Astrometry

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Outline

- GAIA as a target finder
- HST Astrometry
- AFTA Astrometry
    - Nearby M star survey
    - Optimizing for bright stars (Guyon et al. style pupil mask)

Gaia

- 8 µas astrometry per observations for 6 <G < 12
- 25 µas astrometry per observations for G = 15
- ~70 observations/star over 5 year period
- For bright stars (2 < G < 6), Lindgren reports "plan to derive the image centre from the wings, but since the image structure in the wings is very complex due to a combination of optical and CCD effects, and there are not many stars/ observations that can be used for the calibration, it is very uncertain...learn more during the commissioning."

Dec 19, 2013

Coronagraph Targets

- Gaia should be able to detect planets with m_p/M_* >24 μas and periods between 1 - 5 yr (Casertano et al. 2008)

$$\alpha = \left(\frac{M_p}{M_*}\right)\left(\frac{a}{1\ \mathrm{AU}}\right)\left(\frac{d}{1\ \mathrm{pc}}\right)^{-1}\ \mathrm{as}$$

- Uranus mass planet around a solar mass star would be detectable at distance where coronagraph is operating.

$$\left(\frac{M_p}{M_*}\right) > 2 \times 10^{-4}\left(\frac{\theta}{100\ \mathrm{mas}}\right)^{-1}$$

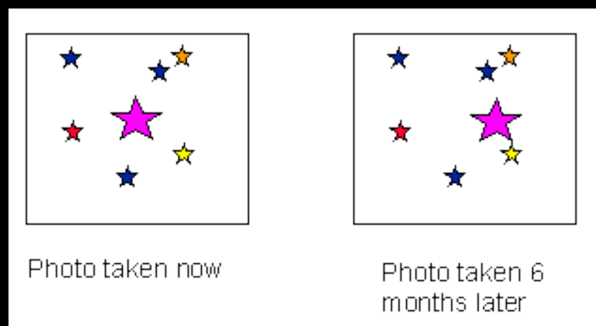
Target Stars

- Stars within 10 parsec:

2	$2 < V < 3$
5	$3 < V < 4$
7	$4 < V < 5$
17	$5 < V < 6$
13	$6 < V < 7$

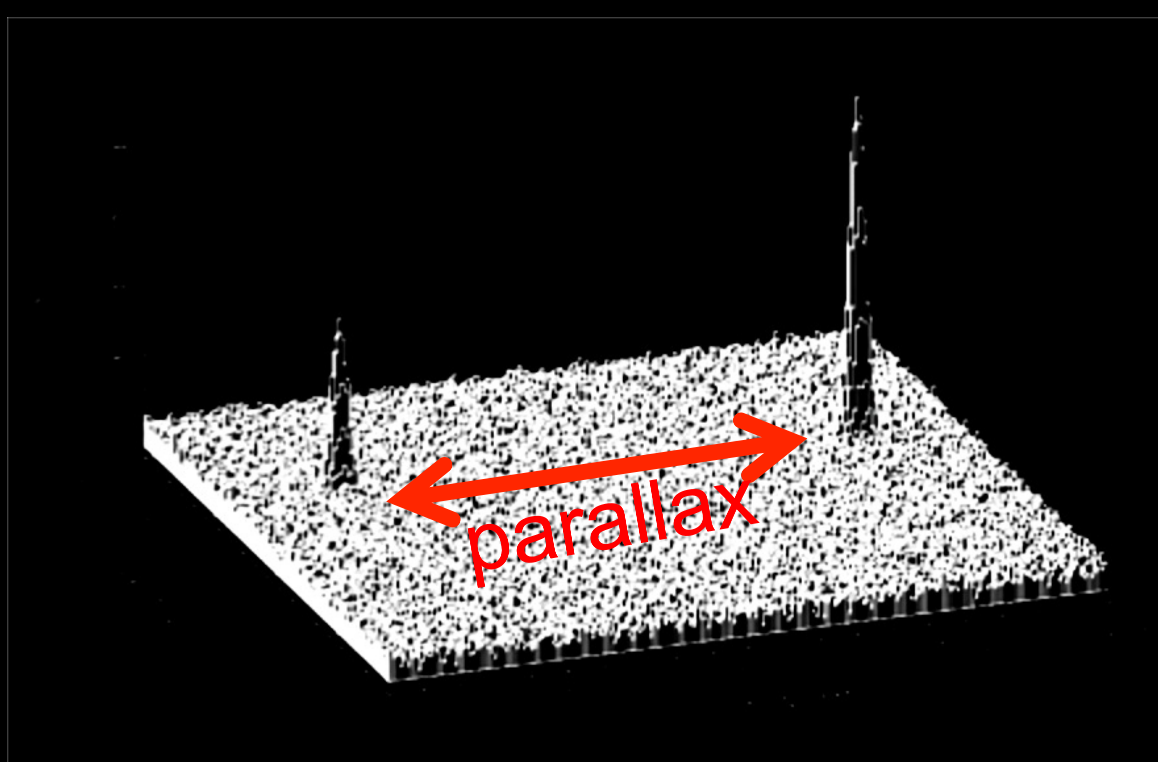
FROM ADAM RIESS

Precision Astrometry with Spatial Scanning (PASS)

