FLAMINGOS Performance – II

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1. Introduction

This report summarizes the continuing effort to understand the performance of FLAMINGOS for both imaging and spectroscopic applications. This report focuses on the performance when used for spectroscopy.

2. Spectroscopic Thermal Background

As noted in the previous report (17 August 2006), 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 large, background near the center of the array. This has been described by one observer as the "coffee bean" effect (Figure 1).

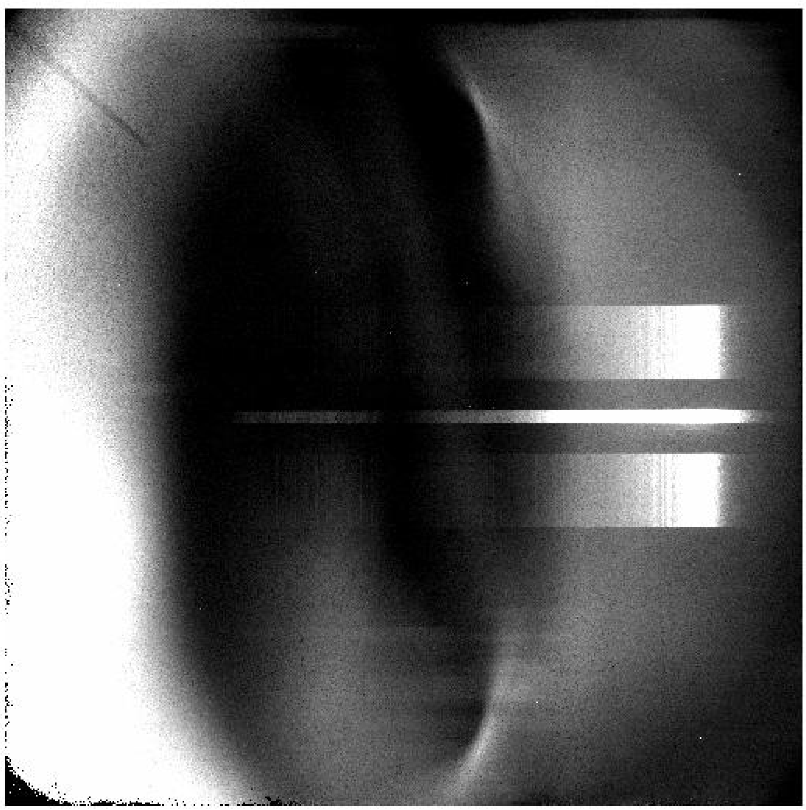

Figure 1. Raw frame of spectrum using the HK grism and HK filter through the NOAO custom 3 pixel slit; exposure time 300 s, 8 LNR.

This elevated background is not seen with J, H, or JH blocking filters with the HK grism. Interestingly, observations with the JH grism using the H and JH blocking filters indicate a low-level overall background with the latter filter, suggesting that there may be a small thermal leak in that filter. Table 1 shows the measured background above the dark current for a region [1200:1225, 605:630] near the center of the array for various grism/filter combinations.

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

Grism	**Filter**	**Background (ADU/s)**
JH	H	0.18
JH	JH	0.95
HK	H	0.17
HK	Ks	12.7
HK	K	19.6
HK	HK	47.3

This excess background 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.

The background levels are significant. The highest values, on the left side of Figure 1, are near 200000 ADU (300s, 8 LNR), which is equivalent to 83 ADU (340 e)/s. Fortunately, this is outside the region covered by the longslit HK spectrum, but even in the lowest background regions near the center of the array, the typical levels are ~ 80000 ADU (130 e/s), and on the right side, at the long end of the K band, the levels rise again to ~ 200000 ADU. The shot noise per pixel associated with a background of 80000 ADU with 8 LNR is ~ 200 e. By contrast, the detector read noise determined from dark frames taken under the same condition (300 s, 8 LNR) is on the order of 12 e, except in the well-known noisier upper right quadrant, where it is approximately 27 e (Figure 2).

While one expects some background within the spectral aperture from OH lines and thermal continuum in the K band, the level of this background is clearly less than that of the internal instrument, except at the very long wavelength end of the K band (Fig. 1). One is, in fact, barely able to identify in Fig. 1 the strong OH lines in the H band. The upper limit on the performance degradation is about 3 magnitudes; accounting for the likely background within the spectroscopic windows would decrease this to 1 – 2 magnitudes, depending on wavelength. Estimated sensitivity will be revisited in section 4.

