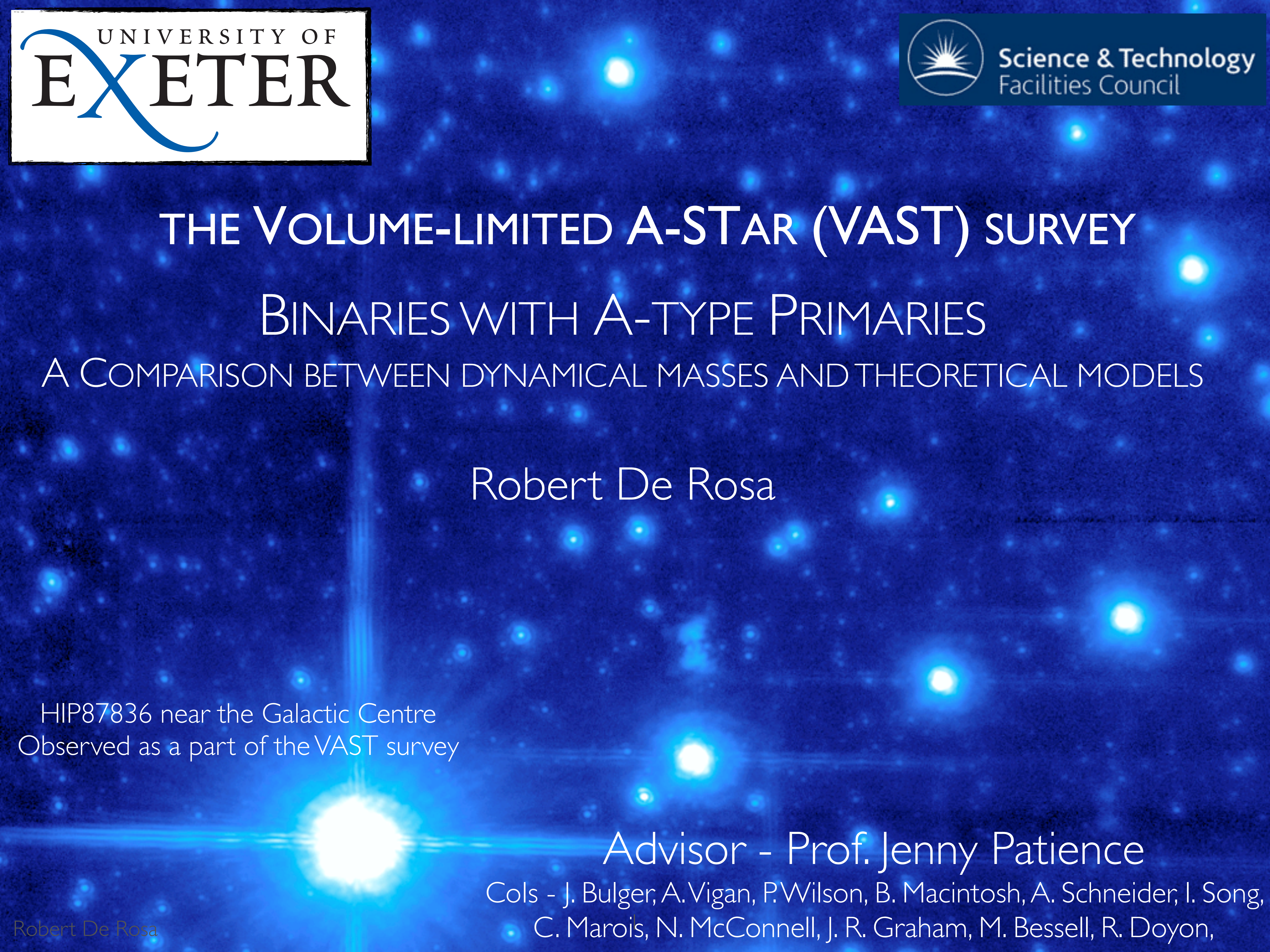


THE VOLUME-LIMITED A-STAR (VAST) SURVEY

BINARIES WITH A-TYPE PRIMARIES

A COMPARISON BETWEEN DYNAMICAL MASSES AND THEORETICAL MODELS

Robert De Rosa

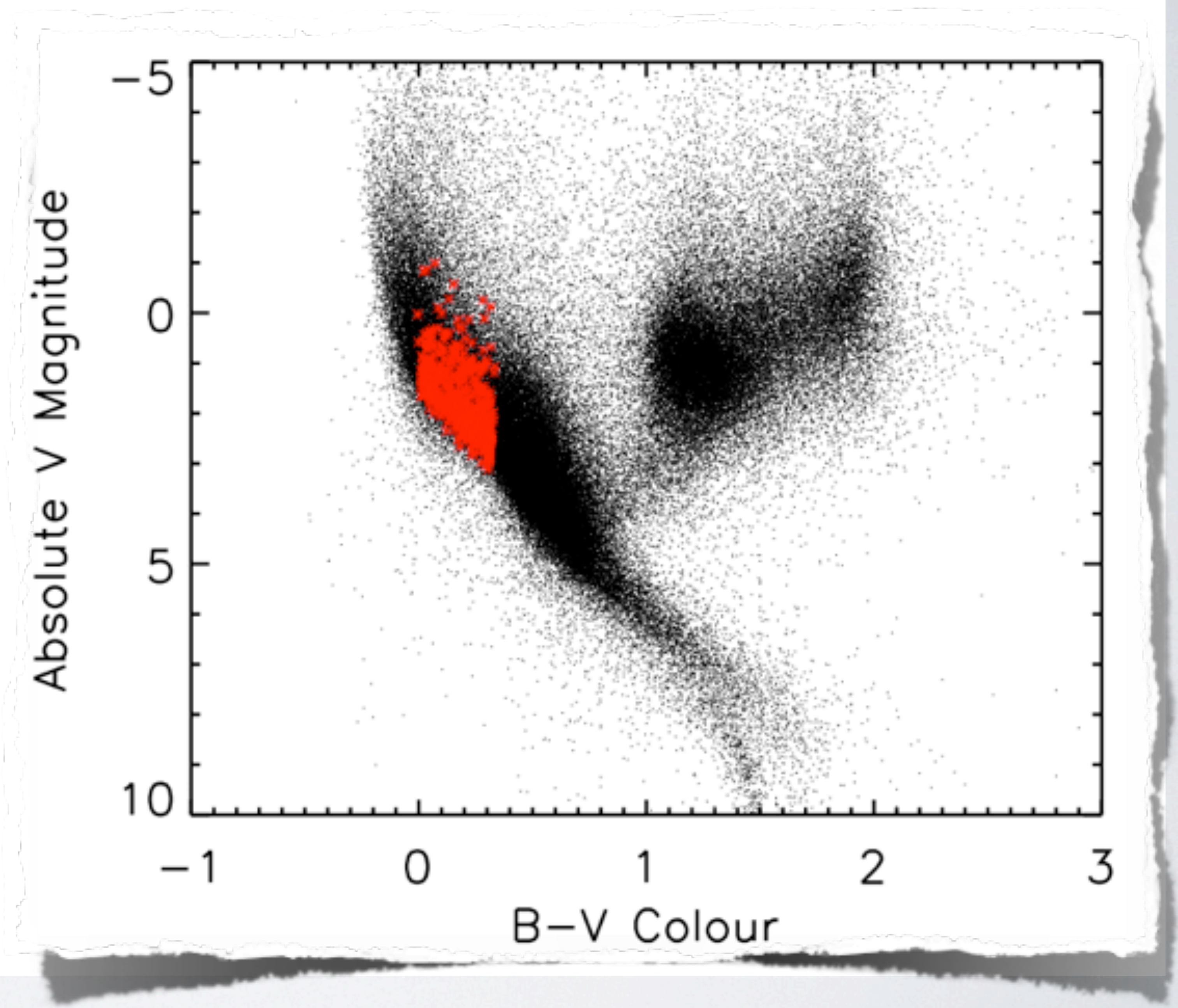
HIP87836 near the Galactic Centre
Observed as a part of the VAST survey

Advisor - Prof. Jenny Patience
CoIs - J. Bulger, A. Vigan, P. Wilson, B. Macintosh, A. Schneider, I. Song, C. Marois, N. McConnell, J. R. Graham, M. Bessell, R. Doyon,

UNIVERSITY OF EXETER
Science & Technology Facilities Council

THE VAST SURVEY

- Adaptive-optics survey of 500 A-type stars within 75pc
- Will provide first constraints on multiplicity within 10-1000s of AU.
- Comparable to studies of Solar-type stars (Duquennoy & Mayor, Raghavan et al.) and M-dwarfs (Fischer & Marcy)



The Hipparcos catalogue (ESA 1997)

WHAT CAN WE DO?

We have a large dataset which can be used to investigate numerous topics

VAST Survey

Debris Disks

Correlation between disks and companions? (Bulger+11, *in prep*)

Brown Dwarfs

Frequency currently unconstrained

Orbits

Determine system masses
Comparison to mass-mag relations

X-Rays

Why are some A-stars detected in X-ray surveys? (De Rosa+11)

White Dwarfs

Correlation with hard X-ray/UV emission?

Spectroscopy

Use solar-type companions to date A-stars

Exoplanets?