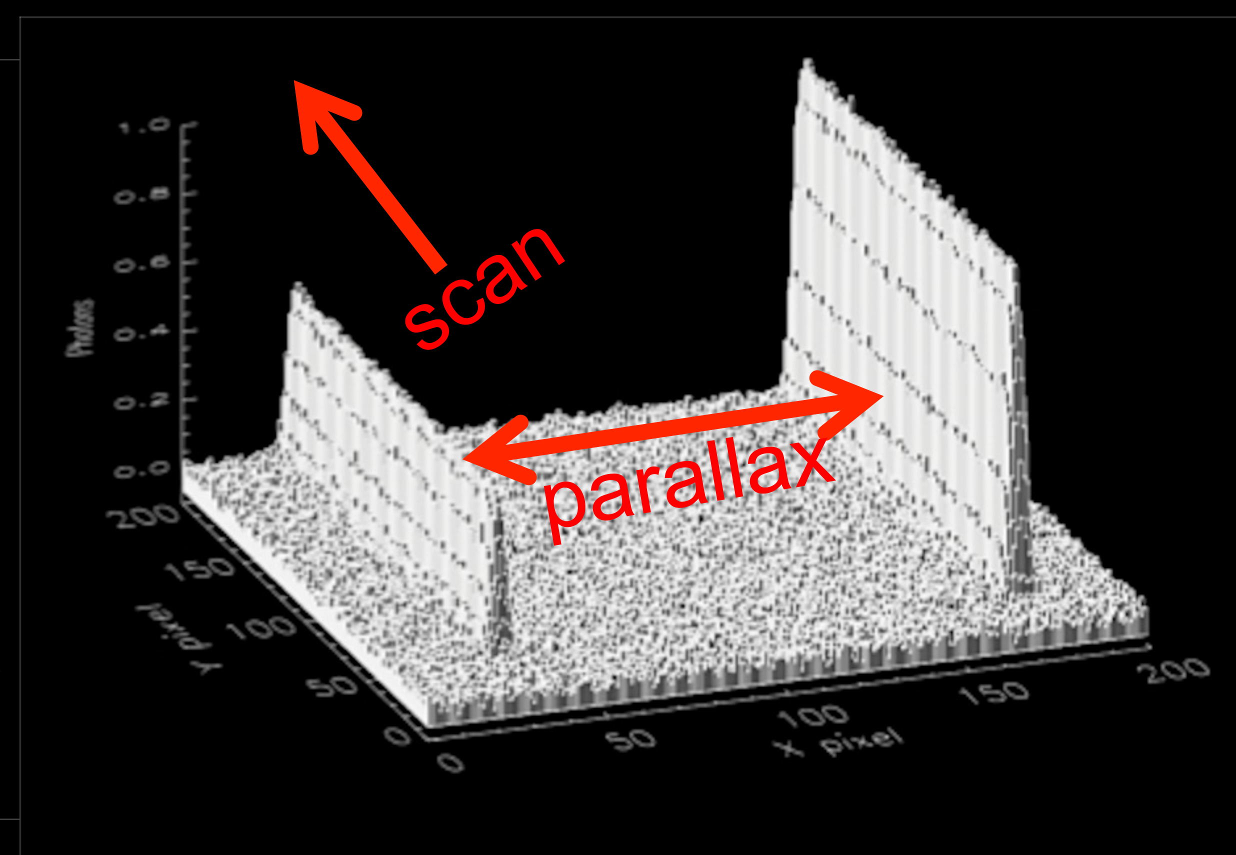


WFC3-UVIS, 0.01 pixel=400 μas~2σ @ 2 kpc

Imaging, PSF σ_θ=0.01 pix



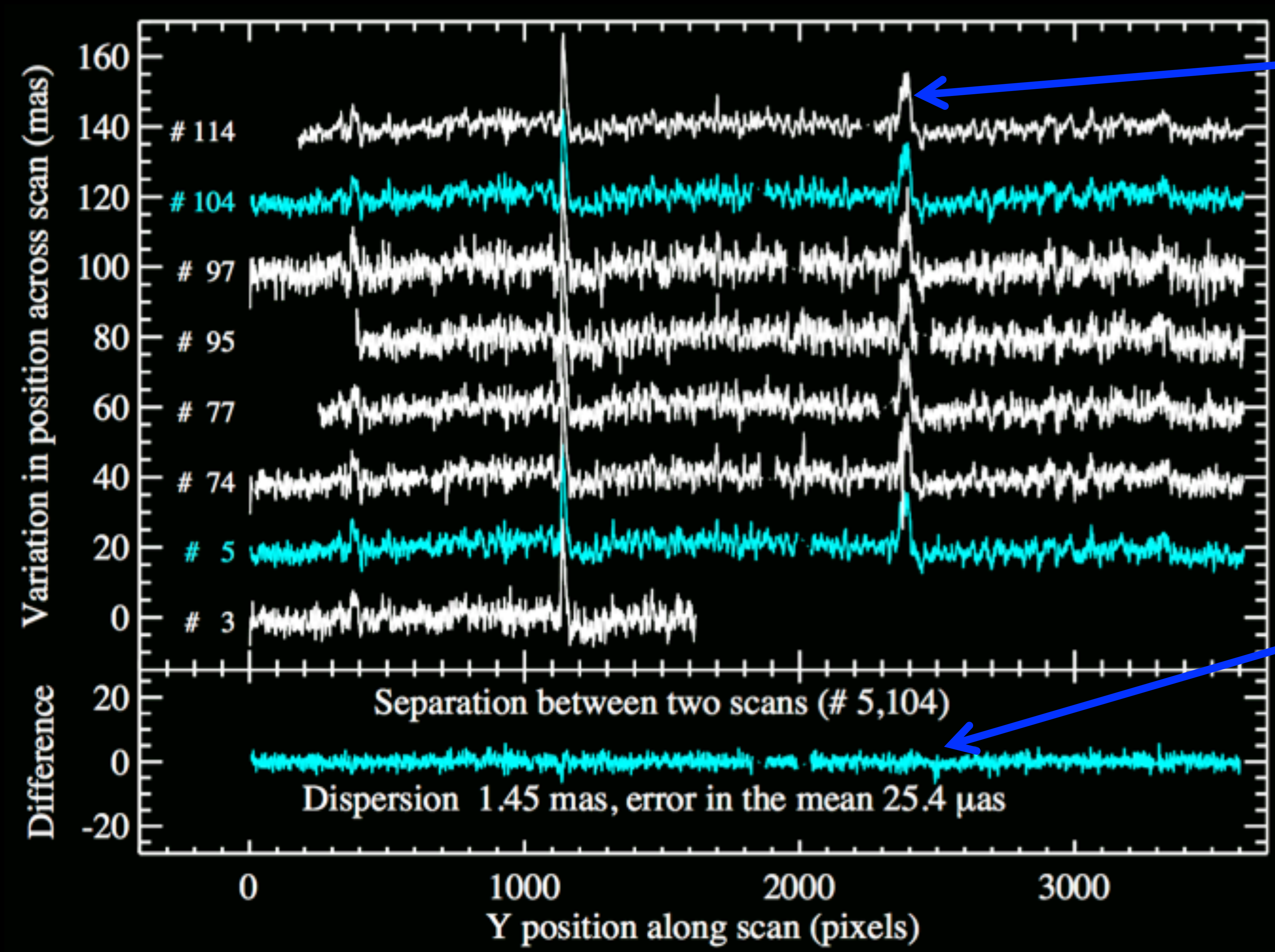
Scanning, $\sigma_\theta=0.01/\sqrt{N \text{ samples}}$ pix



