PISCES Infrared Imager Performance with the Large Binocular Telescope Adaptive Optics System.

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1. SUMMARY

The instrument PISCES has shown that it can deliver images with high Strehl ratio. The performance is typical for a good quality HgCdTe detector, and the instrument has the potential for delivering exciting science with AO imaging. The technical characterization of the instrument for use with LBTO is currently preliminary due to several issues: because of intense schedule pressure, laboratory testing was limited. Observing conditions in June were unusual because of high temperatures and forest fires creating smoky conditions.

The detector characteristics determined from the data available are:

- Gain: 4.55±0.04 c'/ADU.
- Read noise at the telescope: 5.13±0.04 ADU.
- Dark current on the telescope: 0.03 ADU/sec/pix
- Linearity: 3% non-linearity at 80% full well.
- Cross talk correction: This “corquad” procedure is required for the correction of “misplaced flux” and bright image tails. The corquad coefficients show good stability from night to night. “corquad” produces an increase of the mean counts of the background in uniformly illuminated images. It leaves minor artifacts in the presence of saturated images.

At system level, the minimum exposure time is 0.8 second, with a total fixed overhead time for read-out, labeling, and storage of ~6 seconds.

2. INTRODUCTION

To provide early science with the LBT AO system before the arrival of the facility camera, we have the opportunity to utilize the PISCES infrared camera provided by the University of Arizona. PISCES is a PI instrument designed and built by Don McCarthy of Steward Observatory, students, and collaborators. PISCES utilizes a HAWAII-1 1k x 1k HgCdTe detector, with 1 – 2.5 µm sensitivity. The optical design uses six lenses with spherical surfaces which all are cooled to 77 K by liquid nitrogen. The design also incorporates accurate pupil reimaging and cold baffling to block thermally emissive telescope structures. A single 10-position filter wheel provides a selection of broad and intermediate-band filters. Interested users can find additional details in the description of the instrument provided by McCarthy et al. (McCarthy, 2001)

At the LBT, the f/15 Gregorian beam is reimaged in the instrument to a focal ratio of f/22 providing a field of view of about 21 arcsec in diameter at a pixel scale of 0.019 arcsec/pixel. When used at the LBT, PISCES slightly under-samples the diffraction-limited stellar core in J, critically samples it in H, and over-samples it in K.

2.1 General characteristics.

The general characteristics of the PISCES array are summarized in Table 1.

Table 1. General specification of the PISCES array.
<table>
<thead>
<tr>
<th>Detector</th>
<th>Hawaii-1 (HgCdTe) array 1024x1024.</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE</td>
<td>60% in J band.*</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1-2.5um.</td>
</tr>
<tr>
<td>Input f/ratio</td>
<td>f/15, reimagining f/22.</td>
</tr>
<tr>
<td>Pixel size.</td>
<td>18.5um/pixel.</td>
</tr>
<tr>
<td>FOV.</td>
<td>21x21 arcsec.</td>
</tr>
<tr>
<td>Plate scale.</td>
<td>19 mas/pixel.</td>
</tr>
<tr>
<td>Gain</td>
<td>4.55 e^-/ADU.</td>
</tr>
<tr>
<td>Read noise.</td>
<td>5.13 ADU **</td>
</tr>
<tr>
<td>Dark current.</td>
<td>~0.03 ADU/sec.</td>
</tr>
</tbody>
</table>

*The QE of the detector comes from the specification of the detector*.  
** Read noise from the telescope measurements.

Figure 1. Comparison of two images of BD+303639 from Hubble Space Telescope (left) and LBT+AO system (right). The false color LBTO image of BD +303639 is composed of a stack of 10 exposures with 60 seconds exposure time in H2 and J band.

1 http://www.astro.umass.edu/~rfinn/pisces.html
Figure 2. The figure shows a “quick and dirty” reduction image of HD511525 observed in the FeII band. This is a stack of 30 exposures of 2 seconds each. The separation of the two stars is 80mas. There is not a literature record that this star is a double star.

