GNIRS

GEMINI NEAR INFRA-RED SPECTROGRAPH

USERS MANUAL

GNIRS
Users Manual

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1. Introduction

This is the Users Manual for the Gemini Near-Infrared Spectrograph (GNIRS). GNIRS is a 0.9-5 μm spectrograph that supports a variety of observing configurations, including long-slit, cross-dispersed, IFU, and polarization analysis modes, as well as two different pixels scales and several different spectral resolutions.

The GNIRS Users Manual is organized in several major sections, plus this introduction.

The first major section comprises an overview of the instrument. It is intended to provide the information a prospective user of the instrument might need, first, to determine whether the instrument is suitable for his or her scientific needs, and then to write a proposal to use the instrument on Gemini.

The second major section describes how to observe with the instrument. The information contained therein allows a user to prepare an observing program, and to carry it out at the telescope. For observers assigned queue time, not all parts of this section are relevant. Calibration data and initial data reduction procedures are also discussed in this section. Portions of this section may be relevant when writing a proposal, if calibrations or observing strategies are a concern.

The remaining sections are primarily relevant for people responsible for supporting the instrument - that is, the instrument scientist and other observatory staff more than the visiting classical observer. Procedures for setting up and shutting down the instrument are described, as well as basic trouble-shooting procedures. In general, visiting astronomers will not find themselves carrying out procedures described here, and should certainly embark on them with caution.

Additional procedures related to servicing and calibrating the instrument are found in the Service and Calibration Manual.

2. Instrument Overview

This section provides an overview of GNIRS, including a functional description (2.1), on-telescope performance of the science channel (2.2), including a discussion of observing modes (2.3), and performance of the available wavefront sensors (2.4).

2.1 Instrument Description

GNIRS is a cryogenic 1-5 μm spectrograph with an on-instrument wavefront sensor (guider). The spectrograph can be operated in a variety of different observing mode, including a choice of 2 pixel scales, 3 spectral resolutions, different cross-dispersion options, and an integral field mode. The two pixel scales are provided by cameras with different focal lengths.

The light flow through the instrument is shown in Figure 2.1

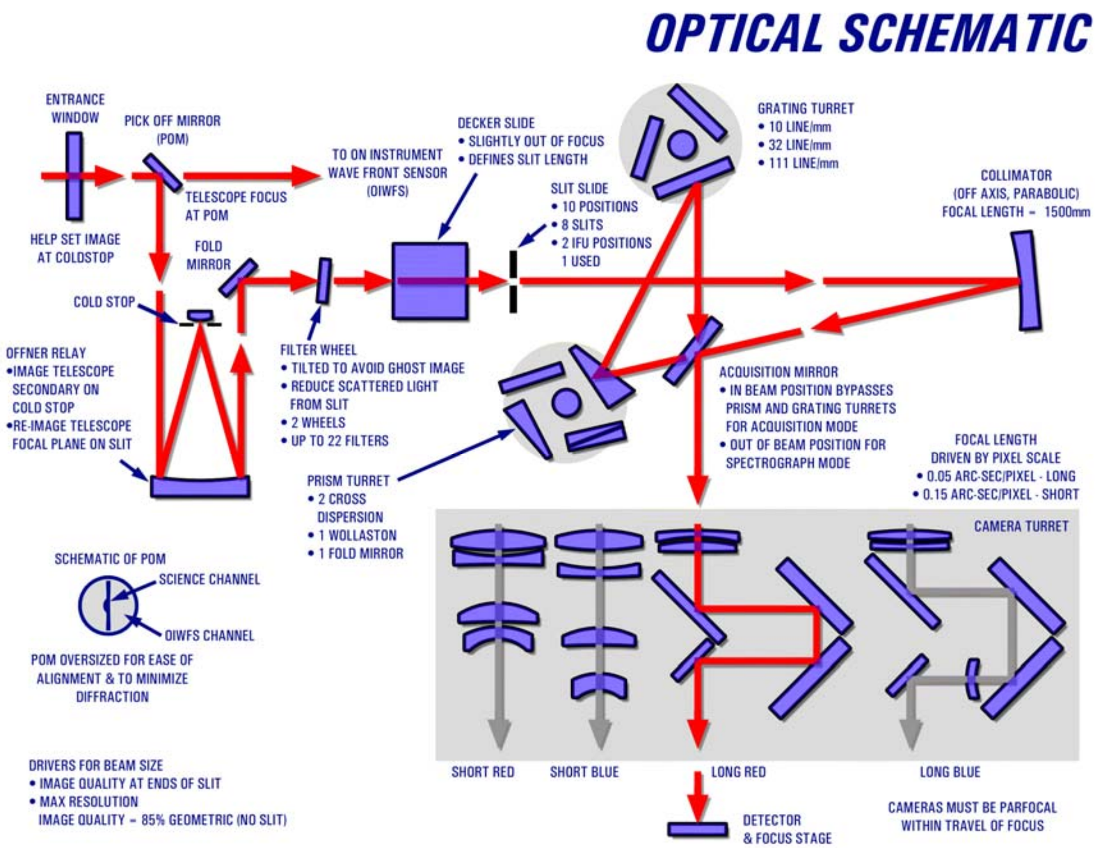

Figure 2.1. "Optical schematic" for GNIRS, showing light flow through the science channel.

The instrument opto-mechanical layout is shown in Figure 2.2.

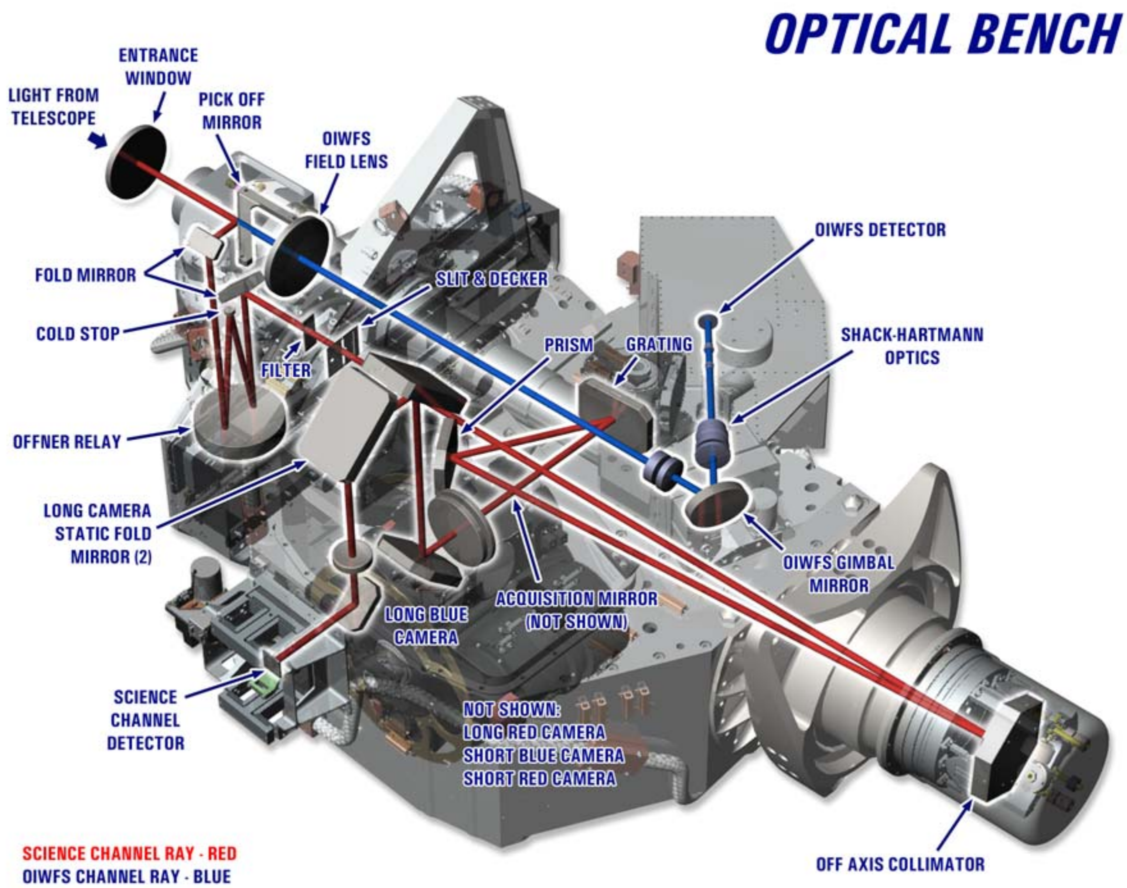

Figure 2.2. Instrument internal structure, showing light paths. The light path in red is the path through the spectrograph, starting at the entrance window (which is not shown). The light path in blue is the path through the OIWFS, starting at the pick-off mirror. The actual internal structure of the instrument differs in some details from this figure.

Both the science channel and the on-instrument wavefront sensor are mounted within a cold structure contained within a vacuum vessel. The instrument electronics are mounted externally. The cold structure is operated at a temperature of ~60K in order to minimize excess background on the detector.

2.1.1 Spectrograph Description

The spectrograph design is a fairly conventional one for infrared spectrographs. There are two main sections: a fore-optics section, which provides field and pupil stops to limit excess background, and a spectrograph section, which disperses light from the object of interest.

2.1.1.1 Fore-Optics

The fore-optics comprise the following elements:

- Entrance window
- Pick-off mirror
- Entrance fold mirror
- Offner relay (primary and secondary mirrors)
- Exit fold mirror
- Filter wheels

The entrance window also acts as a weak lens, in order to ensure that the telescope secondary is imaged on the Offner secondary mirror, which is where the cold stop is placed.

The pick-off mirror acts as a crude field stop, defining the field accessible to the spectrograph. Light from the rest of the instrument field (roughly 3 arcminutes diameter) is available in principle to the OIWFS (see 2.1.3). The unvignetted field defined by the pick-off mirror is basically a 10 x 100 arcsecond strip with a superposed half circular field 15 arcseconds in radius centered on the optical axis, as shown schematically in Figure 2.3.

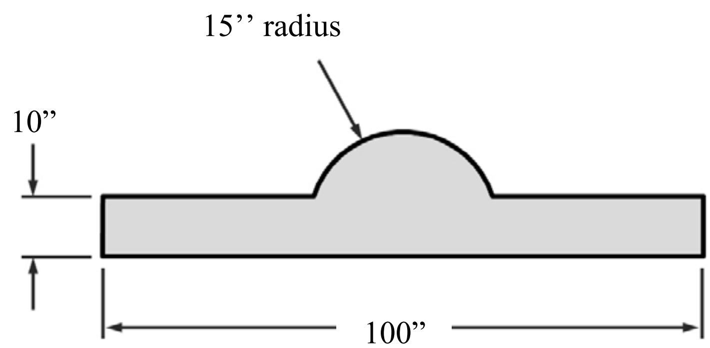

Figure 2.3. GNIRS spectrograph field of view. The long dimension is 100 arcsec; the width is 10 arcsec except for the additional 15-arcsec semi-circle.

The purpose of the semi-circle is to provide a somewhat larger field for target acquisition and identification, while at the same time allowing use of guide stars close to targets of interest. The pick-off mirror is tilted at 45 degrees, and is therefore exactly at the telescope focus only in the center of the slit. The mirror widens away from its center to ensure that the spectrograph field is unvignetted. The field available for guiding is discussed in section 2.1.3.

The Offner relay is serves two functions: it produces an image of the telescope secondary on the Offner secondary, where a cold stop is located, and it re-images the telescope focal plane onto the spectrograph slit. The scale at the slit is the same as at the telescope focal plane.

The spectrograph contains two filter wheels. Each wheel can accommodate 9 filters, in addition to an "open" position. The first wheel uses several of the positions for focus masks, a dark position, and a lens used to view the telescope pupil during alignment (see below). These can be used in series with filters in the second wheel. The remaining positions in the first wheel can be used for back-up filters.

The current filter complement for the instrument is listed below; prospective observers should verify (e.g., via the Gemini web site) that these are the filters that will be available at the time they wish to observe.

Table 2.1 GNIRS Blocking Filters

Position Number	**Filter Wheel 1**	**Filter Wheel 2**
0	open	open
1	pupil viewer lens 1	order 1 (4.4-6.0 μm)
2	cross disp (0.9-2.5 μm)	order 2 (2.90-4.25 μm)
3	order 2 (2.90-4.25 μm)	order 3 (1.92-2.54 μm)
4	open	order 4 (1.47-1.80 μm)
5	open	order 5 (1.17-1.37 μm)
6	open	order 6 (1.03-1.17 μm)
7	dark	cross disp (0.9-2.5 μm)
8	left mask	open
9	right mask	open

Note that the sorting filters for orders 3, 4, and 5 are roughly equivalent to broadband K, H, and J filters respectively. The long wavelength cut-off of sorter 3 is significantly longer than for standard K filters; as a result, the sensitivity for target acquisition will be worse due to increased background (see section 3.1.4 for more on acquisition procedures).

The filters are slightly tilted (2.7 degrees) to reduce ghost images; this is also why the filters precede the slit.

Because the filters are located in a converging beam, they all have the same optical thickness in order to avoid refocusing the telescope each time a filter is changed. This also ensures that filter changes keep the object centered on the slit. Any user-supplied filters must have the same thickness (equivalent to 3 mm of BK7) in order to operate properly. (Users considering supplying such filters *must* check with Gemini beforehand, as installation of such filters requires considerable prior planning.)

2.1.1.2 Spectrograph

The spectrograph section consists of the following elements:

- Slit/Decker/IFU (2 mechanisms)
- Collimator
- Acquisition mirror
- Prism turret
- Grating turret
- Camera turret
- Focus stage/detector mount

The spectrograph entrance slit is defined by two mechanisms. The width of the slit is defined by the one of several slits in a photo-etched mask located in the slit slide, while the length of the slit is defined by one of several openings in the decker slide. The integral field unit (IFU) is also mounted in the slit slide; there is a location for a second IFU unit, currently occupied by a dummy module of similar mass.

