Detecting Giant Planets in Hot Binary Systems with CHARA / VLTI

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Talk Outline

- Why search for planets around “hot” stars?
- Using astrometry method to discover planets
- MIRC Pilot Study: del del + detection limits
- ARMADA survey – CHARA and VLTI
- Initial results

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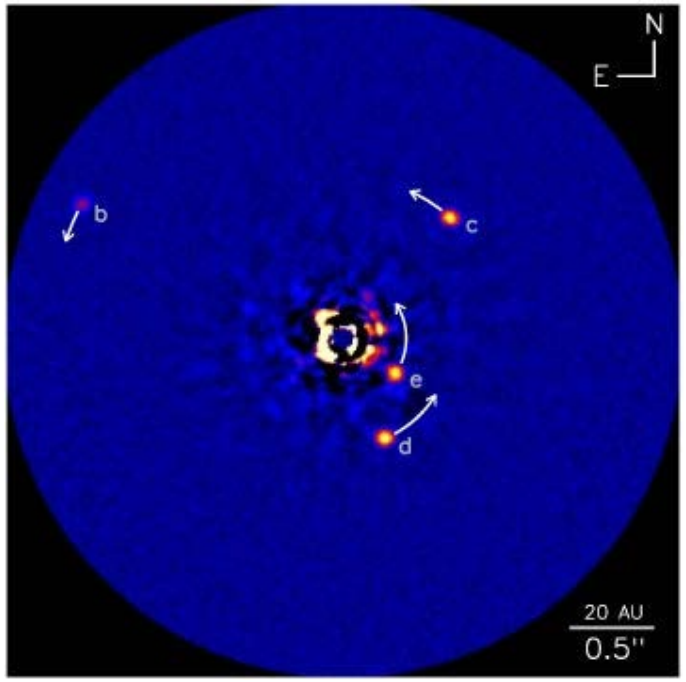
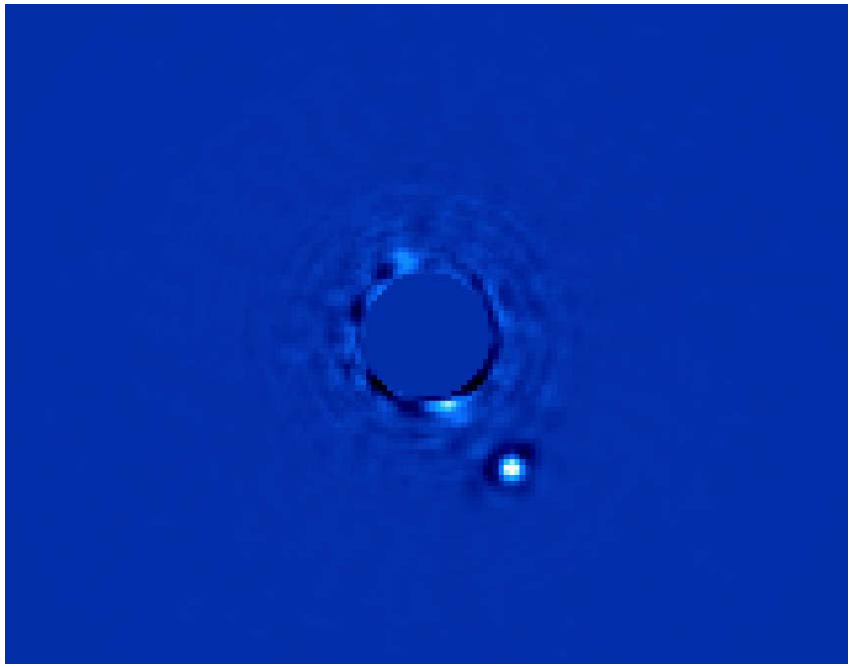
Planets around A-Type Stars

HR 8799, Keck



Beta Pic, GPI



Several known transiting planets around A-stars:

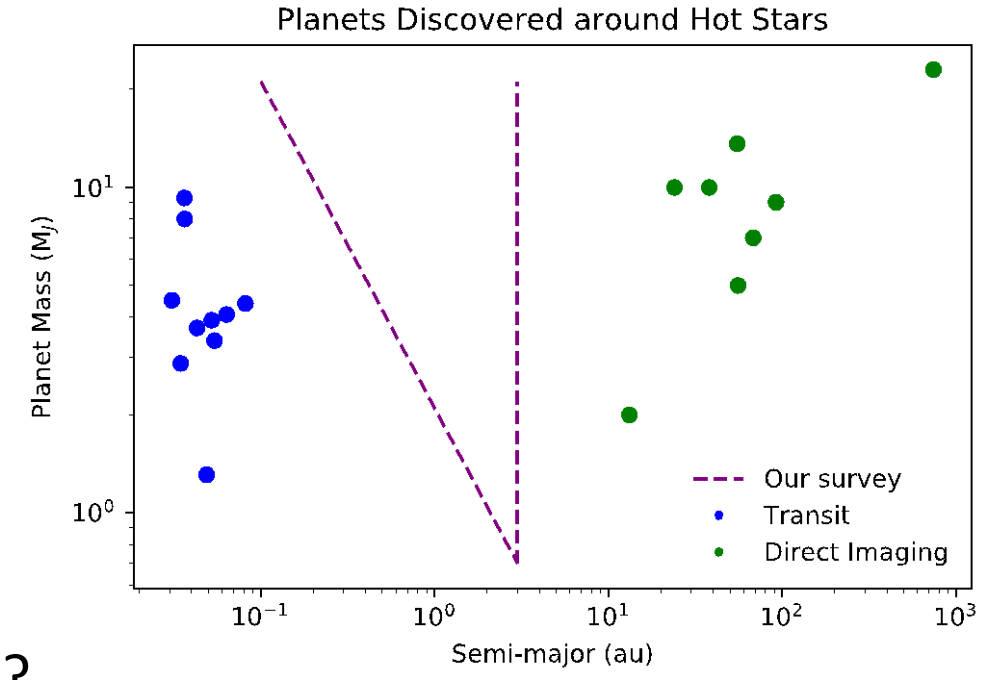
KELT-20, WASP-33, Kepler-13 A, HAT-P-57, KELT-17, KELT-9, Kelt-21

(Lund et al, 2017 ; Johnson et al, 2018)

Planets around A-Type Stars

Difficulties

- RV nearly impossible (weak/broad spectral lines)
- Most transit surveys focus on solar-type



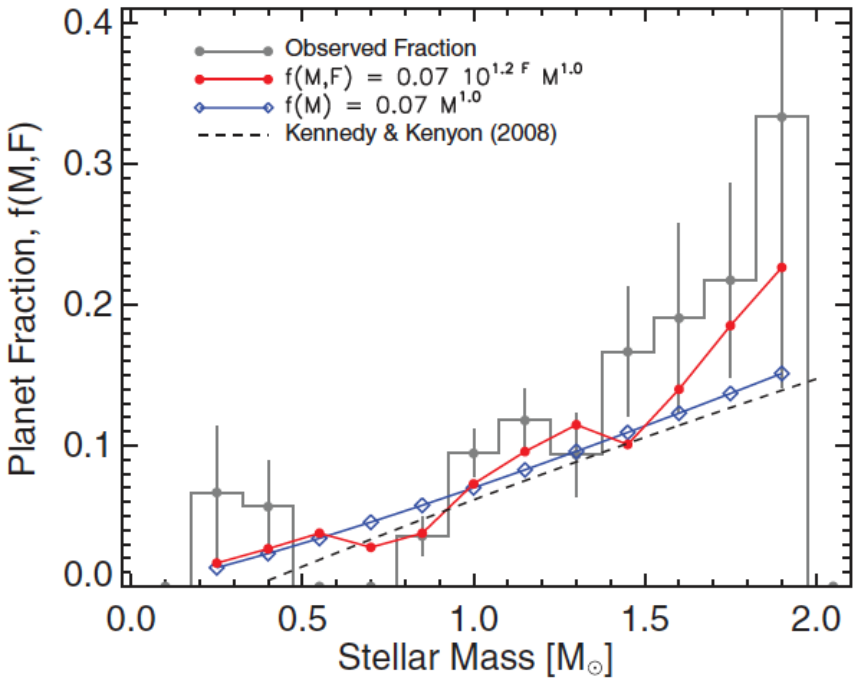
Planet occurrence rate as function of stellar mass?

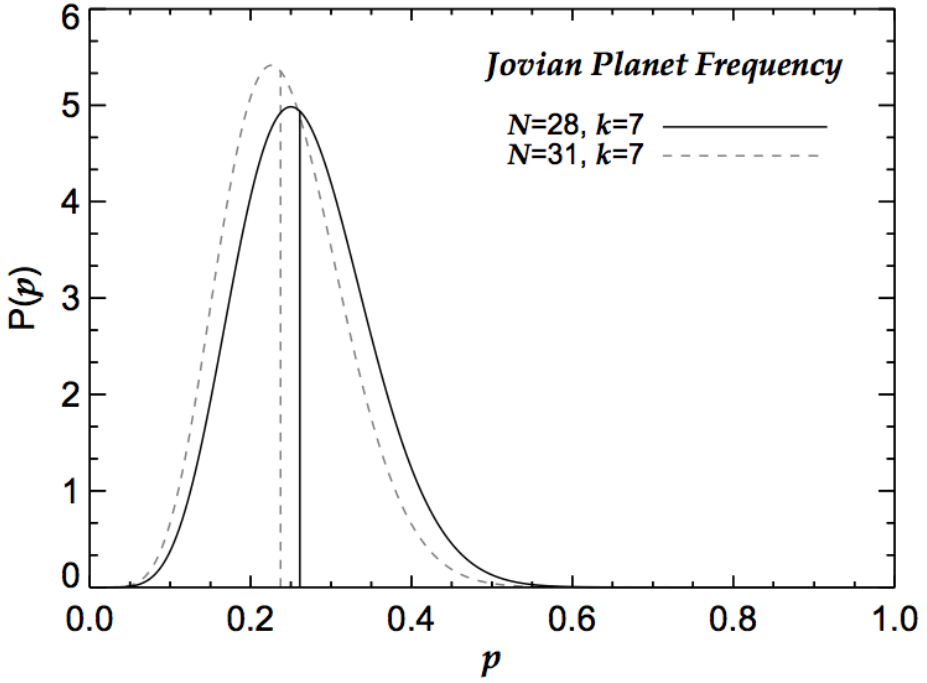
- RV surveys of **retired A-stars** used to infer main-sequence planet occurrence rate *(Johnson et al 2010, Bowler et al 2010)*

RV Surveys of Retired A-stars:

AU Giant planets up to 5x more common for A-stars?

Interior to ~3 AU





Issues: 1) Progenitors truly A-type stars? (Lloyd et al, 2010 ; Ghezzi et al, 2018)
2) Stellar Variability masking planet signals (Hatzes et al, 2018)

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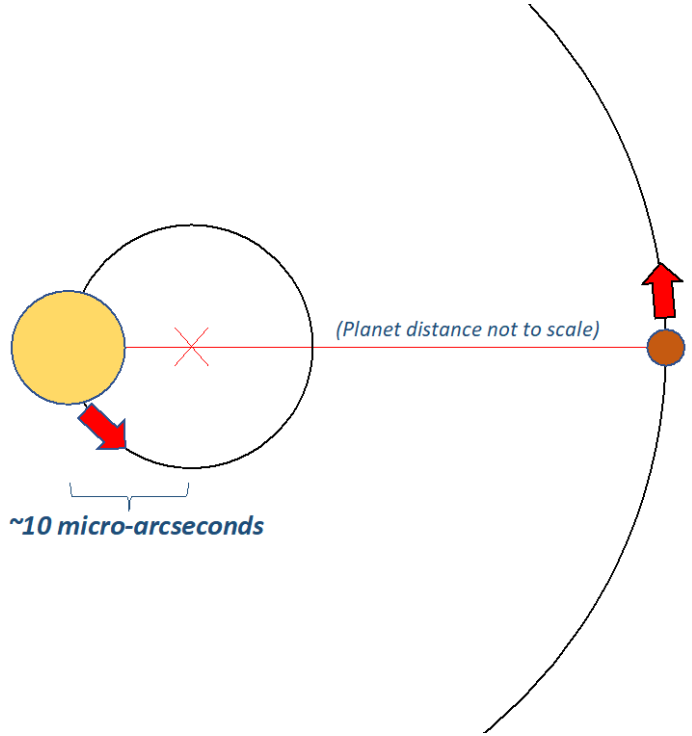
Confirming Top-Heavy Planet Distribution

