FLAMINGOS USER INFORMATION

1. Introduction

FLAMINGOS, the Florida Multi-object Imaging Near IR Grism Observational Spectrometer, has been in use at Kitt Peak since 2001.

The information on this web page is intended primarily for scheduled users and those interested in proposing to use the instrument. The information will be updated as needed to reflect the most recent status of the instrument. This information is current as of November 2010.

In the past, FLAMINGOS has been shared between Kitt Peak, the MMT and Gemini South, but it is presently scheduled only at Kitt Peak, although there may be occasional periods when it is out of service for maintenance or upgrades. The full suite of instrument capabilities is being offered, as described below, but prospective long-slit or MOS users should read the caveats in the spectroscopy section.

IMPORTANT NOTE FOR PROPOSERS: In order to make it easier to schedule and support the MOS mode, any programs that will use multislit mode should identify the instrument as **FLMNM** in the proposal. Requests for imaging or long-slit mode (or both) should identify the instrument as **FLMN**.

2. Instrument Description

FLAMINGOS is a wide-field IR imager and multi-slit spectrometer designed and built by Richard Elston at the University of Florida, with some collaboration and support from NOAO. The imaging mode is provided by a fairly conventional optical train, consisting of a refractive collimator, filters, cold stop and a camera, which images the focal plane onto a 2K x 2K HgCdTe detector.The detector characteristics are summarized in the following table:

Table 1: Detector Characteristics

	Imaging	Spectroscopy
Wavelength Response	0.9 - 2.5 microns	
Bias Voltage (v)	1.0	0.75
Full Well (ADU)	~ 50000	~ 38000
Typical Signal (ADU)	~ 25000 - 30000	~ 15000 - 20000
CDS Read Noise (e)	40	40
Gain (e/ADU)	4.9	4.1

The instrument can be used on both the 2.1-m and 4-m telescopes; pixel scale and useful field of view values for each telescope are summarized below:

Table 2: FLAMINGOS Imaging Parameters

Telescope	**4-m**	**2.1-m**
Scale (arcsec/pixel)	0.316	0.606
Field of View (arcmin)	10 x 10	20 x 20

Optical Mechanisms

The filters available for imaging are J, H, K and Ks. The filters are located in a collimated beam, but with large field angles, so that narrowband filters will not work very well over the full field, and there are no current plans to provide any.

The cold stops are on the Lyot wheel, so that an optimized cold stop is available for each telescope.

The image quality of the optics (as designed and toleranced) is well-matched to typical image quality on the 4-m, and is about 2 pixels FHWM over most of the field (a little worse at the corners and at the very left-hand side of the array). This does mean that imaging on the 2.1-m will mostly not be seeing-limited, particularly at the corners, where field curvature becomes significant.

The spectroscopic mode is provided by a cold slit mask placed at the telescope focal plane, which is in front of the camera dewar, and by a grism placed after the cold stop. The slit masks are mounted in a wheel in a separate MOS dewar in front of the camera section at the telescope focal plane. The MOS dewar can be warmed up and cooled down quickly, allowing the masks to be changed during the day. The MOS wheel can accommodate 11 slit masks (enough for 2 - 3 nights of typical observing), in addition to permanently-mounted long slits. The unvignetted width of a slit mask mounted in its frame is roughly 1/3 of the imaging field (i.e., about 3.1 x 9.5 arcmin on the 4-m). A second wheel contains deckers, which restrict the field of view as appropriate for imaging, long-slit spectra, and multi-slit spectra.

At present, there are two grisms covering the JH and HK atmospheric windows which provide two-pixel R ~ 1000 - 1800, depending on the wavelength and filter/grism combination. At this resolution, one obtains full spectral coverage even for off-center slit locations at the edges of the slit masks for HK spectroscopy, but there will be some spectral vignetting for JH spectroscopy for slit locations at the edges of the masks. The Grism wheel also has an open position for use when imaging and a cold blocker. The second open position is for a higher resolution grism which was never installed. **The "true-dark" position of the Grism wheel provides the only cold dark slide in the instrument and should be used for all Dark observations.**

The positions of the Decker, Filter, Lyot, and Grism wheels are given in Table 3.

Table 3: Decker, Filter, Lyot and Grism Wheels

DECKER		FILTER		LYOT		GRISM	
9000 steps		**1250 steps**		**1250 steps**		**1250 steps**	
dark	0	J	0	Hartmann1	0	open1	0
imaging	2250	H	208	Hartmann2	178	JH	250
slit	4500	K	417	open	357	true-dark	500
mos	6750	HK	625	gemini	536	open2	750
		JH	833	mmt	714	HK	1000
		Ks	1042	4m	893		
				2.1m	1071		

2-m Declination Limit

The instrument will run into the fork of the 2-m telescope at declinations north of +80°. There is no hour angle limit, (although the instrument doesn't clear the control room roof by much). Anyone who needs to observe fields north of +78° must propose to use the 4-m telescope.

3. FLAMINGOS Imaging Performance

Measured values for imaging performance are given in the tables below. Prospective users need to remember that near-infrared background can vary by a factor of three or more; for the K and Ks filters, where the background is mainly thermal emission, it is correlated with temperature and therefore quite seasonal. At J and H the background is primarily OH airglow and levels are unpredictable. A detailed discussion of background variation provided in the SQIID manual is equally applicable to FLAMINGOS.

The performance values for the 2.1-m and 4-m telescopes are based on actual data, although from a limited number of nights and at different times of the year, so they are not exactly self-consistent. The 4-m performance numbers are nominally the same as those for ISPI at the CTIO Blanco 4-m.The observed performance from the extensive GOODS survey at J and Ks agree to within 0.1 - 0.2 mag.

NOTE:The upper right quadrant of the array has a higher read noise than the other three quadrants. This can also be seen on dark images as an apparent periodic pattern. Extensive work during the summer of 2003 on the MCE-4 controller did result in improved performance, except in this quadrant, and the cause remains unknown. This should not seriously affect imaging applications, since the limiting noise is determined by the sky background, but it could have some effect on lower-background spectroscopy. *For single-object longslit spectroscopy, one may wish to keep the spectra on the lower two quadrants*.

Point Source Sensitivity

One should estimate the imaging performance on the KPNO 4-m telescope using the ISPI Exposure Time Calculator, since the performance of the two instruments is virtually identical. The IRAF Exposure Time Calculator, which uses the IRAF task ccdtime, may be used to estimate the performance of FLAMINGOS on the 2.1-m telescope; this will also work for the 4-m, but for consistency, we recommend that the ISPI performance be used.The ccdtime task assumes that the effective aperture is 1.4 times the seeing, so to duplicate the performance given in the 2.1-m table below, a seeing of 2.1 arcsec must be used. Different values for the assumed seeing will, of course, result in different results for the predicted performance.