The slit mask is located at the re-imaged focal plane, while the decker apertures are slightly ahead of it, and therefore somewhat out of focus (by a few pixels). The decker sizes are matched to the full width of the array in long slit mode, or to the minimum spacing between adjacent spectra when the prisms are used. The slit mask in the instrument can be changed, although it should not be considered a routine operation. The slit widths currently available are listed below, as are the decker lengths (Tables 2.2 and 2.3).

Table 2.2 GNIRS Slit Widths

Mask Position	Slit Width		
	arcsec	short camera pixels[a]	long camera pixels[a]
1	dark		
2	3.0	20	60
3	1.0	6.7	20
4	0.20	1.3	4
5	0.15	1.0	3
6	0.10	0.7	2
7	acquisition (Figure 2.2)		
8	0.30	2	6
9	0.45	3	9
10	0.60	4	12

[a]Widths in pixels are for lowest resolution grating and the acquisition mirror. Projected widths with the 32 l/mm and 110 l/mm gratings are reduced by 5% and 22% respectively.

In addition, the slit slide can be positioned to use the integral field unit (see 2.1.1.4) or to use the pupil viewer; for the latter a second lens is placed in the beam (used in series with the lens in filter wheel 1).

Table 2.3 GNIRS Decker Lengths

Decker Position (Configuration)	Usable Length (arcsec)
Spare	1.2
Long Camera Cross-Dispersion	3.1
Short Camera Cross-Dispersion Integral Field Unit	6.1
Wollaston Prism (both scales)	14.3
Long Camera Long Slit	49.4
Short Camera Long Slit	99
Acquisition	99
Spare	1.2
Pupil Viewer	Not Applicable

The partially vignetted lengths of the slits are all approximately 0.5 arcsec longer than the values given above.

There is also a decker position for the pupil viewing configuration.

The next element after the slit and decker is the collimator, an off-axis paraboloid of 1500 mm focal length. The collimator mount includes a system of adjustable weights, which provide partial compensation for internal flexure in the instrument. This is a passive system, where gravity acts on a set of weights and levers to tilt the mirror slightly with varying orientation of the instrument. The largest corrective tilt of the mirror is less than 7 arcseconds.

After the collimator, a mirror can be inserted in the beam to direct the light into the spectrograph cameras, without being dispersed. This acquisition mirror allows the observer to identify, acquire, or recenter objects via broadband imaging, without the need to alter grating and prism tilts. This facilitates prolonged observing sequences on faint objects, since the dispersive settings remain stable even while target positions are checked.

The position of the acquisition mirror is shown in Figure 2.2, where the return beam from the collimator crosses the beam into the camera. When inserted, it diverts the light at the point where the two beams cross.

If the acquisition mirror is out of the beam, light goes from the collimator to the prism turret. The prism turret has four possible positions.

Table 2.4 GNIRS Prisms

Position	Application
Mirror	Long slit mode for all 4 cameras
Long camera cross-dispersion	Used with long blue camera, 10 l/mm grating for 0.9-2.5 μm coverage
Short camera cross-dispersion	Used with short blue camera, 32 l/mm grating for 0.9-2.5 μm coverage
Wollaston prism	Polarization mode for all 4 cameras

The mirror is used for work beyond 3 μm, or when one wants to work with a long slit at shorter wavelengths. The two cross-dispersion prisms provide a cross-dispersed low resolution spectrum over the approximate range 0.9-2.4 μm, where the two prisms are matched to the two pixel scales produced by the cameras. A complete spectrum is produced at a resolution of ~1700 (2 pixels); use of higher spectral resolution results in more or less parallel portions of multiple orders but not a complete spectrum. The Wollaston prism separates the two linear polarization components of the light, and can be used through the L band. Because there is substantial internal polarization in the spectrograph itself, the Wollaston prism configurations must be used with GPOL on the telescope's up-looking port.

From the prism turret, light goes to the grating turret. The grating turret contains three gratings.

Table 2.5 GNIRS Grating Resolutions

Grating	Long Camera Resolution	Short Camera Resolution
10.44 l/mm	1700	570
31.7 l/mm	5100	1700
110.5 l/mm	17800	5900

All three gratings are blazed for 6.8 μm (first order Littrow), which provides an effective first order blaze wavelength of 6.6 μm in the configuration actually used (scattering angle of 27 degrees).

The different orders of the gratings then correspond fairly well to the atmospheric windows at 5, 3.5, 2.2, 1.6 and 1.2 μm for orders 1 through 5 respectively; the sorting filters specified in Table 2.1 cover the free spectral range of the individual orders, with some allowance for filter roll-off. A filter for order 6 is also supplied; the orders above 5 don't match the atmosphere particularly well.

The resolutions provided by the gratings are tabulated above (Table 2.5). The values given are with the gratings operated at the blaze peak. Tilts to longer wavelength provide somewhat higher resolution, while tilts to shorter wavelengths provide lower resolution. (The resolution in wavelength units is nearly constant for a given order, regardless of tilt.)

The quoted resolutions are all for 2 pixels at the detector, specified as $\lambda/\Delta\lambda$.
The detector is 1024 x 1024 pixels, so there are roughly 512 resolution elements in the dispersion direction. For the R=1700 mode, this corresponds to coverage $\Delta\lambda/\lambda$ of roughly 30%.

From the grating turret, light then passes to the camera turret. The camera turret contains four cameras.

Table 2.6 GNIRS Cameras

Camera	Wavelength Range	Focal Length/Pixel Scale
Long blue camera	0.9-2.5 μm	1305 mm/0.05 arcsec
Long red camera	2.9-5.5 μm	1305 mm/0.05 arcsec
Short blue camera	0.9-2.5 μm	435 mm/0.15 arcsec
Short red camera	2.9-5.5 μm	435 mm/0.15 arcsec

The blue cameras will not work at longer wavelengths; the red cameras can be used at shorter wavelengths, but with somewhat degraded image quality and transmission. The main short wavelength use of the red cameras below 3 μm is for acquisition of targets in the K band (sorter 3). (See 3.1.4 details.)

All four cameras are close to parfocal; the longer focal lengths are achieved by folding the beam with a combination of mirrors in the camera barrel and external to the turret. The light path shown in Figure 2.2 is for one of the long cameras, so one can see the folded light path.

The detector is mounted at the output of the cameras, on a focus stage. The focus stage provides correction for the small focus differences between the different cameras (and potentially other small focus changes produced by other changes in configuration). The detector is a 1K x 1K ALADDIN III InSb array, which is operated at a temperature of approximately 31K.

The detector and its controller can be operated at frame rates in excess of 1/sec, allowing operation at 5 μm with either camera at any spectral resolution (imaging at 5 μm for acquisition purposes is [probably] not possible). Individual frames can be co-added and then sent to the Gemini Data Handling System (DHS) to ensure a more manageable data flow.

For these high background observations, the main concern is minimization of overhead, since the principal noise source is photon noise from the background. At shorter wavelengths, especially at higher spectral or spatial resolution, detector read noise can be significant, even for relatively long exposures. In these situations, the detector can be read out non-destructively, so the read noise is reduced by multiple sampling (Fowler sampling). For long exposures and low background, the improved noise performance more than compensates for the increase in overhead involved.

2.1.1.3 Detector and Controller Properties

The two detector/controller properties that directly affect signal to noise are read noise and dark current. Read noise can be reduced by multiple sampling ("Fowler sampling"), at the cost of additional overhead in the form of time spent on the extra reads. In addition, the effective well size limits how much signal can accumulate.

The relevant properties are tabulated below, for the GNIRS ALADDIN III array (Ser. # 410793):

Table 2.7 - GNIRS Detector Properties

Read Noise (single read)	37 electrons
Read Noise (max useful multiple reads)	7 electrons
Single Read time	0.185 sec
Max. Useful Read Time	~36 sec
Mean Dark Current	0.1 electrons/sec/pixel
Well size (<10% non-linearity)	110,000 electrons
Gain	13 electrons/ADU

Further details on this subject are found in section 2.3.1.

2.1.1.4 Integral Field Unit

The integral field unit (IFU) is an additional optical system, provided for GNIRS by the University of Durham (UK). The IFU takes a rectangular input field, of approximate dimensions 3.3 x 4.8 arcsec, and divides it into 22 slices 0.15 arcsec in width. The IFU optics (see Figure 2.4 eventually) map the slices of the rectangular field onto the input plane of the spectrograph, aligning the slices more or less along the regular input slit position (the slices are offset from each other by roughly 2 pixels/slice).

The optics also change the input scale to 0.12 arcsec/pixel along the slit, and 0.075 arcsec/pixel in the dispersion direction. The IFU is intended to feed the short cameras, and therefore can be operated at a maximum resolution of ~5900.

[Figure 2.4 here]

Figure 2.4. Integral Field Unit Optics Layout.

2.1.2 Spectrograph Configurations

With multiple filters, slits, prisms, gratings, and cameras, there are in principle a very large number of possible configurations. Although the instrument can be configured to any of these, in practice only a much smaller number are of interest. These are tabulated below for reference.

Table 2.8 Acquisition Configurations

ID #	Name	Filter	Slit	Decker	Acq Mirror	Prism	Grating	Camera
1	SBAcq	sorter 3-7	acquisition	acquisition	in	N/A	N/A	short blue
2	SRAcq	sorter 1-3[a]						short red
3	LBAcq	sorter 3-7						long blue
4	LRAcq	sorter 1-3[a]						long red

Notes:
[a]Ability to read array with sorter #1 uncertain, not a requirement

Table 2.9 Spectroscopic Configurations

ID #	Name	Filter	Slit	Decker	Acq Mirror	Prism	Grating	Camera
5	SB10	sorter 3-7	0.3 arcsec[b]	100 arcsec	out	mirror	10.44[c]	short blue
6	SB31						31.7	
7	SB111						110.5	
8	SBXD	broad-band		6 arcsec		short prism	31.7[d]	
9	SB10P	sorter 3-7		14.4 arcsec		Wollaston	10.44[c]	
10	SB31P						31.7	
11	SB111P						110.5	
12	SB10IFU		IFU	6 arcsec		mirror	10.44[c]	
13	SB31IFU						31.7	
14	SB111IFU						110.5	
15	SR10	sorter 1 & 2	0.3 arcsec	100 arcsec			10.44[c]	short red
16	SR31						31.7	
17	SR111						110.5	
18	SR10P			14.4 arcsec		Wollaston	10.44[c]	
19	SR31P						31.7	
20	SR111P						110.5	
21	SR10IFU		IFU	6 arcsec		mirror	10.44[c]	
22	SR31IFU						31.7	
23	SR111IFU						110.5	
24	LB10	sorters 3-7	0.1 arcsec[b]	50 arcsec			10.44	long blue
25	LB31						31.7	
26	LB111						110.5	
27	LB10XD	broad-band		3 arcsec		long prism	10.44[d]	
28	LB10P	sorters 3-7		14.4 arcsec		Wollaston	10.44	
29	LB31P						31.7	
30	LB111P						110.5	
31	LR10	sorters 1		50 arcsec		mirror	10.44	long red

32	LR31	& 2					31.7	
33	LR111						110.5	
34	LR10P			14.4 arcsec		Wollaston	10.44	
35	LR31P						31.7	
36	LR111P						110.5	

Notes:
[b]Slit listed is width optimally sampled at detector; other widths can be used
[c]Spectrum does not fill entire detector width
[d]Grating listed provides complete 0.9-2.5 µm spectrum; other gratings can be used

In principle, *any* configuration can be used for diagnostic purposes. However, the two main optical diagnostics contemplated for the instrument are pupil viewing and focus tests. Note that, unlike the configurations listed in the two preceding tables, there are more variables in entries below.

Table 2.10 Regular Diagnostic Configurations

ID #	Name	Filter	Slit	Decker	Acq Mirror	Prism	Grating	Camera
37	Pupil View	FW 1: pupil view lens #1; FW 2: sorters 2-4	pupil view lens #2	pupil view	in	N/A	N/A	long blue or long red
38	Focus test	FW 1: pupil masks; FW 2: any	Focus tests may be done on any configuration listed in Table 1 and Table 2 except for filters in FW 1.					

2.1.3 On-Instrument Wavefront Sensor

The OIWFS was built for GNIRS by the Institute for Astronomy (Hawaii). The light path is also shown in Figure 2.2. Light from the guide field - anything in a 3 arcminute diameter field that misses the pick-off mirror - enters the OIWFS field lens and then passes to a collimator doublet and then a 2-axis gimbal mirror.

The gimbal mirror can be tilted precisely to direct light from any part of the guide field to the rest of the OIWFS optics. The usable field is roughly 10 arcsec diameter, which is sufficient to acquire individual guide stars.

Light from the selected patch of sky is reflected off the gimbal mirror, through a second doublet, and the guide star is re-imaged on the filter wheel, which contains JHK filters and apertures.

From the filter wheel, light enters the Shack-Hartmann optics, which are mounted on a "snout" on the detector mount. The Shack-Hartmann optics form a pupil image at a shallow four-facet prism, then reimage the star on the detector. Because the light has passed through the S-H prism, four images of the star are actually formed, corresponding to 1/4 of the pupil each. Only a small portion of the array is read out, allowing rapid data rates, which permit the OIWFS to provide high-speed tip-tilt and focus correction in addition to slower flexure and tracking correction. For fainter guide stars, fast correction is limited to tip-tilt and does not include focus.

The OIWFS filter wheel contains standard JHK filters. In principle, users should select the filter that provides the best signal to noise on the guide star (normally H), since the telescope's acquisition and guide (A&G) system adjusts the OIWFS gimbal mirror position to compensate for differential refraction between the guide wavelength and the observing wavelength.

See section 2.4.1 for OIWFS performance, and 3.2.2 for information on OIWFS operation.

