Astrometric Follow-Up of GPI Discoveries

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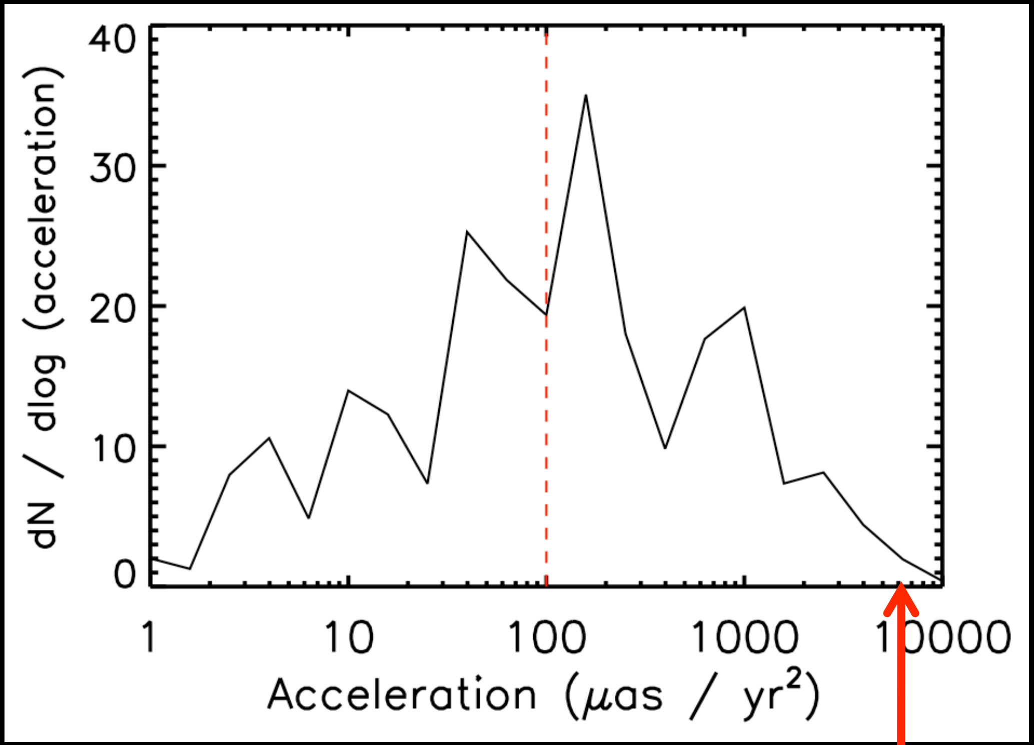
- Astrometric follow-up of GPI planets permits measurement of planet mass for individual planets
- Astrometric signal divided by Doppler signal goes as semi-major axis to the 3/2 power, favoring astrometric over Doppler followup for planets in wide orbits
- GPI targets young, active stars, for which astrophysical radial velocity jitter is significantly higher than the instrumental error (>> 1 m/s)
- Ground-Layer Adaptive Optics with 2-5' field ideal for high-precision, robust astrometry
- Need particular stiffness in imager optomechanics

Histogram of Astrometric Acceleration for Expected GPI Sample

- D. Savransky generated simulated orbits for suite of planets observable by GPI
- Red line marks best available single-star astrometric precision (Keck AO, crowded field)

