FLAMINGOS imaging report - March 14, 2007

L. M. Macri

National Optical Astronomy Observatory

lmacri@noao.edu

ABSTRACT

I characterize the imaging quality of the FLAMINGOS instrument at the KPNO 4-m telescope based on a set of JHK_s observations taken during a T&E run under good seeing conditions ($0.6''$). I performed a standard set of data reduction tasks followed by PSF photometry that was matched to the 2MASS Point Source Catalog.

The FLAMINGOS PSF exhibits little variation over 80% of the field of view of the instrument. The zeropoint can be regarded as constant in this area, with variations below 0.05 mag. Image quality degrades noticeably at the left-most 20% of the array, with a consequent variation in the photometric zeropoint if a constant PSF is adopted.

1. Observations

During a T&E run on 2006 October 10 at the KPNO 4-m telescope, I used the FLAMINGOS instrument to image a field located at (α, δ)=19:18:12.6, +19:13:20.0 (J2000.0). This field was previously observed with a pre-refurbished FLAMINGOS by Huard et al, and will hereafter be referred to as the "L0723" field. The quality of the seeing was very good ($0.6''$). Conditions were non-photometric but fairly stable (see §3).

I obtained a set of JHK_s observations of the field. Each frame had a single co-add with an exposure time of $5s$. I followed the standard FLAMINGOS 4×4 dither pattern (`pat_4x4`) with a $15''$ step size. The pattern was repeated a total of 3 times, yielding 48 images in each filter. The complete sequence of observations was carried out in 70 minutes.

Prior to evening twilight, I obtained a standard set of dome flats (lights on, lights off, dark frames) in the JHK_s bands. Additionally, I obtained sets of dark frames matching the exposure times of the L0723 field observations.

2. Data reduction

The images were reduced following these steps:

- Subtraction of a dark frame, prior to correction for non-linearity of the array, as prescribed by the UF Flamingos team. The non-linearity correction coefficients were subsequently posted in the KPNO FLAMINGOS web page with permission of the UF team.
- Division by a flat field frame. The flat field frames were created by median-combining the set of flat field observations obtained during the afternoon.
- Masking of bad pixels, as determined from the dark frame and by visual inspection of the edges of the array. Approximately 20 pixels on all sides were masked out.
- Sky subtraction. The L0723 field is sparse enough to serve as its own sky field, provided the stars are properly masked out. This procedure was carried out in two steps.
  - A first-pass sky subtraction was carried out using the `xdimsum.xslm` task, which created a "running mean" sky frame by median combining a set of 11 frames closest in time to each target image. Each frame was suitably scaled according to its mean sky value. The two highest pixels were rejected before medianing to provide some measure of object masking.
  - Each sky-subtracted image was analyzed using the DAOPHOT 4.0 stand-alone package. Briefly, this consisted of: detection of all 5σ point-like sources; aperture photometry; automated selection of bright isolated stars to determine the PSF; PSF photometry. See §3 for a more detailed explanation of the DAOPHOT photometry.
  - The PSF photometry results of all frames were matched to derive accurate frame-to-frame offsets. As a by-product, the program outputs the changes in zeropoint from frame to frame; these were fairly small over each set of observations, with the cumulative difference below 0.2 mag.
  - The transformations were used to create a median image. DAOPHOT was run once again on this combined frame to detect any remaining 5σ point sources, which were added to the previous list.
  - A master object mask was created by blocking all pixels within a 10-pixel radius of every detected object. The mask was visually inspected to add a few other sources (mostly faint galaxies) and increase the blocking radius around the brightest stars in the field.

- The master object mask was propagated back to the coordinate frame of each individual image. The individual masks were used by `xslm` to compute more precise sky values for each frame and to create running median sky images free of any stars.

- Finally, the second-pass sky-subtracted images were median combined using the transformations derived during the previous DAOPHOT processing. These median images were used in the subsequent photometric reduction.

3. Photometry

Photometry on the median images was carried out using the DAOPHOT 4.0 stand-alone package, as follows:

- The FIND procedure detected all point-like sources above a certain threshold, which was set to 10, 25 and 35 ADU for JHK_s, respectively. Approximately 7,000 sources were detected in each image.