2.1.4 Cryostat

The cold structure shown in Figure 2.2 is contained within a larger cryostat, shown in cutaway view below (Figure 2.5). The internal structure is maintained at a temperature of approximately 60K using 4 Leybold RG 5/100 cryocoolers. The initial cool-down of the instrument can be done either with the cryocoolers alone, which takes over a week, or with the assistance of a liquid nitrogen pre-cool system, which allows the instrument to reach operating temperature in 3 days.

The cryostat is a large vacuum vessel, which contains two aluminum passive shields and a third shield that is connected to the cryocoolers. These act to minimize heat radiated and conducted into the cold structure, which would otherwise produce unacceptable temperature gradients and gradient variations under varying ambient conditions. In addition, a temperature control system adds varying amount of heat to the cooling system to ensure that the structure is maintained at a constant temperature (±1K or better).

The window at the front of the cryostat has a motor-operated cover that is closed to protect the window when the instrument is not in use. As it is an external warm device, it cannot be used as a "dark slide". There is a manual override on the cover so that the window can be protected even in the event of a power failure.

The window can cool below the dew point in conditions of high humidity, so the window mount provides a slow flow of dry air across the window to avoid condensation. This also helps to keep dust off the window.

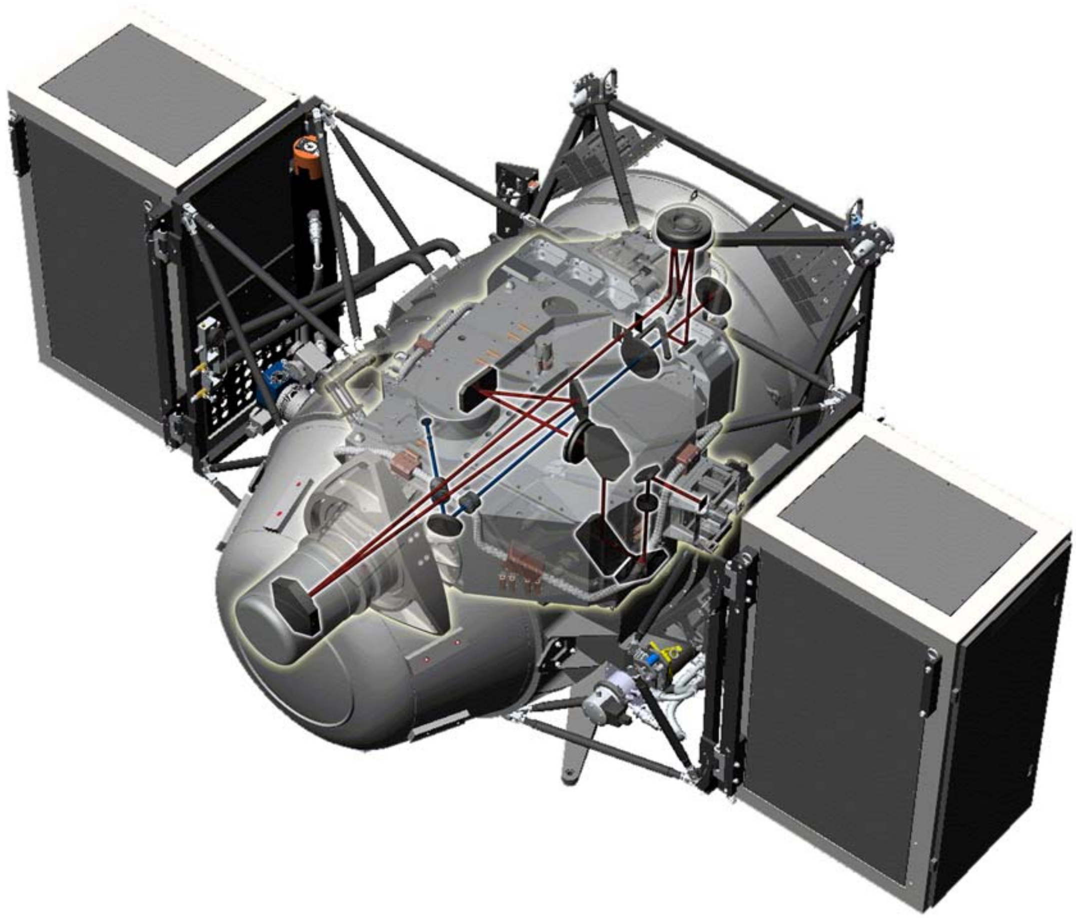

Figure 2.5. Cutaway view of instrument assembly, showing cold structure inside cryostat, electronics boxes and trusses. The instrument is shown mounted on a face of the Gemini ISS. Note that the bench structure is upside down compared with Fig. 2.2.

2.1.5 Electronics Enclosures

As with all Gemini instruments, the GNIRS electronics are mounted on the instrument to facilitate instrument changes and minimize the complexity of the connections between the instrument and telescope. The electronics are mounted in two thermal enclosures, which are insulated, glycol-cooled boxes that minimize heat dissipation from the electronics into the telescope environment.

One of the enclosures (lower right in Fig. 2.5) contains the science array controller, which handles operations of the ALADDIN array, including initial processing steps such as non-destructive reads and co-addition.

The second enclosure (upper left in Fig. 2.5) contains all the other instrument electronics, including the OIWFS electronics, instrument motor and temperature controls, and the instrument's VME crate.

The instrument fits (barely) within Gemini's allowed instrument envelope, and is approximately 2.2m long x 2.5 m wide x 1.3 m high (side-looking orientation). The instrument weight is just under 2 metric tons; ballast is added to bring its weight up to 2000 kg to balance it against other instruments on the Gemini instrument support structure.

2.2 Science Channel Performance

The performance of the science channel depends on the instrument configuration and details of the observations. In general, though, all observations with GNIRS can be thought of as comprising a measurement of the object and a measurement of the background, which are then differenced.

The signal is the flux from the object, minus any light losses (slit losses, absorptions and reflections, etc.), converted to detected electrons.

The noise is the combined effects of photon noise from the object+sky, photon noise from the subtracted background, photon noise from dark current and internal background, and detector read noise.

Summary sensitivity tables are given below (2.2.1) for some standard configurations and conditions; details are provided in subsequent sections (and yet more information in Appendix A). In general, the Gemini integration time calculator (ITC) should be used, when it becomes available, for best estimation. However, the following sections and the appendix can be used until then, and also serve to show the considerations that go into the ITC.

2.2.1 Sensitivity Summary

2.2.1.1 Baseline Observing Sequence

For observations of objects comparable in size to the slit length or IFU dimensions, the background observation is actually a separate observation taken by moving away from the object onto blank sky. For observations with a small object or a long enough slit, it is possible to position the object successively at different positions on the slit, and thus use a single observation for both object measurement and background measurement. For example, if one can measure 5 different slit positions, at any one position there is one "object" measurement and 4 "background" measurements, which can be combined. In the limiting case of very many slit positions, the noise contribution from the background determination become negligible, and has taken no additional time. Compared with the simple "on-off" case, the multi-position observation will take roughly 1/4 the time to achieve the same signal to noise.

This discussion assumes that it is possible to provide the same type of spectral extraction for the different cases. If doing a smaller number of positions provides enough signal to noise for optimal extraction, but this is not possible for a large number of positions, then the smaller number may be better. Also, for the shorter slits (cross-dispersed modes in particular), there may not be enough positions except in very good seeing. Again, use of the ITC should help in these decisions.

All the tabulations below *assume* that data were taken at a large number of positions along the slit. Therefore, for objects comparable in size to the slit, observation times must be increased by a factor of 4. For objects where only a small number of positions can be observed (2 or 3), there is a smaller increase in the time required.

2.2.1.2 Overheads

The tabulations do not include any allowance for overhead. This should be allowed for explicitly. The following rules can be applied provisionally:

- Initial set-up. This includes moving the telescope to the object, acquiring the guide star in the OIWFS, acquiring the object on the slit, and configuring the instrument. Allow 15 minutes.
- Instrument reconfiguration. This occurs when the instrument configuration is changed but the object to be observed is the same. For most changes (filters, grating tilt), the time required will be <1 minute.
- General overhead. This includes allowance for moving the telescope between positions on the slit (or on and off), detector readout and write time, periodic checks of object centering (for long observation sequences). 10% of the calculated total integration time should be allowed for these purposes. This will increase for longer wavelength observations, especially M band, where it may approach 50%.

Note that the calculated observing time required for standards will approach half an hour for typical observations, even though the actual integration time will be a few minutes. The manual should include an estimate of time requirements for standard star observations once we have experience at the telescope.

2.2.1.3 Performance Completeness

The night sky background is not a smooth function of wavelength, as demonstrated in Figures 2.6 and 2.7, which show low-resolution night sky spectra.

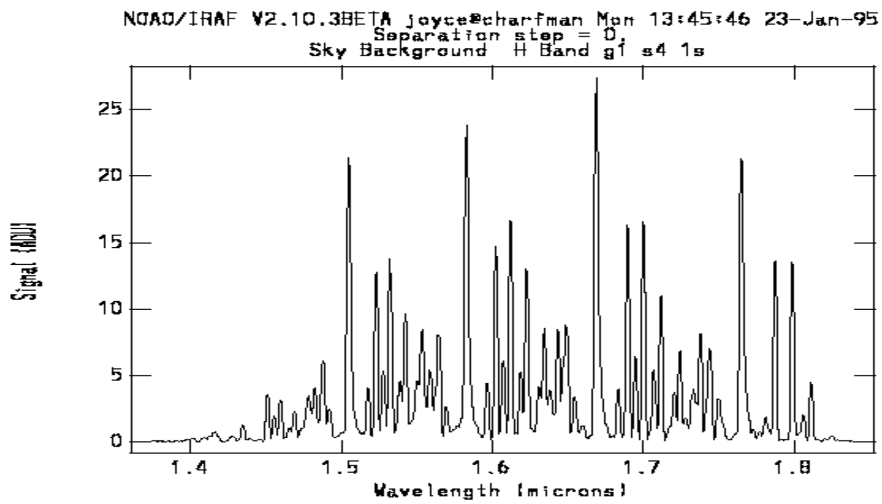

Figure 2.6. CRSP H-band night sky spectrum at resolution ~1400. [Replace with R=1700 GNIRS spectrum when we have one.] At this resolution, the background varies by well over an order of magnitude between different wavelengths in the band. As a consequence, signal to noise will also vary by substantial factors, possibly approaching a factor of 10 in this case.

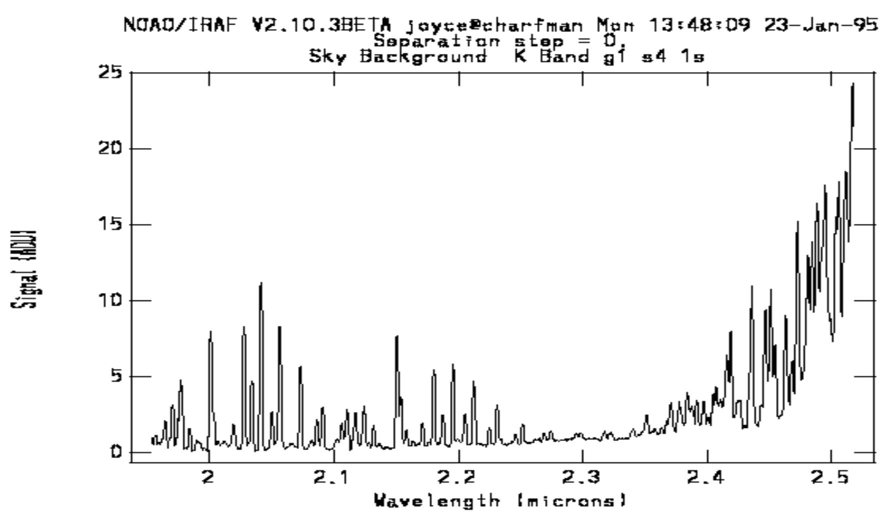

Figure 2.7. The same as Fig. 2.6, but for the K band. Note the rising thermal background beyond about 2.4 μm.

The situation in other bands and at other resolutions is generally similar, although it is the case that at longer wavelengths there is more continuum flux (so maximum contrast is less). Also, at higher resolutions the spectrum increasingly breaks up into resolution elements with and without lines; at R~18000 roughly 90% of the spectrum does not contain strong lines. (There will still be enough lines for a reasonable wavelength calibration.)

It is clear, therefore, that a sensitivity estimate based on the *average* background within a spectral window is not necessarily that useful, though it is easy to calculate. Therefore, for this manual, *90^{th} percentile* sensitivity is also calculated, which is the value where 90% of the resolution elements in the spectrum will have greater than the specified signal to noise, and 10% will have less. It turns out that, due to the nature of the night sky spectrum, average background is roughly equivalent to 75^{th} percentile background.

The ITC should be used when available, as this provides the most accurate estimates. This is particularly true when what is of interest is a specific feature or features rather than a complete spectrum.

2.2.1.4 Standard Observing Conditions

Since many Gemini observations are taken in queue mode, where observing conditions are specified, it is necessary to indicate which conditions are relevant, and also which were used for the baseline calculations provided here.

There are five main observing constraints:

- Image quality ("seeing")
- Cloud cover
- Water vapor
- Sky background
- Air mass (zenith distance)

Image quality values relevant to GNIRS are tabulated below. Note that these are the values used in computations in this manual; if Gemini changes the specifications both this table *and* the computations must be changed.

Table 2.11 - Gemini Image Quality Constraints
Image FWHM (arcsec)

Wavelength	20^{th} percentile	50^{th} percentile	85^{th} percentile	"any"
0.9 µm	0.40	0.75	1.05	1.70
1.2 µm	0.35	0.55	0.80	1.55
2.2 µm	0.30	0.50	0.75	1.40
3.4 µm	0.30	0.45	0.70	1.25

Image quality at wavelengths beyond 3.4 μm will be similar to that at 3.4 μm.

