.

8.5 Delete the Files

Once assured that your data is safely backed up on tape, be courteous and delete the leftover files. Even if paranoid, you can delete the `.hdr` and `.img` files on the SPARC.

Wait until the end of the run to delete files on SAM. Once all the data is safe on the tape or CD, exit Mirella and delete files:

[1] I know this is not new to anyone, but what can I say—I've already gone overboard and I can't seem to stop myself.

```
M> /end_night                    (stows hardware)
M> bye
$ del *.hdr.*                    (this wipes out all your data)
$ del *.img.*                    (this wipes out all your data)
```

And that's it. Go home.

Appendix A

Finder Charts

The following is an IDL routine meant to create a grayscale finder in PostScript form for a 300×300 pixel SkyVeiw-generated fits file (`infile`) that is 500″ on a side. The second argument, `outroot`, is the root filename to use for output. Two files are generated: a normalized fits file (zero median and sky noise of 1.000), and a "`.plt`" file, which is to be executed at the IDL prompt via an "at" (@) command.

```
pro finder,infile,outroot

if strpos(infile,´fits´) eq -1 then infile = infile+´.fits´

im = readfits(infile,h)
med = median(im)
sig = noise(im)

im = (im - med)/sig

fitsfile = outroot+´.fit´
writefits,outroot+´.fit´,im,h

outfile = outroot+´.plt´
openw, 1,outfile

printf,1,"; skyview image is "+infile
printf,1,"old_dev = !D.NAME"
printf,1,"set_plot, ´PS´"
printf,1,"device, filename=´",outroot+´.ps´,"´"
printf,1,"device, bits_per_pixel=8,scale_factor=1.0"
printf,1,"fullx = 8.49"
printf,1,"fully = 10.99"
printf,1,"device, /inches, xoffset=0.0,yoffset=0.0,xsize=fullx,ysize=fully"
printf,1,"deg = string(176B)"
printf,1,"mm = string(180B)"
printf,1,"ss = string(168B)"
printf,1
printf,1,"im = readfits(´",fitsfile,"´,h)"
printf,1,"imtitle = ´XX:XX:XX.XX, +XX´+deg+´XX´+mm+´XX´+ss+´ (1950.0)´"
printf,1,"size = [1.375,3.375,7.25,9.25]"
```

```
printf,1,"psize = size/[fullx,fully,fullx,fully]"
printf,1,"dx = psize[2] - psize[0]  &  dy = psize[3] - psize[1]"
printf,1,"imtmp = bytscl(im,min=-15,max=5)"
printf,1,"tvscl, -imtmp,psize[0],psize[1],xsize=dx,ysize=dy,/normal"
printf,1,"x = (-findgen((size(im))[1])+(size(im))[1]/2.0)*500.0/(size(im))[1]"
printf,1,"y = ( findgen((size(im))[2])-(size(im))[2]/2.0)*500.0/(size(im))[2]"
printf,1,"contour,im,x,y,xstyle=1,ystyle=1,position=psize,$"
printf,1,´  xtitle="!4Da!N!3 (arcseconds)",ytitle="!4Dd!N!3 (arcseconds)",$´
printf,1,"  xrange=[x[(size(x))[1]-1],x[0]],title=imtitle,c_color=[254],$"
printf,1,"  /nodata,/noerase"
printf,1
printf,1,"theta = findgen(361)*3.14149/180.0"
printf,1,"xcirc = 200.0*cos(theta) & ycirc = 200.0*sin(theta)"
printf,1,"plots,xcirc,ycirc"
printf,1,"plots,[[00.0,200.0],[00.0,40.0]]"
printf,1,"plots,[[0.0,-200.0],[0.0,-40.0]]"
printf,1,"plots,[[-200.0,0.0],[-40.0,0.0]]"
printf,1,"plots,[[200.0,00.0],[40.0,00.0]]"
printf,1,"plots,[[00.0,40.0],[00.0,20.0]],color=!d.table_size-1"
printf,1,"plots,[[0.0,-40.0],[0.0,-20.0]],color=!d.table_size-1"
printf,1,"plots,[[-40.0,0.0],[-20.0,0.0]],color=!d.table_size-1"
printf,1,"plots,[[40.0,00.0],[20.0,00.0]],color=!d.table_size-1"
printf,1
printf,1,"device,/close"
printf,1,"set_plot,old_dev"

close, 1

end
```

The above routine calls a procedure known as `noise.pro`, which is a crafty little routine that calculates the Gaussian-like noise background in an image, ignoring positive or negative features in the image (assumes some level of sparseness). This is my own routine, so don't trust it for everything. But for most of what I do, this is a real nice thing to have.

```
function noise,im

; function to find the std dev of a block of pixels

; sort the array

imsort = im(sort(im))

; find the number of pixels

npix = (size(imsort))[1]

; pick the integer that is closest to 2/3 of the number of pixels
; this is an integer

num = 2*npix/3 + 1

; find the noise as a the minimum difference between
; the averages of two pairs of points approximately 2/3 of the
; entire array length apart
```

```
noise =  $min(imsort(num-1:npix-1)+imsort(num-2:npix-2)-imsort(0:npix-num)-imsort(1:npix-num+1))/2.0

; now correct the noise for the fact that it´s not exactly over 2/3 of the
; elements

noise = noise / (1.9348+(float(num-2)/float(npix) - 0.66667)/.249891)

; now correct for the finite number of pixels

if npix gt 100 then $
        noise = noise/(1.0-0.6141*exp(-0.5471*alog(npix))) $
        else $
        noise = noise/(1.0-0.2223*exp(-0.3294*alog(npix)))

return, noise

end
```

Appendix B

Atmospheric Calibrator Stars

The following is a list of F8–G9 main sequence stars, generated on SIMBAD. The stars cover the entire sky, and all have $3.5 < V < 6.5$. Every star has an SAO number, but not all have an HR designation. These are instead given letters as a means of labeling the analog computer plot (see Section 1.4.1).