- ***Astrometry method*** could probe this regime

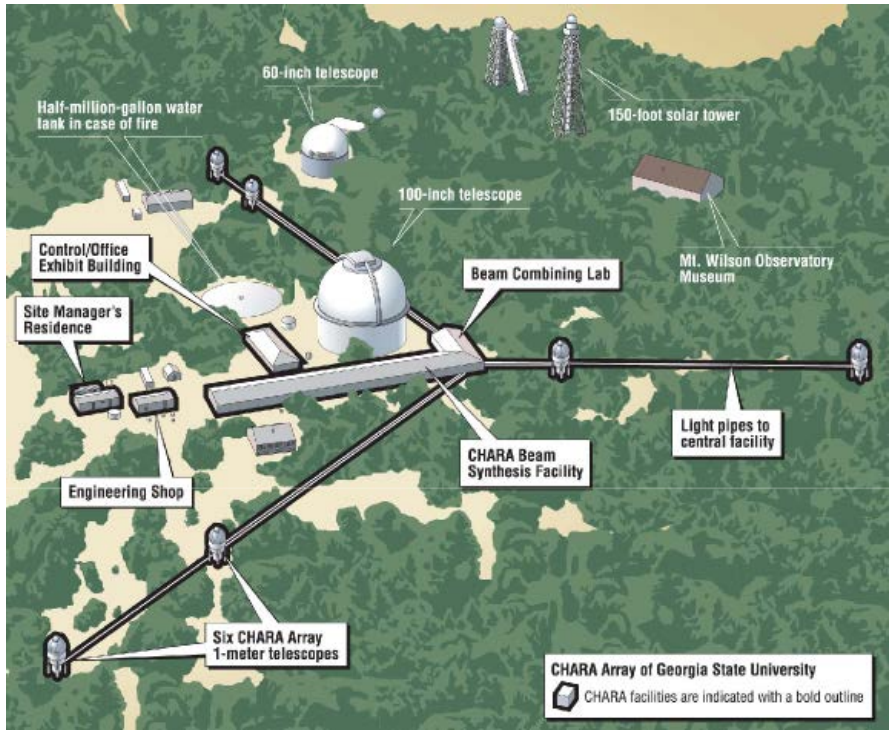
  - Need *micro-arcsecond* precision to detect “wobble”



$$"wobble" = \frac{separation}{1 + M_{star} / M_{planet}}$$

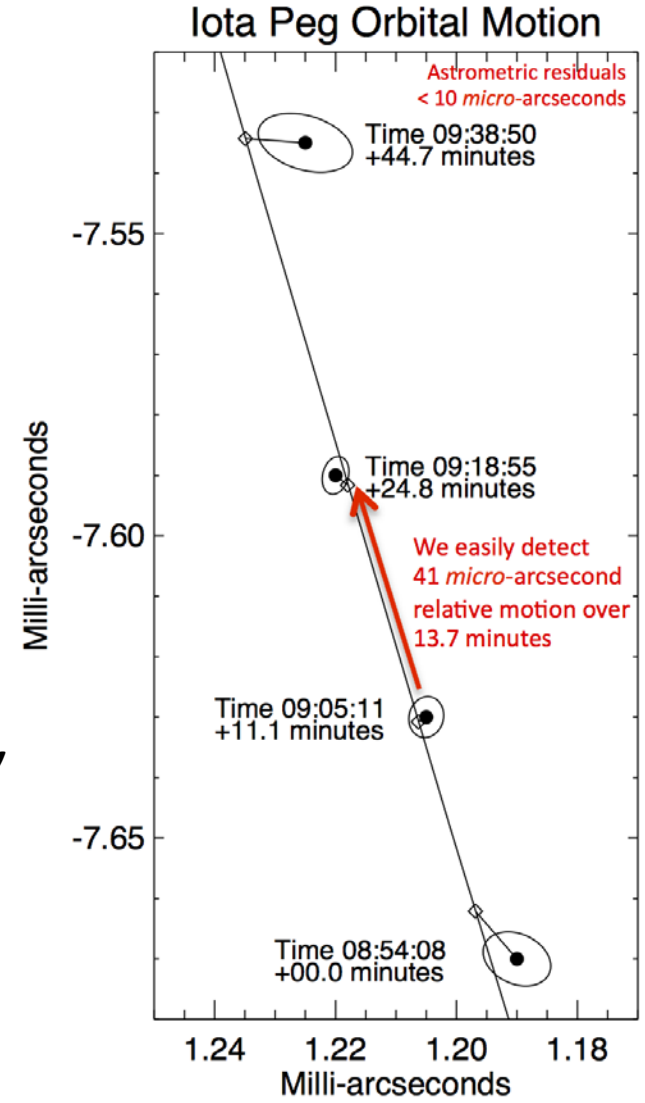
Long-Baseline Interferometry: Differential Astrometry

- **Michigan Infra-Red Combiner** (MIRC) at the CHARA Array
  - 6 telescopes - baselines up to 330 meters
- **GRAVITY** at VLTI
  - Combines 4 telescopes, K-band



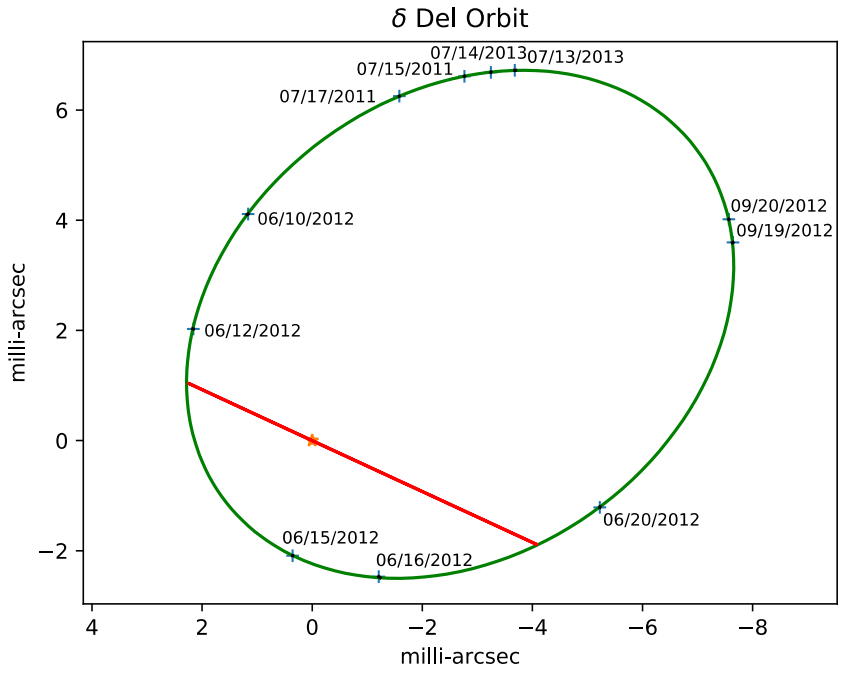
Binary Star *Differential Astrometry*

→



Astrometric Planet Detection via Interferometry

Binary Orbit:



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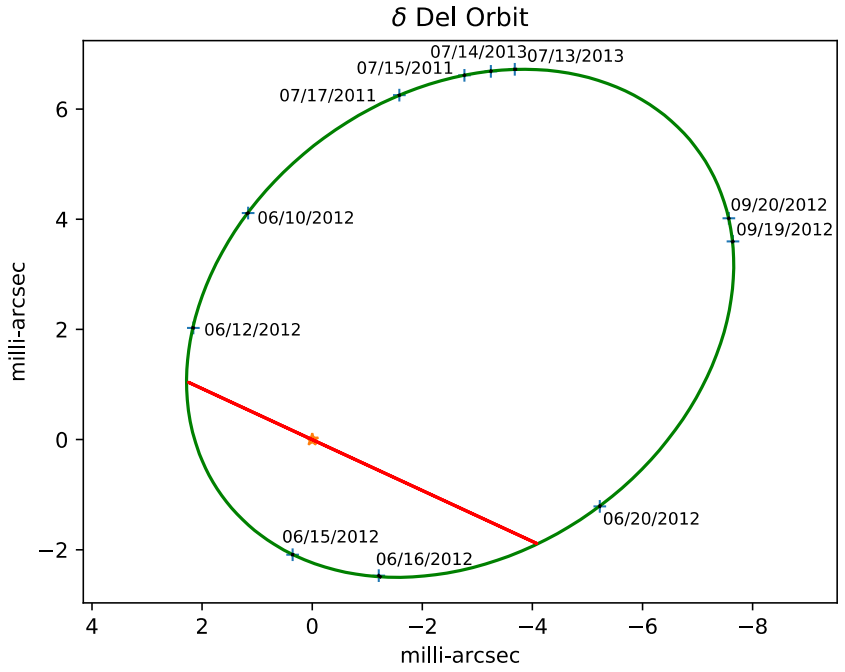

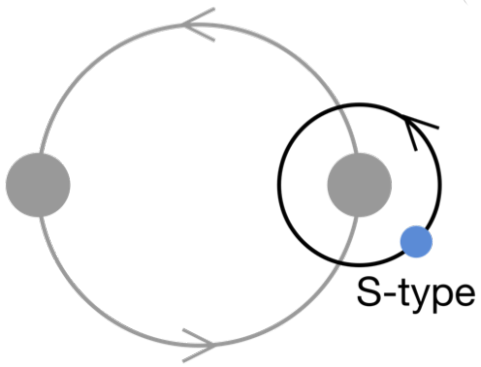

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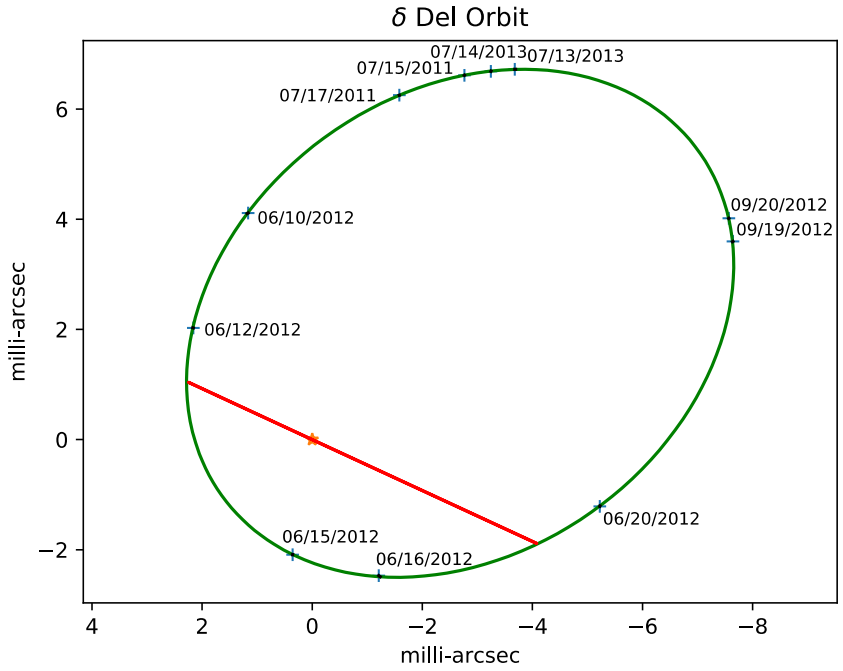
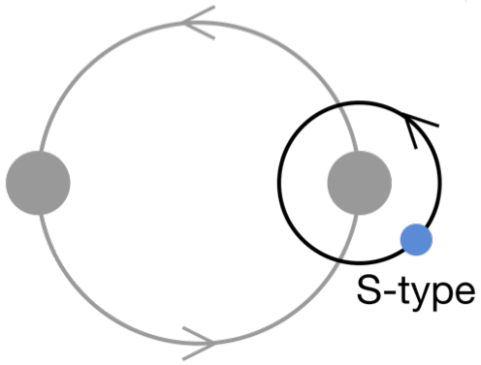
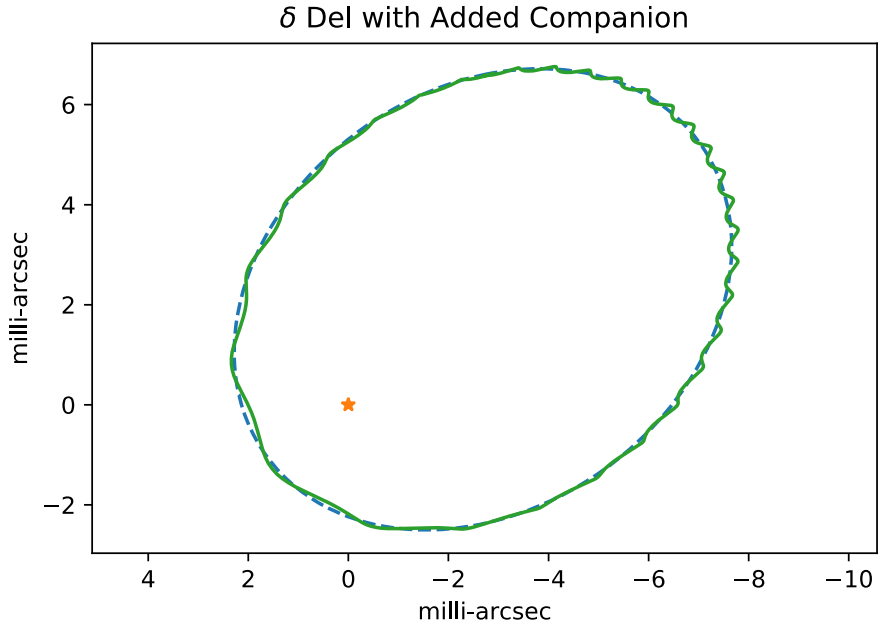




With “S-type” companion:



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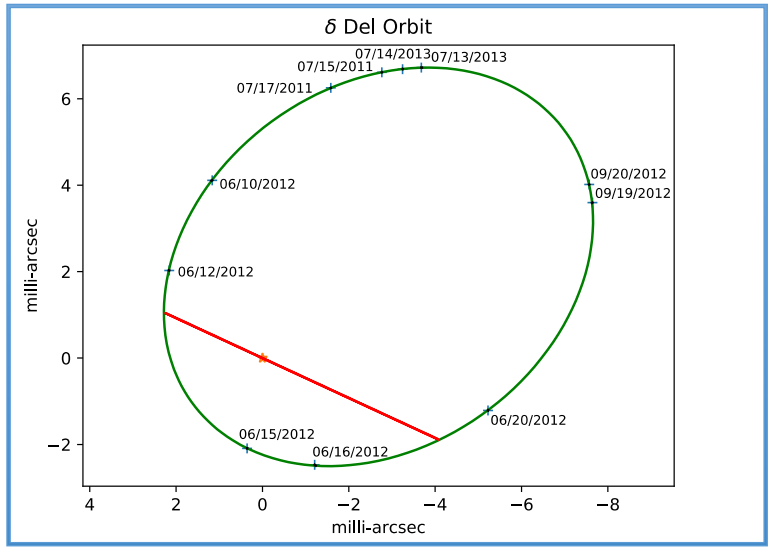
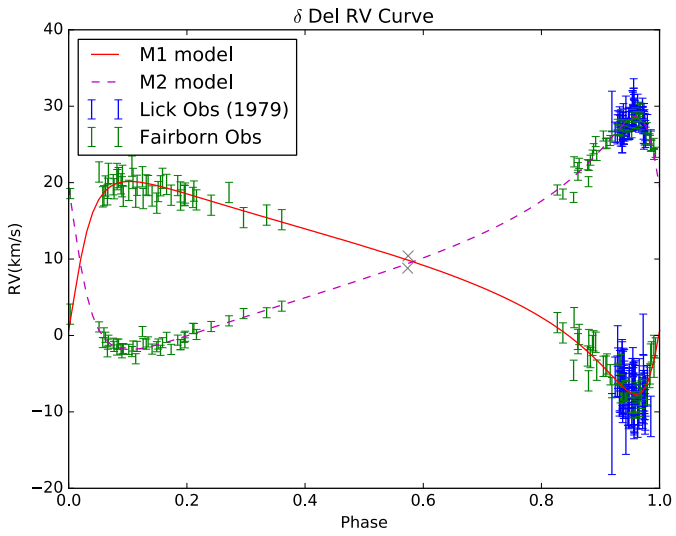
MIRC at CHARA Array: Delta Delphini

Close binary (<10 milli-arcsec)
late A-type components
40-day period

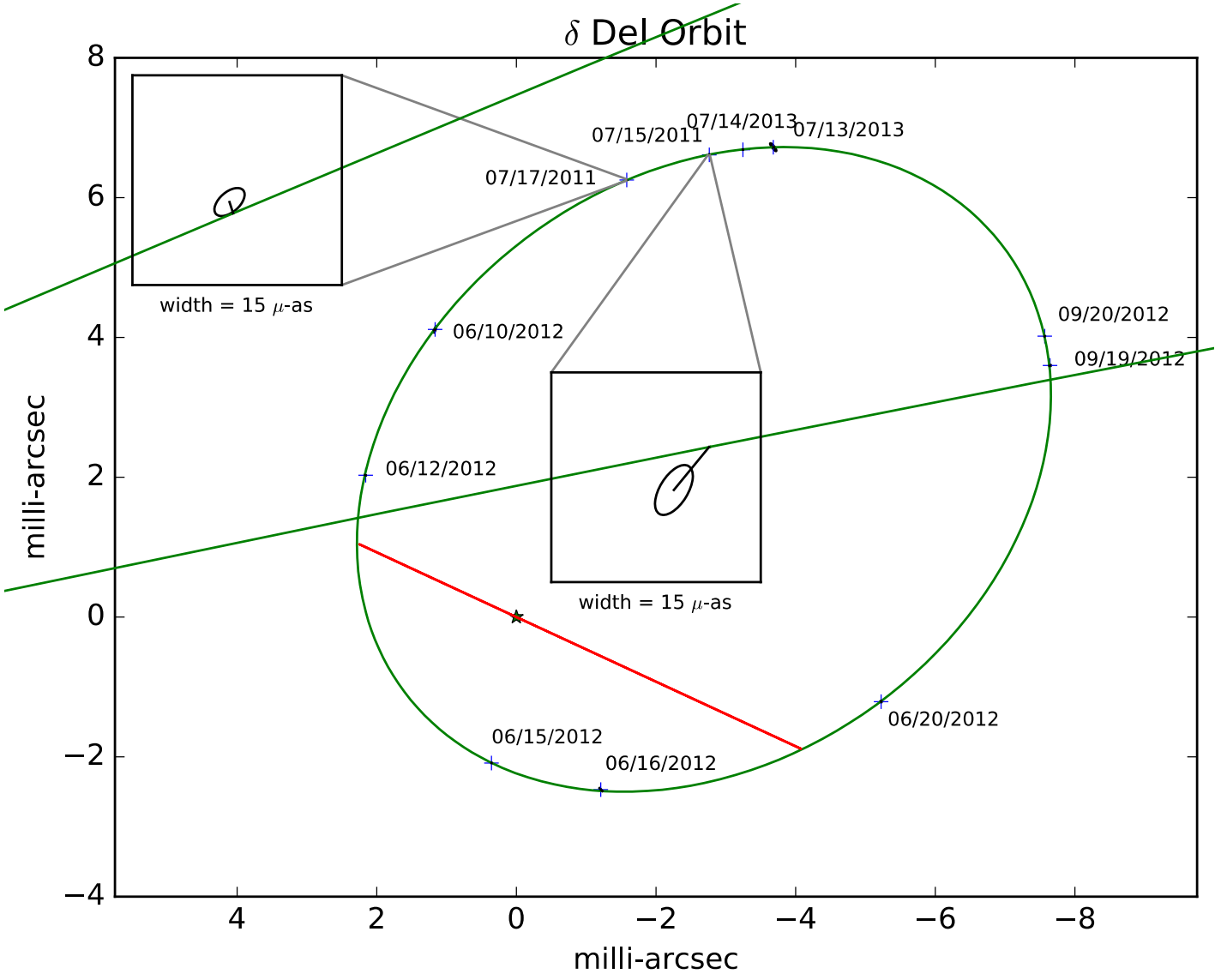
Recent paper:
Gardner et al, *Precision orbit of δ Delphini and Prospects for Astrometric Detection of Exoplanets,* 2018, ApJ **855** 1

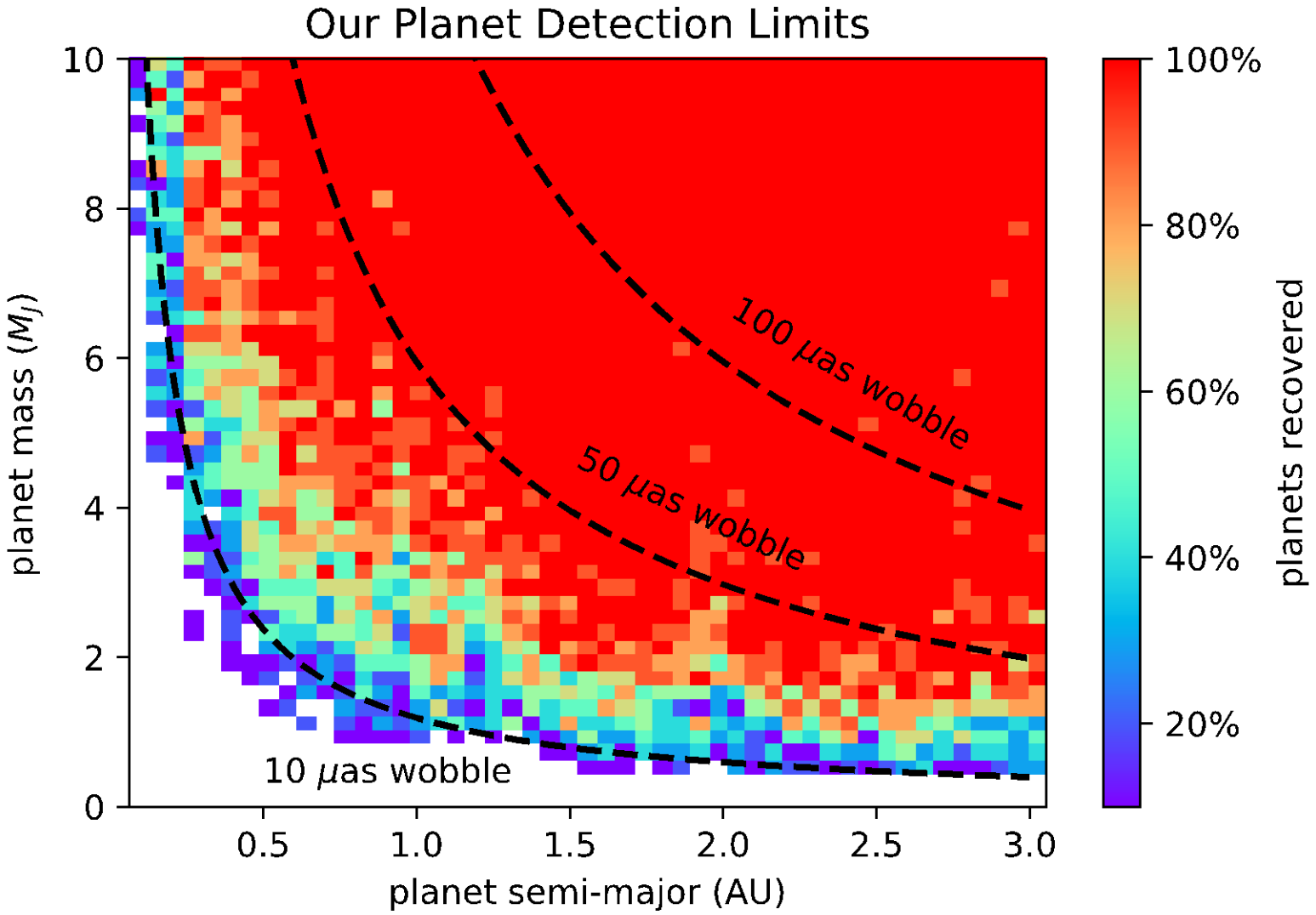




Visual Orbit from CHARA:

<10 μ-as precision!





- Can detect most planets > 2 M_J on orbits > 0.7 AU

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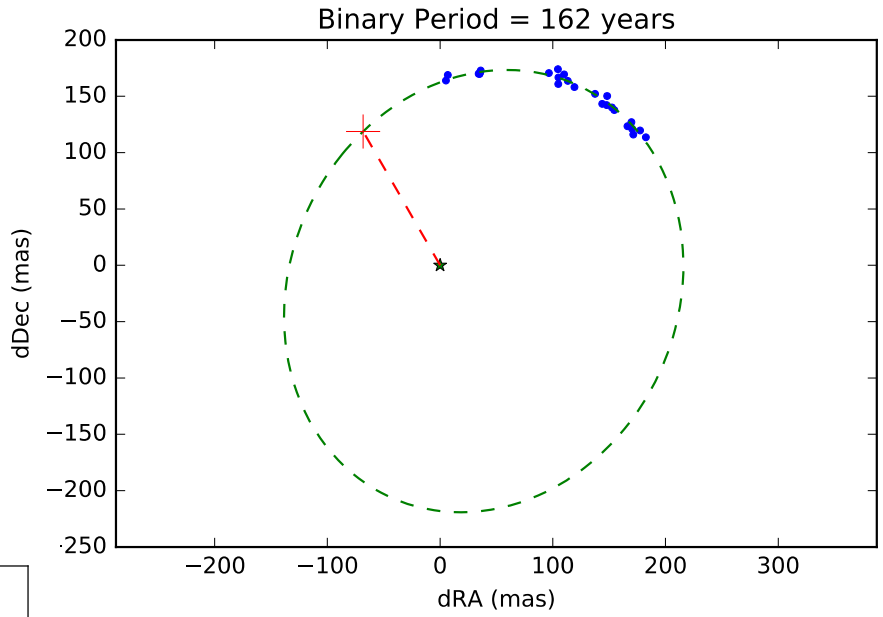
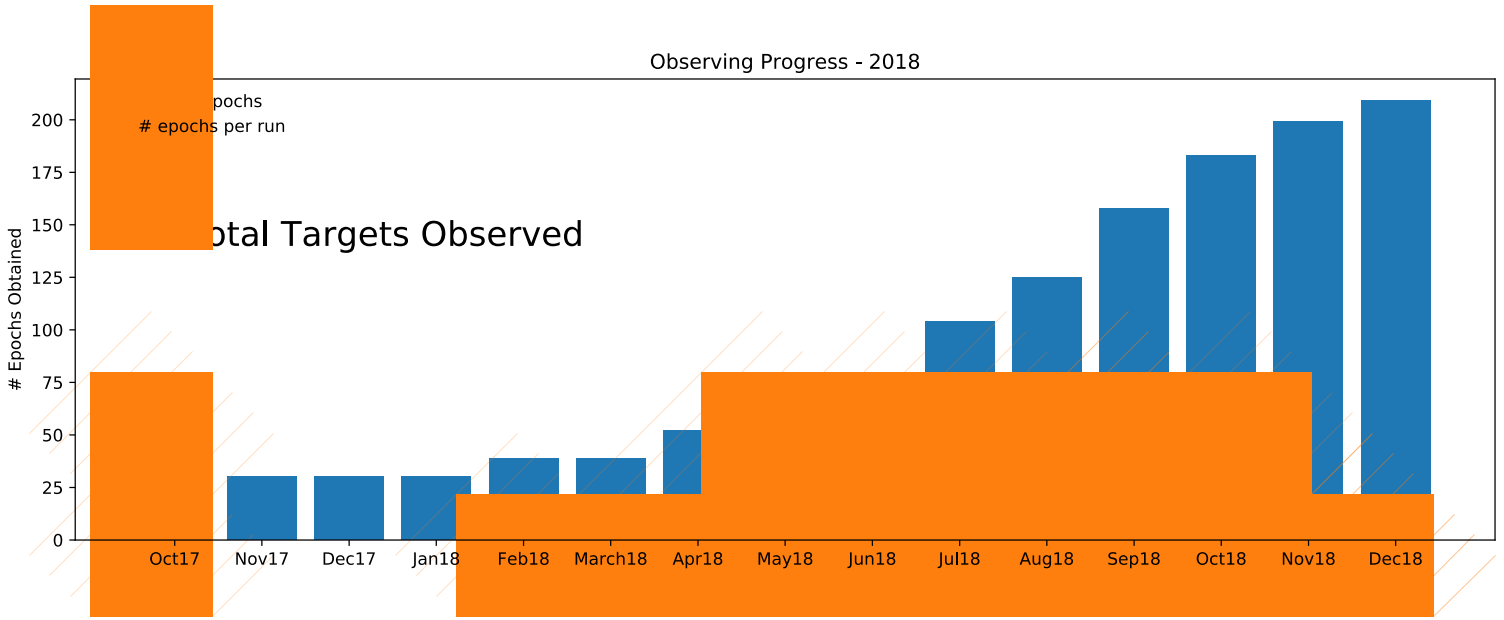
ARrangement for Micro-Arcsecond Differential Astrometry (ARMADA)