Results are provided below for both 20th and 50th percentile conditions. Trade-offs involved in selecting better or worse image quality are discussed in 2.2.2.

Cloud Cover. All calculations assumed conditions were "photometric", which corresponds to 50th percentile cloud cover. The presence of cloud is undesirable for two reasons - signal is attenuated, and background will be more variable, complicating sky subtraction. Note that observations under marginally photometric conditions are reasonable, since GNIRS spectra will not normally have high absolute photometric accuracy anyhow (see section 3.4).

Water Vapor affects much of the L and M bands, and the edges of atmospheric windows (near water bands). You should investigate the exact circumstances of your observations (look at atmospheric spectra in the ITC) to determine whether drier conditions will make enough difference to request them. See Figure 2.7 (below) for an example of calculated transmission for dry conditions. Water vapor at Gemini South has a strong seasonal dependence, so observations requiring dry conditions will be far more difficult in the summer (essentially, 20th percentile conditions will occur much less than 20% of the time then). Because the affected regions typically contain strong, saturated lines, observations that require dry conditions will be best done with the driest conditions realistically available.

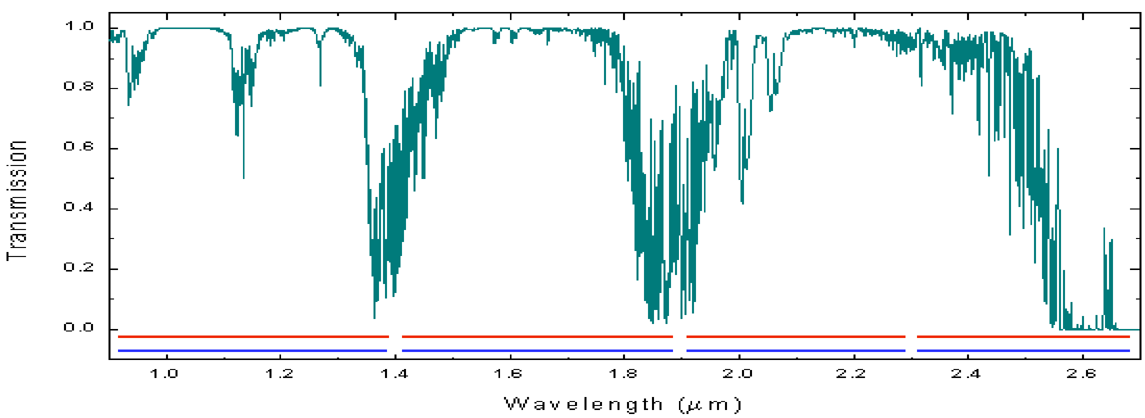

Figure 2.7. Calculated transmission for 0.9-2.7 μm for 1.6 mm precipitable water on Mauna Kea. This corresponds to very best conditions on Cerro Pachón. One can see which regions might be usefully observed in dry conditions, but not otherwise.

Sky Background in the near infrared effectively divides into "night" (80th percentile) and "twilight". Background is both higher and variable during twilight, so observers will seldom gain much by trying to observe at these times. All calculations use standard night sky conditions (2.2.4). Note that there is no reason to request gray time even for the shortest wavelengths; scattered moonlight is not significant. The only exception will be for objects located in the ecliptic, where moonlight scattered off the telescope itself will cause problems.

Air Mass should generally be modest, as background, image quality and differential refraction all get worse with increasing airmass. All calculations assumed an airmass of 1.0, since the standard sky background and image quality specifications refer to zenith.

2.2.1.5 Sensitivity Tabulations

The following table provides magnitudes (referred to Vega=0.0) reached at 5 sigma in 1 hour of integration. For low background situations, the measurements are assumed to comprise 4 exposures of 15 minutes; for high background situations the lengths of the individual exposures are not relevant. The values tabulated are all for the long slit mode, i.e., with no prisms present. These are for a resolution element (2 pixels) and extraction of an optimal window (but not optimal, i.e., weighted, extraction).

Table 2.12 - GNIRS Sensitivity
5-sigma in 1 hour, 20th percentile IQ

Resolution/ Scale	Background	Order					
		6 ("x")	5 ("J")	4 ("H")	3 ("K")	2 ("L")	1 ("M")
1700/0.05"	ave	21.50	21.42	20.36	19.43	15.28	12.03
	90%	21.23	21.13	19.96	19.11	14.90	11.59
5100/0.05"	ave	20.09	19.97	19.24	18.47	14.35	11.21
	90%	19.98	19.84	18.94	18.20	13.97	10.78
17800/0.05"	ave	19.16	19.04	18.54	17.77	13.83	10.80
	90%	19.11	18.98	18.33	17.57	13.45	10.36
1700/0.15"	ave	21.93	21.76	20.52	19.59	15.32	12.18
	90%	20.54	21.36	20.08	19.26	14.94	11.74
5900/0.15"	ave	21.32	21.16	20.04	19.07	14.90	11.77
	90%	20.98	20.81	19.61	18.74	14.42	11.33

5-sigma in 1 hour, 50th percentile IQ

Resolution/ Scale	Background	Order					
		6 ("x")	5 ("J")	4 ("H")	3 ("K")	2 ("L")	1 ("M")
1700/0.05"	ave	20.68	20.60	19.54	18.61	14.45	11.21
	90%	20.41	20.31	19.13	18.29	14.07	10.77
5100/0.05"	ave	19.28	19.15	18.42	17.65	13.52	10.39
	90%	19.17	19.03	18.12	17.38	13.15	9.95
17800/0.05"	ave	18.35	18.22	17.72	16.95	13.00	9.97
	90%	18.29	18.17	17.51	16.75	12.62	9.54
1700/0.15"	ave	21.26	21.10	19.85	18.91	14.64	11.50
	90%	20.86	20.69	19.41	18.58	14.26	11.06
5900/0.15"	ave	20.66	20.50	19.37	18.39	14.12	11.09
	90%	20.31	20.14	18.94	18.07	13.74	10.65

For observations with the Wollaston prism, there will be two spectra, plus some reflection losses and vignetting in the prism, so the magnitude required to get 5 sigma in each spectrum is roughly 0.5 mag brighter than the tabulated values for background-limited observations, and roughly 0.9 mag brighter than the tabulated values for detector-limited observations.

For observations in cross-dispersed mode, there are some reflection losses in the prism, as well as absorption losses in the K window (mainly at the red end). The color of the object determines whether the limiting sensitivity is set at the short or long wavelength end of the spectral region covered with the prism; the decrease in sensitivity ranges from ~0.1 mag at the shorter wavelengths to ~0.3 mag at the longest wavelengths.

Sensitivity with the IFU is more complicated, because one wants to look at sensitivity for each spatial sample. IFU observations will generally be done under very good seeing conditions. A rough approximation is to use the *long camera* sensitivities, even though the actual configuration uses the short camera.

2.2.1.6 Long vs. Short

Under the same image quality conditions (except for very best conditions, i.e. ~10th percentile), the short cameras will provide better performance than the long cameras. The difference is most significant at R=5100/5900, where the short camera configuration uses a more efficient grating. At R=1700, the short camera grating is less efficient and performance is more nearly comparable. The short camera configurations use fewer pixels along the slit, so there is a reduced contribution from read noise and dark current, which is significant at short wavelengths (mainly xJH).

The long camera is therefore mainly recommended in two cases:

- R=17800 is needed
- High spatial resolution along the slit is needed

2.2.2 Wavelength Calibration

The night sky will always have enough well-defined emission features to provide a good wavelength calibration. In addition, the on-telescope calibration unit (GCAL) provides the ability to observe arc lamps for set-up when the dome is closed.

One should not rely on the instrument control software for more than rough calibration (good to about 10 pixels for center wavelength). The accuracy is limited by the grating turret repeatability and the approximations used in modeling the wavelength as a function of grating tilt and array position.

2.2.3 Slit Tilt and Curvature

The instrument is configured so that the spectrograph slit is aligned with the array columns when in long slit mode. This alignment is not exact, however:

- There is some residual error in the alignment, which leads to a net rotation of <1 pixel along a slit running the full width of the array (~1024 pixels).
- As with any long-slit spectrograph, there is also curvature along the slit. The size of the effect depends on the configuration. The displacement of the center position relative to the ends varies from less than 0.1 pixel to almost 3 pixels. The effect is larger for higher resolution and for the short cameras. There can be some change in the dispersion as well, in that the curvature varies slightly as a function of wavelength on the array.
- The cross-dispersed modes introduce a tilt of the slit image, which is a function of position on the array. For the short slits used in these modes, the tilt is modest but still significant, typically around 0.5 pixel end to end for extreme positions. In addition, the spectra themselves run at an angle on the array (i.e. constant slit position is not constant x position on the array). The angle is such that wavelengths seen in more than one order are at the same x position.
- The separation of the two polarizations in the Wollaston mode is a weak function of wavelength (decreases with increasing wavelength).

In general, these tilts should not have a substantial effect on the data. However, in some circumstances, it may be useful to shift spectra slightly before co-adding them. In the case of spectra using the full slit length, it may also be necessary to interpolate between multiple wavelength calibrations if precise wavelengths or velocities are required.

2.2.4 Spatial Resolution

In general, the optics in GNIRS provide spatial resolution along the slit as good or better than that implied by the pixel sampling. For the most part, even the short camera (0.15 arcsec pixels) samples the delivered image quality. Therefore, the instrument's spatial resolution should be considered to be that defined by the delivered image quality, except for 20th percentile image quality or better.

For this level of image quality, the resolution along the slit will be limited to ~0.3 arcsec for the short cameras, and will continue to be limited by the actual image quality for the long cameras.

The spatial resolution for the IFU is similar to that with the short cameras (0.12 x 0.15 arcsec samples), so the IFU resolution will also be "seeing-limited" until image quality reaches approximately 20th percentile.

2.2.5 Flexure

GNIRS undergoes flexure as the orientation of the instrument changes. There are three types of flexure that are relevant:

- Flexure of the instrument as a whole relative to the telescope (instrument support structure).
- Flexure of the OIWFS relative to the spectrograph slit (or PWFS if OIWFS cannot be used).
- Flexure between the spectrograph slit and the detector

The flexure of the instrument relative to the ISS has components of tilt and displacement. The displacement (under 2 arcsec maximum) is taken out by the OIWFS, and is small enough that effects on the image quality or plate scale are negligible. Note that if no guide star is available to the OIWFS, so that the PWFS must be used, flexure will be significant, and will require compensation using look-up tables. Recentering may need to be more frequent in this case.

The effects of tilt are to decenter the image of the telescope secondary on the instrument's cold stop (in the Offner relay). This leads to some vignetting and loss of signal. The maximum decenter is approximately 1% of the pupil diameter, which leads to an equivalent loss of signal. This effect is not significant, either in terms of overall sensitivity or photometric accuracy.

Flexure of the OIWFS relative to the spectrograph slit leads to progressive decentering of the object on the slit. This effect is (predicted to be) relatively small, with the dominant effect being flexure by the OIWFS mechanisms. The shifts on the slit produced by flexure are less than 20 microns for 1 gravity; light losses exceed 5% with the long camera for a 10 micron shift, which implies that recentering should be done approximately every 2 hours. The short camera can tolerate decentering 2-3x larger, so one needs to recenter for this purpose only every 4 hours or so.

Flexure between the slit and the detector leads to smearing of the spectrum in both directions for long accumulated exposures. The spectrograph collimator has a passive mechanical compensator that slightly adjusts tilt with varying gravity to minimize this effect. The residual flexure is approximately 0.3 pixel/hour or less. This is very small, but for some observations cannot be neglected. Specifically:

- Observations requiring very accurate wavelength calibration (velocity measurements, for example) should ensure that the wavelength calibration is an average for the observation, not just data from the beginning or end.
- For very long observation sequences (several hours), it may be useful to group the observations and then shift and add them to retain maximum resolution. This decision can be made after the fact by examining shifts in the night sky lines.

- Observations requiring cancellation of telluric absorptions, which require observation of a reference star to provide an absorption template, should be carried out with the reference star close to object, and with the spectrograph in the same orientation (slit angle).
- Flexure in acquisition mode is larger, as much as 1 pixel/hour with the long cameras. See 3.1.4 for a discussion of object acquisition.

2.2.6 Repeatability

The mechanisms in GNIRS are not perfectly repeatable. That is, once a mechanism is moved, a return to the same nominal position will be close but not exact. The nominal performance specification is 10 pixels repeatability with the long cameras (<1 pixel with the slit). From the point of view of exact wavelength calibration, this means that each configuration of the instrument is a new configuration requiring its own calibration - even it is nominally the same as a previous calibration.

There are a couple of exceptions to this rule. Filter changes do not change the configuration after the slit at all, so one can cycle through orders at a fixed grating orientation and maintain calibration. Also, the acquisition mode inserts a mirror in the beam, but does not move the prism, grating, or camera, so checking centering will not alter the spectroscopic configuration. Note that the acquisition mode itself is only repeatable to a few pixels, [TBD], so one should check centering relative to the image of the slit and not relative to absolute pixel coordinates.

These considerations would affect observations where one wants to observe both an object and a reference star in the same, identical configuration (probably so as to divide out telluric absorptions). In this case, it would be possible to set the grating and measure orders 3-6 on the object by changing filters, and then go to the reference star and the repeat the same sequence. If, on the other hand, one wanted to observe at several grating tilts (perhaps at higher resolution), one would have to observe the object at one tilt, then the reference star, then change the tilt, then observe the reference and the object at the new tilt, and so on. Any calibrations that cannot be done later need to be done as well.

2.3 Observing Mode Trades

2.3.1 Instrument Configuration Trades

This section discusses alternative configurations for some types of observations. The discussion is general, so it is useful to compare situations for specific programs using the ITC.

