LARGE BINOCULAR TELESCOPE	**AO SCIENCE WORKING GROUP** REPORT	
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Best practice for AO NIR observations with PISCES at LBT

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ABSTRACT

This document describes the best practices for imaging with PISCES+FLAO@LBT, emphasizing the main differences with common Near InfraRed (NIR) imaging. This document is based on the experience made on the first run of the PISCES+FLAO @ LBT commissioning that did not cover all the possible aspects. Fir this reason, this is not a complete document, and it will be updated as more data are acquired and reduced

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Abbreviations, acronyms and symbols

Symbol	Description
LBT	Large Binocular Telescope
FLAO	First Light Adaptive Optics
AO	Adaptive Optics
NIR	Near InfraRed
PSF	Point Spread Function
AOSWG	AO Science Working Group
PI	Principal Investigator
ETC	Exposure Time Calculator

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1 Introduction

In the following we present what should be a typical observing procedure using PISCES (or a similar NIR camera) and Adaptive Optics, given the present status of knowledge of the system. Moreover we describe a procedure to take images with PISCES using the software tools at the moment easily available.

1.1 PISCES Installation

The FLAO run#7 was (also) devoted to PISCES installation and first functional verification. First data on the camera were acquired daytime June the 1st, while first night on-sky images June the 9th and the last the 15th.

2 Photometric Calibration

Little data on photometric calibration have been taken during run#7, and as a consequence this document will not cover this subject.
We just remind a common practice, valid also for PISCES, in case of a photometric night, where the observer sees apparently clear skies at sunset and sunrise, plus no evidence of extinction variations.
In this case we suggest to take an initial calibration with multiple observations of standard stars distributed throughout the night and covering a range in elevations to properly fit the extinction coefficients as well as demonstrate that the night was photometrically stable.

On the assumption of a photometric night and considering the full calibration previously done it is convenient to take one or two standards per night and per filter in order to use the previous calibration.

In any case photometric standards should be taken in seeing-limited mode, or at best with tip-tilt correction only, in order to minimize the pixel to pixel differences and/or flat variations and errors.

Because of a large number of warm (but with a linear response) pixels better sky flats could be computed (see below).

The first calibration may take 15-20% of the overall night, therefore if important to plan it if photometry is actual important for the science case.

In some cases, the presence in the FoV of (unsaturated) 2MASS stars or other sources of know magnitude can improve the photometric calibration, especially under poor atmospheric conditions.

3 Sky flats

Sky flat needs to be taken in high signal condition during the same night of observation. A large number of sky flats images are needed in order to give a negligible contribution to the final noise It is under study if differential flats (subtraction of two sky flats with different count levels, typically taken during sunrise or sunset) are useful to improve photometry, sec also sect. 14. A way to avoid differential flats is to acquire dark images, using identical integration times to the one used to acquire the sky flats.

Valid nighttime sky flats are difficult to be obtained being the pixelscale ~0.019arcsec/pixel and sky background level very low.

3.1 Linearity

All HgCdTe detectors are non-linear in their response to infrared light. It is an artifact of the nature of how the photo-electrons are collected and the detectors are read out. Typically, HgCdTe detectors are ~4% non-linear at 80% full well, and in this sense PISCES is completely normal. Not correcting for linearity has the largest impact on high-contrast observations, e.g. bright standard stars used to photometrically calibrate faint targets, or anything requiring accurate PSF fitting (quasar host galaxies) that covers a significant fraction of the dynamic range of the detector.

Linearity issue and its stability have to be calibrated, possibly in day-time.

4 Cross- talking between the quadrants

There are two electronic effects visible in raw PISCES data, a quadrant-to-quadrant crosstalk and a fading "tail" behind (in a readout sense) high-contrast sources. These are both tied more to the electronics and the geometry of the wiring than anything particular to the detector itself. Both are correctable to some level with proper modeling. A procedure, corquad, is available to correct for this effect, but it does no work for saturated objects. This affects the dithering strategy (see below) and may be important for some projects: the main point would be to avoid square dither patterns with spacing of exactly 512 pixels.