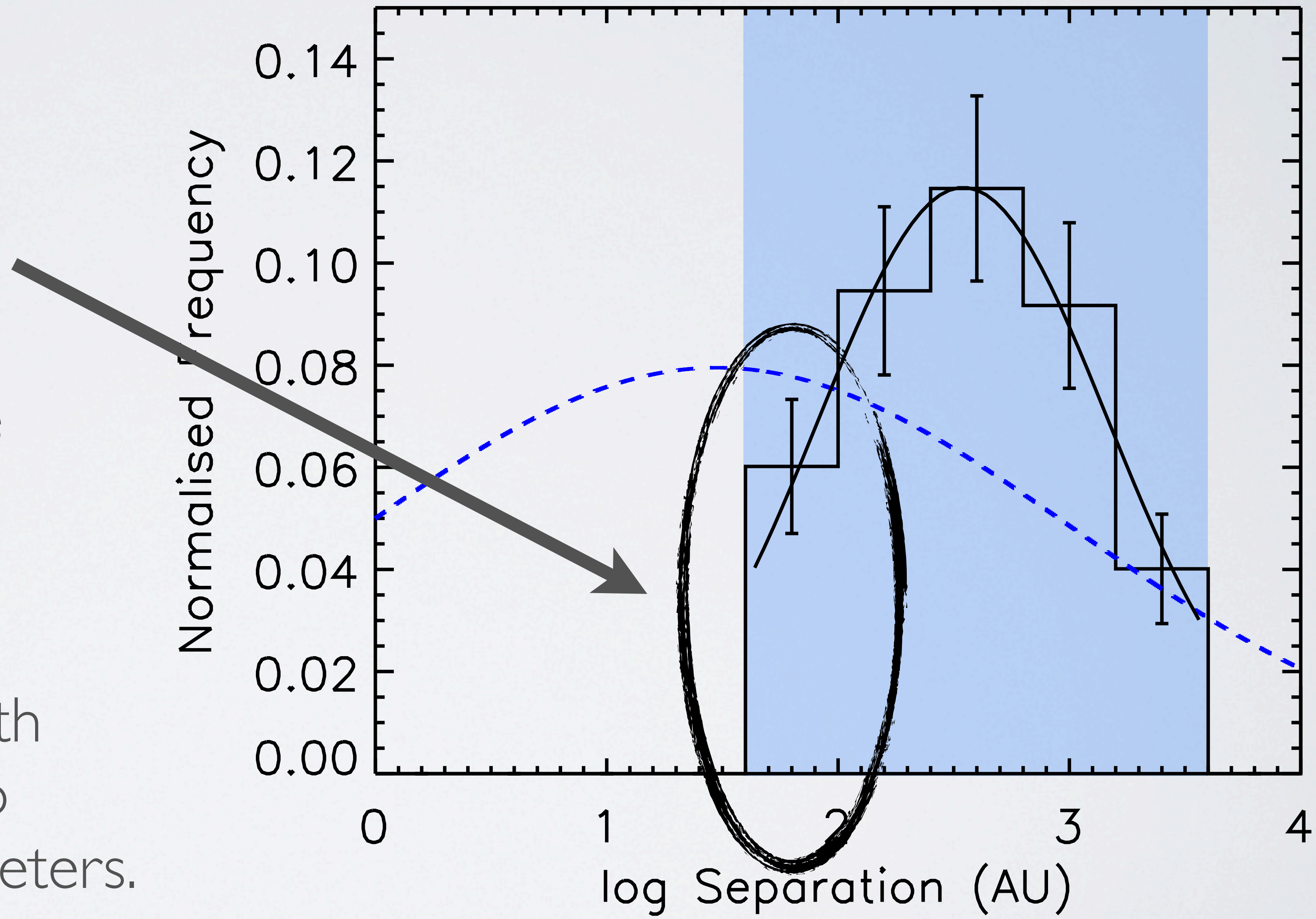
Target selection for future GPI mission

Hierarchical

Does wide companion indicate presence of inner companion?

Sub-100AU Binaries

- Focus in on one bin of the separation distribution.
- Orbits short enough to be resolved within reasonable baseline.
- All 26 systems used, 13 with sufficient measurements to estimate the orbital parameters.