- Long vs short cameras. The long cameras will give better performance only when image quality is good enough so slit losses don't exceed the gains due to reduced background. Unless maximum spatial or spectral resolution is required, the short cameras will probably be preferred. Note that for a resolution of 18,000 the long camera *must* be used.
- Long slit vs cross dispersed. Cross dispersion provides cover of multiple orders, but at the expense of slit length. If only one atmospheric window is of interest, use long slit mode. If two or more windows are desired, then the loss of sensitivity due to limited slit length (limited number of different dither positions) is normally offset by the ability to observe several orders at once.
- IFU vs slit. The IFU is the only efficient way to get 2-dimensional coverage, so it is clearly the choice when observing objects with structure or in very crowded fields. It is possible that in poor seeing, the IFU could be used as an image slicer for point source observations, provided only a single atmospheric window is of interest (otherwise the multiplex gains from cross-dispersion should offset the gains from image slicing).

2.3.2 Observation Configuration Trades

This section discusses guidelines for optimizing one's observations in terms of number of exposures, Fowler sampling, and "dithering" (positional sampling). The emphasis is on measuring faint objects; for bright objects total time is dominated by overhead, so one should mainly ensure enough measurements are made at slightly different positions to provide adequate sky subtraction and flat-fielding.

For faint objects, one would like to measure at different positions along the slit, ideally enough so that the noise contribution from sky subtraction is negligible (see 2.2.1). At some point, the number of positions required will become too large to fit along the slit, and the overheads involved - relative to the decreasingly short exposure times - will also lead to diminishing returns. For most applications, 5 different positions is a reasonable compromise.

For the cross-dispersed long camera, where the usable slit length is ~3 arcsec (Table 2.3), it may not be possible to use this many positions unless image quality is quite good (20^{th} percentile or better).

Alternatively, for programs requiring very high signal to noise, flat fielding may prove to be a limitation and additional positions - presumably in long slit mode - would then be useful.

A second set of choices relates to the read-out mode used - whether one does a single read or multiple reads. (Note that *all* exposures actually consist of an array reset, an initial read-out, integration, and then a final read-out from which the initial read is subtracted. The read noise given in Table 2.14 is for such sequences.) The use of multiple reads decreases the effective read noise by up to a factor of 4, but at the price of increased overhead.

The difference in overhead between the minimum number of reads and the maximum useful sampling is about 4 seconds, so if one is in fact read noise limited, multiple sampling is justified for any exposures longer than a few seconds. In practice, observations below 2.5 µm will benefit from multiple sampling, and observations at longer wavelengths will not.

The maximum exposure time to be used is set by one of three considerations: the total integration time required for the object, sky variability, and saturation of the array.

Saturation of the array occurs relatively rapidly in the "M" window (order 1), where exposure times under a second will be required with the short cameras to avoid saturation. For these observations, one would co-add multiple short exposures at each slit position to keep the quantity of data manageable. Because sky subtraction is critical, one would want to limit the time at each position to tens of seconds, or a few minutes at most. (Experience with actual conditions at Gemini will be helpful here.) One would then cycle through the slit positions multiple times to accumulate signal to noise. For high background situations, the detector bias can be increased to increase the well capacity. The read noise is also higher at higher bias, so it should be used only in these high background situations (basically any case where you are limited to exposures of seconds or less). Always use the same bias for the same configuration.

In the next order, between 3 and 4 µm, backgrounds are substantially less, but still high enough to limit exposures to under a minute at low spectral resolution. Depending on the spatial and spectral resolution, one might co-add a small number of images, but still keep time at any slit position to a few minutes at most, and cycle through the positions as needed. At the lowest resolutions, use of the high bias may be required (TBD).

At still shorter wavelengths, exposure times could be tens of minutes or even hours without danger of saturation, so the primary limitation is instead sky variability. A 15-minute exposure time would allow one to cycle through 5 slit positions in under 90 minutes (allowing for overheads), which is a reasonable limit if there is still a need to subtract sky emission lines. For higher resolution (especially R=17800), it may be possible to ignore the lines, in which case somewhat longer exposures would be reasonable.

2.4 WFS Performance

For guiding, either the On-Instrument Wavefront Sensor (OIWFS) or the telescope's Peripheral Wavefront Sensors can be used. The OIWFS is preferred, if a suitable star is available (see 3.1.1).

2.4.1 OIWFS Performance

The OIWFS performance can be calculated from first principles, or can be assumed to be very similar to the performance of its equivalent in NIRI. Both assumptions lead to similar predictions.

For use with the Shack-Hartmann prism, which is permanently installed, the 5-sigma magnitude *per spot* for a 10 msec integration is approximately magnitude 13.8 for J or H, and 13.1 for K. This calculation is for 50^{th} percentile image quality. Performance for 20^{th} and 85^{th} percentile image quality is estimated to be roughly 0.7 mag better/worse respectively.

Since image quality is slightly better at H, this is probably the best choice for OIWFS filter under most circumstances.

In unobscured regions, stars of the required brightness correspond (roughly) to $R<16$.

The unvignetted GNIRS patrol field is effectively a 3 arcminute diameter circle minus a strip roughly 20 arcsec across; the area is approximately 6 square arcminutes. Models of the guide star distribution on the Gemini WFS web page suggest that stars of the required magnitude will be relatively common at galactic latitude 30 degrees, but less frequent at higher galactic latitude (roughly half the all fields).

Fainter stars can in principle be used, at the price of losing full tip-tilt and focus correction. For large, high-latitude samples, guide star availability may be useful way to select smaller sets of objects for observation.

2.4.2 PWFS Performance

See the Gemini web pages (follow Science Operations link to Telescope, then to WFS and Guide Stars).

3. Observing With GNIRS

This section describes how to observe with GNIRS. The first sub-section (3.1) discusses preparation for observing. Some of its content may be needed to prepare a proposal, and all of it is relevant to preparing the actual observing program. The next sub-sections discuss the interfaces to the instrument - section 3.2 describes the engineering interface, which is what the early user must confront, and section 3.3 will eventually describe the user interface. Calibrations are discussed in section 3.4, and preliminary data reduction is discussed in section 3.5.

3.1 Preparation for Observing

This section assumes that you have already specified the instrument configuration you require - spatial and spectral resolution, filters, grating tilts, and the like. This section considers some additional aspects of the observations that need to be specified prior to carrying them out. These comprise:

- Guide Stars
- Standard Stars
- Slit Orientation

3.1.1 Guide Stars

Observations with GNIRS cannot be carried out efficiently without a suitable guide star. The only (probably) exception to this is observations of bright standards, where exposures are short and the guider set-up time will be substantially longer than the added exposure time required to compensate for lack of a guide star.

(This is a reasonable assumption, but it should be verified and amplified after we go to the telescope.)

If a guide star suitable for the OIWFS can be found (see 2.4), this is preferred, since the OIWFS provides both tip-tilt correction and full compensation for instrument flexure relative to the telescope. Failing this, a PWFS guide star will provide good compensation, though the tip-tilt correction will be less effective because of the greater distance between the guide star and the object.

3.1.2 Standard Stars

Two types of standard stars may be needed - flux standards and telluric absorption standards.

Flux standards are needed if you intend to measure relative fluxes at different wavelengths (or absolute fluxes). A flux standard is not needed if you are only measuring the intensity of individual features as equivalent widths, whether in absorption or emission.

Normally, a flux standard is used to produce a curve of response vs. wavelength for each configuration. If only narrow slits are used, this is affected by slit losses and (potentially) by differential refraction (see 3.1.3). Wide-slit observations of both objects and standards can be used to convert observation to an absolute flux scale (true spectrophotometry).

There are really no spectrophotometric standards in the near-infrared. Instead, observers customarily use photometric standards with spectral types that indicate they should have relatively featureless spectra. The broadband magnitudes are then fitted to produce a smooth flux vs. wavelength curve for the stars.

(Provisionally, use the LCO standards, which are mostly G-type in the magnitude range 10-12.)

Flux standards are not necessarily measured at the same time and airmass as the objects they are calibrating, and therefore will be affected differently by absorptions in the Earth's atmosphere. If one's program looks only at features in relatively clean regions of the atmospheric windows, such as the centers of the H and K bands, dividing by a standard will provide adequate correction. For messier regions, it is useful to observe a correction star at the same time at a location near the object, and then construct an atmospheric absorption correction normalizing the "clean" portions of the stellar continuum. The star used for this purpose does not need to be a photometric standard, though it must have a relatively featureless spectrum. For lower resolution, F and G stars work well, because they have relatively weak features. At higher resolution, more lines become evident and early-type stars may be preferable outside the H I lines. (A list of recommended standards will need to be developed.)

In many cases, it will be possible to arrange the observations so that the same star is used for both flux calibration and telluric correction. This essentially requires one standard observation for each object observation, unless objects are close together in the sky and are fairly bright (e.g., stars in a cluster).

3.1.3 Slit Orientation

Two factors affect the orientation of the slit (and the IFU). One is the structure of the object to be observed, and the other is differential refraction.

The orientation relative to the object is dictated by the science to be done, and is therefore specified by the observer.

The optimum orientation from the point of view of differential refraction may be quite different; observers need to understand the effects involved. Differential refraction smears the spectrum of an object by an amount that is significant on the scale of the narrow slits used in GNIRS.

For example, the differential refraction between 0.9 and 2.5 µm (roughly the wavelength range of the cross-dispersed mode of the spectrograph) is slightly over 0.2 arcsec at a zenith distance of 45 degrees (airmass ~1.4), and is over 0.4 arcsec at a zenith distance of 60 degrees (airmass ~2.0). If the dispersion is perpendicular to the slit, particularly in good seeing, the losses at the extreme wavelengths can be considerable.

Ideally, the slit should be oriented in the same direction (parallactic angle) as the refraction (or an average over the observation), in which case the spectrum may be slightly skewed but no light will be lost. For point sources, this is not a problem, but for objects where a particular orientation is desired for scientific reasons there can be a conflict.

Several approaches are possible to mitigate the problem:

- Plan the observation so the parallactic angle and the desired position angle on the sky more or less coincide. This may involve observing the object while rising or while setting. The desired angle may not always be such that this can be done.
- Plan the observation so that observations are done only near zenith.
- Use the short camera instead of the long camera.
- Don't work in cross-dispersed mode, and center the object in each order of the grating for the observation in that order. The dispersion across any one order is less than 0.1 arcsec for reasonable zenith distances, so slit orientation is far less critical.

3.1.4 Acquisition and Centering

The acquisition mode of GNIRS allows observers to find objects and center them on the slit efficiently, and to verify centering during the course of long observing sequences.

The sensitivity of the acquisition mode should be comparable to that of NIRI in its f/6 configuration. Note, though, that sorter 3 (K band) extends to longer wavelengths than a conventional K filter, and will therefore have higher background and lower sensitivity by a few tenths of a magnitude.

It is not necessary to acquire the object with the filter through which you intend to take a spectrum (but allow for differential refraction - see 3.1.3). Although the red cameras don't perform well below 3 µm, it is possible to center objects with these cameras using the H or K band order sorters. It is also possible to acquire using the equivalent blue camera, center the object, then change camera and filter.

Because the acquisition mirror is inserted without disturbing any of the dispersing elements, it is possible to check centering on long observing sequences without losing the wavelength zero point. Changing the slit or camera during the check will change the zero point.

For sufficiently faint objects, it may be desirable to center on something brighter nearby, and then perform a precision offset with the WFS to center the object itself.

In all cases, it is important to realize that flexure and positioning repeatability are such that the object should be centered relative to the slit itself, and not on an absolute position on the array (though the slit center should be constant within a few pixels).

The recommended procedure is as follows:

- Configure for acquisition, with the filter/camera combination required, and the acquisition decker and slit. Set up the WFS and start guiding. Image the field. If necessary, take two images with the object displaced (use the WFS for the offset) and difference them.
- Put in the slit/decker combination required for the spectroscopy. Take an image and determine the slit center.
- Using the WFS, offset the object from its position measured in the first step to the slit center position. As a check, you can take two images with the object displaced along the slit and difference them, to verify this step.
- Complete the spectroscopic configuration.

If you are offsetting from a reference object to a very faint target, you can either center and check the reference object, then offset, or combine the offsets.

Centering checks should be done for long sequences. The recommended time interval depends on the camera choice somewhat: (TBD - probably 1-2 hours). The procedure that affects the wavelength zero point least is to insert the acquisition mirror and change the filter (if desired), then check that the object is still on the slit as above. For a more accurate check, a wider slit should be inserted and one should more or less repeat the acquisition process given above (though any offsets should be very small). If necessary, the camera can be changed, although the repeatability will then be several pixels (as opposed to 1 pixel or less for slit motions only).

3.2 Engineering Interface

The engineering interface is not intended as the primary user interface to GNIRS while observing, but can be used for that purpose. (At present, there is no user interface, so there is no alternative.)

The engineering interface consists of a set of EPICS windows, which can be used to monitor and control the instrument configuration, data taking and some operations of the OIWFS. For routine observations, the OIWFS is controlled by the telescope acquisition and guiding system, and the user needs to interact only with the mechanisms (components controller) and the array (array controller). In addition, users may wish to open windows to run IRAF or some other data reduction/analysis package.

The descriptions below cover only those screens required for *routine* operation of the instrument. Additional windows used for diagnostics are covered in the Service and Calibration Manual and in the Software Maintenance Manual. Detailed data reduction procedures are outside the scope of the manual (but see section 3.5 for an overview).

These descriptions also assumed that the instrument and its associated software are running - see section 4 for start-up procedures.

The windows for GNIRS are EPICS dm screens, which can be used to monitor and modify EPICS variables. The diagnostic windows are an interface to the CAD, CAR, APPLY records, and also show the current status of the system. Several display buttons will display a menu when right clicking with the mouse. Some of these menus are dynamically loaded, so if the system is rebooted, or the menu is reloaded after the dm screen is already displayed, the right click menu won't be updated. This is easily fixed by exiting the affected window and re-displaying it from its parent window.

