AO Imaging and Astrometry

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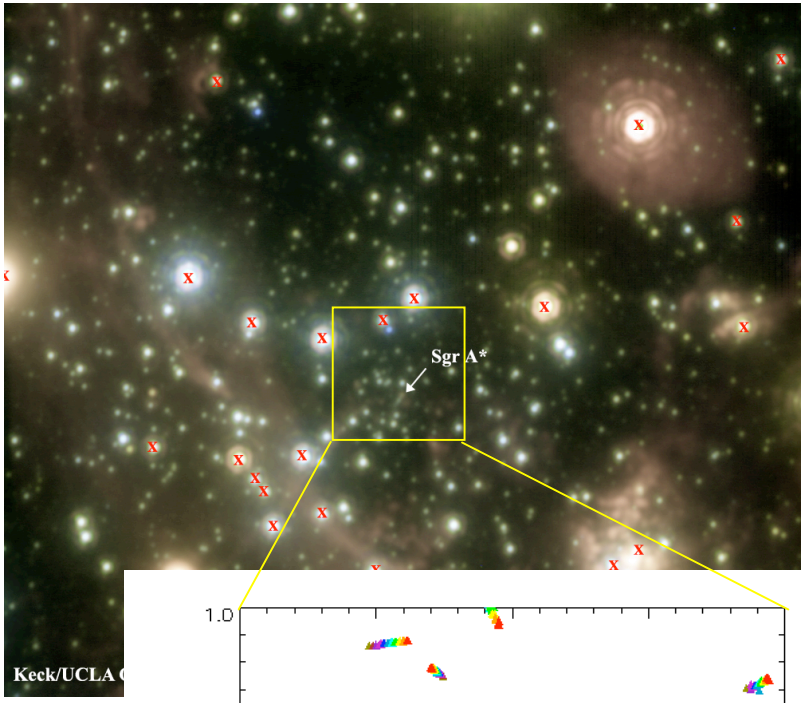
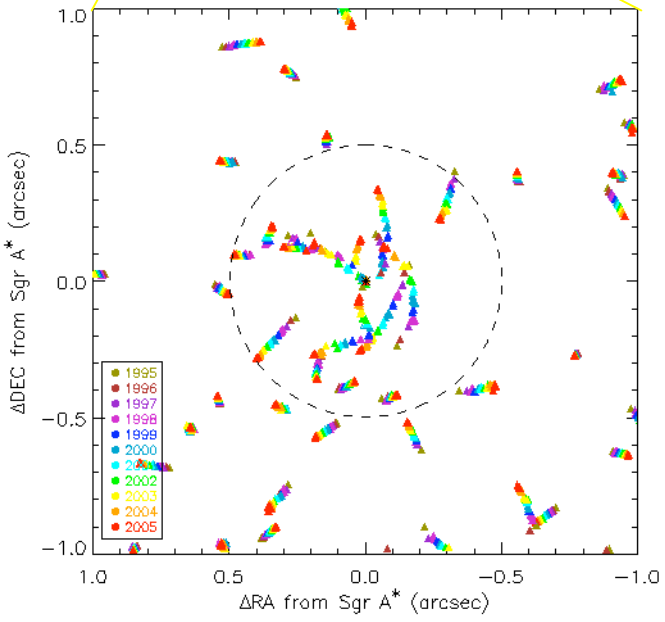
Galactic Center science requires good astrometric precision and astrometric accuracy.





Reasons to study GC stellar dynamics:

- black hole mass
- extended mass distribution
- general relativistic effects
- origin of young stars
- hypervelocity stars

Steller positions must be measured with high relative precision:

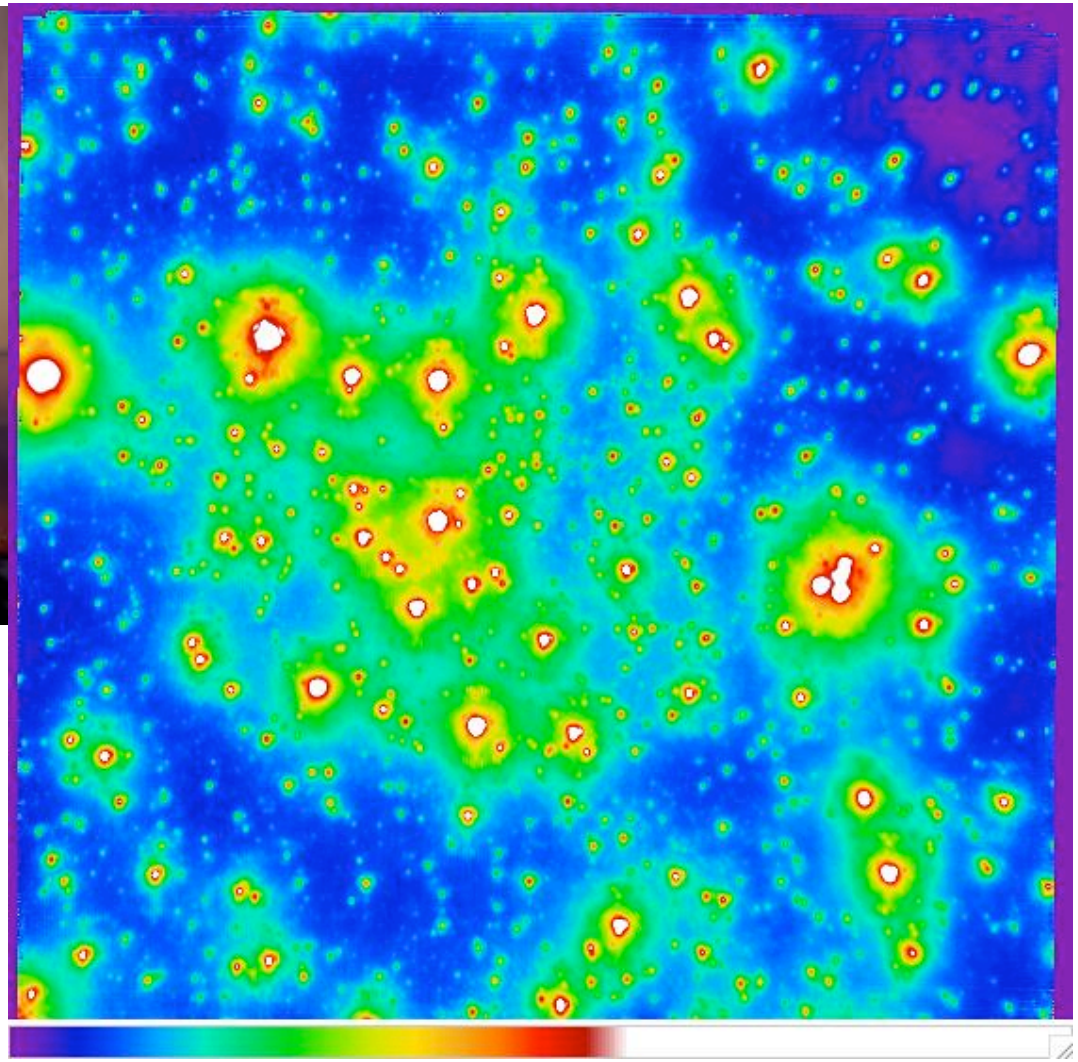
- velocities
- accelerations
- full orbits

Stellar positions must be measured with high absolute accuracy:

- stars projected distance from the black hole.

Galactic Center imaging observations use the Keck II LGSAO system with NIRC2.