GPI Astrometric Acceleration

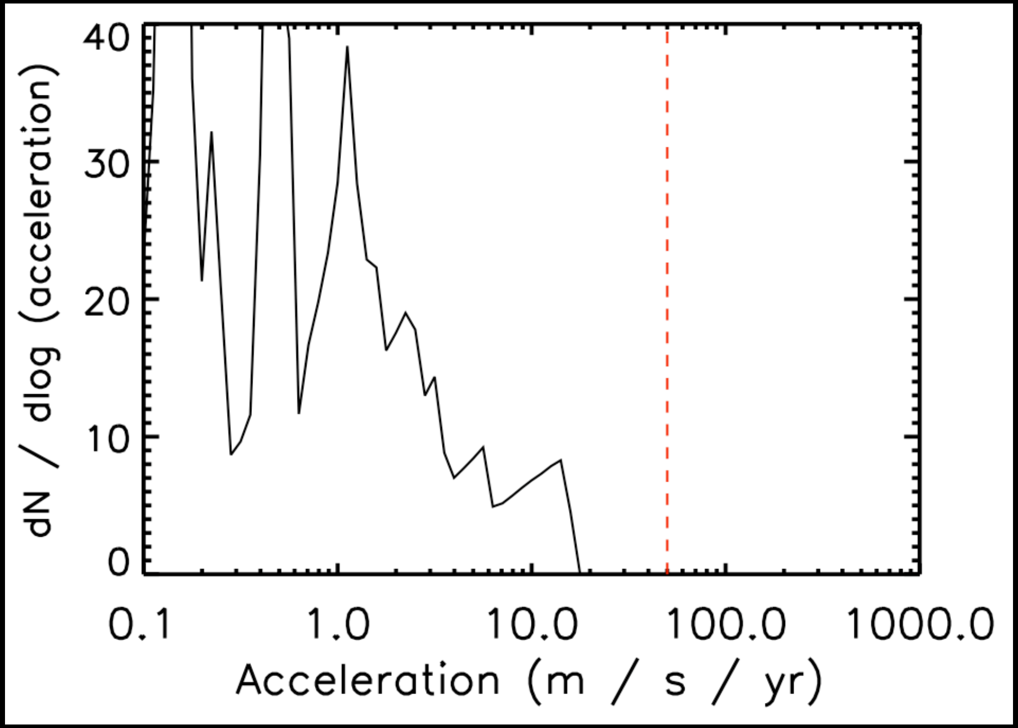


Large accelerations possible, but typically do not last long (so minimal excursion)

Histogram of Doppler Acceleration for Expected GPI Sample

- Red dashed line marks typical Doppler precision for young, active stars (50 m/s)

GPI Doppler Acceleration



Histogram of Ratio of S/N on Acceleration for Astronomy vs. Doppler

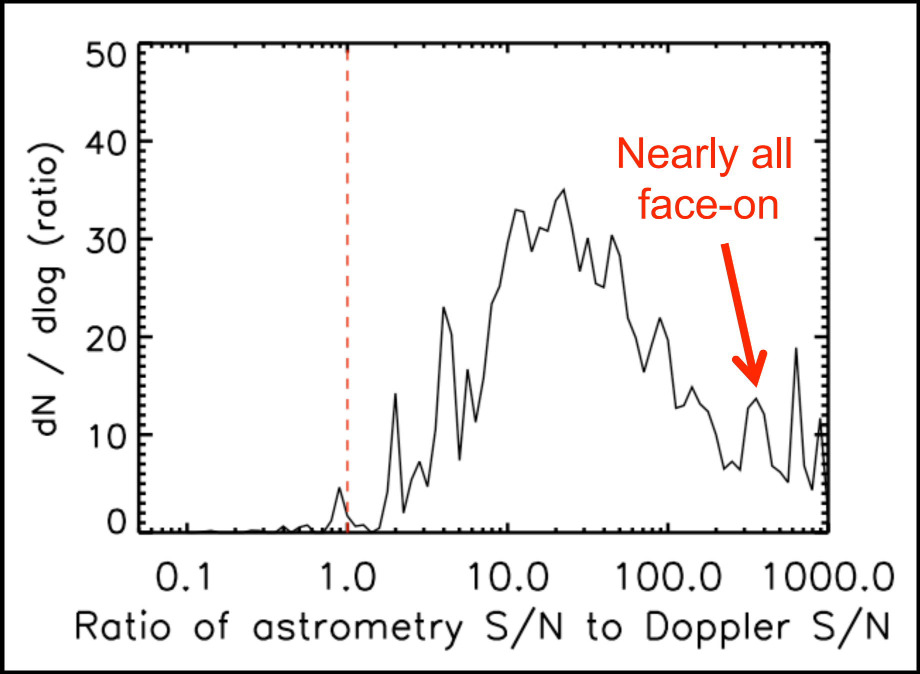
- Histogram of the ratio of S/N on acceleration measurement using astrometry vs. the S/N on acceleration using Doppler, for simulated GPI sample