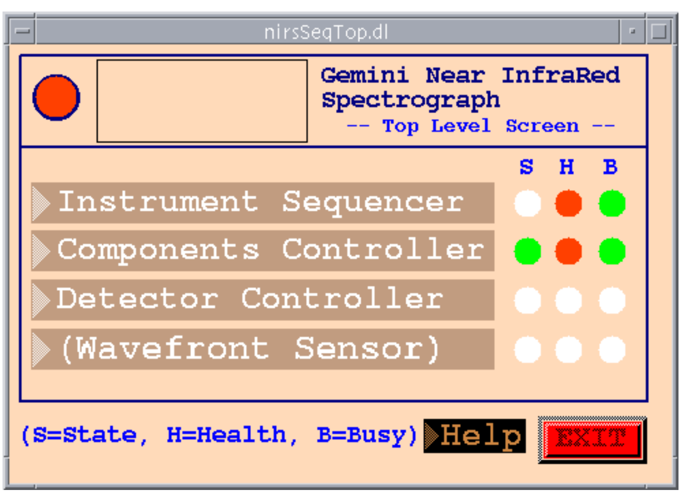

Figure 3.1. GNIRS Top Level Engineering Window

The window shown above (Figure 3.1) is the top level engineering window for GNIRS.

On this window, there are four buttons and status indicators that correspond to the four major components of the system (see the Service Manual for a complete description).

This window *must not* be closed, though it can be minimized. The buttons on the left bring up additional screens, including the screens used for observation. The State/Health/Busy indicators provide a top-level indication of the instrument status. Normally, all indicators in the two left columns should be green; the busy indicators may be busy. (*Note:* operation of the motors can induce pickup in the temperature sensors, so it is possible for the components controller health indicator to change color while mechanisms are operating. If it does, do not be concerned unless it does not change back to green within 2-3 minutes.)

3.2.1 Instrument Configuration

The opto-mechanical configuration of the instrument can be controlled from a single Mechanism Control screen (Figure 3.2). This is opened by first opening the Instrument Sequencer screen from the top-level screen (above), and the opening the Mechanism Control screen from the IS screen. The IS screen can then be closed.

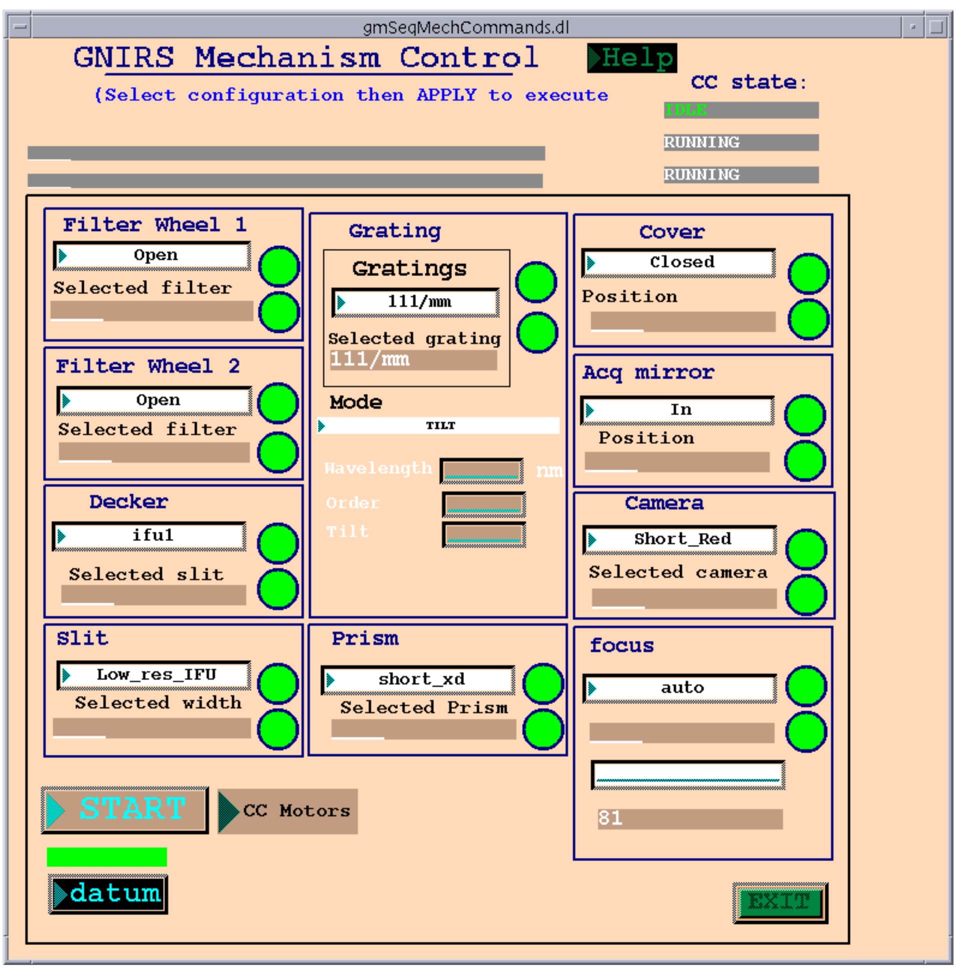

Figure 3.2. Mechanism Control screen. This provides control for all mechanisms.

The user selects mechanism positions for each of the discrete mechanisms. The grating is positioned using a wavelength and order. The focus is positioned by step number. One enters all desired changes into the configuration displayed on the screen, and then uses the "apply" button to reconfigure the instrument. If another configuration or an observation with the science array is in progress, an error message will be generated. You will need to use the "apply" button again when the current activity stops.

Note that there is no "common sense" filter applied to the configurations requested. In particular, if you are making major changes in the configuration, check the following:

- Make sure that only one filter is in use - that is, if you select a filter in Filter Wheel 2, make sure Filter Wheel 1 is on "open" (except for diagnostics).
- Make sure that the camera corresponds to the filter - going from xJHK to LM requires going from the blue to the red cameras (and vice versa).
- If you change pixel scale, make sure you change both the slit and the camera. Remember also that spectral resolution changes by a factor of 3 when pixel scale changes.
- Remember also that the mechanisms are not perfectly repeatable, so once you change from a given configuration you will not be able to go back to it *exactly* (but you will be within 10 pixels or less)
- Don't forget the window cover needs to be open!

Consult section 2 for useful configurations (Tables 2-8 - 2-10 and elsewhere).

3.2.2. OIWFS Configuration

Configuration of the OIWFS is normally done through the telescope's acquisition and guiding system, and is done by the telescope operator rather than the instrument user.

It is possible, if needed, to access the OIWFS from the top-level screen (Fig. 3.1) by opening the OIWFS top-level screen and then the OIWFS CC screen.

3.2.3 Data Taking

Two screens are required to set up the array controller and take an observation. The first screen (Figure 3.3) is the GNAAC main control screen; from that you can access the Observing Set-Up screen (Figure 3.4), which is used to set up the observation.

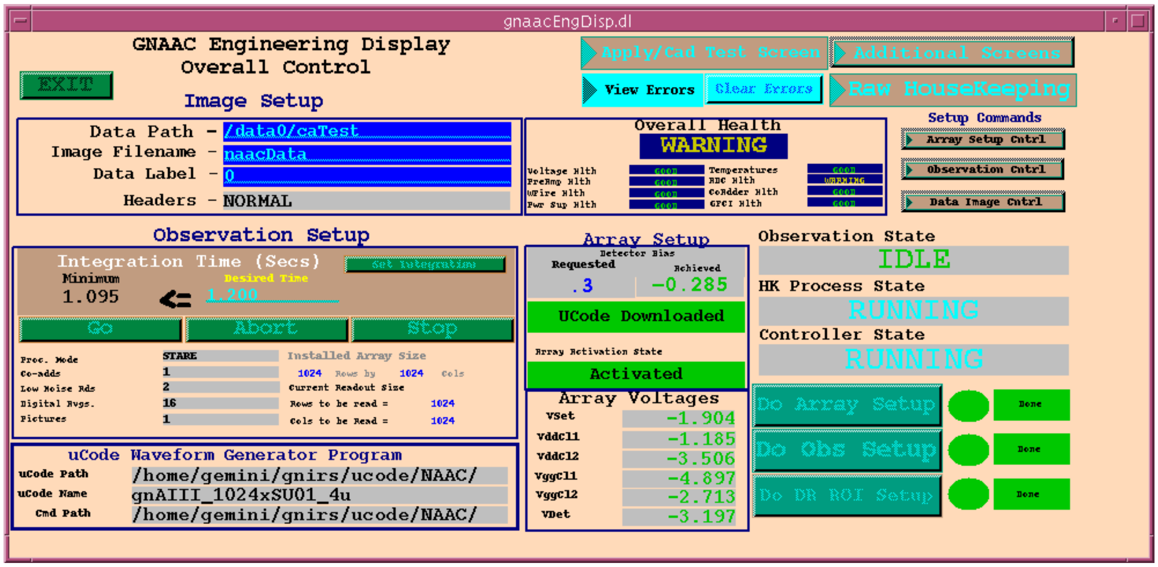

Figure 3.3. Array control screen. Used to start an observation and control some parameters.

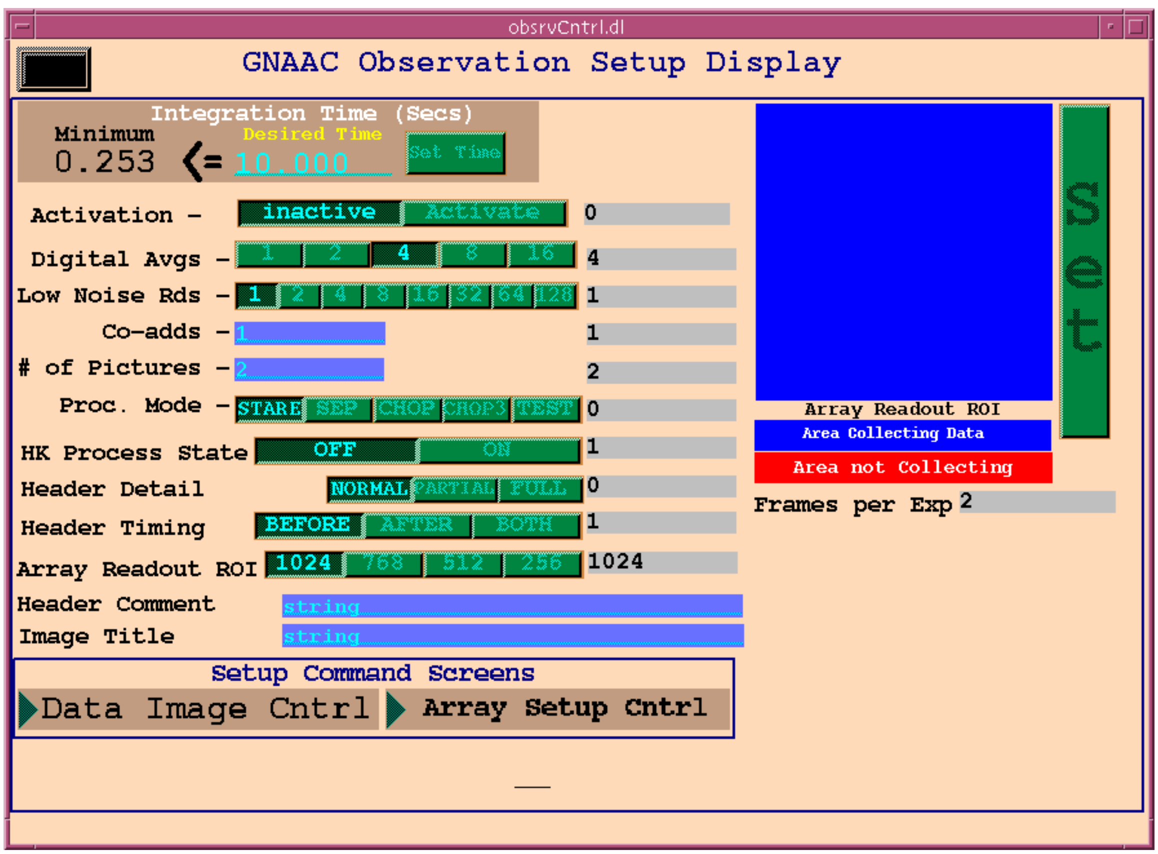

Figure 3.4. Observing Set-Up. Used to set up array control parameters.

The observing set-up screen provides more functionality than is normally needed for observations. Don't alter parameters that are best left alone. The following items (mainly on the left side of the screen) are relevant:

- Activation. This starts up defaulting to inactive, so you must activate manually when starting up the instrument. Once the detector is activated you can leave this alone.
- Integration time. This should be set as needed.
- Digital averages and low noise reads. Digital averages should be set to 16 except for L and M band acquisition (set to 1 in these cases). Low noise reads should be set to 1 for exposures under ~1 minute, and to 64 for exposures >5 minutes. For exposure times between these values, consult the ITC.
- Co-adds. This is the number of frames to be added together. Co-addition is useful if you have many short exposures, since you save on time writing to the DHS and the number of images you have to manipulate is less. However, if any one frame is bad, the co-added image will be bad, so co-addition is not recommended if you are taking longer exposures.
- Number of images. This is the number of separate images to be taken. Note that if you are also co-adding, the number of exposures is the product of the number of co-adds and the number of images.

The only other parameter that may need to be changed is the array bias, which is changes from the array set up screen (not shown), which is also accessed from the main screen. Use bias of 0.3V for low background and bias of 0.6V for high background. The low bias has fewer “hot” pixels but less well depth. *Do not change any other voltage on this screen!*

In order to start an exposure, one needs to use the main window, shown above in Figure 3.3. The observe button the top level sequencer screen (not shown) has the same function.

This window has only one function in routine use, which is starting an exposure or exposure sequence. Note that with the appropriate configuration (see above) it may produce several images that are sent to the DHS. It is possible to change the exposure time from this window as well as the observing set-up window.

