The CRSP User's Manual

1. Introduction

The infrared Cryogenic Spectrometer (CRSP) is a longslit spectrometer utilizing a SBRC 256 X 256 InSb array designed for use at the f/15 Cassegrain foci of the KPNO 2.1-m and 4-m telescopes. CRSP operates over the 1 - 5 micron range, and interchangeable gratings permit spectroscopy at low (~ 300), moderate (~ 700), or intermediate (~ 1500) spectral resolution. Five slit widths, ranging from 1.2 to 7 pixels at the array, may be selected to achieve the desired compromise between spectral resolution and throughput. A dedicated instrument rotator permits slit position angles between -5 and 185 degrees on the sky.

2. Instrument Description

Optical Description

The optical layout of CRSP, also known as "SALLY", is shown in Fig. 1. The f/15 telescope focal plane is located just outside the entrance window on the top of the instrument. The input mirror M1 forms an image of the telescope exit pupil on the mirror M2, which is masked to the exit pupil image diameter to serve as an optical cold stop. M2 reimages the focal plane onto the physical slit S, which is located behind the filter wheel FW, containing the order separation filters. The spectrometer section consists of the collimator M7, the four-grating turret G, and the achromatic camera C, which focuses the spectrum on the array. The actuator used previously for switching from f/15 to f/30 foreoptics has been converted to manually insert a dark slide (DS) into the beam for dark observations.

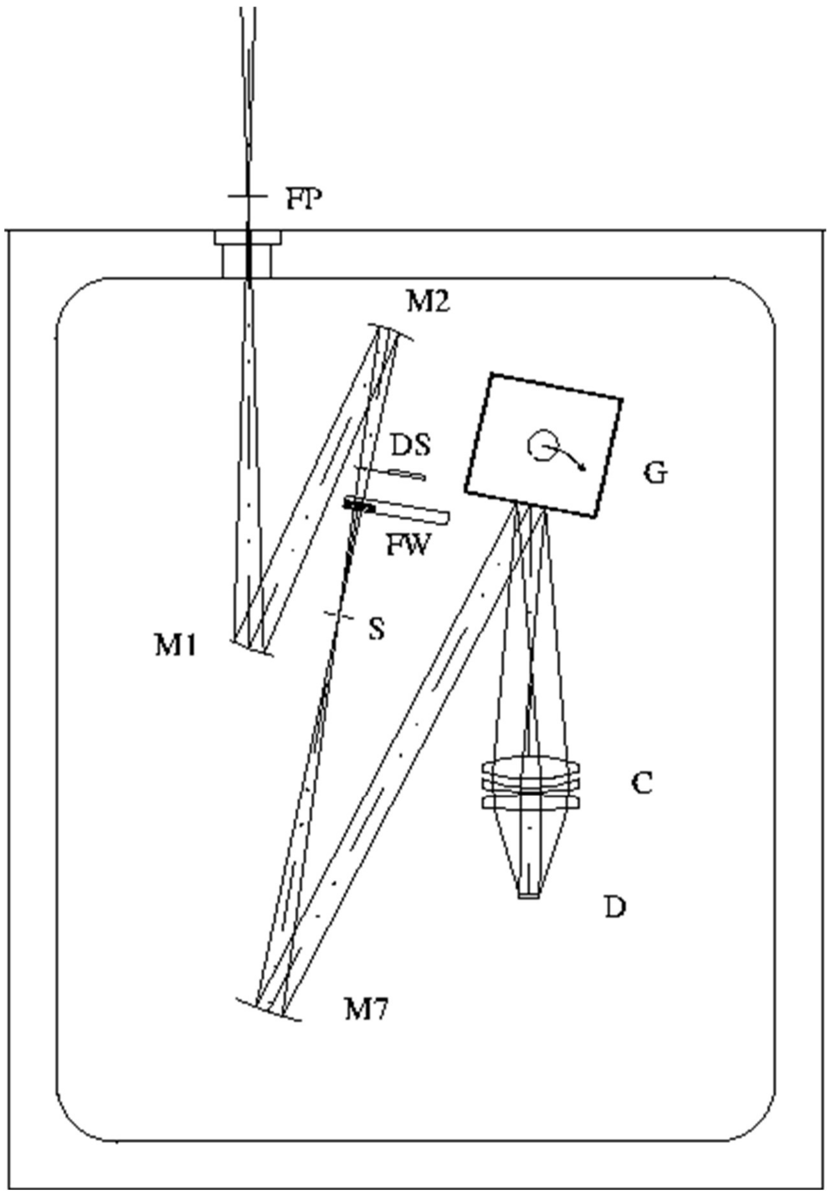


Fig. 1 Optical layout of CRSP. The elements are identified in the text.

Because this instrument was modified from an earlier prototype, some compromises were inevitable. The 25° off-Littrow operation results in significant anamorphic magnification of the slit at large grating angles with the high-resolution grating. The inherent spectral line curvature is also exaggerated somewhat at large grating angles. The available space within the spectrometer section limits the collimator diameter, resulting in coverage of only 135 pixels in the spatial dimension. The pixel scale and spatial coverage at the two telescopes are summarized in Table 1.

Table 1				
Telescope	**f/ratio**	**arcsec/pixel**	**#pixels**	**field (arcsec)**
2.1-m	15	0.61	135	81
4-m	15	0.349	135	49

Filters

The filter wheel contains filters for order separation. All of the gratings are blazed in the vicinity of 4 microns, so operation at shorter wavelengths requires isolation filters to prevent order overlap. Selection of the desired filter is through a computer-controlled stepper motor. The filter bandpasses and the expected order for typical use with high and low-resolution gratings (Table 4) are given in Table 2. Due to the width of the I filter, order overlap at M=4 will occur for wavelengths > 1.12 microns.

Table 2. Order Separation Filters					
position	**bandwidth (microns)**	**band**	**order (low)**	**order (med)**	**order (high)**
1	2.90 - 5.50	L, M	1	1	1
2	1.92 - 2.58	K	2	2	2
3	1.40 - 1.82	H	3	2	2
4	1.14 - 1.36	J	4	3	3
5	0.90 - 1.20	I	4	3	4

Entrance Slit

The spectrometer slit jaws are razor blades, one of which is supported by parallel leaf springs and positioned by a cam, which determines its separation from the stationary edge. Control is by a motor identical to that used for filter selection; the five possible widths in microns, pixels (one pixel is 96 microns at the focal plane), and arcsec at the telescopes are tabulated below in Table 3.

Table 3. CRSP Slits				
position	**width (microns)**	**pixels**	**arcsec (2.1-m)**	**arcsec (4-m)**
1	610	6.4	3.9	2.3
2	510	5.3	3.3	1.9
3	380	4.0	2.5	1.5
4	270	2.7	1.7	1.0
5	125	1.3	0.8	0.46

Gratings

The gratings are mounted in a turret capable of holding four gratings which rotates, on an axis passing through the front surface of the selected grating, to the desired angle. To change gratings, the turret itself rotates about a central axis, accessible from outside the cryostat when the grating tilt is set to the proper value. There is one grating providing low resolution (~ 300), two of intermediate resolution (700), and one of high resolution (1200 - 2000); a resolution element is assumed to cover two pixels. A single setting of grating 2 will provide complete coverage of each of the I,J,H,K, and L bands. Grating 3 is blazed at 4 microns to yield optimum performance in the short K band; with the 256 X 256 array, it can cover the entire J band and most of the K band at a single setting. However, the efficiency in the H band is very poor. Grating 4 will work efficiently in the L (m=1), H (m=2) and I (m=3) bands. Operation in the I band at m=3 alleviates the order overlap encountered at m=4 with this relatively broad filter.

Table 4. CRSP Grating Specifications				
No.	**lines/mm**	**blaze (°)**	**blaze (microns)**	**bands**
1	300	36.8	4.0	I,J,H,K,L
2	75	10.	4.5	I,J,H,K,L
3	150	17.5	4.0	I,J,K,L
4	200	17.5	3.0	I,J,H,K,L

Mechanical Description

Located at the telescope focal plane are the spectrometer cryostat, instrument rotator, and associated warm electronics in two boxes mounted to the instrument. This assembly mounts to the off-axis acquisition/guiding box also used with IRIM for operation at the 4-m telescope, or to the standard guider at the 2.1-m. Fig. 2 shows a top view of the instrument and identifies the important parts. Additional drawings may be found in the Technical Manual. CRSP communicates with a remotely located instrument computer and ultimately with the user in a remote observing room (Fig. 3). Even though the f/15 focal plane at the 4-m is well back from the "nominal" focal plane of the telescope, a reimaging lens in each guide probe assembly permits them to be used for guiding and precision offsetting.

