Astrometry with Wide Field Infrared Survey Telescope (WFIRST)

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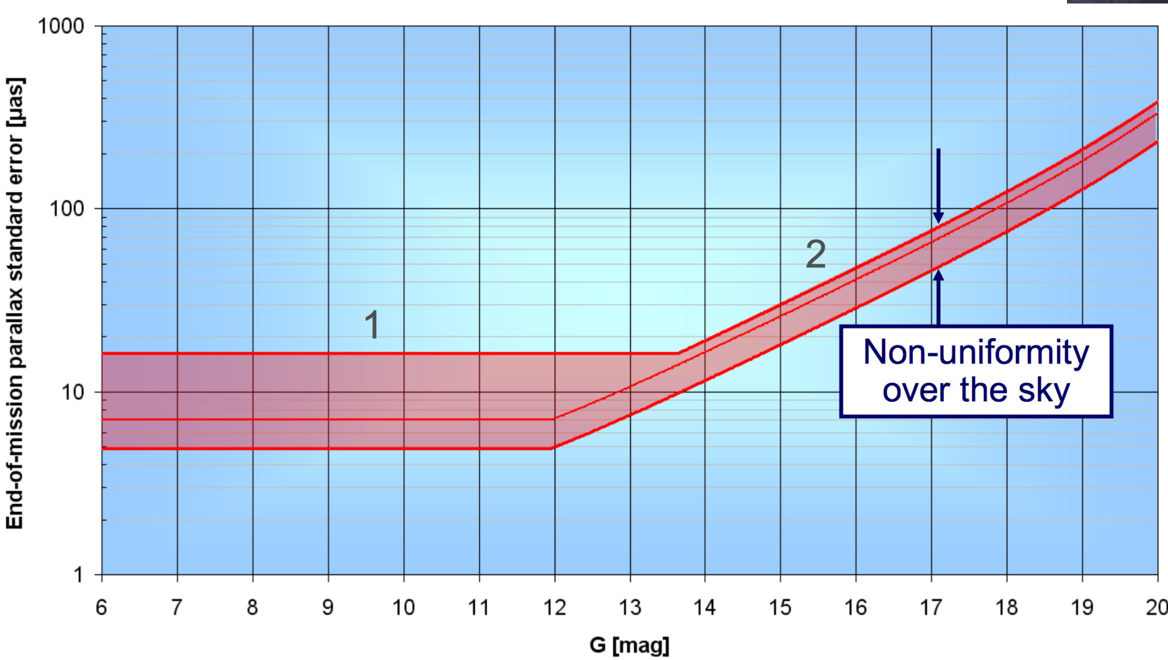
GAIA Revolution

- GAIA is mapping the sky now and will provide accurate astrometry for a billion stars across the sky. GAIA will provide an astrometric frame for calibrating WFIRST data.



eBruijne
ww.rssd.esa.int/gaia

GAIA and 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.

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

GAIA as a reference frame

- Even at the galactic poles, there are
  ~50 stars brighter than g=15th magnitude with 30 μas positions.
  ~500 stars brighter than 18th magnitude with 100 μas positions
  - At J=13.5, S/N = 400 and saturate central pixel in one second (reading up the ramp)
  - In a 3 minute integration, stars brighter than J = 19 are saturated. Store information as we read up the ramp.

- WFIRST should be able to position each of these stars to ~0.005 of a pixel, 500 μas

- These will provide a reference frame for calibrating distortions in the optics and the camera in every observation
  - These will provide a reference frame for calibrating distortions in the optics and the camera in every observation. We should be able to register camera to better than 50 μas
  - In a 3 min. integration, we should be able to obtain ~500 μas for stars brighter than 23rd magnitude

Observing Modes

- High Latitude Survey
  - ~20 observations per star spread out over ~5 years
  - Should have better than ~100 μas per year proper motions for stars brighter than 23rd magnitude
  - Extends GAIA's sensitivities 5-6 magnitudes fainter and into the infrared
- Bulge fields [See Papers by Gould and collaborators]
  - Repeated observations (40,000!)
  - Should achieve sub-μas astrometry (Systematic floor?)
- GO Mode
  - Like HLS, should get good absolute astrometry
  - Scanning mode (Riess et al. 2014)