Table 4: Predicted FLAMINGOS Performance on KPNO 4-m

FWHM = 3 pixels; aperture = 2.2 arcsec

Filter	**Mag=15** $e^- sec^{-1}$	**Sky** mag $arcsec^{-2}$	**Sky** $e^- sec^{-1} pix^{-1}$	**60 sec** 10 sigma	**600 sec** 10 sigma	**3600 sec** 10 sigma
J	3450	15.7	180	18.8	20.0	21.0
H	4480	13.9	1250	18.0	19.2	20.2
K	4360	12.9	3050	17.5	18.7	19.7
Ks	3800	13.1	2210	17.6	18.8	19.8

Table 5: Predicted FLAMINGOS Performance on KPNO 2.1-m

FWHM = 2 pixels; aperture = 2.8 arcsec

Filter	**Mag=15** $e^- sec^{-1}$	**Sky** mag $arcsec^{-2}$	**Sky** $e^- sec^{-1} pix^{-1}$	**60 sec** 10 sigma	**600 sec** 10 sigma	**3600 sec** 10 sigma
J	1050	15.1	335	17.6	18.8	19.8
H	1320	13.1	2815	16.7	17.9	18.9
K	1300	12.7	4030	16.5	17.7	18.7
Ks	1140	12.9	3920	16.3	17.6	18.6

The instrument gain is approximately 4.9 electrons/ADU for imaging (bias = 1.0 v).

The sensitivity values are based on aperture photometry for the diameters listed above the tables. Sensitivity will scale with aperture size, since most of the photons in an aperture will be due to sky.

Note that the exposure times do not include overheads associated with writing data to disk, moving the telescope between dithers, acquiring the field, etc. For short exposures, overhead will significantly reduce efficiency. The instrument overhead is quite short (less than 10 seconds) to read out the array and write the data to disk, so for most observing programs the time between images is determined by telescope overheads involved in dithering or rastering. For short offsets, the offset and settling times combined should be around 10 seconds.

The detector full well is sufficiently large that maximum exposure times at K are around 30 seconds (at least in the winter), 45 seconds at Ks and a minute or more at J and H. As noted above, the overhead in writing to disk is modest.

Although the minimum legal exposure time is under 2 seconds, in practice the instrument cannot keep up with exposure sequences for times that short, and a minimum practical time is around 5 seconds. Users should also be aware that even at longer exposure times, a small fraction of the images in any sequence may be lost, and should plan so that loss of a single frame does not seriously compromise their program. (This is a good rule for IR imaging in general).

Extended Source Sensitivity

One may use the numbers in Tables 4 and 5 to make an estimate of the sensitivity for observations of extended sources. Since the pixel area at the 4-m is almost exactly 0.1 arcsec^2, one may easily convert the point source sensitivity values into surface brightness equivalents. Table 6 presents the results using the 4-m values from Table 4, assuming that the individual integration times are sufficiently long that one is background limited. Table 6 presents both the maximum integration time, based on keeping the maximum signal/pixel below 20000 ADU, and a more typical rounded value. As long as one is background limited, the results for 3600 s of on-source time should not depend on the individual frame time, except for the observing overheads.

Table 6: Predicted FLAMINGOS Performance on KPNO 4-m for Extended Sources

Filter	**Mag=20** $e^- sec^{-1}$	**Sky** $e^- arcsec^{-2}$	**Maximum Frame Time** sec	**Typical Frame Time** sec	**S/N** 3600 s
J	34.5	1800	540	360	48
H	44.8	12500	78	60	24
K	43.6	30500	33	30	14
Ks	38.0	22100	44	30	15

Because this is a surface brightness estimate, the values for the 2.1-m telescope should be similar. Several caveats must be considered in the estimate presented here. First, this estimate is for 3600s of on-source time and does not include the overheads associated with each integration; for the short 30 sec K band observations, the integration overhead and telescope dither motions can add at least 50% to the on-source time. Secondly, this estimate assumes that the source is sufficiently compact to fit well within the FLAMINGOS field of view so that sky information may be obtained from the observations. Separate off-source sky observations will naturally add additional time to the observation. Finally, this assumes no systematic effects such as errors introduced by sky subtraction and flatfielding. For a long deep integration where the source is significantly smaller than the array size, one can generate both a master sky frame and a sky flatfield from the data itself. Both sky subtraction and flatfielding will add some noise to the data, although the degree is difficult to estimate. A sky or flat generated from nine images will have a statistical noise of 1/3 that of the source images and would therefore add about 10% to the noise. But the major source of systematics for this type of observation may come from the fact that the sky level is not constant. The OH airglow which accounts for the majority of the J and H background is temporally and spatially variable, so sky subtraction will in general leave a residual which will may or may not flatfield to a constant level. Observations in the K bands under unusually warm conditions will increase the sky background above the levels listed here and will impact the performance due to both increased noise from the background and increased overhead from the shorter integration times required.

Imaging Linearity

The linearity correction (courtesy of Anthony Gonzalez at UF) for the imaging mode can be expressed as a third-order polynomial:

$$y = 1.00425 * x - 1.01413 * 10^{-6} * x^2 + 4.18096 * 10^{-11} * x^3$$

where x is the raw signal and y is the linearity corrected signal in ADU.For the IRAF irlincor task, the coefficients are:

$$a = 1.00425,\ b = -0.03323,\ c = 0.04489$$

4. FLAMINGOS Spectroscopy

FLAMINGOS presently contains two grisms, one optimized for the JH bands and the other for HK, with a resolution (2 pixels) of approximately 1300 for both at the middle of the wavelength band. Blocking filters for JH (0.9 - 1.8 microns) and HK (1.25 - 2.5 microns) provide coverage of the combined bands with the appropriate grism. As shown in the table below, the JH spectrum covers almost all of the array, so there will be some spectral loss for MOS slitlets which are offset near the edges of the masks. This is not the case for the HK spectra, which cover significantly less than the full width of the array.

The designations "left" and "right" in Table 7 refer to the orientation in the ds9 display with WCS not enabled; i.e.; positive X is to the right and positive Y is up on the display. In this orientation, the position angle of the mask and instrument rotator is *down*, and the projection is in *earth parity*, with east clockwise from north. Thus, a mask with PA=90 will have east down and north to the right on the display. In this orientation, a slit to the right side will result in a spectrum shifted to longer wavelengths, so the coverage on the array will be shifted to shorter wavelengths.

Table 7: Approximate Spectroscopic Format

Band	Pixel 1 (A)	Pixel 2048 (A)	Δλ/pixel (A)
JH	8910	18514	4.680
HK	10347	27588	8.511
JH left	10286	19890	4.680
HK left	12849	30090	8.511
JH right	7534	17138	4.680
HK right	7845	25086	8.511

For spectroscopy, one uses a different bias (0.75 v) than for imaging, and the conversion gain is slightly different (4.1 e/ADU).

At the 4-m, the instrument rotator may be used to rotate the position angle of the slit between 0 and 180 degrees. At the 2.1-m, the slit orientation is fixed N-S.