FROM ADAM RIESS

Two Features of Spatial Scans, Jitter and Repetition

Average all scan lines to produce “reference line”

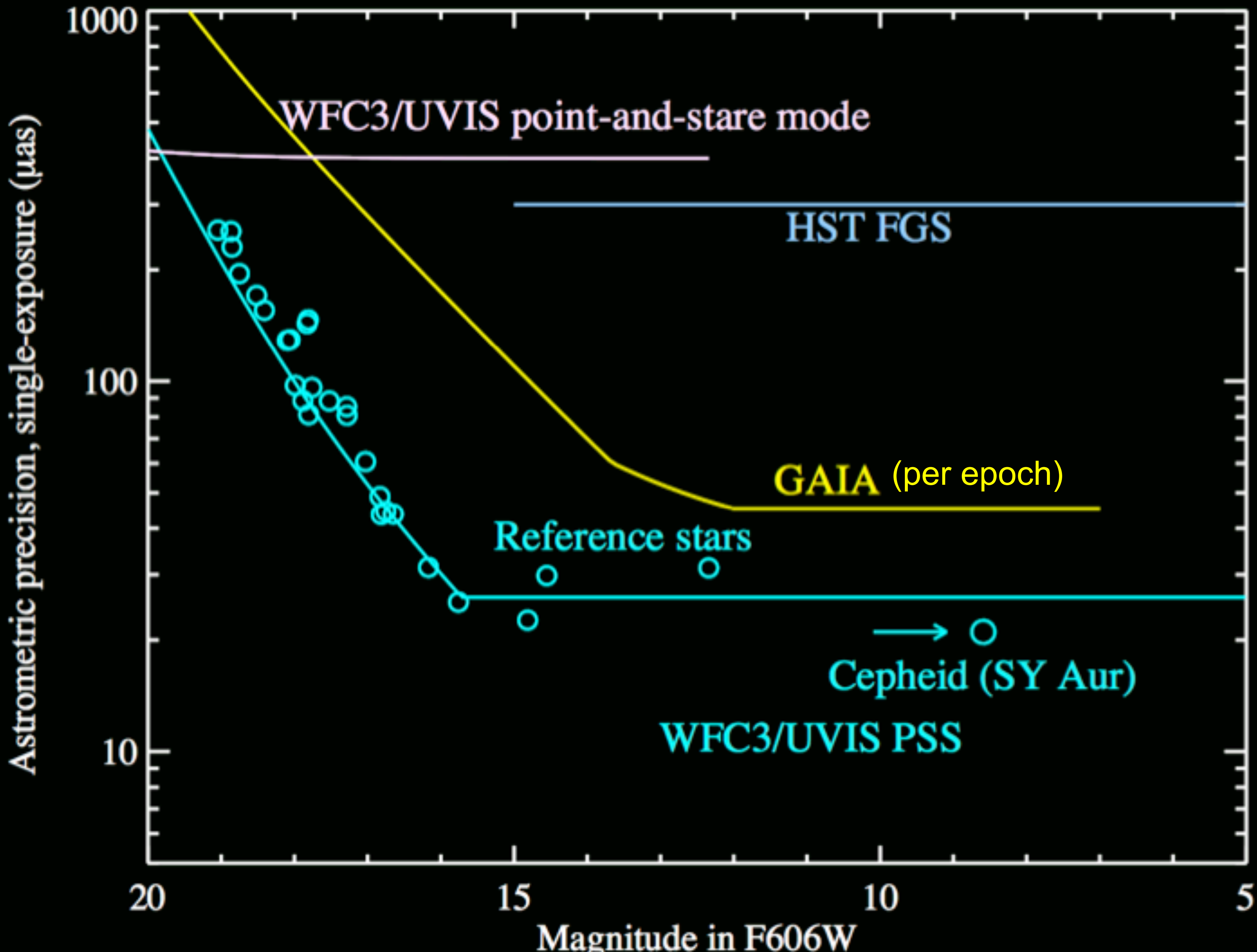


Jitter between lines is *coherent*, subtracted in line separations (vs time) *approach is doubly differential*

Target scanned over ~4000 pix, improves snr by up to ~40 (or 10 for correlated errors on scales of 40 pix)