10” x 10”



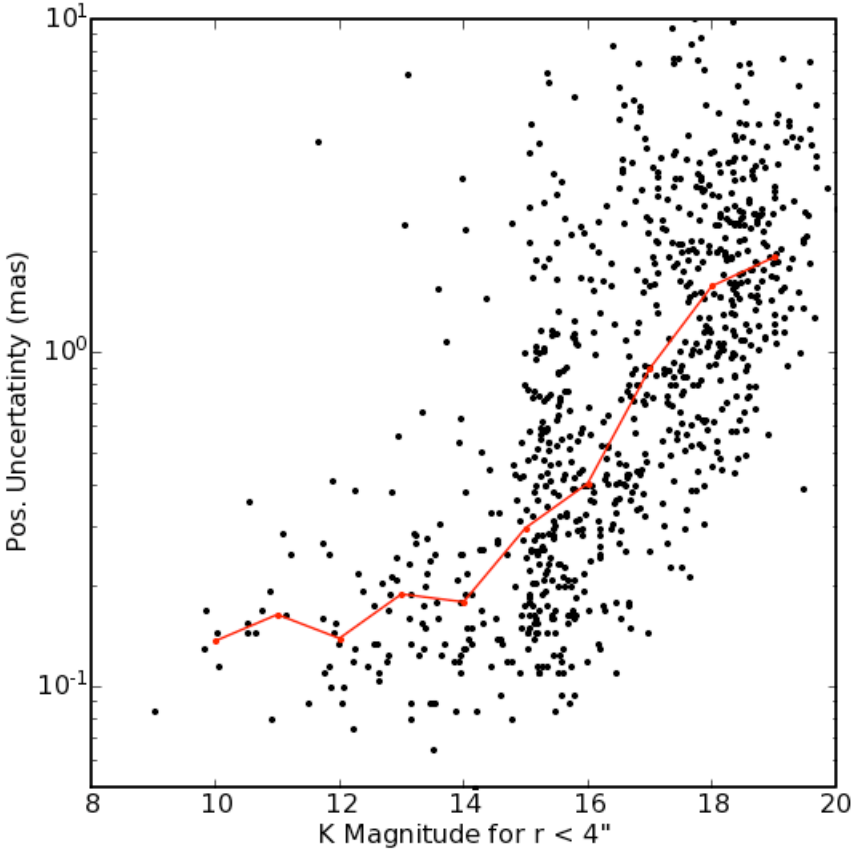
- 28 sec exposures
- ~180 images
- ~3 hours (clock time)
- K-band (2.2 microns)
- Dither within 0.7” box
- Airmass: 1.5 - 2.0
  (best images at
  < 1.8 airmass)

Astrometry extracted using *StarFinder*
(Diolaiti et al. 2000)

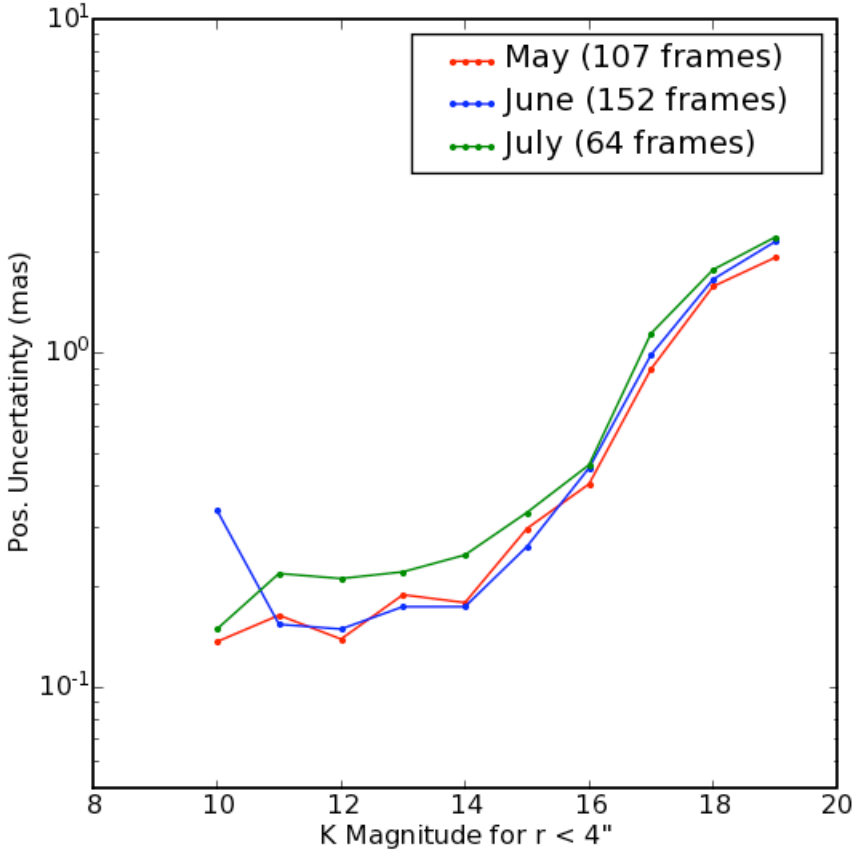
Keck LGSAO is a giant leap forward in astrometry for the Galactic Center.

100 micro-arsecond relative astrometric precision is possible

Individual stars in one night (May)

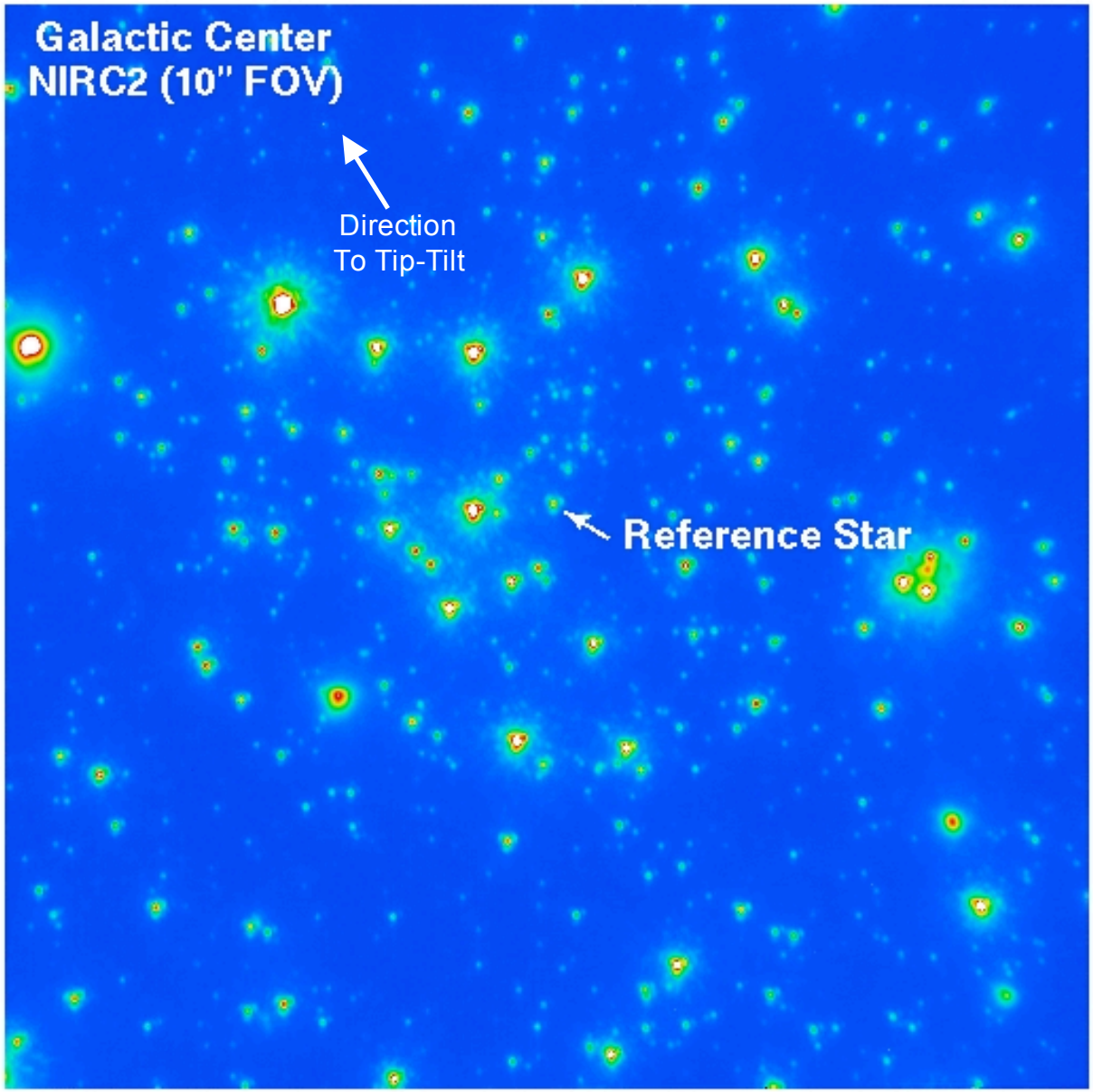


Nightly averages for 3 different nights.



What limits the astrometric precision?