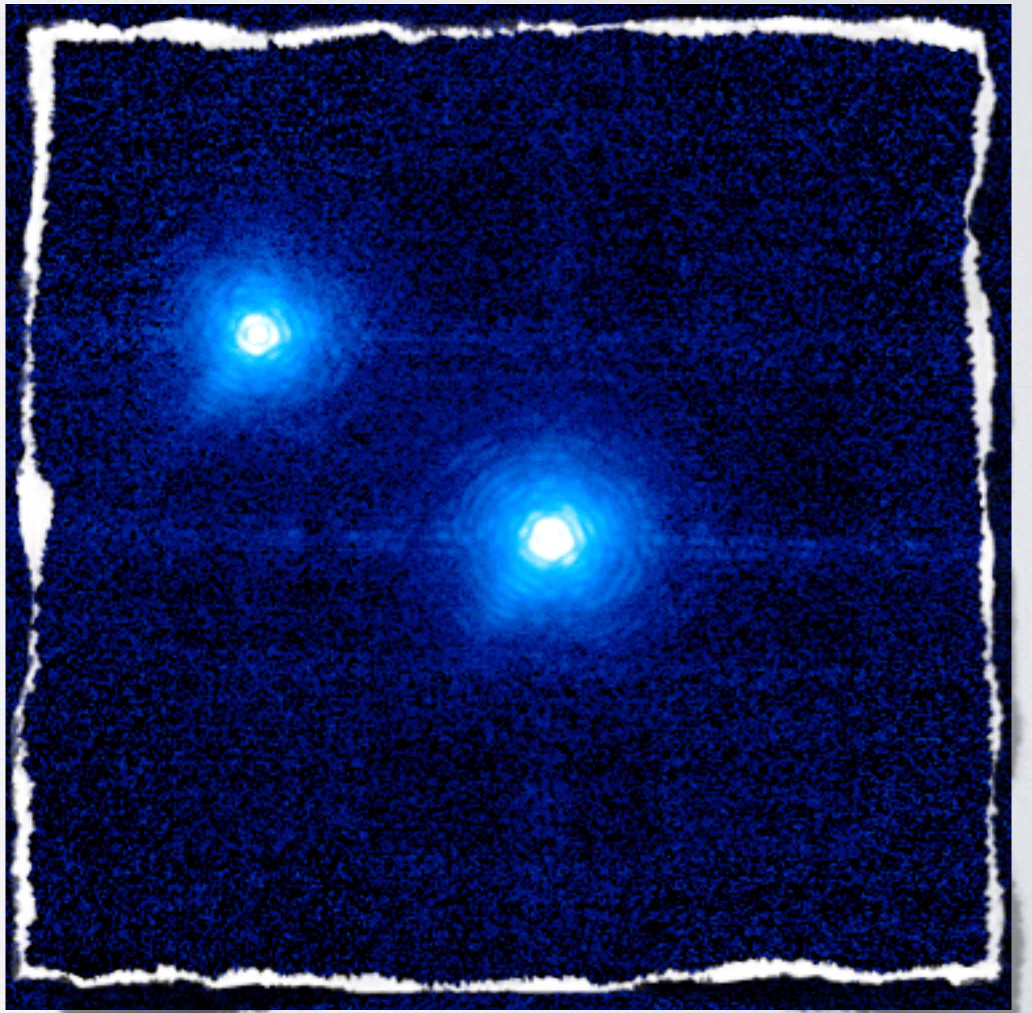


Sub-100AU Binaries

- Combining with historical measurements (WDS - Mason et al. 2001) allows for an estimate of the orbital parameters and dynamical system mass

Our primary motivations:

- Refinement of orbital parameters
- Comparison with theoretical mass-mag relations - can we provide benchmark for the models?
- Lower-limit of the higher-order multiplicity of A-type stars (companions within ~100AU).



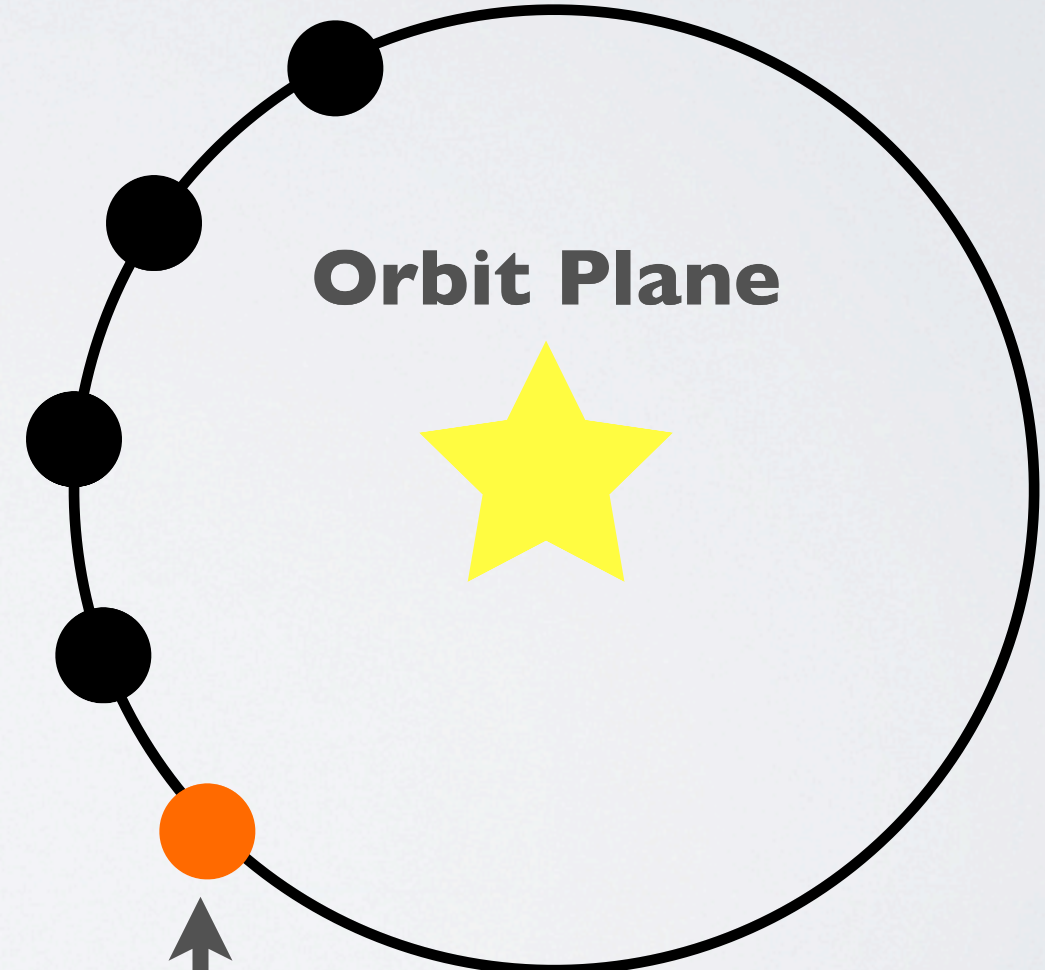
ORBIT DETERMINATION

- Can determine companion position (x_i, y_i) within orbit plane based solely on the period (P), eccentricity (e), time of periastron passage (T_0) and the epoch of observation (t_i).