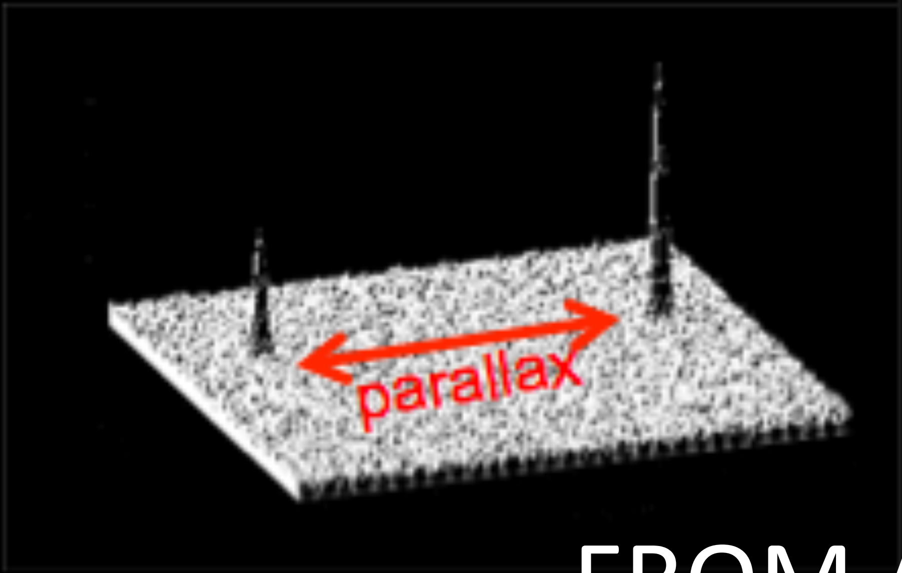
Science Applications

- Galactic astronomy (see papers in Appendices of 2014 SDT report)
  – Trace formation history of galaxy
    - Is the bar long-lived?
    - Use substructure to trace galaxy evolution
  – Dark matter
    - Extent of dwarf galaxies
    - Tidal tails: interactions with substructure, role as tracer of halos
    - Distinguish between CDM, warm dark matter, axionic dark matter by measuring masses and profiles of dwarfs (complements strong lensing [see Treu talk])
- Fundamental stellar astronomy: What will be the key questions after GAIA?

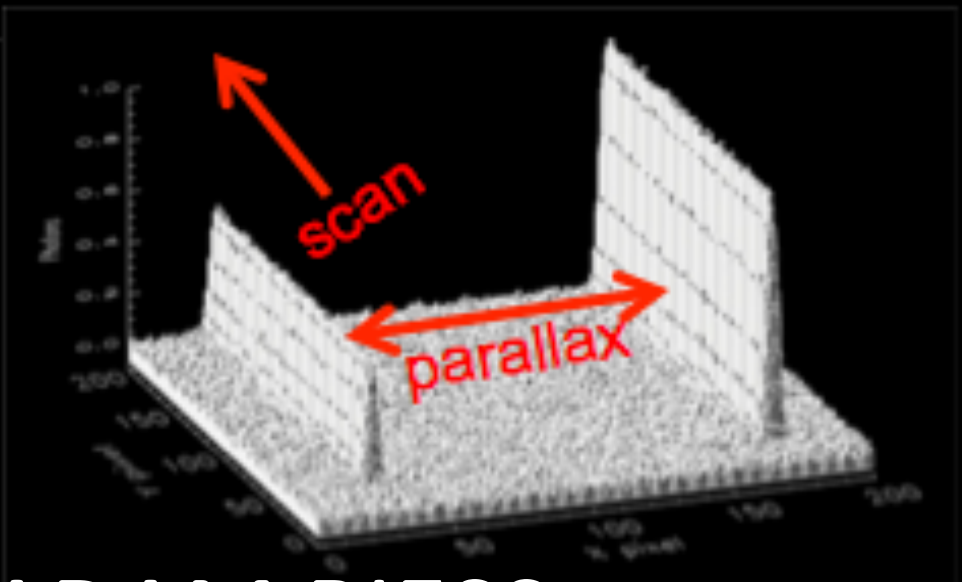
Precision Astrometry with Spatial Scanning (PASS)

