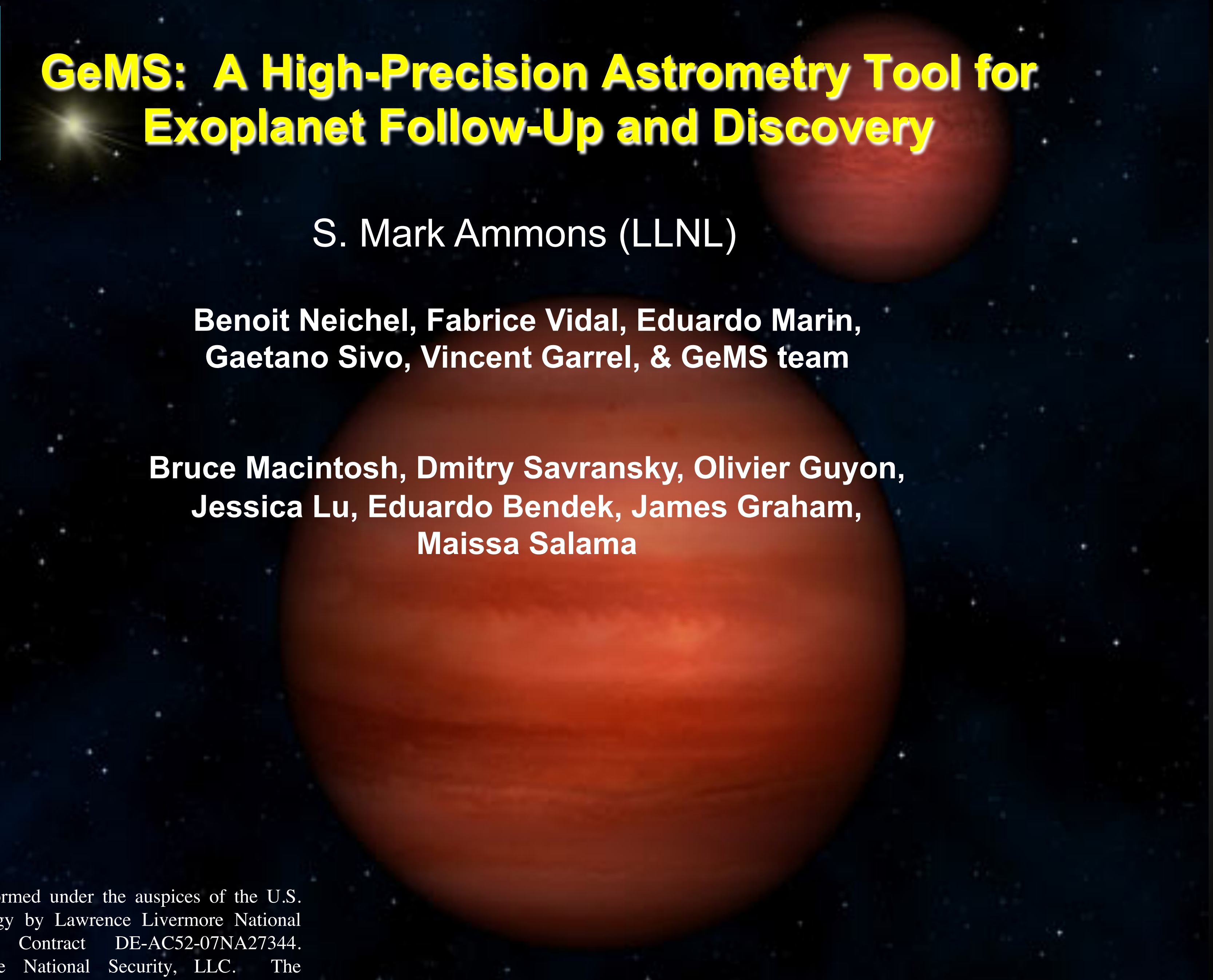
GeMS: A High-Precision Astrometry Tool for Exoplanet Follow-Up and Discovery

S. Mark Ammons (LLNL)

Benoit Neichel, Fabrice Vidal, Eduardo Marin, Gaetano Sivo, Vincent Garrel, & GeMS team

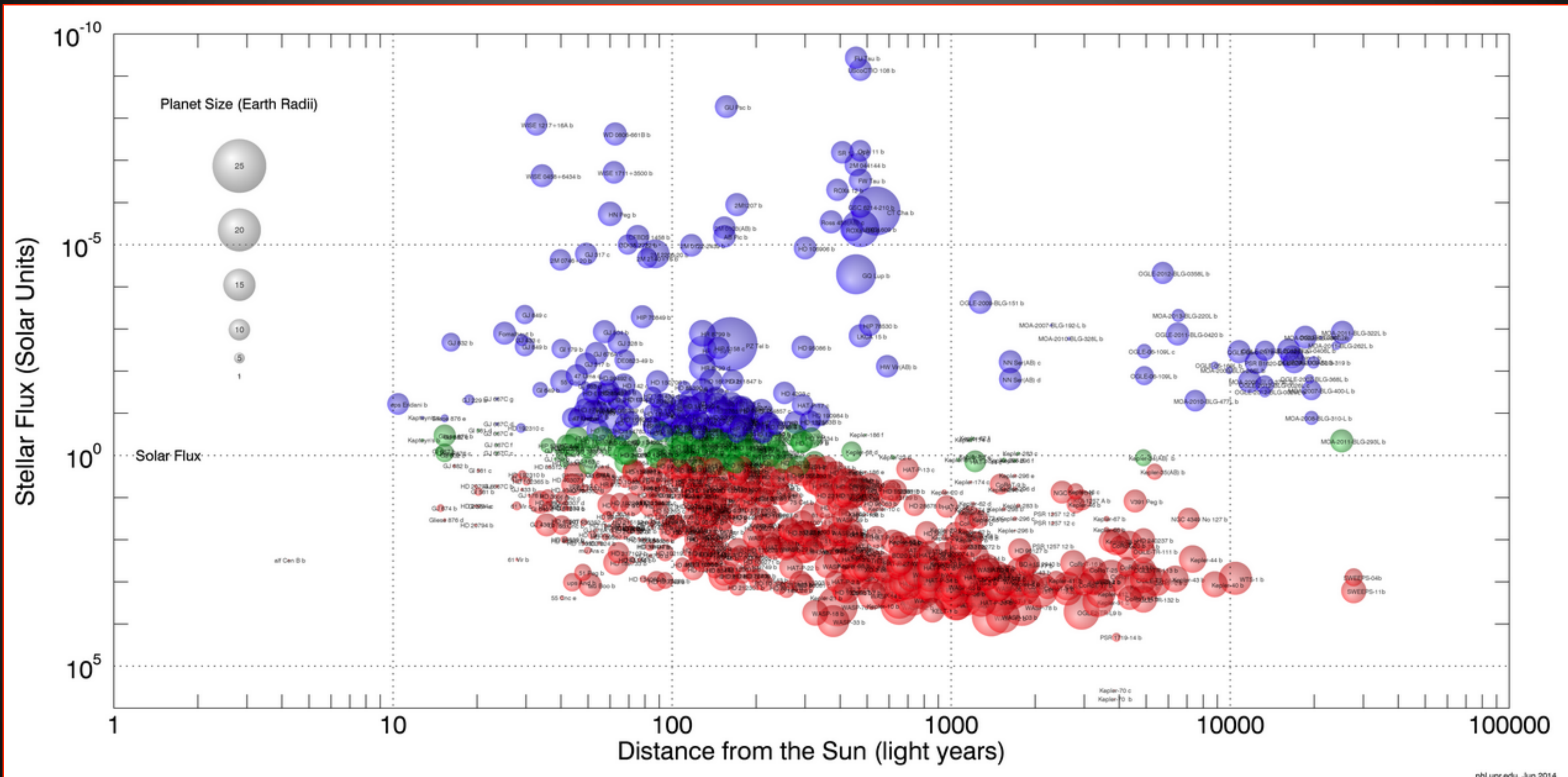
Bruce Macintosh, Dmitry Savransky, Olivier Guyon, Jessica Lu, Eduardo Bendek, James Graham, Maissa Salama