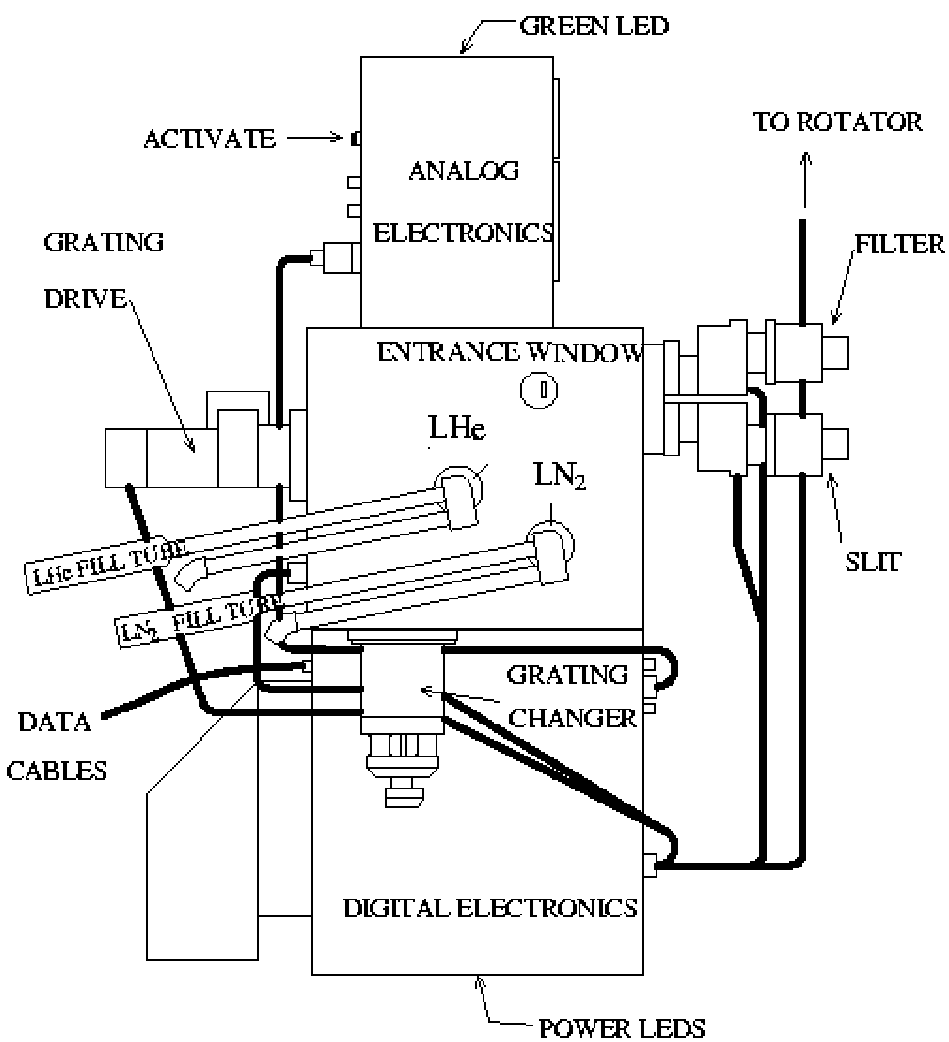


Fig. 2 Top View of CRSP

Because the instrument rotators on the 2.1-m and 4-m telescopes differ in capability and operation, a dedicated rotator was constructed for this instrument. Slit position angles from -5 to 185 degrees are possible, although there will generally be some motion of the optical axis after a position angle change, since the optical and mechanical axes of the instrument may not be precisely coincident.

Cryogenically, CRSP is a double reservoir system. Most of the internal parts, including the gratings, optics, and filters, are cooled to 77 K with LN_2. The array itself is operated at ~ 30 K by a thermal strap to a LHe reservoir plus a closed loop heater circuit. The hold time of the LN_2 is ~ 20 hours; the LHe will last ~ 14 hours with power applied to the heater and ~ 24 hours with the power off. On long nights a LHe refill may be necessary during the night, particularly if the system is operated at large zenith distances. Special "in-place" transfer lines on the instrument permit refilling the LN_2 and LHe without removal from the telescope. Thus, after installation by the support scientist, the user need never concern herself with removing the dewar from the telescope. In any event, **the cryostat should not be removed from the telescope without contacting mountain technical staff and/or the support scientist**. Cryogen transfers are the responsiblity of the mountain technical staff; observers should work out a mutually agreeable schedule for cryogen refill with the staff if a nonstandard observing schedule is anticipated.

Refer to Fig. 2 to identify the external features of the instrument. CRSP will be cabled upon installation, and **should not be uncabled for any reason without contacting KPNO staff first.** The only necessary user contacts with the focal plane instrument are the blue "activate" button on the analog electronics box, the mechanism for inserting the dark slide, and the mechanism for changing from one grating to another. The activate button closes the last relay between the external electronics and the array; the user will be prompted to push this button as part of the startup procedure. This will also turn on a green LED visible through a hole in the analog electronics box. The grating change mechanism can be used only if the grating angle has been preset to the proper position; its use will be covered in the procedures section. Finally, note that there is no external index or means of inspection to verify the grating angle independent of computer control. Its position is derived from an absolute encoder coupled to the stepper motor, and so does not require any initialization upon startup or rebooting.

3. Command, Communication, and Control

CRSP is operated by the user from the SUN workstation in the telescope control room, through the WILDFIRE system, a transputer based system which communicates over optical fibers. WILDFIRE supports fast co-adding in place, movie mode, and data transfer directly to the SUN.

The WILDFIRE system uses transputers and transputer links to control and acquire data from CRSP. A transputer is a single-chip microcomputer with its own local memory and communication links, which can operate either by itself or in conjunction with other elements linked to form computing arrays and networks. The WILDFIRE system consists of three main hardware components:

- The CRSP instrument control unit inside the DCU (Digital Control Unit) box contains two transputers which provide housekeeping data and control and generate the sequences which operate each array. The motor controller module is also inside the DCU, eliminating the need for a separate motor controller box. All motor, data, and power cables are connected to the DCU.
- The DSP unit (a VME based Digital Signal Processor system located inside the black Heurikon box in the computer room) contains eight transputers which provide the math processing needed to do coadding as the data are taken and buffer space for finished data before it is transferred to the SUN computer.
- The B016 unit (a programmable dual-port memory and interface board located inside the black Heurikon box in the computer room) interfaces the transputers and the SUN and handles the formatting of data before it is saved to disk.

Communications between CRSP and the DSP take place over transputer links implemented on an optical fiber cable. The B016 interconnects the transputer DSP to the SUN SparcStation computer via a VME to SBUS converter within the Heurikon box.

The WILDFIRE user interface on the SUN is implemented within the TCL (tool command language) environment. The data appear as IRAF images, produced (in IEEE 32-bit floating point format) via IMFORT routines so that they can be manipulated and archived to tape inside IRAF. It is important to note that these images are NOT PROTECTED in any way and can be overwritten if the full path names of existing and new images are the same. The data may be written to Exabyte or DAT on local tape drives or sent via 'ftp' to one's home institution. Depending on the amount of header information, a single FITS file of a 256 X 256 image is about 270KB.

At each of the telescopes where CRSP is used are two SUN workstations for data acquisition and reduction. Under the present version of WILDFIRE, the workstations khaki (4-m) and royal (2.1-m) are used for data acquisition. The other workstations [pecan and lapis at the two telescopes] have common access to the data disk, so additional observers can reduce and analyze the data independently. A third SUN serves as the telescope control, with a terminal at the LTO station; a hardwire link between the TCS and instrument control computers is used to send TCS commands to the telescope (singly, or within TCL scripts) and to retrieve telescope information for the image header. A schematic depiction of this arrangement is shown in Fig. 3.

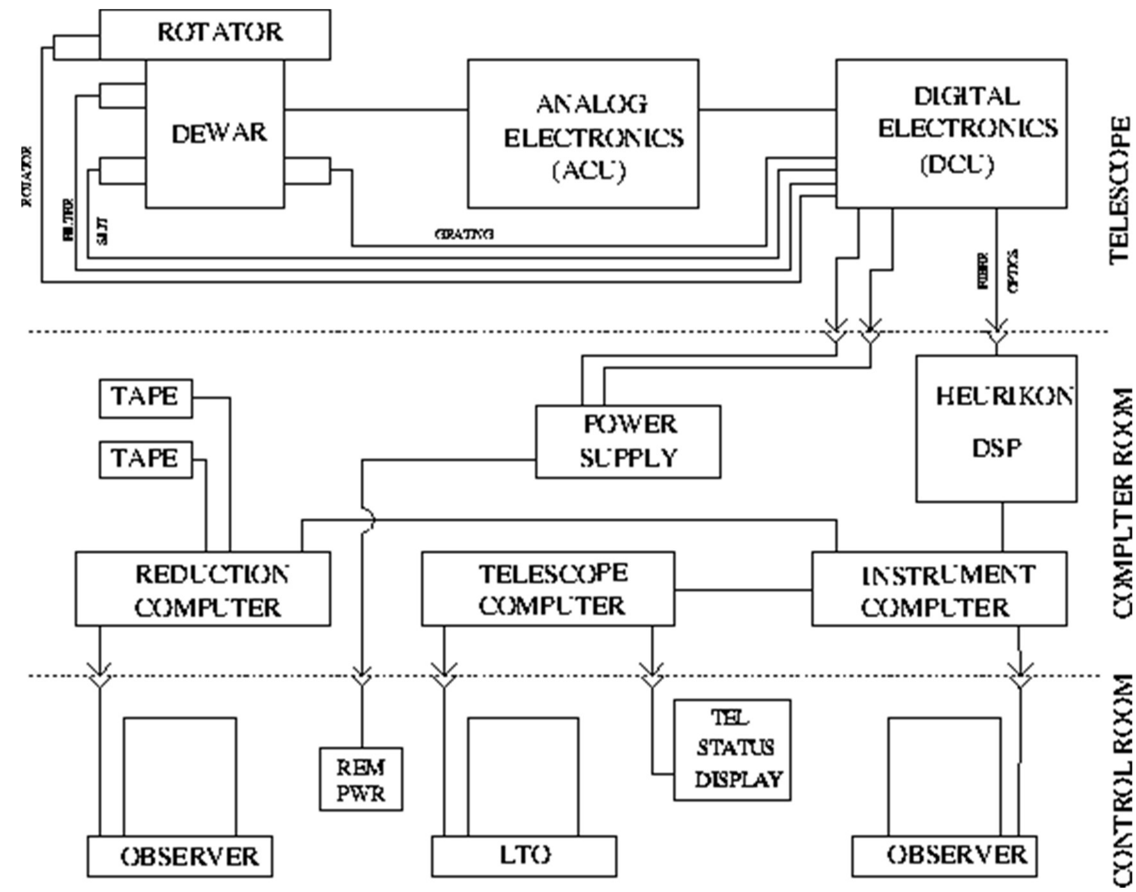


Fig. 3 Schematic configuration of electronics and computers used with CRSP/WILDFIRE

Important Note: The disks within the primary workstations khaki and lapis are designated /data1. At the 2.1-m, WILDFIRE is run on the secondary workstation royal, whose partition is /data2. The disks are cross-mounted so that access to both is possible from either machine. However, such cross-accessing (e.g., /data1 from royal) is significantly slower than accessing the disk resident in the workstation. Therefore, it is *imperative* that the partition used for storing data taken by WILDFIRE be /data2 on the 2.1-m telescope! While it is possible to designate /data1 as the WILDFIRE data partition, operation will be much slower and subject to crashes, so don't do it. At the 4-m, one may designate either /data1 or /data2 as the data partition.