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

Imaging, PSF σ_θ=0.01 pix



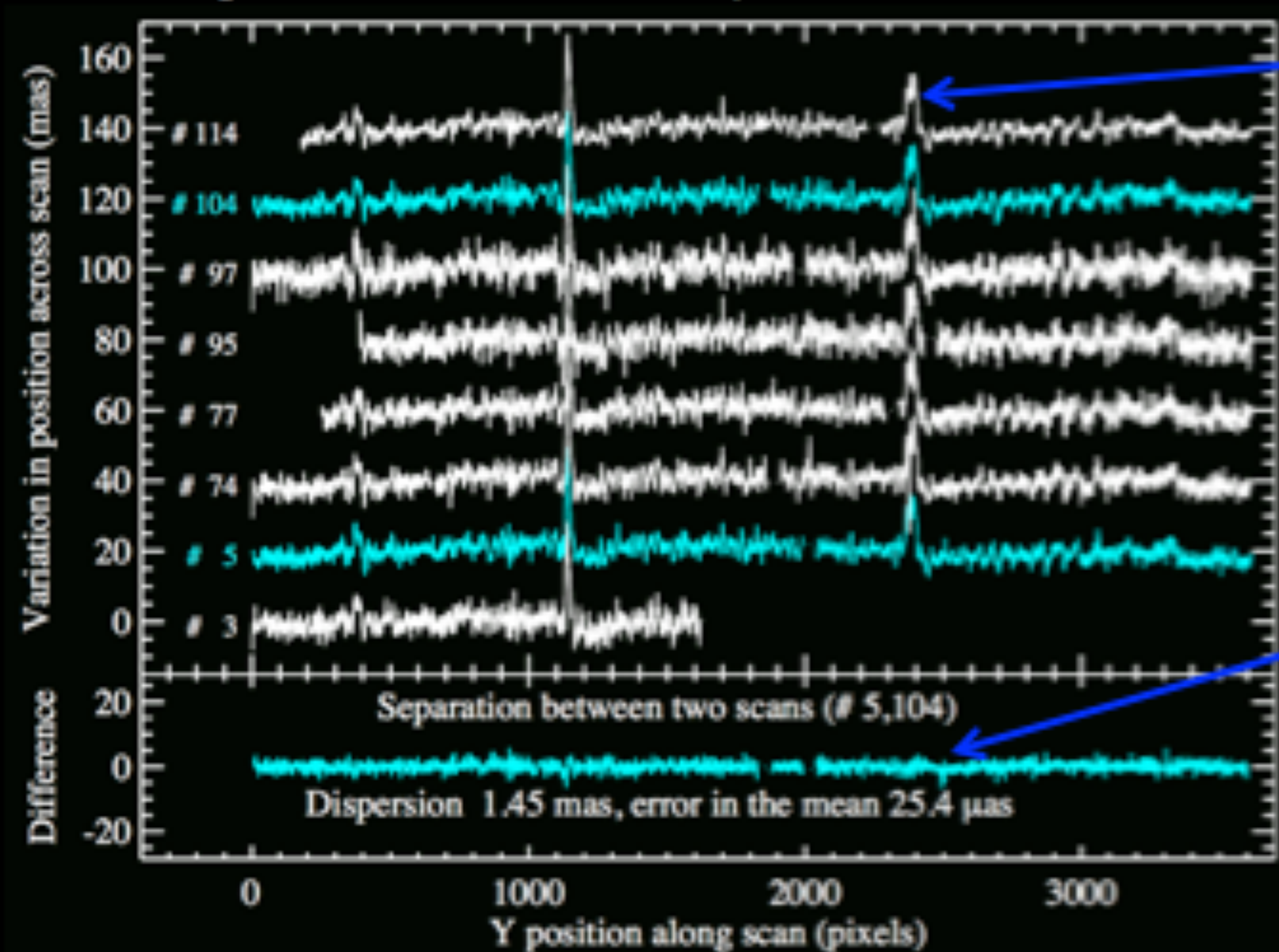
Scanning, $\sigma_\theta=0.01/\sqrt{N \text{ samples}}$ pix



