FLAMINGOS Performance – I

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1. Introduction

This report summarizes a continuing effort to understand the performance of FLAMINGOS for both imaging and spectroscopic applications. Particular areas of concern are the photometric uniformity over the imaging field, focus of the MOS slits on the detector array, and background when used for spectroscopy in the HK range.

2. Historical Background

FLAMINGOS has been in use at Kitt Peak for a number of years at both the 2.1-m and 4-m telescopes. The majority of non-Florida NOAO community time is utilized for imaging, although there have been a number of MOS runs (which are supported only at the 4-m). During 2004 and 2005, questions about the photometric quality over the field led to analysis by Steve Eikenberry (UF), who concluded that the degradation of the AR coating on the BaF_2 lens which also serves as the window for the camera dewar was causing field-dependent scattering of light from targets, resulting in extended low-level halos which would be missed by typical photometric extraction apertures, leading to an undermeasurement of the signal.

In November 2005, the BaF_2 lens was removed and sent to the vendor (Janos), who removed the coating and repolished the lens without applying any coating to the surface. The lens was reinstalled in early December, prior to a long UF observing run used for both imaging and MOS. Since that time, FLAMINGOS was used for a number of imaging runs and three NOAO-supported MOS runs. The chronology of the MOS runs, including one prior to the lens rework, is given below:

Table 1. Chronology of MOS Observing Runs

Observer	Dates of Run	Bands	Slit Width
Megeath	22-26 Sep 2005	JH	3 pixels
Lada	7 – 29 Dec 2005	JH	4 pixels (?)
MacDonald	9 – 14 Feb 2006	JH	4 pixels
Edwards	6 – 8 June 2006	JH + HK	3 pixels
Mercer	30 June-4 July 2006	HK	2 pixels

The first three of these runs apparently proceeded uneventfully. We rarely, if ever, receive feedback from the UF observers, and the setup of the Megeath and MacDonald runs suggested that the system was performing nominally. During the Edwards run, the observers reported that the slit images in acquisition mode (imaging) were greatly broadened, leading to an initial suggestion of poor vendor fabrication. However, analysis of the images and (later) inspection of the slit plates showed the masks to be as specified and the problem due to significant axial displacement of the MOS slits from the input focal plane. Prior to the Mercer run, Ron Probst and Dick Joyce investigated the focus and determined the camera dewar focal plane to be displaced downward (towards the camera dewar) 2 – 2.5 mm from the location of the MOS masks. Aluminum tubing shims fabricated in the shop were used to displace the masks for the Mercer run, resulting in nearly perfect focus of the masks on the detector array. Measurement of the MOS wheel in the shop showed some intrinsic warpage, although the sense appeared to be opposite that expected.

During the Mercer run, which was rendered virtually unusable by weather, the observers commented on the very high background seen on the array in the HK spectroscopy mode. This has been a long-standing feature, although its effect on the limiting spectroscopic performance has not really been determined.

3. Slit Image Quality

The NOAO data archive was employed to retrieve datasets from 24 Sep 2005 (Megeath), 16 Dec 2005 (Lada) and 9 Feb 2006 (MacDonald). Selected images from the Edwards run (9 June 2006) were sent by the observers at the time, and the Mercer data were still on the host computer at the 4-m telescope. Representative slit acquisition images from each of the five observing runs are shown in Figure 1.

Although the resolution of these reproductions in the figure makes it difficult to evaluate the quality of the slit images, the degradation in the Edwards run (next to bottom in Fig. 1) is sufficient to be easily visible. The slit images are significantly broadened and the square alignment boxes are noticeably rounded at the corners. By comparison, the 2 pixel slits in the Mercer run (bottom in Fig. 1) are sharp. Inspection of the earlier data from September and December 2005 and February 2006 shows these slit images to be somewhat defocused, although not nearly to the extent of those in June 2006. The defocus was not sufficient to be easily noticed at the time of the observing runs.