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC. The document release number is LLNL-PRES-792060.



Luhman 16AB / Janella Williams / PSU

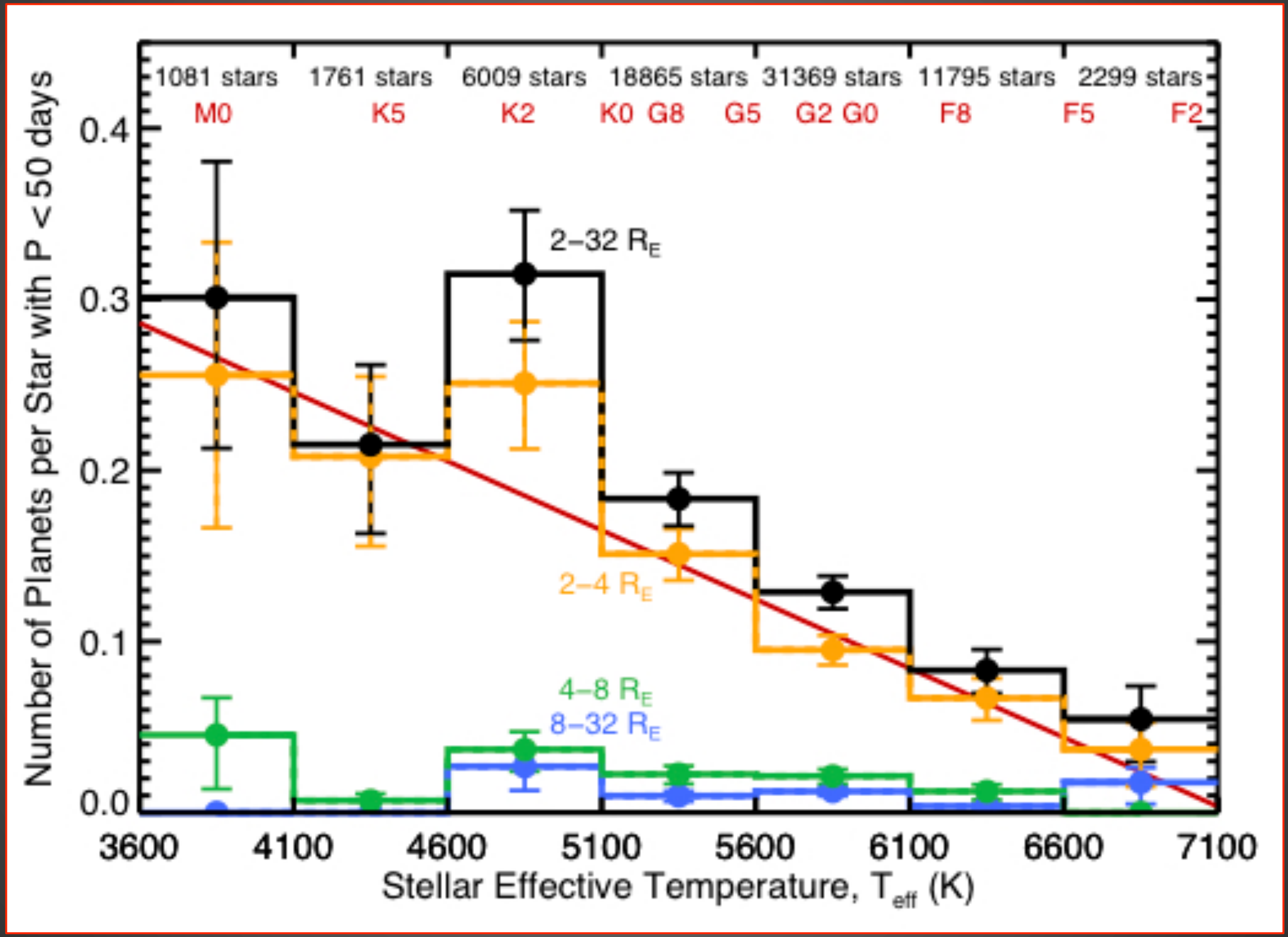
Most Known Exoplanets are "Hot"



Phl.upr.edu, Jun 2014

- Majority of planets are at high incident stellar flux or self-heated
- Planet occurrence rates for substellar hosts unknown