FROM ADAM RIESS

Astrometric Precision Per Exposure



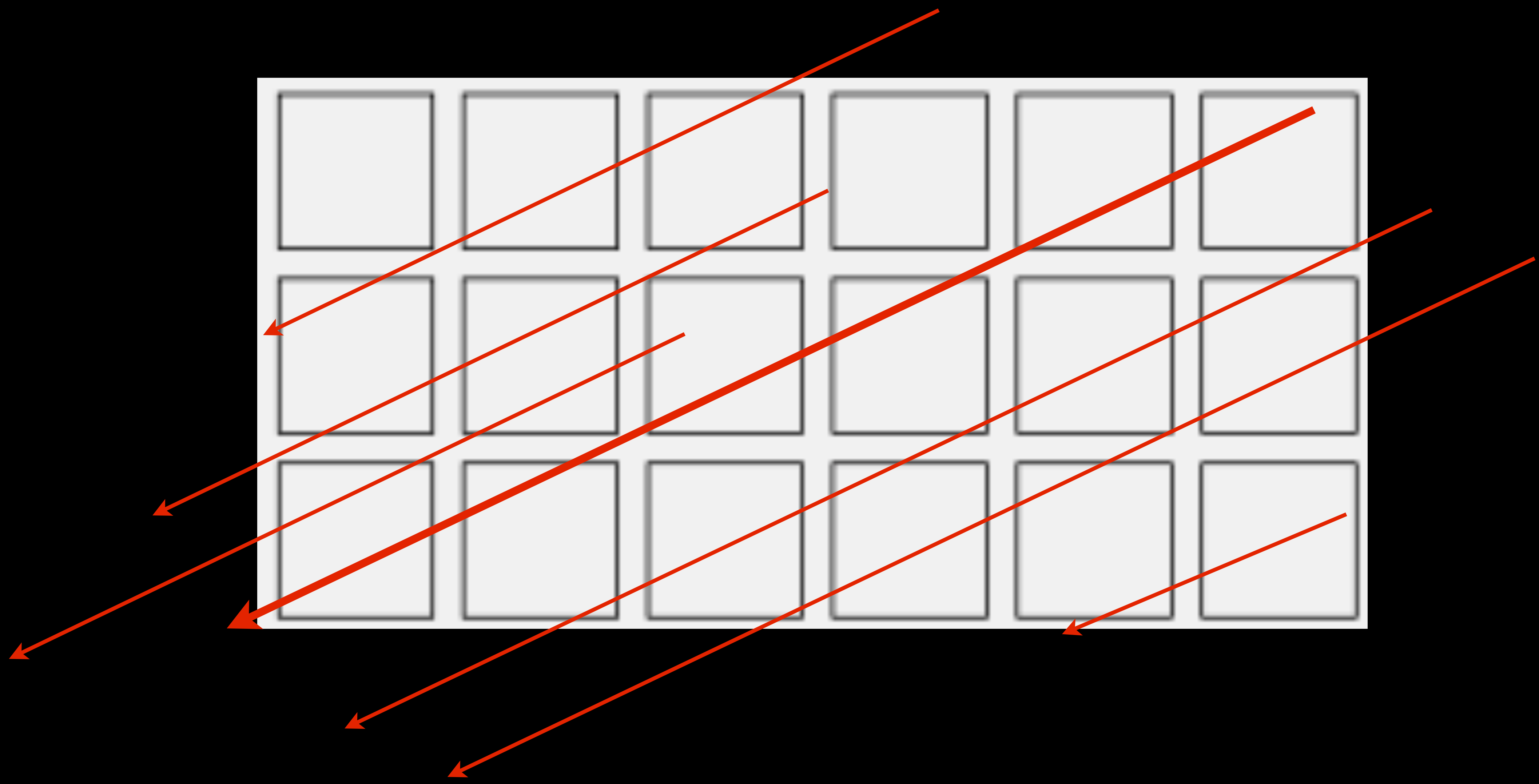
Need high snr *per pixel* so bright targets give best results (350 sec scan In F606W)