$$
\begin{aligned}
x_i &= \cos E - e \\
y_i &= \sqrt{1 - e^2} \sin E
\end{aligned}
$$

$$
\begin{aligned}
x'_i &= B x_i + G y_i \\
y'_i &= A x_i + F y_i
\end{aligned}
$$

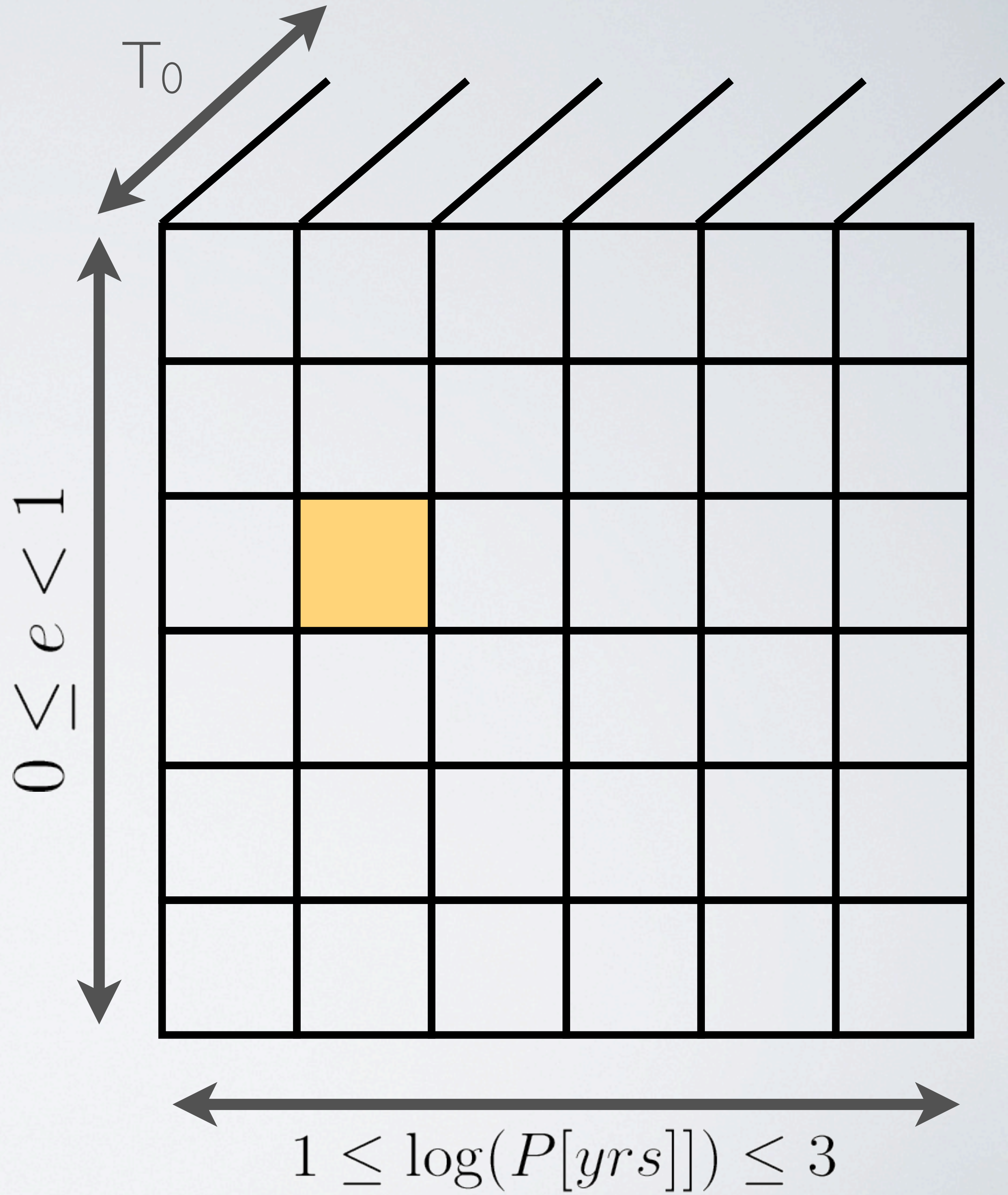
Corresponding position within observed tangent plane



x, y position in orbital plane based on (P, e, T_0, t_i)