- Assumes measurement noise of 50 m/s for Doppler and 100 μas for astrometry

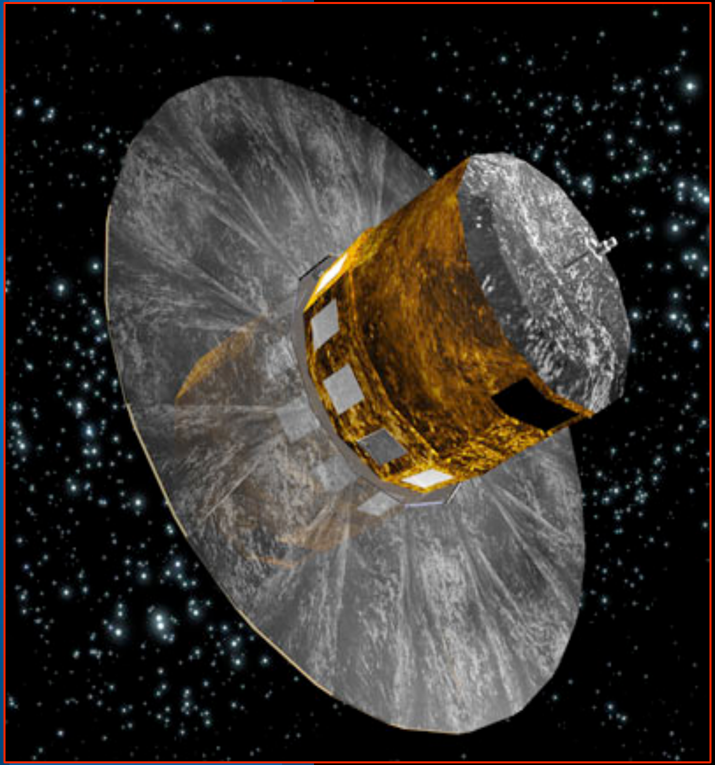
- Includes extra noise factor of 3.8 for astrometry due to taking derivative of position rather than velocity

- Assumes comparable exposure times and observing strategies for both follow-up program techniques, and a cadence of ~3 months

Ratio of S/N, Astrometry vs. Doppler



Advantages of Astrometric Measurements from the Ground



- GAIA will measure the positions of bright stars ($V < 10$) to better than 10 μas single-axis precision over its mission lifetime, but is not targeted.

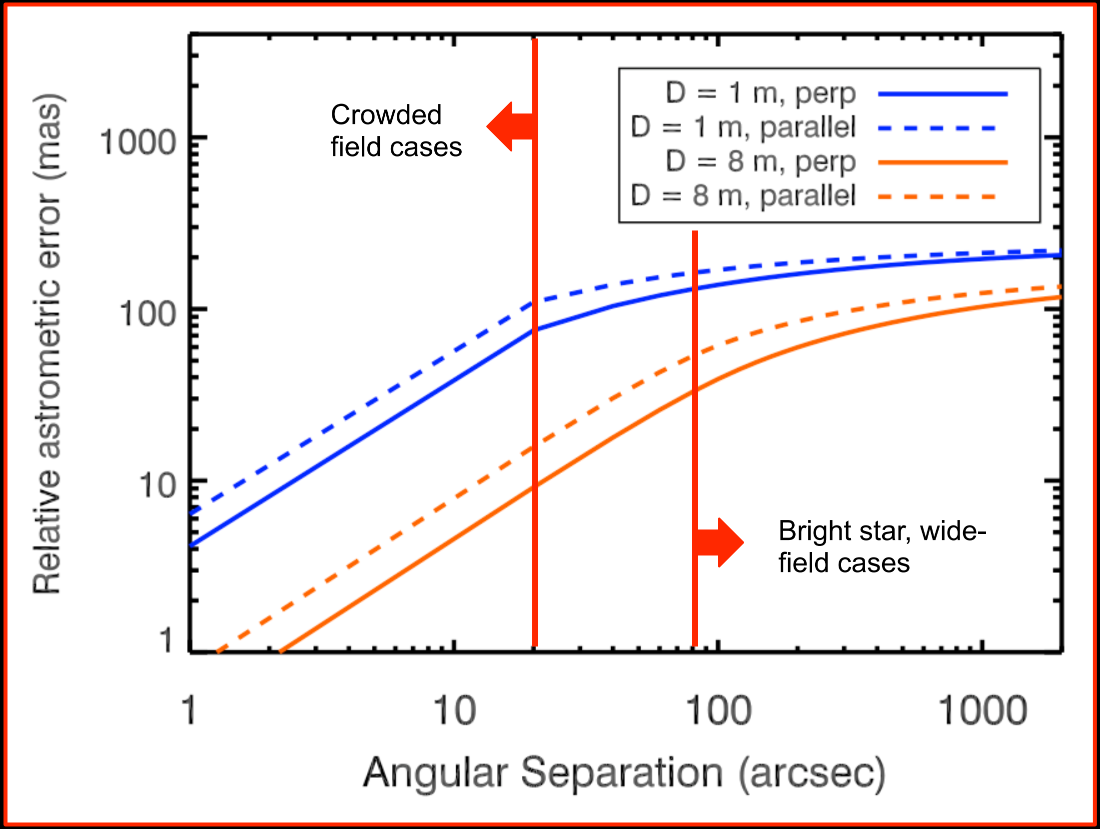
- Targeted, ground-based astrometric surveys can be valuable with < 100 μas performance for bright stars.