2.2 Filters

The instrument is equipped with broad-band and narrow-band filters. Table 2 shows the filters available and their central wavelengths. Figures 3 and 4 show selected filter transmission versus wavelength.

<table>
<thead>
<tr>
<th>Number #</th>
<th>Filter</th>
<th>Central wavelength (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.14</td>
<td>2.14</td>
</tr>
<tr>
<td>1</td>
<td>H2</td>
<td>2.12</td>
</tr>
<tr>
<td>2</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Blind/Dark</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>J</td>
<td>1.27</td>
</tr>
<tr>
<td>5</td>
<td>Ks</td>
<td>2.12</td>
</tr>
<tr>
<td>6</td>
<td>H</td>
<td>1.63</td>
</tr>
<tr>
<td>7</td>
<td>Br_gamma</td>
<td>2.169</td>
</tr>
<tr>
<td>8</td>
<td>FeII</td>
<td>1.64</td>
</tr>
<tr>
<td>9</td>
<td>2.086</td>
<td>2.086</td>
</tr>
</tbody>
</table>

Table 2. Filters available for LBTO observing.
Figure 3. The figure shows the plot of transmission versus wavelength for the H band filter. The x-axis shows the wavelength (nm) and the y-axis gives the percentage transmission.

Figure 4. The figure shows the plot of transmission versus wavelength for the Ks band filter. The x-axis shows the wavelength (nm) and the y-axis gives the percentage transmission.
3. DATA ACQUISITION

The measurements used in this analysis come from two sets: laboratory and telescope measurements. The instrument in the laboratory was set on a table with the entrance window pointing up. During the one limited opportunity for laboratory test, there was some uncertainty about the actual filter position and the entrance window was not fully shielded from ambient light when taking dark frames. Uniform illumination of the array was achieved with an informal diffuser by placing a piece of paper in front of the entrance window with the source lamp illuminating it. The data were stored locally and a post-processing corquad correction was applied.

The telescope data are a series of darks, sky flats and standard stars at different elevations.

On photometric nights, a set of images of standard fields were taken using the filters J, H and Ks. These images were stored with corquad corrections. Next we used IRAF’s imexamine to mark the positions of the standard stars. The standard position was fed into the simple fast aperture photometry task qphot. We used several different apertures depending upon the seeing during the test. The ADU fluxes were then corrected for the gain and exposure time to get a flux in ADU/second. These were then converted into magnitudes and compared to the actual standard star magnitude to compute the magnitude zero-point offset.

Apart of the instrument characteristics, the efficiency and overhead are also important to analyze, to characterize the operations of this new AO system. To perform this test a full scripting operation in automatic mode was set up to observe M92 in the J band with the following approach: 1) total exposure at one pointing: six frames of 10s each. 2) dither pattern: 9 positions on a square grid of 2 arcseconds on a side, each position separated by 1 arcsec.

4. DATA ANALYSIS

Two analyses of the measurements are used to find the detector characteristics. One is signal versus exposure time in which the spatial trends are taken into account and the other is variance versus signal where the spatial trends are ignored.

The images from an illuminated source at a series of integration times are used to produce the variance versus signal representation. The gain factor is derived from that series by computing the variance of the difference of image pairs all taken at the same exposure level (image2-image1, image3-image4 and image 4-1), then repeating for each different exposure level and finding the best-fit relationship between variance and total signal. The read noise in electrons can be calculated from the difference of two darks with minimum exposure time and corrected by the gain factor. A more extensive analysis was used employing darks of various exposure times, because two specific sets of darks at shorter exposure times showed unexpected values and had to be excluded. This effect can be seen in Figure 5.

The zero point and the sky brightness were calculated from standard stars with positions and FWHM measured using IRAF imexamine. The list of positions was fed into the simple fast aperture photometry task qphot. Different apertures are selected depending upon the seeing during the test.

5. RESULTS

A series of test images in the laboratory and in the telescope were used to measure the gain factor, read noise, the dark current and the detector non-linearity.