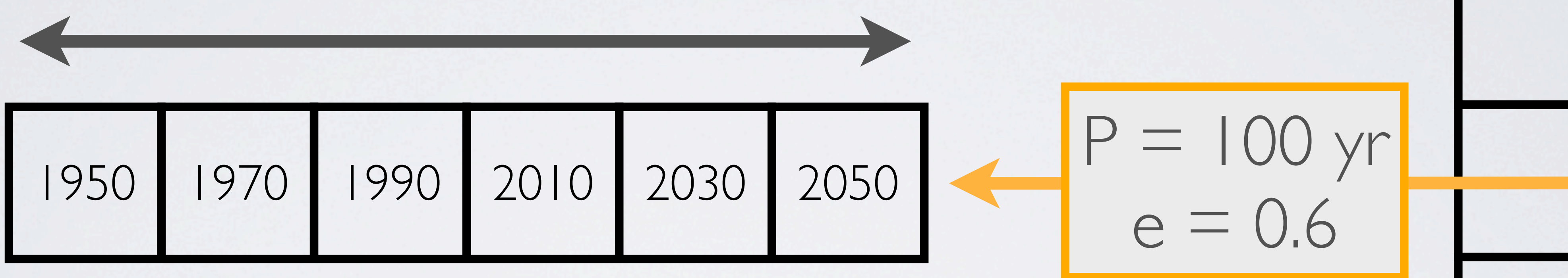
ORBIT DETERMINATION

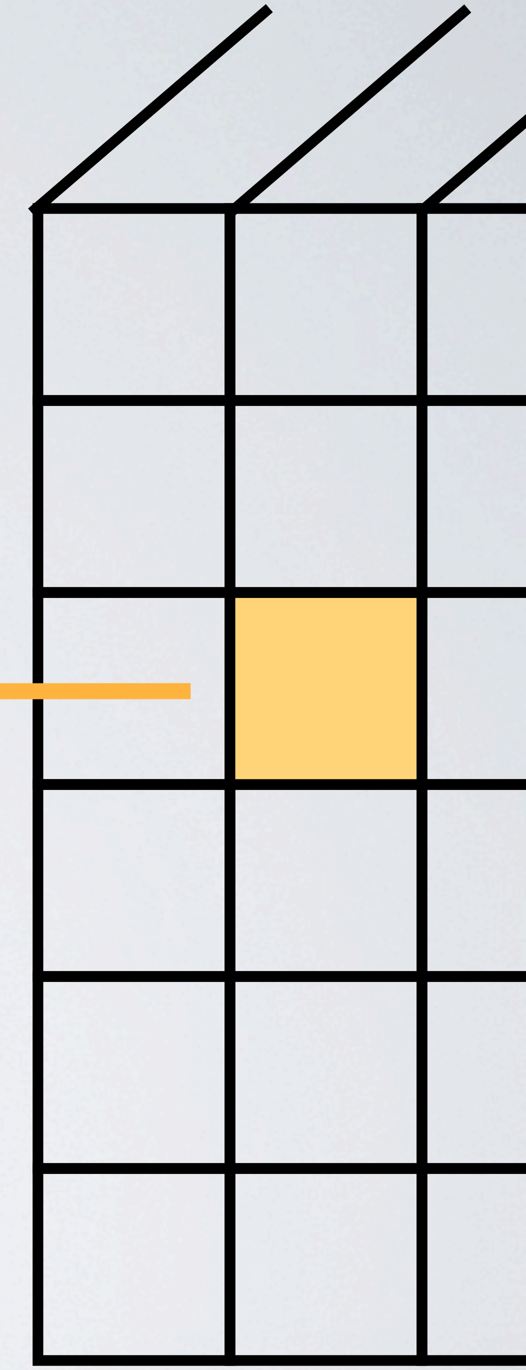
- Our implementation of method presented by Kohler et al. 2008 and Hilditch 2001
- Reduces problem from 7D to 3D
- Set up a 2D grid of P and e with sensible ranges.
- For each (P, e) position, a range of T_0 values will be tested



ORBIT DETERMINATION

$$\left(2000 - \frac{P}{2}\right) \leq T_0 \leq \left(2000 + \frac{P}{2}\right)$$