HR	SAO	RA (2000.0)	Dec (2000.0)	M_V	Spectral Type
9088	91669	00 02 07.0	+27 05 45	5.75	G5Vb
9107	53622	00 04 50.5	+34 39 31	6.10	G2V
5	21085	00 06 14.2	+58 26 11	5.93	G5V
A	166137	00 14 20.2	-27 31 46	6.46	G5V
B	147208	00 17 57.4	-13 27 20	6.50	G2V
72	128690	00 18 40.4	-08 03 04	6.46	G0V
77	248163	00 20 04.2	-64 52 29	4.20	F9V
88	147237	00 22 50.3	-12 12 37	6.38	G3V
108	166296	00 28 21.5	-20 20 00	6.44	G3V
142	128839	00 35 13.4	-03 35 33	5.20	F8V
176	232143	00 40 19.8	-59 27 39	5.88	G1V
173	166475	00 40 30.5	-23 47 59	6.14	G3/G5V
203	147432	00 45 28.7	-12 52 41	6.15	G2V
209	215232	00 45 44.6	-47 33 11	5.80	G1V
225	92099	00 48 58.6	+16 56 36	5.07	F8V
219	21732	00 48 59.1	+57 49 24	3.45	G0V
244	11444	00 53 04.6	+61 07 18	4.82	F8V
321	22024	01 08 16.4	+54 55 13	5.12	G5Vb
340	36984	01 10 19.3	+42 04 55	5.70	F8V
370	215428	01 15 07.9	-45 32 03	4.96	F8V
458	37362	01 36 48.3	+41 24 28	4.09	F8V
512	258271	01 37 52.4	-82 58 36	5.87	G2V
483	37434	01 41 43.4	+42 36 56	4.90	G1.5V
506	232501	01 42 28.3	-53 44 22	5.52	F9V
509	147986	01 44 10.0	-15 56 58	3.50	G8V
523	54994	01 48 42.1	+32 41 10	5.79	F8V
535	193326	01 49 48.8	-38 24 26	6.37	F8V

650	129752	02 12 46.2	-02 23 34	5.68	F8V
660	55420	02 16 58.5	+34 13 40	4.90	G0.5V
683	167697	02 18 59.2	-25 57 07	6.34	G5V
695	167736	02 22 31.8	-23 48 56	5.19	G2V
706	215892	02 24 32.8	-40 50 31	6.18	G2V
720	75391	02 28 48.7	+29 55 51	5.89	G0V
741	92998	02 32 54.2	+15 02 03	6.00	F8V
761	55711	02 37 06.1	+32 53 28	6.20	F8V
788	55793	02 42 14.9	+40 11 47	4.90	F9V
810	232864	02 42 31.6	-50 48 12	5.40	G0V
937	38597	03 08 57.5	+49 36 53	4.05	G0V
962	130355	03 12 45.7	-01 11 43	5.06	F8V
1006	248770	03 17 36.5	-62 35 04	5.54	G2.5V
1010	248774	03 18 03.2	-62 30 56	5.24	G1V
996	111120	03 19 20.7	+03 22 08	4.83	G5Vvar
1008	216263	03 19 41.7	-43 04 48	4.27	G8V
1024	130457	03 23 17.7	-07 47 28	6.20	G2V
1099	111291	03 36 47.3	+00 35 24	5.71	G9V
1232	130860	03 58 52.5	-05 28 03	5.83	G9V
1262	76438	04 05 19.6	+22 00 38	5.90	G5V
1294	248945	04 07 20.0	-64 13 37	6.37	G3V
1405	233506	04 24 12.8	-57 04 14	6.28	G4V
1489	57377	04 41 49.2	+38 16 53	5.99	G0V
1532	149888	04 47 35.8	-16 56 13	5.50	G3V
1538	149901	04 48 32.4	-16 19 48	5.75	F8V
1536	131504	04 48 35.3	-05 40 14	5.77	F8V
1608	150060	04 59 50.3	-10 15 41	5.38	G4V
1651	217153	05 03 53.8	-41 44 50	6.31	F8V
C	150156	05 07 09.9	-19 23 45	6.44	G2V
1665	150159	05 07 24.4	-12 29 22	5.97	G2V
1656	94332	05 07 25.1	+18 38 41	5.01	G4V
1747	150326	05 18 49.1	-18 07 51	5.96	G0V
1780	94526	05 24 24.5	+17 23 01	5.00	F8V
1828	25241	05 32 33.1	+57 13 27	6.40	F8V
1912	234026	05 33 43.9	-54 54 09	6.42	F8V
2022	258421	05 37 04.0	-80 29 01	5.67	G1V
1980	170756	05 44 28.4	-20 07 37	6.34	F8/G0V
1988	113119	05 46 35.1	+01 10 12	5.95	G4V
2007	132554	05 48 34.7	-04 05 29	5.97	G4V
2047	77705	05 54 23.5	+20 16 38	4.41	G0V
2141	58739	06 06 08.9	+35 23 30	6.12	G0V
2261	256274	06 10 13.0	-74 45 00	5.09	G6V
2208	95394	06 13 12.2	+10 37 53	6.44	G2V
2225	171428	06 13 45.3	-23 51 49	6.39	G5V
2274	234418	06 16 18.9	-59 12 33	6.43	G0V
2254	171502	06 17 03.1	-22 42 42	6.04	F8/G0V
2251	113683	06 17 16.8	+05 05 53	5.71	F9V
2313	133229	06 25 15.6	-00 56 34	5.90	F8V
2400	234551	06 31 17.7	-51 49 39	5.60	F8V
2431	196987	06 35 54.2	-36 05 15	6.35	G0V
2468	249604	06 38 00.7	-61 32 03	6.18	G1.5V
2493	172264	06 44 51.9	-27 20 44	6.43	G2V
D	78717	06 46 10.4	+23 22 14	6.4	G8V
2401	5946	06 46 15.9	+79 34 24	5.45	F8V
2483	41330	06 46 44.3	+43 34 31	5.27	G0V
2569	78866	06 55 18.7	+25 22 31	5.70	G0V
2643	79009	07 03 29.8	+29 20 55	5.93	G4V