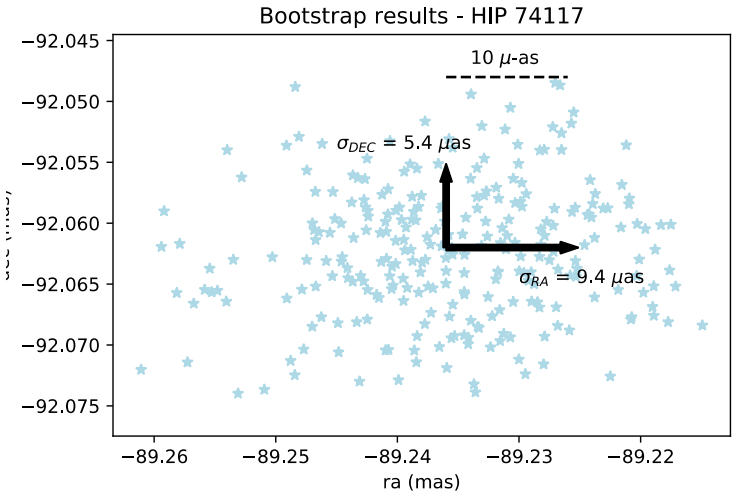
- Northern Sky: CHARA
- Monitor sample of A/B type binaries
  - Low projected sep (<0.2 arcsec)
  - Hmag<5.5
- Finished 1st year of observing

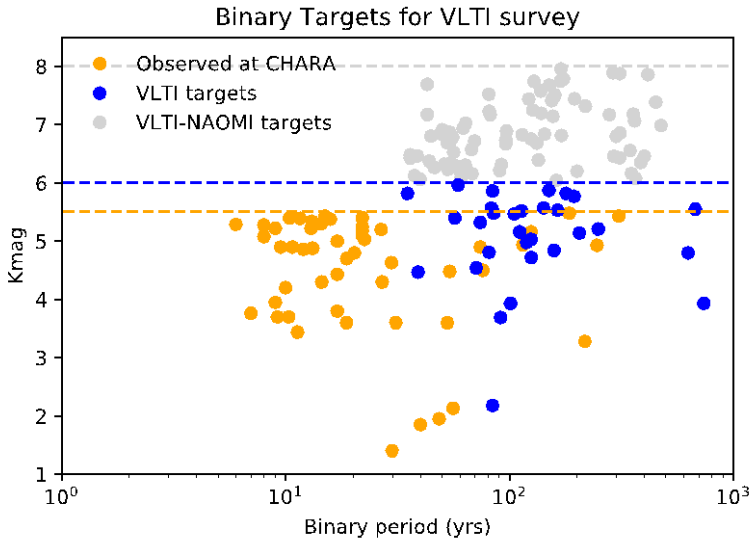


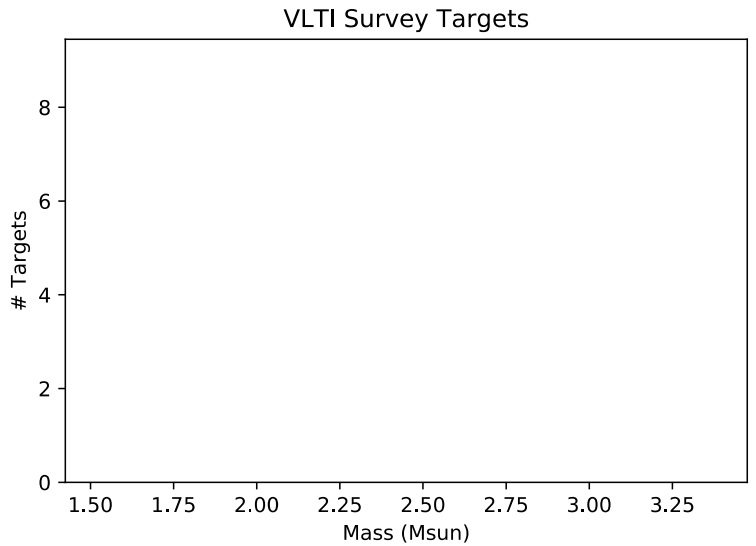


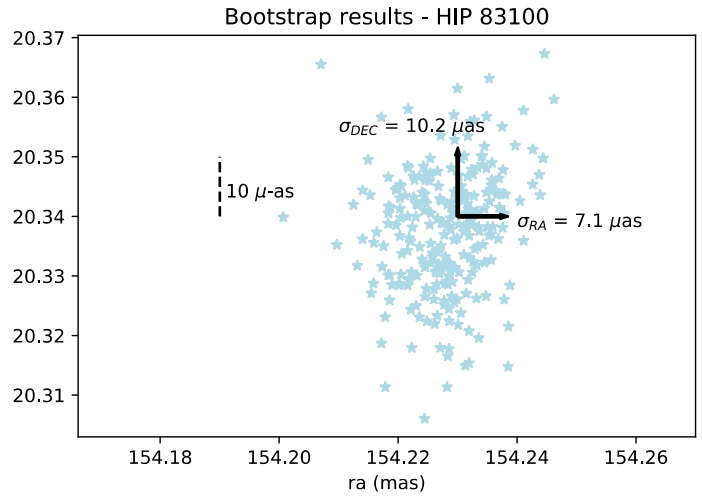
ARMADA Survey at VLTI

- Southern Sky: GRAVITY at VLTI
  - Can probe wider binary targets
- Pilot study in 2018
  - Achieved desired precision
- 2-year Large Program Accepted
  - 30 targets









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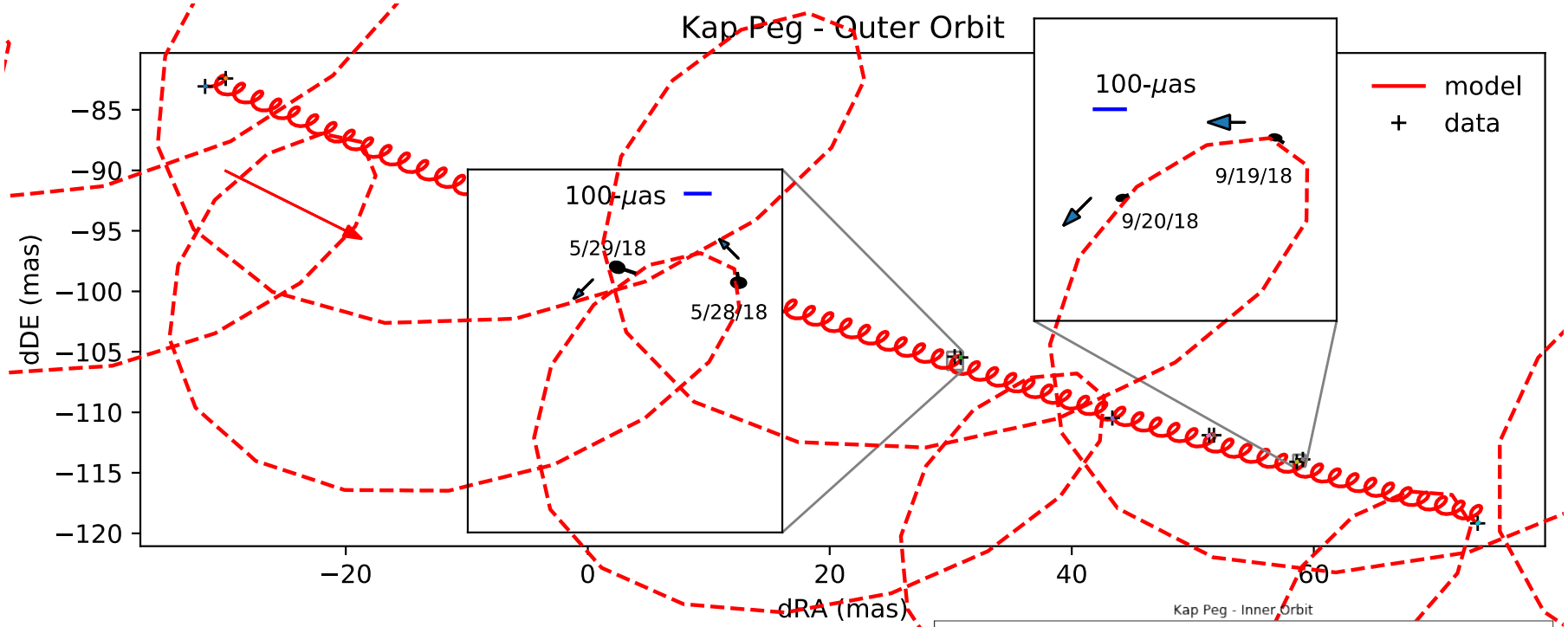
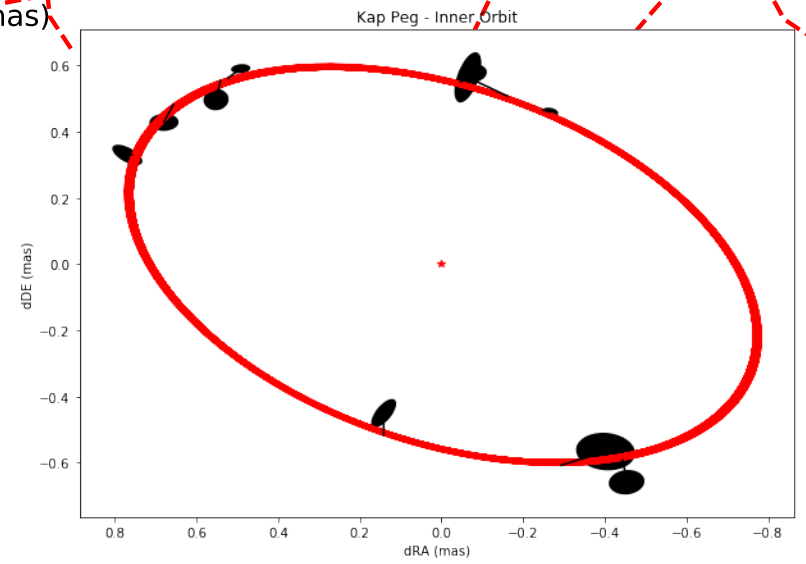


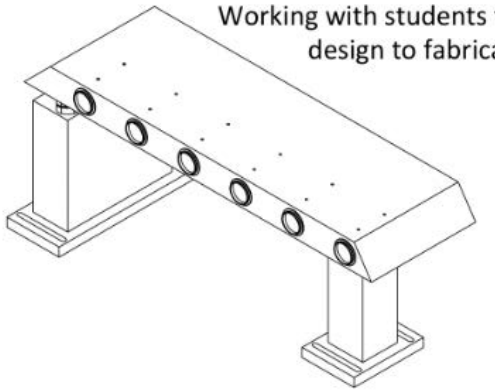


Kappa Peg – Triple System

Confirmed companion detected by Muterspaugh et al (2010)

Getting to 10 micro-as → Systematics

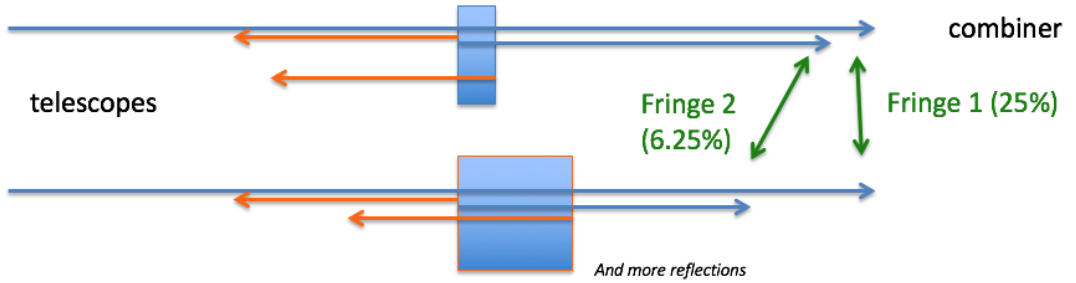
- 10-microarcsecond precision desired
  - 1e-4 for 100 mas binary
  - 300 m long baseline --> 3 cm (easy)
  - 1e-4 wavelength knowledge harder



- ETALONS allow us to calibrate our wavelength solution between nights at CHARA
  - Custom made by John Monnier & student Keith Johnson

Etalon Calibration

- Simulates binaries of known separation
- Wavelength-dependent visibilities and phases act as a wavelength reference