And we can measure Cepheid photometry on same system

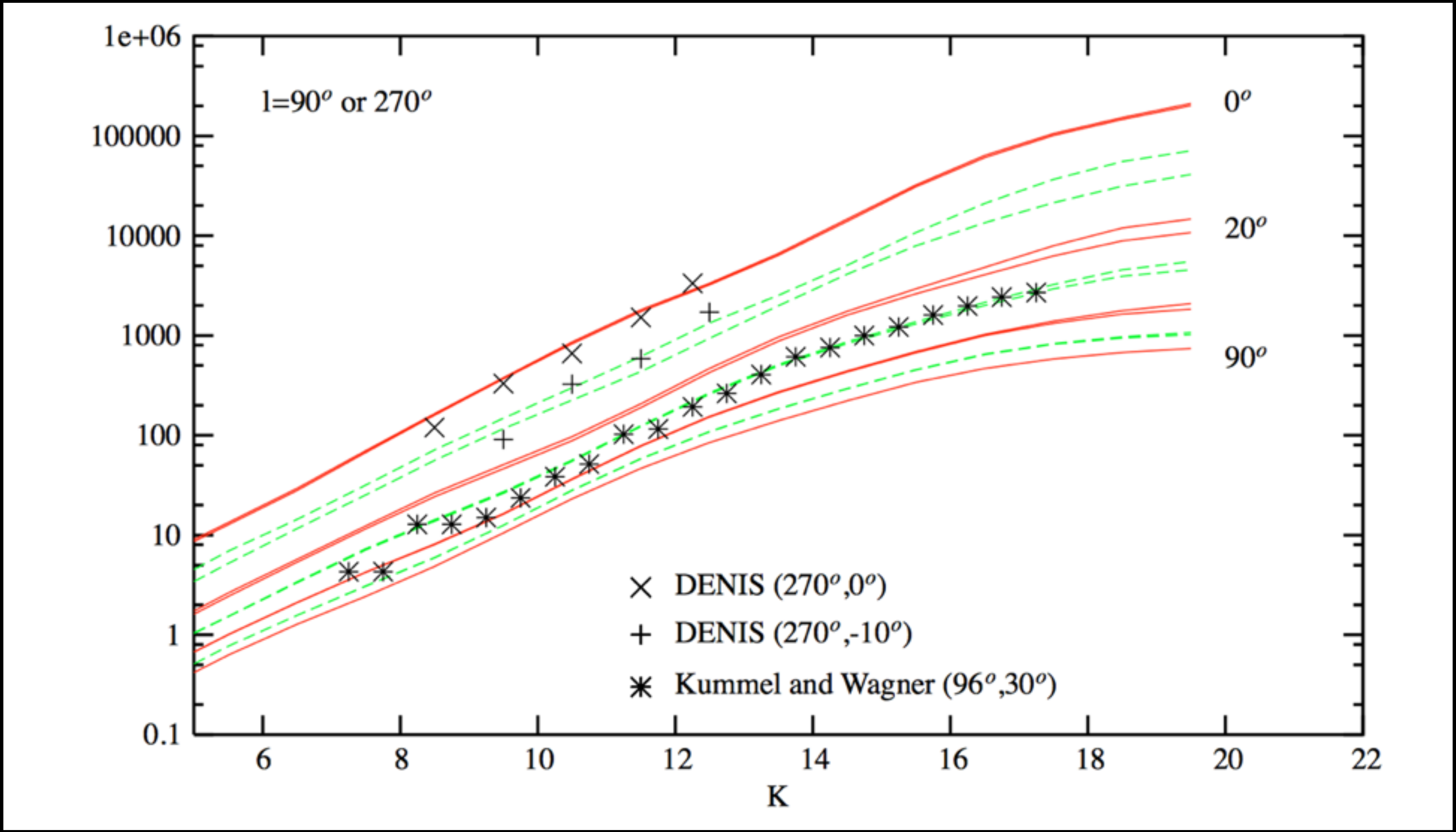
Applying Same Approach to AFTA

- Bigger camera should enable improved sensitivity- scales as $\sqrt{N_{pixel}}$
- At J=13.5, S/N = 400 and saturate central pixel in one second (WFC3 simulator).
- In a 3 minute integration, stars brighter than J = 19 are saturated.
- Scan at 3 degree/minute = 1600 pixels/second
- Spreads signal over 24,000 pixels
  - Assume 5x improvement over HST's 1/2000th pixel performance or 1/100th of a pixel /$\sqrt{24{,}000}$ (7 μas)
- Repeated 30 second integration. Achieves 10 μas astrometry for J < 10 in each integration, 50 μas for the ~30 stars with J < 14 and 200 μas for ~200 stars with J < 19

Scanning



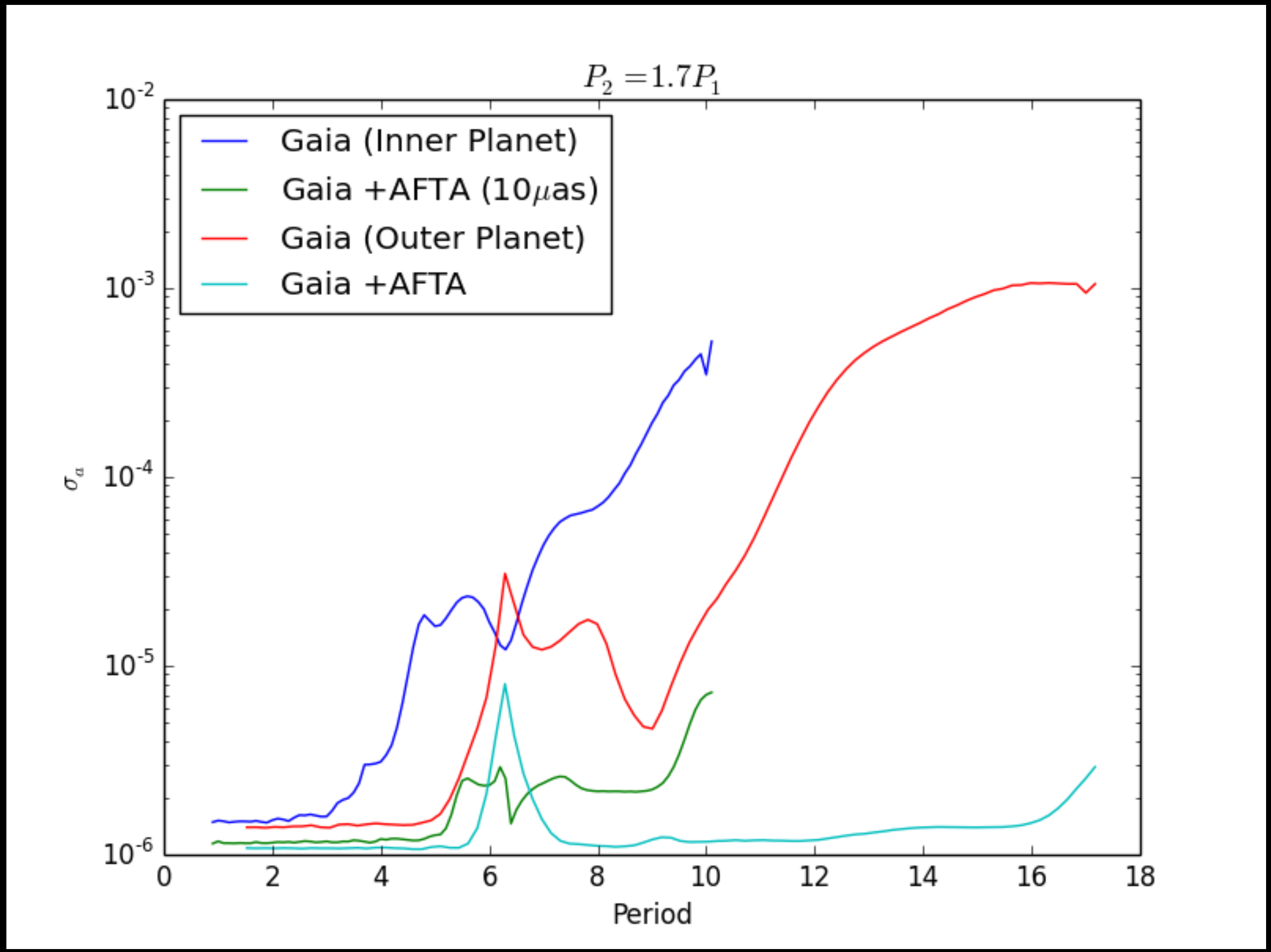
- Ties together detectors, determines Zernicke's