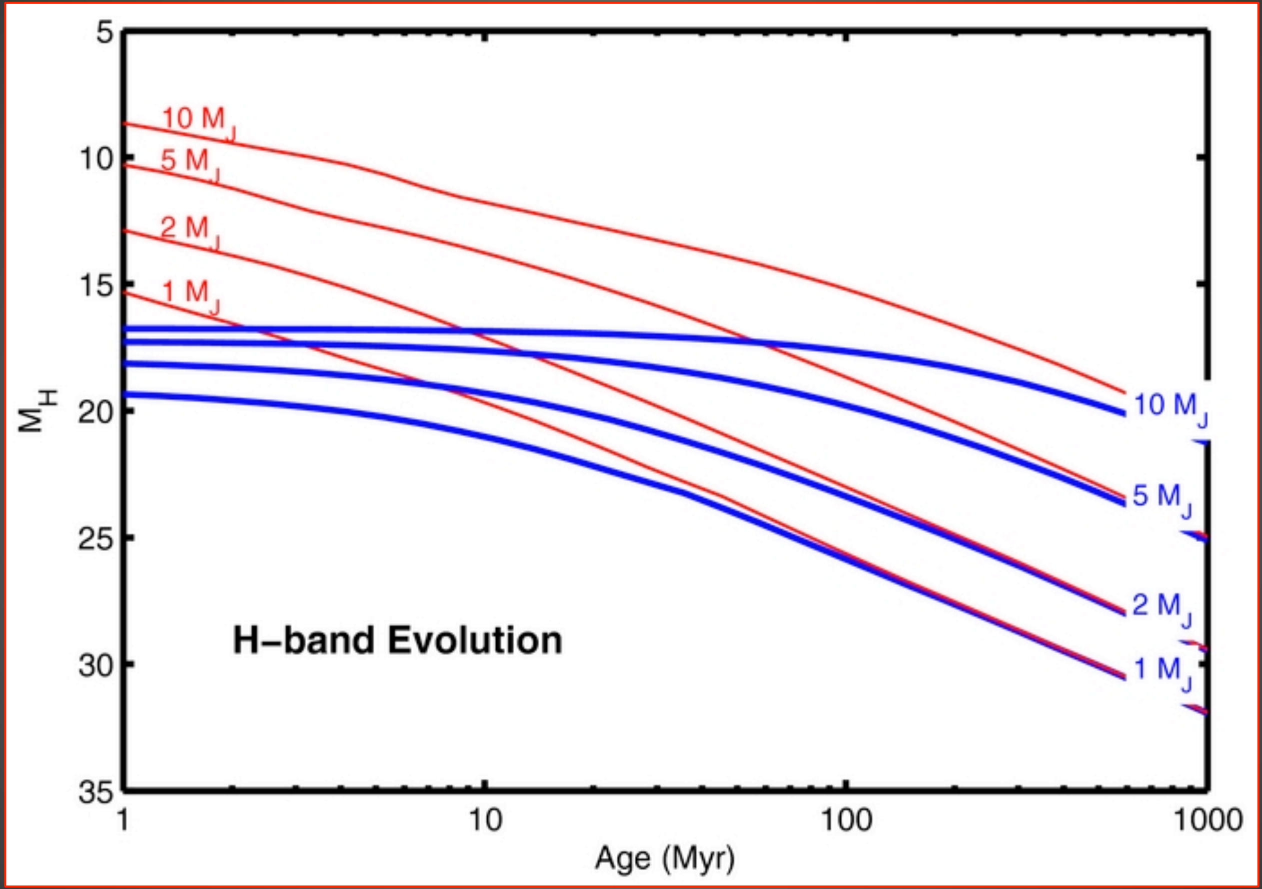
Short-Period Occurrence Rate around M Dwarfs is High



Howard et al. 2012

- Number of planets per stars is 2-3x greater for M dwarfs than for FGK stars
- Occurrence Rate for brown dwarf hosts is unknown

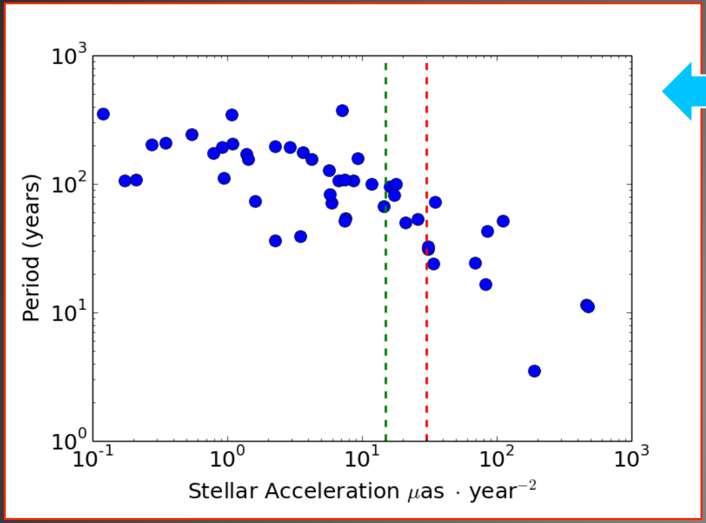
Exoplanet Masses and Luminosities Constrain Planetary Formation Models



Spiegel and Burrows 2012

- Measurements of exoplanet mass will help distinguish between “hot start” and “cold start” planetary formation models

Precision Astrometry Enables Exoplanet Mass Measurement and Surveys of Brown Dwarfs



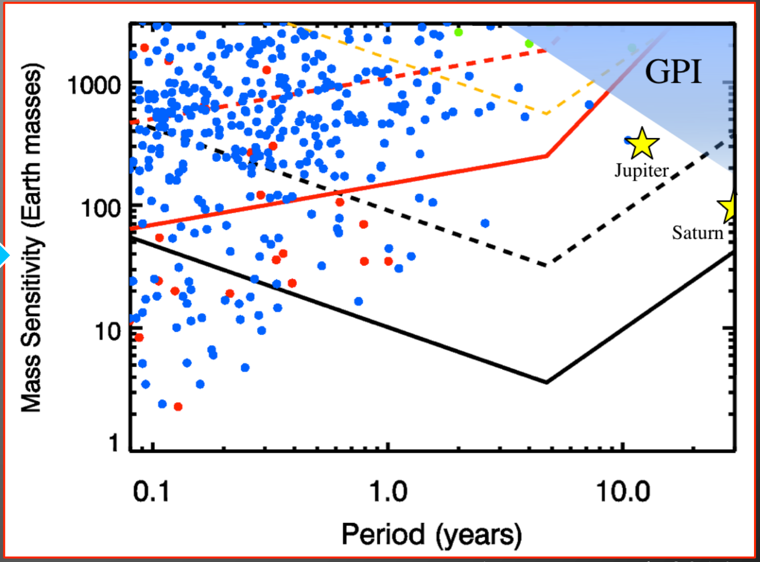
Credit: D Savransky

Stellar accelerations induced by simulated GPI exoplanets

~1/3 have masses measurable by current ground-based capabilities (~0.1 mas)

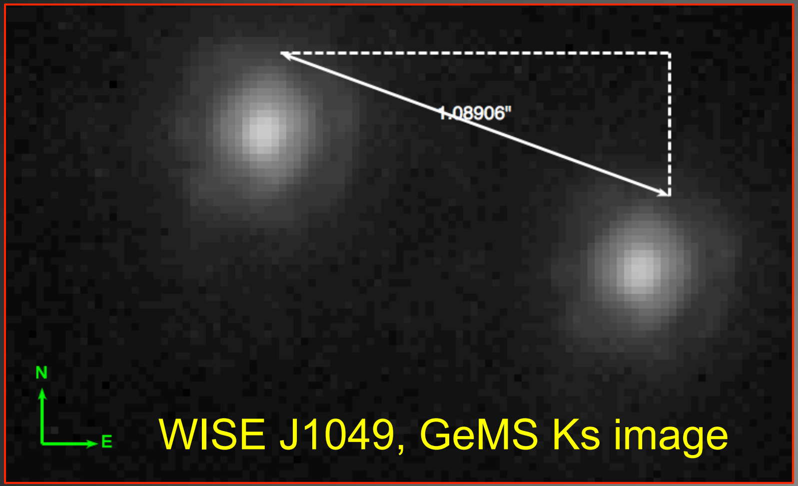
Exoplanet mass sensitivity curves (5-sigma) for a 5-year astrometric brown dwarf survey