4.1 Corquad calibration

We don't know how corquad parameters may change. Therefore a corquad parameters check should done every night, at least until in this initial phase. An idea is to point a bright object and projecting it on the four quadrants (having care to do not place it exactly at 512,512 px distance on the detector).

The result of the optimized parameters result with the standard one will give the stability and effectiveness of the new correction.

The user will receive as final result of the observation the original files, the corquad routine and the calibration files taken to calibrate the corquad coefficients. It is under discussion to provide corquad processed image files.

5 Distortion

The re-imaging optics in PISCES has a radial scale distortion that is of order 6% or so from the center to the corners. This effect is large enough that observations with large dithering steps will most likely require distortion correction on stacking, like DRIZZLE was used for HST data.

This effect it is not yet calibrated (but probably was already done). Differences in plate scale with filter are also possible.

6 Integration time and Background limited observations

During standard sky conditions, PISCES measures ~30 ADU/sec/pixel in the Ks band, and about 6 times less in J. Given the read-out-noise RON of 20e-, and the gain of 4.5e-/ADU, the typical time to be background limited (sky=2*RON) is ~6sec in Ks and ~30sec in J. The minimum integration time is 0.8sec.

The ETC should be used to predict the peak counts in the brightest source in your image that you do not want to saturate. This could in some cases be a faint source not visible in individual images, in which case the brightness of the sky background is the relevant datum. If you are not going to linearize your data, set the exposure time such that this source stays below ~1/3 full well (<18000DN). This represents the longest exposure time you should use for your source.

7 Dithering strategy

Dithering strategies, i.e., the way of moving the telescopes between two following exposures, depends mainly on target size. As in all other NIR cameras, when the target is extended and cover a significant fraction of the detector, an ON-OFF strategy must be used. In the opposite case, when the target only covers a small part of the detector, an ON-ON strategy can be used, doubling the efficiency. Differences with common cameras are needed in the PISCES+AO case. In any case OFF sky frames are taken in open loop.

- ✓ **Extended objects** (such as globular clusters). The system takes about 3 minutes for a large (>400") movement of the telescope, because the AO loop must be opened and closed again (once back on the target) with a corresponding fast-optimization. For this reason it is very inefficient to obtain an OFF image after each ON image. A possible strategy consists in obtaining a certain number (5-15) ON images, with a

small (~10 pix) dithering offsets in between, followed by a similar number of images taken on the sky, using large (>2") offsets. As sky objects must be removed, the sky images are combined using a clipping and without taking into account the offsets.

For smaller distances of the OFF-sky frame direction the re-optimization of the AO-loop is not needed and the restart of the AO loop may start much faster.

For a short sequence of ON-OFF observations, you need at least a few sky frames. For a long sequence you should spend about 1/3 of the time on sky, with the sky frames interleaved with the science data.

- ✓ **Small targets with saturated peaks** (such as a planetary system around a bright star). A ON-ON strategy can be used, but a few warning must be considered
  a. Even a point source will cover a significant fraction of detector (~1/9 in linear dimensions) when considering diffraction pattern and seeing halo. The following image of HR8799 shows for sake of clarity two images, taken with a vertical 2.86"arcsec separation, subtracted one to the other. This distance is marginally enough to allow to build a sky frame from the a set (unfortunately not available) of so dithered images. As a consequence, no offsets smaller than ~3" should be used
  b. Corquad cannot adjust the effect of saturated pixel at (512,0) (512,512) and (0,512) px far from the saturated peak. For this reason, when a bright, saturated star is present in the field, these offsets should be avoided.

  As a consequence of these two effects, only dither patterns with a limited (~9) number of positions are advisable.

  The current version of the control software does not allow for closed-loop offsets and dithering, therefore each telescope movement requires ~20 sec of overhead time. A new version of the software is under development to allow for a faster, closed-loop dithering (considering that maximum distance between the center of the field and the AO guide star is 60 arcsec).

- ✓ **Small targets without saturated peaks:** A ON-ON strategy is suggested, but with respect to the previous case:
  a. In this case the corquad routine is expected to properly work on the whole image. The dither strategy may work also to reduce the noise introduced by not perfect flats and corquad coefficients: random dithering patterns larger than the largest structure we want to investigate.

  Again consider that maximum distance between the center of the field (PISCES) and the AO guide star is 60 arcsec.

