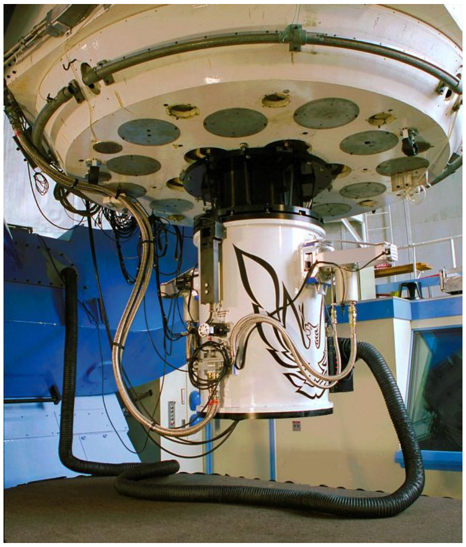
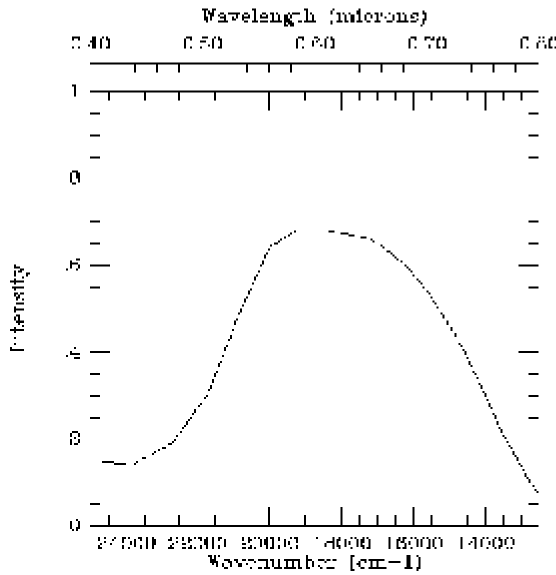
Phoenix Instrument Manual





December, 1999

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With contributions from C. Kulesa & J. Valenti

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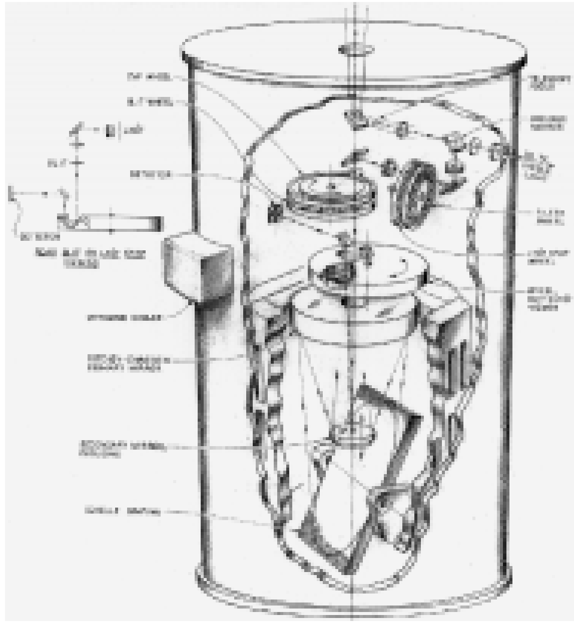
1. Overview of the Instrument

Phoenix is a cryogenic, high-resolution spectrograph designed for the f/15 Cassegrain focii of the Kitt Peak 2.1 m and 4 m telescopes. Resolutions of 50,000, 62,000, or 75,000 are provided depending on slit width (see foreoptics module, a spectrograph module, and a detector module. The foreoptics reimage the telescope secondary at a cold (Lyot) stop and then reimage the field onto the slit. A mirror which can be placed in the beam behind the slit to bypass the grating, effectively converting Phoenix into an infrared imager. Imaging is provided an aid in acquisition and guiding. The spectrograph unit consists of a Ritchey-Chretien camera-collimator which illuminates an echelle grating. A conceptual drawing is shown in the figure below.



Overview of optical layout;

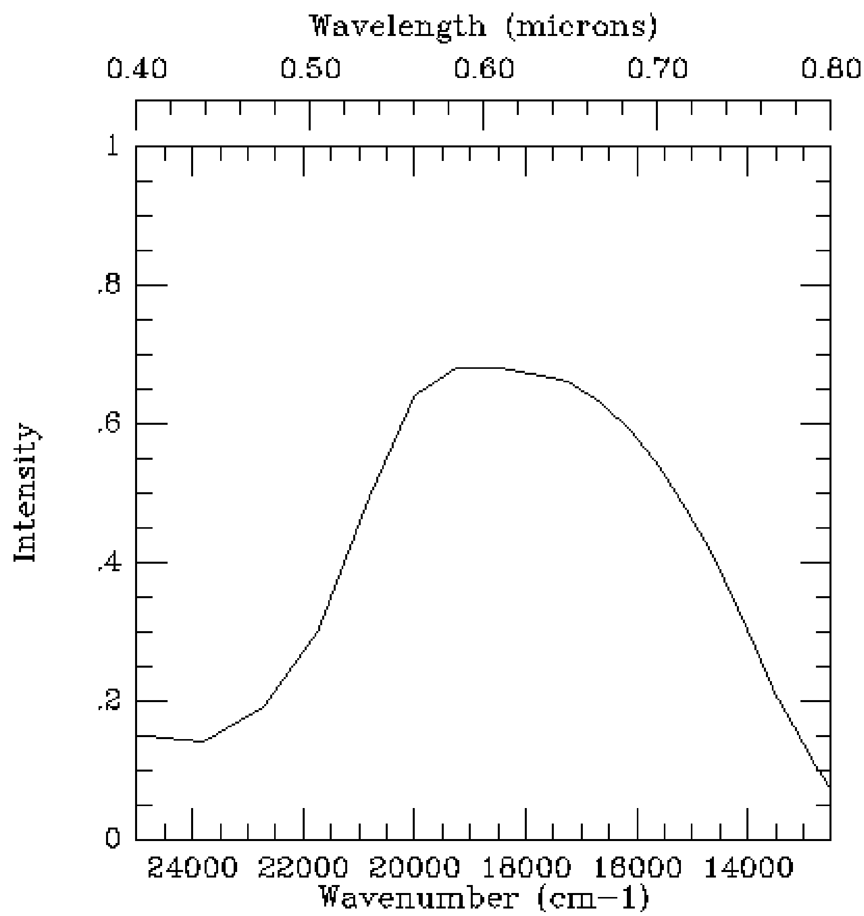
Phoenix is controlled using *Wildfire* software. *Wildfire* is a NOAO software package that delivers data *IRAF* format. *Wildfire* runs in a window on a SUN or SPARC computer. A discussion about running *Wildfire* is folded into the discussion of each Phoenix unit. Users of Phoenix will be expected to be familiar with *IRAF* when they arrive at the telescope. Users who do not know the basics of *IRAF* should spend a day in Tucson before their run taking the *IRAF* tutorial.

1.1. Foreoptics

The foreoptics changes the plate scale, separates the visual and infrared light, reimages the Lyot stop, and finally reimages the focal plane onto the slit. Bandpass filters can also be inserted into the beam at two locations in the foreoptics. Changes in the plate scale are transparent to the user and were done to optimize the size of the collimator. Details of the optical design can be found in SPIE 3354 810.