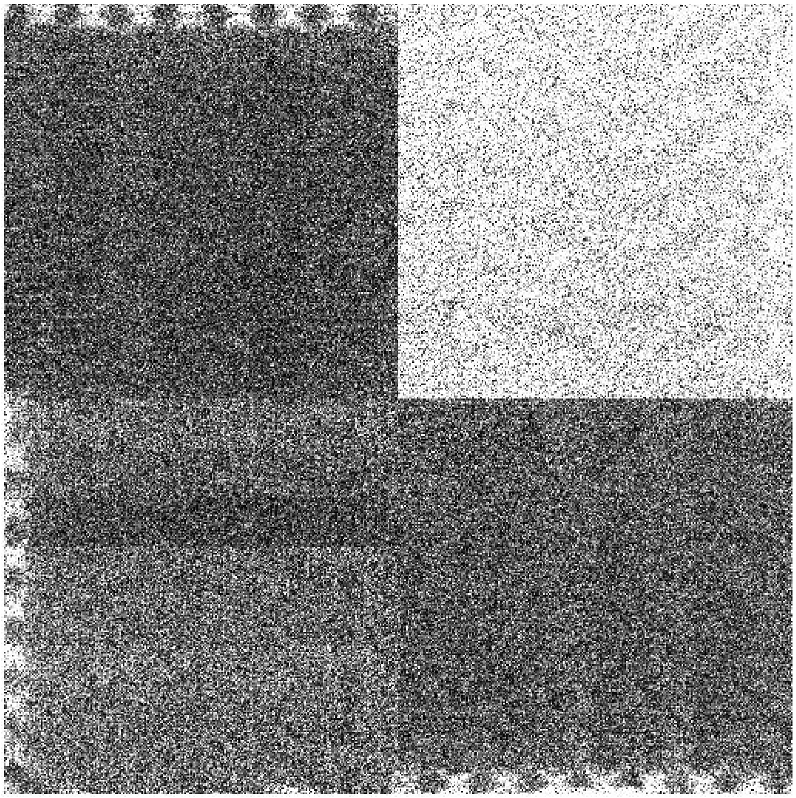

Figure 2. Sigma image from a sequence of four 300s dark frames with 8 LNR and spectroscopic bias (0.75 v). The typical levels in ADU within the four quadrants are: 23 (LL), 21 (LR), 53 (UR), and 20 (UL). The bias level for the dark (away from the edge structure) was approximately 690 ADU.

3. Signal Levels

On 28 September 2006, spectra of the standard star HD 203856 (J = 6.896; H = 6.873; K = 6.840) were obtained through the KPNO custom 3-pixel slit using several combinations of grisms and filters (JH grism with JH and H filters; HK grism with H, Ks, K, and HK filters). The purpose was to look for significant throughput anomalies and to measure the scaling of the scattered background with the blocking filter cutoff. The spectra were obtained with both the 3-pixel slit and the 10 arcsec box to check that the slit throughput was reasonable for the seeing (~ 0.9 arcsec FWHM) and to obtain signal levels in the absence of the slit. To verify that the background scales with integration time, exposures of 20 and 30 sec were used (0.75v bias; 8 LNR), and dark frames were taken under the same conditions.

The JH and HK spectra of HD 203856 are shown in Figure 3. These spectra were taken through the 10 arcsec box and have not been flatfielded, to illustrate the raw signal levels properly without making assumptions on slit throughput. The background levels for a region near the center of the array were listed in Table 1 above; the 20 and 30 sec data gave nearly identical background fluxes.