.

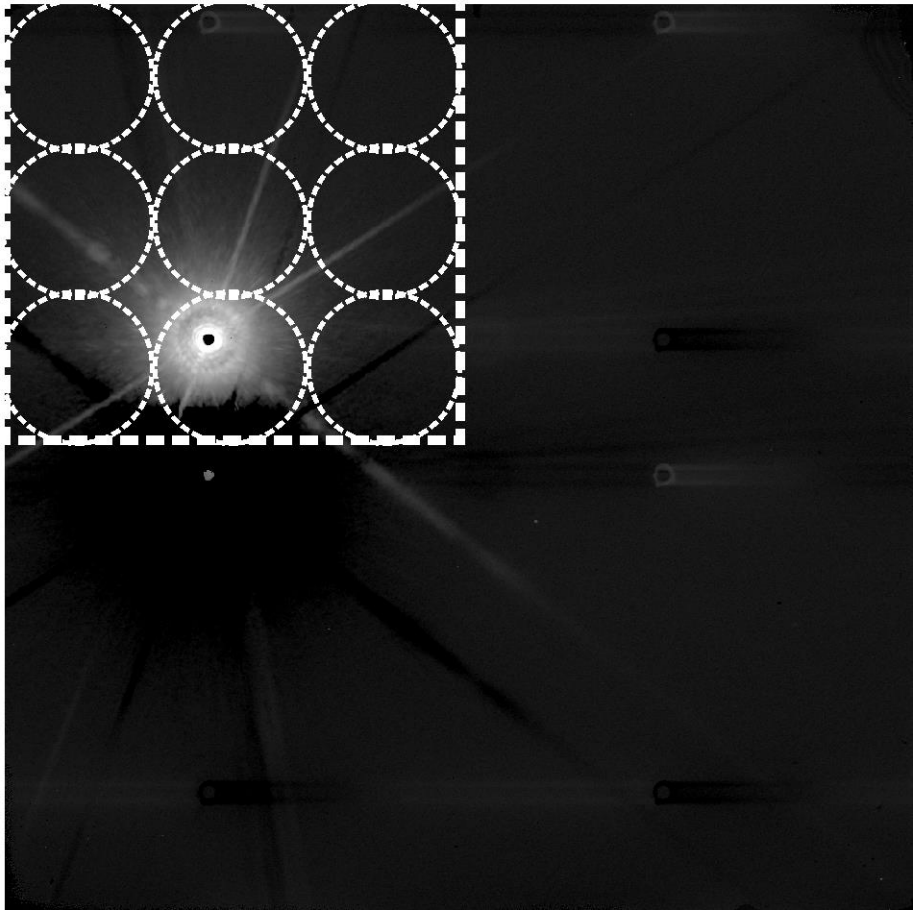

Figure 1 This picture shows two different (2.8" arcsec separated) images of HR8799 subtracted one to the other, in order to show the effect of the saturation, which is uncorrected by the corquad (the positive and negative circles with the corresponding tails). Here it is possible to see also the actual dimension of a bright source on the chip. Being the physical dimension about 1/9 of the chip one possible dithering strategy is marked by the dashed circles, each about 3" in diameter.

7.1 How bright can you go? How faint can you go? (ToBeCompleted)

Very bright targets: The ~6-second overhead on the 0.8 sec exposure time significantly limits the open-shutter efficiency on bright targets that you don't want to be saturated. This makes searching for planets take much longer than might be expected.

Very faint targets: On Q2051, a stack of thirty 60-sec exposures in Ks got us down to a sky noise level of 105 ADU/pixel which is still Poisson limited. In the case the individual 60-sec exposures had a sky level of 1730 ADU. This allowed detections of galaxies with nuclei down to Ks=21 in 30 minutes with Strehl of ~0.1. Fainter point sources would be detectable with higher Strehl.