Visual Guide Signal: A visual light/infrared dichroic mirror is located between the main Phoenix window and the first mechanism (the filter wheel). This mirror separates the visible light sending it out a side port of the vacuum enclosure to a visual (CCD) guide camera. (In the following we will frequently refer to the vacuum enclosure by the technical name "dewar".) Since the dichroic occurs before any mechanism visible light entering the input window will exit the visual light side port window regardless of the orientation of any mechanism inside the vacuum enclosure. If the Guide camera does not see light it is not arriving at the Phoenix window!

The dichroic defines the boundary between the infrared that passes into the spectrograph and the visual light that exits the side port. Hence the dichroic response curve is one of the factors setting the blue limit of sensitivity of Phoenix. The foreoptics lens anti-reflectance coatings are other factor as is the optical material of the transmissive elements. Infrared light is reflected off the dichroic. The dichroic is 90 percent reflective at 1 micron and 99 percent reflective from 1.6 microns through 5 microns. Visual light is transmitted. The dichroic has a red response curve as does the guide camera.



Red response curve

The visible light passing through the dichroic is transmitted through reimaging lenses and then out the side of the dewar to a standard CCD guide camera intended for guiding and acquisition. The internal and external mounts are very stiff and there is no measurable flexure between the optical guide camera and the infrared array. The sensitivity of the guide camera has been measured on the KPNO 2.1 m telescope. For A stars, V=13 is easily visible while V=15 is barely visible without the use of the leaky (integrating) unit. V=16 is faintly visible for acquisition using the leaky but not practical for guiding. Remember when looking at the guide channel images that the camera and dichroic are red sensitive.

The optics for the visual guide channel have a separate focus mechanism from the infrared optics. To focus the telescope, place Phoenix into IR imaging mode (see below--viewer open; slit open) and focus the resulting image by moving the telescope secondary. The image diameter should be measured in both x and y axes. An in-focus image is small and round. Then, the optical guider camera should be focused by adjusting the guide camera lens and/or sliding the camera itself. Once this alignment step is done (and this is normally done by the instrument setup person at the start of each run block), any further refocusing of the telescope can be done using the star image from the optical guider alone. The 2.1-meter telescope focus is temperature and position sensitive so refocusing the telescope on the guide camera image will be required during the night. The 4-meter telescope focus is stable. Checking the 4 meter focus about once per night, by refocusing the telescope by looking at the visual guide camera output, is recommended.

Filter wheel: The discrete filter wheel is the first user operable mechanism in the light path, situated immediately in front of the Lyot stop. This wheel is populated with the Echelle order-sorting filters. The wheel has 13 positions occupied by 12 filters and one blank (open) position. The filter wheel mechanism is latched with a pawl for precise positioning, and therefore only turns in one direction.

The filters are all wedged, have FWHM bandpasses of approximately 100 cm^{-1}, and are blocked by 10^{-4} for wavelengths more than +/-88 cm^{-1} from the band center. The total list of filters available, with transmission curves, is given in this table. *Only 12* of these filters are in the instrument at any one time. The filters you need should be loaded by the support staff when your run is scheduled. The dewar must be warmed and opened to install a filter. This can only be done in the downtown clean room. Warming, opening the dewar, and recooling takes about a week and must be scheduled. If you have questions concerning filters contact the support staff. Similarly, if you need a filter that is not in the table please contact the support staff as soon as possible. The filters are custom made by a vendor. The filters cost in excess of $2,000 each and have a lead time of many months. Several users have purchased filters of special interest to their projects. If you are considering this you must contact the support staff for detailed specifications.

A 3 AM Pitfall. The filters were wedged to reduce fringing in the spectrum. This was largely successful but a result is that due to the manufacturing process the wedge of each filter is unique. This has the effect that the slit appears on a different place in the sky for each filter. After changing filters the slit must be relocated. The two alternate techniques for doing this are discussed below. When changing filters the apparent position of the slit on the sky *always* changes. The approximate offset in arcseconds required for some of the available filters is given in the table below.

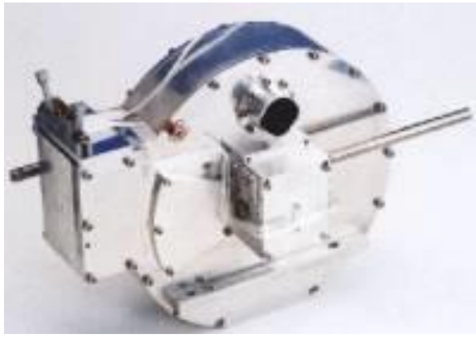
Filter	**E--W offset**	**N--S offset**
4132	0.0	0.0
4220	-0.3	-4.8
4308	-0.5	-2.6
4396	-1.1	-6.5
4484	-0.8	-4.6
4578	0.5	0.7
4667	0.7	0.4
4748	-0.4	-4.0
6420	-0.1	-1.3

The *Wildfire* command for moving the filter wheel is filt < position >, where < position > is a number from 1 through 13 or a name, i.e. open. Position 1 is always the open, i.e. no filter, position. help filt lists the filters currently available. With the filter as well as the other mechanisms, several aliases can be used for the command. filter and filt both work. Previous users of *Wildfire* motor commands should note that the word "to" is no longer allow (the previous syntax was "filt to < position >").

The filter wheel can be initialized with the command filt init. Initializing moves the filter position in the beam to an initial filter position which is stored in the computer. For the filter wheel this position is the open. Recognition of the home position is done by the use of registration LEDs in the mechanism. All but one of the mechanisms have these LEDs. Under normal use it should not be necessary to initialize the mechanisms.

The filter wheel, lyot wheel, and slit wheel are pawl mechanisms, i.e. the wheel rests in a latched stop. A frequent difficulty with these mechanisms is sticking in the pawl. If the mechanism will not turn when commanded to do so, the kick command will give the mechanism an extra push. The syntax is kick mechanism position. An extra parameter to increase the force of the kick also exists.

The default value is 2. Use this only if instructed since it is possible to damage the mechanism (and terminate your observing!) with this command.


Filter and Lyot wheel assembly

Lyot wheel: The Lyot wheel holds 16 stops to mask the edges of the telescope optics. The telescope structure glows in the thermal infrared and is a source of background radiation. The Lyot and filter wheels are both in a section of the optical path where the pupil is in focus. The diameter of the stop that should be selected is determined by the telescope and the radial position by the wavelength.

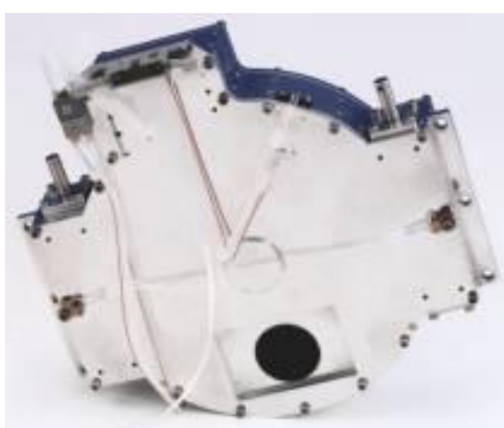
The Lyot wheel is of a pawl design which allows motion in only one direction. In addition to the normal Lyot stops the wheel also contains a dark and 5 special Lyot stops: 3 Hartman-type masks for a 2.5 magnitude intensity reduction, 1 Hartman-type mask for a 5 magnitude intensity reduction, and 1 mask that covers the secondary as well as the edges of the primary. The special stops are provided mainly for alignment and diagnostic applications. The following table lists the available stops.