- The PHOT procedure performed aperture photometry at a variety of radii, ranging from 3 to 10 pixels. A local sky annulus was defined from 10 to 15 pixels.

- The resulting photometry file was cleaned to select stars with valid, monotonically increasing, photometry as a function of radius. The resulting file was used to select 100 stars that might be suitable for determination of the PSF.

- The PSF candidates were visually inspected, and any stars located in crowded regions or with close bright neighbors were rejected. Approximately 40 stars passed the inspection.

- A PSF was determined using these bright, isolated stars. DAOPHOT was allowed to choose the best-fitting functional form for the PSF among three options: Gaussian, Moffat with index 1.5, or Moffat with index 2.5. DAOPHOT was not allowed to fit for positional variations in the PSF (ie, the PSF was held constant across the field of view). The Moffat profiles were a slightly better fit to the data, with index 2.5 for J and H and index 1.5 for K_s. The Moffat scale lengths were 1.5, 1.5 and 1.2 pixels for JHK_s, respectively.

- PSF photometry for all detected objects was performed using the derived PSF. The star-subtracted images were searched for additional objects using the same thresholds.

Approximately 500 additional stars were detected. These were added to the input list and PSF photometry was performed once again.

- The final photometry files contained 6×10^3, 9×10^3 and 8×10^3 objects in JHK, respectively.

The 2 Micron All-Sky Survey Point Source Catalog (2MASS PSC) was queried for sources in a $15'$ region centered on the L0723 field. The 2MASS catalog contains approximately 2,500 sources in this area, with limiting magnitudes of $J = 17, H = 16, K_s = 15.5$ mag. The FLAMINGOS photometry was matched to the PSC catalog, resulting in 1,500 objects in common. As a by-product of the matching process, I derived a plate scale of $0.3163''$/pix for FLAMINGOS.

I plotted the difference between 2MASS standard magnitude and FLAMINGOS instrumental magnitude (ie, $-2.5\log_{10}(ADU/s)$) versus 2MASS standard magnitude for stars spanning the the brightest three magnitudes of range in common between the two data sets (roughly $9 < mag < 12$). The resulting plots exhibited a clearly-defined zeropoint offset, but the scatter about the mean was somewhat assymetric. Eventually, I plotted the delta-magnitude as a function of distance from the center of the field and found a that it followed a quadratic dependence, with a typical amplitude of 0.03 mag for radial distances between 0 and 1000 pixels. These curves are plotted in Figures 1 and their functional form is:

$$ZPT = ZPT_0 + \Delta ZPT_1 \times r + \Delta ZPT_2 \times r^2 \quad (1)$$

where ZPT_0 is the value of the zeropoint at a position (x_c, y_c) near the center of the field and the radial distance r is calculated as:

$$r = \sqrt{(x - x_c)^2 + (y - y_c)^2} \quad (2)$$

For this particular field, the best-fit values of x_c and y_c were 1250 pix and 1150 pix, respectively. The values of the radius-dependent coefficients in Equation (1) had typical values of $\Delta ZPT_1 = 2.5 \times 10^{-3}$ mag/pix and $\Delta ZPT_2 = -2.0 \times 10^{-6}$ mag/pix^2.

In all three cases, a tail of outliers can be seen at radii greater than 1000 pixels (plotted as filled symbols). The location of these outliers are plotted in Figure 2 (same arrangement as Figure 1). Additionally, I plotted contours of zeropoint values, using a solid line to indicate the radius where the zeropoint has its highest value, dotted lines to denote each decrement in steps of 0.025 mag up to 0.05 mag, and dashed ines to represent each additional decrement in steps of 0.05 mag up to 0.2 mag. The outliers (once again plotted using filled symbols) are mostly located on the left and bottom edges of the array.

Once this quadratic dependence is taken into account, and limiting the analysis to stars within 1000 pixels in radius of the field center and within 3 magnitudes of the brighest star in the matched catalog, the r.m.s. scatter in the zeropoint is ~ 0.05 mag, with errors in the mean below 0.01 mag. Figure 3 shows the magnitude-scatter relations for the L0723 field stars.

4. Conclusions

Most FLAMINGOS users will be glad to know that the PSF delivered by the instrument at the KPNO 4-m can be considered to be constant within ± 0.05 mag over 80% of the surface of the array. Those with more precise photometry needs will need to take this variation into account in their data reduction.