8 Reference star selection

The adaptive optics sensor sensitive to photons in the 0.75μm ±0.175μm band, i.e, is sensitive to a band similar to R+I. A suitable reference stars for the Adaptive Optics correction has R+I magnitudes (average of the two) in the 6-17 range. The reference star must be closer than 60arcsec to the science target (if it is at the center of the PISCES field of view)

larger distance can be used but consider that at distance larger than ~40arcsec the correction is negligible and PSF strongly elongated. The PI should have clear that performances depends on:

1. Reference star brightness
2. Reference star distance from the requested sky direction
3. Seeing Condition

Reference star can be the observed target, if the source has a point like appearance: this means that most part of the object energy is within a circle of radius of at most one arcsec (close loop observation of Io Jupiter Moon have been successfully done), In the case of not diffraction limited object the performance will decrease increasing the angular size (for one arcsec about a factor 5-10 in Strehl Ratio, value to be verified).

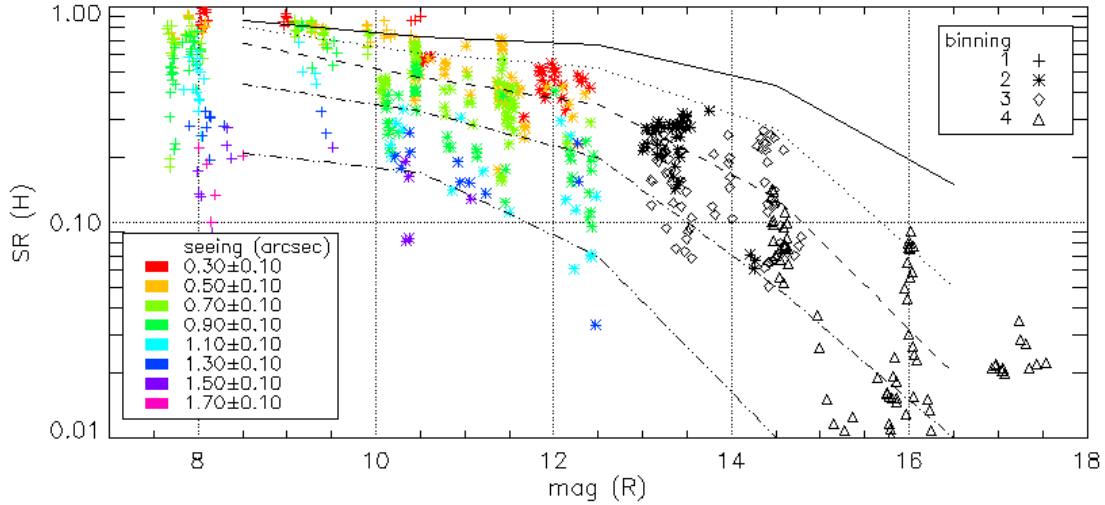

Figure 2 In this plot we show a summary plot of the FLAO#1 performance commissioning results. Strehl Ratio in H band versus star magnitude (R) and for different seeing values (estimated from AO real-time data). Points (MR >13) for which seeing values are strongly under-estimated are shown in black. Different binning modes are indicated with symbols (but these are not selected by the astronomers). Lines correspond to expected performance from numerical simulations with different seeing values; from top to bottom: 0.6", 0.8", 1.0", 1.2", and 1.5".

Larger and larger distances of the object from the guide star will worsen the performance according to the simple relation:

$$SR_{obj} = SR_{Reference} \times \exp[(\theta/\theta_0)^{-5/3}]$$

Where θ is the distance and θ_0 is the so called isoplanatic angle which depends on turbulence stratification and power but usually it belongs to the range 30-50 arcsec in K band and 20-40 arcsec in J.

Of course point 3 is not depending by the user, but in some way could be specified.

9 Observing procedure

In our scheme the PI propose an observation that is realized at the telescope by the team on site. The team is composed by a PISCES operator (typically he is an astronomer) coordinating the telescope operator (that makes sure that the telescope keeps running and acts in case of problems) and the AO operator (similar to telescope operator but for the AO side).

Operatively if you (PI) are expecting the Telescope Operator to point the telescope (send presets), then a catalog with Targets, Off-Fields, Reference Stars and Guide Stars must be prepared in advance.