4. The InSb Detector Array

The detector in CRSP is a 256 X 256 hybrid focal plane array from Santa Barbara Research Corporation. It consists of a photovoltaic InSb detector array mated to a silicon direct readout multiplexer via indium bumps. The readout is a p-channel MOSFET device.

The device is presently operated in a destructive readout mode providing double correlated sampling. A representation of the voltage on a single pixel during an integration and readout is shown in Fig. 4. An address cycle consists of a "reset" to the canonical detector bias voltage, a "read", followed by a second "read". During the reset operation, the voltage on each pixel is set to the value V_R. When the reset switch is opened, the voltage left on the sense node will differ slightly from V_R, due to charge spillback from the reset gate and from kTC noise. After a time 'fdly', the voltage on the pixel is sampled nondestructively (i.e., without resetting), yielding V_1. After a second time interval, defined as the integration time, the voltage is again sampled, yielding V_2. The "signal" is the difference between the two reads. Note that this technique, known as "double correlated sampling" eliminates the effect of the transient following the reset operation. The intervals indicated (not to scale) at the bottom of Fig. 4 represent the time required to carry out each operation on the entire array; thus, on an absolute frame, the time at which a given pixel is reset and read depends on its location in the array.

The operating microcode includes a provision for "multiple correlated sampling", in which the "reads" consist of a series of N nondestructive reads coadded to yield the values V_1 and V_2. This greatly reduces (by approximately $N^{0.5}$) the array read noise on long, low-background integrations.

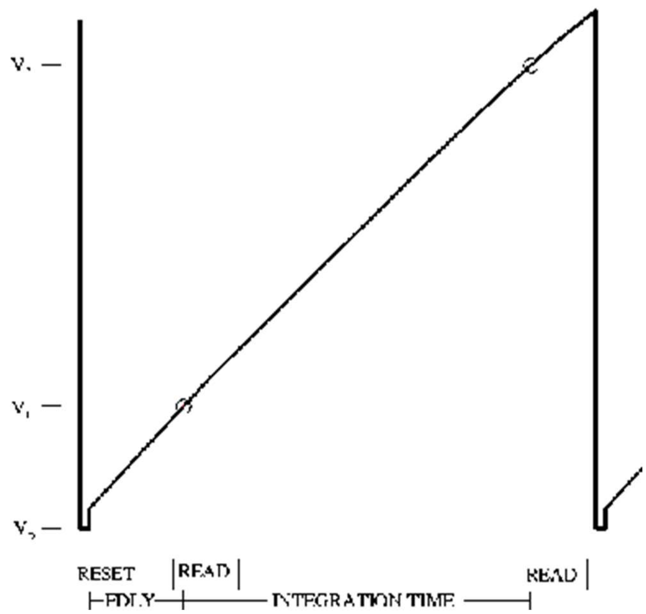


Fig. 4 Schematic representation of the voltage on a single pixel as a function of time. The intervals labeled "reset" and "read" represent the time over which these operations occur on the entire array, and are not to scale.

The time interval 'fdly' (Fig. 4) between the reset and first read is designed to permit the array to thermally stabilize after the heat input from the reset process. This is nominally set to 1 sec, except for integration times less than this value, in which case the value of 'fdly' is equal to the integration time.Thus, at a minimum integration time of 315 ms, the reset, read, read operations occur with no intervening pause. Because the actual length of the reset cycle is about 70 ms, the actual 'fdly' on a pixel will vary from 70 to 315 ms, depending on the location of the pixel in the array. The interval between reads will be a constant 315 ms for all pixels. Note that when one operates at the minimum possible integration time, the interval over which the array accumulates charge is up to **twice** the integration time, and one will be filling the wells to twice the charge level suggested by the observed signal. Nonlinearity and saturation effects will thus occur for smaller observed signals.

Table 5 summarizes the device characteristics and measured performance levels of the CRSP array SBRC 41. Telescope performance will be covered in a later section. Due to imperfect bonding, a section of the array (row > 170) is inoperative, but the operable portion meets the specifications for a science-grade array. Since the slit covers only 135 pixels in the spatial dimension, the array was installed so that the spectrum covers the full 256 pixel column axis and is centered in the operable portion of the row axis.

Table 5. Device Characteristics for the CRSP 256 X 256 InSb Array	
Array geometry	30 X 30 micron pixels, > 90% fill factor, 256 X 256 format; overall size 7.68 mm square
Well capacity	10^5 electrons (600 mv bias)
Read noise	30 - 35 electrons/pixel, single read; ~ 15 electrons with 8 low-noise reads
Dark current	< 2 electrons/pixel-sec (600 mv bias). Much of this is probably scattered thermal radiation within the instrument
Gain	7.2 electrons/ADU
Quantum efficiency	0.9 (1-2 microns); 0.85 (2.2 microns); 0.8 (3.3 microns)
Response uniformity	15%; see Fig. 6c
Cosmetics	A few isolated dead pixels and a few with higher dark current within the illuminated portion of the array; more high dark current pixels at bias > 600 mv. See Fig. 6c

Further information on the array design and operation may be found in Fowler et al., *Opt. Eng.*, **26**, 232 (1987), and in Fowler and Heynssens, *Proc. SPIE*, **1946**, (April 1993). The multiple correlated sampling technique used for read noise reduction is described in Fowler and Gatley, *Ap. J. (Letters)*, **353**, L33 (1990).

5. Observing Run Preparation

The limiting performance of CRSP depends on a number of factors. It is considerably more difficult to estimate the signal/noise for a given observation than with IRIM, since the noise limitations in a spectrum often result from uncorrected systematic effects rather than statistical noise. In addition, even the statistical noise in a spectrum is wavelength dependent, being limited by the shot noise of the sky background. At wavelengths short of 2.3 microns, the sky background consists of a series of emission lines, primarily OH airglow, which is both strong and temporally variable. At longer wavelengths, atmospheric absorption lines in continuum spectra will also show up as emission lines in the sky background. Because the sky background has numerous spectral features, it cannot be used for flatfielding, as with IRIM; observations of the dome "white spot" are necessary.

System Responsivity

Typical signals for representative grating settings are listed in Table 6. These are the maximum within the bandpass, summed over the width of the spectrum, in ADU/s, for a 0.0 magnitude star. These were measured on the 1.3-m with a 4 arcsec slit, so use of a narrower slit or bad seeing will result in less signal, which will be distributed over more than one row of pixels on the array. The values were converted to those expected at the 2.1-m telescope through multiplication by the ratio of collecting areas of the two telescopes (2.8). Keep in mind that these signals would be equivalent to those measured with the widest slit (#1) on the 2.1-m, so that one might expect smaller signals with the slit widths likely to be used for observing. The conversion gain is 7.2 e/ADU. For gratings 2 and 3, virtually all of a photometric window (except for L with grating 3) is covered at a given grating setting, so the signal in Table 6 is the maximum within the window. For grating 1, the signal in Table 6 is the maximum seen throughout the photometric window, which is typically 4 times wider than the free spectral range on the array. Observations at wavelengths other than those listed will probably yield less signal. The maximum integration times listed are for the same telescope and slit width, to avoid saturation at the wavelength of highest background within the bandpass. Refer to the Standard Star Spectra for more information.

Table 6. Typical Signals for 0.0 mag Star on 2.1-m

grating	**filter**	**order**	λ_o	**$\Delta\lambda$/pixel**	**0.0 mag (ADU/sec)**	**t_{max} (sec)**
1	I	4	0.98	.00031	2.7×10^5	> 1000.
1	J	3	1.24	.00043	7.6×10^5	> 1000.
1	H	2	1.65	.00069	8.4×10^5	500.
1	K	2	2.05	.00051	3.1×10^5	1000.
1	L	1	3.50	.00133	1.8×10^5	0.5-2.
2	I	4	1.05	.00175	2.2×10^6	> 1000.
2	J	4	1.22	.00173	2.0×10^6	500.
2	H	3	1.50	.00227	3.3×10^6	300.
2	K	2	2.12	.00346	2.0×10^6	60.
2	L	1	3.60	.00700	7.8×10^5	0.315

3	I	3	1.07	.00133	1.3×10^6	> 1000.
3	J	3	1.25	.00110	2.0×10^6	600.
3	H	3	1.50	.00104	4.2×10^5	> 1000.
3	K	2	2.05	.00158	7.8×10^5	600.
3	L	1	3.50	.0033	3.9×10^5	0.5 - 1.
4	I	3	0.99	.00082	1.3×10^6	> 1000.
4	J	2	1.28	.00126	2.8×10^6	600.
4	H	2	1.55	.00120	1.7×10^6	500.
4	K	1	2.12	.00254	1.4×10^6	300.
4	L	1	3.50	.00239	3.3×10^5	0.5 - 1

Sky Background

There are two predominant sources of sky background, which are essentially independent, both physically and spectrally. The transition between the two occurs at approximately 2.3 microns. Short of this wavelength, the sky is dominated by emission lines from OH in the upper atmosphere (typically 90 km altitude). The strength of these lines can vary over the course of a night; in addition, upper level winds create inhomogeniety and motion of the airglow. As a result, the intensity of the background emission can vary unpredictably during the night. Because of the low transition probability of these lines, they do not produce observable absorption effects, so the airglow is superposed on astronomical spectra.

Beyond 2.3 microns, thermal emission from the telescope optics and sky is the predominant background. This roughly follows a blackbody at ~ 300K temperature and increases very rapidly with increasing wavelength. To further complicate matters, atmospheric lines (primarily H_2O, HDO, CH_4, and N_2O), which show up as absorption features in spectra, appear as emission features in the sky background, making the data reduction more challenging.