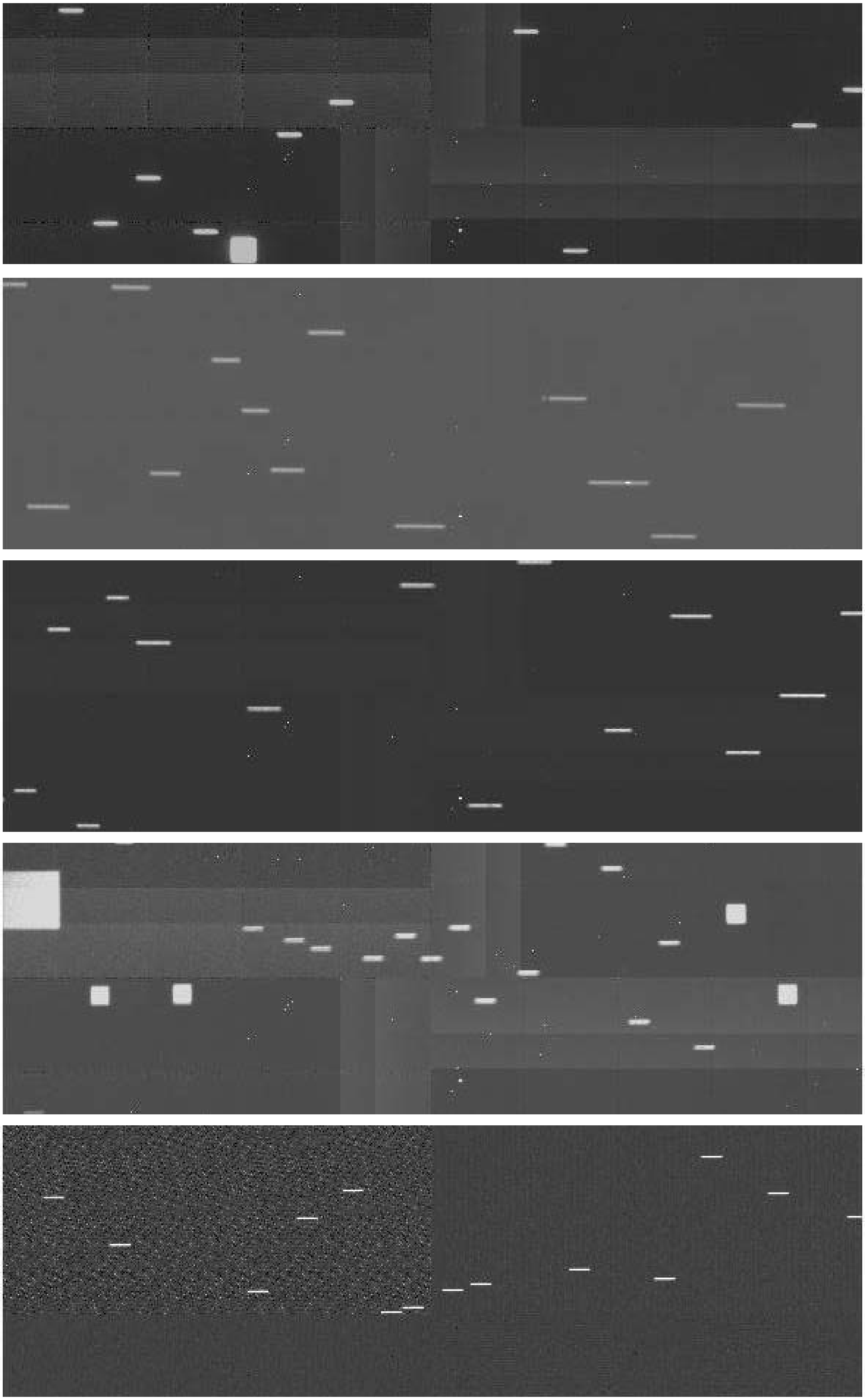

Figure 1. Slit acquisition images from (top to bottom) 24 Sep 2005, 16 Dec 2005, 9 Feb 2006, 8 Jun 2006, and 30 Jun 2006.

Table 2 shows the measured FWHM (using imexam in IRAF) of a Gaussian fit to the width of the slit image. The numbers represent the range in FWHM for slits near the top, middle, and bottom of the array as well as the difference between the observed and actual slit width. The Gaussian fit will tend to underestimate the width of a top hat profile, but the relative numbers are indicative of the image quality.