Performance is more difficult to characterize for spectroscopy than for imaging, since both the signal and sky background have spectral structure, so that "sensitivity" is a strong function of the particular wavelength of interest, especially at resolutions around 1000. An illustration of the sky background in the JH spectroscopy mode is shown below in Figures 1 and 2.

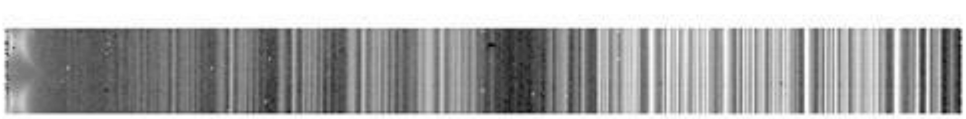

Figure 1: A selected subregion of the FLAMINGOS array (2048 x 190) showing the night sky spectrum in JH spectroscopy mode with a 4-pixel slit. The integration time is 600 s. Wavelength increases from left to right.

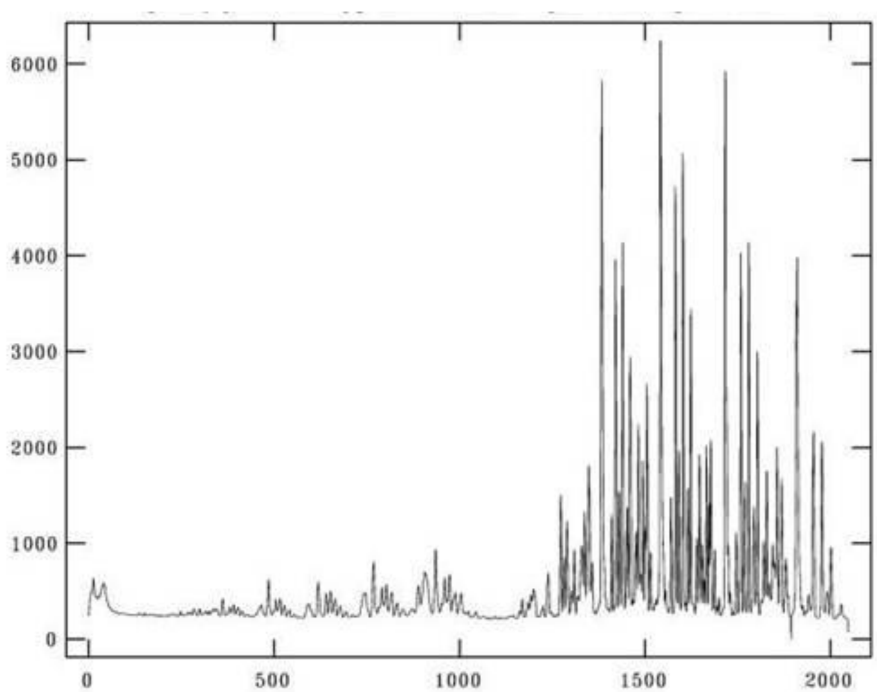

Figure 2: Plot of the JH sky spectrum from Fig. 1, showing the atmospheric OH emission lines. Signal is ADU (NREADS=1) in 600 s. Ordinate is in pixels.

The FLAMINGOS signals for JH and HK spectroscopy are illustrated in Figure 3. These were obtained on the Kitt Peak 4-m through a wide (10 arcsec) box, so that slit losses are not a factor. The signals are raw (no flatfielding) levels normalized to a 0.0 magnitude star in 1 sec with NREADS=1, at the spectroscopy detector bias of 0.75 v.

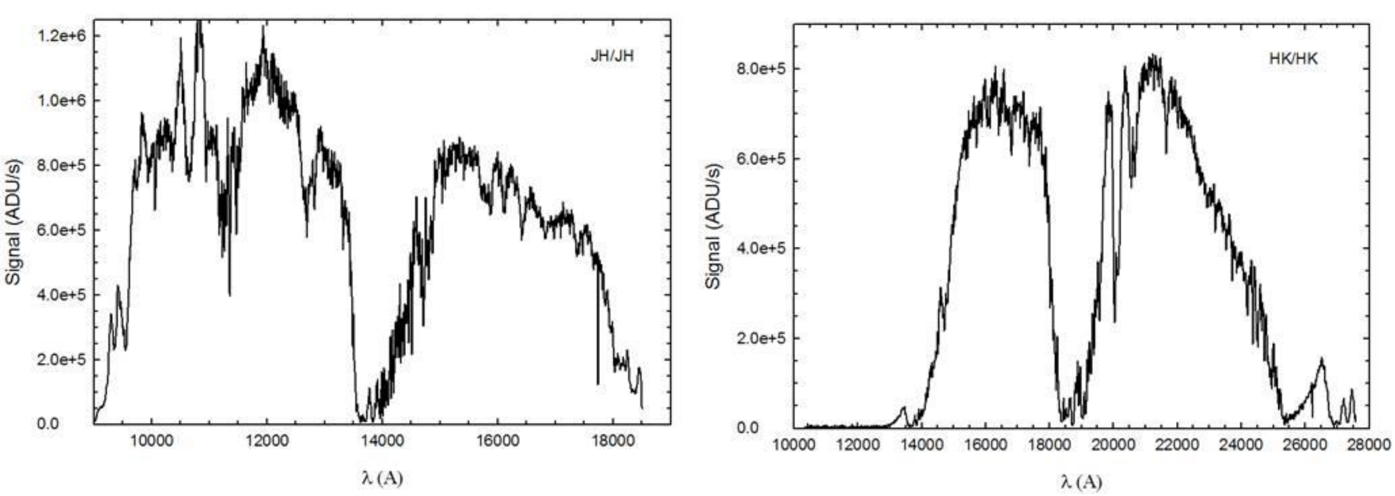

Figure 3: Raw FLAMINGOS signal levels in ADU/s for a 0.0 mag star through a wide slit for the JH region (left panel) and HK region (right panel). The signal in the HK spectrum redward of 2.5 microns is second order H band signal.

Spectroscopic Background

Ideally, the performance of a spectrograph is limited by the sky background, which consists primarily of emission lines from OH in the upper atmosphere in the J, H, and short K bands (Figure 1) and thermal continuum which increases sharply beginning at approximately 2.2 microns. The division of FLAMINGOS into separate MOS and camera dewars requires a vacuum-tight transparent interface between the two to permit bringing the MOS dewar up to atmospheric pressure for mask changes; this is the BaF_2 field lens which also serves as the camera dewar window. The presence of a warm optical element behind the slit plane results in significant additional thermal background which is dispersed by the grism onto the detector and limits the performance of the instrument for spectroscopy.This is particularly significant for HK spectroscopy, where the dispersed thermal background completely dominates the spectral image (Figure 4).