FROM ADAM RIESS

Two Features of Spatial Scans, Jitter and Repetition

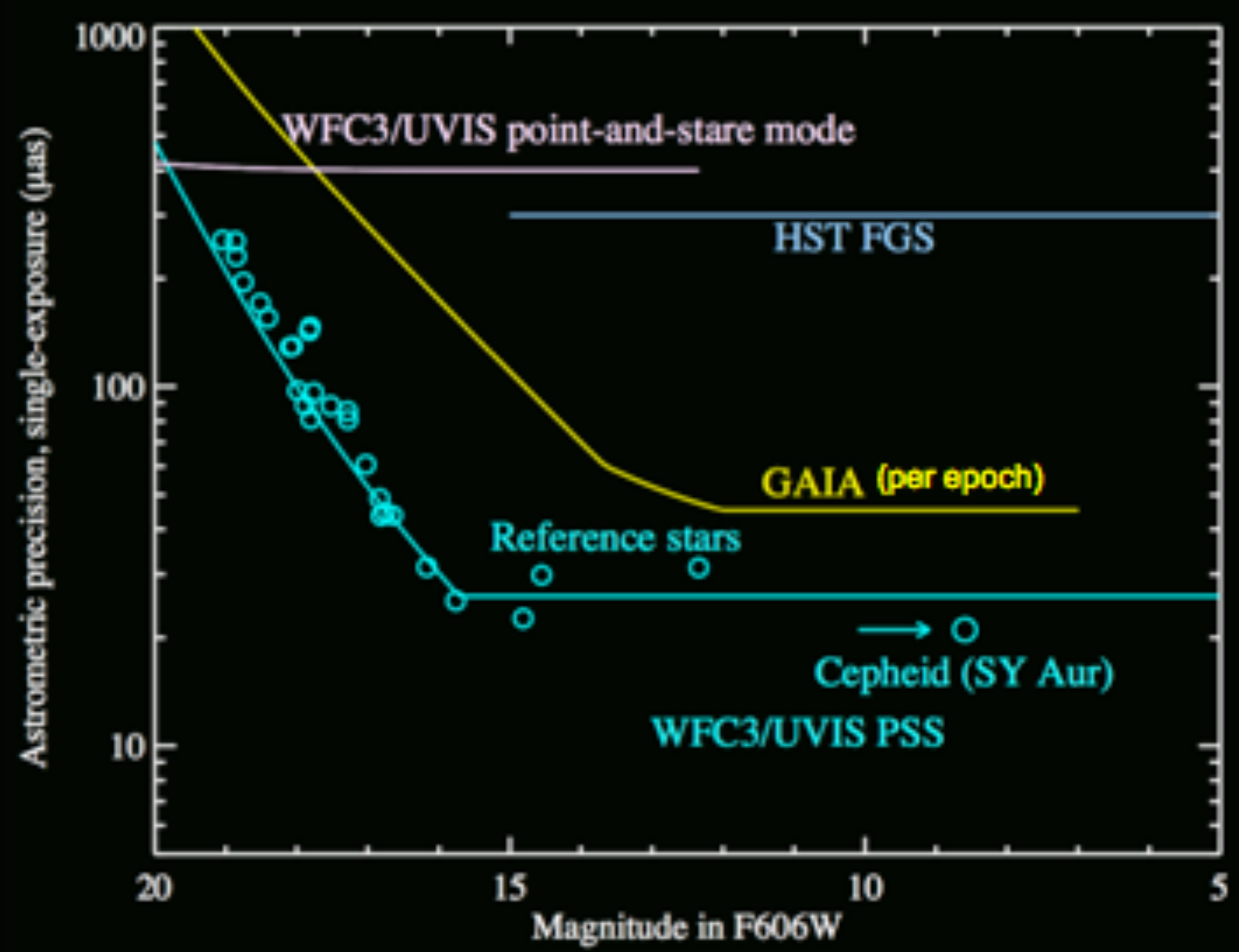
Average all scan lines to produce "reference line"



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)