Looking to the past experience we found that the best observation made was the one relative to Globular cluster M92, data were not collected by the LBTO on June 13, 2011 and the "Observe" routines were not properly used, the wiki-log was fully written and it is well descriptive, dithering strategy was fine and sky frames were following the same acquisition strategy used for the images. In other words it is possible to read in the log and it is actually true that images and sky frames were acquired in very similar way (filter, exposure time, number of frames). But also in this case the lack of a well established procedure (now existing, the one used the 22nd and 23rd) generated problems, such as the failing of the corquad because of unknown reasons (this failure was realized only a posteriori).

The "Observe" routines are a package of IDL routines written Doug Miller at the LBTO to execute an observing block with the AO+PISCES system. This package is written in IDL. Prior to the observing night the Astronomer, with the assistance of the LBTO staff, will create a simple ASCII file with a list of "Observe" commands with appropriate arguments and keywords to, for example, preset the telescope, offset, set filters, set exposure times and number of images per set, dither, etc. An observing script (ie this ASCII file with a list of command that has the suffix .obs) can include the collection of sky frames and target images, each with several possible dither patterns, including observer defined, and images in several filters at the same dither position.

A description of the "Observe" routine is available on line at the address:

http://wiki.lbto.org/twiki/bin/view/AdaptiveOptics/Observe_routines

9.1 Observation Preparation

PI (defines the science target to be observed)

- ✓ Provides J2000 Coordinates (positions and proper motions) for:
  - Science target
  - AGw (seeing-limited) guide star
  - AO reference star
  - PSF reference target (AO refstar and PSF star) if needed
  - Off-source sky field if needed
- ✓ Defines filters to be used
- ✓ Makes best estimate of the exposure times expected based on ETC
- ✓ Defines dithering strategy
- ✓ Provides useful finding chart (FC)
- ✓ Provides science goals summary sufficient to adjust observations

Before an observing night the astronomer and the AO Operator must prepare several items:

1) Determine Target Object coordinates, AO Reference star coordinates and Guide Star coordinates possibly according to the PI proposal;
2) Prepare a target catalog containing the three coordinates listed above and the LBTO standard catalog format (the AO Operator can build this) ;
3) Prepare a script (.obs) for the "Observe" routines to execute. This script can be check for both syntax and function before the night of observing with routines provided by the "Observe" package. An example of an .obs script is given at the of this document.

9.2 Observation Procedure

Astronomer defines the science target to be observed according to the PI's instruction and science goals summary:

1. Reference Star coordinates J2000
2. Object coordinates J2000
3. Checks a suitable field for sky frames acquisition if any
4. Checks the dithering strategy

5. Checks the filters to be used
6. Checks the exposures time

Telescope Operator points the telescope

7. Sends an ADAPTIVEACE Preset to point the telescope off target on the sky field:

   this initial pointing is done in order to take sky frames. In fact we think that is more convenient to take a set of sky frames before the start of the close loop operations both because of persistence of bright object on the NIR detector and to save time because of the open loop/close loop switch. One point behind this choose is also that sky frames can be taken either using open loop or close loop state of the AO.

Astronomer/PISCES Operator takes sky frames

8. sky frames measurements

   The sky frames have the same exposure time and filter of the image, and should follow a dither pattern in order to minimize the effect of the bad pixel and objects present in the sky field,

   Points 7 and 8 may be avoided if dithering images are enough to generate sky-frame or in the case of short exposures (less than 15min, in this case the sky can be acquired at the end of the last exposure on the object).

Telescope Operator points the telescope on the target

9. Sends an ADAPTIVEACE Preset to point the telescope on the target

The Astronomer/PISCES Operator

10. field identification (use fiducials/finding charts/previously collected frames given by the astronomer)
11. Image acquisition
12. Follows dithering strategy
13. will keep a log of observing information in the LBTO Adaptive Optics TWiki and the automatically generated observing log created by the "Observe" routines will be cut and pasted into the TWiki.

One limiting factor of the run#7 data are the amount of information saved in the fits headers, which are very incomplete and often wrong. As a consequence, taking an accurate and complete logbook is very important. This should be significantly improved before the next run (see below)

We have been informed by Doug Miller that “the data fits files are written to the LBTO archive with a minimal header by the instrument PISCES. The "Observe" routines reads these original PISCES fits files and writes, into the archive, fits file with the original image data with a much more extensive header with important information about the state of the telescope, the AO system, weather conditions, seeing conditions, PISCES information and observing block information. In addition, a TWiki ready, ASCII log is automatically written listing the names of the image collected and a few important parameters of each. A document will be released in the next few days describing in detail the use and syntax of the "Observe" routines.”Actually during the nights two different wiki-logs have been filled. This was the source of confusion, the existence of the two logs was not well communicated by the team(s) that were at telescope. We propose to have a single log text including all the information needed to fully describe the PISCES imaged saved.