Table 2. Measured Slit Width for Observing Runs

Run	Slit width	Top	Middle	Bottom
Sep 2005	3	3.4 – 4.3	3.5 – 4.2	3.4 – 3.5
		0.4 – 1.3	0.5 – 1.2	0.4 – 0.5
Dec 2005	4	5.0 – 5.1	4.7 – 5.3	4.0 – 4.2
		1.0 – 1.1	0.7 – 1.3	1.0 – 1.2
Feb 2006	4	4.5 – 4.7	4.5 – 5.3	3.9 – 4.0
		0.5 – 0.7	0.5 – 1.3	0.0
Jun 2006	3	4.2	5.8 – 6.2	3.6 – 4.0
		1.2	2.8 – 3.2	0.6 – 1.0
Jul 2006	2	1.9 – 2.0	1.9 – 2.0	1.9 – 2.0
		0.0	0.0	0.0

3.1 Discussion

Although the amount of defocus observed in the Edwards run was significantly larger than that in the Megeath, Lada and MacDonald runs, the MOS slits do not appear to have been in sharp focus during the earlier runs. In general, the focus was better for slitlets imaged on the left and at the bottom of the array. The Mercer run, for which the slits were in focus, showed little variation in focus across the field, unlike the others. This may simply be a consequence of the depth of field near focus, combined with some astigmatism in the FLAMINGOS optics, but would require more expert analysis to confirm.

External influences seem to have had minimal effect. The BaF_2 window removal and rework occurred between the Megeath and Lada runs, yet the images were virtually identical in both. Between the MacDonald and Edwards runs, when the focus deteriorated significantly, the MOS and camera dewar were never separated.

The effects of ambient temperature on the relative locations of the MOS wheel and camera dewar focus should be small, although this has never been systematically studied at NOAO. While it was clearly warmer during the June 2006 run than during the Dec 2005 and Feb 2006 runs, it was also fairly warm in Sep 2005, and no change was seen between then and December.

The effort to determine the proper slit focus prior to the Mercer run was carried out at ambient temperature, and the slits remained in good focus when the MOS dewar was cooled, so axial motion of the MOS wheel with temperature appears to be small

3.2 Tentative Conclusions

It is clear that something between February and June 2006 caused a significant motion of the MOS wheel with respect to the camera focal plane. Since the MOS and camera dewars were not separated during this time interval, the logical explanations are: 1). Some sort of axial motion of the MOS wheel with ambient temperature; 2). A change inside the camera dewar itself, possibly due to a position shift in one of the optical elements or the detector. The latter may or may not show up in imaging data, since the telescope focus is a free parameter in this application.

Since there are no MOS runs scheduled until the UF run in late December 2006, there is some time to decide what, if any course of action is needed. The 2.1-m Clemson runs in November and December request longslit spectroscopy. A minimal effort approach is to check the focus of the MOS/slit wheel prior to each run and shimming the slits as needed to ensure good focus. Among other things, this approach will let us see if the focus does change with ambient temperature. The long slits in FLAMINGOS can presumably be shifted in the same manner as the MOS masks, and as long as the error is in the same direction, it can be resolved by shimming up the masks. This requires some effort (probably 1 day prior to each run), but should be done. As a new operations partner, Clemson should have a spectrograph with the slit in focus on the detector.

A longer term and more significant effort would be to solve the problem, assuming that the focus offset remains fixed. This would mean addressing both the axial offset and apparent runout (axial shift with rotation angle) of the MOS wheel and would require some effort. At the very least, removal of the MOS dewar, opening up the top, and removal/repair of the MOS drive mechanism would be required.

4. Spectroscopic Focus

This issue was noted during the Mercer run in July 2006. Although the science objectives of this run required HK spectroscopy (more on this below), the observers made some diagnostic observations with the JH grism as part of attempting to characterize the background.

Figure 2 shows portions of the lower right quadrant of the detector, corresponding to the H band for slitlets near the hub end of the mask, for JH grism spectra of atmospheric OH emission lines taken on 16 Dec 2005, 9 Feb 2006, and 2 Jul 2006. The last was taken using the H, rather than the JH blocking filter, but all used the JH grism.

The first two spectra show relatively uniform line widths on the order of 3.3 – 3.6 pixels for the unblended (non-Q branch) lines. Given that the slit width is 4 pixels and the imaging data showed some defocus (although less so in this portion of the mask), the only plausible explanation is anamorphic demagnification in the grism. Verifying this will require obtaining the specifications for the grism. The data of 2 Jul 2006 are somewhat disturbing in that the OH lines, which are on the order of the slit width (2 pixels) near the center of the array, are significantly defocused on the right side of the detector. In the earlier data, including Sep 2005 (not shown), the lines near the edge of the array were broadened, but this was a small effect seen only close to the edge.