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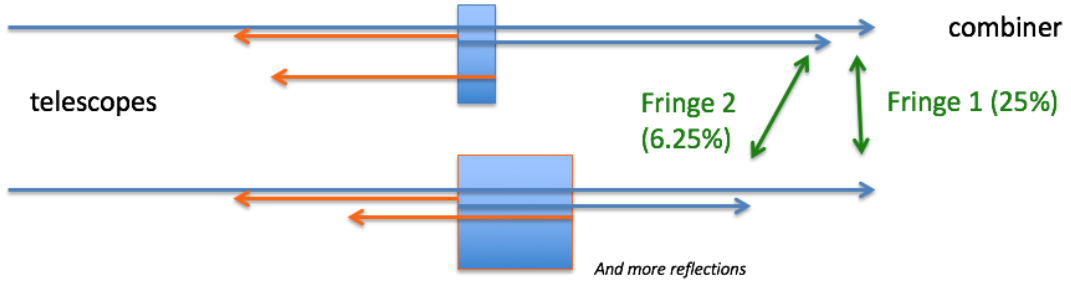
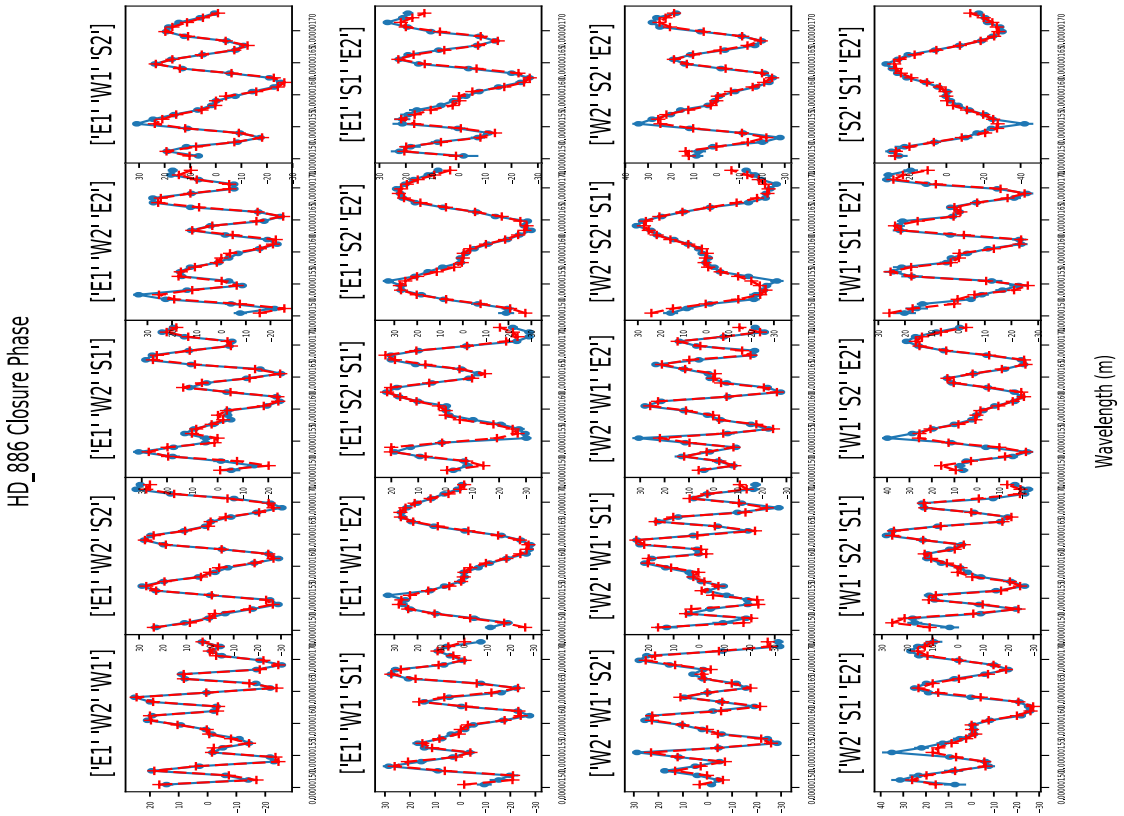


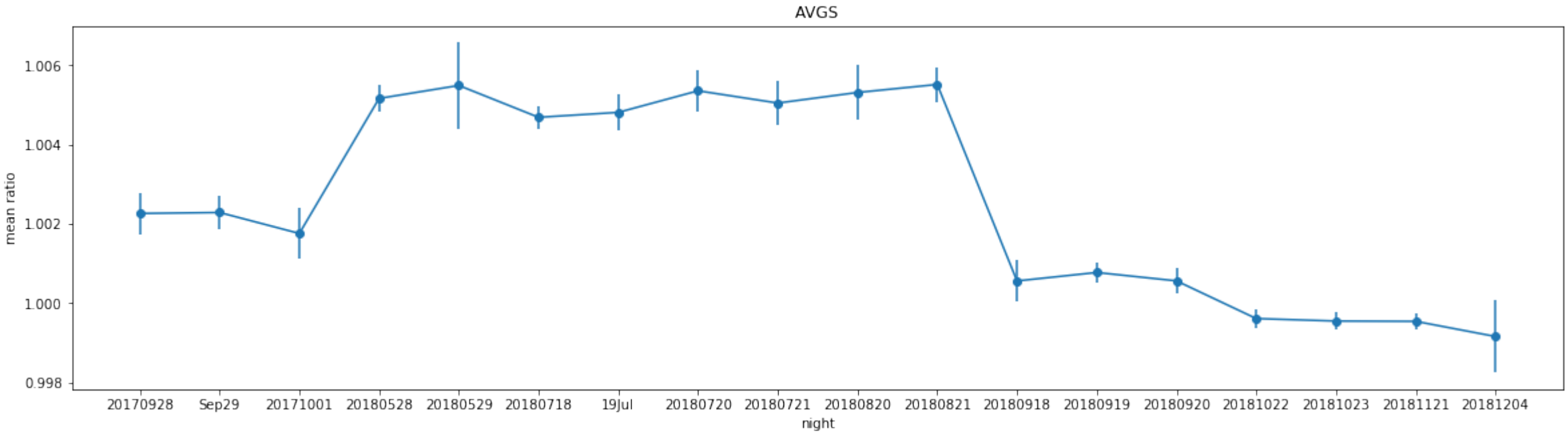


← On-Sky Data (red dashed line is model)

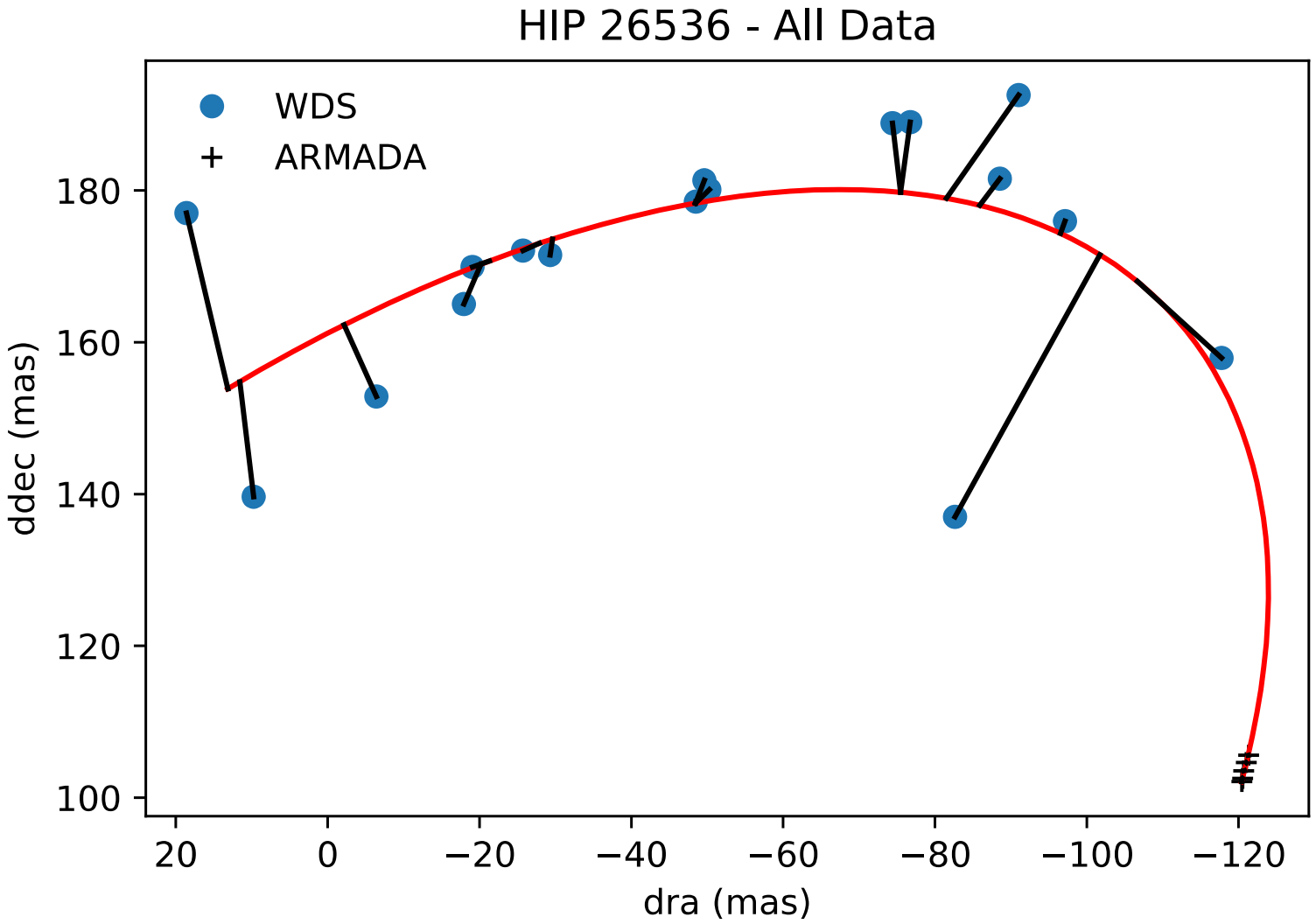
Etalon Results

- Model includes dispersion, flux ratio, 6 etalon thicknesses
- Fit to many nights → Pick reference etalon thicknesses → Measure % off reference

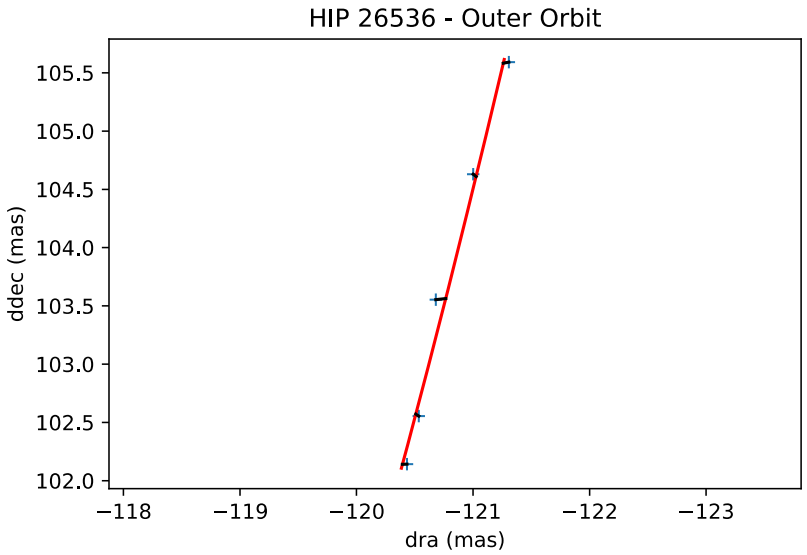
- This “etalon factor” is then applied to our data for that night



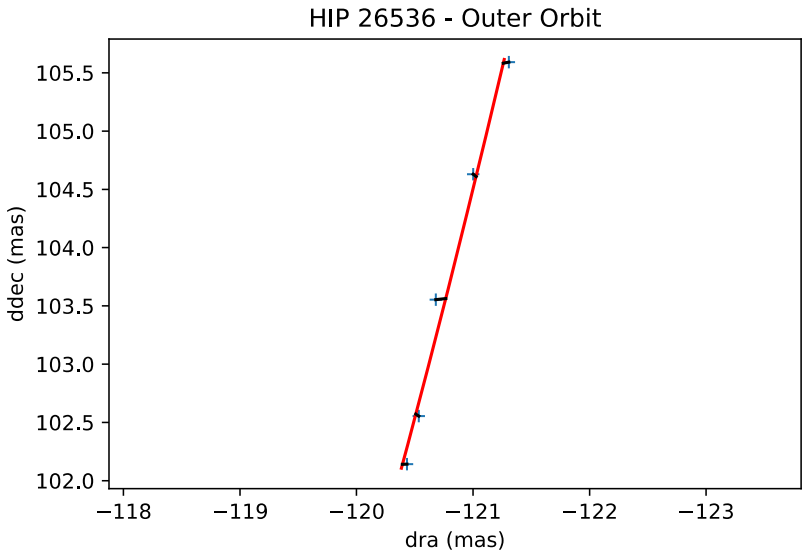
First Results from Some Binaries



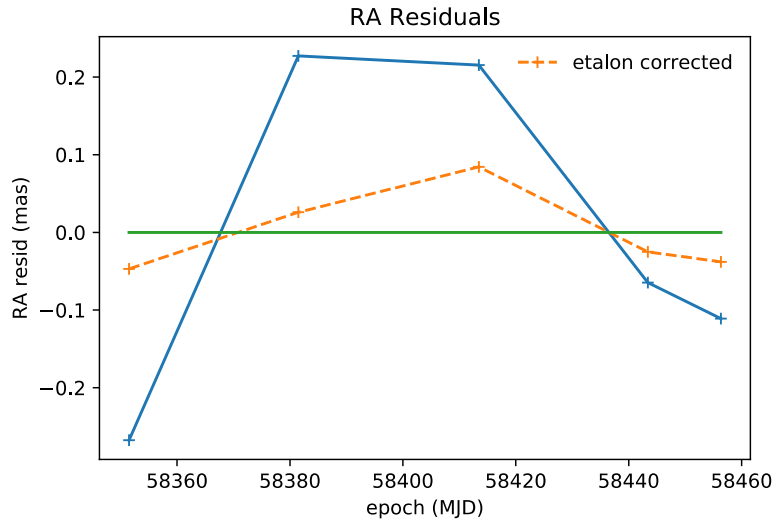
HIP 26536

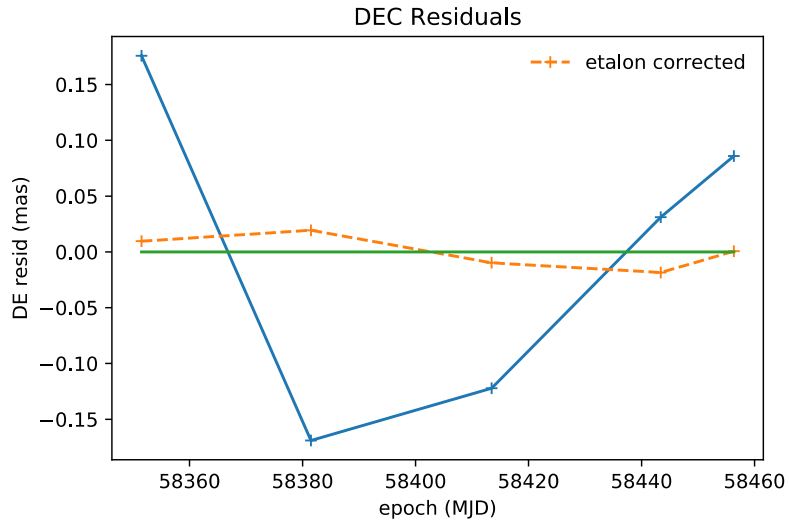

HIP 26536 - Outer Orbit
105.5
105.0
104.5
104.0
103.5
103.0
102.5
102.0
ddec (mas)
−118
−119
−120
−121
−122
−123
dra (mas)