Position	feature	telescope	wavelength
1	dark	--	--
2	lyot stop	4 meter	1 micron
3	lyot stop	4 meter	1.6 micron
4	lyot stop	4 meter	2.3 micron
5	lyot stop	4 meter	3.3 micron
6	lyot stop	4 meter	4.6 micron
7	lyot stop	2.1 meter	1 micron
8	lyot stop	2.1 meter	1.6 micron

9	lyot stop	2.1 meter	2.3 micron
10	lyot stop	2.1 meter	3.3 micron
11	lyot stop	2.1 meter	4.6 micron
12	hartman mask-big hole	4 meter	2 micron
13	hartman mask-big hole	4 meter	4.6 micron
14	hartman mask-big hole	2.1 meter	--
15	hartman mask-small hole	4 meter	--
16	central spot mask	--	--

The Lyot wheel is moved with the command lyot < position > where < position > is a number or dark. lyot init sets the Lyot wheel to the initialization position. help lyot lists the lyot stops available.

Preslit Filter Wheel: The instrument design called for a circular variable filter (CVF) located immediately above the slit. There was insuffient money in the Phoenix budget to buy a custom CVF. An attempt was made to use CVFs from decommisioned instruments but these CVFs had very large amplitude fringing. After considerable experimentation the CVFs were replaced with narrow band order sorting filters. By using the preslit filter wheel in addition to the filter wheel most of the filters available can be mounted in Phoenix. A 1 percent transmission infrared neutral density (ND) filter can also be found in this wheel. This filter fringes and is NOT suitable for spectroscopy applications. However, it can be useful for thermal infrared imaging due to the 1 second minimum integration time of the electronics.



Pre-slit filter and slit wheel assembly

The preslit filter wheel is controlled with the *Wildfire* command cvf < position >, where < position > is an angle running from 0 to 360 degrees. cvf nd and cvf open are also recognized. cvf init sets the cvf to the a preset initialization position.

Slit wheel. The entrance slit for the spectrograph is provided by a series of slits in a wheel not, as in the coudé feed or 4-meter echelle spectrograph, by a continuously variable jaw device. All the slits have the same length, 163 pixels in spectroscopy scale (4400 microns). Three widths are provided, 2 pixel (54 microns), 3 pixel (81 microns), and 4 pixel (107 microns). (The widths of the slits given here are the physical widths. At the slit plane the beam has been reduced to f/7.5. The slits are effectively twice as wide at the f/15 focus. Thus the width of the "54 micron slit" on the 2.1 m telescope at the f/15 focus is effectively 108 microns or 0.7 arcseconds.)

Each slit has a pupil reimaging lens located behind it. This lens has a high index of refraction and must be AR coated. The 2 and 3 pixel wide slits have lenses that are narrow-band AR coated. The lens behind the 4 pixel wide slit is broad-band coated. As a result the user selects both the appropriate width and wavelength for the slit desired. Also provided in the slit wheel are an open position for imaging, a dark, and several diagnostic positions (pin hole, cross, lyot viewing). The options are listed in the following table.

Position	feature	width	wavelength
1	pin hole	54 micron	--
2	slit	54 micron	0.9-2.0 microns
3	slit	54 micron	1.9-2.8 microns
4	slit	54 micron	3.0-5.0 microns
5	slit	81 micron	0.9-2.0 microns
6	slit	81 micron	1.9-2.8 microns
7	slit	81 micron	3.0-5.0 microns
8	slit	107 micron	1.0-5.0 microns
9	lyot viewer	4400 micron	--

10	open	4400 micron	--
11	open with plus	4400,255 micron	--
12	dark	--	--

The command to move the slit wheel is slit < position > where < position > is a number or a name (such as open, dark, etc). slit init moves the slit wheel to a preselected initialization position. help slit lists the positions of the slit wheel.

Viewer wheel. Immediately behind the slit, on top of the spectrograph, and beside the detector is a thick wheel that has four positions. One is a dark slide that closes in front of the detector. Another is a hole that allows light to enter the spectrograph. The other two positions allow Phoenix to be used as an infrared imager. One position images the slit plane and hence the field of view of the instrument. This can be used either with the open position in the slit wheel to view the entire field or with a slit to confirm that the star is in the slit. The last position on the wheel is a viewer for the lyot stop. The lyot viewer must be used in combination with special lyot position on the slit wheel. The Lyot viewer position is typically used only by the support staff to align the instrument to the optical axis of the telescope.

The Phoenix imaging mode is provided for acquisition and guiding and is not optimized for general purpose IR imaging. In particular, the minimum integration time is 1 second. This is too long for bright stars at any wavelength and for thermal infrared images. A 1% neutral density filter in the CVF wheel is provided to make thermal infrared images possible in a 1 second integration time with thermal IR sky background. Specific suggestions for use are given in the sections below regarding observing techniques.

The *spatial scale in imaging mode* is 1.6 times larger than the scale in spectroscopy mode (imaging scale = 0.24 arcseconds per pixel on the 2.1-meter; spectroscopy scale = 0.35 arcseconds per pixel on the 2.1-meter). Furthermore, the slit imager uses a set of mirrors and a single lens to image the slit on the detector. As a result the cardinal directions of undispersed images are flipped from the normal spectroscopy mode. Tests of the images across the field of view indicate that there are no major problems with aberrations. A detailed characterization of the image quality and astrometry has not been undertaken.

Unlike the other wheels in Phoenix, the viewer wheel does not have a position initializing diode or a latch mechanism. Instead this wheel is finely geared and runs from a hard stop at one end of the travel to a microswitch at the other end. Initializing the wheel runs it to the hard stop.

To move the viewer wheel, use the *Wildfire* command viewer < position > where < position > is one of the words lyot, spec, image, or dark. open is a synonym for spec. viewer init moves the viewer wheel to the home position which is the image position. help viewer lists the commands. view is a synonym for viewer. Due to the fine gearing the viewer wheel is the slowest mechanism on Phoenix. It takes about 20 seconds to move from the open to spectroscopy mode.

The Phoenix mechanisms are controlled by Ethernet commands to a motor controller on the side of the dewar. A feature of this control system is that certain pairs of mechanism may run simultaneously. It happens that the slit and viewer mechanisms are such a pair. The slit and viewer must both be turned to go from imaging to spectroscopy mode. Use of the option to move them simultaneously reduces the time overhead (due mainly to the user waiting and then responding to each command) by a total of about 2 minutes as well as reducing the potential for pilot error. The command tog turns both wheels simultaneously.

tog i - moves to imaging mode and stores current slit position
tog s - moves to spectroscopy mode with stored slit location
tog < nn >- moves to spectroscopy mode with slit location < nn >

The command toggle is also an alias for tog.