If one is doing a raster pattern of some sort, for example multiple positions along the slit, the observing sequence would consist of configuring the instrument and the array controller, positioning the object to the first location, clicking on the observe button, waiting for the exposure(s) to finish, offseting the telescope and OIWFS, clicking on the observe button, and so on. Normally this is done automatically through the sequence executor, and the screen shown above will not be used.

3.3 User Interface

The user interface, to be provided by Gemini, will provide a more complete interface to the instrument and relevant telescope systems. It provides the capability to program a series of rastered ("dithered") observations of a single object, including OIWFS control. It will also be possible to program a sequence of observing configurations - for example a sequences of dithered observations with multiple filters.

The interface, despite these added capabilities, will not involve a profusion of windows or "don't change these" parameters.

This section will contain a complete description of the interface once it is available (or in test).

3.4 Calibrations

Several types of calibration frames must be obtained for proper data reduction. These fall into four categories:

- Darks and flats
- Wavelength calibration
- Standard stars
- Polarization calibration

3.4.1 Darks and Flats

Dark and flat-field frames are required to remove the detector signature. Dark frames are produced by putting "dark" filter in Filter Wheel 1 in position and taking appropriate exposures. In general, it is a good idea to take dark frames that match the regular data frames in terms of bias, exposure time and numbers of digital samples and low noise reads. Some interpolation on the times is permissible, but in general you will get better results carrying out your program with a limited number of different integration times.

Flat fields are produced using the on-telescope calibration unit (GCAL). The flat field produced by this unit is flat to 1% [TBD] over the longest slit used in GNIRS, which is adequate for nearly all programs. For more accurate calibration of the long slit, the best alternative is building up a flat using twilight sky exposures (or daytime if the background is not too high). The sky flat should be viewed as a supplement to the GCAL flats and will not be needed for most programs.

For exposures done using GCAL, a flat field determination requires measurements with the light source "on" and "off", which are differenced. For details of the operation of GCAL, consult the relevant manual [REFERENCE].

The flat field is relatively independent of wavelength, so a separate flat field for each wavelength setting is not a necessity if there are many similar settings. It is preferable, though, to have a flat field associated with each setting. This is especially important in the low resolution and prism modes, where a given configuration will not produce signal on the entire array. This means that portions of the image will need to be masked off to produce a reasonable flat field, which will not necessarily be useful for another configuration.

It is convenient to divide each flat field by an average value to normalize the corrections.

Darks and flat fields should be produced using the average (or median) of a large number of frames, typically 20-50 for each dark time or flat field configuration.

3.4.2 Wavelength Calibration

The easiest way to determine the wavelength calibration is to use the night sky lines, which are present in every spectrum taken with the instrument. Suitable lines are identified in the spectra in Appendix B.

GCAL also provides arc lamp spectra, which can be observed to determine wavelength settings during the day (or when the dome is closed by weather). The GCAL lamps can be useful for diagnostic purposes or for verifying exact wavelength coverage, but are otherwise not needed. Consult the GCAL manual for operation of the arc lamps. It is not absolutely necessary to subtract darks or flat-field these GCAL frames.

3.4.3 Standard Stars

Selection of standard stars is discussed above (section 3.1.3). Standard star observations are generally fairly short, so it is [probably] possibly to carry out the observations without setting up the OIWFS, which can save a certain amount of time. It is still advisable to measure the star at several slit positions. This is especially true for telluric standards used with the long slits, where one should really measure at each position on the slit that is used for objects.

If a large number of positions are involved, or the exposures are longer than a few seconds, it is probably advisable to take the trouble to use the OIWFS rather than letting the star drift off the slit.

3.4.4 Polarization

[The issue here is that one would like to calibrate the *relative* instrument response in both polarization, yet it is not clear that there is an appropriate unpolarized flat field to be used for this purpose. It may be that the only solution is to rely on standard stars as unpolarized light sources and accept the fact that the flat field normalization in the two polarizations may be somewhat different.]

3.5 Preliminary Data Reduction

The following steps are recommended to carry out preliminary data reduction. They may in fact suffice for final data reduction as well, but don't delete raw data until you have had the chance to assess the reduced data calmly.

- Linearity correction
- Dark subtraction
- Flat fielding
- Sky reference generation
- Sky reference subtraction
- Spectrum extraction
- Absorption standard division (optional)
- Flux calibration (optional)

The first three steps remove the detector signature; the second two steps remove the night sky (and telescope) emission, while the final steps produce a spectrum with the instrumental signature removed.

3.5.1 Linearity Correction, Dark Subtraction and Flat-Fielding

These procedures are essentially automatic if there are always matching dark frames and flat fields.

The linearity correction is optional if all count levels are low (below 10,000 [TBD] ADU). If used, the recommended coefficients for the IRAF procedure `irlincor` are a= 1.0, b=xxx, c=yyy (TBD - actually will need separate values for each bias value). See the IRAF documentation for an explanation of these coefficients; also confirm that you are using the most current values for the coefficients.

To remove dark and flat field, subtract the equivalent dark frame and then divide by the appropriate flat field. Bad pixels or unexposed areas should be masked off in the operation. If no exact match exists for the dark frame, either interpolate using exposure times that are close, or use the closest dark frame.

If unmasked bad pixels are noisy in the flat-fielded frames, it is desirable to limit their maximum and minimum values to reasonable numbers - this ensures that IRAF's statistical processes are more reliable.

3.5.2 Sky Reference Generation and Subtraction

The details of the sky reference generation depend on the observing procedure. If the object was measured at many slit positions, the sky reference can be generated by calculating the scaled median of all images. If a simply "on/off" or "A/B" procedure was used, then the sky reference is the "off" image (or the mean of the adjacent "off" images). For a modest number of positions, one can construct a reference for each position by determining the average of all the other positions. This is the preferred procedure.

The reference should be scaled to the object position flux values and subtracted.

3.5.3 Extraction

If multiple positions on the slit were observed, it is generally preferable to extract individual spectra, which can then be wavelength calibrated and added. For faint objects, one can add images taken at the same slit position, then do the extraction.

Note that distortions and tilts require one to determine an extraction profile, even in long slit mode where the spectrum runs approximately along the rows of the array.

3.5.4 Standard Stars

The summed, extracted spectra in many cases provide enough information to see whether the observation is successful. Even if this is true, it is still often useful to remove the atmospheric and instrumental signatures.

The following steps will produce an approximate calibration, but not an optimal one:

- Divide by a standard star extracted spectrum
- Multiply by an artificial curve having the nominal flux distribution of the standard. (For most purposes this can be a blackbody fit to the standard's broadband magnitudes.)

This procedure will remove weak atmospheric absorptions, but not strong absorptions. It will correct for instrumental response. It will also introduce spurious emission features wherever the standard has absorption features. The result is also uncorrected for differential light losses at the slit.

4. Set-Up and Operation

This section describes the procedures required to verify that the instrument is working, and to get ready to observe with it. This section assumes that the instrument has been properly installed on the telescope (see the Service and Calibration Manual for installation procedures). The section describes a complete start-up after installation; for daily start-up see section 4.8.

Software troubleshooting is covered in the Software Maintenance Manual.

4.1 Software Start-Up

The Engineering screens are started by typing `nirsSeqStart` in a terminal window. This script is located in {GNIRSROOT}`/bin/solaris`. If this is not in your path, use the whole path to invoke it.

This command will (eventually) bring up the top-level instrument screen, as well as a small screen labeled DM2.4. Both screens *must not* be closed, although they can be minimized.

From the top-level screen you can bring up the following additional screens (see 3.2):

- Mechanism control screen (brought up from instrument sequencer screen, which can then be closed)
- GNAAC top-level screen ("overall control")
- GNAAC observing control screen

No other screens are required for routine observing. Screens required for diagnostic purposes are described in the Service and Calibration Manual; these are generally accessed through the components controller main screen (accessed from the top-level screen).

4.2 Initialize Spectrograph Mechanisms

The mechanisms can be datumed ("home" position is located) using the global datum command on the CC screen. This will take a couple of minutes to execute, depending on where the mechanisms happen to be.

At the completion of the datum, all mechanisms will be left near (but not quite at) the zero-step position. You should then position all the mechanisms to the initial configuration that you want. *Important: The prism turret in the zero position will partially vignette the beam.* Therefore, even if your initial configuration is with the acquisition mirror, you should position the prism turret to one of its four positions (or to "park").

4.3 Initialize Detector

The detector is initialized from the GNAAC Engineering Interface. Individual detector parameters may need to be adjusted from subsidiary screens (see 3.2.3). The most useful parameters to adjust are the number of digital averages, low noise reads, and number of co-adds and images. The region of interest (area to be read out) can also be modified, as well as other array-control parameters. The bias is changed when one switches between low background (small full well, low noise) and high background (large full well, higher noise).

In general, it is advisable to leave most parameters unchanged, as this greatly simplifies subsequent data management and data reduction.

The array is initialized using the three buttons on the lower right of the GNAAC interface screen.

4.4 Initialize OIWFS

The OIWFS is started as part of the instrument start-up procedure described above. Any further initialization (e.g., datuming mechanisms) is done by the A&G system. These procedures are fairly slow (~15 minutes) so make sure they are carried out promptly. You can initialize the OIWFS, if necessary, from its own engineering screen (accessed from the top-level screen)

4.5 Sensor Checks

The health of the temperature and pressure sensor values is indicated on the top-level CC screen. If both health indicators are green, then all values are within range, and there is no need to check further. If the health indicators are yellow (warning) or red (bad), one or more readings is out of range. Open the relevant sensor screen and examine the faulty value or values. Consult the Service and Calibration Manual for details on the individual sensor values.

If the health is yellow due to a single, slightly out of range sensor, it may be reasonable to continue observing. However, in this case one should check the relevant screen periodically to confirm that the situation has not gotten worse.

4.6 Configuration Checks

This section describes simple functionality checks that can be carried out without need to access the low-level code. Additional checks are described in the service and calibration manual.

4.6.1 Basic Configurations

The instrument's ability to correctly configure can be checked by setting up a few configurations, taking an image, and comparing the results with expectations.

For these tests, GNIRS should be looking at GCAL with the arc lamp (Ar) on. Exposure times of 1 second [TBD] are sufficient. Make sure the window cover is open! Try the following:

- Configure in acquisition mode (mirror in, acquisition slit and decker) with the H (sorter 4) filter. Use the short blue camera. The acquisition field should be roughly centered on the array, and the field should not be vignetted.
- Configure with any grating and any of sorters 3-6, a blue camera, and the short camera long-slit decker. Use a moderately narrow slit (180 microns). Specify a wavelength corresponding to one of the figures in Appendix B, and verify that the wavelengths are about the same (to within 20 pixels) as in the Appendix, and that the slit is centered on the array to within 20 pixels. Confirm that the FWHM of the lines is 2.2 pixels or less. *Note:* at low resolution, some lines are blends; check the labeling in Appendix B to avoid these.
- Configure to a cross-dispersed mode. Verify that orders 3-7 fall on the array, and that the lines remain narrow (FWHM ~2 pixels for short camera, closer to 3 pixels for long camera).

4.6.2 Repeatability

The repeatability test is fairly simple: set up a configuration like one of the ones listed above, take an exposure, move one or more mechanisms out of position and then back, and then take another exposure.

The apparent position of spectral lines in both directions should move by less than 10 pixels when the prisms, gratings, and cameras are moved, and by less than 1 pixel when the filter, slit, decker, and focus are moved. These effects are at least 3 times larger with the long cameras than with the short cameras, so the tests are best done with a long camera configuration.

4.6.3 Background and Throughput

The instrument internal background should be measured in two configurations:

- Filter wheel 1 in "dark" position, filter 2 in sorter 1 position, 180 micron slit, short camera long decker, short red camera, prism turret in mirror position, 110 line grating set to 5.0 μm (1^{st} order). Use an exposure time of 300 seconds. The observed count levels (includes dark) should correspond to ~0.1 electrons/sec/pixel. (Gain is 13 e/ADU, don't forget to divide by number of low noise reads.)

- Same as above, except that grating is now set to 2.2 µm (3rd order), filter wheel 2 in sorter 3 position, and short blue camera is used. The observed count should still correspond to ~0.1 electrons/second/pixel.
- Optionally, the same configuration can be repeated with the short camera cross-disperser in place instead of the mirror; the measured counts should be the same.

In general, the best measurements of system throughput are done on the sky. However, an initial check can be done with GCAL and the continuum flat field source. For the second configuration above, the count level at the center of the array should be approximately [TBD] ADU/sec. [Needs more detail]. The measured value should be within 10% [TBD] of this. *Note*: this assumes that the GCAL configuration is fairly stable.

4.6.4 Detector Noise

In conjunction with the background tests, one can also look at the detector noise performance. This is best determined using multiple frames; use IRAF imcombine. The noise should be measured using minimum Fowler sampling (16 digital average and 1 low-noise read) and maximum sampling (16 digital averages and 64 low-noise reads). Use a bias of 0.3V. The respective median noise values measured should be ~40 and ~7 electrons in the sigma images.

It is also useful to visually inspect the difference frames for evidence of noise pick-up, which would appear in the form of patterns superposed on the random noise. Some pick-up will probably be present in the minimally-sampled frames, but it should be averaged out fairly well with multiple samples.

4.7. Night-Time Tests

The following tests should be carried out at the start of the night. The weather does not need to be photometric.

- Pupil viewing test. Configure for pupil viewing through the K (sorter 3) filter and acquisition mirror. Use the long blue camera for best results. Verify that the telescope secondary is centered on the internal cold stop. The images (Fig 4.1) below show a properly centered and somewhat decentered image. Decentering at the 1% level is not critical.

Figure 4.1. Pupil viewing images of secondary well-centered on cold stop (left) and slightly decentered (right).