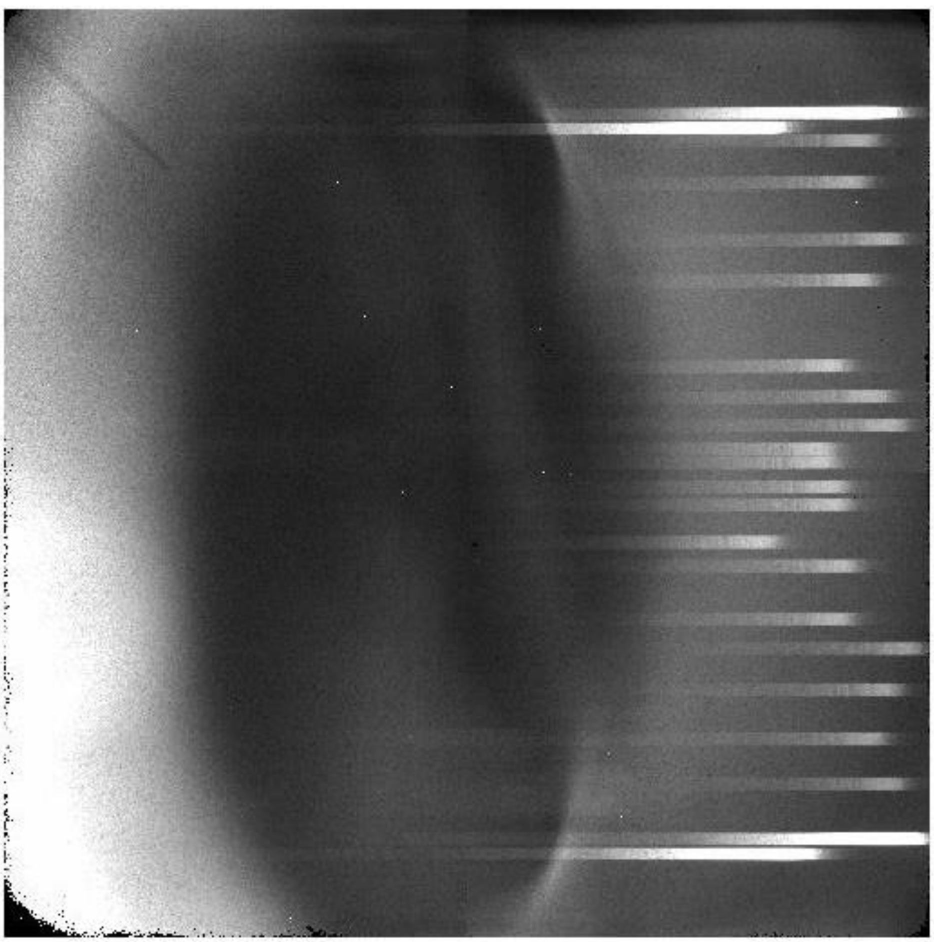

Figure 4: Raw image of a MOS spectrum in HK mode, showing the substantial dispersed thermal background superposed on the spectra of the MOS slitlets. The higher background spectra at the top and bottom are from the four square acquisition boxes on the MOS mask.

The background near the lower center of the array [1200:1225,605:630] was measured for various combinations of grism and blocking filter; the results are displayed below. As expected, the background with the HK grism correlates with the long wavelength cutoff of the blocking filter. In addition, the imaging filters (J, H, K, Ks) are of excellent quality and have higher throughput than the spectroscopic JH and HK blocking filters. Therefore, *observers who have scientific interest only in the K band (or a portion thereof), should consider using either the K or Ks filter as a blocker with the HK grism* to take advantage of both higher signals and lower background. A somewhat surprising result is that the background through the JH blocker is significantly higher than with the H filter when used with the JH grism; this is probably a result of the slightly longer wavelength JH cutoff (see filter plot links at the end of this page). This background (~ 4 e/s) is sufficient to degrade the predicted performance between OH lines by almost one magnitude.

Table 8: Background (ADU/s; 1 LNR; 0.75v bias) in Different Spectroscopic Modes

Grism	Filter	Background
JH	H	0.18
JH	JH	0.95
HK	H	0.17
HK	Ks	12.7
HK	K	19.6
HK	HK	47.3

Approximate spectroscopic sensitivities based on the observed signal and background levels are summarized below. These were estimated using a slit throughput of 0.5, which is typical for a 2 or 3 pixel slit at the 4-m under nominal seeing conditions. The JH background is fairly uniform across the array and, as noted above, limits the performance between the OH lines, but not at the OH line wavelengths.

Table 9: Approximate Spectroscopic Sensitivies

Band	Magnitude in 1 hour; 10 sigma	
	4-m	**2.1-m**
JH, between OH lines	15.5	14.5
JH, on OH line peak	14.5	13.8
HK,mid-array	13.4	12.7

Single Slit Spectroscopy

The FLAMINGOS MOS wheel contains single slits of widths 2, 3, 6, 9, 12, and 20 pixels. The 3 and 6-pixel slits cover almost the entire array length, but the others cover approximately 65% of the array. In addition, there is a 3-pixel long slit usually installed in one of the 11 MOS positions.

Additional 2, 3, and 4-pixel wide custom slit masks useable for observations of compact objects also can be installed in the MOS wheel. These masks have two 60 arcsec long slits (at the 4-m) offset by 60 arcsec on either side of the center. At the center is a 10-arcsec square hole which can be used for target acquisition. This permits one to acquire and center a target in the hole prior to offsetting to the slit without the need to move the MOS and decker wheels between imaging and spectroscopic positions. For easily-identified targets, this can save some acquisition overhead at the telescope.

Important Note: In June 2006, the MOS wheel was found to have shifted axially from the actual input focal plane defined by the camera dewar optics by approximately 2 mm. This produced a significant defocus of the MOS slitlets and long slits in the MOS wheel. The cause of this is unknown, but might have been within the camera dewar. Subsequent investigation of the collimator and camera optics showed them to be operating as designed, so the ultimate cause remains a mystery. This problem was initially addressed by shimming the MOS masks in the wheel so they (and any long slits mounted in mask frames) were in focus. In May 2008, the detector itself was shifted axially to bring the MOS wheel nearly back into focus, so both the MOS positions and built-in slits can be used.

There is variation in spectroscopic image quality (FWHM of unresolved spectral lines) with wavelength, which is particularly noticeable in JH spectra, since they subtend the entire width of the detector. This is a consequence of the skew aberration within the large angle (35°) of the prism component of the disperser and is inherent to the design of the instrument. Fortunately the effect is most noticeable in the center of the spectrum (corresponding to the telluric absorption between the J and H windows) and only at the long end (1.75 - 1.80 microns) of the H band.

MOS Mask Information

NOAO presently supports multi-object spectroscopy from the community only at the Kitt Peak 4-m telescope.

Masks will be made from user-supplied celestial coordinates (α, δ), in either sexigecimal or decimal format (the latter being preferred). These will need to be provided to NOAO **several weeks in advance of the observing run** (see below). Details will be provided to successful proposers. In addition, it is possible to use the .pos output files from the University of Florida mask design program working with FLAMINGOS pre-images, although NOAO cannot provide operational support for use of this program. The slit mask field on the 4-m is 3.1 x 9.5 arcmin, with the long axis along the slits (perpendicular to the dispersion).