Trouble Shooting. The foreoptics mechanisms have a high level of reliability. However, occasionally a mechanism will not move when commanded to move. The *Wildfire* software reports the new position following a command. The user should look at the reported position and confirm that the mechanism actually moved to the new location. *Wildfire* should beep if the move failed. If the move failed first repeat the command. There is frequently noise in the communication between the Phoenix and instrument control computers. Many times the move has worked but has not reported correctly. In the event that this does not work, next try the kick command (kick mechanism position). It may be necessary to repeat the kick command or increase the force. If all else fails it may be necessary manually to move the mechanism. This is rarely necessary. Beware that most mechanisms will only turn in one direction. It is possible to do serious damage to the inside of the instrument by manually turning the knobs in the wrong direction. Should users have any question about the correct procedure they are urged to phone one of support staff regardless of the hour.

1.2 Spectrograph

The spectrograph is Ritchey-Chretien camera-collimator that produces an 8 inch diameter collimated beam. This illuminates a 31 line per millimeter R2 (63.4 degree) replica echelle. Light is returned from the echelle through the same collimator to the array. The input and output beams are in an over/under configuration with angular separation of +/-1.8 degrees. The separation is the minimum angle needed to physically separate the input (slit) and output optics (bending flat in front of the detector). The angle is as small as possible because the optical aberrations increase with off-axis angle. There are two moving parts in the spectrograph assembly, a collimator focus mechanism and the grating rotation mechanism.

Collimator Focus. Focusing of the collimator optics is tedious and is done by the instrument set-up person at the start of the run. However, the procedure is straightforward and users can refocus. It is strongly recommended that refocusing be undertaken only during daylight hours allowing at least one hour for the procedure. The collimator is focused by taking a series of spectra of the hollow cathode lamp located in the interface unit. The secondary is moved by the focus motor on the side of the dewar. The focus mechanism can also be turned by hand. The computer readout should match the focus readout counter on the side of the dewar. The *Wildfire* command to move the focus mechanism is focus nnn.n where nnn.n is the desired focus encoder reading.

IMPORTANT! In the 1999-2000 observing season there is a bad bearing in the focus mechanism in a location so inaccessible it will take months to replace it. We would appreciate users limiting the use of the focus mechanism. As a result of the bearing problem the torque required to turn the focus mechanism is higher than the motor specifications and hand operation may be required.

Typical numbers near focus are in the range 150-170. To correctly position the secondary, the focus must be approached by moving to larger numbers only. Moving to smaller numbers decenters the secondary. The procedure is start by running the focus to small numbers, around 20 but never less than zero, then to increase to around 140. This moves the secondary to a starting position and recenters it. Set the grating to a bright hollow cathode line (a favorite is at 4763.8 cm^{-1}). The two pixel slit should be used and the appropriate filter and lyot stops selected. (Of course the viewer should be "open" and the cvf open.) A few second integration time is adequate. An exposure at encoder 140 should show a doubled line. By moving the secondary perhaps five units and taking another exposure the two components will move closer together. This is continued until the lines merge into a single line and then continued to produce the narrowest possible line width. Steps of a few tenths of a encoder setting are appropriate as the line becomes narrow. Remember that it is not possible to go back once the focus is passed. Moving the focus to smaller encoder values decenters the secondary! A sample focusing run using the 2-pixel, 54 micron slit from the 2.1-meter telescope in September 1999 exhibited the following behavior:

Focus Encoder Value	FWHM at line 300 (pixels)	FWHM at line 550 (pixels)	FWHM at line 800 (pixels)
158.4	3.21	3.74	3.60
158.6	3.16	3.61	3.58
159.0	3.18	3.55	3.55
159.2	3.13	3.57	3.53
159.4	3.14	3.55	3.55
159.6	3.07	3.43	3.45
159.8	2.90	3.21	3.31
160.0	2.93	3.07	3.29
160.1	2.95	3.02	3.28
160.3	3.00	3.01	3.28
160.5	3.10	3.08	3.19
160.8	3.28	3.19	3.21

Collimator Focus Summary:

- The best focus value depends upon where you look on the array.
- Best resolution seems to come from the lower half of the array, where R=75,000 was readily obtained.
- When focusing towards increasing encoder values, the bottom of the array comes into best focus before the mid-array, and the mid-array before the top of the array. One's intuitive tendency to center the calibration line in the middle and focus leads to overall good performance across the array, with a loss of resolving power of at most 10,000-15,000 at the edges of the array (with the 54-micron slit).
- At best focus, the 84-micron slit yields a FWHM of 3.47 pixels, for a resolving power of 62,000. The resolution gradient across the array is less significant.
- At best focus, the 107 micron slit yields a FWHM of 4.21 pixels, for a resolving power of 51,000.
- The collimator focus is stable provided the instrument temperature is similarly stable.

Setting the Grating. The grating is a standard R2 echelle (blaze angle 63.4 degrees) of dimension 200x400 mm. The free spectral range is constant in wavenumbers, 177.255 cm^{-1} (this value takes into account the dimension change of the grating from room temperature to operating temperature). As a result orders span an increasing range of angle as wavelength increases (i.e. wavenumber decreases). For observations near 1 micron the grating should be within a degree of the blaze angle, by 5 microns the full range of travel ((~57 to 69 degrees) of the grating may be required to position to the desired location in the order.

The *Wildfire* command used to set the grating angle is grat, and the syntax is:

```
grat [position] [units] [offset]
```

where position is the desired grating position, units indicates whether the position has been given as wavenumbers (K), microns (m) or raw encoder units (no units given), and offset refers to a relatively-fixed encoder offset to center the designated observing frequency on the array. As an example:

```
grat 4763.80 K 1700
```

will send the grating to a central wavenumber of 4763.80 cm^{-1}, or 2.09916 microns, with an offset of 1700 encoder units. The following example will move the grating to a determined encoder value:

```
grat -11100
```

NOTE: Double-check your actions when moving the grating, especially if using raw encoder values. *Wildfire* prints the values you have requested and asks for confirmation before moving the grating. Always take a spectrum of a bright star to verify that the correct wavelength range is being observed. The grating can never be moved back to precisely the same spot. Always take flats before moving to a new grating position.

The grating program computes the beginning and ending wavenumber limits and other useful observing parameters. For planning purposes these can be computed from the following few simple equations. The order is the nearest integer to the wavenumber divided by 177.2553. The grating angle is then the arcsine of 158.63201 times the order divided by the wavenumber. The inverse linear dispersion for Phoenix in units of cm^{-1} per pixel is given by 9x10^{-6} sigma/tan (theta) where sigma is the wavenumber of the setting and theta is the angle of the grating. Thus on blaze the 1024 element array covers 0.46 percent of the spectrum in any given setting (i.e. 19.8 cm^{-1} at 4300 cm^{-1} or 9.9 cm^{-1} at 2150 cm^{-1}).

The grating is positioned with encoder units. The relation between encoder units and grating angle is a cubic. The calibration in 1999 gives: encoder=8573129 - 402584.5 θ + 6355.8478 θ^2 - 33.771986 θ^3. The spectrum observed in a single integration covers about 2000 encoder units.