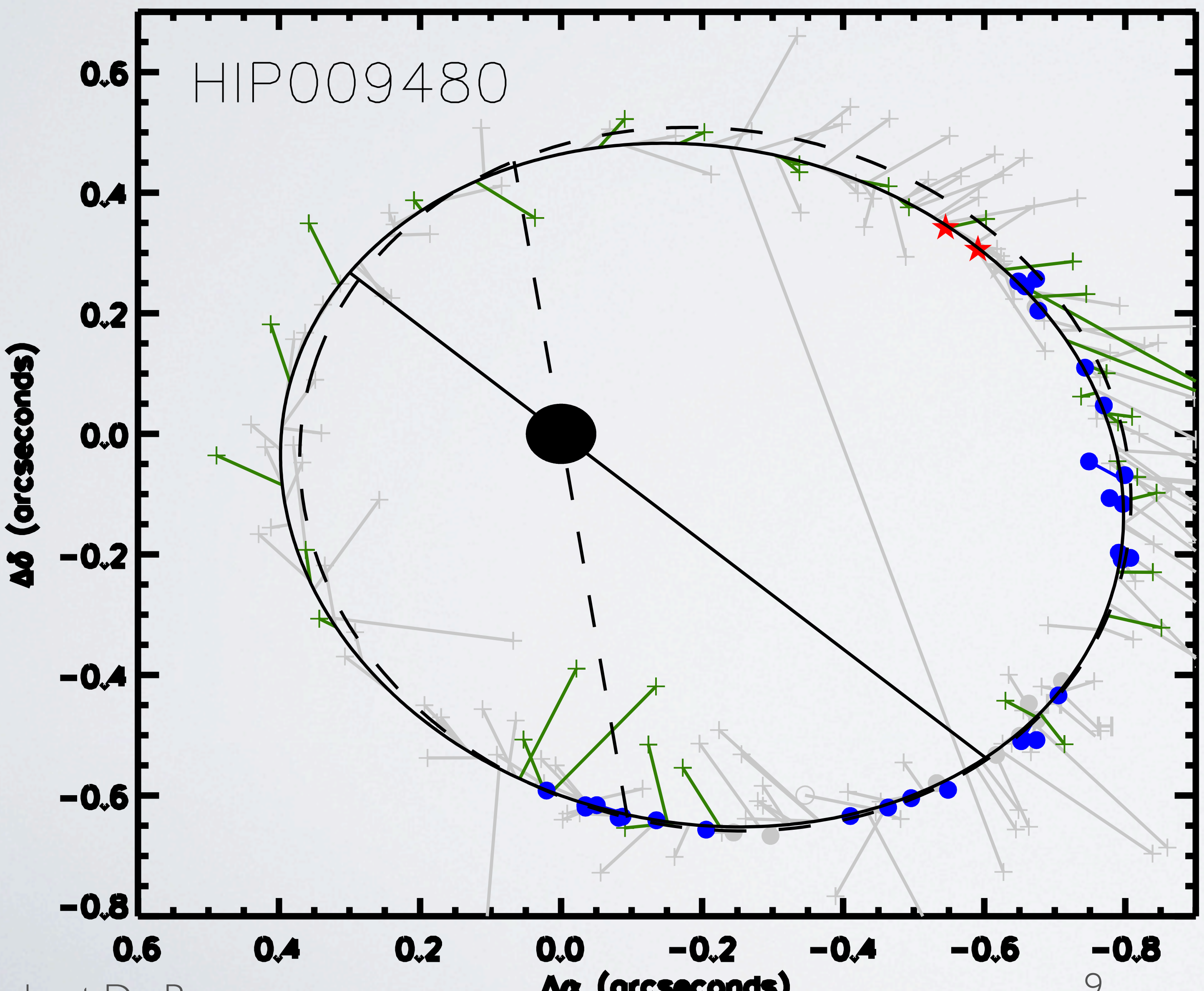


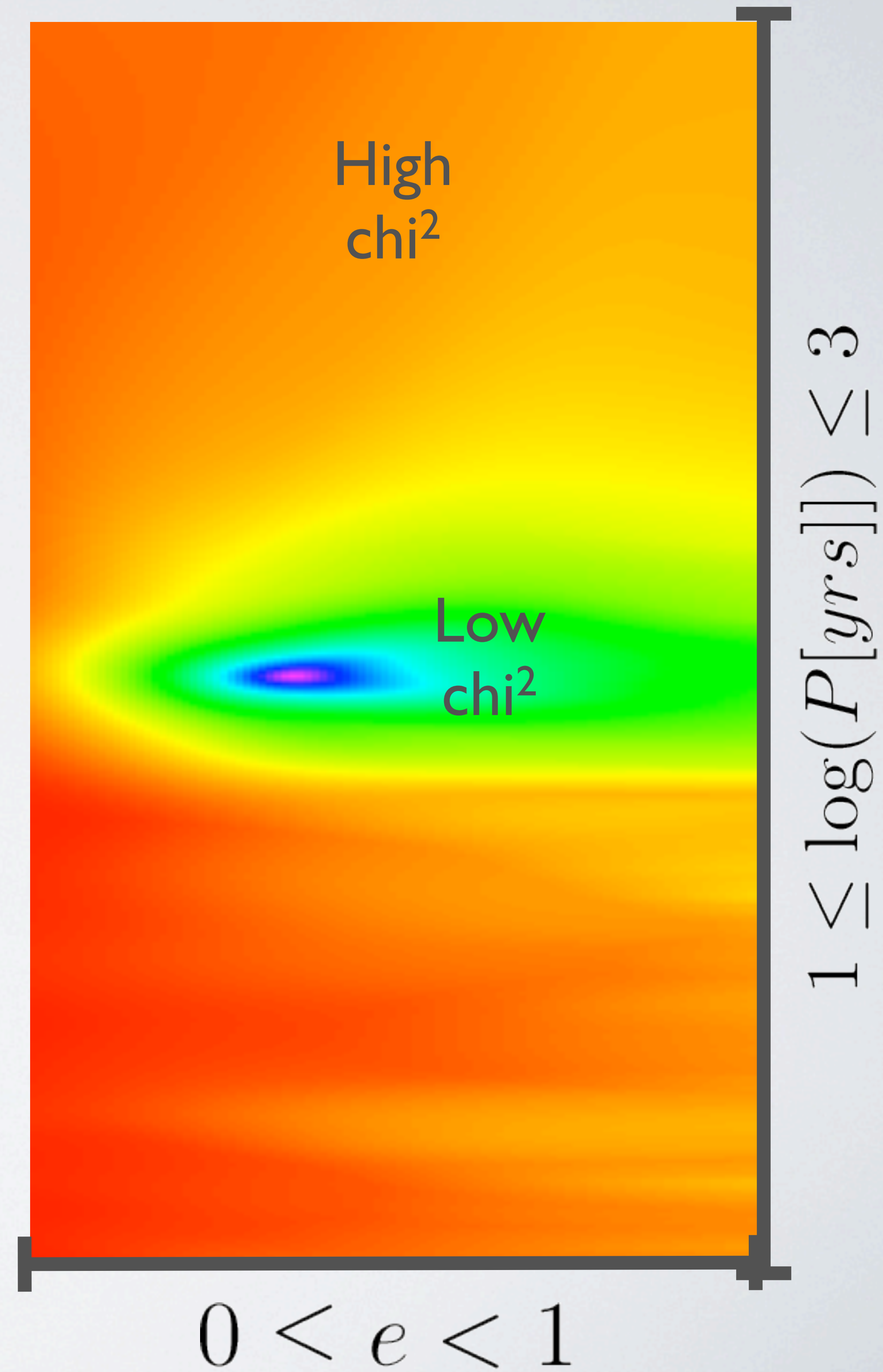
- Companion positions calculated for each position within the (P, e, T_0) grid through a least-squares fit to the Thiele-Innes elements (A, B, F, G)