Astrometric precision is a function of location in the field.



Use 1 night of GC data:

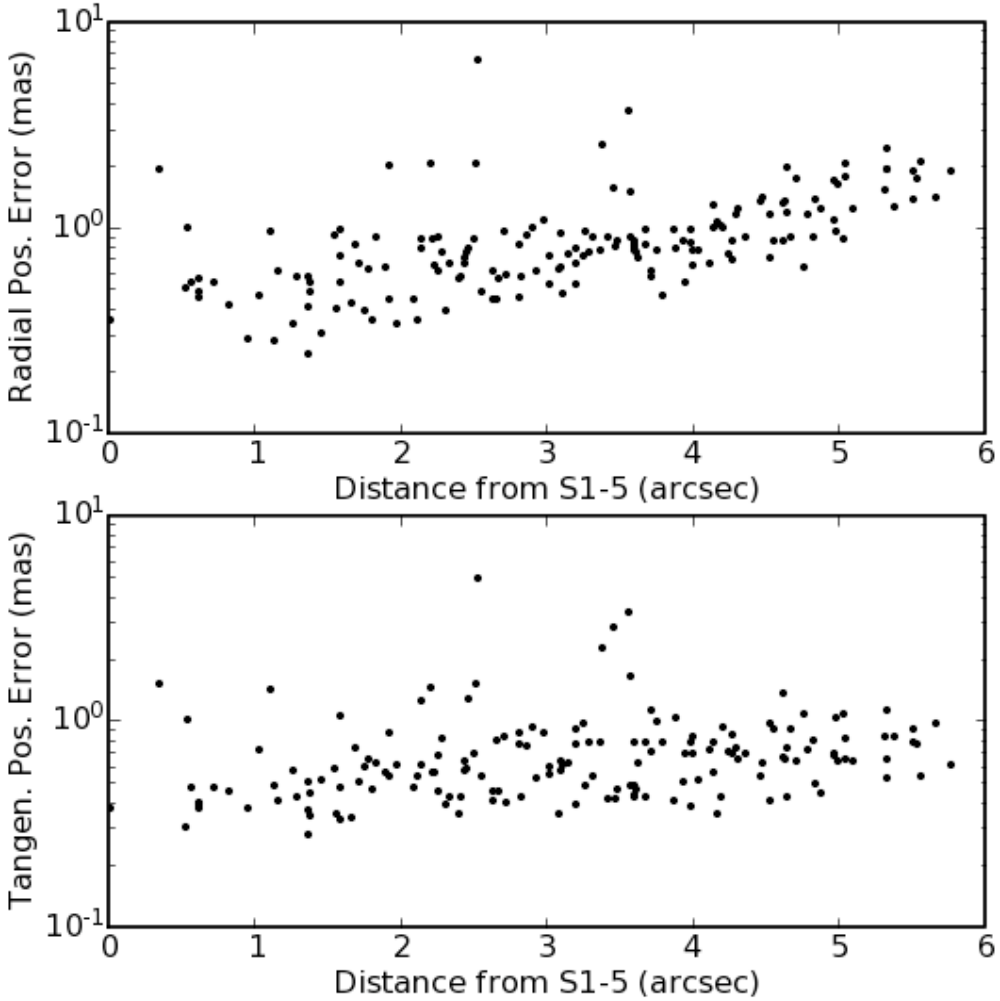
- Strehls: 0.3 - 0.4
- FWHM: 53 - 63 mas
- WFE ~ 345 nm *(Marechal)*

Simultaneous MASS/DIMM:

- r_0 ~ 11 cm (14 at zenith)
- θ_0 ~ 1.3” (2.7” at zenith)

Courtesy of Matthew Britton:
http://eraserhead.caltech.edu/keck/galactic_center/turbulence_plots/turbulence_plots.html

Galactic Center data shows a radial dependance.



• In each frame, measure the position relative to a reference star, which is close to the laser spot.

• Take the RMS from all frames.

Possibilities:

• plate scale
• PSF variations
• differential atm. refraction

Plate scale changes do not yet dominate our astrometric precision.

Change reference to star not in center of FOV.

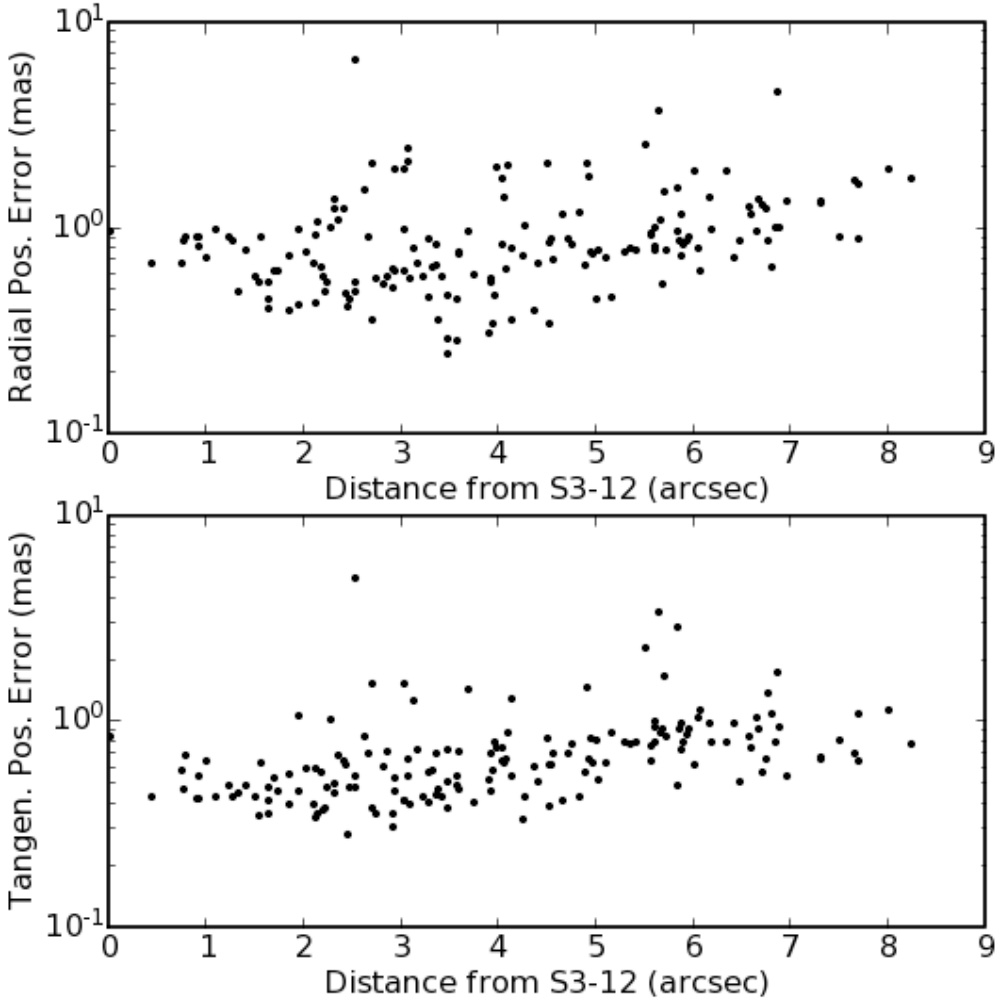
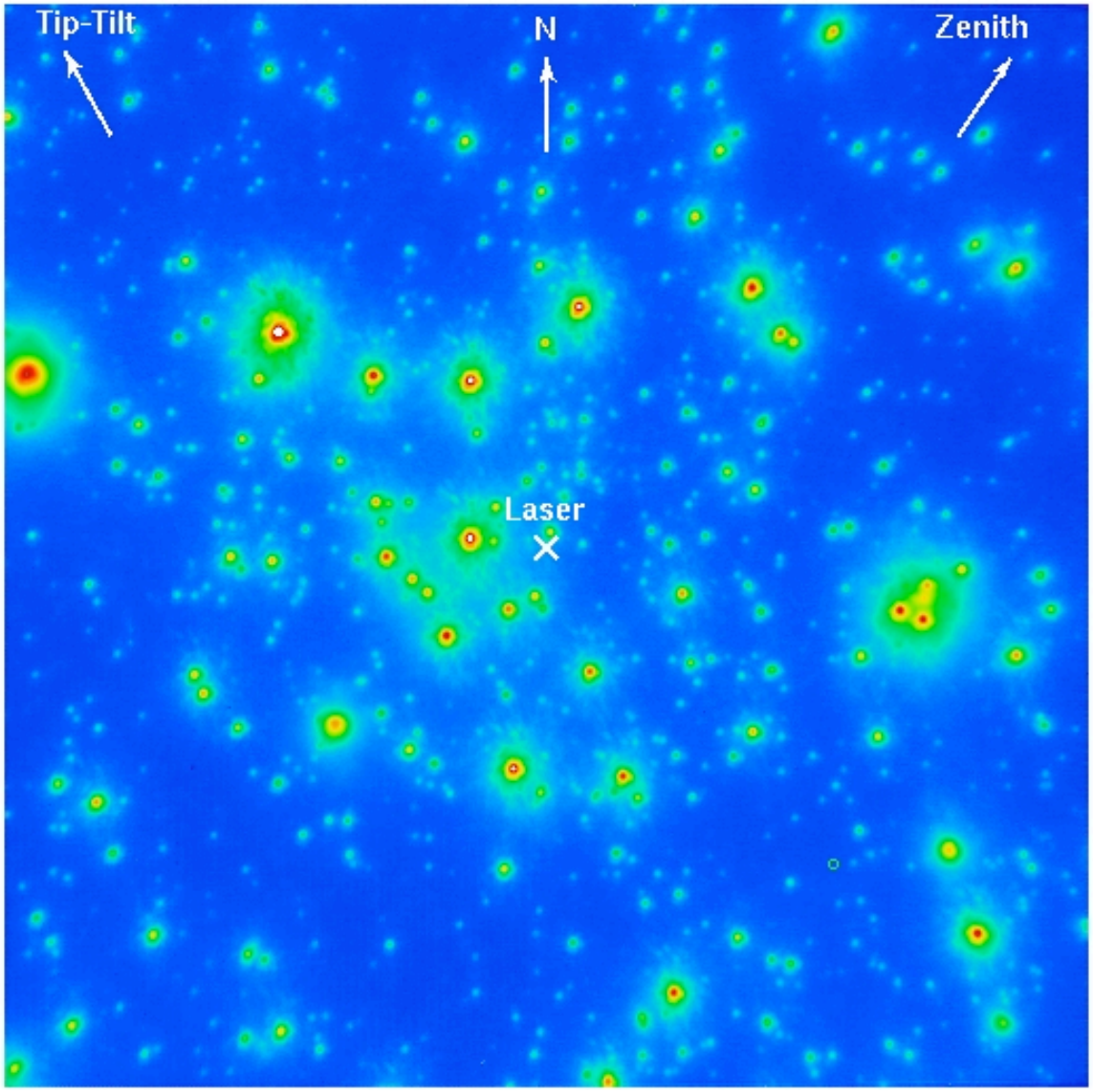