Sky spectra for the I, J, H, K, and L bands taken on the 1.3-m telescope with slit 4 and gratings 1, 2, and 3 are given in the spectral plots. Because one is measuring surface brightness, the background levels on the 2.1-m and 4-m telescopes through the same slit will be similar, **although the higher thermal emissivity of the 4-m will result in higher continuum background long of 2.3 microns**. The spectra have been normalized to 1 s integration time, primarily as an aid for estimating the maximum integration time possible before saturation and/or nonlinearity effects become significant (typically ~ 10000 ADU). In conjunction with Table 6, one can then estimate the expected object signal in a single frame. Depending on the ambient temperature and airglow excitation, the background levels illustrated in the plots may vary a factor of two either way. The maximum strength of the airglow in the I band is ~ 1ADU/s, so it is not a limiting factor of the integration time. Backgrounds with grating 4 are similar to those with grating 3.

Most of the airglow lines are resolved from each other in the high-resolution spectra; use of a slit wider than 1 pixel will broaden the resultant lines in the spectrum, but will not greatly increase the amplitude, except in the case of several closely spaced lines. At low resolution, the airglow lines are blended into a quasi-continuum, so use of a wider slit is likely to increase the background proportionally. The same is true of the thermal continuum longward of 2.3 microns.

Other Preparations

Object Coordinates for any epoch can be entered into the telescope computer for use during the run. This is often done by the telescope operator during the course of the night, but lengthy observing lists are best entered by electronic submission (see below). These may include objects, standards, offset and guide stars, etc. Acquisition of optically faint or invisible objects will require initial acquisition and coordinate updating on a nearby bright star, so advance selection of these offset stars can save considerable time while observing. Guide stars can be located by the operator at the telescope.

Conscientious observers may send coordinate lists via email (two weeks or more before the run) to *coords@noao.edu*. Files should be ASCII text, no longer than 2000 lines. Start the file with your name, a cache name, telescope, and dates of the observing run. Coordinates will be checked for format, loaded into the appropriate telescope computer, and acknowledgement will be sent. Each object should be one line of text. The format is object name, RA (starting column 16 or greater, delimited by first blank after col 15; hours, minutes, seconds), DEC (degrees, minutes, seconds), and epoch. Each field should be separated by one or more spaces (NO TABS); the delimiter in the RA and DEC fields may be spaces or colons. Example:

- alpha nuti 12:34:56.7 -89:59:59.9 1734.4

Further details may be found in the June 1992 *NOAO Newsletter* or the new Observers Handbook.

Grating settings for grating 1 observations should also be calculated before the observing run. Since gratings 2 and 3 cover an entire spectral window (except for the L band with grating 3), only one setting is required. Two settings with grating 4 will cover a spectral window with significant overlap. Appendix IV tabulates the settings for the low-resolution gratings for each band. One may also use the lambda command to center a particular wavelength on the array.

For observing programs involving both low- and high-resolution spectroscopy, we recommend that individual nights (or at least half-nights) be dedicated to a single grating. The process of changing gratings is not lengthy (5 - 10 min), but it does require the observer to visit the instrument. On the 2.1-m and 4-m, this entails returning to the zenith or moving the platform under the telescope. In addition, separate calibrations must be obtained when the grating is changed, increasing the overhead time. If time or scientific constraints dictate the use of more than one grating during a night, the observations should be planned to minimize the number of such changes.

Coverage of a photometric window with grating 1 requires several separate observations, allowing sufficient overlap for registration of adjacent spectra. It is important to keep in mind that each observation must be regarded as independent of the others and will necessitate individual sky and calibration star measurements. Because the dispersion is a function of the grating angle, a composite spectrum generated by this method will not have a linear wavelength vs pixel relation. In addition, the dispersion/pixel will vary across the array for a given grating setting. Appendix V briefly summarizes the required calibration procedures involved in reducing the data. Appendix IV lists a conservative sequence of grating positions to cover the photometric windows.

Standards are a subject of continuing discussion, and probably will remain so for some time. For the purposes of determining and removing the effects of telluric absorption and throughput in the instrument, it is desirable to observe a calibration star as near as possible to the object in both space and time. This can be done most easily as part of the normal sequence of setting up on the object (see section on observing procedures). A-type dwarf stars are useful for this purpose, although they exhibit strong, broad Brackett and Paschen absorption lines in the I, J, H, and K bands. Late-type giants show very weak Br absorption, but contain a host of atomic and molecular absorption features. Kleinmann and Hall (1986, *Ap. J. Suppl.*, **62**, 501) is a useful atlas of K band spectra of mid- to late-type standard stars covering a range of luminosity classes. Solar-type dwarf stars are a useful compromise between atomic and molecular features. G. Rieke has suggested the use of these stars for telluric removal, followed by multiplication by a solar spectrum (convolved to the instrumental resolution) to remove the stellar features. Photometric calibration is a tricky issue, due to losses at the slit; observations through the widest slit may be useful for this purpose, although they cannot be used for extinction unless the object itself is also observed through that slit. The list of "CIT" standards (Elias *et al.* 1982, *Astron. J.*, **87**, 1029), although relatively bright for imaging purposes, is well suited for spectroscopy. These standards, which are maintained in permanent caches at the telescopes, are a mix of early- and late-type dwarf stars; the latter contain many atomic and molecular lines and are unsuitable for standards.

Visitors should arrive on the mountain at least by early afternoon of the first night. This will allow time to become familiar with the instrument, create and test observing parameter sets, and enter object coordinates into a cache. First-time users of CRSP may wish to arrive a day early and spend some time in the evening looking over the shoulder of the previous observer, with her prior permission.

6. The IR Instrument Control System -- WILDFIRE

This is a CRSP-specific synopsis of the WILDFIRE manual written by Nick Buchholz. Observers interested in a more in-depth analysis of WILDFIRE are referred to that manual.

Initializing the Environment with OBSINIT

The optical CCD (ICE) and infrared (WILDFIRE) environments are both operated from the same account on the 2.1-m (*2meter*)and 4-m (*4meter*) telescopes. The all-important obsinit command performs a number of functions relevant to this operating procedure.

- Switching from ICE to WILDFIRE environment on the first night of an IR observing run.
- Efficiently and gracefully cleaning the disk of data from previous observers.
- Storing the current observer name and proposal number for archiving.

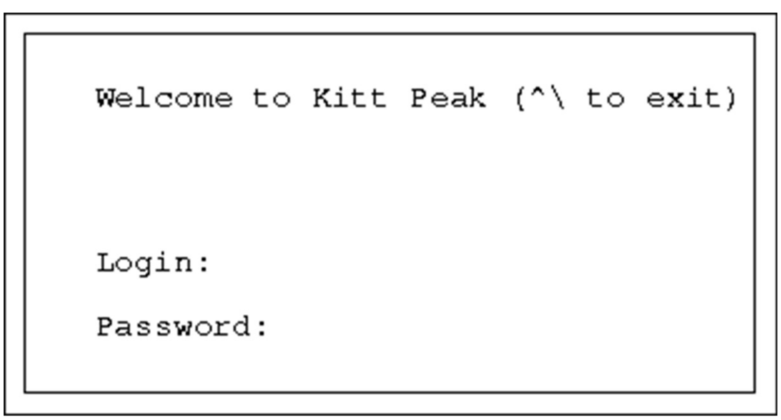
First Night of CRSP Block

On the first night of an IR block, the ICE environment will still be active (the presence of the "CCD Acquisition" and "CCD Reduction" windows will verify this). It will be necessary to run obsinit to change to the WILDFIRE environment, as well as for the other reasons above; since the hardware may be in an unknown state, it is recommended to run through a complete hardware initialization on the first night of an IR block as part of the obsinit process. This will involve rebooting the observer's SUN workstation with the DSP (in the computer room) powered on and the CRSP instrument power off.

The CRSP instrument power supply is located in the computer room; with the switch on "remote", the power may be controlled by a small switchbox next to the observer's console.

- Verify that the DSP power is ON.
- Verify that the power to CRSP is OFF
- Quit both the "CCD Acquisition" and "CCD Reduction" windows
- Logout of any other IRAF processes
- Enter the command obsinit in a Shelltool or Xgterm window. One will be led through an interactive process:
    - name(s):
    - Proposal ID: (check the schedule or Preparation Form)
    - Operation (fire/ice): (enter fire)
    - Delete old data from disk and initialize (y/n): [this can take a while if you choose y]
    - Replace wfpar and tclSamples (y/n): (n will leave any changes)

Once this is complete, it is necessary to reboot the instrument computer with L1 A or Stop A; again, the instrument power must be off. After rebooting, the UNIX login prompt "[hostcomputer] login:" will appear; **IGNORE THIS**. After a few seconds, OpenWindows will automatically load and present the login window shown below:



Login as *[telescope]* with the current password posted on the workstation terminal. The WILDFIRE system will then load automatically, resulting in a terminal screen layout approximately like Fig. 5 below; the dashed window labeled Instrument Status will appear in the approximate position shown only after the instrument microcode has been loaded.

New Observer

On succeeding CRSP runs, obsinit is run only to enter the new observer and proposal ID information. It is NOT necessary to power down CRSP or reboot the computer. After logging out of all IRAF processes and running obsinit, simply exit OpenWindows from the desktop menu and log back in when the login window appears.

Normal WILDFIRE Startup

The Windows

Once the environment has been set to WILDFIRE by obsinit, it will remain in that state, even if it is necessary to reboot the instrument computer for any reason. There should be no reason to execute obsinit more than once during a run. If a reboot is required, the login procedure in the window displayed above will automatically bring up the WILDFIRE windows.