5.1 Gain factor.

A test has been carried out to determine the linearity and the gain of the system using a thermal source instead of a light source. The thermal source is an aluminum plate placed in front of PISCES entrance window. The instrument was set to use the K-band filter and we took a series of exposures of increasing exposure time. A control frame was taken to determine the stability of the source.

Figure 5 shows the control frame (1.9” exposure time) through the following set of exposures:
1,20,1,31,1,43,1,60,1,80,1,120,1,170,11,240,1,340.
Figure 5. Mean counts of the thermal source as a function of time through different sets of frames.

Figure 6. Measurements of a set of flat frames at different exposure times. The fitting parameters are: Intercept: 13.20 ± 5.47, a1:0.220 ± 0.002 and a2: -3.458e-07 ±9.254e-08.
5.2 Read Noise and Dark Current.

Dark frames with the cold blank inserted were taken at a series of integration times, and they were converted to variance versus signal. The analysis takes a subframe clean of hot pixels or any other defects and the second order fitting was performed on the variance to the median. The result is shown in Table 3. The results are shown in ADU.

The variance versus exposure time is shown in Figure 5, in which it is noticeable that the 1.9 and 2.9 seconds series show unexpectedly high values. Those two sets of exposure times (1.9 and 2.9 seconds) were removed and a new plot is shown in Figure 6. Table 3 shows the summary of the read noise values from the laboratory and for three samples of data at the telescope.

<table>
<thead>
<tr>
<th>date</th>
<th>Source</th>
<th>σ[ADU]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory (05/10)</td>
<td>Dark (blank)</td>
<td>2.85 ±0.39</td>
</tr>
<tr>
<td>Laboratory* (05/10)</td>
<td>Dark (blank)</td>
<td>2.72 ±0.39</td>
</tr>
<tr>
<td>LBT (06/13/2011)</td>
<td>Dark (blank)</td>
<td>5.18 ±0.24</td>
</tr>
<tr>
<td>LBT (06/15/2011)</td>
<td>Dark (blank)</td>
<td>5.27 ±0.18</td>
</tr>
<tr>
<td>LBT (06/22/2011)</td>
<td>Dark (blank)</td>
<td>5.76 ±0.41</td>
</tr>
<tr>
<td>LBT (09/07/2011)</td>
<td>Dark (blank)</td>
<td>5.16 ±0.38</td>
</tr>
<tr>
<td>LBT (09/13/2011)</td>
<td>Dark (blank)</td>
<td>5.13 ±0.04</td>
</tr>
</tbody>
</table>

* set of measurements removing the first two exposures times; 1.9 sec and 2.6 sec.

Table 3. Read noise calculated from the laboratory and telescope darks. There is no temperature information in the image header.

The read noise shows to be higher in the telescope than in the laboratory and that could be due to the change of the detector from the laboratory test to the telescope. The large value of the read noise on June 22nd can be due to warm up of the detector. Figure 8 shows the variance versus exposure time for three days data at the telescope.

The images of darks in a series of exposure times are fit to a linear regression as a function of time. The first order coefficient is shown in Table 4. A different array was measured in the laboratory test than the one that is in use on the telescope. June 22nd shows a higher value of the dark current that could be due to light or thermal leakage, but it is consistent with the result in September. Subsequent examination of the system in September showed that the optics slide had slipped, allowing some stray light into the dark frames. The optics slide is now secured.

Table 4. Summary of the dark current in the laboratory and on the telescope.