Robin et al. 2003

Nearby K and M Star Survey

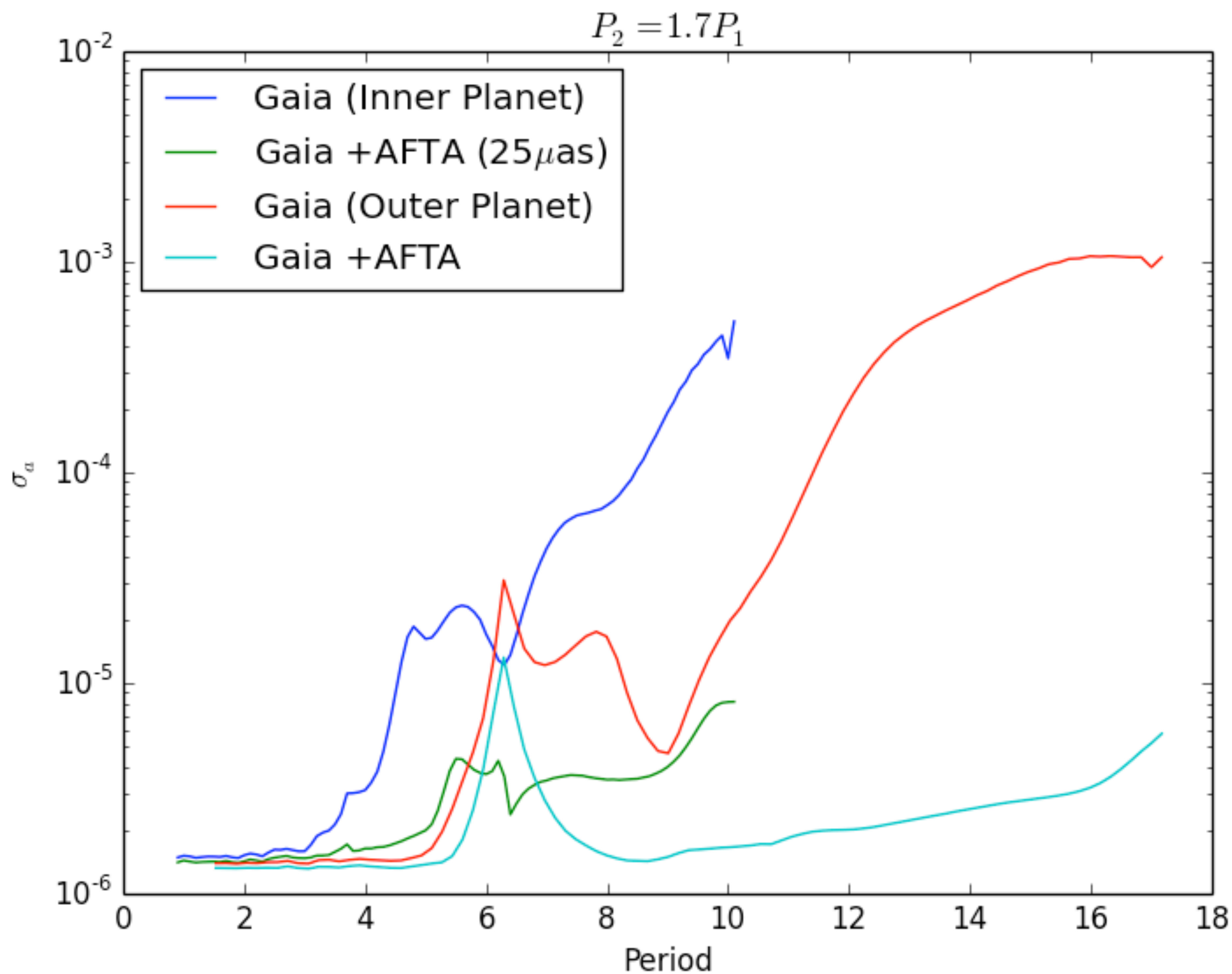
- Combine GAIA and AFTA data for 5 < V < 12 and J > 3 stars.
- Make use of 15 year baseline!
- 119 stars (G8-M4.5) d< 10 pc
- Can detect Earth mass planets around nearby stars with period less than 18 yr
- 8400 obs. x 2 min= 280 hr



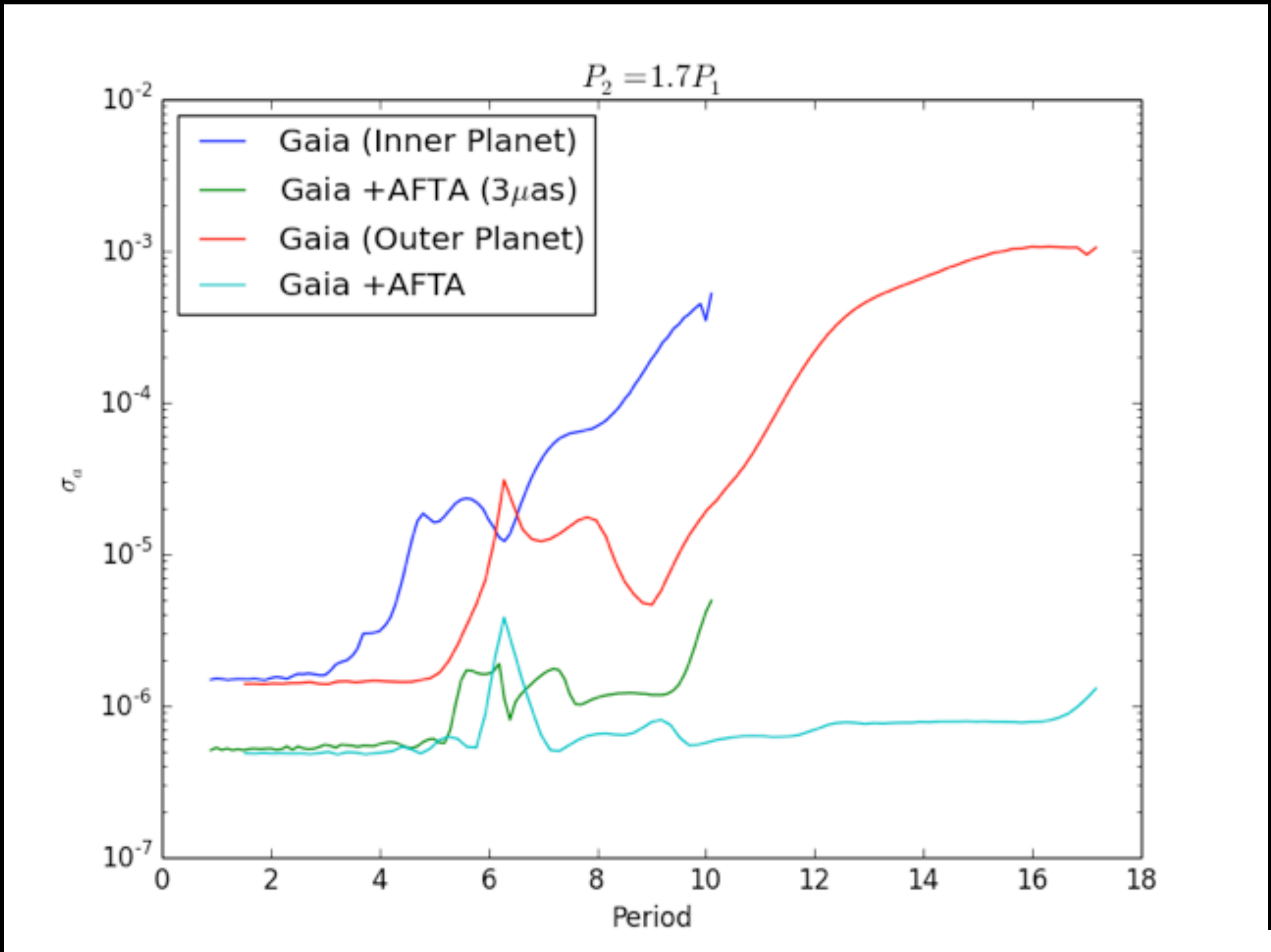
$$M_p > 3\ M_{\rm Earth} \left(\frac{d}{7\ {\rm pc}}\right) \left(\frac{M_*}{0.5\ M_\odot}\right)^{2/3} \left(\frac{\tau}{3\ {\rm yr}}\right)^{-2/3}$$