At the very end merging the information in the two logs is in most of the cases is enough, but still some .fits saved is not usable because .fits header is missing or is not reliable being clearly wrong and not described in any of the two logs.

An automatic procedure such as the one D. Miller describes could provide the required information and standardization. In this case we ask that the header of the files provided to the community will not present conflicting information with respect to the log.

10 Acquiring images procedure both for sky/flat/technical/science images

It is necessary to run the corquad program on each raw file acquired because of the errors introduced by the double-correlation on the raw image taken by PISCES. This procedure works on single images and not on stacked images (cube of images). As far as we know PISCES generates one file per exposure with no header. The header will be added later by an ad-hoc IDL routine.

As far as we know two different software tools exist:

1. the IDL routine "fix_pisces_header.pro" which adjust and complete the header of the image saved in the .fits file
2. the corquad executable which adjust the error introduced by the correlator.

We propose to use, each time a single images is acquired, both software procedures in an automatic way if that is possible. An IDL routine or script to be called "prepare_pisces.pro" running the two is strongly suggested.

Here we propose a procedure to take data, notwithstanding they are flat or sky or science images. Because of the larger variability of PSF during closed loop operation is better to save all frames acquired separately.

A common way to save data in NIR imaging is to write on the disk a fits file, which is the average of a certain number of consecutive measurements (usually called NDIT) taken with the same exposure time (usually called DIT). Given the possibility that bad adaptive optics correction occurs or that the user could decide to use only the best fraction of the available data it is a good idea to save all the NDIT frames separately, stacked on a single cube, in order to allow an a posteriori images selection.

In the following we will consider the NDIT number of frames above, but we propose to write on the disk all the frames and not only the average one.

PISCES Operator takes the images (EXAMPLE NDIT images of DIT exposure in sec)

1. captures NDIT images using the same DIT exposure time
   After each single acquisition uses prepare_pisces.pro (see below)
   a. *prepare_pisces.pro:
      i. run fix_pisces_header.pro
      ii. run corquad
2. As soon as a new file set of NDIT images is taken the NDIT files are assembled into a cube, therefore containing similar data (identical dither position, rot angle, exposure time and filter): the cube contains almost identical images
3. An header for this cube has to be generated and attached
4. The cube is saved using a standard filename: tracking numbers are the most useful, in order to use existing routines to analyze them.
5. He/she writes the log file

Appendix I. Some useful numbers

Measured pixelscale in J and Ks is 0.0192±0.001 px, small variations are possible according to the filter used and camera status.

Some numbers regarding the Ensquared Energy

Band	SR_λ	<0.02"	<0.05"	<0.1"	<0.2"
H	~90%	24%	67%	78%	86%
H	~50%	20%	55%	67%	75%
K	~90%	10%	58%	78%	87%
K	~70%	9%	51%	70%	80%

Pisces magnitudes zero point:

J:23.3,H:23.17 and Ks:22.75 (measured in seeing limited)

Read-out time (including saving the download of the fits 7seconds per frame)

Appendix II. Requests for software development

Here we place a set of requests that will facilitate the data reduction work at the of the end of the commissioning run:

- insert specific keywords and/or use specific filenames, in order to organize the data automatically at the end of the night?
- use the “imagetype” keyword in the fits header: imagetype=science, dark, bias, flat....
- use a unique fits header
- optimize the exposure time prior to the data collection, per filter.
- if the sky frames are collected as a series of dithered images, be sure that the number of position is enough to allow a valuable statistical sky evaluation

Appendix III. General problems to be fixed

Looking into the images collected we found some problem inconsistency between data:

1. Integration time may change within the data cube (when naxis=3),
2. data are typically in the form 1024×1024×n, but also n×1024×1024 cubes have been found
3. some fits header contains not readable characters, so that corquad fails
4. five different types of fits header were found. It must be uniform
5. HEADFITS ERROR - Extension past EOF Input header does not contain required SIMPLE keyword
6. format the filter keywords, trimming away the blank spaces
7. UTstart must be attached in the header
8. Correction of the POSANGLE (from John Hill):
    a. # Equations to Fix PISCES position angle (PA) data from June 2011
    b. CorrectedPA(the actual PA of image) = POSANGLE(what is in the header) - 90 deg
    c. StellarPA = ApparentPA + POSANGLE - 90 deg

Appendix IV. Observation Preparation Example

From Doug Miller’s mail:

Before an observing night the astronomer and the AO Operator must prepare several items:

1) Determine Target Object coordinates, AO Reference star coordinates and Guide Star coordinates
2) Prepare a target catalog containing the three coordinates listed above and the LBTO standard catalog format (the AO Operator can build this)
3) Prepare a script for the "Observe" routines to execute. This script can be check for both syntax and function before the night of observing with routines provided by the "Observe" package.

A more detailed description of each of these three items follows:

1) The Astronomer must provide the following information for the target object and the AO Reference star (of course these may be the same star):

```
# Proper Motion
# Coordinates (J2000) (mas/yr)
# Ra Dec Ra Dec Epoch Equinox R mag
#-----------------------------------------------------------------------------------------------
17 17 07.372 +43 08 09.02 -29.6 36.0 2000.0 J2000 10.00
```

In addition, a B-V color can be specified, but is not used by the "Observe" routines or by the telescope.

The astronomer can specify a Guide star used by the Acquisition, Guide and Collimation subsystem (GCS) to guide and perform active optics before the AO loop is closed. An appropriate guide star can also be provided

by the AO Operator from the UCAC3 catalog.

2) The AO Operator will take the information provided in 1) above and build an LBTO standard catalog need to preset the telescope. An example of the LBTO standard catalog is:

```
#====================================
#
# Target Star
#------------------------------------
# Name = Pisces_9 = HD 156711
# B_Mag = 11
# R_Mag = 10
# H_Mag = ~
# Type = ~
# Ra = 17:17:07.372
# Dec = +43:08:09.02
# El_Max = 79
#
# Guide Stars
#------------------------------------
# Mag_Limit = 16.0
# Radius = 5.5
# Coord_Error = less than 100 mas
#
# Catalog Information
#------------------------------------
# Catalog = UCAC3
# Server = #======== UCAC3 server (2009-09-09, V3.1) ======== CDS, Strasbourg ========
# Request = finducac3 -c 17:17:07.372 +43:08:09.02 -r 5.5 -lmR 0.0,16.0 -e s -s r -m 500
# Created = Fri Jun 10 23:18:10 2011
# User = dlmiller
# Modification = None
#
# Proper Motion
# Coordinates (J2000) (mas/yr)
# id Ra Dec Ra Dec Epoch Equinox R mag B-R Dist(")
#-----------------------------------------------------------------------------------------
0 17 17 07.372 +43 08 09.02 -29.6 36.0 2000.0 J2000 10.00 0.00 0.00
1 17 17 20.1396 +43 09 42.058 -20.8 -14.0 2000.0 J2000 15.204 0.00 167.87
2 17 17 15.7222 +43 10 35.482 +7.4 +67.4 2000.0 J2000 15.942 1.15 172.63
3 17 17 10.4373 +43 11 07.648 -7.6 -2.5 2000.0 J2000 15.193 1.56 181.75
```

A description of the "Observe" routines is available at the Twiki-LBTO web pages which http address is: http://wiki.lbto.org/twiki/bin/view/AdaptiveOptics/Observe_routines.
To create these Observe script files, the astronomer will have the provide the AO Operator with exposure times, number of images in each set, filters, dither patterns and distances, sky field coordinates or offsets, sky field dither patterns (if desired), etc so scripts can be written.