Although they are not shown here, spectra taken with the HK grism and the H filter (which fall near the center of the array in the dispersion direction) in July 2006 show uniformly focused OH lines of 1.8 – 2.2 pixels FWHM.

4.1 Tentative Conclusions

This effect is difficult to understand, since it represents a field-dependent focus which was not previously seen. The only difference in setup, which was the use of the H rather than the JH filter as a blocker, seems unlikely to be a factor. A simple shift in detector position, which might have been invoked to explain the MOS plate defocus, does not explain the well-focused OH lines near the center of the array.

During the initial setup, we should obtain calibration spectra for all possible combinations of grism and blocking filter using both long and MOS slits.

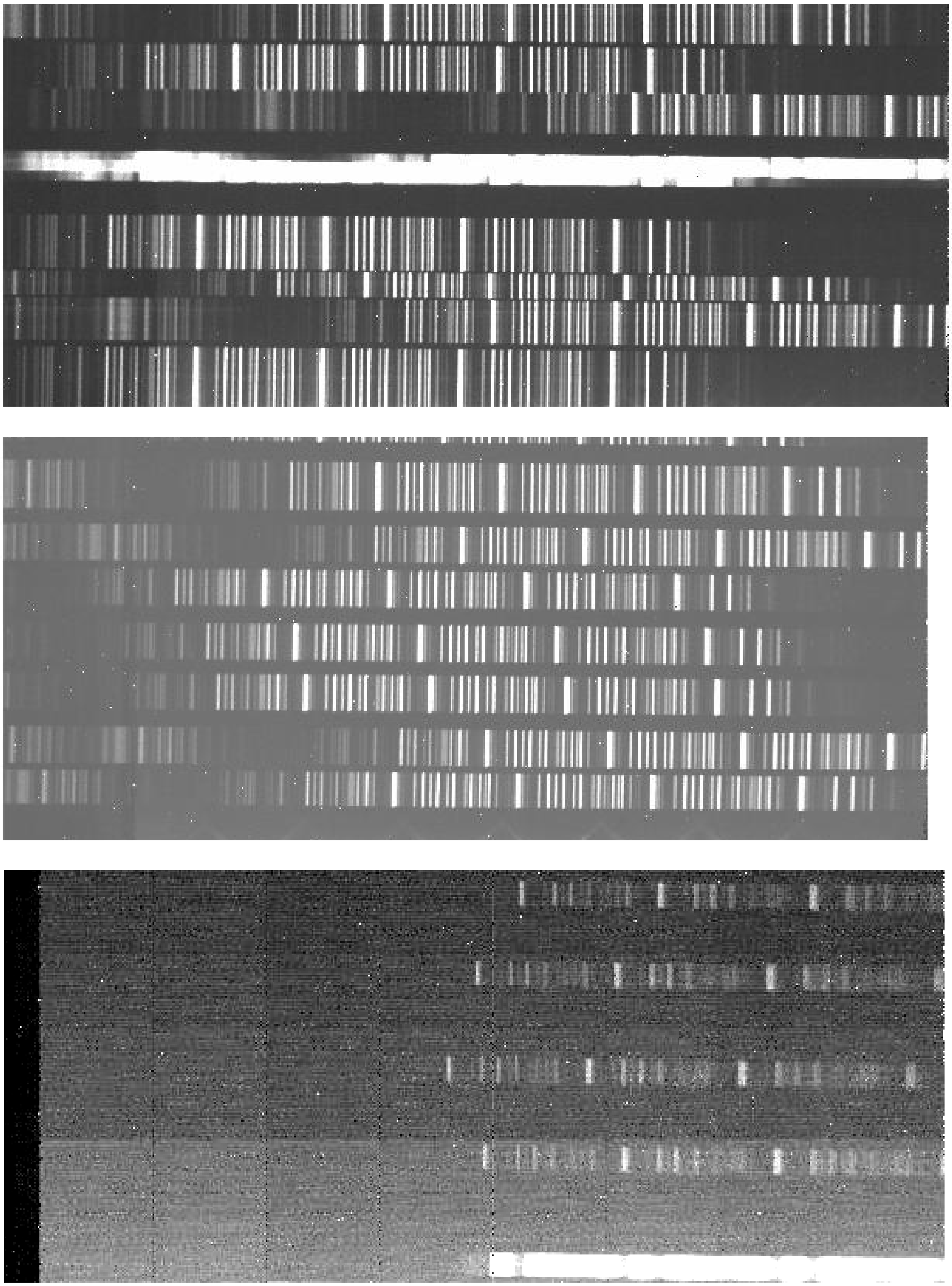

Figure 2. Lower right corner of array in JH spectroscopy setup on nights of 16 Dec 2005 (top), 9 Feb 2006 (middle), and 2 Jul 2006 (bottom), showing atmospheric OH emission lines. Broad spectra are from alignment star boxes.