The coordinates will need to be accurate enough to ensure that objects are centered on the slit (a 2-pixel slit is ~0.6 arcsec at the 4-m). Each mask must contain at least three well-distributed setup star apertures typically 8 arcsec square. These stars are required to acquire the field and center the target objects on their respective slits, since it is seldom practical to check mask alignment using program objects directly. Note that these stars will produce their own spectra during the observations, so the real estate in the dispersion axis occupied by the setup stars is not available for program objects. The acquisition and centering procedures involve the use of the IRAF ucsclris.xbox task and are fully described in the 4-m FLAMINGOS Observers Guide.

However, recent experience suggests that by ensuring during the afternoon that the MOS masks are precisely aligned with the columns of the array (by adjusting the zero point of the MOS wheel motion), almost no rotational tweaking of the masks is necessary to set up on the alignment stars. In addition, if one of the alignment star apertures can be made sufficiently large (25 arcsec), it may not be necessary to move back and forth from the mask to the imaging aperture during the setup process and it is often possible to properly center the alignment stars within their respective boxes without resorting to the rather time-consuming ucsclris.xbox task.

The mask wheel holds 11 masks; cycling the MOS dewar containing the mask wheel takes a good part of the day, so one is limited to 11 MOS fields per night. In general, one is doing well to use 4 - 5 masks/night, so one can usually use a set of masks for 2 - 3 nights.

Spectroscopic Cautions

The full suite of spectroscopic capabilities is being offered, but prospective users should read the caveats on spectroscopy below.

- Setup of spectroscopic observations can be time-consuming, and observers will need to do significant pre-observation planning.
- For long slit spectroscopy, unless the program objects are bright enough to be easily centered (H<17 or so on the 4-m), a nearby offset star is strongly

recommended. This should be close enough to permit guider-controlled offsets on the 4-m. Long-slit observations on objects fainter than H~16 are probably best done on the 4-m rather than at the 2.1-m.

- Long-slit spectroscopy at the 2.1-m is possible, but more complicated than at the 4-m. The 2.1-m does *not* have a movable guide probe, but instead utilizes a fixed off-axis mirror feeding the guider ICCD camera. The guide field is approximately 5.5 x 4.2 arcmin and is roughly 200 arcsec E and 1500 arcsec S of the FLAMINGOS field center. Although one can position a cursor to guide on a star anywhere in this field, it is not possible to reposition the mirror to cover a wider patrol field. Note that one must allow sufficient clearance from the N-S edges of the field to beam switch along the slit while keeping the guide star in the field of view. We strongly recommend that investigators check for potential guide stars prior to submitting a proposal for 2.1-m spectroscopy, particularly for fields out of the galactic plane. Alternatively, one should be prepared to observe alternate program objects in the event that some of the primary targets may not be observable due to the lack of a suitable guide star.
- Note, too, that large offsets along the slit (as opposed to typical 10 arcsec or so of "dither") on either telescope will require careful setup to ensure that the object is centered on the slit at both beam positions.
- For multi-object spectroscopy, observers will need accurate coordinates of their program objects, and of three setup stars in the program field. Details of the coordinate requirements will be provided to successful proposers. Anyone planning such observations should also plan to obtain the required coordinates and provide them to KPNO support **at least 4 weeks in advance of scheduled time to permit vendor fabrication of the masks**. The input coordinate files must be converted at NOAO to a machine-readble form and then sent to the mask vendor, who must fit the work into their schedule, so we strongly advise allowing a comfortable time margin. In addition, because personnel at both NOAO and the mask vendor are often on vacation at the end of the calendar year, **observers for MOS runs scheduled in January should plan on having their coordinates submitted prior to the beginning of the preceding December.**
- In writing proposals, observers should allow approximately 20 minutes for acquisition and set-up for standard (point source) long slit observations. They should allow at least 45 minutes for MOS observations, probably more for the first field of the run, or if non-cardinal position angles are used. Anyone considering observations different from the standard types described above should consult with NOAO (or Florida) staff beforehand to confirm that the observations are practical, and to properly allow for overheads in their proposal.

5. Spectroscopic Calibration

Flatfielding

Because the sky background has spectral structure (see Figure 1 above), there is no spectroscopic equivalent to flatfielding on the sky, as is commonly done for imaging. It is therefore necessary to obtain dedicated flatfields using the telescope flatfield lights to illuminate the interior of the dome. As with imaging dome flats, one should take a number (> 10) of images of the illuminated dome, followed by an equal number with the lights off for bias subtraction. Because there is a thermal continuum component (particularly in the HK mode), one should *not* use darks as the bias reference for the flats.

- Since there is some flexure within the instrument, we recommend that dome flats be taken with the telescope in approximately the same orientation as used during an observation. This is particularly important for MOS observations, since the slit lengths are generally short, and any flexure will result in a relative displacement of the observation and flatfield slit illumination functions. For MOS observations, it is important to obtain separate flatfields for each MOS mask to ensure that the same portions of the array are illuminated by both the observations and flatfields. The easiest way to accomplish this is to rotate the dome in front of the telescope after an observation (or one may want to move the telescope back to its position at the observation midpoint) and illuminate the interior of the dome with the flatfield lights.
- For longslit observations, the effects of flexure will be evident only at the ends of the slit, so it may be acceptable to obtain a single set of flatfield observations at the beginning or end of the night using the standard White Spot.
- The comparison source built into the 4-m rotator/guider has a limited projection field (since it was designed for the RC spectrograph) which will not fill the 3.1 x 9.5 arcmin field of the MOS or longslit input, so its use for flatfielding is not recommended. If one is using one of the KPNO custom slits with the acquisition box in the center and two 1 arcmin long slits on either side, it is possible to use the 4-m comparison source.

Wavelength Calibration

The atmospheric OH emission lines which appear in the raw observations provide a natural template for wavelength calibration. These lines are well-distributed throughout the J, H, and most of the K bands, out to about 2.32 microns.When doing MOS observations, each spectrum will have a unique wavelength zero point, which is a function of the location of the slit in the dispersion coordinate, so the OH lines are generally the most useful calibrator. It is possible, on the 4-m telescope, to use the HeNeAr emission line calibration source in the guider/rotator (there is no guider or calibration source at the 2.1-m telescope). However, because this source (like the continuum source) does not fully illuminate the MOS input field, it may not be useful for MOS calibrations.

At the spectral resolution of FLAMINGOS, many of the OH lines (and some of the HeNeAr lines) will be blended. Therefore, it is important to select isolated lines which can be confidently identified when wavelength calibrating the spectra. Figures 5 and 6 show calibrated spectra of the HeNeAr source taken through a 4-pixel slit. Files of both the OH lines and HeNeAr lines may be downloaded for use in calibrating spectra. The files have multiple columns corresponding to vacuum wavenumbers, vacuum wavelengths, and "air" wavelengths. One may select the desired column to create the calibration of your choice by using the IRAF fields task. For example, to pick column 4 in the file "OH_lines.txt" (air wavelengths), execute in IRAF:

fields OH_lines.txt 4 > OH_lines.ang.dat

The latter file can then be used as the line reference source for the identify task (you may need to sort the file so that the numbers are monotonically increasing for the automatic identification to work properly).