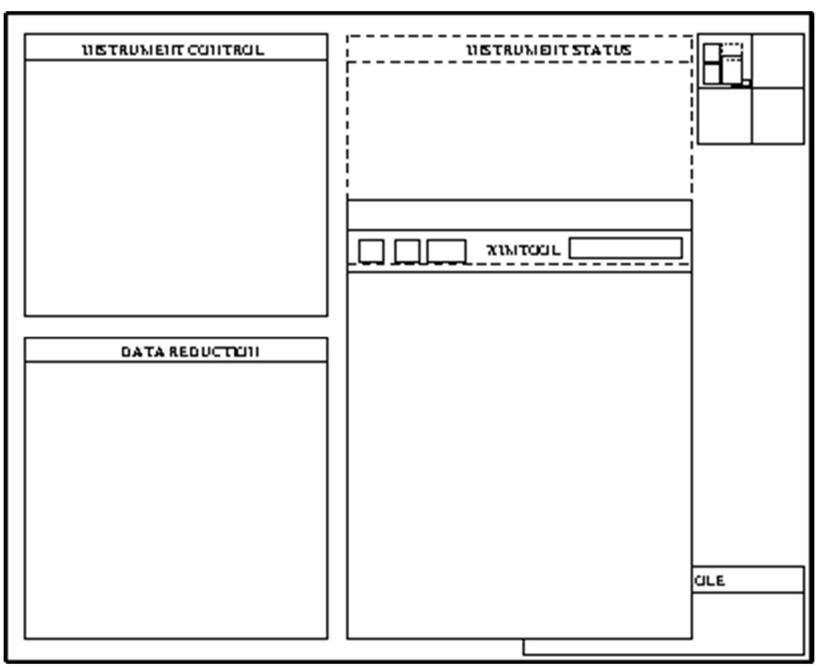


Fig. 5 Windows layout after initiation of WILDFIRE

A brief description of the windows follows:

1. Instrument Control -- This is the window for entering all commands controlling the instrument or telescope. It will initially have a "[instrument computer]" prompt, and a "%" prompt when the instrument microcode is running.
2. IRAF XGTERM -- This window is used for IRAF commands for analysis of data or for shell commands such as creating directories, moving, or archiving data.
3. Instrument Status -- Once the instrument microcode has been loaded, this window will appear. Instrument, voltage, detector status commands in the Instrument Control window will output here. The existence of this window is a diagnostic of WILDFIRE, as a system crash will often close it.
4. Display -- This is an XIMTOOL window which may be accessed either through the Instrument Control window, where images may be automatically displayed as they are taken, or through the IRAF XTERM window via the IRAF *display* task. Those who are desperately attached to the SAOimage display may use it in place of XIMTOOL by killing the XIMTOOL process in the Console window (enter ps -ax in the Console window to get a listing of the process numbers, then kill -9 [process #]), and then entering saoimage & to bring up the SAOimage window.
5. Console -- This is generally used only for diagnostic or emergency purposes, such as killing a hung process or the entire WILDFIRE when it hangs up.

Bringing up WILDFIRE

There are three basic steps in the complete startup of WILDFIRE: hardware initialization; starting WILDFIRE; instrument initialization. The procedure below will go through all three steps, as would be necessary on the first night the instrument is on the telescope.

Hardware Initialization

This procedure establishes the link between the DSP box and the computer, by rebooting the observer's SUN workstation with the CRSP power off. The *obsinit* procedure for the first night of an CRSP block (described above) includes these steps.

Starting WILDFIRE

NOTE: *The startup script for WILDFIRE has been simplified significantly in 1999. The microcode will be loaded automatically and the bias for CRSP set to the default value of 0.6. It will still be necessary to push the Blue Button to activate the array. In addition, the syntax for operating the mechanisms has been unified.* Refer to the Command Reference Sheet for details.

At this point, the windows should be present as in Fig. 5. Go to the Instrument Control Window and enter:

startwf

This will lead you through an interactive startup procedure. READ THE QUESTIONS CAREFULLY; simply entering [cr] will return the default, which may not be appropriate. For the full startup, the replies are:

- Has the DSP box been off since last startwf? Y
- Was the computer rebooted with the instrument power off? y (a short initialization process follows)
- Has the instrument power been off since last startwf? Y
- Is the instrument power on now? n (you will be prompted to turn on the instrument power) [cr]
- Do you want windows? Y
- What instrument is being used? CRSP (the instrument name may now be in either capital or lowercase letters!)

At this point, the transputer nodes will bootstrap, and four .tld files will load. Shortly thereafter, this downloading procedure will complete with a "%" prompt.

You will see messages regarding the downloading of the microcode, setting of Vdoff0 (-2.515), Vdoff1 (-2.000), and Voff (0.44), followed by a message that the array will be activated with the default bias of 0.6. When this is complete, the final message will appear:

- Push the button, Max!

At this point, go to the instrument and push the blue ACTIVATE button on the right side of the ACU box. Ensure that the green LED, visible through the hole on the ACU cover, has come on. The instrument is now ready for operation.

A bias value other than the default (e.g., for L band operation) may be manually set using the setbias command.

Problems?

If difficulties are encountered in startup, entering *trouble* in any of the windows (except the Instrument Control) will open a troubleshooting diagnostic, listing symptoms and possible solutions. However, most problems occur during the initial installation, and are often hardware related. The most common problems are listed below:

red LED(s) in DCU	Bad fiber connection. With the instrument power on, the green LED in the DCU should be on, and the two red LEDs off. If either or both red LEDs is lit, there is a fiber problem which must be repaired. A similar set of LEDs in the DSP box can diagnose fiber problems at that end.
halt after "Configuring C004"	Bad fiber optic connection (see above). Even if red LEDs are off, one or more fibers may have poor throughput, which must be measured. Power supplies may be connected improperly. Check that the analog connector goes to "CCD Power" and not "PS-10 Power" on the telescope.
halt after "bootstrapping node 100"	Bad fiber optic connection (see above). C004 may not be configured and a full startup may be necessary (DSP cycle, reboot, startwf).
"error #16 (cannot open link)"	System stuck in funny state. Full startup may be required. If that does not help, check for proper power connection and fiber throughput.
"cannot read telescope status"	Link to TCP computer is down. This is usually solved by rebooting the TCP computer. WILDFIRE will still work, but cannot move telescope or retrieve telescope status information for header.

In addition, comments, suggestions, and descriptions of persistent problems should be emailed to *wfire@lemming*, which has been set up as an equivalent to *service* for WILDFIRE instrumentation.

Parameter Sets

"parameter sets" are used to control the attributes of data acquisition. A listing of the parameters is given below. Because the data are saved directly as IRAF images, note that parameters include not only observation-specific items such as integration time, but archiving items such as the IRAF filename and the header and pixel directories.

Observing Parameters	
title	IRAF header title
coadds	number of coadded integrations per image
lnrs	number of low noise reads
pics	number of pictures per observation
integration_time	integration time (seconds)
filename	IRAF filename
header_dir	image header directory
pixel_dir	pixel file directory
mode	process mode [stare, sep, hphot]
nextpic	picture index
ucode	microcode
display	channels to display [only one for CRSP]
ra	RA of object #
dec	DEC of object #
epoch	epoch of object #
offset	observation offset
imag_typ	type of observation [object,dark,flat..]
airmass	airmass of object #
comment	comment
im_list	filename of image list
save	channels to be saved to disk [only one for CRSP]
archive	channels to be archived [only one for CRSP]

In general, the parameters fall into three categories: 1). those which one may wish to modify for an observation (integration time, title...); 2). those which one might want to change on an infrequent basis (comment, header directory...); 3). those which are never changed (mode, display) or are automatically entered into the header through the link to the TCS computer (marked with # above). The command `ped` will open an editing session on the current parameter set, listing each parameter in turn and prompting for new entry ([cr] returns the present value). At the beginning of a run, one should execute `ped` and set up those parameters falling into categories 2 and 3 above. NOTE: One cannot specify a non-existent header or pixel directory in ped; it is necessary to go to the IRAF XTERM window and create those directories first! Since it is cumbersome to go through the entire parameter list for each observation, there is a command eask, which runs through the entire parameter list, permitting the observer **to specify which parameters should be queried at the beginning of each observation**. Entering la for a parameter selects it for the "observation menu"; entering l excludes it. NOTE: The "up arrow" key may be used to back up through the ped list if one wishes to change a previously entered parameter.

When this is complete, save the parameter set with the command psave [filename]. This will save both the edited parameter set and the menu selected by eask in the file '[filename].par'. Should the system crash, this information may be retrieved by the command puse [filename]. Should major changes be made to the parameter file, such as change of header or pixel directory (say on another night of the run), it is a good idea to psave the updated file so it, and not the previous version, will be recovered by puse.

Observing Words

The basic observation is initiated by the command observe. The system will print on the screen, one at at time, those parameters selected by eask, and the current value [], prompting for entry of a new value or [cr], which will enter the current value. The command go will begin an observation, but will use the current values for the parameters (except the picture index, which will be automatically incremented). The command movie will begin a loop consisting of an observation (using the current parameters!) and a display; this may be terminated with end at any time. The observation in progress will be completed and displayed. **Movie observations are stored on disk!** This is unfortunately necessary to prevent orphaned pixel files from filling up the disk. A recommended procedure is to include the 'filename' parameter in the ask menu and change to a dummy filename at the beginning of a movie. When returning to data taking, one may reset the filename to that used for the data. If one wishes to retain continuity in the index number, it is also necessary to reset 'nextpic' to the value before the movie observations. Keep good logs!!

The ask command will cycle through the selected parameters, prompting for changes, just as with obs, but will NOT begin an observation. This command is useful for checking parameters, and is **essential** before executing movie, which will use the parameters for the previous observation, even if it were 600s in length. The combination of ask and go is a perhaps preferable alternative to observe.

One may abort an observation (such as an unintentional 600s movie) by entering abort in the Instrument Control window; the observation should terminate gracefully in a few seconds. **This can sometimes turn off the display and save operations**, so it is advisable to enter save only and display only after an abort.