2667	218421	07 03 57.7	-43 36 48	5.54	G3V
2692	79131	07 10 07.3	+21 15 13	6.43	G9V
2711	79170	07 12 48.9	+27 13 34	6.44	F8V
2721	41644	07 15 49.9	+47 14 33	5.60	GOV
2779	115269	07 19 47.5	+07 08 38	5.90	F8V
2866	134742	07 29 25.4	-07 33 11	5.90	F8V
2918	115693	07 36 35.0	+05 51 42	5.90	GOV
E	235442	07 43 21.8	-52 09 58	6.5	GOV
3018	198404	07 45 36.0	-34 11 46	5.37	GOV
3064	153500	07 51 46.5	-13 53 36	5.16	G2V
3138	250035	07 57 43.4	-60 18 17	5.60	GOV
3119	26634	08 02 35.9	+57 16 28	6.49	F8V
3191	79995	08 10 27.4	+25 30 44	5.73	G7V
F	97645	08 12 12.4	+17 38 59	5.05	F8V
3210	97646	08 12 12.9	+17 38 57	6.20	G5V
3271	135783	08 20 12.9	-00 54 29	6.20	F9V
3309	42369	08 27 36.8	+45 39 28	6.30	G5V
3368	236032	08 29 36.4	-55 11 26	6.36	GOV
3404	199402	08 35 12.2	-39 58 15	6.47	G1V
3395	116929	08 35 51.4	+06 37 19	6.00	F8V
3430	176226	08 39 08.8	-22 40 04	5.05	G3/G5V
3391	14609	08 39 11.9	+65 01 11	5.60	G1.5Vb
3510	98168	08 51 01.8	+15 20 59	6.38	G1V
3522	80478	08 52 37.6	+28 20 03	5.95	G8V
3538	136389	08 54 19.3	-05 26 05	6.00	G2V
3625	61288	09 08 51.8	+33 53 02	5.90	F9V
3648	14819	09 14 20.6	+61 25 25	5.20	F9V
3677	200152	09 14 57.1	-37 36 08	5.86	GOV
3750	136872	09 27 47.5	-06 04 12	5.40	G2V
3754	117717	09 28 27.2	+09 03 25	5.41	F9V
3862	177866	09 42 15.8	-23 55 09	4.94	GOV
3901	137185	09 51 22.0	-06 10 57	6.42	F8V
3916	178130	09 52 59.0	-27 20 01	6.30	G1V
3992	201109	10 09 33.5	-35 51 25	6.13	F8V
4013	201186	10 13 26.2	-33 01 57	6.35	G1V
4012	81250	10 14 30.2	+21 10 08	6.02	F9V
4027	81259	10 16 28.3	+28 41 01	6.49	GOV
4039	81270	10 17 16.0	+23 06 27	5.80	F8Vbw
4051	27606	10 20 15.2	+53 46 43	6.40	F9V
4085	118278	10 24 12.9	+02 22 06	6.32	G9V
4098	43351	10 28 03.4	+48 47 49	6.44	F9V
4112	27670	10 30 38.6	+55 58 52	4.80	F8V
4168	62178	10 39 08.5	+37 54 39	5.85	F9V
4277	43557	10 59 29.3	+40 25 46	5.10	G1V
4285	43564	11 00 21.1	+42 54 48	6.00	F9V
4298	201998	11 00 41.0	-31 50 27	6.07	F8V
4345	62451	11 12 33.2	+35 48 57	6.41	GOV
4375	62484	11 18 12.6	+31 32 15	4.41	GOV
4437	99648	11 31 46.0	+14 22 02	6.20	GOV
4443	179967	11 32 16.1	-29 15 55	5.77	F8V
4444	179968	11 32 16.4	-29 15 47	5.68	F8V
4439	15542	11 32 20.8	+61 05 01	5.48	F8V
4486	43841	11 38 47.6	+45 06 30	6.44	GOV
4489	180065	11 39 00.2	-24 43 03	6.42	G6/G8V
4496	62655	11 41 03.0	+34 12 25	5.32	G8V
4498	180098	11 41 09.5	-29 11 57	6.44	GOV
4523	223020	11 46 37.7	-40 30 21	4.89	G5V