Science Cases:

- Follow-up of radial velocity discoveries with known cadence to constrain mass of companions
- Discovery of low-mass companions:
  - ~50 μas for nearby brown dwarfs
  - ~10 μas for nearby massive planets

Differential Tip/Tilt Jitter is a Concern for Ground-Based Bright Star Astrometry

- Differential Tip/Tilt Jitter is the error in measuring relative positions of stars due to high-altitude atmosphere
- DTTJ averages down with square root of exposure time



Relative astrometric error between two stars due to DTTJ

Astrometric Error Terms

Achromatic differential atmospheric refraction

$$\delta R \approx \Theta_{\mathrm{FoI}}[\mathrm{rad}] \times 44''/\cos^2 z$$

Fritz+10

Θ = astrometric baseline (rad)
z = zenith angle
δR = IR DAR image shift (mas)

A full linear transformation reduces this to the second-order effect:

$\delta R = (1.2\ \mu\mathrm{as})\ \theta^2$

Or ~30 mas for θ = 5' in i-band

- But this can be fitted and removed with atmospheric models at the μas level (Fritz+10)

Chromatic differential atmospheric refraction

$$(n-1)\times 10^6 = 64.328 + \frac{29498.1\times 10^{-6}}{146\times 10^{-6} - s^2} + \frac{255.4\times 10^{-6}}{41\times 10^{-6} - s^2}$$

Trippe+10

Can be fitted with atmospheric models including temperature and pressure to ~100 μas level for i-band for individual stars at *z* = 60°

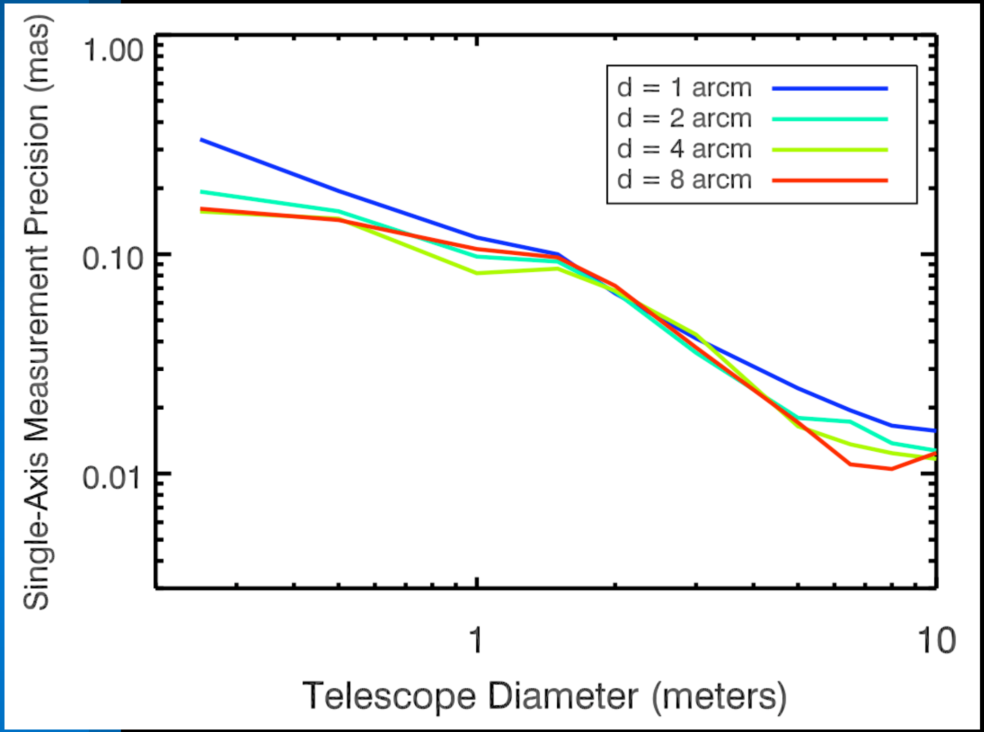
Temperatures of background stars need to be known to ~100 K