Scripts

The user interface is written in the Tool Command Language (tcl), which is well-suited to the construction of scripts for data taking. Scripts are a powerful tool for executing a sequence of tcl commands, including telescope motions, instrument motor commands, and observations, as a single executable program. Even for those who are not veteran programmers (most of us), simple scripts are fairly easy to construct. Scripts are highly recommended for spatial sampling (dithering) and linearity calibrations. The best recipe for starting out is to copy an existing script to a new file, then edit that file as desired. The first line of the script file contains the basename of the script file ("proc "), and must be edited to reflect the new name of a script created in this manner. Before the initial use of a script (or after a system restart), it must be identified as an executable in the Instrument Control window, using the full path name of the file; e.g.,

```
source  /data2/4meter/tclSamples/[scriptname].tcl
```

To execute the script, enter the basename [scriptname] as a command in the Instrument Control window. A sample script is given in Appendix VI.

Scripts may be found in directory "tclSamples" under the "[telescope]" directory, as in the path above, and also in /usr/wfire/tcl. This latter path is the system response to query pwd in the Instrument Control window. When creating a custom script, please copy a system script into an observer directory and then rename and modify it, to avoid confusion.

7. Observing Practices

The installation of the instrument and cables will be handled before the beginning of the run by the mountain technical staff and are not of concern to the user. The CRSP Reference Manual provides coverage of the details of installation and setup for those who are interested. CRSP remains on the telescope for the entire observing run and the LN_2 and LHe cryogen flasks are filled twice per day by the observing technicians.

Getting Started

After CRSP is installed on the telescope, go through the WILDFIRE startup procedure outlined previously. Once the system is operational and the detector activated, check the detector and temperature status with status s and compare with the nominal values below:

CRSP InSb Status Display	
Detector Temp = 1.099	Detector Htr Power (mw) = 20.444
LN2 (cy7) = 0.938	LHe (cy7) = 3.103
Stage (cy7) = 1.138	
VDet = -3.038	VDDuc = -3.624
Voff = 0.444	
VDDout : = -1.055	VGG = -1.514
V3 = -2.686	
Data Offset 0 = -2.515	Data Offset 1 = -2.002

Verify that all the instrument motors are functional. Check the status with ?filter, and move all the motor positions, checking with ?filter to ensure that they are moving correctly. The software commands for the motors are listed in Appendix II.

Techniques

Focus

Open up, acquire star in TV, move mirror out of beam. Use (H, slit 1, 128 ECU) and movie. initially, search in coordinate perpendicular to slit orientation. Keep in mind that the spectrometer is essentially a 7 X 135 pixel imager in this application. Once the star is found, focus the telescope, resetting display limits and integration time as necessary, until a tight image is obtained. For optimizing focus, it is best to obtain single images, using observe or go, and analyze the image quality with the IRAF task 'imexam'. Move the star along the slit until it is centered. Move the guider mirror into the beam, focus the acquisition TV and note position on monitor or leaky cursor. Once this is done, it should be sufficient to keep the star in focus on the TV throughout the run. Remember that it may be necessary to relocate the beam when moving to a new object and it will almost certainly be required after changing the rotator position angle. However, it is not necessary to return to zero order to do this, as one may peak up the signal using the spectrum of a bright star. One technique is to obtain spectra of a star at different focus settings, then use the IRAF task 'imexam' to measure the FWHM profile in the cross-dispersion direction to determine the focus setting which yields the narrowest profile. Since only one slit jaw is moveable, the beam center will change slightly when the slit width is changed.

Tmove

Mike Merrill's provisional IRAF script *tmove* may be used for centering stars on the array, using an image displayed in the ximtool window. Because this is not yet a standard IRAF task, it will probably have to be manually installed for an observing run.

- If the file "tmove.cl" is not found in the [telescope] or [tclSamples] directory, create it from this code:

```
# TMOVE: 23AUG95 KMM
# TMOVE: 12DEC95 KMM
# TMOVE: 16FEB95 KMM
# TMOVE: 23MAR94 KMM
# TMOVE: 23JUN94 KMM
# TMOVE: 04JUN99 RRJ
# TMOVE: 04JUN99 RRJ; MODIFIED FOR N-S TIFKAM ORIENTATION OPTION

procedure tmove ()

#  Edit instrument and telescope string below for your configuration.
#  Default orientation for TIFKAM is E-W slit.  If slit is N-S, then
#  set 'rotate = yes' in line 76 and uncomment lines 160,161

#  You may wish to edit the "center" coordinates for the particular
#  detector configuration for use with the 'c' key

#  Install edited file in data directory and identify as an IRAF task
#  with 'task tmove=tmove.cl'.  Enter 'tmove' to execute

string instrument  {"CRSP",
                    prompt="IR instrument
(SQIID|PHX|IRIM|CRSP|TIFKAM|none)?",
                        enum="SQIID|PHX|IRIM|CRSP|TIFKAM|none"}
string telescope   {"2.1m", prompt="KPNO telescope (1.3m|2.1m|4m|none)?",
                        enum="1.3m|2.1m|4m|none"}
bool   verbose     {yes,  prompt="Verbose reporting"}

imcur   *starco

begin

   int    stat, nin, nout, slen, wcs, rid, prior
   real   xin, yin, xref, yref, xshift, yshift, dist, adist, foo
```

```
   real   xscale, yscale, xcenter, ycenter
   bool   xinvert, yinvert, rotate
   string uniq,sjunk,sname,key
   struct command = ""

# Get offset between master reference and reference frames

   if (instrument == "SQIID") {
      xcenter = 128.; ycenter = 128.
      xinvert = no; yinvert = yes; rotate=no
      if (telescope == "2.1m") {
         xscale = 0.76; yscale = 0.76 # K channel
      } else if (telescope == "4m") {
         xscale = 0.43; yscale = 0.43
      }
   } else if (instrument == "PHX") {
      xcenter = 128.; ycenter = 512.; rotate=no
      if (telescope == "2.1m") {
         xscale = 0.25; yscale = 0.25 # Viewer Scale
         xinvert = yes; yinvert = no
      } else if (telescope == "4m") {
         xscale = 0.125 ; yscale = 0.125
         xinvert = no; yinvert = yes
      }
   } else if (instrument == "IRIM") {
      xcenter = 128.; ycenter = 128.; rotate=no
      if (telescope == "2.1m") {
         xinvert = no ; yinvert = yes
         xscale = 1.09; yscale = 1.09
      } else if (telescope == "4m") {
         xinvert = no ; yinvert = yes
         xscale = 0.60; yscale = 0.60
      }
   } else if (instrument == "CRSP") {
      xcenter = 85.; ycenter = 128.; rotate=no
      if (telescope == "2.1m") {
         xinvert = no ; yinvert = yes
         xscale = 0.61; yscale = 0.61
      } else if (telescope == "4m") {
         xinvert = yes ; yinvert = no
         xscale = 0.36; yscale = 0.36
      }

   } else if (instrument == "TIFKAM") {
      xcenter = 200.; ycenter = 502.7; rotate=no
# Set rotate=yes if slit is N-S and uncomment lines 160, 161
      if (telescope == "2.1m") {
         xscale = 0.34 ; yscale = 0.34
         xinvert = yes; yinvert = yes
      } else if (telescope == "4m") {
         xscale = 0.18 ; yscale = 0.18
         xinvert = no; yinvert = yes
      }
   } else if (instrument == "none") {
         xinvert = no ; yinvert = no ; rotate=no
   }
```

```
   if (!xinvert && !yinvert)
      print ("NORTH at top and EAST at left in frame XY system")
   else if ( !xinvert && yinvert)
      print ("NORTH at bottom and EAST at left in frame XY system")
   else if ( xinvert && !yinvert)
      print ("NORTH at top and EAST at right in frame XY system")
   else if (xinvert && yinvert)
      print ("NORTH at bottom and EAST at right in frame XY system")

   print ("Use image cursor to indicate current position...")
   print ("Allowed keystrokes: |c(to center)|spacebar(here)|q(skip)|")
   while (fscan(starco,xin,yin,wcs,command) != EOF) {
      if (substr(command,1,1) == "\\")
         key = substr(command,2,4)
      else
         key = substr(command,1,1)

      if (key == "c") {
         xref = xcenter; yref = ycenter
         print ("")
         print ("==> Offset position: ",xin,yin," to frame center:
",xref,yref)
         break
      } else if (key == "040") {                      # 040 == spacebar
         print ("Current position is = ",xin,yin)
         print ("Indicate where you want to be..")
         while (fscan(starco,xref,yref,wcs,command) != EOF) {
            if (substr(command,1,1) == "\\")
               key = substr(command,2,4)
            else
               key = substr(command,1,1)

            if (key == "c") {
               xref = xcenter; yref = ycenter
               print ("Desired position is frame center = ",xref,yref)
               break
            } else if (key == "040") {        # 040 == spacebar
               print ("Desired position is = ",xref,yref)
               break
            } else if (key == "q") {
               print ("Safe exit!")
               goto err
            } else {
               print("Unknown key: ",key," allowed = |c|f|spacebar|q|")
               beep
            }
            break
         }
         print ("")
         print ("==> Offset position: ",xin,yin," to: ",xref,yref)
         break
      } else if (key == "q") {
         print ("Safe exit!")
         goto err
      } else {
         print("Unknown key: ",key," allowed = |f|spacebar|q|")
         beep
```

```
      }
   }

# Eastward motion of telescope is defined as positive
   xshift = 0.1*real(nint(10.0*(xscale * (xref - xin))))
# Northward motion of telescope is defined as positive
   yshift = -0.1*real(nint(10.0*(yscale * (yref - yin))))

   print(xinvert,yinvert, rotate)
   if (xinvert)
      xshift = -1.0 * xshift
   if (yinvert)
      yshift = -1.0 * yshift
#  if (rotate)
#     foo = yshift; yshift = -1.0 * xshift; xshift = foo

   dist = sqrt(xshift ** 2 + yshift ** 2)
   adist = 0.01*real(nint(100.0*dist))
   dist  = adist/((xscale+yscale)/2.)
   print ("Separation = ",dist," pixels : ", adist," arcsec")

   if (xshift >= 0)
      print (xshift, " east")
   else
      print (-1.0*xshift, " west")

   if (yshift >= 0)
      print (yshift, " north")
   else
      print (-1.0*yshift, " south")

   print ("Within the instrument control window type: toffset
",xshift,yshift)

   err:

   xref = 0.0

   end
```