4525	202811	11 47 16.7	-30 17 00	6.48	G5V
4540	119076	11 50 39.2	+01 46 07	3.61	F9V
4550	62738	11 52 41.8	+37 47 58	6.45	G8Vp
G	157003	11 56 56.0	-13 45 09	6.5	G1/G2V
4688	82244	12 19 30.3	+28 09 31	6.33	F8Vs
4708	119360	12 22 32.5	+05 18 22	6.40	F8V
4734	223443	12 26 51.3	-48 54 43	6.26	G4V
4758	157326	12 30 05.6	-13 23 33	6.35	G1/G2V
4767	28413	12 30 49.9	+53 04 26	6.20	F9V
4785	44230	12 33 47.6	+41 21 12	4.26	G0V
4788	223527	12 34 42.7	-44 40 13	5.77	G1V
4845	63177	12 45 00.9	+39 16 37	6.00	G0V
4864	82511	12 48 48.2	+24 50 30	6.31	G7V
4903	223753	12 54 59.4	-44 08 56	5.89	G1V
4979	204227	13 12 04.7	-37 48 13	4.85	G3V
4980	240653	13 12 55.8	-59 48 54	6.21	G0V
5011	119847	13 16 47.6	+09 25 18	5.22	G0Vs
5019	157844	13 18 28.0	-18 17 47	4.74	G5V
5070	16071	13 26 02.7	+63 15 29	6.50	G6V
5072	100582	13 28 26.5	+13 47 12	5.00	G4V
5213	16186	13 49 45.0	+61 29 26	5.96	G3V
5209	182026	13 51 22.4	-24 23 11	6.45	G5V
5258	139666	13 59 49.3	-03 32 56	6.40	F8V
5268	205123	14 03 01.5	-31 41 06	6.18	F8V
5273	100832	14 03 32.0	+10 47 28	6.27	G8V
H	224702	14 07 41.5	-49 52 08	6.5	G3V
5322	139806	14 14 22.2	-05 56 56	6.36	F9V
5325	224798	14 15 38.0	-44 59 55	6.31	F9V
5346	83259	14 16 33.2	+20 07 23	6.25	F8V
5384	120424	14 23 14.5	+01 14 54	6.30	G1V
5423	45075	14 29 36.0	+41 47 56	6.40	G5V
5472	83458	14 40 21.8	+21 58 31	6.05	G0V
5504	182858	14 46 11.0	-21 10 28	6.40	G2V
5534	83553	14 50 15.2	+23 54 41	5.85	G1V
5596	2459	14 50 15.8	+82 30 54	5.64	F9V
5544	101250	14 51 22.7	+19 06 09	4.55	G8V
5542	206035	14 52 34.3	-30 34 35	6.29	G1V
5550	101273	14 53 23.3	+15 42 16	6.41	F9V
5566	225328	14 58 08.7	-48 51 29	6.35	G4V
5583	140256	14 58 53.9	-04 59 16	6.09	F8V
5618	45357	15 03 49.3	+47 39 14	4.76	G0Vnvar
5630	64503	15 06 35.3	+36 27 19	6.34	F8V
5639	101403	15 08 53.5	+13 14 03	6.10	G6V:
5632	253043	15 10 45.9	-61 25 20	6.30	G2V
5657	183275	15 13 30.1	-25 18 30	6.45	G5V
5699	225697	15 21 56.2	-48 18 49	5.65	G4V
5698	225703	15 22 08.9	-47 55 33	5.00	F8V
I	64673	15 23 11.7	+30 17 26	5.02	G2V
5734	64687	15 24 31.4	+37 20 47	6.50	G1V
5853	121152	15 44 01.8	+02 31 02	5.88	G2.5V
5868	121186	15 46 27.3	+07 21 15	4.43	G0V
5864	206976	15 47 30.7	-37 54 48	6.01	G6V
5914	45772	15 52 38.5	+42 26 34	4.62	F8Ve...
5911	101792	15 53 12.5	+13 12 16	6.10	G0V
5996	159706	16 07 04.2	-14 04 16	6.32	G5V
J	207479	16 14 12.2	-31 39 36	6.4	G1V
6094	207622	16 24 00.9	-39 11 35	5.40	G5V