2. Refrigeration

The operating temperature of Phoenix is lower than that of liquid nitrogen. A temperature less than 65 K is required because the InSb detector is sensitive to radiation with wavelengths as long as 5.5 microns. Thermal radiation from surfaces above 65 K would be reflected off the grating to the detector. The detector itself requires a stable temperature of 38 K. Stability of collimator focus also depends on having a stable instrument temperature. Fortunately, the correct operating temperature can be maintained indefinitely by the use of mechanical refrigerators.

Phoenix uses a pair of closed cycle coolers for refrigeration to cryogenic temperatures (standard operating temperature is near 50 K). No liquid cryogens are used. Phoenix takes three days to cool from room temperature to operating temperature (see the cooling curve) and can be warmed to room temperature in a day by using internal resistive heaters. The coolers are operated by a closed cycle cooler controller located in the computer room. Under normal conditions both heads will be running, however in the event of a catastrophic failure it is possible to keep Phoenix cold (but not to cool it from room temperature) with only one functioning head.

The coolers run on compressed ultra-pure helium that circulates in a closed loop from a compressor/heat exchanger. The compressor unit is located on the ground floor of the 2.1-meter building and in the room to the east of the control room at the 4-meter. At the 2.1-meter the heat is exchanged in this unit to glycol lines which then run to a glycol chiller unit outside the building. The chiller looks like an air conditioning heat exchanger and is located on the west side. At the 4-meter the heat is exchanged into the building air conditioning glycol.

The closed cycle cooler controller monitors the cold heads and the compressor. The controllers are located in the computer room at both the 2.1 m and 4 m. These systems have been reliable and observers will most likely never have to look at them. However, should any part of the system fail the controller activates a sonic alarm and an autodialer. The first step in diagnosing the problem is to silence the auto dialer alarm by press the black button on the bottom of the autodialer for three seconds. A second sonic alarm is located inside the controller itself and can be silenced by resetting the unit. The failure mode can then be determined by either reading the message on the front of the closed cycle cooler controller or by calling the autodialer. Complete instructions are found in the page on the closed cycle cooler controller . The most common cause of failure is a power failure. In the event of a power failure nothing needs to be done. When the power is resored the unit should start up again by itself.

Should a failure of the hardware occur you may be asked to provide technical information over the telephone. The glycol lines contain thermostats to monitor the performance of the heat exchanger. At the 2.1 m the output temperature is typically about 80 F and the return flow 20 F cooler. Should the temperature of both lines exceed 100 F the heat exchanger is not functioning and it is likely that the compressor will shut down. Similarly if there is no flow of glycol the compressor fails. At the 2-meter, a flow gauge is located on one of the glycol lines near the compressor. It should read about 30. The compressor also must supply helium to the refrigerators at the correct pressure. The supply helium pressure should be between 350 and 250 psi. The return pressure should be around 150 psi. In the event of a problem with the refrigeration, as with other problems with Phoenix or the telescope, do not attempt to fix anything yourself. Call for technical help.

Inside Phoenix there are numerous temperature sensors. These may be read out with the *Wildfire* status t command. A typical temperature for the interior of the instrument is about 50 K (1.07 diode units) and the detector 38 K (1.106 diode units). The figure gives a nominal temperature printout. Diode voltages are printed rather than degrees K. 1.0 is roughly 77 K with temperature decreasing as diode voltage increases (i.e. 0.4 is room temperature while 1.1 is 40 K).

Phoenix Temperature Status Display

Detector Temp	=	1.106	Mount Temp	=	1.116
Det Htr Pwr (mw)	=	30.409	Mnt Htr Pwr (mv)	=	552.620
Top Outer Shield	=	0.588	Top Inner Shield	=	1.046
Head 1: LN2	=	1.084	Head 1: LHe	=	1.498
Head 2: LN2	=	1.718	Head 2: LHe	=	1.084
CVF/SLIT Cover 1	=	1.060	Mirror Mount	=	1.059
CVF/SLIT Cover 2	=	1.058	Lyot Cover	=	1.060
Fixed Filter Cover	=	1.059	Grating	=	9.994
Grating Frame	=	9.994	Grating Tipper	=	1.073

Fixed Filter Right Angle Drive	=	1.068
Diagnostic Wheel	=	1.067
Lyot Stop Right Angle Drive	=	1.068
Visible Dichroic Mirror Mount	=	1.057
Secondary Mirror Focus Frame	=	1.070
Secondary Mirror Focus Mount	=	1.070
Collimator Box Bottom Cover	=	1.071
Bottom Inner Heat Shield	=	1.049
Bottom Outer Heat Shield	=	0.587
Primary Mirror Mount Cover Plate	=	1.072

The standard *Wildfire* status display is generated by status s. This includes basic information on the temperatures. Unless there is reason to be concerned about the refrigeration this readout is sufficient.

Phoenix Status Display

Detector Temp	=	1.106	Mount Temp	=	1.116
Det Htr Pwr (mw)	=	30.409	Mnt Htr Pwr (mv)	=	548.779
VDet	=	-3.201	VddUC	=	-3.503

Observation Settings
File name = "data%03d " Index = 40 Space Available
Header Dir = "/data2/2meter/n4 " 1702047kb
Pixel Dir = "/data2/2meter/n4/pixels " 1702047kb
Integration Time (secs) = 1800.000
coadds = 1 lnrs = 1

The Filter Wheel	(filt) is at wn_4308
The Lyot Stop Wheel	(lyot) is at 2m_2.5
The CVF Wheel	(cvf) is at position 0
The Slit Wheel	(slit) is at 84u_1.9-2.8
The Viewer Wheel	(viewer) is at open
The Grating	(grat) is at position 4032

3. The Interface Unit

A spacer and calibration unit goes between Phoenix and the telescope. This unit has one movable part, a window cover. At the start of your run it will be necessary to open the window cover with the *Wildfire* command cover open. Note that the position of the window cover appears in the status window.

Operation of calibration sources: The backside of the window cover contains a hollow cathode source. If you should want to use the hollow cathode source close the window cover with cover closed The *Wildfire* command to turn on/off the Th-Ne-Ar hollow cathode lamp is:

hlamp on/off -- to control the hollow cathode

Observers take note! Please do not burn the hollow cathode any longer than necessary as this bulb has a finite lifetime. The supplier of this lamp is very difficult to deal with and there may not be a spare. Furthermore the lamp is difficult to access. Make sure you do a hlamp off command when you are done with the lamp and check the status window to make sure it is off.