- There is some small distortion of the FLAMINGOS field from the wide field camera.In addition, a grism (unlike a reflection grating) will not in general have a linear relation between pixel and sin(b), since the prism itself has some dispersion. As a result, it may be necessary to use a relatively high order function (i.e., Legendre order 4 or 5) to get a fit over the entire JH or HK region. One can experiment with breaking the spectrum into separate bands and fitting the wavelengths within each band separately.
- The HK spectrum covers significantly less than the full 2048 pixels. We recommend truncating the spectral image at the end of the K band (2.45 microns) before carrying out the wavelength identification to keep the fitting function well-behaved.

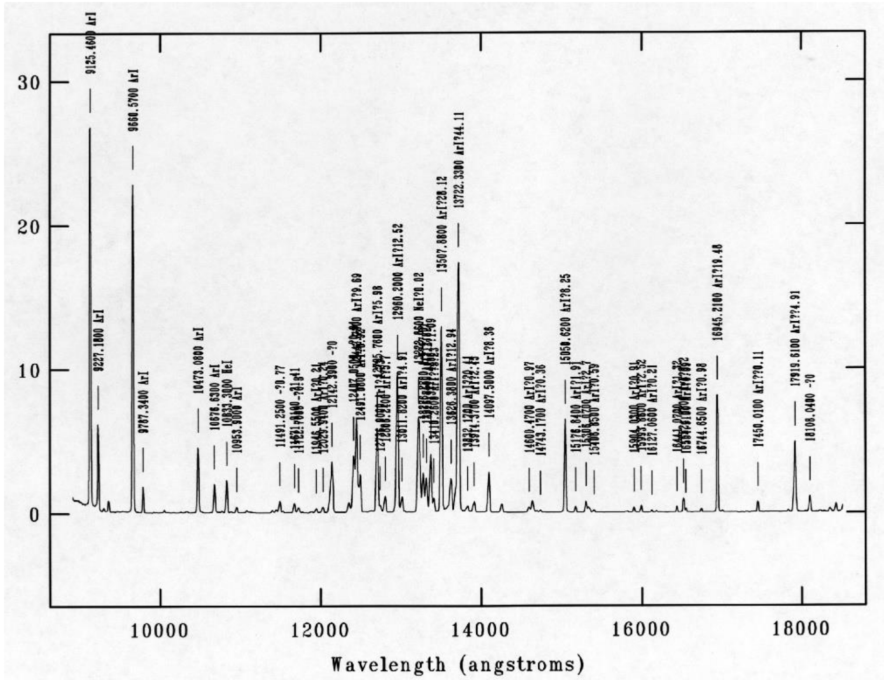

Figure 5: Wavelength fit for the JH spectroscopy mode to a HeNeAr spectrum. The fit used 50 lines, a Legendre order 5 polynomial, with an rms of 1.4 A.

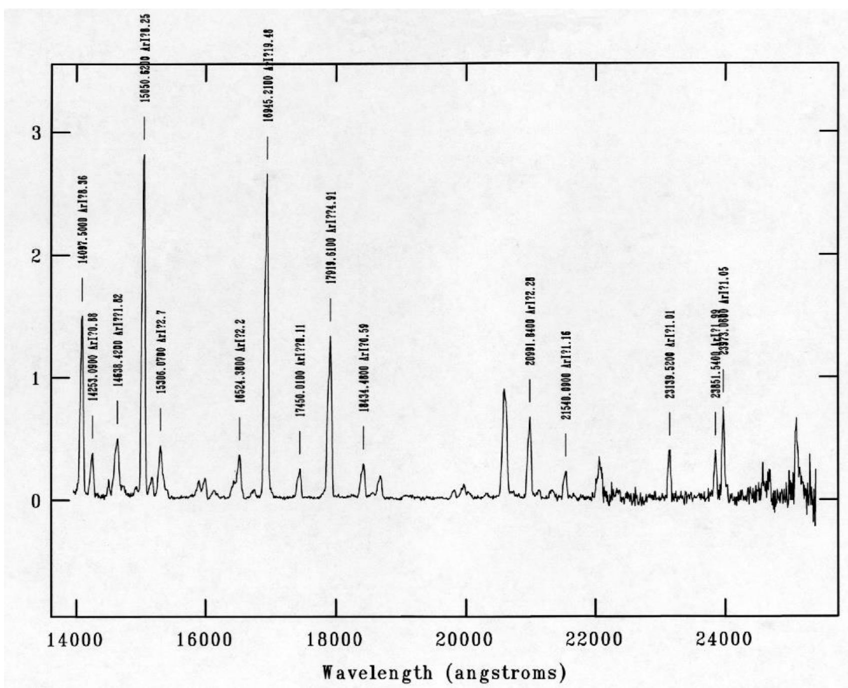

Figure 6: Wavelength fit for the HK spectroscopy mode to a HeNeAr spectrum. The fit used 15 lines, a Legendre order 4 polynomial, with an rms of 1.7 A. The spectrum was truncated to ~ 1400 pixels prior to the fitting.

6. Operations Issues

Temperature Readout

The temperatures of both the detector mount and the work surface of the MOS dewar are logged every 10 minutes and stored on flmn-2m-1a and flmn-4m-1a in the subdirectories /home/2mguest/Temperature_Data and /home/4mguest/Temperature_Data when FLAMINGOS is in use at the 2.1-m and 4-m telescopes, respectively. Every time the temperature daemon is restarted, a new logfile is created with the general form "Temperature.4mguest.2005.Mar.29.0001.dat" The current open file is also plotted on the terminal. It is important to keep an eye on the temperatures by periodically referring to either the temperature plots or the Status GUI, to ensure that neither the camera nor the MOS dewars have exhausted their supply of LN_2. Ideally, the camera dewar holds ~ 30 hr and thus needs refilling only once/day. The MOS dewar holds > 14 hr and thus should be filled twice/day, at the beginning and end of the night. There are some circumstances which can result in shorter hold times, with the risk of running out of cryogen during the night:

- A poor vacuum will result in accelerated boiloff and a shorter hold time. This is primarily an issue with the MOS dewar, which is brought up to atmospheric pressure and re-pumped every time the masks are changed.
- It is possible to misinterpret splashing of LN_2 from the vent port as a full dewar and thus end up only partially filling the tank. When filling, ensure that there is a steady stream of LN_2 from the vent port.
- If the telescope is moved to an unusual position during the daytime (e.g., to the SE annex at the 4-m), the instrument may end up in an orientation which results in spilling significant amounts of LN_2 from the dewar.

It is also important to recognize what can be considered "normal " behavior, in contrast to a clear sign of cryogen exhaustion.