Can measure exoplanet occurrence rate for brown dwarf hosts – *but need wide field for reference stars!*

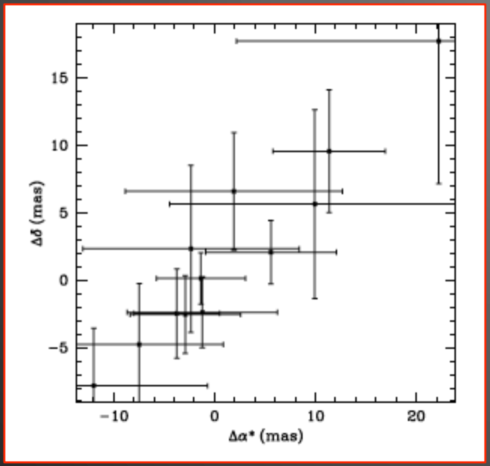


Ammons et al. 2014

GeMS Monitors the Closest Known Binary Brown Dwarf WISEJ1049



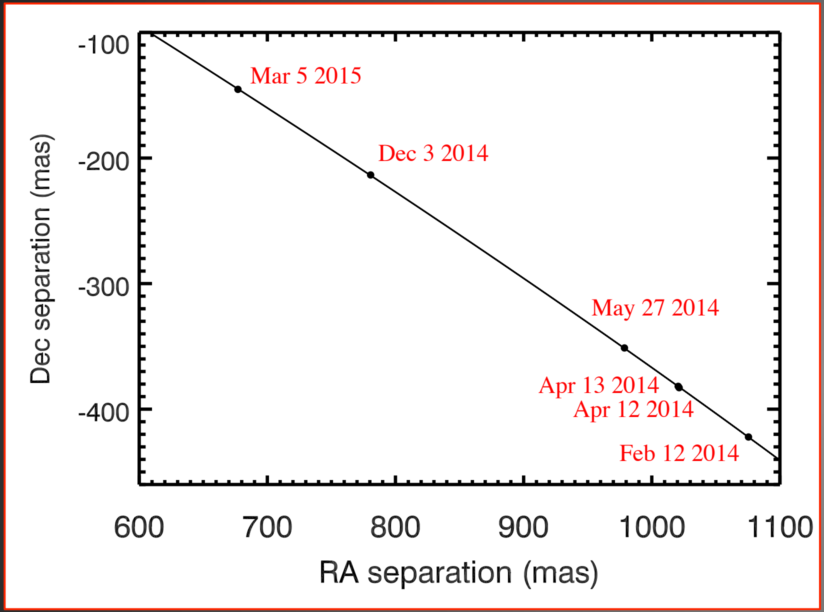
WISE J1049, GeMS Ks image

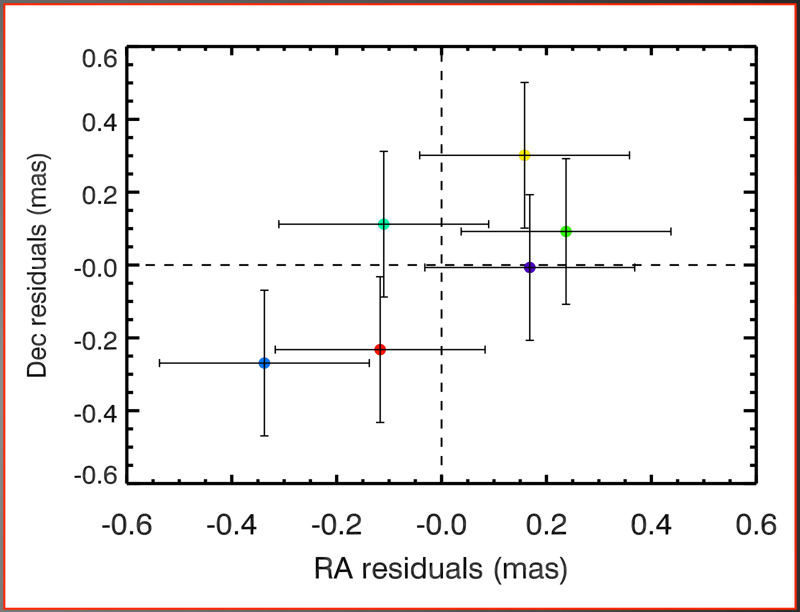


Boffin+14 astrometric residuals (2 months baseline)

- **Closest known binary brown dwarf system – 2.02 pc**
  - **Luhman et al. 2013**
- **Exoplanet announced orbiting one of the dwarfs**
  - **Boffin et al. 2014**
  - **Uses ~4-5 mas precision astrometry**
- **Good trial system for GeMS astrometry**
  - **1 arcminute field needed for absolute reference stars**
  - **Can improve astrometry by 20x over Boffin+14 data**

MCMC Keplerian Orbit Fits GeMS Data to Within 0.22 Milliarcseconds (No Obvious Planet Seen…)