4. The Detector Array

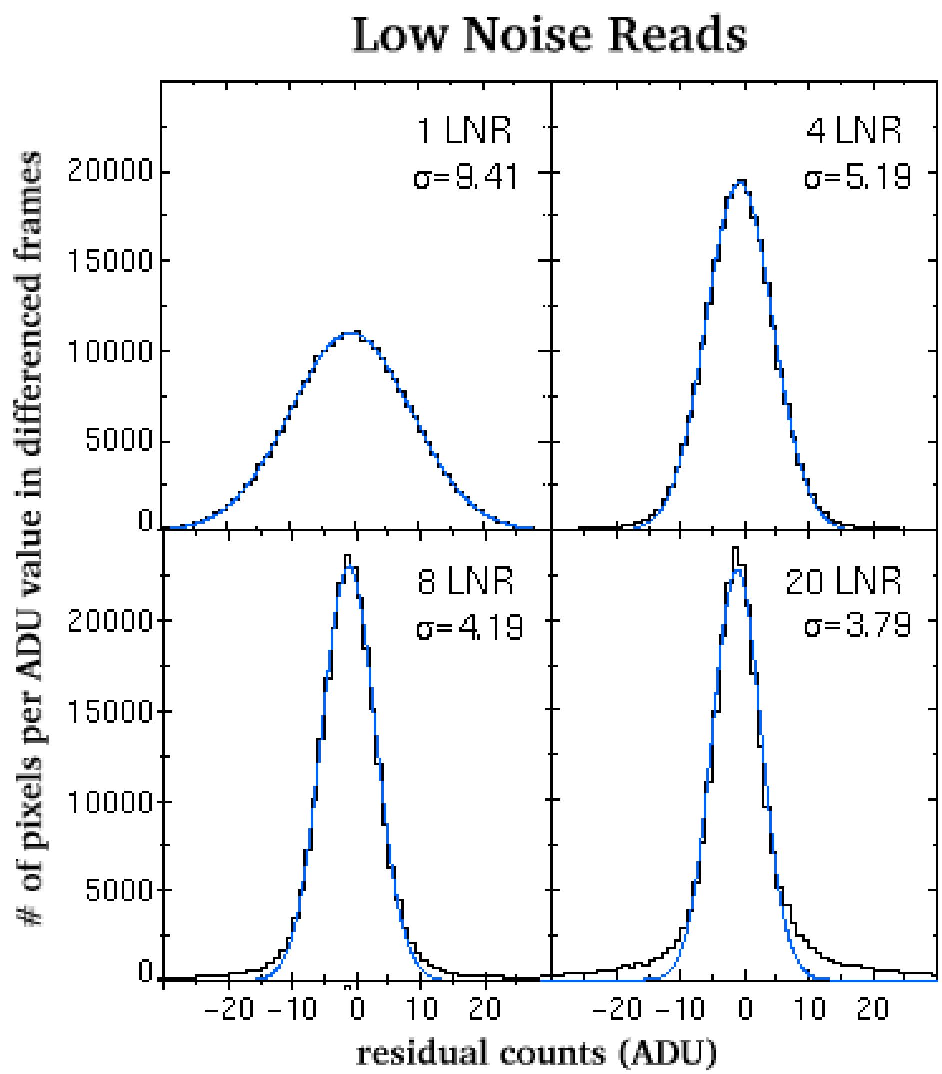
The detector is an InSb array from the first foundry run of the Aladdin project, i.e. a 1024x1024 InSb array with 27 micron pixels. The Aladdin arrays are divided into four 512x512 quadrants. Phoenix's array has two unusable quadrants, which turns out to be optimum for use in Phoenix since in spectroscopy mode the optics illuminate 163 columns along the slit and 1024 rows along the spectrum. The spectrum has been moved to the best portion of the usable section of the array and an image measuring 256 columns by 1024 rows is read out. In imaging mode the field is a 260 pixel circle so both imaging and spectroscopy are covered by the 256 x 1024 read out.

The array is linear to 10,000 counts. Saturation occurs a few thousand counts above this value. Saturated pixels may appear near zero in the readout. If the array is heavily saturated over a large area the dark current will be substantially increased in subsequent images. Should this occur the dark current will eventually return to normal but the decay time can take hours. The normal dark current is on the order of 1 electron per second. The conversion from ADU to electrons is 8.3 electrons/ADU. The read noise is approximately 60 electrons in the normal double-sampled readout mode.

A feature of InSb arrays are high dark current pixels. These pixels play a dominant role in the performance of Phoenix. In short exposures (a few seconds) the S/N performance of the array follows photon counting statistics. For exposures of a few minutes and longer we find that the S/N is dominated by the noise from the high dark current pixels. The result is that the S/N of an extracted spectrum that does not deal explicitly with the high dark current pixels follows the square root of the number of ADU rather than the square root of the number of photons. There are various reduction processes that possibly may restore the missing factor of 2 in the S/N. Examination of the images shows regions dominated by pixels of low dark current and photon counting statistics. The required reduction steps are at the next higher level of complexity than the usual reduction discussed here.

Multiple (low noise) reads are available with Phoenix. These are recommended only on long exposures of many minutes in length as additional readout overhead is added. The optimal number of low noise reads is 8, which reduces the read noise to approximately 35 electrons. However, each low noise read dramatically increases the number of pixels with high dark current. Over 5% of the pixels in the array must be discarded with 8 low noise reads. While many of these pixels can be mapped out in software, Phoenix's sensitivity is even more limited by the large number of "warm" pixels when the multiple reads are enabled. While there may be a measurable advantage to using multiple (low noise) reads, at this time it is unknown what additional overheads may be encountered in data processing. Low noise reads are turned on with the *Wildfire* command lnrs < number > where < number > is an integer. lnrs 1 turns off the low noise reads.

A histogram of the number of pixels with a certain residual signal after differencing two similar frames is provided below, and sample images taken during runs at the Kitt Peak 2.1-meter are provided in the following section.



5. Observing Procedures

5.1. *Wildfire* start up

The infrared equipment at NOAO is operated under *Wildfire* software run on a SUN or SPARC workstation. Phoenix uses a dedicated computer so it should not be necessary to start *Wildfire*. However, if this is required, *Wildfire* will questions about the electronics. The DSP box (also known as the Heurikon box) is a black rack mounted electronic box in the computer room. Unless computer power has been down, this box will not have been turned off. The instrument has two electronics boxes mounted to it that run the array. The larger has a green light visible through a hole in the front. Should it be necessary to cycle power on this electronics, this is done by commands in the Saver/Daemon window. Type a return in the Saver/Daemon window and get a prompt. Then type inter status 3 to get the current status. To control the instrument power, the command is inter control ip [on/off]. Note that this command will not function unless typed exactly. It is also possible to use this command to cycle power to the motor controller. The command is inter control mp [on/off]

The last question *Wildfire* asks is if you wish to activate the Aladdin array. Do not activate the array unless you intend to use the array. The array can be actived at any time by typing activate. Activation of the array will set the array bias. The bias should read back 0.300. If the output bias differs from this by more than a few thousandths, use the word setbias n.nnn, where n.nnn is a new bias value (typically 0.320) to adjust the input bias up or down from 0.300 to achieve an output value of 0.300. The read out bias is always a few hundredths less than the input bias. To deactivate type deactivate. A deactivated array remains sensitive to light but the resulting image is negative.

For a comprehensive description of frequented *Wildfire* commands as used by Phoenix, click here.

In rare circumstances, *Wildfire* will hang. This is usually the happens if a second command is issued before the first has finished or if an integration is aborted (this is a hint to the alert reader!). To unhang try "control c" in the *Wildfire* window and typing hung and/or hung2 in the console window. The goal is a clean exit from *Wildfire*. Should it be necessary to reboot the computer, hold down the "stop and A" keys simultaneously. Type b for boot. The b is sometimes requested by a white letter on white background prompt!

5.2. Setting up for an observation

Several steps are necessary to set up an observation. A number of these are only required once for any wavelength setup.