The left and bottom edges of the array ($X < 300$ pix; $Y < 200$ pix) exhibit significant variation in the PSF. When planning an imaging survey with FLAMINGOS at the 4-m, users may consider overlapping their fields so that this area of the array is not needed in their final mosaic. Alternatively, the use of a position-dependent PSF or aperture correction should be considered.

I would like to thank Dick Joyce and Anthony Gonzalez for a careful review of this report and for their comments.

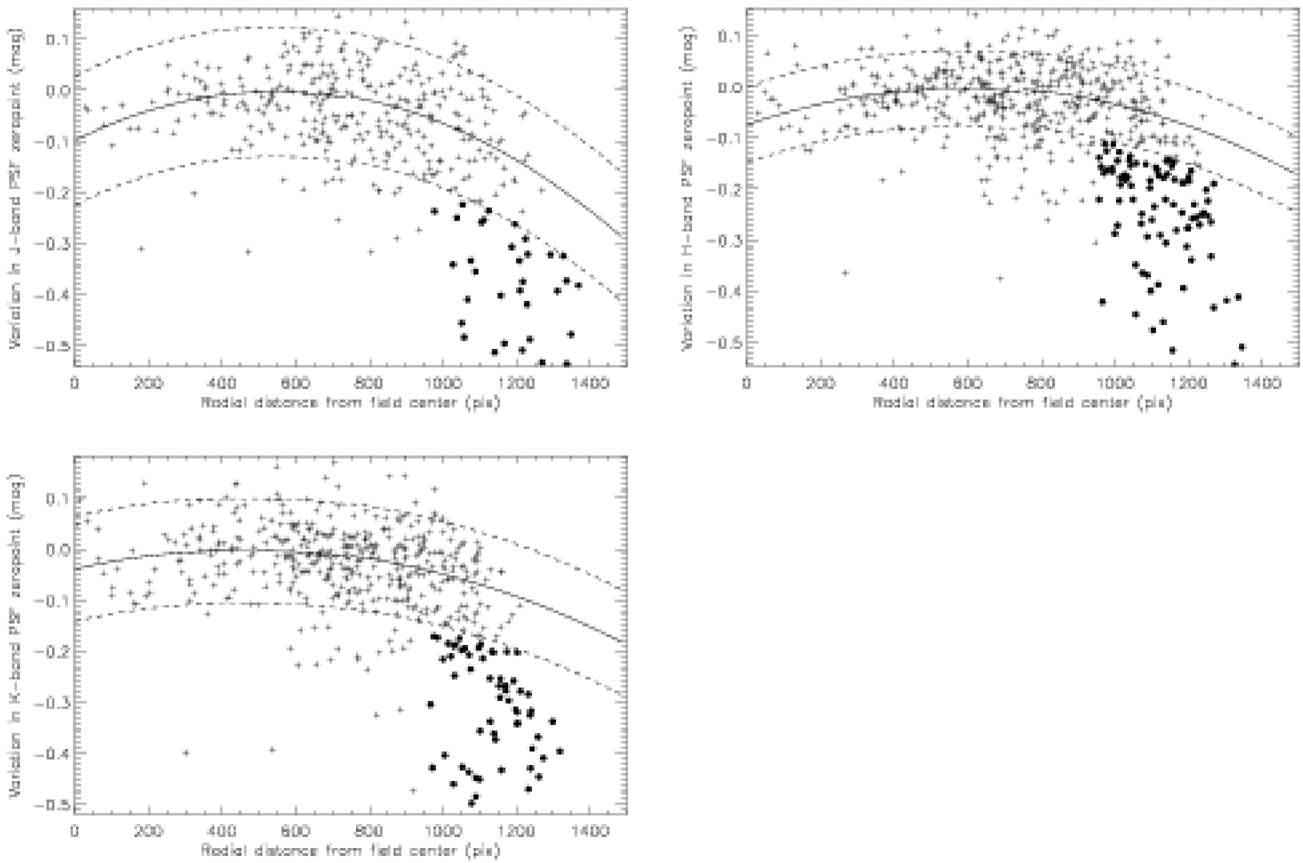

Fig. 1.— Variation of the JHK_s zeropoints (top left, top right, bottom) as a function of radial distance from the center of the field. Outliers at large distances from the center of the field ($r > 1000$ pix) are plotted using filled symbols.