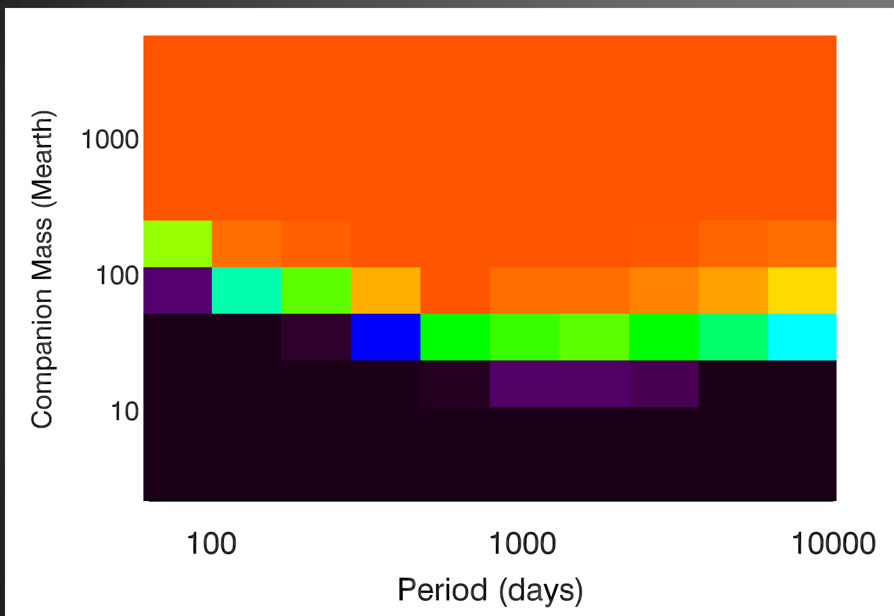


6 epochs of astrometry obtained over 13 months

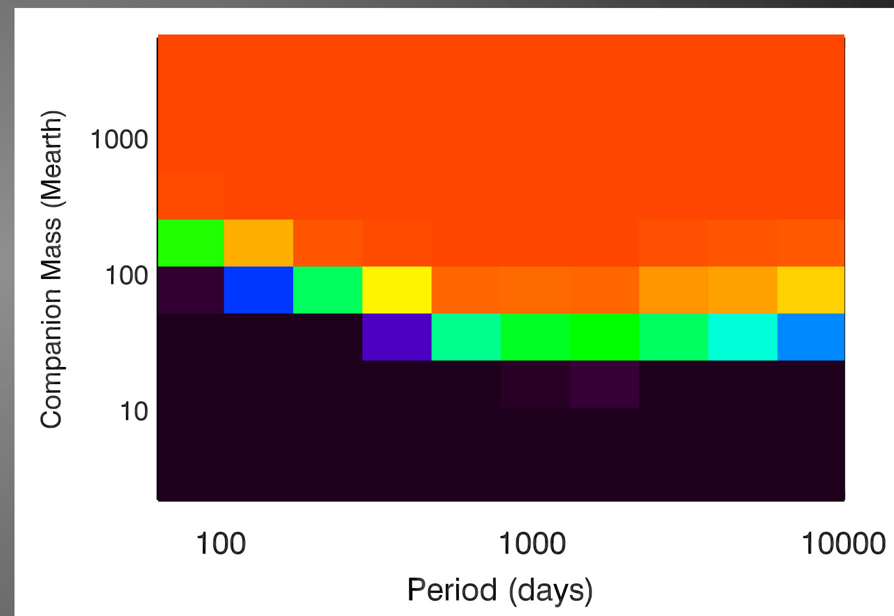
Astrometric residuals = 0.22 mas for Keplerian orbit

- GeMS delivers narrow-angle stability of ~0.2 mas over months
- GeMS' larger field needed for reference stars!
- *Inconsistent with planet proposed in Boffin et al. 2014*
- Total open shutter time ~ 20 minutes

GeMS Places Neptune-Mass Limits on Companion Mass



T dwarf companion limits (3-σ)

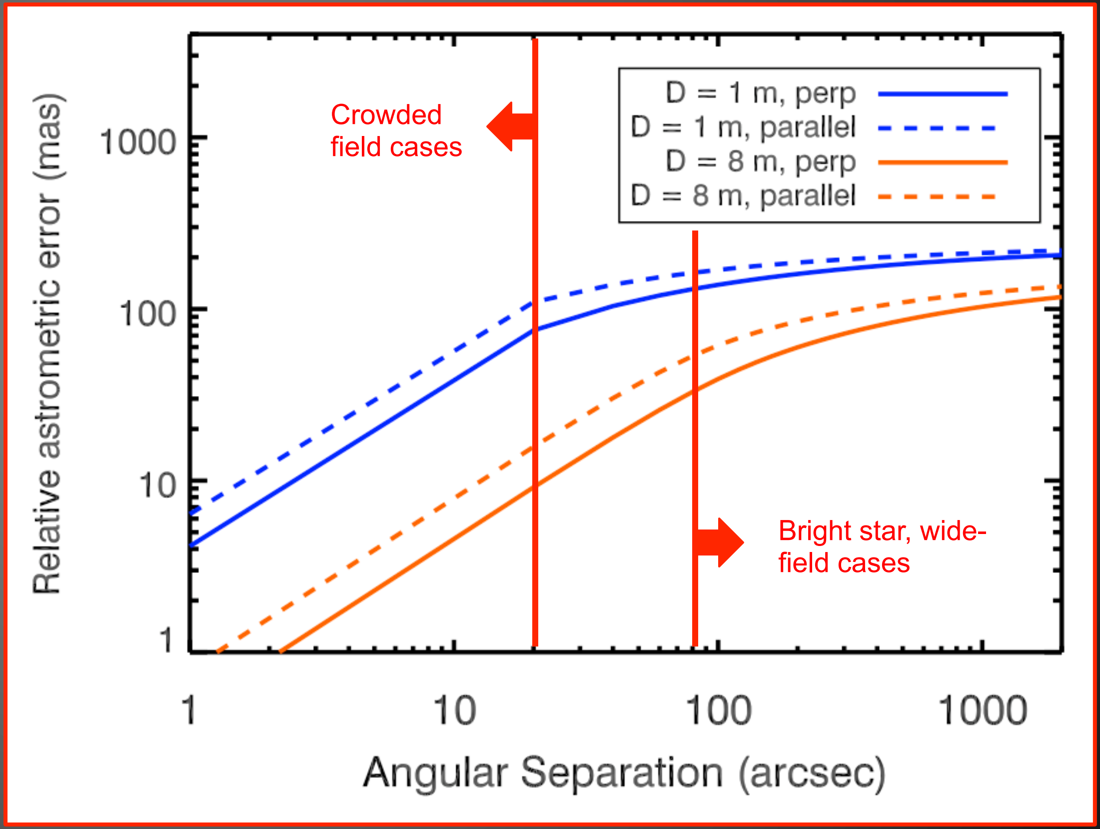


L dwarf companion limits (3-σ)

- Monte Carlo simulation of planet detectability, given epoch timing

For Wide-Field AO, Atmospheric Tip/Tilt Jitter is a Major Error Term

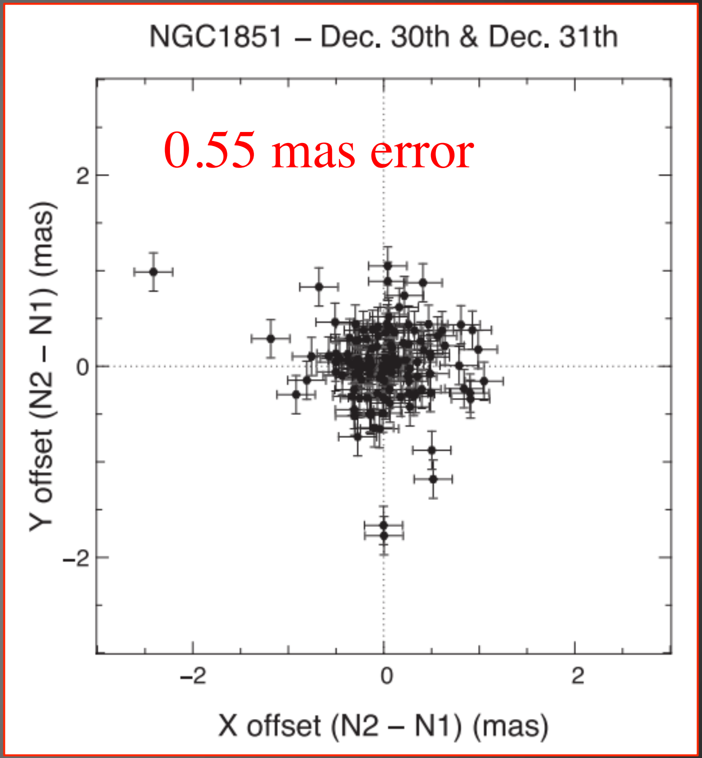
- Differential Tip/Tilt Jitter is the error in measuring relative positions of stars due to high-altitude atmosphere
- MCAO *actively cancels DTTJ: Use GeMS*