1. *Set the observing parameters:* To set the observing parameters, first type eask. This reviews the list of possible parameters and lets you decide which parameters to use. Selected parameters are identified with la, other parameters with an l. Parameters that are typically selected are the exposure time, title, number of low noise reads, and the destination file name and directory for the image. ask allows you to update the parameters you have selected with eask. An observation is started with go.
2. *Set the mechanisms:* Move the filter wheel to the appropriate order sorting filter (filt < nn >) and set the Lyot wheel to the correct stop (lyot < nn >). Move the slit to the desired slit (slit < nn >) and make sure the viewer wheel is open by checking the status. Set the grating angle (grat). The instrument support person should have told you the value of the offset in the grating program. This offset value is important because the program sets quite accurately but has a systematic offset from the lab calibrated value.
3. *Check the wavelength:* If the wavelength is in the 1-4 micron range there is some likelyhood that a few hollow cathode lines will be present in the observed wavelength interval. The grating program prints the wavelength (wavenumber) limits of the observation. Using the hollow cathode catalog (paper copies are in the 2.1 and 4 meter domes), you can see if any lines will be present. In the 1-2.5 micron region, lines that are bearly visible in the catalog will be strong in a 60 second Phoenix integration. Also the ratios of line strengths may be slightly different between the catalog and the Phoenix hollow cathode source. To use the hollow cathode source in the interface module, slide it into the beam and then turn it on using hlamp on. Please remember to turn it off when done (hlamp off) and slide it back out of the telescope beam. The grating can be nudged by changing the offset value in the grating program. There are approximately 2 encoder units per pixel. Larger encoder values moves the spectrum down on the display.
4. *Focus the telescope:* Ignore this step if the visual guider is already set to be confocal with the spectrograph. Focusing must be done in the non-thermal infrared (1-2.5 microns). Put Phoenix in imaging mode (viewer image and slit open or use the tog command). Set the exposure time to a few seconds and have the telescope operator point at a SAO star. 7-9th magnitude is appropriate depending on telescope. Take an exposure of this star. Adjusting the exposure time or star selection to make the peak counts fall in the few hundred to few thousand range, measure the size and oblateness of the image with *IRAF* (imexam with the j and k key). Change the focus and repeat.

Run through the range of best value at least two times to make sure seeing is not a factor. At the best value the telescope has been focused onto the spectrograph the slit. Manually refocus the visual guide camera to give best focus at this telescope focus setting (typically the set up person does this -- the guide camera has a lens with a focus mechanism like that on a 35 mm SLR camera.)

5. *Find the slit (method 1):* Recall that the Phoenix slit is buried deep in the instrument and the front of the slit is not visible. The slit can only be viewed from the back side and then only when a spectrum is not being observed. The position of the slit in the field of view must be determined. There are two alternate techniques for locating the slit. This one is carried out in imaging mode. The foreoptics should have the filter, lyot stop and slit that have been selected for the science program. Point at sky (do not attempt to get the star on the slit) and take a long enough exposure to illuminate the slit. If you are working in the thermal infrared, and especially at M-band, the minimum 1-second exposure time will saturate the slit image on the detector. Use the 1%-wide CVF neutral density filter to reduce the number of counts (cvf nd) and increase the integration time if necessary. The exposure time to get an image of the slit depends on wavelength and will range from a few second in the thermal infrared (using the neutral density filter) to 60 seconds at 1 micron. Using *IRAF* display the image into the second ximtool buffer. Now remove the slit (slit opennorth n.n, etc., where n.n is the number of arcseconds, in the *Wildfire* window. Using ximtool's "registration" and "blinking" routines, you can readily compare whether you have the star on the slit. The 2.1-meter does not always move reliably so many moves may be required. The image plate scale is 0.24 arcseconds/mm on the 2.1 m. As a final test you may wish to put the slit back in and image the star through the slit. Once happy mark the star position on the VDU (video display unit) with a grease pencil and have the operator mark this position either with a grease pencil or with the guide box. It will be necessary to mark two positions well separated on the slit but not at the ends of the slit.
6. *Find the Slit (method 2):* This technique uses only spectroscopy. Point at a very bright infrared star (0 magnitude at J, as bright as possible at M). With Phoenix in the spectroscopy setup that you want for taking data, take a 10 second exposure. Now move the telescope about 2 arcseconds perpendicular to the orientation of the slit and take another exposure. (The slit is typically oriented east-west. If this is the case move north or south 2 arcseconds.) Look at the images for a spectrum. March the star across the field of view repeating exposures. When a spectrum is seen move in the direction that increases the signal. Iterate with smaller telescope moves to increase the signal. Beware of saturation. As you get closer to the correct position it may

be necessary to reduce the exposure time or move to a slightly fainter star. Mark the star's position at the location of peak signal. As in method 1, it will be necessary to mark two positions well separated on the slit but not at the ends of the slit.

7. *Confirm the setup:* Place Phoenix in spectroscopy mode. Confirm by looking at the status display that this is the desired set up. Go to a bright star of your choice (some observers prefer A stars, some K stars) and take a spectrum. The star should be placed on the mark you made above on the VDU. You may wish to use the above peak up procedure to maximize signal and re-mark the star position for guiding. At this time also confirm the grating position using the Infrared Arcturus Atlas (available in the domes). The atlas contains both a K star spectrum and a spectrum of the transmission of the Earth's atmosphere (which is what is detected by looking at an A star). Larger wavenumbers are higher on the visible display of the spectrum and to the right in extracted spectra. It is advisable to take spectra at two positions on the slit and then to do a fast reduction of the spectrum to confirm all is well. Following this, program stars can be acquired by centering on the mark on the guide VDU.

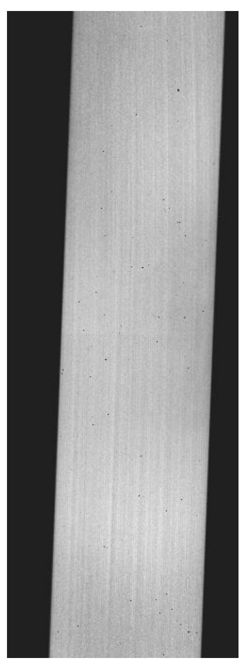
5.3. Observing

While the setup is fairly involved most Phoenix observing is very simple. There are two important rules. First, all spectra must be observed in pairs with either the source moved along the slit from one observation to the next or with the source on the slit for one observation and off the slit for the next. This allows the pairs to be differenced. *Spectra that can not be differenced should be considered unreducible.* Second, a set of flats with darks of matching integration time must be taken at each grating setting.

Differencing removes sky emission and a host of detector related problems (a detailed discussion is presented in Joyce,R. 1992 Astronomical CCD Observing and Reduction Techniques, ed. S. Howell, ASP Conference Series 23 258). One problem that is minimized by differencing are the "warm" pixels mentioned above. Related to this are detector non-linearities. Radiation from bright night sky lines, from OH features in the 1-2 micron region and from all the atmospheric molecules in the thermal IR, can be largely removed by differencing. Longward of 2.5 microns region, even regions of the sky clean of any absorption line contribute conspicuous blackbody radiation. The standard infrared approach to removing these effects is to "nod" the telescope along the slit. With Phoenix, this is implemented by obtaining multiple (at least two) exposures of the same integration time along the slit. Each pair of exposures can be differenced.