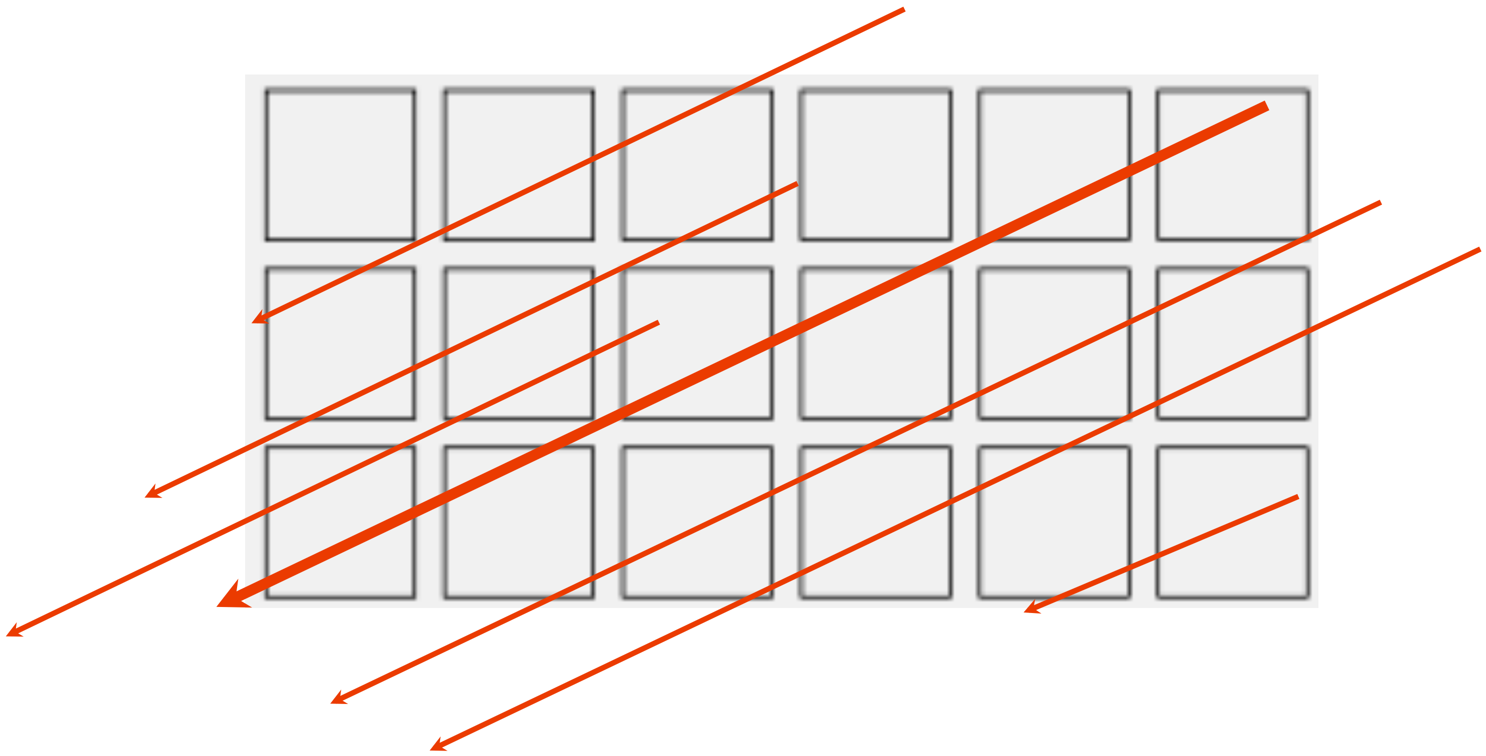
Astrometric Precision Per Exposure



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

Scanning



- Ties together detectors, determines Zernicke's

Exoplanets with WFIRST

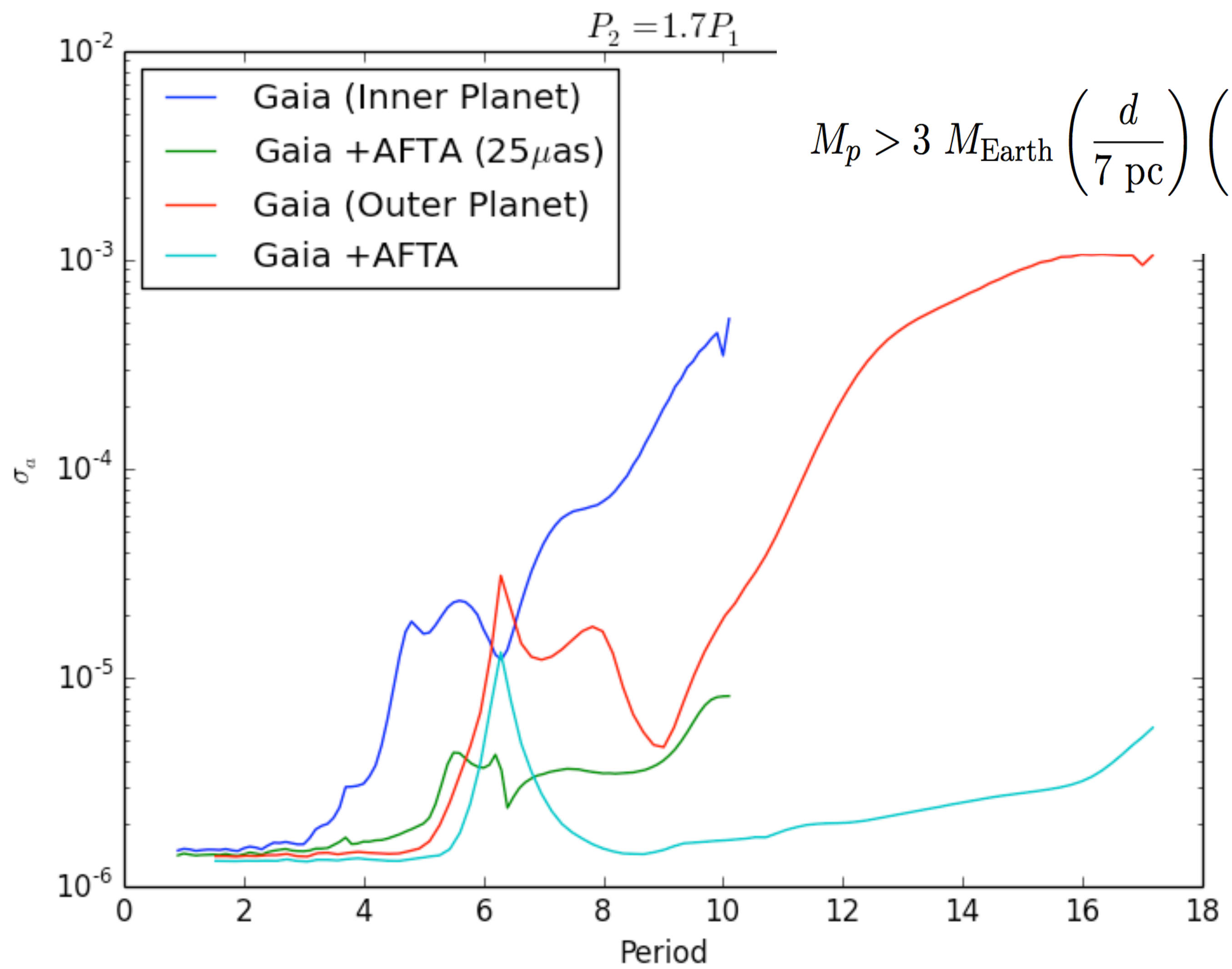
- Bigger camera should enable improved sensitivity- scales as $\sqrt{N_{pixel}}$
- Scan at 3 degree/minute = 1600 pixels/second (50% of maximum slew rate)
- Spreads signal over 24,000 pixels
  - Assume 5x improvement over HST's 1/2000th pixel performance or 1/100th of a pixel /√24,000 (7 μas)
- 6 Repeated 30 second integration with Wide band:
  - J=10 S/N ~100 in each pixel -> 7 μas
  - J=14 S/N ~14 in each pixel -> 50 μas
  - Saturates for J = 7 at 3 deg./min. Follow GAIA and use saturated trails
  - Assume that we can achieve 5 μas astrometry per observation per orientation. 3 min. obs yields 3 μas