6098	253554	16 28 26.1	-70 05 09	4.91	F9V
K	30055	16 42 27.0	+49 56 16	6.47	F8V
6360	17324	17 02 15.6	+64 36 00	6.10	G5V
6439	141611	17 19 59.3	-05 54 53	6.32	G9V
6441	160474	17 20 34.7	-19 19 52	6.50	G1V
6458	65963	17 20 38.9	+32 28 56	5.40	G0V
6469	46664	17 21 43.5	+39 58 31	5.51	F9Vn...
6598	17572	17 36 40.1	+69 34 25	6.42	F9V
6637	8891	17 41 57.5	+72 09 39	5.78	G0V
6669	47009	17 51 14.0	+40 04 20	6.40	F8V:
6697	85575	17 57 14.3	+23 59 42	6.30	G2V
6748	209710	18 06 23.2	-36 01 11	5.95	G5V
6761	254157	18 10 26.6	-62 00 19	5.49	G0V
6847	47343	18 15 32.8	+45 12 39	6.29	G2V
6836	186593	18 17 23.1	-28 17 13	6.40	G0V
6828	254209	18 19 39.8	-63 52 58	6.18	F9V
L	228983	18 24 32.9	-49 39 03	6.47	G1/G2V
6907	186838	18 27 49.4	-29 49 01	5.91	F9V
6981	103886	18 35 53.1	+16 58 33	6.21	G2V+...
6998	187086	18 38 53.5	-21 02 59	5.86	G5V
6994	257625	18 47 49.5	-77 52 11	6.40	F8V
7079	86451	18 48 16.2	+23 30 52	6.20	F8V
7162	67612	18 57 00.8	+32 54 13	5.22	F9V
7172	104308	18 59 05.6	+13 37 27	5.23	F8V
7161	254446	19 03 29.7	-68 45 19	5.88	F8V
7260	104511	19 07 57.0	+16 51 27	6.07	G5V
7291	187883	19 15 32.7	-24 10 40	6.25	F8V
7345	68144	19 19 39.1	+37 19 59	6.31	G8V
7330	211206	19 21 29.4	-34 58 57	6.48	G5V
7368	68239	19 23 33.6	+33 13 11	6.37	G8V
7477	48673	19 37 56.4	+49 16 57	6.47	G6V
7503	31898	19 41 49.6	+50 31 38	5.96	G1.5Vb
7504	31899	19 41 52.6	+50 31 11	6.20	G3V
7522	31923	19 43 13.6	+58 01 02	6.20	G0V
7560	105338	19 51 00.7	+10 25 03	5.10	F8V
7569	105348	19 52 04.5	+11 37 59	6.10	G0V
7597	188722	19 55 49.5	-26 18 02	4.70	G5V:
7637	163168	19 59 48.2	-09 57 10	5.88	F8V
7672	105635	20 04 07.5	+17 04 33	5.80	G1V
7644	254721	20 05 25.4	-67 18 42	6.07	G3V
7674	246444	20 07 34.8	-55 01 00	6.26	F8V
M	246453	20 08 09.5	-52 34 39	6.4	G3V
7783	18796	20 17 27.2	+66 50 59	5.93	G3V
7766	246546	20 21 42.7	-49 59 46	6.28	G0V
7793	106042	20 22 52.0	+14 33 05	6.10	F8V
7855	163686	20 34 11.4	-13 43 20	6.13	G0V
7875	254846	20 40 00.4	-60 32 28	5.12	F8V
7898	189549	20 40 09.8	-23 46 49	6.37	G8/K0V
7914	106373	20 40 44.6	+19 55 52	6.45	G5V
7994	163953	20 53 05.4	-11 34 27	6.38	G1V
8041	145022	21 00 33.6	-04 43 42	6.21	G1V
8077	126535	21 05 26.9	+05 57 36	5.90	F8V
8061	257890	21 09 17.2	-73 10 07	5.68	F9V
8170	50739	21 21 01.4	+40 20 54	6.40	F8V
8283	164580	21 41 33.2	-14 02 36	5.18	G2V
8310	89939	21 44 07.3	+28 44 46	6.08	G2V
8314	107364	21 44 30.6	+14 46 26	6.00	G0V

8323	230846	21 48 14.8	-47 17 59	5.58	G0V
N	90260	22 08 18.9	+24 09 29	6.5	G2V
8455	107706	22 10 18.6	+19 37 04	6.18	G0V
8472	34151	22 11 47.1	+56 50 15	5.20	F8V
8477	231045	22 14 36.0	-41 22 15	6.26	G5V
8501	247400	22 18 13.0	-53 37 07	5.33	G3V
8526	258036	22 25 50.3	-75 00 57	6.11	G3V
8545	165078	22 26 33.5	-16 44 33	6.35	G3V
8631	108094	22 40 51.6	+14 32 50	5.71	G4V
8635	231257	22 42 36.7	-47 12 23	6.02	G0V
8700	231343	22 53 36.7	-48 35 50	6.03	G0V
8737	127870	22 58 33.7	+09 21 32	6.43	G2V+...
8829	255435	23 14 03.1	-62 41 39	6.12	G8V
8883	191840	23 21 15.5	-26 59 12	5.64	G4V
8931	146752	23 31 30.8	-04 05 05	6.49	F8V
8935	258154	23 33 19.2	-77 23 08	5.81	G2V

Appendix C

Photometric Standard Stars

The standards used for PIFS observations are the so-called "HST faint standards" that Eric Persson and company put together. The full sky list with photometric uncertainties can be found in AJ, **116**, 2475, November 1998. Uncertainties are generally better than 0.01 magnitudes.

n	HST	RA (J2000)	DEC	J	H	K	Ks
9101	P525-E	00:24:28.3	07:49:02	11.622	11.298	11.223	11.223
9104	S754-C	01:03:15.8	-04:20:44	11.045	10.750	10.693	10.695
9105	P530-D	02:33:32.1	06:25:38	11.309	10.975	10.897	10.910
9107	P247-U	03:32:03.0	37:20:40	11.934	11.610	11.492	11.503
9108	P533-D	03:41:02.4	06:56:13	11.737	11.431	11.337	11.336
9116	S840-F	05:42:32.1	00:09:04	11.426	11.148	11.077	11.058
9118	S842-E	06:22:43.7	-00:36:30	11.723	11.357	11.264	11.261
9122	P161-D	07:00:52.0	48:29:24	11.680	11.408	11.356	11.352
9126	P309-U	07:30:34.5	29:51:12	11.876	11.522	...	11.450
9131	P035-R	08:25:43.8	73:01:18	10.819	10.546	10.499	10.515
9133	S495-E	08:27:12.5	-25:08:01	11.521	11.048	10.965	10.960
9134	P545-C	08:29:25.1	05:56:08	11.881	11.624	11.575	11.596
9135	S705-D	08:36:12.5	-10:13:39	12.362	12.098	...	12.040
9138	S852-C	09:41:35.8	00:33:12	11.354	11.041	10.981	10.982
9139	P091-D	09:42:58.7	59:03:43	11.683	11.338	11.276	11.282
9141	S708-D	09:48:56.4	-10:30:32	11.081	10.775	10.715	10.718
9142	P212-C	10:06:29.0	41:01:26	11.993	11.729	11.686	11.697
9143	P550-C	10:33:51.8	04:49:05	12.344	12.121	12.067	12.081
9145	P064-D	12:13:12.0	64:28:56	11.958	11.711	11.664	11.675
9148	P266-C	12:14:25.4	35:35:55	11.642	11.378	11.324	11.343
9149	S860-D	12:21:39.3	-00:07:13	12.213	11.917	11.861	11.865
9150	S791-C	13:17:29.6	-05:32:37	11.661	11.310	11.250	11.267
9152	P133-C	13:58:40.2	52:06:24	11.149	10.878	10.831	10.839
9153	P499-E	14:07:33.9	12:23:51	11.947	11.605	11.560	11.540
9155	S867-V	14:40:58.0	-00:27:47	12.045	11.701	11.622	11.633