- The script is defaulted for CRSP at the 2.1-m. If you are at the 4-m, it will be necessary to edit the telescope string parameter in the file "tmove.cl".
- In the data directory, identify the task to IRAF by entering the full path name of the file; e.g,
- task tmove = /data1/4meter/tmove.cl
- To execute, enter tmove. You will be prompted to put the cursor on the star in the ximtool display. Entering c will compute the offset to the nominal slit center (85:128) on the array; entering [spacebar] will prompt you to move the cursor to the target position and enter another [spacebar], in the event the actual slit image center is different from the default. In either case, the computed offsets will be displayed in the IRAF window

- The displayed offset command may be pasted directly into the Instrument Control window

Grating Change

To change gratings, it is necessary to drive the grating table angle to a position where the external mechanism can engage the grating turret. This is **4000 ECU**. The command chgrat will also drive the grating to this position. Once this has been accomplished, one must go out to the instrument to change the grating. Keep in mind that at the 2.1-m and 4-m, this can be done only at telescope positions where access to the instrument is possible. To change the grating, push in the actuator knob on the changer; it should go in all the way. **Keeping the actuator knob pushed in**, rotate the knob until the pointer indicates the desired grating. One must feel the grating detent engage solidly, often with an audible "cllnnngg", to be sure that the grating is in place. Release the pressure on the actuator knob and let it return to its out state. **Ensure that the actuator knob returns to its full out position!!**. It may be necessary to wiggle the knob slightly to align the pin with the pilot hole. Check with ?filter that the desired grating is in place and that the grating is in its detent (if the grating is out of detent, an error message will be given, and motion of the grating drive is not possible).

Performance Checks

CRSP will be installed and checked out at the start of each observing run by a competent and cheerful support scientist. Users may confirm continued proper operation during their run with software interrogation and by comparing dark and flatfield frames against "standard" frames shown below (Fig. 6).

Detector status and temperature information is displayed with the word status s; it is also automatically updated at the beginning of an observation. Standard values for a detector bias of 0.6 v are displayed above. The cryogen temperature readouts do not indicate the levels between "full" and "empty", only whether any liquid is in the flask. If the LHe runs out, the thermal inertia of the detector mount and the heater servo will maintain the detector at the correct operating temperature for a moderate time, so an observation may still be good, even if the LHe runs out while

in progress. The 5.1 k resistor used as the LHe temperature sensor is extremely temperature sensitive in the LHe region, and the readout will decrease very rapidly with time once LHe has run out.

The heater power may vary somewhat around the typical value given. However, a significant and persistent departure from this value and/or a decrease in the cryogen hold time may indicate the dewar is losing its vacuum (going "soft"). If this is suspected, **contact the instrument support scientist**. It may be necessary to pump on the cryostat vacuum jacket during the day. This must **not** be attempted by any non-staff user.

To check for proper electrical, dark current, and responsivity performance, compare the appearance of dark and flatfield data with the "standard" frames shown in Fig. 6. Keep in mind that details of the flatfield frames will depend on the grating setting and filter used, but the general appearance should be the same. The software plotting and statistic routines may be used for quantitative comparison with the typical signal levels given in Table 6. Figure 6a is a minimum exposure dark slide exposure (bias frame); this should be essentially random noise superposed on a mean of near zero. Figure 6b is a 300 s dark frame, illustrating the low level (typical 0.15 ADU/s) of the dark current, much of which may actually be residual thermal radiation within the spectrometer. Figure 6c is a dome flatfield showing the array response to photon flux, highlighting the inoperative pixels and the illuminated portion of the array. Figure 6d is a 100s sky exposure in the H band with grating 1; note the intense OH emission and the curvature of the spectral lines.

Indications of trouble in the dark current are a markedly higher value, especially if it is higher around the margins of the array. At some positions with grating 1, a bright strip on the left-hand side of the array may be seen. This is almost certainly stray radiation, although the source is presently unidentified. Finally, sky- or dark-subtracted frames may occasionally show a dark (or light) potato-shaped artifact about 20 pixels wide. "Phobos effect" in figure 6, results from a region of lower signal in one of the frames, and can appear anywhere on the array. This occurs very infrequently, and has no known physical cause.

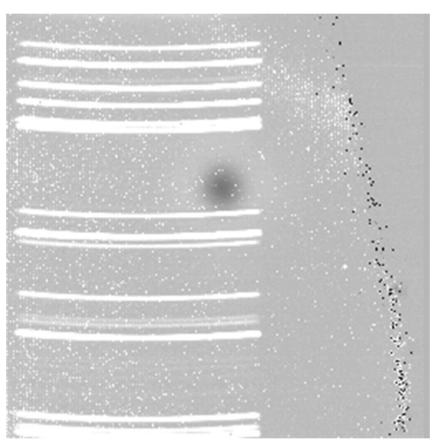


Figure 6. Phobos effect.

Grating Limits

There are five microswitches mounted on the grating assembly read by the motor controller card. Two of these encode the selected grating. The other three act as limit switches to the grating motion. Because of space limitations in the cryostat, the grating tilt motion is limited. Microswitches are positioned short of the hard limits, but beyond the normal range of commanded motions (80 - 4000 ECU), to prevent the grating from being accidentally driven into a hard stop and shearing the flexible coupling on the grating drive shaft. The last switch actuates if the grating turret somehow slips out of its detent, which would result in loss of angle registration and also make it possible to drive the grating into the short hard limit, even with an acceptable motion command. If any of the three limit microswitches is activated, the grating motion will stop immediately.

Instrument Rotator

The instrument rotator was designed as an integral part of the CRSP and should, in theory, work at any position in the sky. However, due to the asymmetric loading of the instrument and (particularly) the DCU heat vent hose, there are telescope positions in which the loading may overcome the friction in the rotator slip clutch. Furthermore, at extreme zenith distances, it is possible for the instrument or the cryogen fill tubes to snag on cables hanging from the telescope. Therefore, it is **strongly recommended**, at least at the 2.1-m, that an observer visit the dome to monitor the instrument rotation for hour angles > 3 hours. Slippage of the clutch may result in the message "servo 2 failed -- JAMMED"; this does not necessarily suggest physical jamming, but rather a difference between the calculated and actual encoder readout. If the rotator appears to be slipping, it is OK (and suggested) to manually assist the motion, as long there is no obvious mechanism, such as a snagged cable, impeding the rotator. In this case, it may be necessary to repeat the `sangle [pa]` command.

The choice of slit width is a compromise between spectral resolution and seeing/guiding accuracy/surface brightness. Use of a wide slit can be advantageous in observing low surface brightness objects from the points of increasing the optical throughput and broadening emission/absorption lines so that the effects of individual noisy pixels are decreased. **However, one must be extremely cautious in interpreting radial velocity information from spectra obtained with a slit wider than the typical image size.** For a pointlike/stellar source, the measured wavelength of intrinsic lines and telluric absorption features will depend on the location of the source within the slit. If radial velocity determination is critical, suggestions are: 1). obtain confirmatory data at different slit position angles; 2). use as narrow a slit as possible, consistent with seeing/guiding accuracy; 3).

whenever possible, utilize terrestrial absorption features in the continuum spectrum (if any) for wavelength calibration.

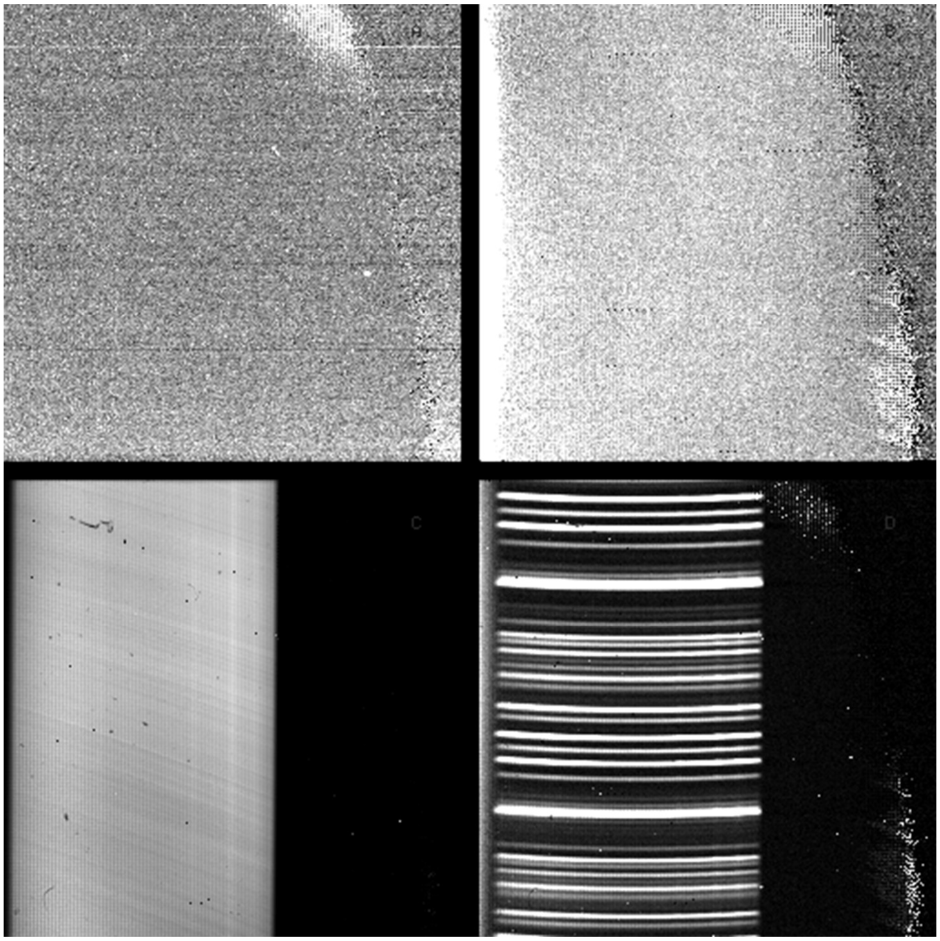


Figure 7. a (upper left): Dark bias frame (0.315 s) scaled from -20 to 20; b (upper right): Dark frame (300 s), scaled from -20 to 50. Note bright strip along left side of array, probably stray radiation; c (lower left): Dark subtracted dome flat (grat 1, H, 2400 ECU), scaled from 0 to 4000. Note isolated dead pixels. Bright columns result from imperfections in slit jaws; d(lower right:) Raw sky frame (grat 1, H, 2260 ECU, 100 s), showing OH airglow lines from 1.53 to 1.70 microns. Scaled from 0 to 500.