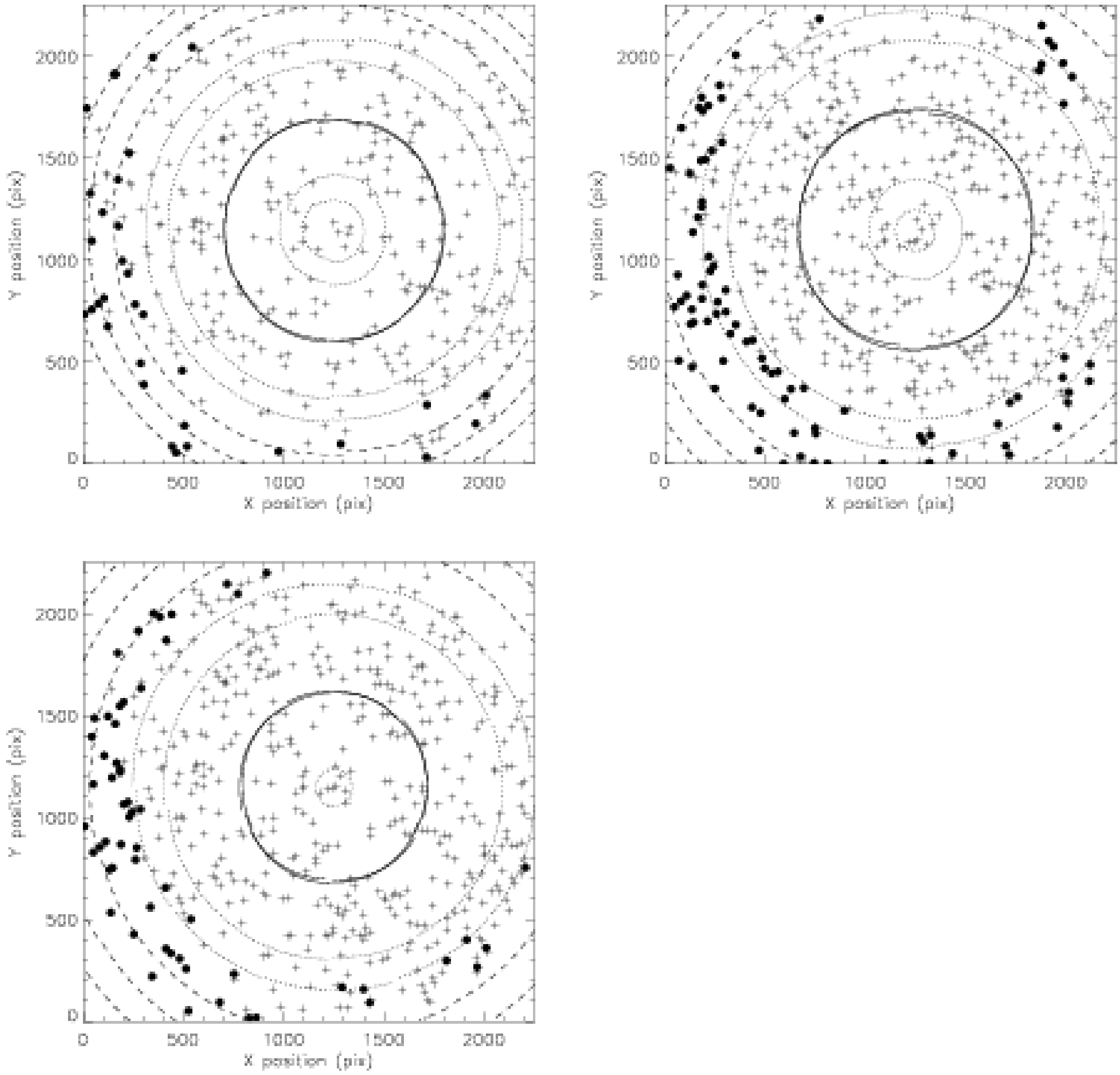

Fig. 2.— Variation of the J-, H- and K-band zeropoints (top left, top right, bottom) as a function of position within the field. The contours indicate areas of equal zeropoint value. The solid line indicates the radius where the zeropoint has its highest value. Dotted lines denote each decrement in zeropoint in steps of 0.025 mag up to 0.05 mag. Dashed ines represent each additional decrement in steps of 0.05 mag up to 0.2 mag. The outliers from Figure 1 are once again plotted using filled symbols and are mostly located on the left and bottom edges of the array.