5. HK Spectroscopic Background

Spectroscopy in the HK bands, using the HK grism and HK blocking filter, has always been plagued by significant background radiation on the detector. The background is greatest on the left and right sides of the array, leaving an area of lower, but still significant, background near the center of the array. This has been described by one observer as the "coffee bean" effect (Figure 3).

This elevated background is not seen with J, H, or JH blocking filters. Moreover, using a Ks filter (cutoff 2.37 μm) rather than the HK filter (cutoff ~ 2.53 μm) for blocking reduces the background level by approximately a factor of three. The background levels on 9 Jun 2006 (clear) and 2 Jul 2006 (heavy cloud) are approximately the same.

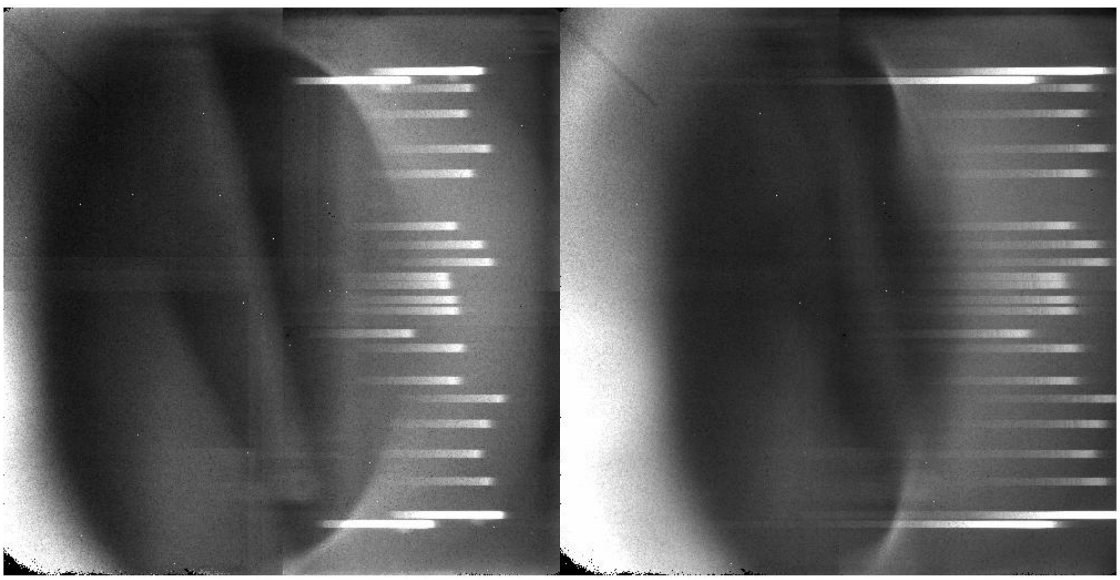

Figure 3. Full array images of the same MOS mask with the HK grism using a Ks filter (left) and HK filter (right) for blocking. Note the greater extent of the spectra using the HK filter. The background level with the HK filter is approximately three times that with the Ks filter.

5.1 Conclusions

The excess background seen in HK spectroscopy is almost certainly ambient temperature thermal radiation scattering into the camera dewar and being dispersed in some fashion by the grism. The dependence on blocking filter cutoff wavelength and the apparent independence on the emissivity within the telescope beam suggests a source within the MOS dewar or the BaF_2 field lens/camera window, which is at ambient temperature. Since relatively little HK spectroscopy has been done with FLAMINGOS, the archive does not appear to have data taken under wintertime conditions, where one would expect the background to be lower.

During the next setup, we can try measuring the background under different MOS dewar conditions (different deckers, mirror over the window), but if, as it seems likely, the background originates with or is scattered in by the BaF_2 field lens, there may be little that can be done. The level (50 ADU/s in the "dark" portion of the array) is sufficient to limit the spectroscopic performance, so we should try to come up with revised performance estimates for the manual.