Detector Temperature

The detector temperature is read by a sensor on the detector mount, which is strapped to the LN_2 flask of the camera dewar. It will generally vary slowly with time, in response to the dome temperature, but usually by no more than 0.5 K over a day. A significant monotonic increase in temperature should be a warning sign of cryogen exhaustion.

MOS Temperature

The MOS temperature is measured by a sensor on the top of the MOS work surface, which is the top surface of the LN_2 tank in the MOS dewar. Copper rods extending down into the LN_2 provide the thermal path to the cryogen. As the LN_2 level drops, the thermal path between the work surface and the liquid becomes longer, so the temperature (under a constant thermal load) will slowly increase. In addition, the orientation of the instrument may increase or decrease the thermal conductance between the liquid and the work surface. As a result, one can see fluctuations of several degrees on top of a monotonic increase during the course of a night. Figures 7 - 9 illustrate the temperature profiles one can expect during normal operation, exhaustion of LN_2, and the forced warmup using the MOS dewar heaters.

The FLAMINGOS User manual notes that the MOS temperature should be nominally in the 75 - 85 K range, but under some conditions and orientations, values above 90 K may be seen. The critical factor which identifies cryogen exhaustion is a rapid monotonic temperature increase which continues even if the instrument is returned to an upright orientation. Temperatures as high as 120 K will not introduce noticeable thermal radiation into either spectroscopic or imaging observations, but one should not attempt to move the MOS or decker wheels under such conditions, since the drive train will not be isothermal, and the mechanisms may operate poorly or not at all.

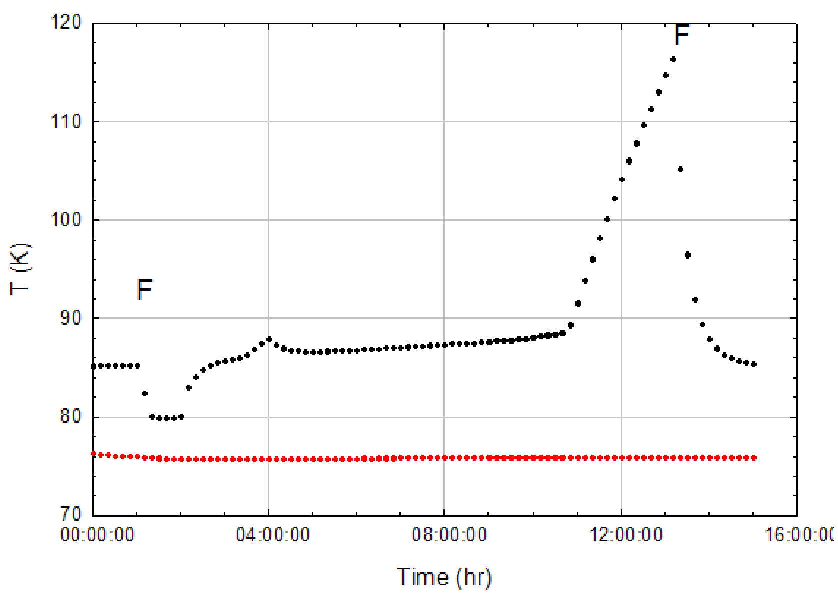

Figure 7: Temperature profile of the detector (red) and MOS work surface (black) over a 16 hour time period. The MOS dewar was filled (F) at about 0100, but the LN_2 ran out at about 1100. Note that the temperature rises approximately linearly at about 12 K/hr. The dewar was refilled at 1300 and required about 30 minutes to return to a normal operating temperature.

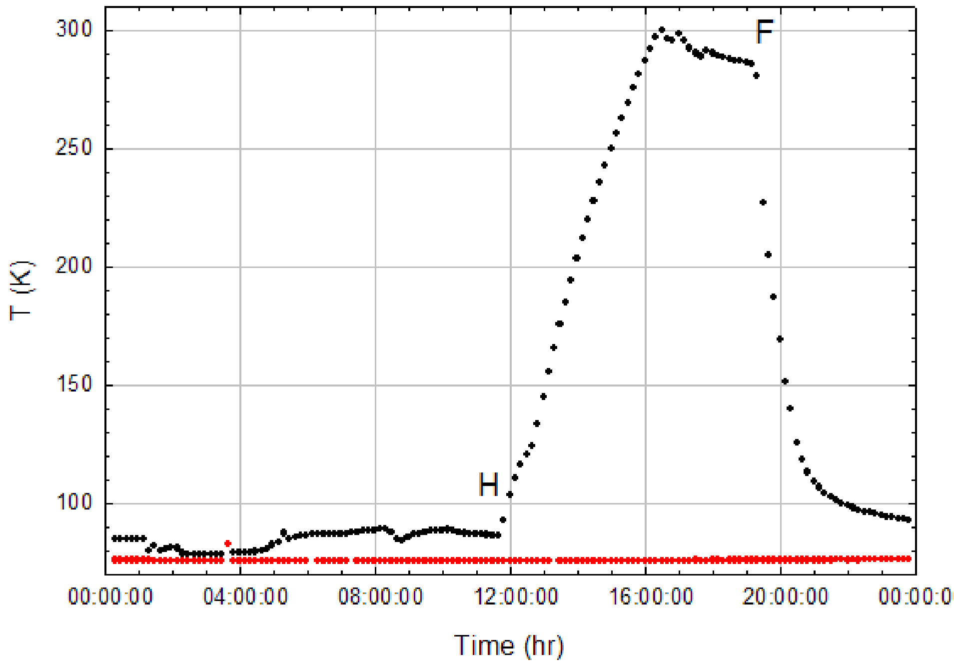

Figure 8: Temperature profile of the detector (red) and MOS work surface (black) over a 24 hour time period. The instrument was used for normal observing until 1140, when the MOS heaters were turned on to permit access to the MOS wheel. This results in an initial rise as the work surface heats up, then a more gradual rise as the residual LN_2 is boiled off. At about 1240, the LN_2 was gone and the warmup accelerated to about 50 K/hr until the target temperature of 300 K was reached. The dewar was refilled (F) at 1900 and reached a normal operating temperature in about 4 hours.