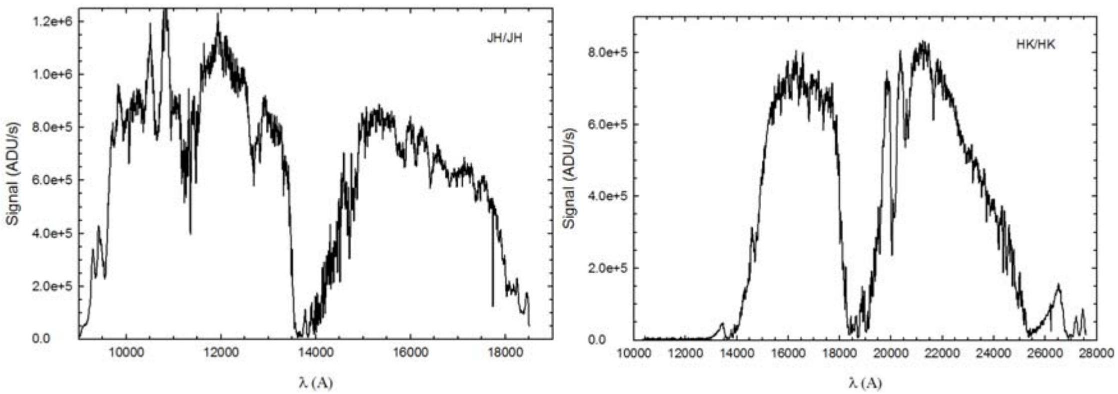

Figure 3. Left panel: Raw spectrum of HD 203856 through a 10 arcsec box with the JH grism and JH blocking filter. The wavelength was calibrated with a HeNeAr spectrum and the entire coverage of the detector array is plotted. The spectrum has been scaled to ADU/s, 1 LNR, for a 0.0 mag star. Right panel: Same as the left panel, except with the HK grism and HK blocking filter. The spectrum redward of 25000 Å is the H band in second order.

Spectra with the HK grism and other blocking filters yielded significantly more signal than those with the HK blocking filter (roughly 40% more for the H filter, 55% more for the Ks or K filter). The photometric imaging filters are known to be of very high quality and throughput, so this suggests that the wider HK filter may not perform as well in this regard. Observers with scientific interest only in K band spectroscopy would thus do well to utilize the K filter for blocking, since this yields an advantage in both increased signal and reduced background.

4. Noise

Sensitivity (S/N) estimation is nontrivial for infrared spectroscopy because both the signal and background are functions of wavelength. Even in the absence of extraneous background, in the nonthermal infrared, the OH emission lines will produce "noise" lines in perfectly sky-subtracted data. In the thermal infrared, the situation is more insidious because telluric absorption lines, which reduce the signal, are associated with sky emission lines, which increase the background noise.

Extrapolating the performance from relatively short exposures on a bright standard to longer exposures on faint objects carries additional uncertainties. We have done this for the JH/JH and HK/HK spectra (which are the most likely to be used by observers) using the HD 203856 data and backgrounds in the [1200:1225, 605:630] subregion as well as the peak OH line background for the JH/JH configuration, assuming:

- Peak signal for the JH/JH and HK/HK bandpass was used
- 3 pixel slit throughput = 0.50
- Extraction aperture = 6 pixels
- Subtraction of temporally adjacent spectra for sky subtraction

Table 2. Magnitudes for S/N = 10 Spectra in 1 Hour

Configuration	Magnitude
JH/JH, low background	15.5
JH/JH, peak OH background	14.5
HK/HK, mid array background	13.2

As a sanity check, HK/HK spectra of V709 Cyg and the standard HIP 1383 obtained on 7 September 2006 yielded an equivalent S/N = 10 for H=13.5 in 1 hour, close to that listed in Table 2. This estimate assumed equal slit throughputs for the two objects and used the signal-free region from 1.8 – 1.95 μm to measure the noise in the spectrum.

On 28 September 2006, the measured throughput of the KPNO custom 3-pixel slit (ratio of signal through the slit to that through the box) was typically 0.55 – 0.67. The assumption of 0.50 for Table 2 yields somewhat lower performance, but may be appropriate for 300 – 600 s integrations on faint targets.

These numbers are significantly less optimistic than those preliminary numbers which are still in the manual. The most likely reason for this is the extraneous background. Even the relatively modest 3.9 e/sec background seen in the JH/JH configuration decreases the performance by a magnitude over that estimated (16.9 for J; 16.6 for H) assuming read-noise limited operation.

5. Spectroscopic Focus

The first report in this series noted that the spectral lines in the JH/JH configuration appeared significantly broadened near the right-hand edge of the array, corresponding to the long end of the H band. This effect had not been particularly apparent in earlier runs, although inspection of archival data from 2005 showed some broadening of spectral lines in the lower right corner.

To eliminate effects due to position in the dispersion coordinate, as is the case with MOS slits, we used the UF 3-pixel slit, which is 1680 pixels long and centered in the X coordinate of the focal plane. The image of this slit (Fig. 4; left) shows the slit to be in good focus near the center, but somewhat defocused at the top and bottom; the mask containing this slit had been shimmed axially approximately 2 mm in the wheel to compensate for the shift noted in Report I.

The image of the OH sky lines in the JH/JH configuration is also shown in Fig. 4. Near the center of the array, the lines are sharp, with FWHM typically 2.5 – 3.0 pixels for unblended lines. At the long end of the H band, however, the FWHM increases to approximately 8 pixels; this is evident on the full detector frame and even more so in the subregions shown in Fig. 4.