Plate scale changes should show separation dependence with respect to ANY star.

Data shows smallest positional error in center of FOV (near laser). NOT at small separations.

PSF is constructed from stars near the center of the FOV and is not a good representation over the whole field.



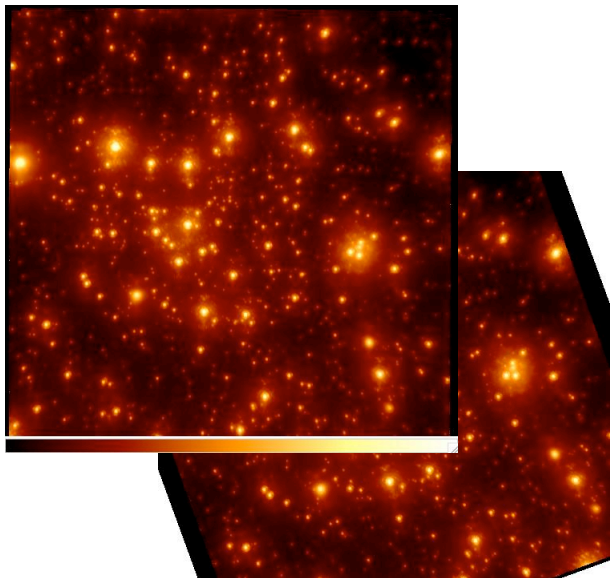
- PSF degrades at edge of field.

- PSF elongation is more extreme along the zenith axis -- wind-shake?

PSF variations may be masking many effects:
- differential tip-tilt jitter
- achromatic differential atmospheric refraction (DAR)
- chromatic DAR

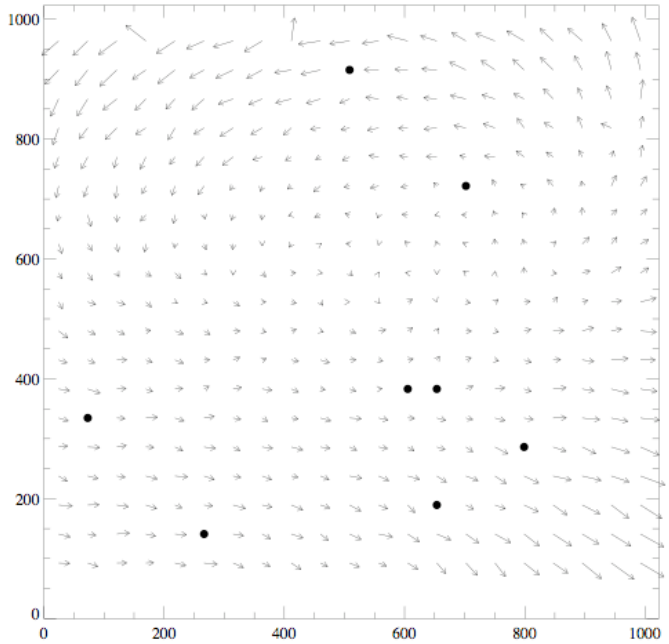
Need to use spatially varying PSF to extract astrometry.

Astrometric accuracy is at least an order of magnitude worse at ~1 milli-arcsecond.



Alignment between NIRC2 frames good to 1 mas.

- several GC images on same night
- different positions on detector (5-pt box with 4” on a side)
- residuals of 1.4 mas even after distortion correction (pre-ship review)