9156	P041-C	14:51:57.9	71:43:13	10.873	10.588	10.523	10.530
9158	P272-D	14:58:33.1	37:08:33	11.640	11.277	11.210	11.223
9160	S870-T	15:39:03.5	00:14:54	10.914	10.701	10.649	10.659
9162	P177-D	15:59:13.6	47:36:40	12.258	11.924	11.857	11.868
9164	P565-C	16:26:42.7	05:52:20	12.180	11.895	11.842	11.844
9166	P330-E	16:31:33.6	30:08:48	11.816	11.479	11.419	11.429
9169	P138-C	17:13:44.5	54:33:21	11.355	11.118	11.075	11.080
9170	S875-C	17:27:22.2	-00:19:25	11.132	10.835	10.739	10.744
9177	P182-E	18:39:33.7	49:05:38	12.104	11.764	11.688	11.696
9178	S808-C	19:01:55.4	-04:29:12	10.966	10.658	10.566	10.575
9182	S813-D	20:41:05.1	-05:03:43	11.479	11.142	11.082	11.085
9183	P576-F	20:52:47.3	06:40:05	12.247	11.940	11.873	11.880
9185	S889-E	22:02:05.7	-01:06:02	12.021	11.662	11.586	11.585
9186	S893-D	23:18:10.0	00:32:56	11.403	11.120	11.045	11.055
9187	S677-D	23:23:34.4	-15:21:07	11.857	11.596	11.538	11.542
9188	P290-D	23:30:33.4	38:18:57	11.634	11.337	11.257	11.262

Appendix D

LaTeX Log Sheet

Log sheets can be produced by via the LaTeX program below, or obtained as PostScript from the PIFS website: `http://www.its.caltech.edu/~tmurphy/pifs/pifs.html`. The following is a LaTeX document which will produce a log sheet for the PIFS. Note the line reading: [repeat 24 times...]. Replace this with the line: `& & & & & & & & & \\ \hline` repeated 24 times.

```
\documentclass [12pt]{article}
\usepackage{portland}
\usepackage{array}
\setlength{\evensidemargin}{-0.5in}
\setlength{\oddsidemargin}{-0.5in}
\setlength{\textwidth}{7.75in}
\setlength{\topmargin}{0.1in}
\setlength{\headheight}{0in}
\setlength{\headsep}{0in}
\setlength{\textheight}{10in}
\begin{document}
\begin{landscape}
\renewcommand{\baselinestretch}{1.18}
\begin{center}
\Large
PIFS Log Sheet \hfill Page\underline{\hspace{0.35in}}of\underline{\hspace{0.35in}} \\
\medskip
\normalsize
Observers\underline{\hspace{3.5in}} \hfill Night
 Assistant\underline{\hspace{1in}} \hfill UT Date\underline{\hspace{1in}} \\

\medskip
\setlength{\tabcolsep}{0pt}
\begin{tabular}{|m{0.5in}|m{1.25in}|m{0.625in}|m{0.875in}|m{0.75in}|
        m{0.5in}|m{0.625in}|m{0.5in}| m{0.625in}|m{0.75in}|m{3in}|}
\hline
\centering Frame & \centering Object & \centering TINT & \centering Filter &
\centering Grating & \centering Flip Mirror & \centering Tertiary Mirror & %
\centering UT & \centering Airmass & \centering Offset & %
\hspace{0.1in}Comments \\
\hline
& & & & & & & & & \\ \hline
```

```
[repeat 24 times...]
\end{tabular}
\medskip
{\large Remarks:} \hfill {\tiny TWM 01/16/99}\\
\end{center}

\end{landscape}
\end{document}
```

Appendix E

Automatic Transfer to SPARC

An automated `ftp` process has been developed for the purpose of reconstructing images on the fly, and as a means of providing a more capable platform with which to look at data. Eiichi Egami wrote a series of shell scripts for the SPARC that automatically transfers new data from SAM to the SPARC as it becomes available. This Appendix briefly documents these routines.

The scripts can be found in `/home/user/egami/sam_to_sparc/` on `rhea`, and are called `cpfile`, `ftpls`, and `ftpimget`. Copy these files, plus the blank file `hdr_blank` into the working directory on the SPARC station.