HIP 26536



Subtract wide binary orbit





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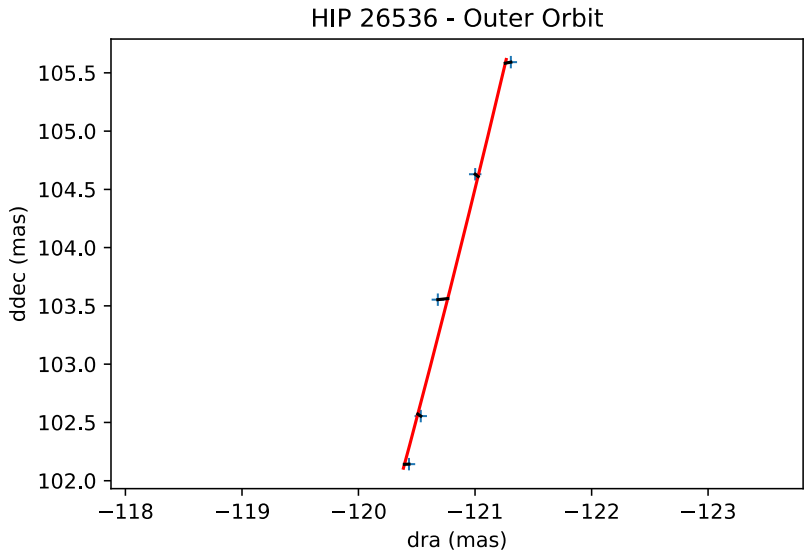

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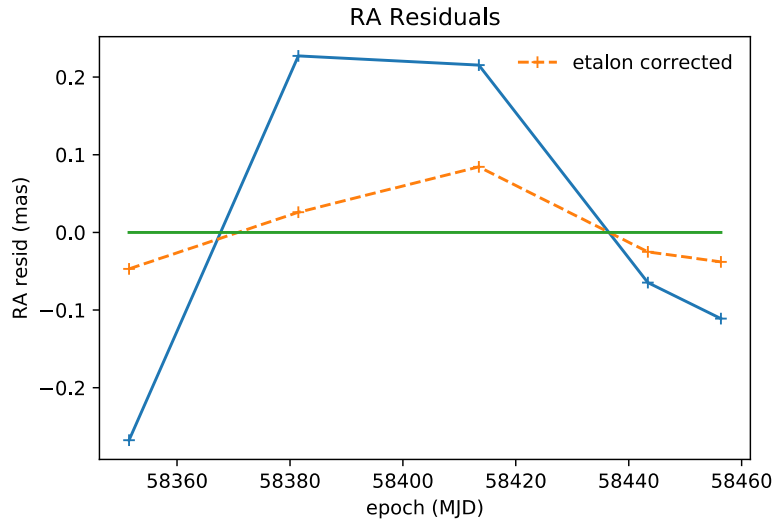
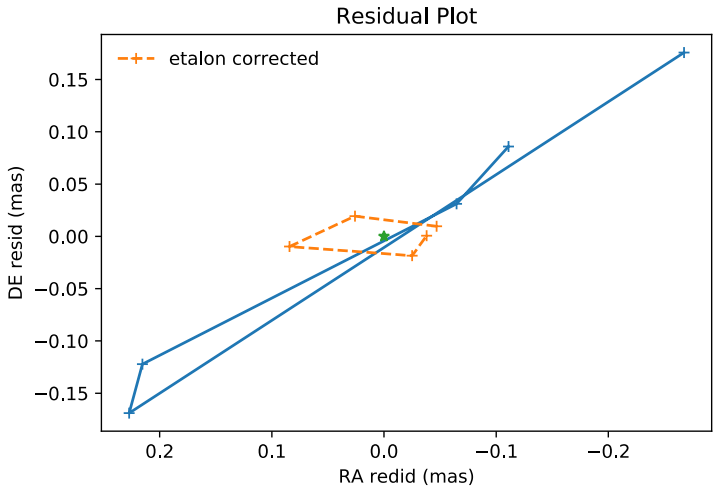
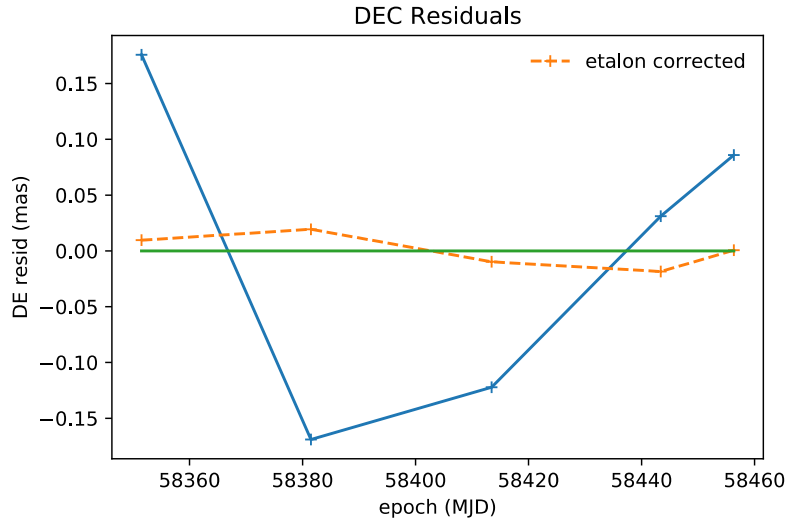
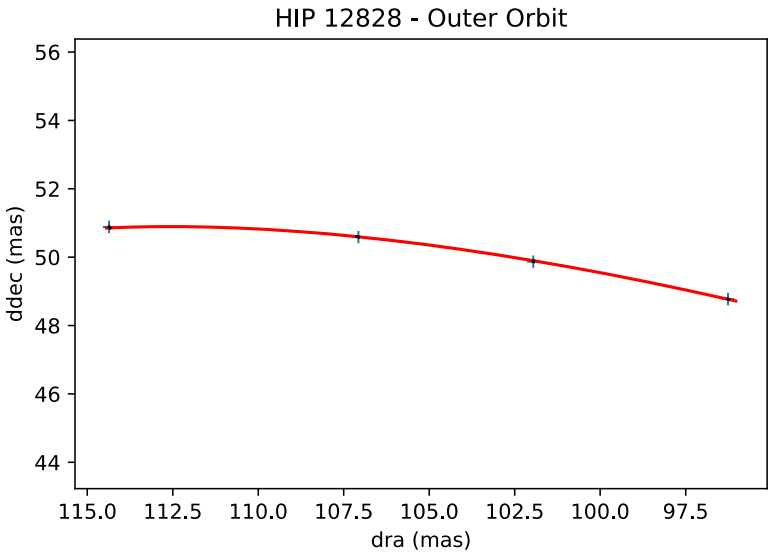


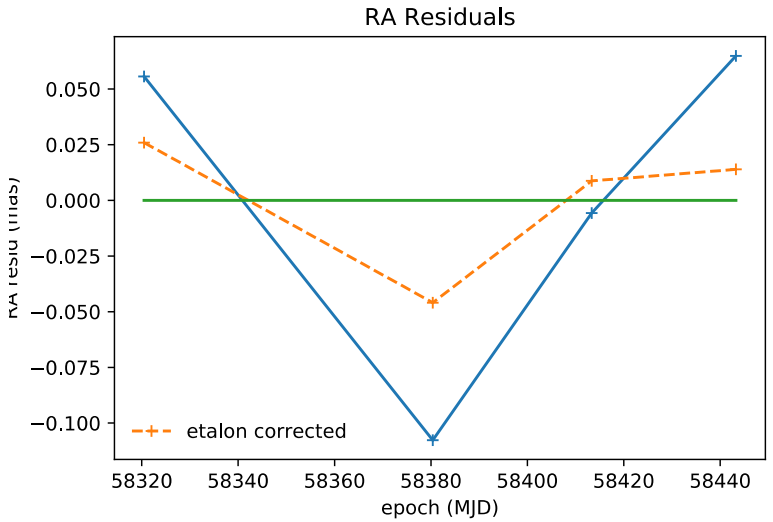


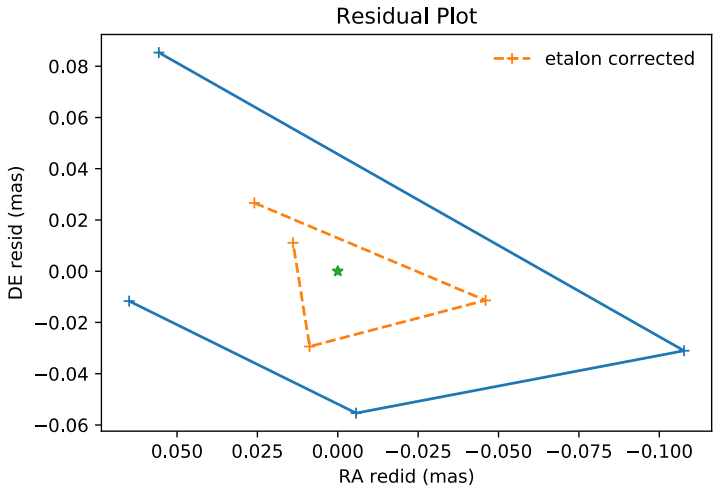


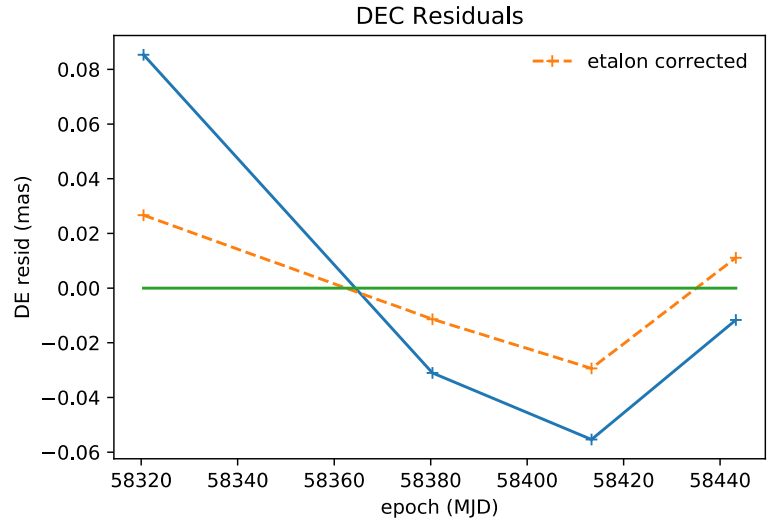
HIP 12828



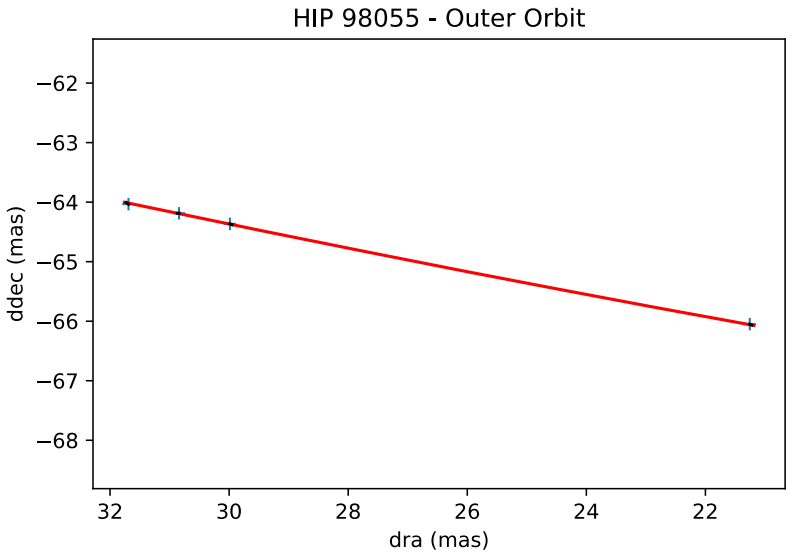
Subtract wide binary orbit







HIP 98055



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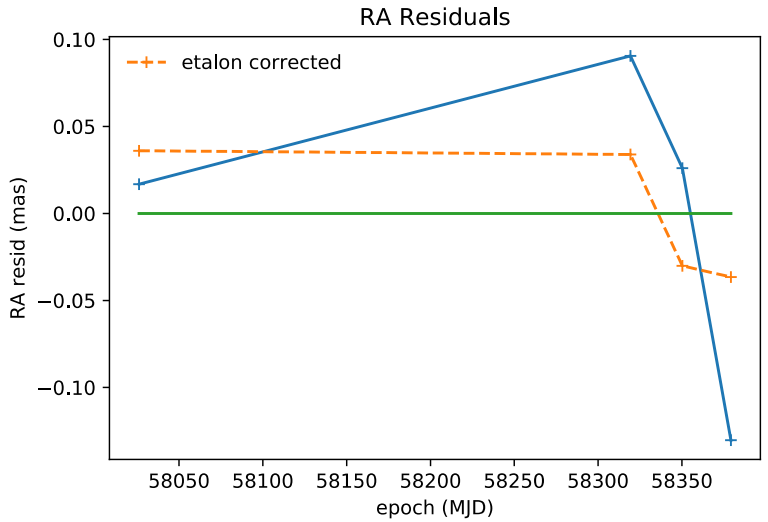