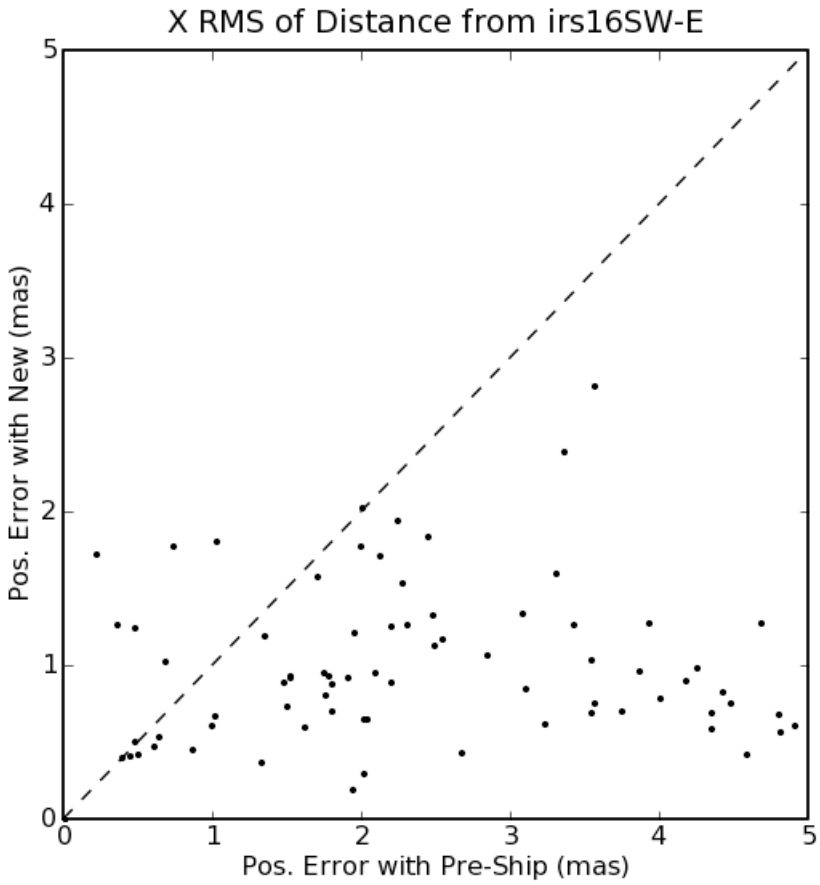


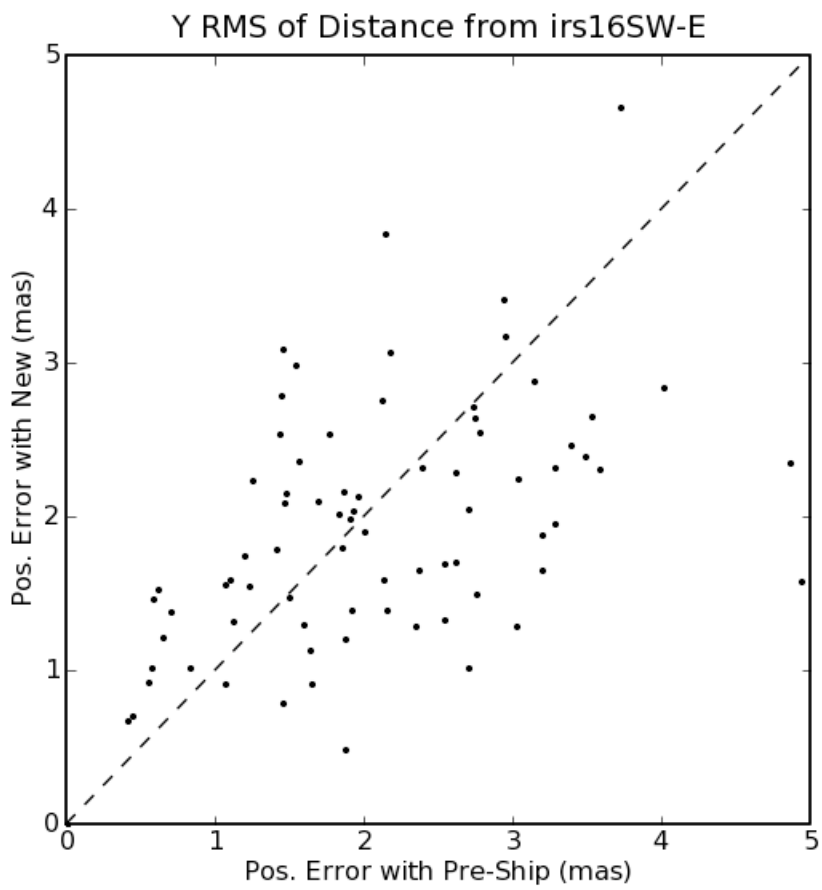
Pre-ship distortion solution:

- pin-hole mask used to derive distortion solution.
- Can the distortion solution be improved using pin holes?
- Does distortion change over time?

Accuracy of 1.4 mas over 4”

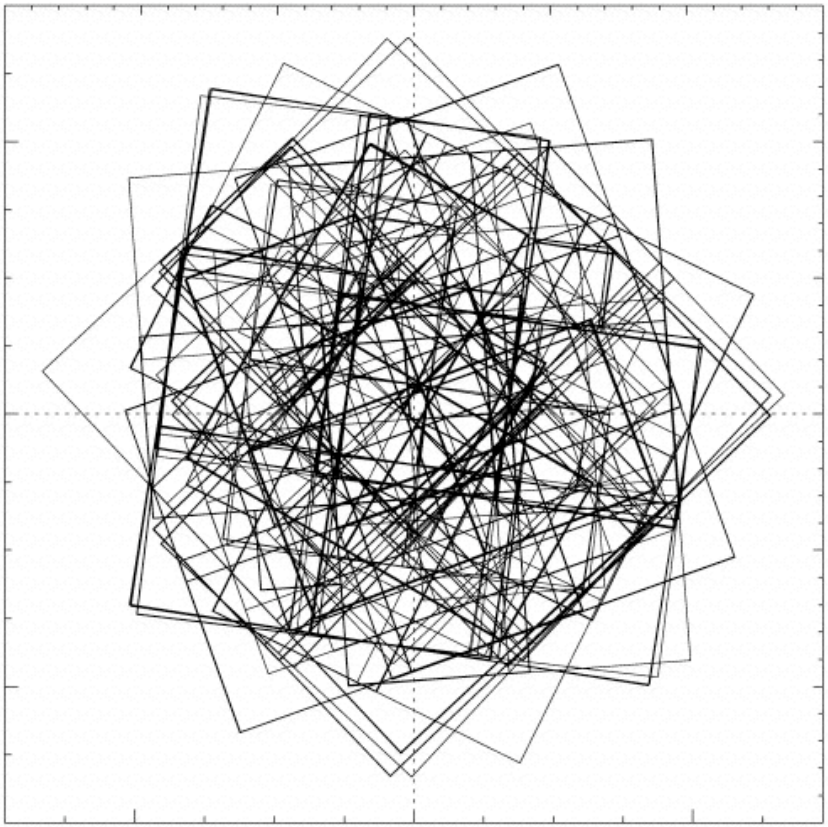
New distortion solution with pin-hole re-analysis does improve the astrometry of our data.





- Large-dither (6”x6”) data set -- maximally samples distortion
- Measure stars distance relative to a reference source
- Examine RMS of distance (positional error)
    - New solution improves the X-residuals by a factor of ~2.

Proposed experiment to solve for NIRC2 distortion.



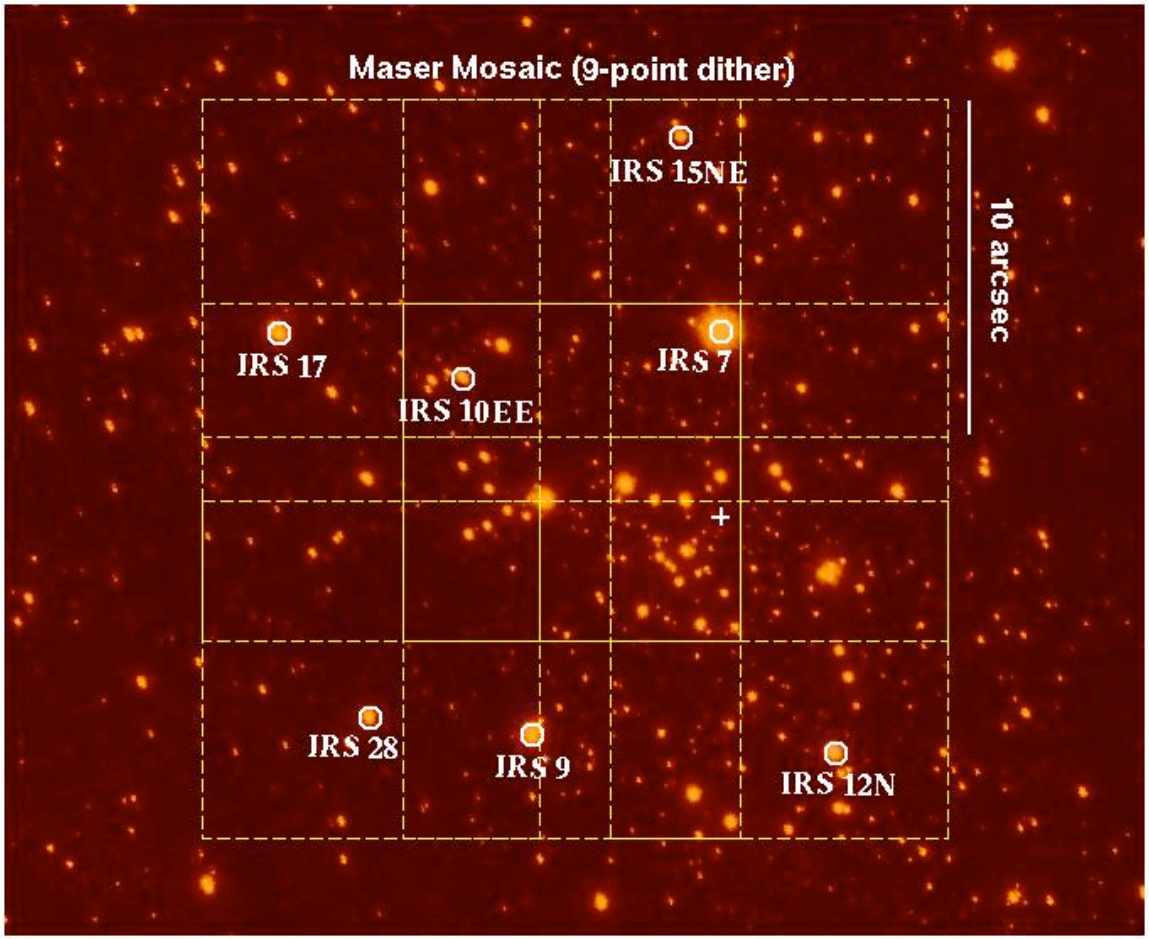
- on-sky experiment -- dense star field

- field with existing ACS data
    - good astrometric check
    - ACS/HRC distortion known to better than 0.01 pixels (0.3 mas).