- Estimate sensitivity based on 70 Gaia + 70 AFTA observations and Fisher mtrix for 19 parameters (position, prop. motion, parallax and 2 planets x 7 parameters)

2x HST astrometry - 25 µas



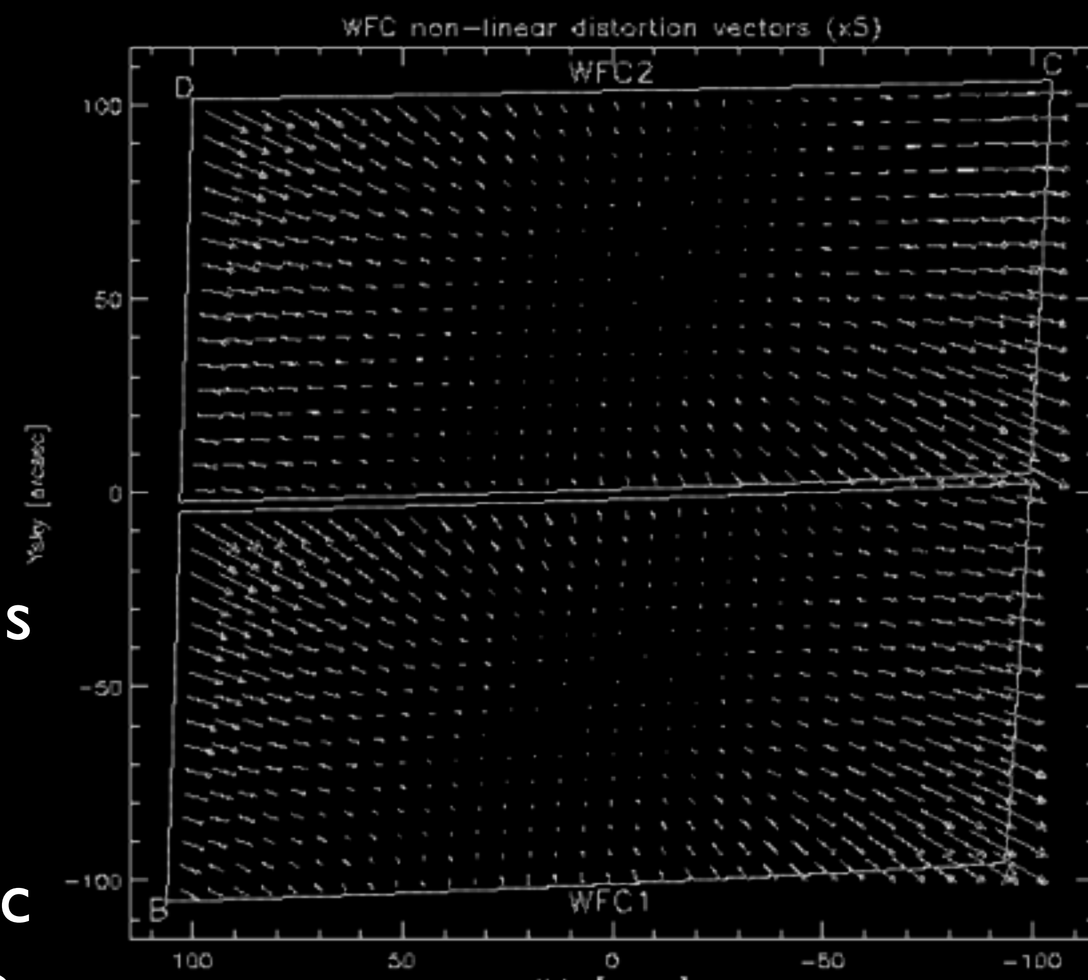
Optimistic Case (10 repeated slews x70 observations)



$$M_p > M_{\rm Earth} \left(\frac{d}{7 \text{ pc}}\right) \left(\frac{M_*}{0.5\ M_\odot}\right)^{2/3} \left(\frac{\tau}{3 \text{ yr}}\right)^{-2/3}$$

Astrometry + PSF

- At high latitudes, there are 10 Gaia stars with positions better than 10 µas positions, 100 stars with 25 µas positions and thousands of stars with mas astrometry. Augment HLS with a quick astrometric observation to tie the ~1000 K =17.5 - 20.5 mag stars to the GAIA grid with sub-mas astrometry?
- Very accurate determination of aberrations in each image. Significantly better than science requirements for imaging survey
  - Ratio of image distortion to astrometric displacement is roughly proportional to ratio of image size to FOV!