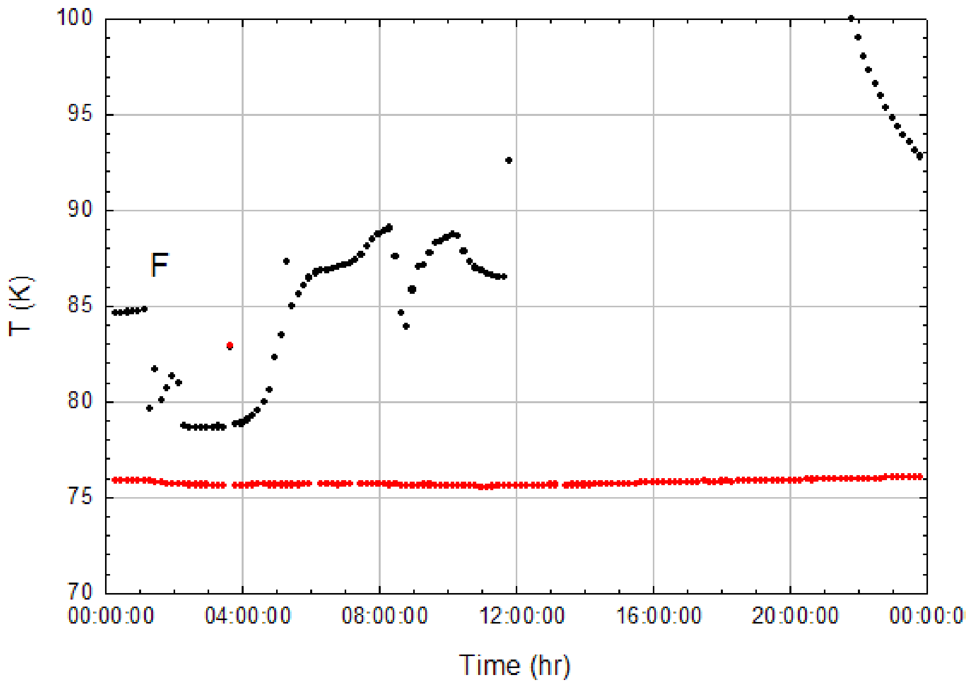

Figure 9: Exploded view of Fig.8, showing the MOS temperature profile during a normal observing period. The MOS dewar was filled (F) at about 0100 and used for observing until 1140, when the heater was turned on. The fluctuations of up to 10 K during this period are due to a combination of a monotonic increase as the LN_2 slowly boils off and changes in the thermal conductance path between the LN_2 and the MOS temperature sensor as the orientation of the instrument changes during the night. Occasional jumps in both the detector and MOS temperature (which occasionally give unphysical temperature readouts) are due to noise during the sampling and are not a cause for concern.

Unusual Images

Occasionally, the MCE4 will read out prematurely and produce an image which looks like a plush pillow. In almost all cases, this is a random event and the following image will appear normal (although the count level may be down). The cause of this is probably noise interference which causes the MCE4 to read out before the integration is completed, resulting in the initial frame of the double correlated sampled image. On some occasions, this behavior will persist, requiring a reboot of the MCE4, as described in the Troubleshooting section of the FLAMINGOS 4-meter Observer's Guide. If this does not cure the symptom, it is possible that the array is actually saturated from excess light or from the detector warming up. We suggest the following checks of the system:

- Ensure that the detector temperature is at its normal value near 77 K. If the temperature rises above 100 K, one will see excess background, and there is the possiblity of damaging the detector. If this is the case, close the MCE4 daemon and refill the camera dewar immediately.
- If the detector temperature is normal, move the grism to the "true dark" position and take an image. This will ensure that no light is falling on the detector. If one is still seeing saturated images, there could be a serious problem with the MCE4 and one should call for help.
- Saturated and "bad" images look qualitatively similar, but there are definite differences. A saturated image will have a mean count level near 49000 ADU, and the dead pixels in the lower left corner will be evident (Fig. 10a). By contrast, a bad read will have a mean count level near 57000 ADU and the dead pixels will be absent or barely detectable (Fig. 10b).

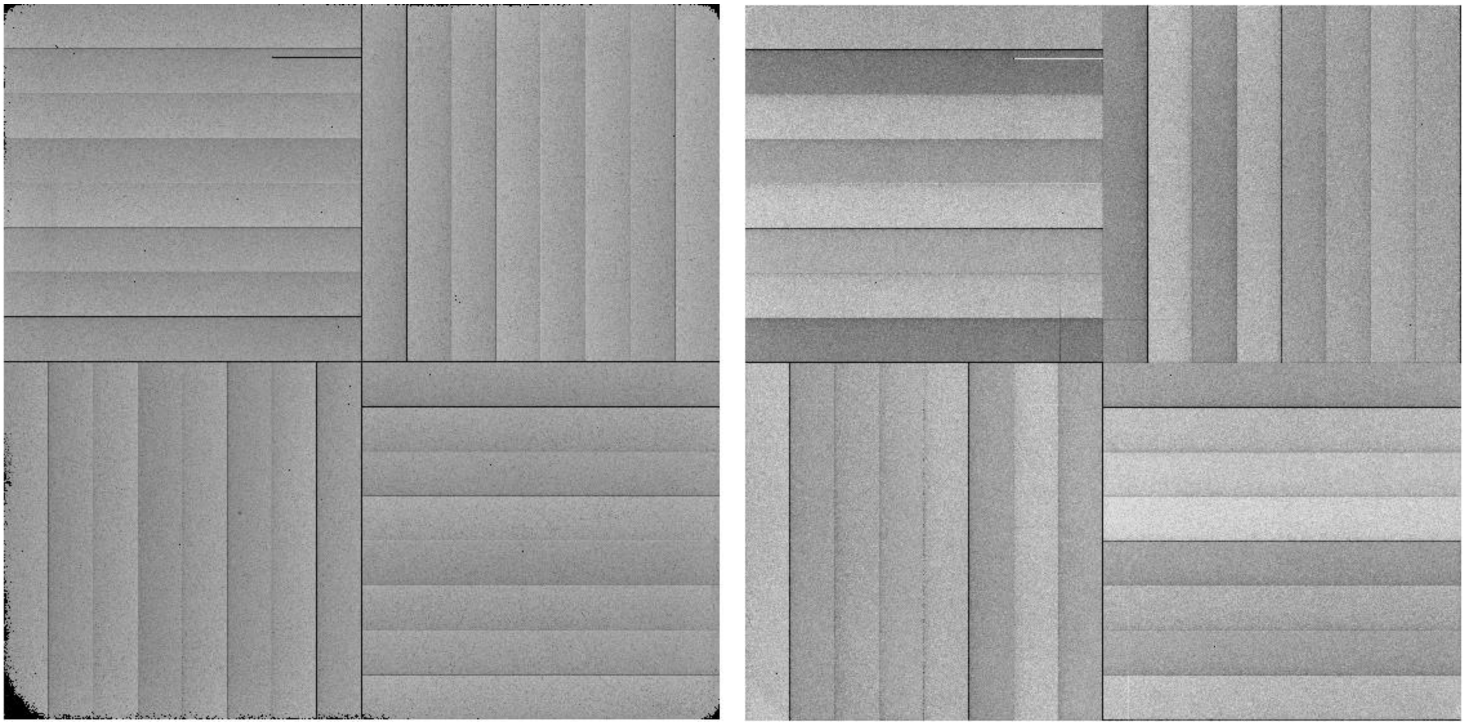

Figure 10: Representative FLAMINGOS images showing saturation due to excess radiation (left panel) and a "bad" read due to a premature readout of the array. Note that the dead pixels in the lower left corner show up clearly in the saturated image, but not in the bad read.