<table>
<thead>
<tr>
<th>date</th>
<th>Source</th>
<th>DC (ADU/s/pix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory (05/10/2011)</td>
<td>Dark (blank)</td>
<td>0.004 ±0.004</td>
</tr>
<tr>
<td>LBT (06/13/2011)</td>
<td>Dark (blank)</td>
<td>0.07 ± 0.02</td>
</tr>
<tr>
<td>LBT (06/15/2011)</td>
<td>Dark (blank)</td>
<td>0.03 ± 0.01</td>
</tr>
<tr>
<td>LBT (06/22/2011)</td>
<td>Dark (blank)</td>
<td>0.21 ± 0.01*</td>
</tr>
<tr>
<td>LBT (09/07/2011)</td>
<td>Dark (blank)</td>
<td>0.25 ± 0.03*</td>
</tr>
<tr>
<td>LBT (09/28/2011)</td>
<td>Dark (blank)</td>
<td>0.04 ± 0.01</td>
</tr>
</tbody>
</table>

*Probably subject to a transient light leak.
Results of the linear regression fitting of the variance vs exposure time for the darks series.

Figure 7. Laboratory dark measurements taken at a series of exposure times and fitting the measurements to the linear regression function. The linear regression fitting parameters are: intercept: $8.141 \pm 0.233$, $a_1 = 0.0032 \pm 0.00076$.

Figure 8. Laboratory dark measurements taken at a series of exposure times, removing those at 1.9 and 2.9 seconds, and fitting the values to a linear regression. The fitting parameters are: intercept: $7.432 \pm 0.089$, $a_1 = 0.0043 \pm 0.0002653$.

From the dark measurements shown in Figures 7, 8, and 9, we can see that there are points that are too high. Those high values correspond with the first image of every set. This effect can be seen clearly in a single plot for every set of exposures. Figure 10 shows the mean of a region (100x100 pixels) free of defects or bad pixels versus the number of image.
Figure 9. Figures of three days at the telescope showing the variance versus the exposure time and its fitting line. The fitting parameters for those data are: Dark of 22\textsuperscript{nd} intercept: 33.206 ±0.126 and value: 0.209 ±0.00702. Dark 15\textsuperscript{th}, intercept: 27.836 ±0.0970, value:0.0325 ±0.0779. Dark 13\textsuperscript{th}, intercept: 26.915 ±0.157, value:0.0695±0.02.

Figure 10. Sample of dark frames taken at different exposure times showing the variation of the mean value with respect to the sequence number of the image.
5.3 Linearity.

Linearity was established using a sequence of flat field exposures where the integration time was increased until the signal reached saturation level. The stability of the source lamp was checked by repeating a sequence of control frames during the set of exposures. The resulting linearity curves are presented in Figures 12 and 13. Note again that these data are representative.

Figure 12. The curve is valid only for those objects that can be observed with exposure times larger than a couple of seconds. The readout format must be reduced to a smaller region of interest for the controller to yield valid data on shorter exposures. Solid dots are experimental data, red line is the fit, the axes are the counts vs the exposure time. The dashed line is the departure from linearity (%) as shown on the right axis vs the counts axis.
Figure 13 Basic non-linearity plot with the fitting curve. The array is about 5% non-linear at about 30000 ADU.
Fitting parameters: intercept=1 ± 1.590e-03 ,a1: -2.325e-06 ± 5.443e-07 , a2=3.096e-10± 3.931e-11, a3= -9.562e-15± 7.135e-16

5.4 Crosstalk corrections. “Corquad”.

The array is corrected for crosstalk using a program called corquad developed by Roelof de Jong\(^2\) and it is used for post-processing. In general, corquad restores small deficits in signal in other quadrants produced through crosstalk by bright sources and corrects the “tails” of such bright images. The experiments described in the following were performed with some quickly derived coefficients, which merit rederivation prior to science observing. In order to investigate the corquad functionality we have done two experiments. The first one is based on three “fake” images (1024x1024) of uniform counts with 0, 2500 and 5000 counts, which were built in order to apply the corquad corrections and to see if there are any changes in the image statistics. The flat images after corquad correction are shown in Figure 10. The output results are shown in Table 5. The images named as zeromConst2500 and 5000 means not corquad corrected. And the images named as Qzero, Qcont2500 and 5000 are corrected by corquad.