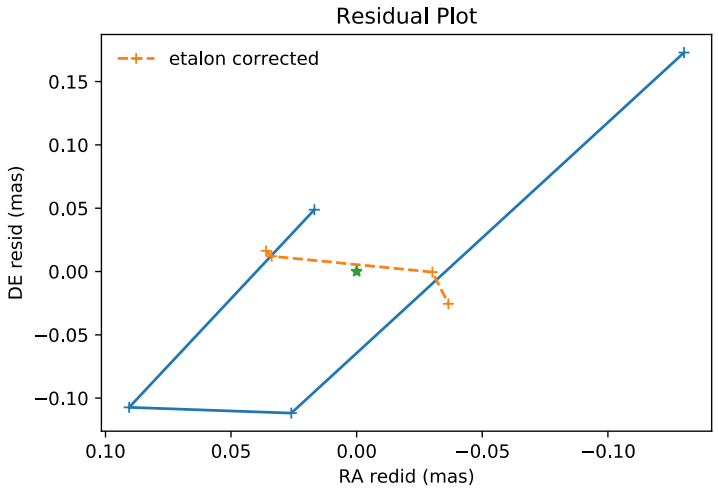

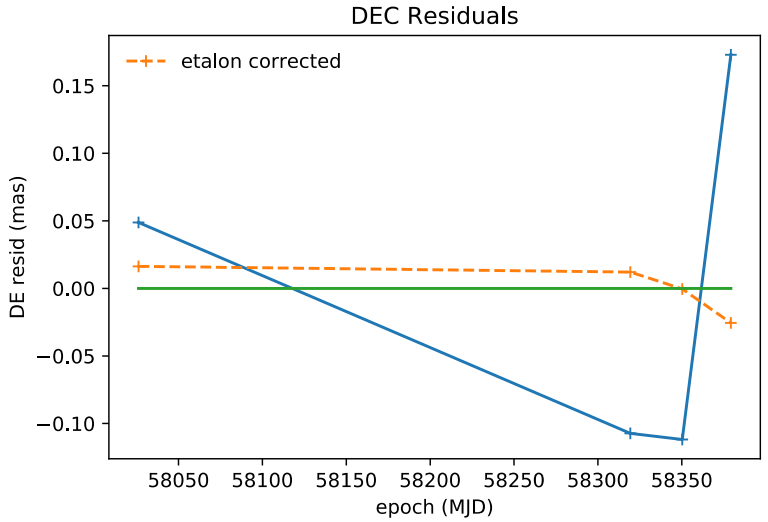

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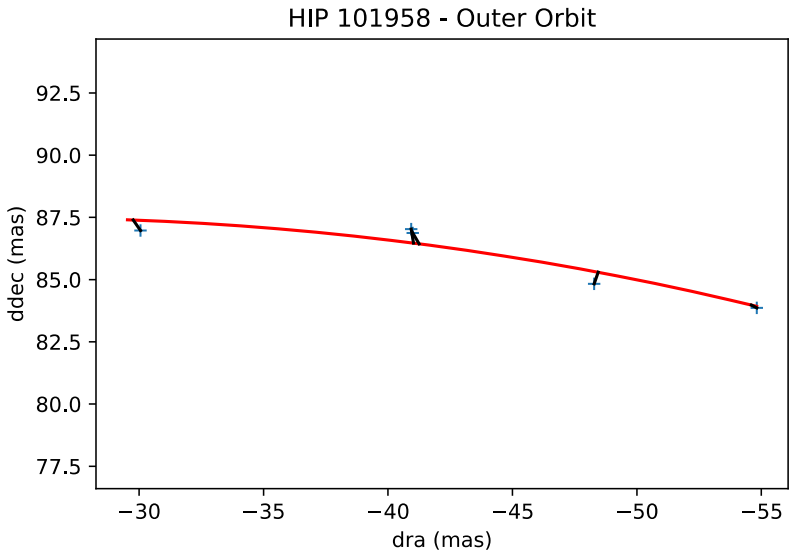

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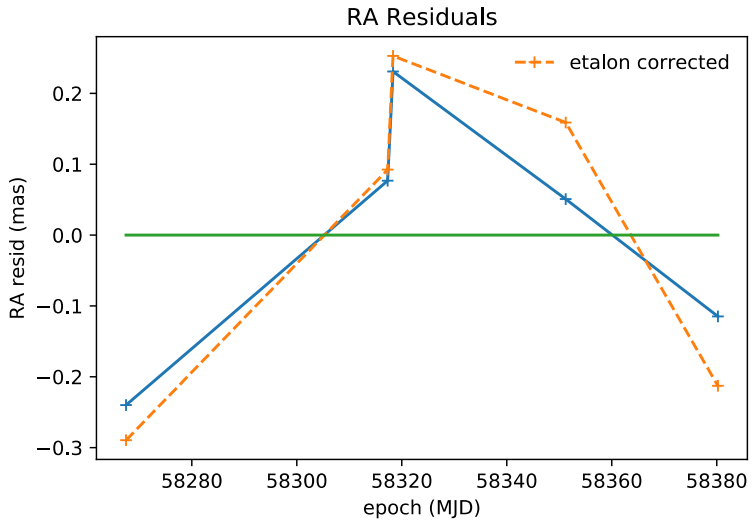

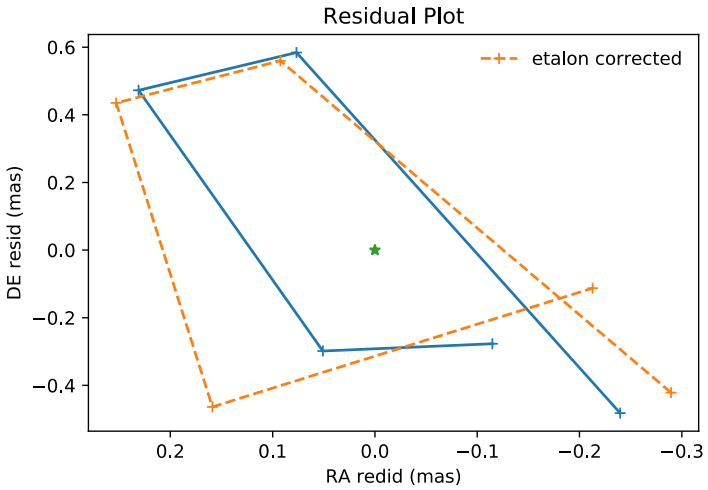

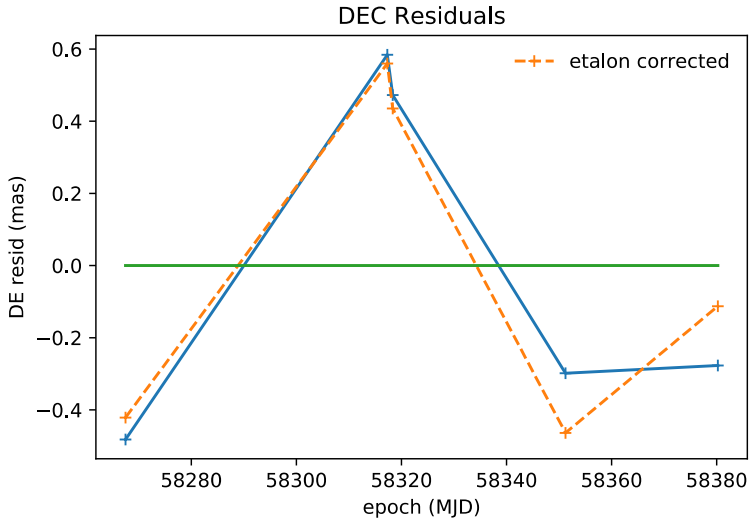

Summary

- Goal: Improve exoplanet census with long-baseline interferometry by targeting A/B-type binary systems
  - Began survey with MIRC-X at CHARA
  - Survey with GRAVITY at VLTI starting soon

- From pilot study, we expect to recover most exoplanets >2 M_J on ~AU orbits

Exoplanets with Gaia

For new detections *(Sahlmann, 2015)*: $S/N = a_1 \frac{\sqrt{N_{Gaia}}}{\sigma_\Lambda} > 20$

σ_Λ = 50 μ-as, N_{Gaia} = 70, a_1 = ”wobble”

Detectability of planet at 3 AU:

	1 $M_\odot$	2 $M_\odot$
1 M_J :	out to 20 pc *(~200 stars)*	
10 M_J :	out to 200 pc *(~25,000 stars)*	

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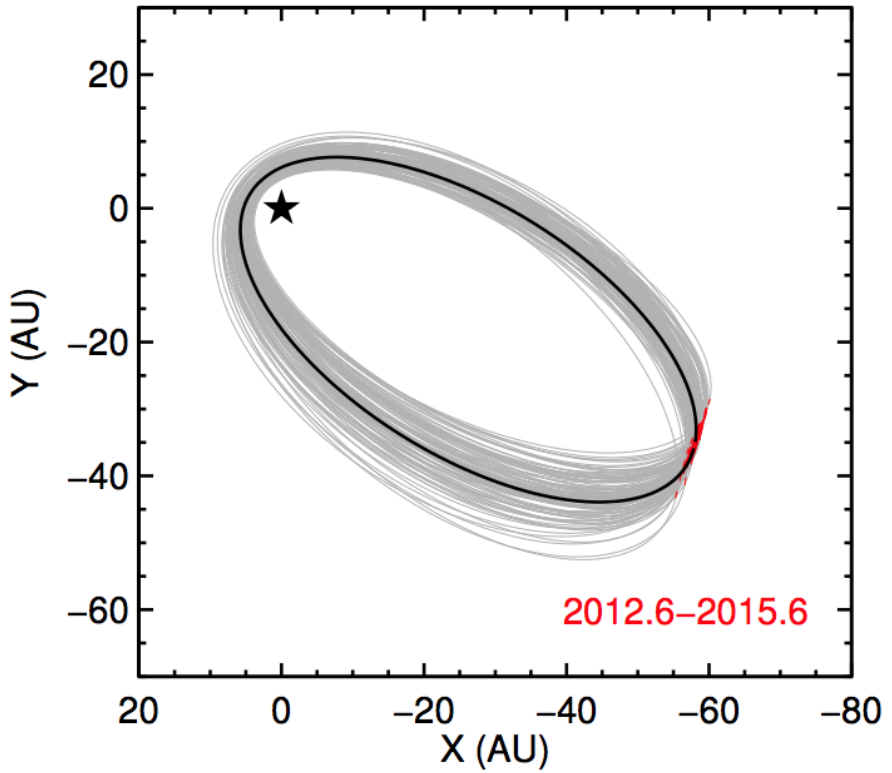
Detectability of planet at 3 AU:

	1 $M_\odot$	2 $M_\odot$
1 M_J :	out to 20 pc *(~200 stars)*	***out to 10 pc*** *(4 stars)*
10 M_J :	out to 200 pc *(~25,000 stars)*	out to 100 pc *(600 stars)*

Complication: **Planets in Close Binary Systems?**

- Suppression for *binary separation* < 50 AU (Kraus et al, 2016)
  - BUT Matson et al, 2018 find *no suppression* in Kepler planets
- Planets still found in these environments
  - 10 planets with *binary separations* <100 AU
  - 5 planets around <20 AU binary
  - (Thebault & Haghighipour, 2015)
- **PHASES astrometry project (Mutterspaugh et al 2010)**
  - 6 substellar companions out of 50 binary targets

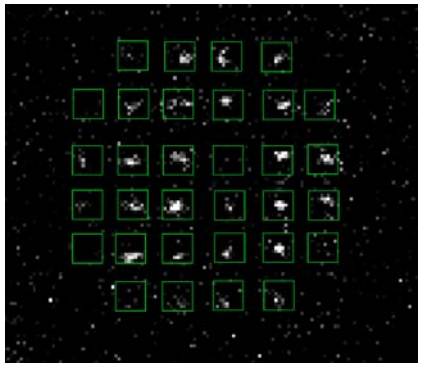
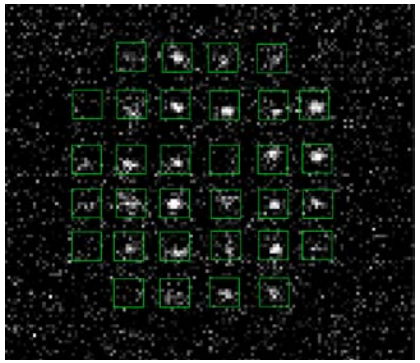
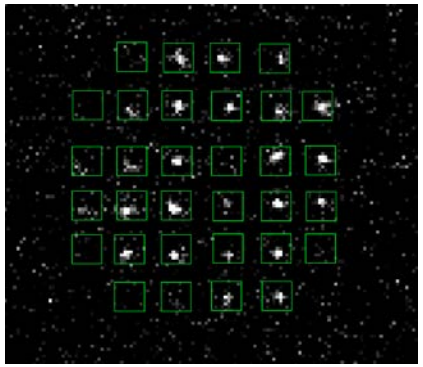
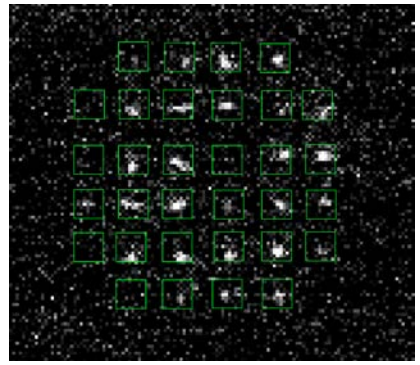
Kepler-444:
5 (non-giant) planets around component A