- Design experiment similar to HST WFPC2/ACS experiment for self-consistent distortion solution
    - large dither pattern
    - multiple rotation angles
    - need weather info (P, T, humidity)

- Key to ACS experiment's success:
    - account for spatially varying PSF
    - model fine-scale distortion as filter dependent

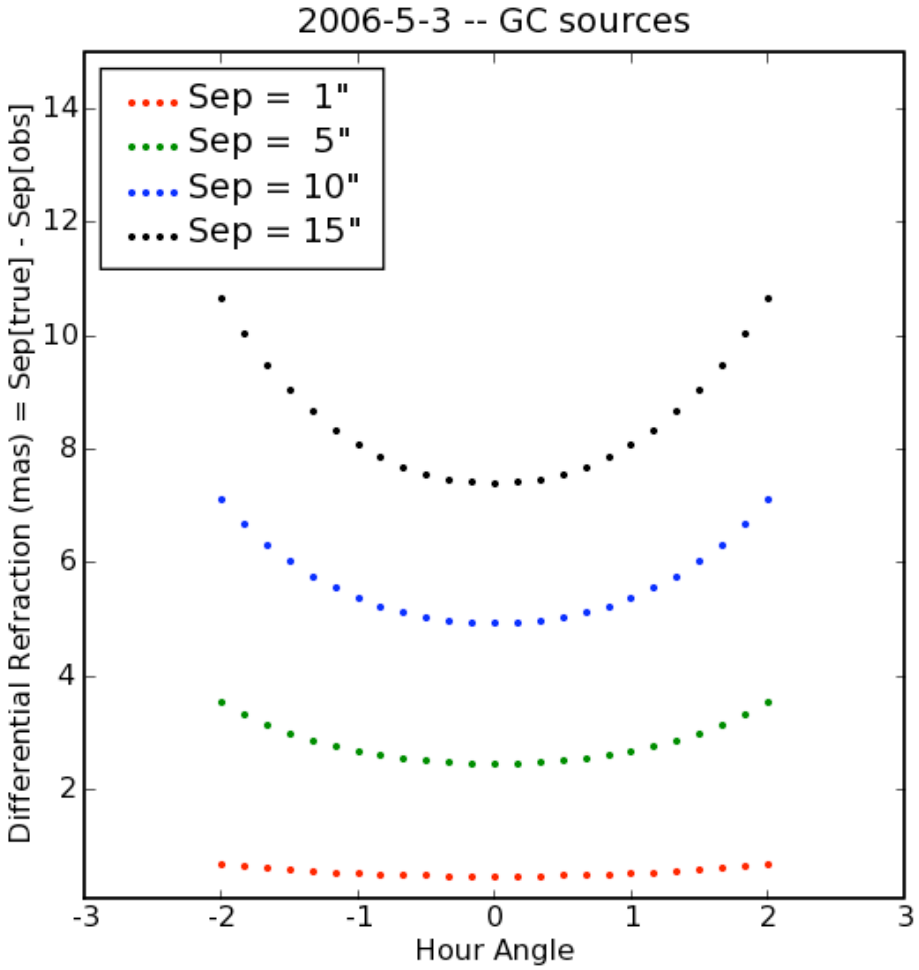
Absolute astrometry achieved by tying the IR frame to an radio reference frame (via radio masers in IR stars).



- use 7 masers to align (r_{avg} = 10”)
- predict IR position of Sgr A*
- compare to radio position of Sgr A*
- difference:
  - dx ~ 1 mas
  - dy ~ 10 mas
- large dY from differential atmospheric refraction??

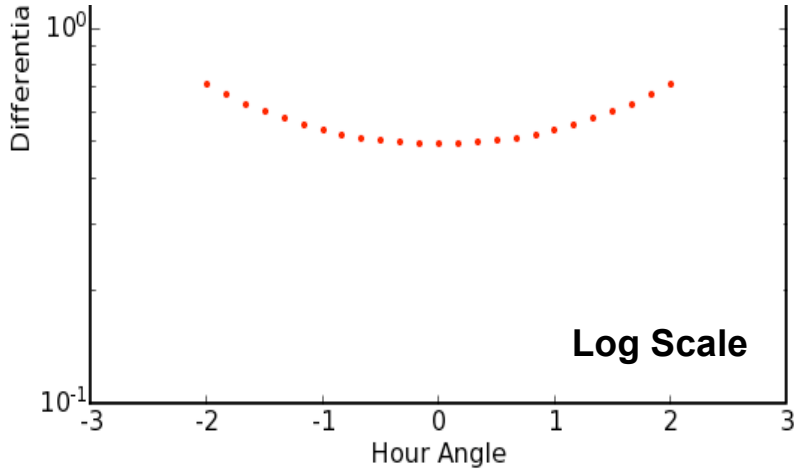
Accuracy of ~10 mas over 20”

Differential atmospheric refraction (DAR) contributes to both absolute and relative astrometry.

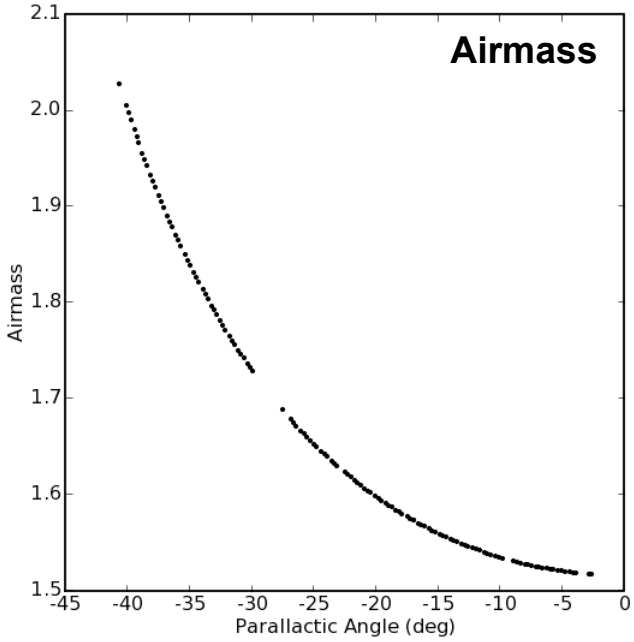


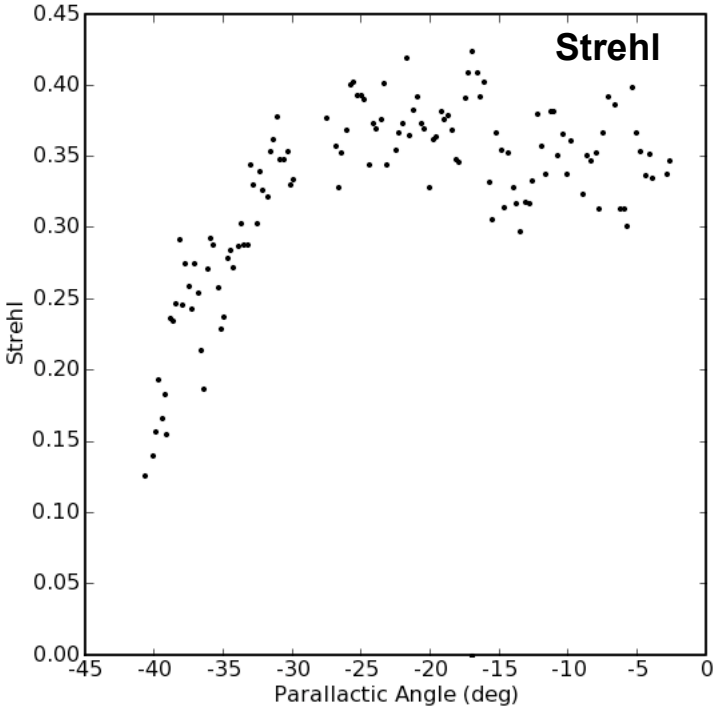
- DAR at transit contributes ~5 mas every 10” in the maser mosaic.