<table>
<thead>
<tr>
<th>Image</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero.fits</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Qzero.fits</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Const2500.fits</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td>Qcont2500.fits</td>
<td>2674</td>
<td>2525</td>
<td>2674</td>
</tr>
<tr>
<td>Const5000.fits</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Qconst5000.fits</td>
<td>5348</td>
<td>5050</td>
<td>5348</td>
</tr>
</tbody>
</table>

Table 5 Summary of the mean of uniform images of 0, 2500 and 5000 counts after corquad corrections.

With this simple experiment we can see that the corquad correction applied some amount of count to the total image. During the June run, all images taken with the instrument were corrected for cross-talk using the last parameters given. In the limit of a completely uniform illumination with the coefficients used for the test, corquad does not preserve flux. Corquad will also produce spurious results in the case of strongly saturated images as seen in the images BD+30 3639

\(^2\) http://www.astro.umass.edu/~rfinn/pisces.html
shown in Figure 12. After applying the crosstalk correction and stacking the images (dark and flat-field corrected), we can still see some residuals of the corrections.

The second experiment was to build a dummy image with a uniform zero count except for a region of 10 x 10 pixels in one quadrant with uniform counts of 5000 and apply the corquad corrections. Figure 11 shows the artificial image and the image after corquad corrections. The corquad correction increases the box of 5000 counts to 5030, the other quadrants show a line of pixels where the first region of 10x10 pixels shows a median count level of 30.44.

The increase in the counts in the images as shown in the artificial images can affect the determination of the gain and read noise of the images, but will be consistent for a uniform application of corquad corrections.

The corquad corrections were checked and new values determined by Craig Kulesa after the detector and the electronics are setup and cooled down for the next sky run. Figure 14 shows that the coefficients are relatively stable over the long dormant period, and quite stable from night to night.

Figure 13. Stability of cross talk correction coefficients.
Figure 14. Fake image with uniform counts of 2500 corrected by cross talk gives a image with a mean value of 2674. After applying the corquad corrections the image shows two lines with 118 pixel width at line 513. The image on the right shows a line plot at line 513.

Figure 15. An artificial image with a region(10x10) of 5000 counts post-processed with corquad shows the resulting image with four rectangles in the four quadrants. After the corquad correction the original box (left bottom quadrant) shows a mean of 5030 counts in the first region. The other quadrants show a mean of 30.44 counts for the first box of 10x10 pixels. The right figure shows a line plot at line 768, showing the tail projection.
5.5 Persistence

The frames taken are of 60 seconds exposure of BD+303639 observed with the H2 filter. The persistence can be seeing clearly after the first image (saturated image) and displaying the difference of two dithered images shows clearly the features of the residual image. This set of images contains a bright-extended source with a central saturated star that produces saturated images. The brightest persistence in the image is about 4.5 ADU s$^{-1}$. Figure 17 shows the plot of the mean flux versus the time after the saturation. The images are in raw format.

A way to find the persistence is to construct the difference images of exposures taken at different dither positions. Subtracting any two images that have dithered will reveal the persistence since the signature of the field you were observing will be largely removed by this procedure, but due to the offset, the persistence will not. In this case, a simple way to check for persistence is to simply step through images displayed in image coordinates and look for features that gradually fade as you step through the images beginning of course with the image that contained a bright star. An example of this is shown in Figure 18.
Figure 17. Plot of the mean counts per second after the saturation. The first image after the saturation is taken after 81.23 seconds. The exposure time per each frame is 60 seconds and the filter is H2.

Figure 2. Cropped set of images centered at [883,887]. A sequence of images obtained with Pisces when a bright star was observed and the following exposures involved large dither steps from the initial position. The exposure time in every image is 60 seconds and the time between two consecutive images is 81.23”. The timing sequence is; 0, 81.23s, 162.40s, 243.69s, 324.92s, 406.25s and 487.5”. 
5.6 Distortion and Drizzle Correction

A sieve mask was used in the lab to derive the distortion correction for the PISCES camera. The absolute scale was set from the focal length determined for the rigid secondary on the SX side of the telescope, giving 19.4 mas/pixel.