If the above setup steps have been completed, observation of visible stars is carried out by moving the telescope to place the program star on the first mark on the guide VDU, setting up the integration with the *Wildfire* command ask and starting the integration with go. When the integration is completed the star is move to the second mark and another integration started. For off star mapping, *Wildfire* can move the telescope and it is possible to write *Wildfire* scripts. The *Wildfire* manual should be consulted. For optically invisible sources, imaging mode must be used to position the source on the slit. The tog command is very useful in switching between imaging and spectroscopy mode. On the 4 meter, after initial acquisition, the guide probes can track field stars to keep the source on the slit. This option is not available on the 2.1 meter and combined with the poor tracking of this telescope it is necessary to frequently check the pointing using the Phoenix infrared imaging mode.

Flat field exposures should be taken at least once in every 24 hour interval and must be taken for each grating setting. For observations in the 1-2.5 micron region the flat field can be either the tungsten filament lamp in the interface unit or the white spot. In the thermal infrared the white spot is probably too faint. Set an exposure time so that several thousand ADU are observed. For the interface flat field the exposure time is typically in the range 10-30 seconds. Multiple exposures should be taken to average out random events. The standard number of exposures is 10 to 20 (the number of exposures can be changed with ask).



This figure shows a typical flat observed in the 2 micron region. After observing the flat field the source should be turned off and the same observing procedure used to observe darks. In the thermal infrared the lyot dark or viewer dark should be introduced for the dark exposures. Bias exposures (integrations of zero integration time) are not done with infrared arrays.

Most regions of the infrared, even at the resolution of Phoenix, are rife with telluric absorption lines. These are typically ratioed out of the final spectrum by observing a hot (spectral type early-A or hotter) star at the same or bracketing airmasses as the program star. Tables of bright A stars are provided on the Phoenix web page. Be aware that hot stars do have spectral features, in particular hydrogen and helium lines. In the thermal infrared, in particular in the 4.6 micron region, the Moon makes a fairly bright comparison. As the Moon is an extended source, it illuminates the optics slightly differently than a point source and may not difference as cleanly as one might naively imagine. The 1-2.5 micron spectrum of the Moon is largely a reflected solar spectrum and is not suitable for comparison.

End of night procedure: Leave the spectrograph with the viewer at dark at the end of the night. This position allows cryopumping of the collimator while keeping the array in the dark. ALWAYS deactivate the array (*Wildfire* command deactivate) when you not using the instrument. Remember to active the array when you next want to use Phoenix (*Wildfire* command activate)! Last, close the dark cover to protect the dewar window (*Wildfire* command cover closed).

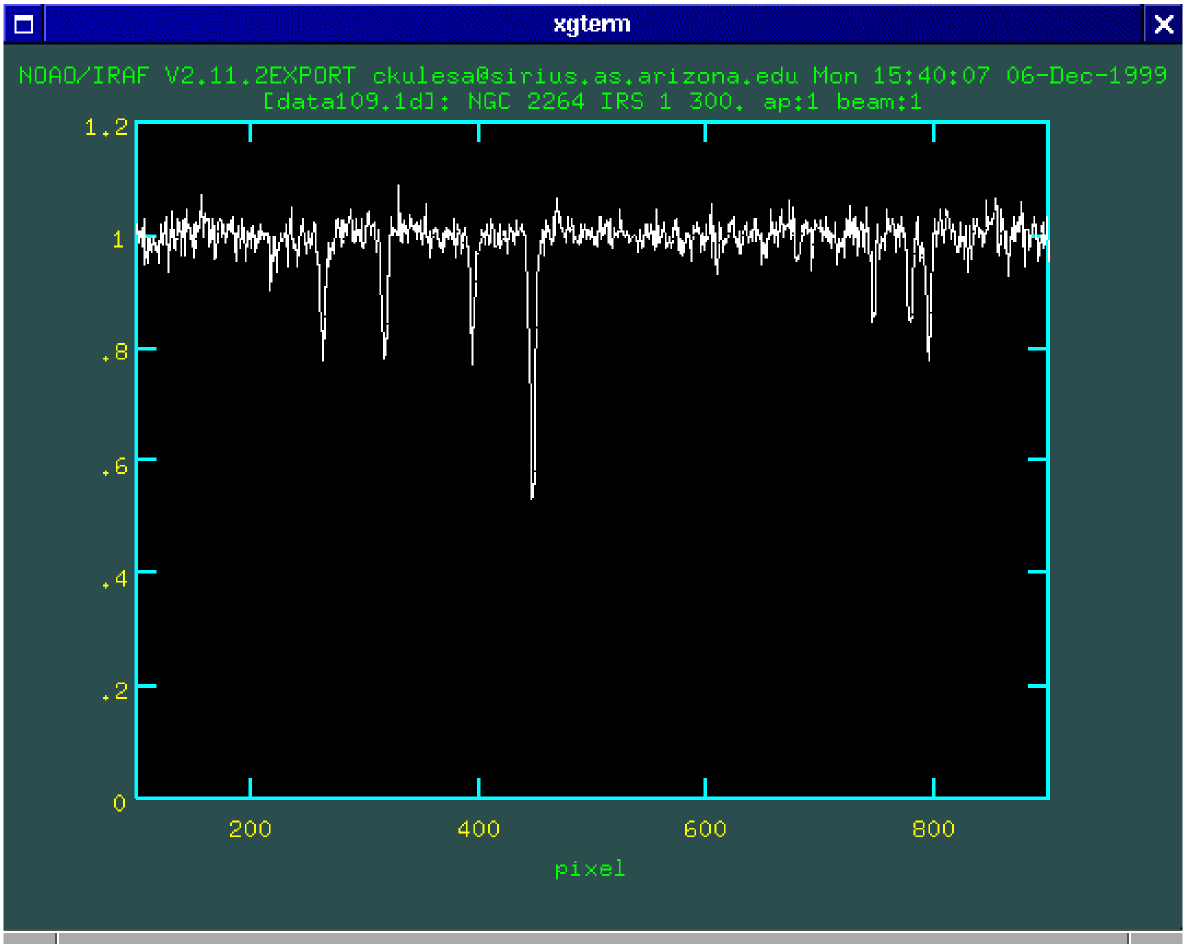
End of run procedure: If you are the LAST observer before Phoenix is REMOVED from the telescope we will be eternally greatful if you would leave Phoenix in the following configuration (this setup protects the detector). viewer dark, lyot dark, filt open, slit plus, cvf open. And of course Deactivate the array!

6. Integration Times

Potential users are referred to the Integration Time Calculators for the 2.1 and 4 m telescopes found on this web site.

7. Data Reduction

Reduction of Phoenix data can be carried out with *IRAF*. Here we will run through the basic steps without getting into the details of the *IRAF* routines. A more complete discussion is available as an *IRAF* tutorial. First, the flats must be processed by combining the flats, combining the darks, and subtracting the dark from the flat. Bad or near zero pixel values can then be removed from this image. The images should be divided by the processed flat. Each set of images should then be differenced. Bad pixels need to be dealt with and the spectrum extracted.



A sample extracted spectrum of a non-stellar object is shown in this figure. Following the extraction of all the spectra, the spectra must be wavelength calibrated

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