Here is an example of an observing script used on June 23, 2011 for BD303639

```
# Science Verification
# 22Jun2011 DM, DT, JCG
preset, OBJECT=SDT_BD303639, MODE=ace, GS=13, RS=0, PA=0
auto_collimate
runao
```

```
set_position
camera, EXP=60.0, FRAMES=1, COADDS=1, FILTER=1
dither, TYPE=list, COORD=detxy, ITER=1
LIST, START
LIST, 0.00, 0.00
LIST, -2.00, 1.50
LIST, 7.00, -7.00
LIST, 7.00, 7.00
LIST, -2.10, -1.30
LIST, 1.70, 1.90
LIST, -7.00, 7.00
LIST, -7.00, -7.00
LIST, 1.80, -1.60
LIST, 0.20, 0.15
LIST, END
```

Another example is the following:

```
# Observing script for Mkn231
# 22June2011  DLM
preset, OBJECT=SDT_Mkn231, MODE=ace, GS=2, RS=0, PA=-45
auto_collimate
runao
set_position
camera, EXP=1.0, FRAMES=1, COADDS=1, FILTER=5
dither, TYPE=list, COORD=detxy, ITER=1
    LIST, START
    LIST,    0.00,     0.00
    LIST,    2.64,     2.72
    LIST,    0.98,    -0.87
    LIST,  -40.00,    -4.00
    LIST,  -37.36,     2.72
    LIST,  -39.02,    -0.87
    LIST, END
```

Appendix V. General comments about sky flats

From Dave Thompson's mail:

There are three relatively standard methods for generating flatfields with infrared cameras, including PISCES. In all cases, one assumes that the input light source is uniformly illuminated, both spectrally and spatially, such that any variations seen are due to either true pixel-to-pixel QE variations of the detector, or larger-scale variations due to vignetting in the optical system. And ideal flatfield would also have the spectral response of the typical science targets, generally a blackbody curve with a temperature of 4-6000K is a reasonable assumption. Unfortunately, additional features can impose additional spatial variability in the flatfields, including dust on optics and pupil ghosts. The three standard methods for making flatfields are:

3a) Dome flats taken with a stable light source uniformly illuminating a flatfield screen on the inside of the dome (or in the case of LUCI and MODS, from a Calibration Unit). This is not possible at the LBT for PISCES, but is useful to include here to better understand the advantages and disadvantages of the other methods. If uniformity and stability of the illumination can be assumed, then domeflats are normally taken in LAMP_ON - LAMP_OFF pairs to correct for dark current, hot pixels, and thermal background or scattered light present in both the ON and OFF data. This represents an "ideal" set of flatfield data.

3b) Twilight sky flats. Observations of the twilight sky, taken at such a time when the sky is still bright enough that reasonably short exposure times can be used. Analogous to the ON-OFF domeflat observations, fading (or brightening) twilight is observed to get data at two levels. Difference data is used to construct the flat. Advantages of this method are that it does not require the lamp and screen, sunlight is reasonably close to a blackbody, and the sky is uniformly illuminated at least over the field of view of the instrument. Disadvantages include instability of the light source, and sensitivity to non-photometric weather. Both of these have stronger effects when the readout time of the detector is longer, as with LUCI (2.0s) vs. PISCES (0.8s). A modified, and less acceptable, approach could be to use darks to the same exposure time do correct for background. This is not expected to work as well because the "dark" filter changes some of the background contributions from scattered light, dust on optics, etc. This seems to be the approach being recommended in S3 of the Best Practices document.

3c) Nighttime "super" sky flats. The thermal and OH emission of the nighttime sky do normally provide a sufficiently high SNR measurement of the flatfield response of the system. Advantages include that the night sky background provides a uniform illumination and is more stable than twilight. Disadvantages include small-scale structure (sources) in the sky, non-uniform spectral input (OH lines, not a blackbody), and the data would need to be dark subtracted with the same disadvantages as mentioned in 3b.

What is often overlooked in flatfielding data is whether the flatfield is photometrically flat. The only way to measure this is on a demonstrably photometric night (i.e. take lots of standards) to dither photometric standards around the field of view with sufficient density to derive any spatial variation in the zero point. This "photometric flat" can then be used to correct a flatfield obtained by methods 3a-c to obtain photometrically flat science data. Not all science programs need this, of course, but if you do then this is something to consider. Note for reference that there is strong evidence in LUCI of a 5% gradient in broadband data and a 25% gradient in narrowband data. It is unknown if this is an issue with PISCES or not.