8. Calibration

Spectral Calibration

Because of the relatively modest resolution of CRSP, no spectral calibration source was built in. Short of 2.3 microns, the annoying OH airglow lines do provide a useful grid for spectral calibration with the high-resolution grating. Longward of this wavelength, atmospheric transitions which show up as absorption lines in continuum spectra or emission lines in the sky background may be used for the same purpose. In low-resolution spectra, the OH lines are blended severely and are much less useful for this purpose, and even atmospheric absorption lines tend to blend into bands whose wavelength is less well defined. For those who wish to confirm the default calibration of low-resolution spectra, the best approach is to observe an object with known emission or absorption lines. On the positive side, the dispersion with grating 2 is sufficiently linear that the identification of two spectral features should be sufficient for calibration.

The HeNeAr or ThAr comparison sources built into the telescope guiders appear to generate a creditable Ar spectrum, with a few He and Ne lines thrown in. In the J and H bands, the emission lines are spaced sufficiently closely to be blended with other than grating 1. One recourse in this case is to use a low-order fit to a few well-separated lines and ignore those which are blended. Use of the narrowest slit (#5) for arc calibration yields better separation of the lines and the IRAF 'identify' task seems to center on the narrower lines more easily. The spectral shift resulting from calibration with a different slit than used for observing is easily calibrated in data reduction (see Appendix V). The thermal emission from the lamp dominates most emission lines long of 3 microns and is sufficiently strong to saturate the detector very quickly. In the L and M bands, one may take calibration spectra at the grating setting used for observing through the H or K filters, as appropriate. This will yield a good fit and simply require that the wavelengths be multiplied by a factor of two.

The calibration line list contains a list of the OH airglow lines. The tabulated wavelength (in vacuum microns) is the average of the two hyperfine components of each line, which are separated by typically < 0.5 cm^{-1} and thus unresolvable with CRSP. Wavelength tables for Ar, Kr, and Xe emission spectra are also included.

Responsivity Calibration

Atmospheric extinction must be calibrated by observations of a star at the same grating and slit setting, and as close as possible to the same zenith distance, as used for the object. This is necessary to calibrate out spectral features due to the atmosphere. As mentioned in the last section, there is no type of star ideal for this purpose, although early-type dwarf stars, except for the wide Br and Pa absorption lines, are usually good candidates. Early G dwarfs are also a good compromise, having much weaker HI absorption and no CO absorption as seen in cooler stars. It is recommended that such extinction stars be observed at several positions along the slit. In conjunction with flatfield frames, this procedure provides redundancy and may be used to eliminate the effect of any bad pixels which may fall on an individual spectrum.

Flatfield exposures are necessary to calibrate the pixel-to-pixel gain variations in the array and the effects of the illumination of the array by the spectrometer optics. Unfortunately, sky observations cannot be used for this purpose, as with IRIM, since the sky itself is rich in spectral features. It is therefore necessary to use the illuminated white spot to obtain "dome flats". These may be obtained at any time, such as in the afternoon, or at the end of the night. The advantage of the latter approach is that the grating positions used for observing are known.

At the 2.1-m and 4-m telescopes, the dome screen is illuminated by lamps mounted on the telescope top ring. The telescope is positioned by mountain technical staff; darkening the dome may require waiting until visitor hours end at 1600 hr. The lamp controls at these telescopes are on the LTO console.

With the low-resolution gratings, the spectral structure in the lamp and spectrometer destroy any semblence of a dome observation to a "flat". More importantly, at the edges of the filter bandpass, the signal (and S/N) falls to near zero, which is an undesirable characteristic for an arithmetic divisor. For this reason, one approach is to use the high-resolution grating 1 to flatten observations made with all gratings. Observations with grating 1 can (and should) be flattened with dome observations at the same grating angle, as long as the setting is chosen to give relatively constant signal (hence S/N) along the dispersion axis. However, it is possible to generate flatfields with the other gratings (even grating 2), but one must keep in mind the S/N limitations resulting from the low signal levels in the flatfield at the ends of the filter bandpass. One should obtain a relatively large number (5 - 10 or more) of flatfield images for postprocessing within IRAF, where floating point arithmetic and sigmaclipping or median combining are possible (the latter to eliminate noise artifacts which may appear in a single observation). **Because there may be wavelength-dependent quantum efficiency gradients in the array, we suggest obtaining a flatfield series within each filter bandpass used for observing**. Within the L band, one will be dominated by the thermal emission from the dome screen, and the lamps are not necessary. Dark current and residual illumination subtraction require obtaining an identical series of observations with the flatfield lights off (for I,J,H,K) or the dark slide in the beam (L band). After subtraction of the "off" or "dark" frame, normalization (using the IRAF 'response' task) and median combining of these observations should eliminate noise spikes or systematic features in the spectra. To stay within the relatively linear portion of the array response, it is preferable to turn down the lamp intensity and use exposure times relatively long in comparison to the readout time of 0.315s (e.g., 3 - 5 s). Keeping the flux at a modest signal level (< 5000 ADU) may also help in this regard; with a read noise ~ 35 e, one is completely background limited by signals > 500 ADU, so multiple reads are neither necessary nor recommended. Since the lamps are color-corrected for use in the visible, their infrared spectra will not be truly flat; this effect will be calibrated out by similarly flattened standard star observations.

It is **vitally** important that the same slit width be used for dome flat and astronomical observations! Changing the width also results in some lateral motion of the moving slit jaw, so irregularities in the slit will translate in the slit direction, changing the illumination function.

Linearity

When a pixel is reset, the voltage difference (bias) between the pixel and detector substrate creates a depletion region which acts as a potential well for the collection of (mostly) photogenerated carriers. Electrically, one may consider this potential well as a capacitor. As charge accumulates in the pixel, the depletion region fills in, increasing its capacitance and that of the entire pixel node. Coupled with the steadily decreasing bias on the pixel, this yields a sublinear voltage-charge relationship, which quickly rolls off (saturates) when the pixel voltage reaches that of the detector substrate (zero bias). Technically, a pixel will continue to accumulate charge even into forward bias, but its response by that time will be significantly nonlinear.

Increasing the bias on a pixel will not only increase the depth of the potential well, but by decreasing the capacitance of the depletion region in relation to parallel components of the node capacitance, will result in a more linear voltage-charge relation. As a result, a bias increase from 0.6 to 0.8 v will effectively double the charge capacity of the pixel. This comes, however, at a significant cost in dark current, which increases dramatically with bias. Therefore, we recommend a bias of 0.6v, except for high-background (L band) observations, where the increased dark current is not important, and a bias of 0.8 may be used.

Raw linearity curves, with 'fdly' = 1 s, were obtained in the lab for bias values of 0.6 and 0.8 v. The curves were inverted and fit to a third order polynomial; to improve the fit, data above a threshhold where the nonlinearity increased markedly were deleted from the fit. Below are tabulated the threshhold signals and polynomial coefficients, including the format for the IRAF 'irlincor' task, located in the 'imred.irred' package.

Table 7. CRSP Linearity Coefficients for 'irlincor' Task				
Bias	**Threshhold**	**A**	**B**	**C**
0.6	13000	1.00	.117	.257
0.8	28000	1.00	.094	.087

Saturation

Eventually, a pixel will accumulate sufficient charge to forward bias it to the point where no more is collected, resulting in a condition known as saturation. The reset-read-read address cycle used in double correlated sampling (Fig. 4) results in a characteristic, but unusual, saturation behavior. For a given integration time, the effect of increased flux is a steeper slope of the voltage-time curve. As the flux increases, the voltage V_2 will eventually saturate, while the voltage V_1 will continue to increase because of the time interval between the reset and the first read; the difference signal will thus decrease with increasing flux. Finally, the detector will saturate in the short interval between the reset and first read, resulting in identical values for V_1 and V_2, or a difference value of zero. Thus, the double-correlated signal relation with flux is initially nearly linear, then increasingly nonlinear, and eventually decreasing to an ultimate value of zero as one saturates. The two A/D channels will saturate at slightly different levels, resulting in an evident odd-even column pattern. These effects are evident in a Saturation Image of the L band at low spectral resolution, in which the flux increases rapidly from the bottom to the top of the array.

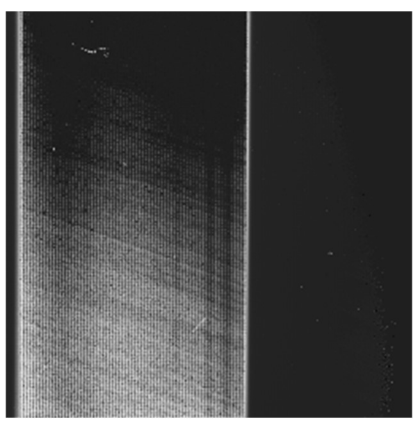


Figure 8. Saturation image of the L band at low spectral resolution.

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