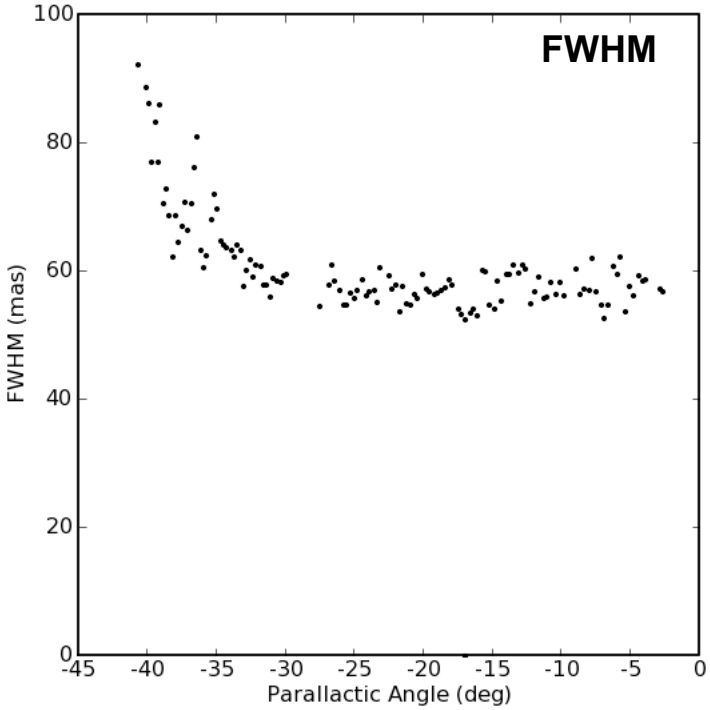
- change in DAR across night introduces error along the zenith direction… can we detect?



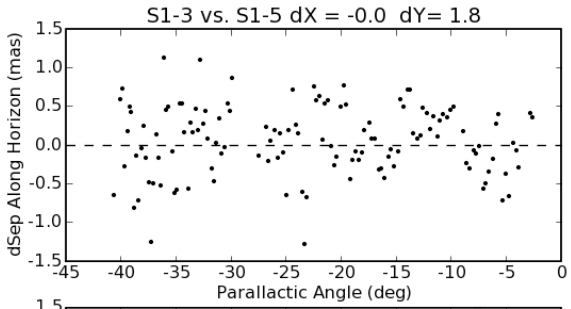
DAR analysis - 2006 May

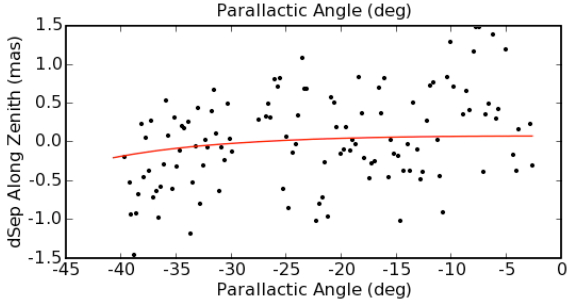


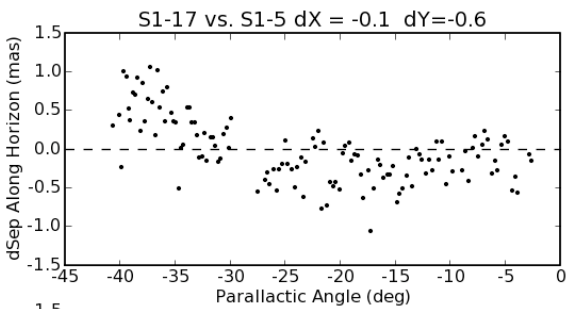


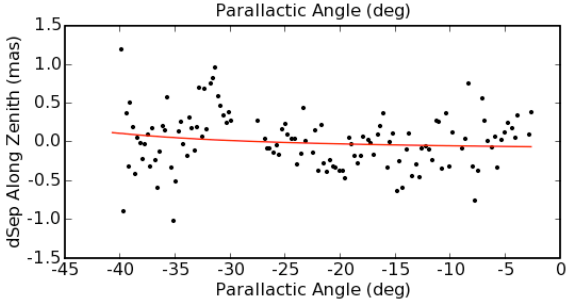


Star separations show systematic trends not consistent with DAR alone.