Relative astrometric error between two stars due to DTTJ

At First: Best Long-Term Precision at ~0.5 mas

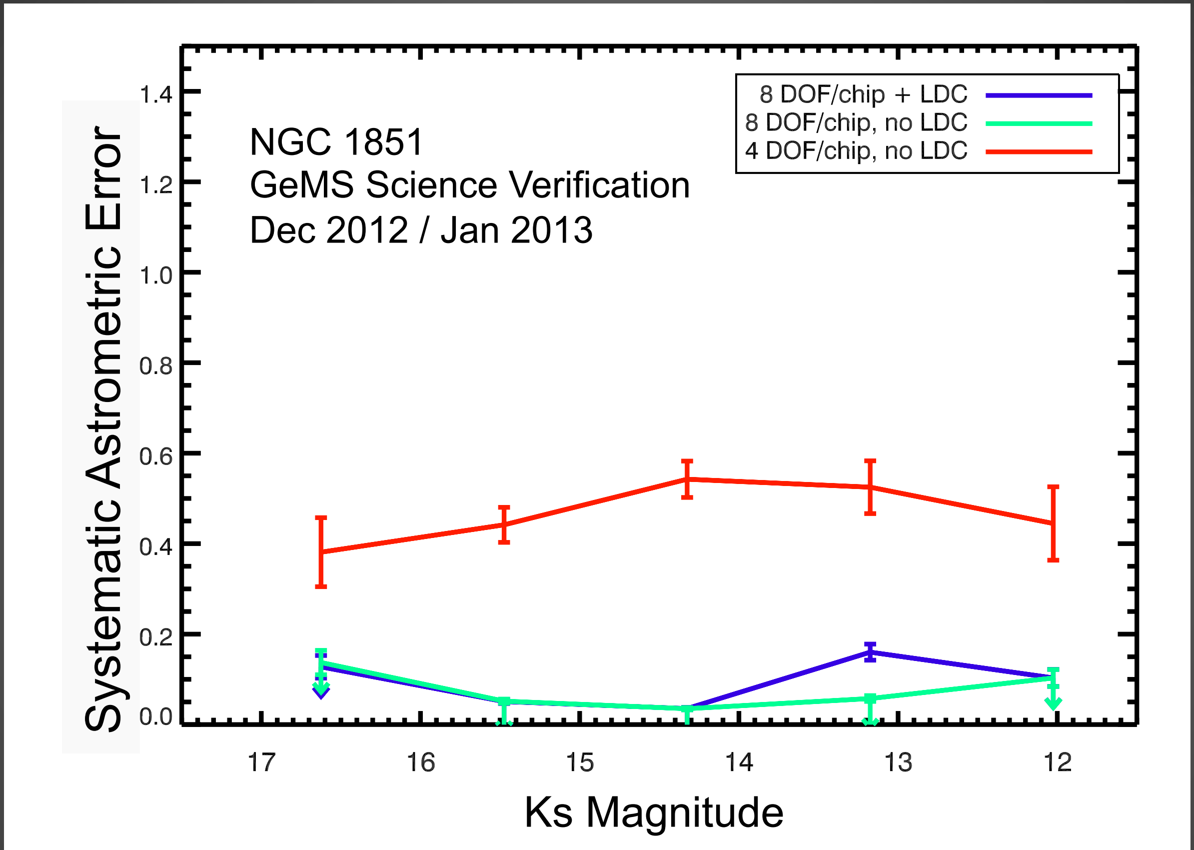
NGC1851, Gemini SV (A. McConnachie, HIA)



1 month baseline (Neichel et al. 2014)
Using Unmodified StarFinder

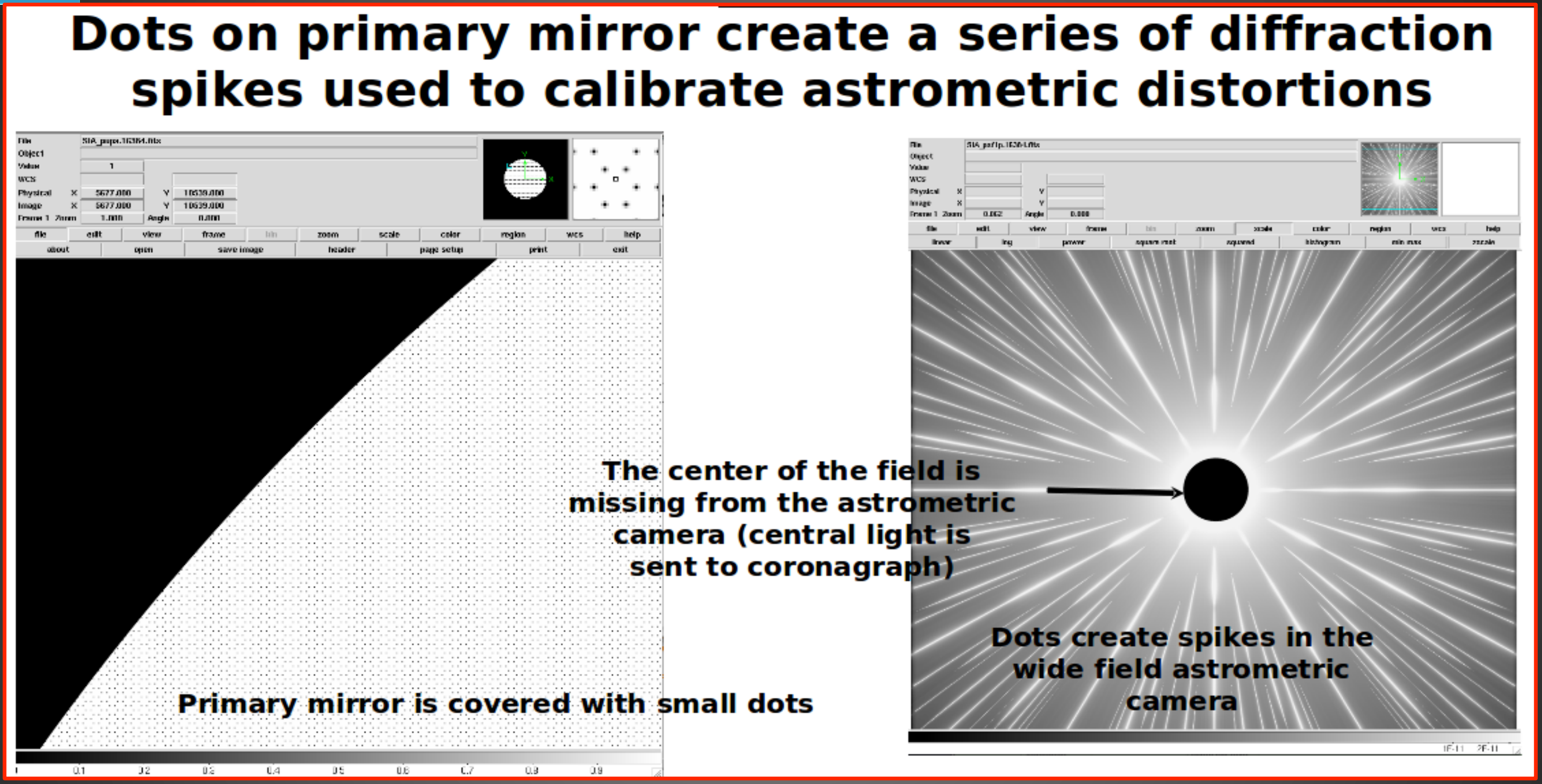
- GeMS shows systematic errors of ~0.5 mas over long time baselines
- *Need more sophisticated code to handle PSF anisotropy in MCAO systems*