- Background test. Go to the configuration with the 32 l/mm grating, short blue camera, and long slit mode, with a 2-pixel slit and sorter 3. Set the grating to 2.2 μm and compare the results of a 60 second exposure with the relevant figure from Appendix B. Compare both the overall intensity of the night sky emission lines and the continuum level at the long wavelength end of the spectrum. Both levels may differ significantly from what is shown in the figure. If the test is done at the start of the night, the night sky emission levels will tend to be higher than the reference values, possibly by a factor of 2. The thermal continuum is affected by ambient temperature, and will be higher if the telescope temperature is higher than the value at the time the data in Appendix B were taken (see the figures).
- Throughput test. Observe a standard star with a *wide* slit in any of the configurations documented in Appendix B (ideally, one you are intending to use that night). A simple extraction will produce values within 20% of those you would get with a complete preliminary reduction (section 3.5); this provides a quick check of performance. Outside of regions of atmospheric absorption, the variations in measured counts should be no more than 10%.

4.8 Nightly Start-Up

Normally, the nightly start-up only needs to reverse the steps from the previous night's shut-down (section 4.9):

- If the EPICS screens have been closed, restart by typing `nirsSeqStart` in a terminal window. (See 4.1 above).
- Check the top-level screen to make sure temperature and pressure health are still good (4.5).
- Re-initialize the detector, including activation (4.3).
- It is a good idea, but not necessary, to re-datum the mechanisms (4.2,4.4). If you are doing afternoon calibrations, do the datum before calibrating.

4.9. Shut-Down

This section outlines the steps required to prepare the instrument for removal from the telescope. This includes all steps up to, but not including, powering down electronics. This is not required except at the end of the run.

4.9.1 Mechanism Positioning

The mechanisms should all be positioned to their "park" positions.

4.9.2 Detector Shut-Down

The detector should be de-activated from the observing control screen. Don't forget to use the "set" button to implement the deactivation.

4.10 Nightly Shut-Down

It is only necessary to de-activate the detector (see 4.9.2 above), and close the window cover ("closed" or "park"). The other mechanisms can be left "as is".

5. Basic Trouble-Shooting

This section is not intended to be provide comprehensive diagnostics of all possible problems with the instrument. Instead, it provides preliminary diagnosis of the most common problems with the instrument.

This section is expected to be revised as experience using the instrument on Gemini accumulates.

Problems, diagnosis, and solutions:

- No signal at detector. This may be due to a number of causes:
  - Detector not activated. Activate the detector. If it does not activate, verify that the detector temperature is correct (low enough).
  - Configuration incorrect. Did you forget to configure a mechanism (including the window cover)? Set the configuration again, and see if mechanisms move; observe again if they do. If all mechanisms are alleged to be in the correct position, do a global datum and reconfigure. If this does not solve the problem, try a configuration with the acquisition positions. Further mechanism diagnosis is covered in the service manual.
- Noise on image. This may be due to grounding problems. Also consider:
  - Was the OIWFS being reconfigured during the readout? If so, try again and see if the noise is absent when the OIWFS mechanisms are not active.
- Image does not appear to be the correct configuration. Check:
  - Did you make a mistake in selecting the configuration (especially grating wavelength)?
  - If one mechanism appears to be the source of the problem, try (a) repositioning it, and if that does not work, try (b) datum and re-position. If this is not correct (and especially if the configuration is still wrong but different) try mechanism diagnosis procedures in the service manual.
  - If the mechanism positions correctly, it may be worth checking repeatability (move away, then back) to confirm reliability.
- Images are fuzzy or otherwise bad. Configuration is otherwise correct.
  - Check focus setting
  - Check instrument temperature
  - Was the telescope slewing or was the instrument rotator changing angle very rapidly? If so, repeat to see if images return to normal.
- Excess background observed.
  - Has the instrument cooled sufficiently? The optics will not fully cool for ~12 hours after the bench itself initially reaches 60K.
  - Something is in the way (dome, PWFS, etc.). Vignetting should produce excesses only at KLM. Pupil viewing may help find the culprit if only a long wavelength excess is seen.
- Temperature health abnormal (yellow or red)

- Open the temperature display screen. If only one sensor is reading abnormally, the diode may be bad. A very low temperature (~23K) is an indication of an open circuit. A single temperature that is slightly out of range should be monitored.
- If multiple temperature readings are out of range, check that the bench temperature control is on (temperatures low) or that the cryocoolers are functional (temperatures high: check operation, also check individual head temperatures for high values).
- Check that dewar pressure is within range; poor vacuum will conduct excess heat into the cold structure. In this case, the pressure health should also be bad (probably red).

- Mechanisms give errors on positioning or datuming.
  - If the system has been rebooted or reinitialized, you must redatum all the mechanisms before you can configure anything.
  - If the mechanism gives an error on going to a position (for example, hitting a limit), redatum and try again.
  - Note that the window cover and acquisition mirror position to limits (open/closed and in/out), so limit messages on these two mechanism are *not* errors. Hard limit (OT) messages are errors on all mechanisms, including these two.
  - Note also that the rotary mechanisms (turrets and wheels) do not have mechanical limits, so any limit message is an electrical or software problem, not a mechanism problem.
  - If the mechanism gives an error on doing a datum, try with the back up home switch and/or do a datum test (see service manual).

Appendix A – Supplementary Information for Exposure Time Calculations

A.1 Throughput

Throughput is affected by two main factors: instrument throughput, which is a function of configuration, and slit losses, which are a function of slit width and image quality. Telescope and atmospheric transmission are also factors.

A.1.1 Slit Losses

Slit losses are calculated assuming a gaussian image profile centered on the slit. Detailed calculations show that a small amount of decentering does not affect throughput greatly. The table below (A.1) gives the percentage of light transmitted through the slit for both 2-pixel and 3-pixel slits, for both pixel scales, for the 20th, 50th, and 85th percentile seeing cases listed in Table 2.11. The values listed are for the K band; there are slightly greater losses at shorter wavelengths, and smaller losses at longer wavelengths. The highlighted values are those used for the calculations summarized in section 2.2.1.

The sampling in the IFU corresponds to a slit width of 0.15 arcsec. One should recognize that a spatial resolution element is effectively two samples, which should be combined in considering overall signal to noise.

Table A.1 GNIRS Slit Transmission as a Function of Seeing

Slit width (arcsec & pixels)	20th Percentile (0.30 arcsec)	50th Percentile (0.50 arcsec)	85th Percentile (0.75 arcsec)
0.10" - long 2 pixels	31%	19%	13%
0.15" - long 3 pixels	44%	28%	19%
0.30" - short 2 pixels	76%	52%	36%
0.45" - short 3 pixels	92%	71%	52%

The signal is directly proportional to the slit transmission, so one can easily estimate sensitivity under difference image quality conditions. The tables in section 2.2.1 for the short cameras provide estimates for 50th percentile image quality. For 20th percentile image quality, the ratio of slit transmission is 1.46, resulting in a sensitivity gain of ~0.4 mag. The loss in sensitivity at 85th percentile image quality is also ~0.4 mag.

In those cases where the object is much fainter than the sky in the slit, the integration time is roughly proportional to the square of the slit transmission - hence one gains a little over a factor of 2 going from 50th to 20th percentile image quality.

Widening the slit to increase transmission also increases background. For the case of faint objects, going from 2 to 3 pixels increases background by 50%, while increasing signal by a lesser amount - typically around 40%. The net gain in signal to noise is about 15%, equivalent to ~0.15 mag or to a factor of 1.3 in integration time for the same object. This may be worthwhile if the associated loss in spectral resolution is not a concern.

The length of the slit used to actually extract the spectrum is also relevant. It is not necessarily optimal to use a wide window and get nearly all the signal, since the increased total background (and total dark current and read noise) may provide a larger increase in noise. Table A.2 tabulates the percentage of transmitted flux extracted as a function of slit window length. Thus the total signal extracted is the product of the factors in this table and the preceding table. For example, a 4 pixel window and a 2 pixel slit with the short cameras and 50th percentile image quality will extract 44% of the flux incident on the slit (52% x 84%). Note that still better results can be obtained by means of optimal extraction using the actual light profile along the slit – but the values in Table 2.11 will be close to those results.

For reference, the relative amount of noise from background (including dark and read noise) is also indicated (it's simply proportional to the square root of the window size).

Table A.2 - Flux Extracted vs. Slit Window Size

Slit Window Length (arcsec)	20th Percentile (0.30 arcsec)	50th Percentile (0.50 arcsec)	85th Percentile (0.75 arcsec)	Relative Background Noise
0.30	76%	52%	36%	0.71
0.45	92%	72%	52%	0.87
0.60	98%	84%	64%	1.00
0.75	100%	92%	76%	1.12
0.90	100%	96%	84%	1.22

The optimum window for a given image quality is highlighted in yellow. If performance is within 2%, multiple values are highlighted. Generally, a window slightly larger than the image FWHM is optimum. Note that the window to be used can be determined *after* data are taken.

Sampling along the slit with the IFU is slightly different than the short camera - about 0.12 arcsec/pixel - so a window of 0.6 arcsec corresponds to 5 pixels rather than 4. Since the purpose of IFU observations is spatial reconstruction, the observer will probably extract spectra row by row rather than defining a wider window.

A.1.2 Telescope and Atmosphere

The remaining contributors to throughput are the instrument itself, the telescope, and the atmosphere. The estimated transmission of the telescope and the atmosphere are tabulated below, in Table A.3. The atmospheric transmission values are for regions free of strong absorption lines. GNIRS is assumed to be on a side port, so the ISS fold mirror is included, as well as the obscuration by the secondary mirror. Telescope reflections are assumed to be clean aluminum. Values are tabulated for the 6 orders for which the instrument currently has blocking filters.

Table A.3 - Atmospheric and Telescope Throughput

Grating Order	Atmospheric Transmission	Telescope Transmission
1 ("M")	80%	93%
2 ("L")	90%	93%
3 ("K")	93%	92%
4 ("H")	93%	91%
5 ("J")	90%	88%
6 ("x")	90%	84%

A.1.3 Instrument Throughput

The instrument throughput is calculated, using (for the most part) measured transmissions or reflections for the optical components, including gratings and filters. The grating efficiency varies across the band somewhat, so an average value is given for the wavelength region defined by the order sorting filters. The detector quantum efficiency is also included.

Table A.4 - GNIRS Throughput
Calculations for Long Cameras

Grating Order	Grating		
	10 l/mm	32 l/mm	110 l/mm
1 ("M")	35%	23%	36%
2 ("L")	52%	28%	38%
3 ("K")	45%	28%	40%
4 ("H")	49%	29%	43%
5 ("J")	50%	30%	41%
6 ("x")	41%	27%	36%

The tabulated values are all for the long cameras (0.05 arcsec pixel scale). The calculated values for the short cameras are all within 1% of the long camera values. The lower values for the 32 l/mm grating are due to the reduced efficiency of this ruling.

The integral field unit is expected to have about 80% throughput. Sensitivity for an object observed in a single slice will be 0.1-0.2 mag brighter, compared with the same slit width (0.15 arcsec), depending on whether the primary noise source is background or read noise and dark current.

The reflection losses in the prisms are 10% or less; in addition the SF57 glass in the cross-dispersion prisms absorbs significantly in the K window. The absorption averages about 80% between 2.0 and 2.4 μm.

A.2 External Background

There are two main contributors to the external background: sky background and emission from the telescope itself (including warm parts of the instrument).

A.2.1 Average Background

The sky background includes airglow, which is dominant at shorter wavelengths; thermal emission from absorbers at lower altitude, which is important at wavelengths beyond about 2.4 μm, and some amount of continuum.

The telescope emission is essentially a gray body, proportional to the effective telescope emissivity, which is typically <10%. (For a well-baffled instrument, such as GNIRS, it is close to 1 minus the telescope transmission given in Table A.3.)

As noted in 2.2.1.3, the structure in the night sky emission means that one needs to use caution in applying average flux values to exposure time estimates. In the absence of detailed night sky spectra taken with GNIRS, the following procedures have been applied:

- Start with broad band sky brightness estimates
- Compare with model night sky emission spectra (taken in this case from the Gemini web site)
- Apply corrections for non-standard filter pass band and for flux distribution with wavelength

This allows one to estimate both an average flux value per resolution element, as well as flux levels at various percentiles in the distribution. It turns out that the average values correspond roughly to the 75th percentile for the different windows (i.e. 75% of the resolution elements in the window have sky fluxes less than or equal to the average). In addition, the flux values corresponding to 90th percentile are typically 2-3 times the average. For the calculations presented above (2.2.1), a uniform factor of 2.3 has been applied.

Table A.5 summarizes the sky background values applied. Note that the fluxes do not include the corrections applied for atmospheric absorption or telescope and instrument throughput. The values tabulated are for R=1700; values at other resolutions are inversely proportional to the resolution.

Table A.5 - Mean Model Night Sky Emission
Resolution 1700

Grating Order	Background (mag/arcsec2)	Background (photons/sec/arcsec2/resolution element)
1 ("M")	-0.2	91,300,000
2 ("L")	5.4	890,000
3 ("K")	13.2	1560
4 ("H")	14.1	1100
5 ("J")	16.35	206
6 ("x")	16.6	215

A.2.2 Variability

The background will vary for several reasons.

The telescope background will change with telescope temperature; emission at 2.4 μm will change by a factor of 3 or so over a 20-degree (C) temperature variation, which is more or less characteristic of seasonal extremes. The thermal emission component of the atmospheric emission will also change by similar amounts. In general, variations of any thermal emission components of the background are slow, typically on scales longer than reasonable integrations.

The airglow component can vary by a factor of 2-3. There is a tendency for emission to be higher at the start of the night and then slowly decrease, but in addition there are variations on a variety of time scales, some of which can be quite short. Because of this, one should be cautious about planning observations with very long individual exposures, since systematic errors in the sky subtraction may result. A good rule of thumb for GNIRS (until experience with the site and instrument indicates otherwise) is to limit individual exposures to 15 minutes.

Appendix B - Representative Calibration and Night Sky Spectra

[many lovely spectra appear here....]