6. Image Quality and Photometric Uniformity

The issue of the "lost flux" was addressed in a 28 July 2005 memo by Steve Eikenberry, Andrea Stolte, and Nick Raines. They carefully investigated the PSFs of stars at various locations in the FLAMINGOS field, concentrating on a location in the upper right quadrant where comparison with 2MASS photometry had indicated significantly fainter fluxes. Other observers had commented on this as well. They determined that stars in that region did not vary significantly from others in the field by "quick look" diagnostics such as Gaussian fitting using IRAF, with perhaps a 10% increase in FWHM. However, PSF fitting showed that stars in this region had very broad wings at radii greater than 4 pixels, resulting in an extended halo which would be typically missed with standard aperture photometric extraction.   As noted in the introduction, this was speculatively attributed to scattering by the clearly deteriorating AR coating on the BaF_2 camera field lens.   The AR coating was removed by Janos in November 2005 was to solve this problem, but feedback on the post-rework image quality has been limited.

During a rare clear period on 9 July 2006, the observer (Ken Rines) kindly obtained a focus sequence of M56 for us to evaluate image quality over the field. The seeing was sufficiently variable that it was difficult to achieve a good smooth focus curve. Nine stars over the field were used to evaluate the image quality. As expected, no single telescope setting gave the best focus over the field (Fig. 4), although good image quality (for the seeing) was achieved at a single focus with the exception of the lower left corner of the array. The often-reported "double" images seen in the upper left result from a combination of defocus and astigmatism; at best focus, the images were not too bad, but only within a narrow range of focus values.

This experiment should be repeated on a clear night with more stable seeing.

11000	10950	10950
10950	10950	11000
10900	10950	11000

Figure 4. Schematic representation of the best focus position for stars in various parts of the array. Focus step interval was 50 units.

Using the M56 data at the focus position (10950) which gave the best general images over the array, the aperture photometry task in IRAF was used to generate encircled energy plots (Figure 5) for eight stars at various locations on the array, three of which were in the upper right quadrant.   Since the image used for sky subtraction contained some stars, there are some small artifacts in a couple of the curves due to faint "negative" stars.

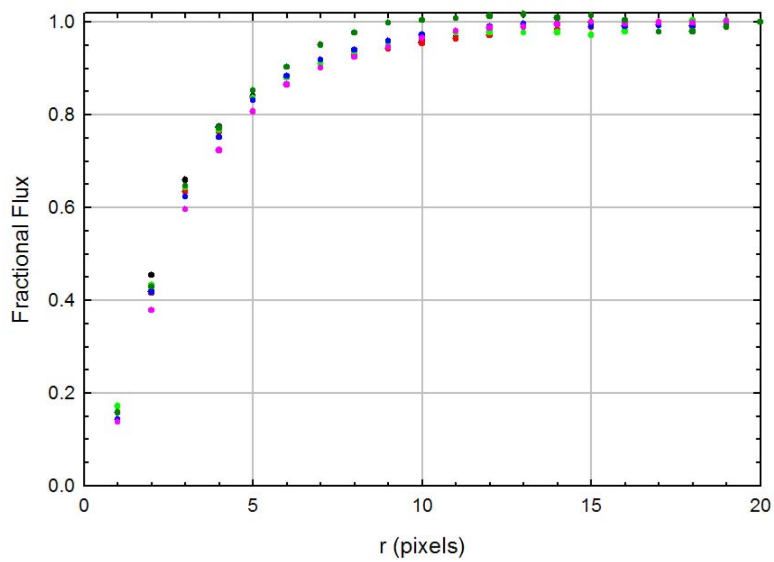

Figure 5. Encircled energy plots for eight stars in M56 at various locations on the FLAMINGOS array.

Although it is not certain that any of the three stars in the upper right quadrant were in the previously noted "troublesome" area, none of the stars in Fig. 5 show the extended halos which were noted in the Eikenberry et al. memo. This provides an encouraging suggestion that the "lost flux" problem may have been a result of the poor quality of the AR coating on the BaF_2 lens and that the removal of this coating has fixed the problem.

If the setup night is clear, we should repeat the observations using both a globular cluster and (if photometric) a standard star observed at a number of positions on the array, including locations which had previously been identified as having photometric uncertainty.