Astrometric Calibration of Image

- Need to study ability to fit for detector positions, orientation (6 parameters x 18) + lower order Zernike's to positions of star tracks
- Technique has been used for calibration of wide field images with Space Surveillance Telescope in New Mexico (Pearce et al. [Lincoln Labs])

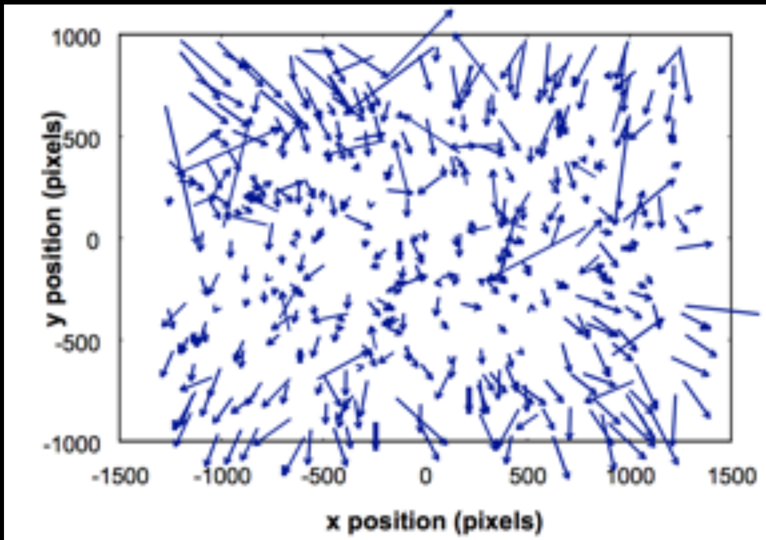
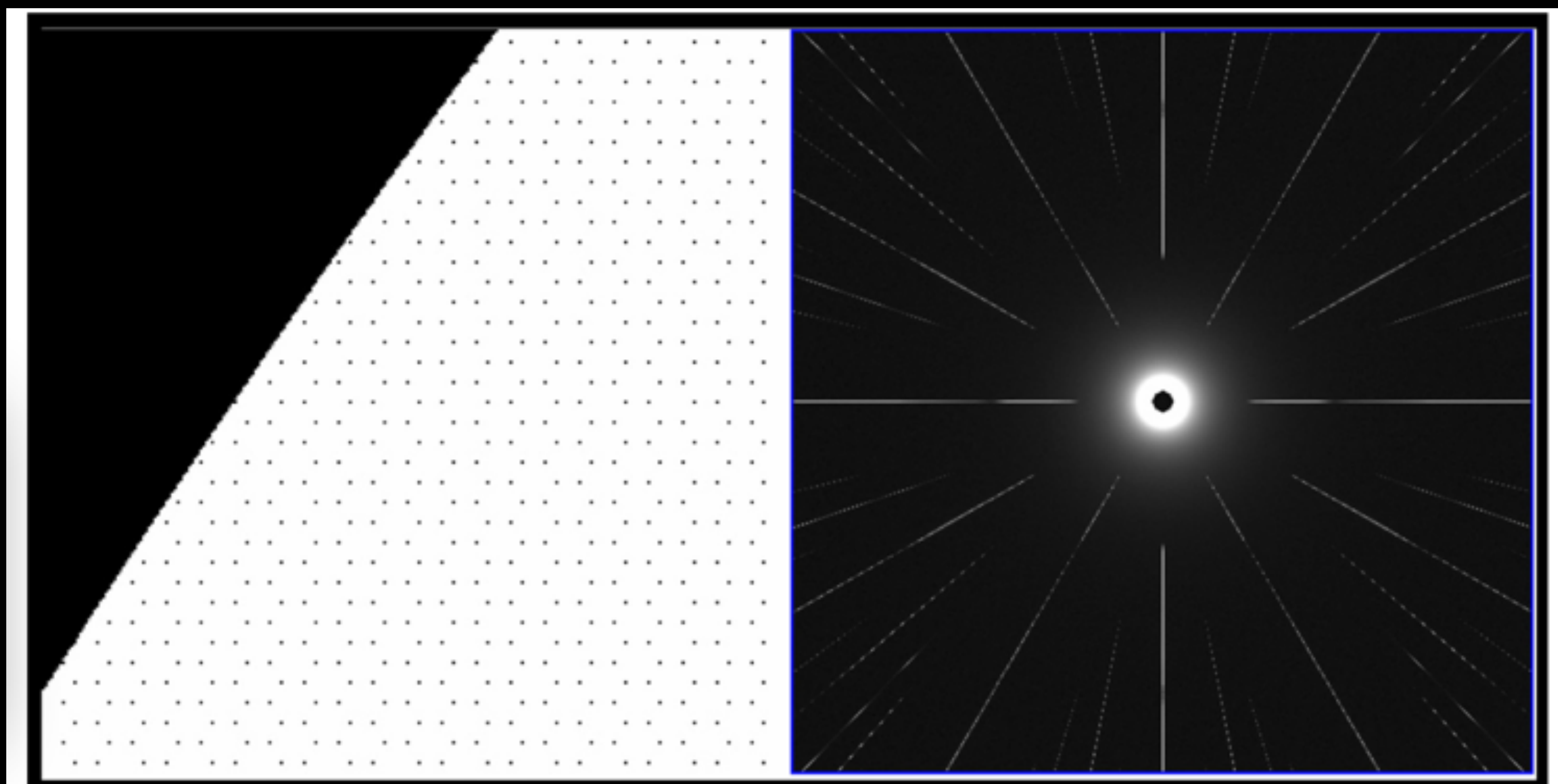


Figure 3. Vector Error Plot of GEODSS Decentering Error.

Alternative Astrometry Approach



- Based on Guyon et al. (2013)
- Put mask in front of one of the filters (Z?, J?)
- Filters near pupil plane

Exoplanet Astrometry

- Stare at field for 30 second integrations
- Use J < 17 stars to define reference frame - 200 reference stars across camera
- Multiple images at different orientations?
- Joint GAIA/AFTA astrometry on bright stars (V < 12) should detect Earth mass planets with periods less than 18 years around all stars within 10 pc!
- Provides complete target list for coronagraphy

Astrometry + Weak Lensing

- At high latitudes, there are 10 Gaia stars with positions better than 10 μas positions and 100 stars with 25 μas positions
- AFTA HLS images with astrometric pupil provide positions of these stars across 0.5 x 0.5 degree field to get absolute distortions of the field.
- Very accurate determination of aberrations in each image. Significantly better than science requirements for imaging survey
    - Ratio of image distortion to astrometric displacement is roughly proportional to ratio of image size to FOV!

Conclusions

- Astrometry from Gaia should provide important pre-cursor science
- AFTA has the potential to carry out exciting exoplanet astrometric science
- Modifying the pupil can potentially enhance astrometric capabilities. This can enhance both exoplanet and dark energy science