Nearby K and M Star Survey

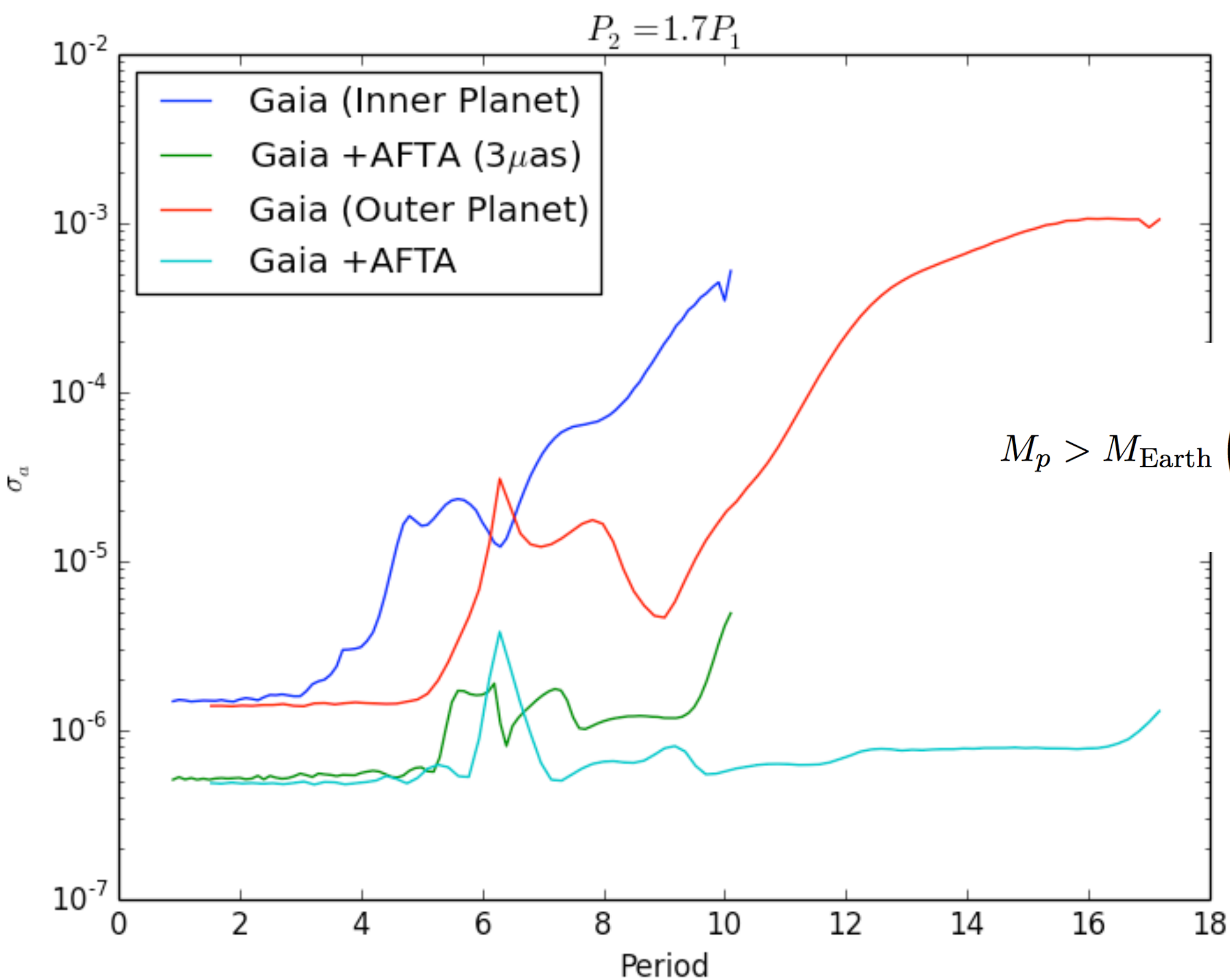
- Combine GAIA and AFTA data for $5 < V < 12$ and $J > 3$ stars.
- Make use of 15 year baseline!
- 119 stars (G8-M4.5) d< 10 pc
- Can detect Earth mass planets around nearby stars with period less than 18 yr
- 70 visits to each star:
  - 70 x 3 x 119 = 416 hrs (x overhead)

2x HST astrometry - 25 µas

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



Optimistic Case



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

Conclusions

- Astrometry from Gaia should provide important precursor science
- Gaia reference frame will register WFIRST data enable sub-mas astrometry for stars brighter than 23^{th} magnitude across the image
- Scanning mode could enable WFIRST to carry out exciting exoplanet astrometric science
- Scanning mode could also yield higher precision astrometry for dimmer stars– potentially, interesting GO observing mode