Sophisticated PSF Treatment Corrects Systematic Errors



- Using PSF tiling and nonlinear distortion correction, the systematic component of GeMS precision improves to < 0.2 mas for bright stars
- Distortion scheme requires at least 30 stars / sq. arcmin.
- *Higher Strehl will improve sparse field precision (brighter LGS, NGS2)*

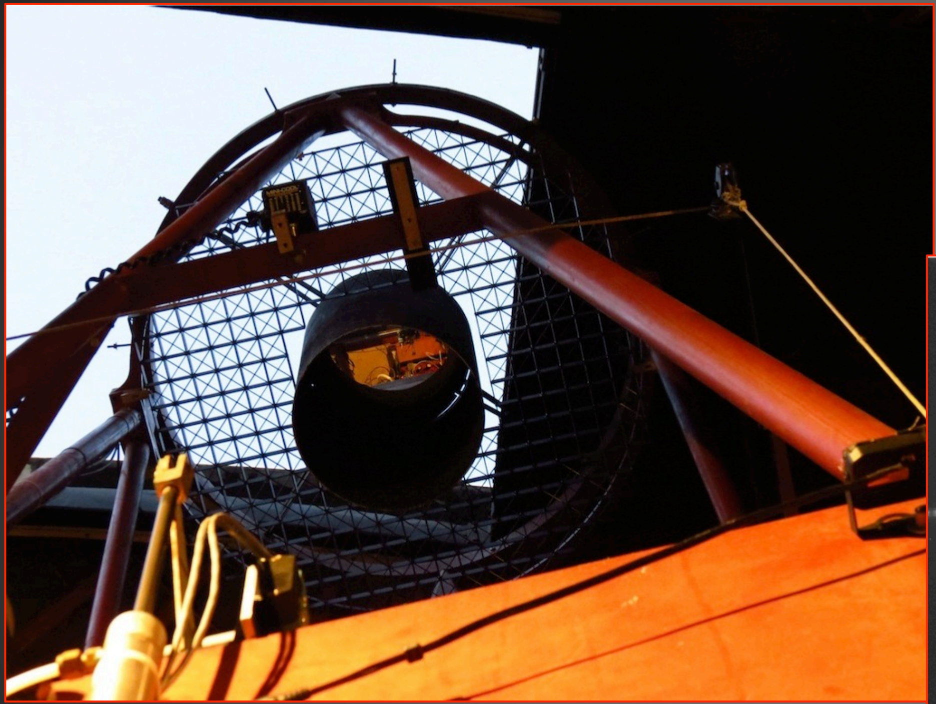
Improving Astrometric Precision with the *Diffractive Grid*



Olivier Guyon

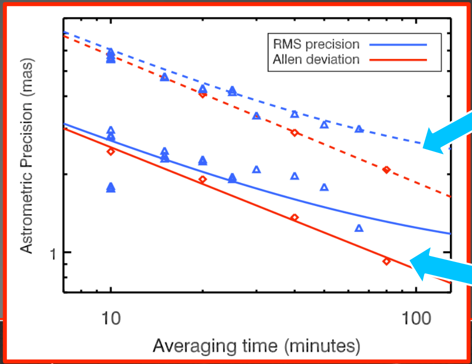
All astrometric distortions (due to change in optics shapes and deformations of the focal plane array) **are common to the spikes and the background stars**. By referencing the background star positions to the spikes, the astrometric measurement is largely immune to large scale astrometric distortions.

Diffractions Spikes Map Optical Distortion, Prevent Star Saturation



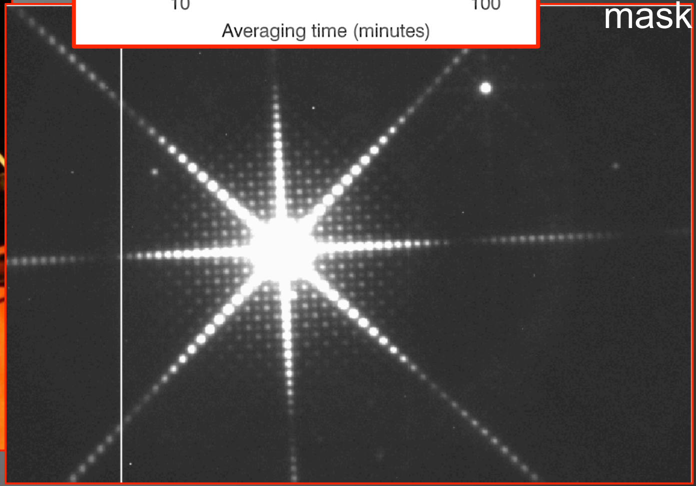
Carbon mask installed on Nickel Telescope (Credit: E. Bendek)