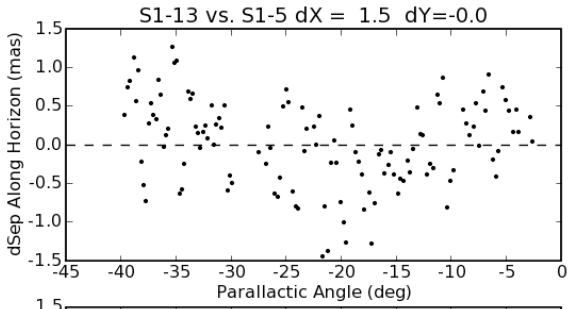


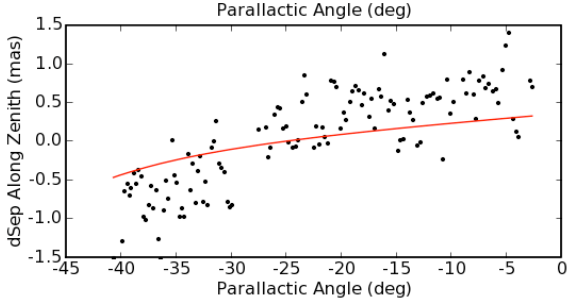


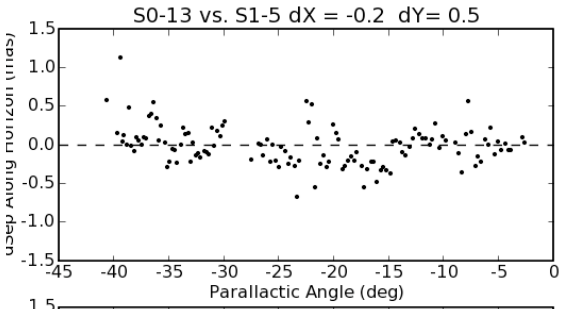
Small separations

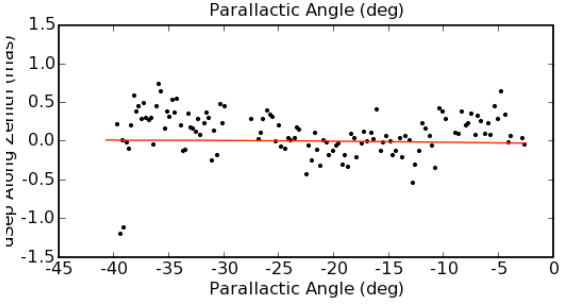
<== horizon axis

<== zenith axis







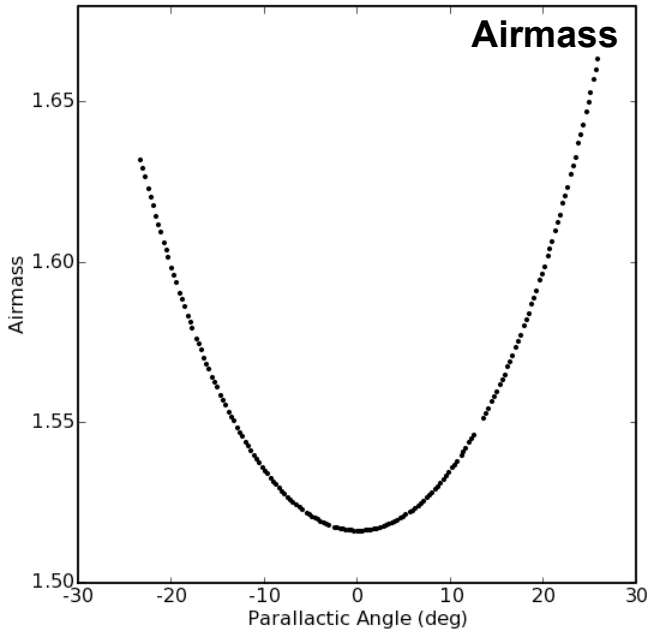


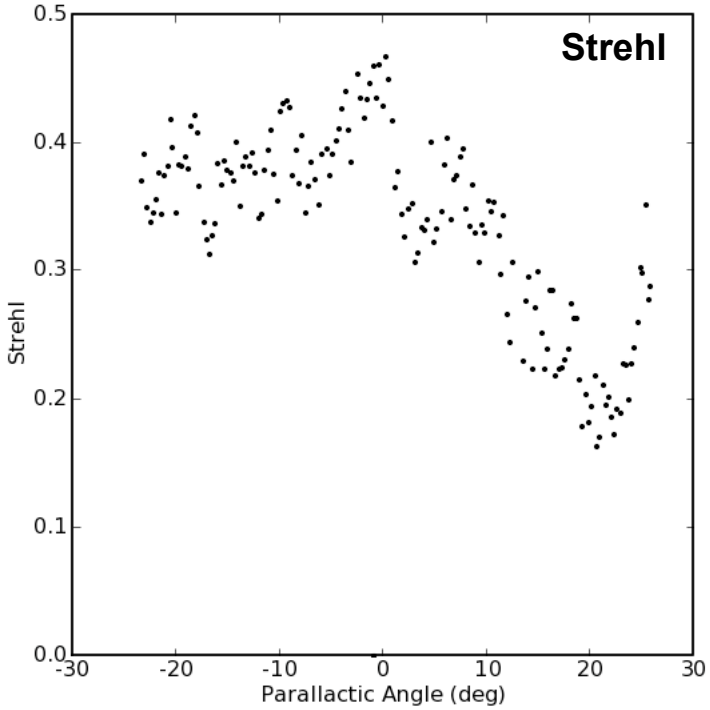
Large Separations

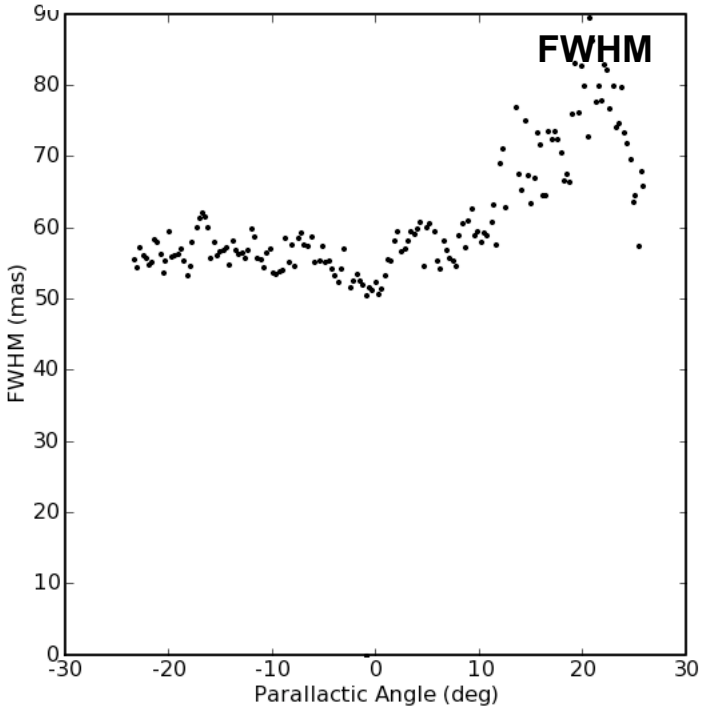
<== horizon axis

<== zenith axis

DAR analysis - 2006 June







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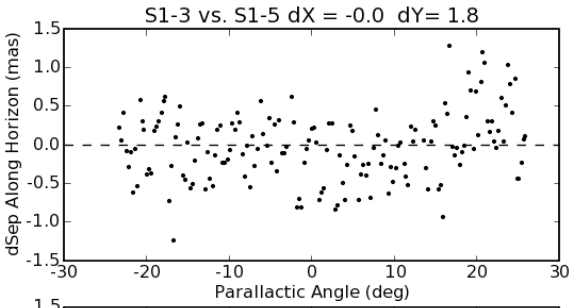
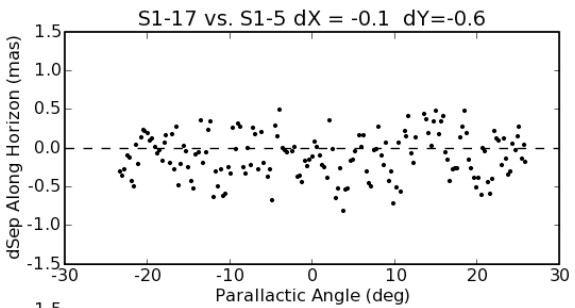
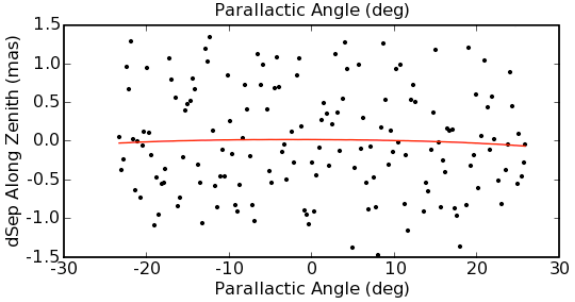
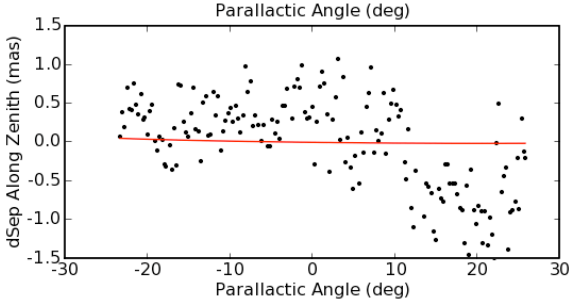
Small separations





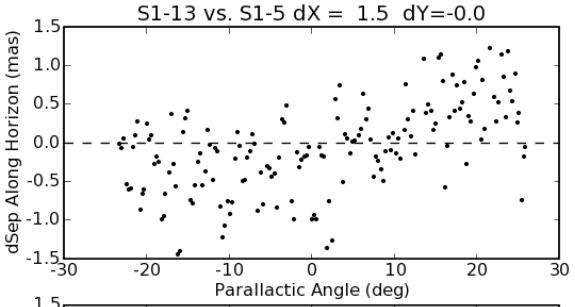
<== horizon axis

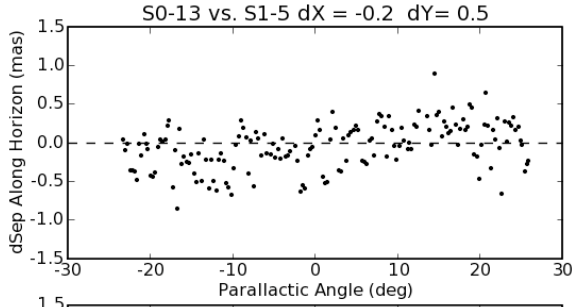




<== zenith axis

Large Separations





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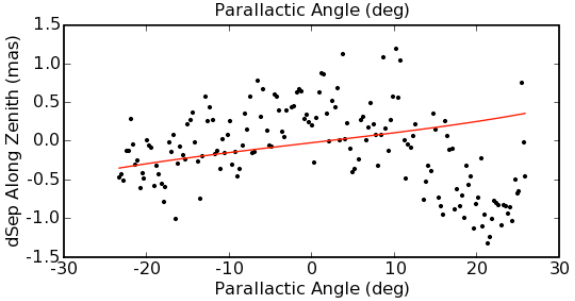

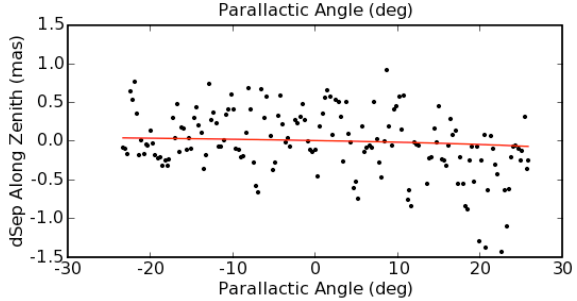

<== zenith axis