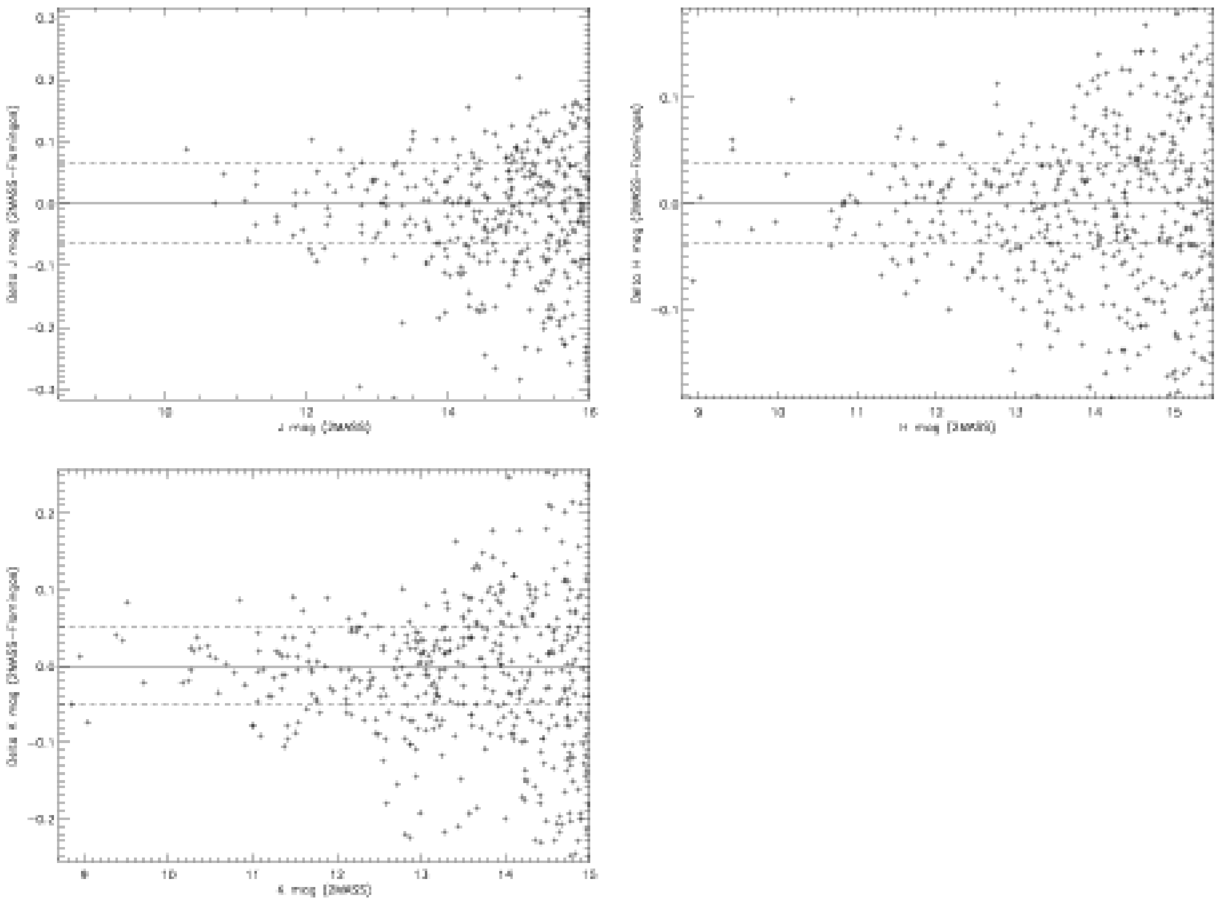

Fig. 3.— Relative zeropoint versus magnitude at JHK_s, after taking into account the quadratic dependence of the zeropoint as a function of position. The stars used in these plots were located within 1000 pixels in radius of the field center.