Ammons et al. 2013



Without diffractive mask

With diffractive mask

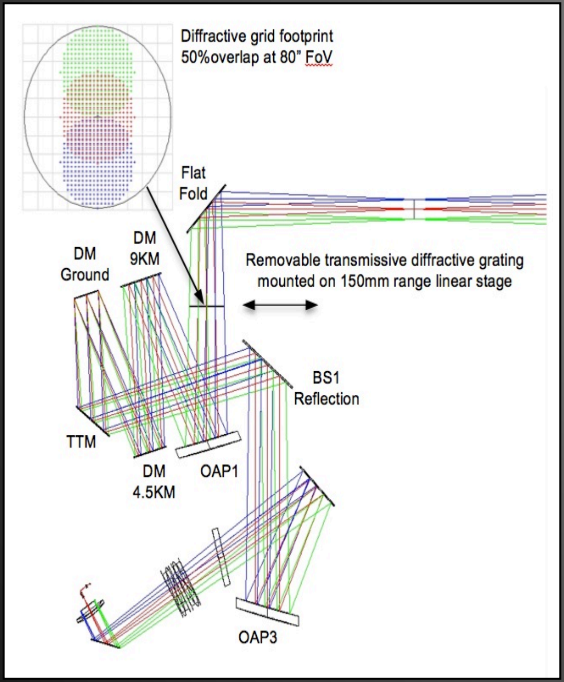


51 Per

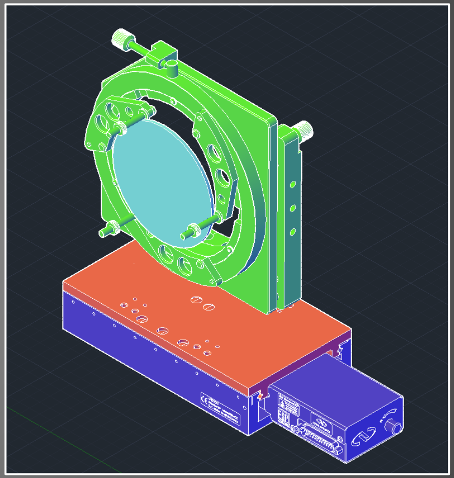
- Stiff CFRP honeycomb mounted at secondary produces diffraction spikes that map changing optical distortion
- Experiment designed to average down random errors and reveal systematics
- Final generation mask manufactured in San Jose and designed by Eduardo Bendek

A Diffractive Mask for GeMS

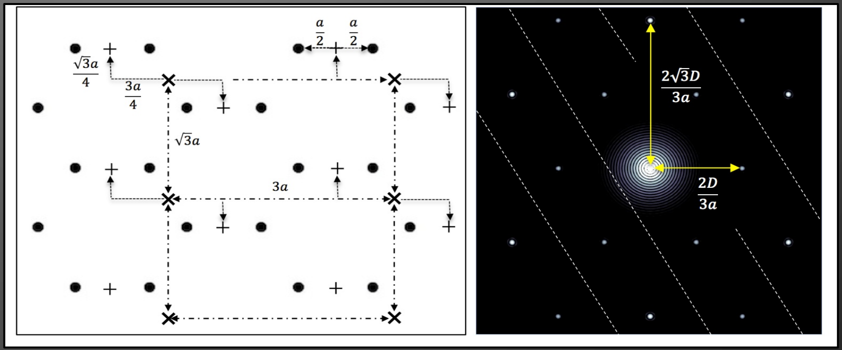
- An LLNL-led visitor instrument for GeMS
- Engineering support from NASA Ames (Eduardo Bendek)
- Procurement in FY15; Installation and testing complete by summer 2016



Optical design within GeMS

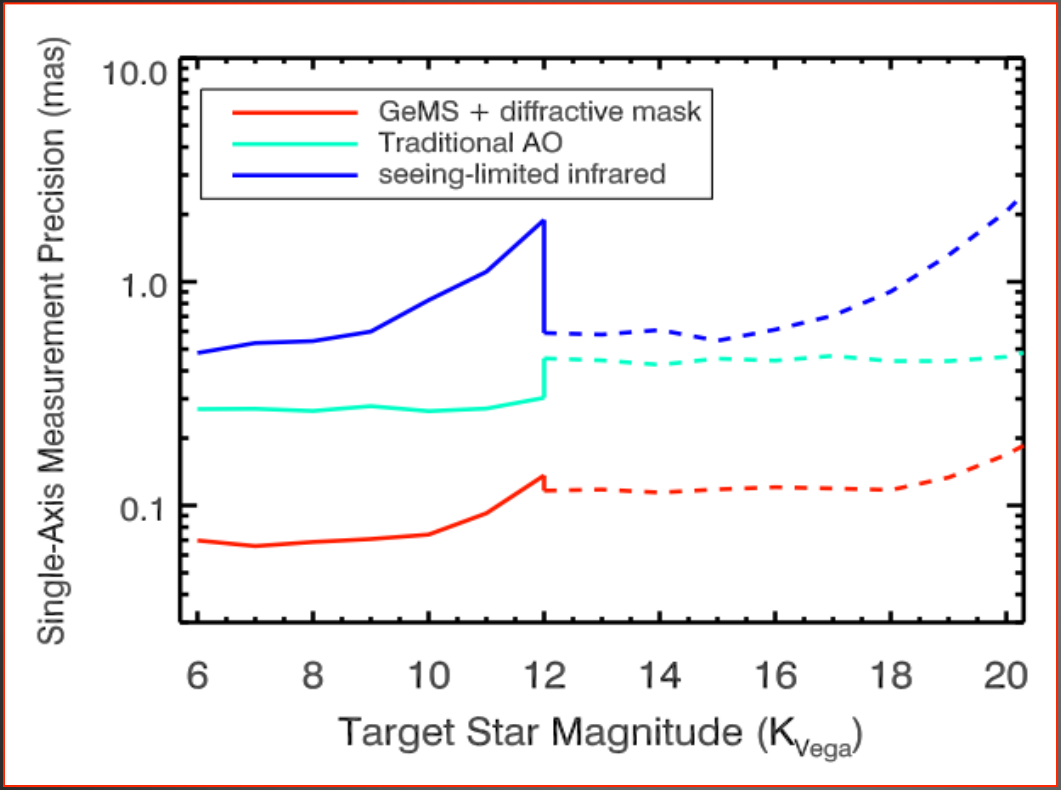


AutoCAD drawing of insertion mechanism



Dot Matrix Pattern Imprinted on Mask

Predicted Astrometric Precision with GeMS Diffractive Mask



- Includes DAR, chromatic DAR, Differential T/T jitter, and SNR of stars
- 15 min exposure
- Reference field: Bahcall & Soneira (1980) star count model to V = 22
- Seeing = 0.8" FWHM
- Bandpass = K
- 30% Strehl

Discontinuity at K ~ 12 represents change in strategy: For K > 12, an injected laser grid or pinhole mask is used to map instrumental distortion, not diffracted images of the target star.

Summary

1. GeMS is a powerful astrometry tool for exoplanet mass measurement and discovery of planets orbiting L/T dwarfs

2. GeMS has mapped the relative orbit of WISE J1049 at 0.2 mas precision - no planet seen

3. Diffractive Mask will improve GeMS sparse-field astrometry to < 100 uas level