Other Systematics – Pupil control

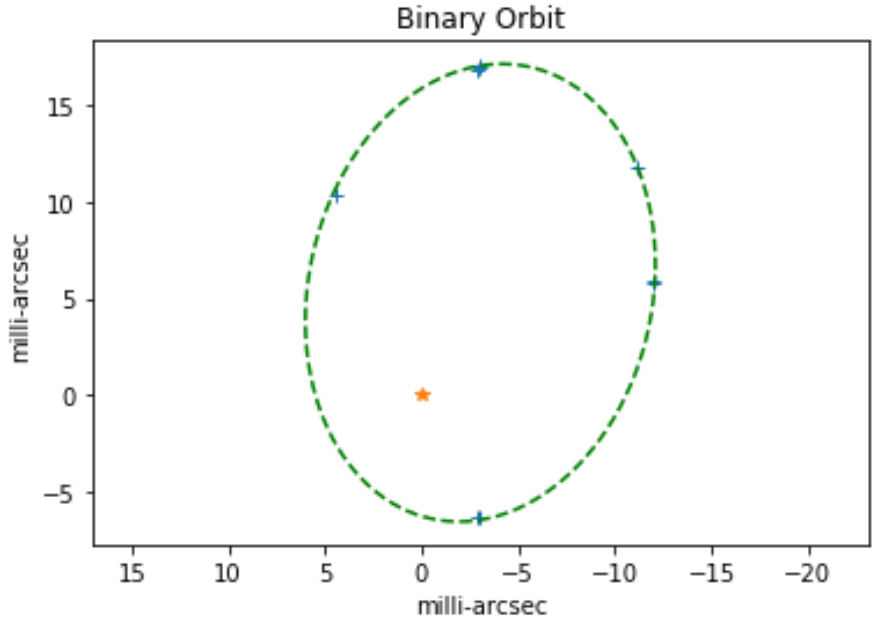
- Potential problem for 1e-4 precision
- Pupil tracking
  - CHARA → labAO (AO soon)

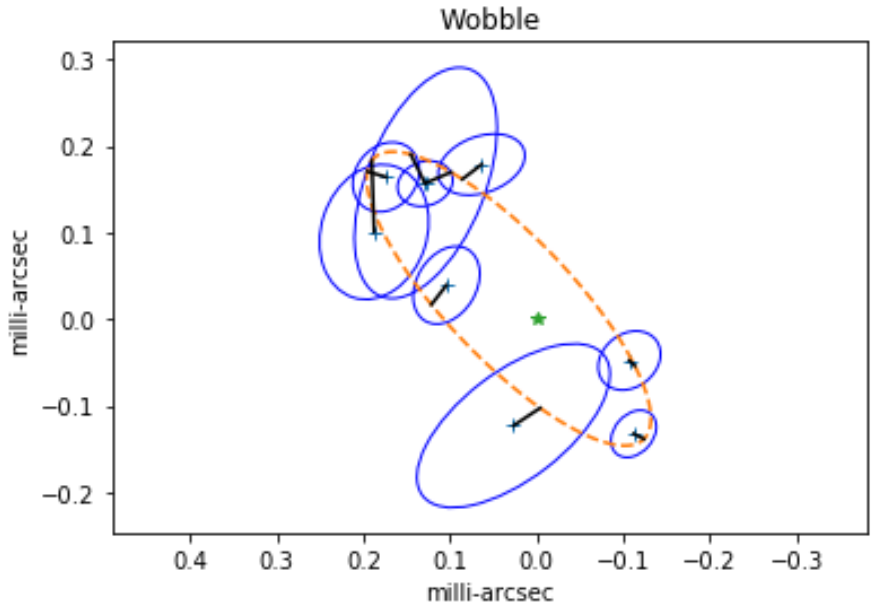
- NAOMI (AO system) just commissioned on VLTI

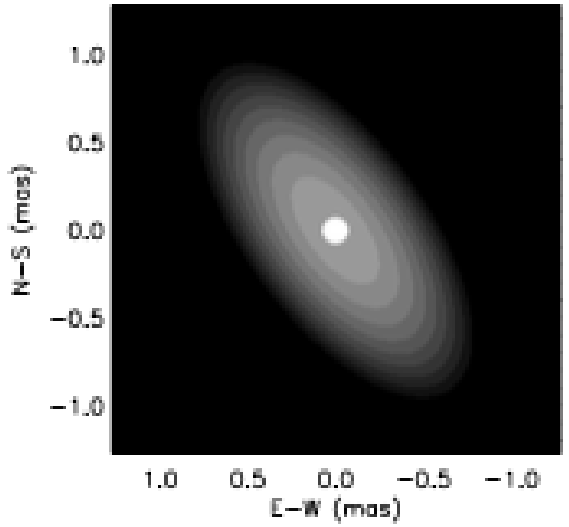
Another MIRC test case: 59 Cyg

- Be star with ~170 mas companion
- Discovered a *new* 900-day companion
- Detected “wobble” from known 28-day companion (*Peters et al, 2013*)

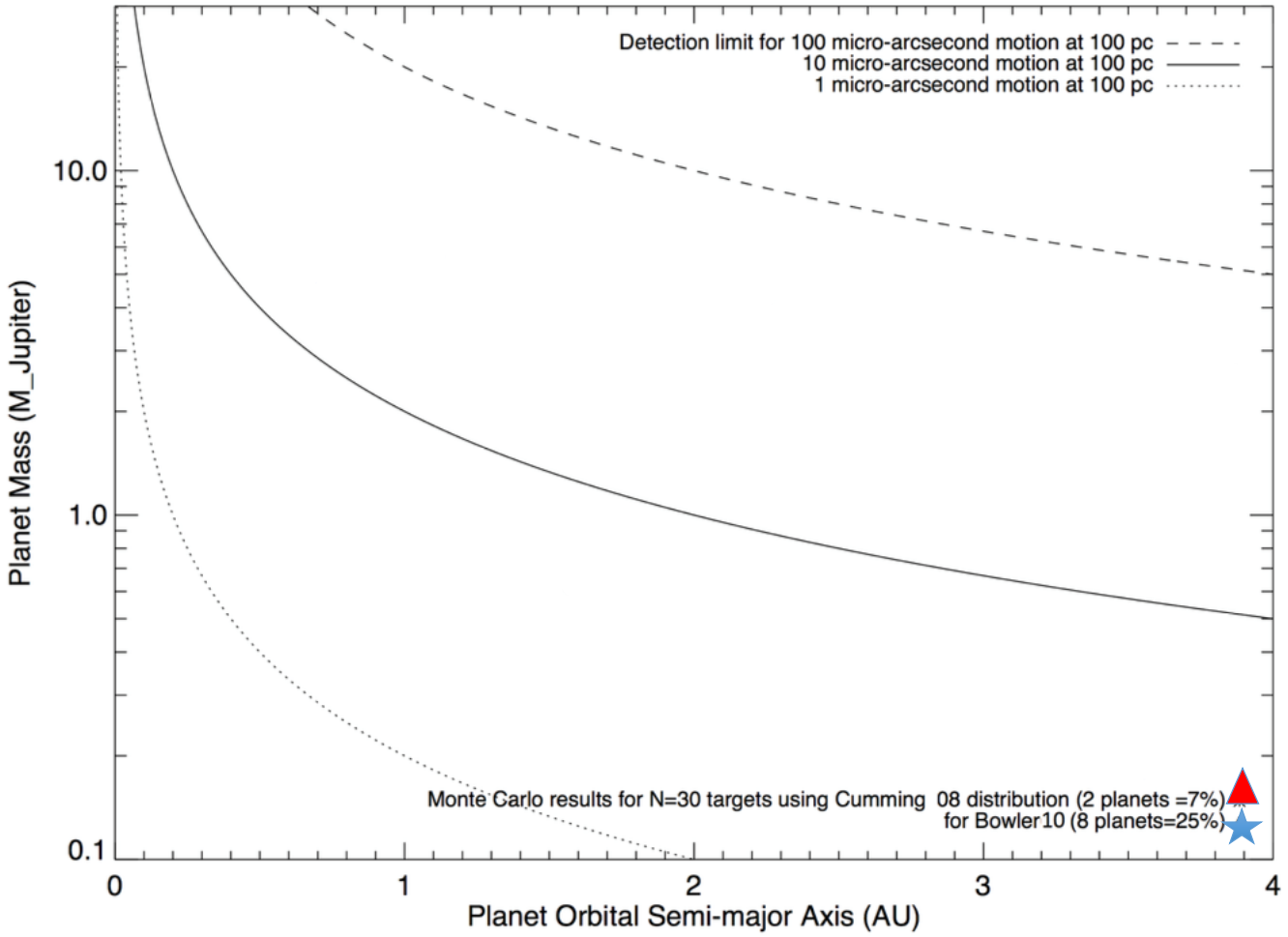




Disk Model



Main Goal of Binary Survey: Distinguish between Planet Distributions



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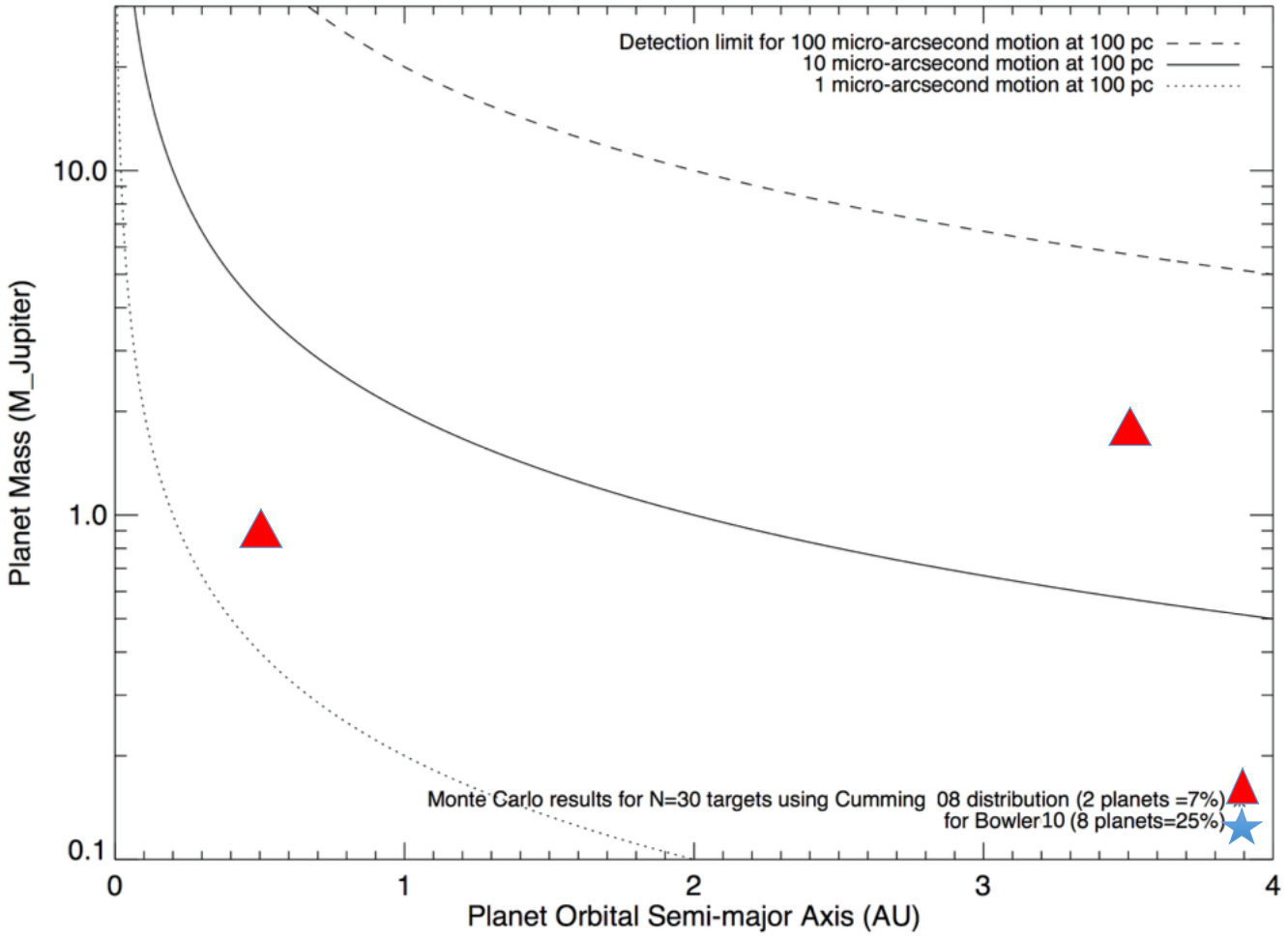

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