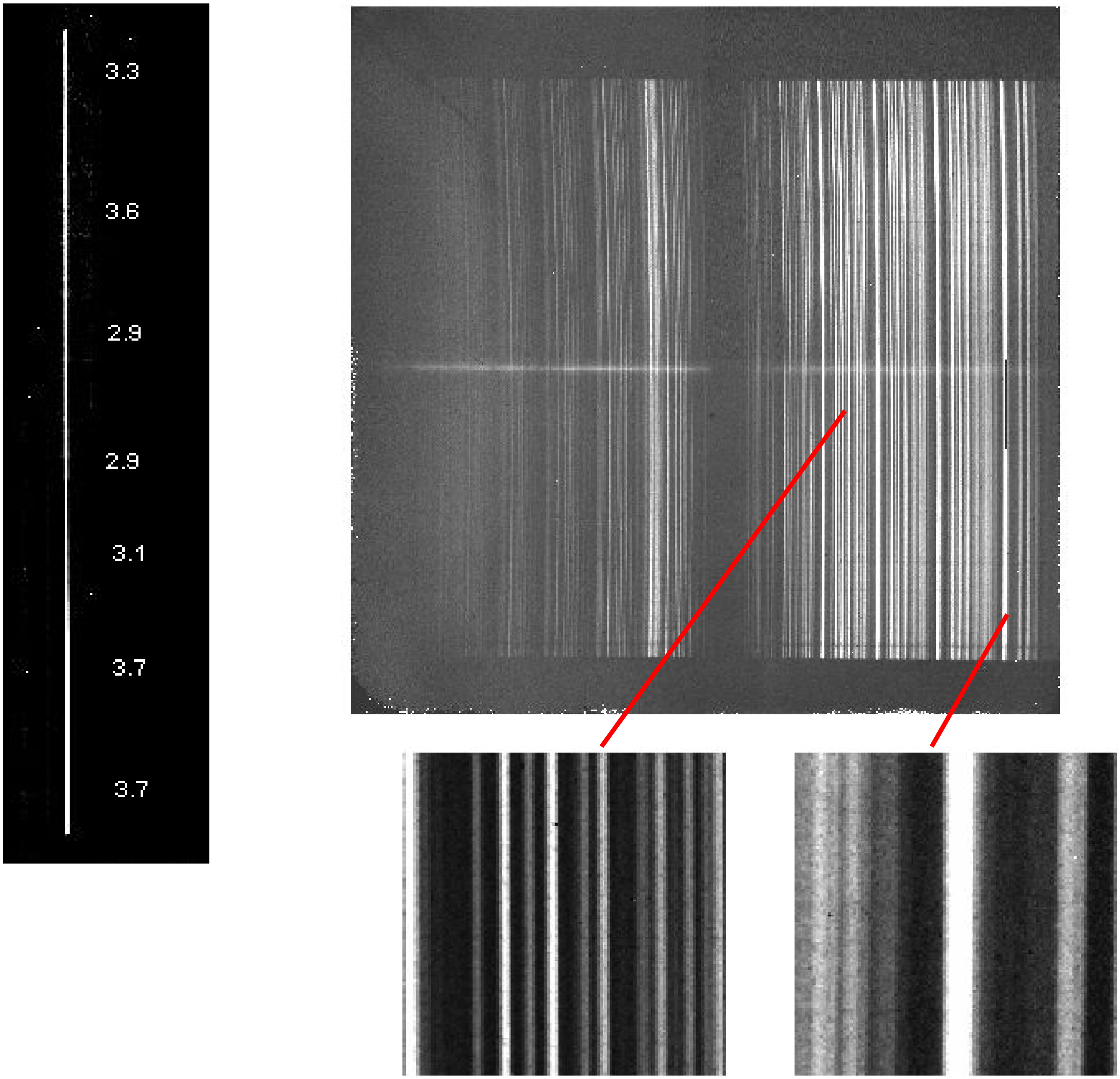

Figure 4. Left: Image of UF 3-pixel slit, with Gaussian FWHM fits to image at various locations along the slit. Upper right: Image of sky background (240 s; JH/JH configuration) showing the OH sky lines; the continuum is from a star just off the slit. Lower: Magnified portions of 128 × 128 regions near the center (left) and lower right (right) of the array, showing the broadening of the OH lines.

The spectroscopic defocus is particularly surprising, since the variation in image quality across the array in imaging mode is far less extreme. The fact that this effect was much less noticeable in archival data suggests a possibly disturbing coincidence with the apparent axial shift of the camera dewar focal plane seen between February and June

2006. If this were a result of a shift of one of the optical elements or the detector within the camera dewar, a significant effort would be required to investigate and/or attempt correction. At the very least, an effort of this scale could not be considered prior to the summer hiatus in 2007.