It is best to have the SPARC situated on the table to the right of the main observing station. Connection to SAM should be done following the example in Section 8.1, which takes the SPARC station off the internet.[1]

The main script, `cpfile`, has at its beginning a set of instructions that you should read and follow. Those instructions are summarized here:

- Copy the files `cpfile`, `ftpls`, `ftpimget`, and `hdr_blank` into the current working directory from `/home/user/egami/sam_to_sparc/`.
- Make sure that `wfpc2fit` is in the path by typing `which wfpc2fit`.
- Set the variables `datadir`, `samuser`, and `sampass` in *all three* files: `cpfile`, `ftpls`, and `ftpimget`. The `datadir` and `samuser` variables will not need to be changed unless using D78, or some other non-standard arrangement is being used.
- Type `cpfile` to run the script.
- A <Control>-C command in the appropriate window will terminate the process.

[1] Sometimes it is necessary to exit the desktop, the re-enter, which requires temporarily reconnecting the internet connection while everything starts up.

The `cpfile` process may be run all night long, but it can also be run intermittently. Every time `cpfile` starts, all the files not listed in `hdr_list.old` will be slurped over.

If `wfpc2fit` was not found, see the suggestions on page 91. If there are problems with the SPARC after disconnecting from the internet, such as IDL hanging up, quit all processes (or kill them) such as IDL, `cpfile`, etc., and exit the desktop. Re-connect the SPARC to the internet repeater (terminate SAM when doing so) and then re-enter the desktop, start IDL, then disconnect the internet and go back to the dedicated SAM connection.

I have found it convenient to make a new working directory for each night, and copy over the `hdr_blank`, `hdr_list.new`, `hdr_list.old`, `hdr.list`, and `hdr.diff` files from the previous night's working directory, then restart `cpfile`. This separates data into the various nights, which makes it easy to write tar files to tape with night-separated data. Another, easier way to do this is to name files according to night number. For instance night one would begin with `w01001.fit`, night two with `w02001.fit`, etc.

Rearranging Image with IDL

After starting IDL, add the following directories to the path such that the following routines, plus supporting routines will be visible.

```
IDL> !path = '/home/user/tmurphy/idl/util:' + !path
IDL> !path = '/home/user/tmurphy/idl/pifs:' + !path
```

There is a package now visible to you called `imtool`, that is a nice display of IDL images. You can pull up files, or type `prep, im` at the IDL prompt, then select "View Array" to view an active IDL array. Functionality is much like SAOimage, but with added features such as statistics in a box, and PSF fitting. If things go squirrelly, type `retall` at the IDL prompt, and things should return to normal.

Once the FITS files are on the SPARC, do with them what you will. I have a few IDL routines that rearrange the slit images into a contiguous box and displays the box. I will try to provide better documentation on these at a later time, but for now will say that the routines are called `deslice.pro` and `redo.pro`. These routines should be located on `rhea` in the `/home/user/tmurphy/idl/pifs/` directory. Each of these routines works on two images (object/sky), with the `deslice` routine assuming nothing and the `redo` routine just applying a predetermined mapping, established by `deslice`. So in practice, `deslice` is run on the very first object/sky pair, and `redo` is used thereafter. The `deslice` routine takes 15–20 seconds to run. The `deslice` routine takes a minimum of two arguments: object frame and sky frame, and an optional name for the output. The object and sky frames could be IDL arrays, or file numbers, as the following examples indicate:

```
IDL> deslice, im,im2,outim
IDL> deslice, 34,35
```

```
IDL> deslice, 45,46,outim,pinim=45
IDL> deslice, 48,49,pinim=stake
```

In the above example, `im1` and `im2` are 256×256 IDL arrays, read in from the fits files via `readfits` or the like. File numbers 34 and 35 are turned into `w00034.fit` and `w00035.fit`. The third example not only displays the result, but puts it into an IDL array for further manipulation. The third and fourth examples pass an optional bit to `deslice`, in the form of a file number or an array name. This image is used to spatially pin the slits together. Without this, the spatial alignment of the slits will be shoddy, but passable for target finding, etc. To get this "`pinim`", chop a star vertically across the slits, and take a short exposure (possibly less than one second for a bright star—use the 1% CVF to help cut down light). Loosely follow the procedure for getting the G-star stake image (Section 7.7.4) to acquire this pinning image.

Once the `deslice` routine has been run once, the image reconstruction goes much more swiftly. The `deslice` routine leaves behind a file, `slicemap.dat`, which contains the interpolating instructions for image reassembly. The `redo` program simply applies this map to pairs of images.

```
IDL> redo, im1,im2
IDL> redo, im1,im2,outim
IDL> redo, 34,35,outim
```

Again, the `outim` is optional. The `redo` command is almost instantaneous, and is therefore much preferred over `deslice`, once the mapping has been performed.

Index

`abort`, 42, 58
`AGG`, 46
analog computer, **11**, 80
atmospheric
    calibration, 11
    transmission, 9
automated `ftp`, 63, 78

blaze function, 17, 19
blind offsets, 8, 67
booting up, 27–32
    logging in, 27
    verifying operation, 29
box statistics, 42

calibration lamps, **12**, 71
    commands, 36
    verifying, 30
camera status, 28
center-field, **52**
    crosshair, 51
    field of view, 15, 52
centering object, 65–67
chopping, **50**, 81
    20dB switch, 50
    amplitude, 50
    angle, 51
    frequency, 51
commands, 35–46
    camera, 37–39
    display, 41–42
    guider, 45–46
    miscellaneous, 42–43
    PIFS, 36–37
    telescope, 39–41
    user defined, 43
connecting to SAM, 89
cookbook, 53–87
    dark frames, 53–54
    dome flats, 54–58
    G-star, 80–85
    object obs., 61–73
    PSF, 75–79
    sky flats, 59–61
coordinates
    G-star, 11, 97
    guide star, 9
    object, 8
crash, *see* restarting
crosshair, **51**
    zeroing, 52
cursor mode, **42**, 59, 60, 83