Diffraction spikes can be used to constrain the spectrum of reference stars

Error is only in zenith direction and averages down with many reference stars

PSF crowding errors are negligible for widely-spaced reference stars

Case #1: V = 8 bright star at 20 deg galactic latitude

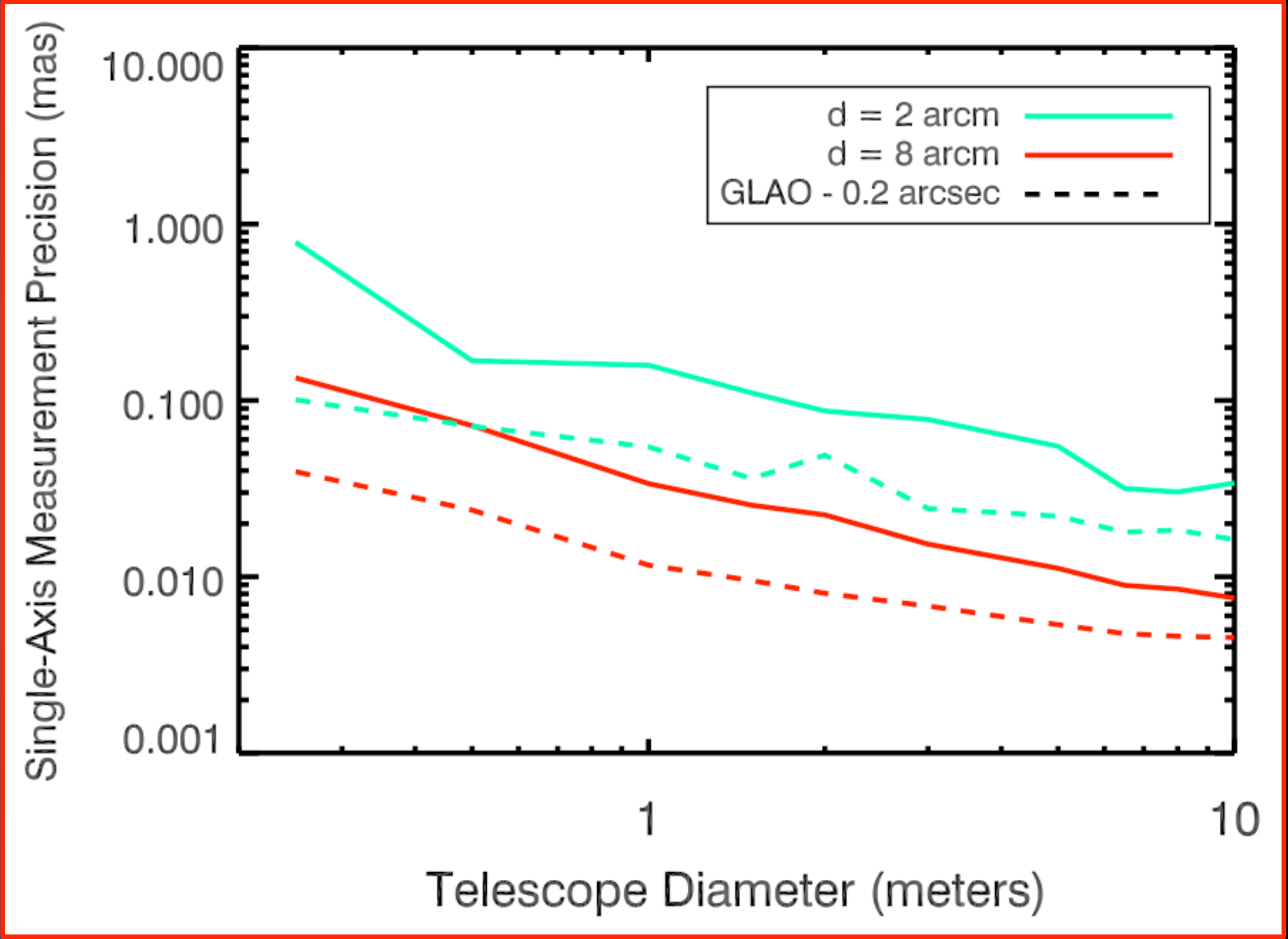


- Includes DAR, chromatic DAR, Differential T/T jitter, and SNR of stars
- 1 hour exposure
- V = 8 central star
- Reference field: Bahcall & Soneira (1980) star count model to V = 22
- Seeing = 0.8” FWHM

Relative astrometric precision of ~50 µas is possible on small telescopes, when large numbers of reference stars are used (> 300) and *systematic effects are ignored.*

Advantages of large telescopes are ***reduced*** *due to CDAR noise, assuming broadband I filter*

Ground-Layer Adaptive Optics Can Improve Astrometric Performance



GLAO reduces error by a factor of ~2-3 by increasing SNR of background reference stars.

Summary

1. For relative astrometry on bright stars, larger telescopes and *larger field diameters* improve performance

2. ~20-50 μas relative astrometric precision can be achieved on $V < 10$ stars with small telescopes ($D < 3$ m) and large fields of view ($d > 8'$).

3. Medium-field GLAO or MCAO can improve performance to 10-30 μas for Gemini in 1 hour integrations.

4. Diffractive pupil “fixes” MCAO – 10 μas precision possible for $b < 10$.