Drizzle coefficients for PISCES distortion and plate scale determination for Drizzled and un-drizzled PISCES images from sieve mask data.

Fitted Drizzle coefficients: \(\{x', y'\}\) are corrected centroid values in pixels, \(\{x_{\text{obs}}, y_{\text{obs}}\}\) are raw data centroid values, in pixels. \(\{x_0, y_0\}\) translate the distortion equation to an appropriate centre for the distortion equation.

\[
x_0 \rightarrow 539.6249900217251, y_0 \rightarrow 488.97496229439
\]

For the Drizzle corrections, \(\{x, y\} = \{x_{\text{obs}}, y_{\text{obs}}\} - \{x_0, y_0\}\),

\[
x' = a_0 + a_1(x - x_0) + a_3(x - x_0)^2 + a_6(x - x_0)^3 + a_2(y - y_0) + a_4(x - x_0)(y - y_0) + a_7(x - x_0)^2(y - y_0) + a_5(y - y_0)^2 + a_8(x - x_0)(y - y_0)^2 + a_9(y - y_0)^3
\]

coefficients as listed below:

\[
\begin{align*}
a_0 & \rightarrow -0.0193323353124672233, \\
a_1 & \rightarrow 0.009158903838893026, \\
a_2 & \rightarrow 3.084902192987938 \times 10^{-7}, \\
a_3 & \rightarrow 0.00001741082797755776, \\
a_4 & \rightarrow 5.4674032866672172 \times 10^{-7}, \\
a_5 & \rightarrow 6.43208697913131 \times 10^{-8}, \\
a_6 & \rightarrow 1.989653039662441 \times 10^{-8}, \\
a_7 & \rightarrow 6.872822072745672 \times 10^{-9}, \\
a_8 & \rightarrow -8.88564018354647 \times 10^{-10}
\end{align*}
\]

\[
y' = b_0 + b_1(x - x_0) + b_3(x - x_0)^2 + b_6(x - x_0)^3 + b_2(y - y_0) + b_4(x - x_0)(y - y_0) + b_7(x - x_0)^2(y - y_0) + b_5(y - y_0)^2 + b_8(x - x_0)(y - y_0)^2 + b_9(y - y_0)^3
\]

coefficients listed below:

\[
\begin{align*}
b_0 & \rightarrow -0.2916136361964138, \\
b_1 & \rightarrow 0.0005644850785422236, \\
b_2 & \rightarrow 0.0070300561525915685, \\
b_3 & \rightarrow -6.975755523347609 \times 10^{-7}, \\
b_4 & \rightarrow -2.693317726213162 \times 10^{-7}, \\
b_5 & \rightarrow 0.000002274566940183336, \\
b_6 & \rightarrow 4.800921931458503 \times 10^{-10}, \\
b_7 & \rightarrow 7.220681707969827 \times 10^{-8}, \\
b_8 & \rightarrow 1.227584769397778 \times 10^{-9}, \\
b_9 & \rightarrow 6.415049753472765 \times 10^{-8}
\end{align*}
\]

Residuals from this correction are small, mostly less than 1 pixel, as indicated by the scatter plot below:
Plate Scale Determination.

In all cases the plate scale determination used here assumes the LBT plate scale is $1.6712 \pm 0.0005$ arc seconds/mm, as measured on the SX telescope.

There are two plate scales to consider. One from the centre of the field of the un-Drizzled images, and the other for the Drizzle corrected images.

For the uncorrected images, using several adjacent pairs of 550 micron spaced holes, that were laser drilled to ~ 10 micron positional accuracy, and sampled from the centre of the field where distortion is low, I obtained the following pixel plate scale:

$$0.01964 \pm 0.0007 \text{ arc seconds per pixel.}$$

For the Drizzled images, where the distortion is essentially the same anywhere in the field. Testing all 380 pairs of (horizontally) adjacent spots the separation mean was 47.4 pixels with a one sigma error of 0.7 pixels. This leads to a plate scale determination for the Drizzle corrected images of:

$$0.0194 \pm 0.0003 \text{ arc seconds per pixel.}$$

(Note that the value differs outside of uncertainties from the un-Drizzled value, because Drizzle coefficients are making a small scale change).
Figure 13. Raw sieve-mask images (violet) and Drizzle corrected (blue). Raw data shows pin-cushion distortion with peak value of about 20 pixels.