D78, 7, 8
    pixel scale, 7
D80, 7
    array characteristics, 14
    commands, 37–39
    pixel scale, 7
dark frames, 53–54
data
    converting to FITS, 91
    deleting, 91
    example, 73
    transfer, 89
    writing to tape, 91
`dcp`, 41
deleting files, 54, 91
display commands, 41–42
dither pattern, 10, **67**
dome flats, 54–58

`/end_night`, **43**, 61, 73, 80, 87
example data, 73

`F70A`, **45**, 51, 62, 85
`F70G`, **46**, 50
faint objects, 65
field of view
    center-field, 15, 52
    guider, 15, 50
    PIFS, 14, 21
filters, **25**
    commands, 38
finder charts, **10**, 93
finding object, 65
FITS files, 91
flexure, 14, 57
flip mirrors, 14
    commands, 36
    motors, 25
focusing, 15, 52, **61**, 78
`forget`, 43
FORTH, 35
    floats & integers, 35
    stringing commands, 35
fringing, 14, 57
`ftp`, automated, 63, 78
function generator, **50**
    20dB noise, 51

G-star
    airmass dependence, 11
    analog computer, **11**, 80
    as calibrator, 11
    as flat-field, 11, **57**
    desired signal, 83
    list, 97
    multiple, 11, 85
    observing, 80–85
    outlined procedure, 81
    selection, 11, **80**
    stake spectrum, 85
gimbal, 8, 25
`goi`, 38
gratings
    angle commands, 37
    blaze function, 17, 19
    motors, 24
    properties, 17–19, 37
    tuning, 36
`gsky`, 40
guide star
    acquiring, 61
    brightness, 8, 9, 15
    faint, 50, 62
    finding, 62
    `guide` program, **9**, 75
    keep & move, 39
    list generation, 9
guider
    commands, *see* MINC
    field of view, 15, 50
    motors, 24
    orbiting star, 47
    positioning, 40, 61
    Quantex, 49–50
    range of motion, 8, 15
    repelling star, 47
    stripchart, 47
    tip-tilt operation, 46
guiding, 61–62
    on chopped star, 81

`HEAD`, 45, 62
HNA spectrograph, 8

IDL
    hung, 108
    image reconstruction, 108
imaging flats, 59–61
imaging mode, 14, 29, 63–67, 75
    interpreting, 15, 63, 108
integration time, *see* `tint`
interrupt, 42

lamps, *see* calibration lamps
`lastfile` example, 78
lens, 25, 38
lid, *see* secondary
log sheets, 12, 105

MINC, **44**
    @ prompt, 47
    commands, 45–46
    `GO`, 44, 45
    query value, 45

restarting, 47
stripchart, 47
motion
commands, 39–41
nod, 40, 63
motors, 24–25
failure, 28, 33
homing, 28, 33
`mparm2`, 14, **37**, 44
`mspect`, 36
`mt`, 39
`mtg`, **39**, 72, 76, 77
`mvpix`, **40**, 65, 71

nod, 40, 63

`/o`, 36
object observation, 61–73
`odiff`, 41
offset guider, *see* guider
`og`, 40
OGX,OGY, 40, **65**
OH lines, **9**, 12, 73

`photometric`, 42
photometric standards, 12, 79–80, 103
PIFS
commands, 36–37
cryogen, 14
design considerations, 23
field of view, 14, 21
flip mirrors, *see* flip mirrors
gratings, *see* gratings
layout, 21
modular approach, 24
optical path, 21–23
pixel scale, 14
sensitivity, 14
specifications, 14
throughput, **14**, 23
pixel scale
D78, 7
D80, 7
pointing, 52, **61**
position angle, *see* ring angle
prompts, 27, 32, 42, 43, 47, **53**, 58, 73
PSF, 75–79
finding, 75
guided, 75–77
measuring, 108
unguided, 77
pupil imaging lens, 25, 38

reconstructing image, 15, 63, 108
restarting
hardware, 33
software, 32
ring angle, 10, 15, 40

saturation:D80, **14**, 59, 60
`sdiff`, 41
secondary, 15
chop angle, 51
chopping, **50**, 81
lid, 39, 57, 59
shell, *see* `spawn`
sky flats, 59–61
sliced image, 63, 108
`snapi`, 38
spatial sampling
asymmetry, 10, 67
dither pattern, 10, **67**
`spawn`, **43**, 54
specifications, 14
spectral coverage, 14, 17, 29
center pixel, 30
spectral mode, 29, 69–72
resolution modes, 14
stake spectrum, 85
standards
atmospheric, *see* G-star
photometric, 12, 79–80, 103
statistics in box, 42
status display, 28
`sweep`, **40**, 82, 83
system crash, *see* restarting

tape, 91
tertiary
commands, 36

motors, 24
thermal regime, 7, 24
`tint`, 15, **37**, 44, 59, 68
tip-tilt, **44**
commands, *see* MINC
operation, 46
tipping-up, 25
transfer of data, 89

user defined commands, 43

VAX shell, *see* `spawn`
vignetting
D80, 29
spectral, 29

`wait`, 41
wavelength
range, 10, 14
selection, 14, 36
standardizing, 10
`wfpc2fit`, 91