5.7 Zero point and sky brightness.

The photometric zero points were measured in the J, H and Ks bands. We also report the average sky brightness. We would like to point out the fact that the observing nights were a week with high nighttime temperatures for Mt Graham of about 17 degrees Celsius and the special event of many brush fires in the mountains near Mt Graham. The sky brightness values are unusually high compared to typical values recorded during LUCI observations earlier in the semester. Figure 13 shows the zero points and the rms versus the airmass and the values are not corrected by the gain factor. The zero point is fitted at airmass one.

The zero points and sky brightness calculated for three filters are summarized in the table 6.

<table>
<thead>
<tr>
<th>Zp</th>
<th>Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J</td>
</tr>
<tr>
<td>Mag.</td>
<td>21.83 ±0.004</td>
</tr>
<tr>
<td>Sky</td>
<td>Filters</td>
</tr>
<tr>
<td></td>
<td>J</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>Mag/arcsec$^2$</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Figure 14. Zero points calculated from the data available. The measurements are fitted to a linear regression given the fitting functions: 

- J: $-1.93(\text{airmass}) + 25.25$
- H: $-1.82(\text{airmass}) + 24.99$
- Ks: $-1.73(\text{airmass}) + 24.52$

5.8 Operations performance.

Important issues are the integration of the instrument to the telescope systems and how the efficiency of the observations and the observing plans can be improved. During the June run many tests were done with the AO system and science program target acquisition. An example of performance is given by the observation of the center of M92. The observing script was built, and the script efficiency and the overhead are reported.

A fully scripted operation in automatic mode for observation of M92 in J band was executed with the following set up:

- Number of exposures: 6 frames.
- Exposure time: 10 seconds each.
- Dither pattern: 9 positions on a square grid of 2 arcseconds on a side, each position separated by 1 arcsec.

With this setup, the total time for script execution was: 18min during which the open shutter time was 9min. The overall observation efficiency was 50%. The execution time figure in this case is dominated by the single full frame read-out and storage time of PISCES of about 8s. The total time dedicated to readout is 7.2 minutes, the open shutter time is 9 minutes so that the overhead due to dithering operations is found to be 1.8 minutes. The readout and storage time was subsequently reduced to ~6 seconds.

It was found that the repeatability of the offsets could not be guaranteed beyond 20 arcseconds without target reacquisition, requiring a new pointing and collimation, thus greatly increasing the overhead. After the June run, a new procedure for collimation has been implemented which will reduce the overhead due to this issue. In addition, the rotation of the X-Y stage of the wavefront sensor will be calibrated, increasing the accuracy of closed-loop offsets.
The instrument PISCES has shown that it can deliver images with high Strehl ratio. The performance is typical for a good quality HgCdTe detector. The technical characterization of the instrument for use with LBTO is very preliminary due to several issues: because of intense schedule pressure, laboratory testing was performed only on a detector array that was ultimately changed out to provide a superior array for use in the telescope. Observing in June was done under the special circumstance of big fires around Mt. Graham, making the sky possibly non-photometric and anomalously bright in the near-IR; combined with limited measurement statistics the results are not yet of high confidence level. Based on the experience gained gathering and analyzing these preliminary results, we should be able to provide a more complete characterization with sky time in September and October.

A key issue in near-IR astronomy is the sky background subtraction. This is generally performed by following dithering patterns on the sky, which involves a good deal of interaction of the instrument data acquisition with the telescope. The LBT has the experience with LUCIFER and it has been prepared for this. A scripting approach for a similar level of control of the telescope through the PISCES instrument interface has been developed to provide efficient control for the synchronization of the telescope+AO system with the instrument data acquisition.

REFERENCES