- For each (P, e) grid point, find T_0 which minimises the chi^2 statistic through iterative method.

Orbit Determination

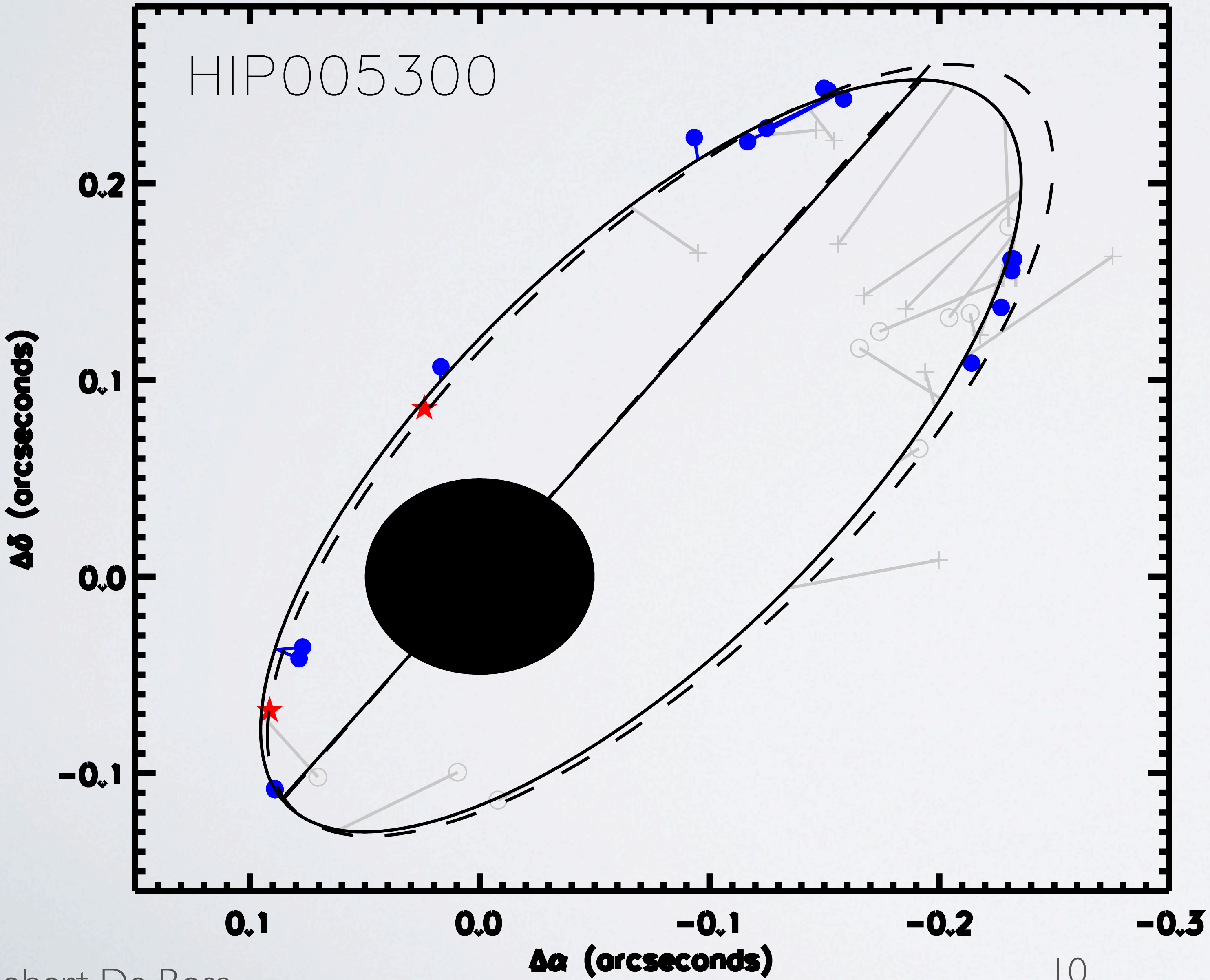
- Example of minimum chi^2 distribution
- Period and eccentricity well constrained

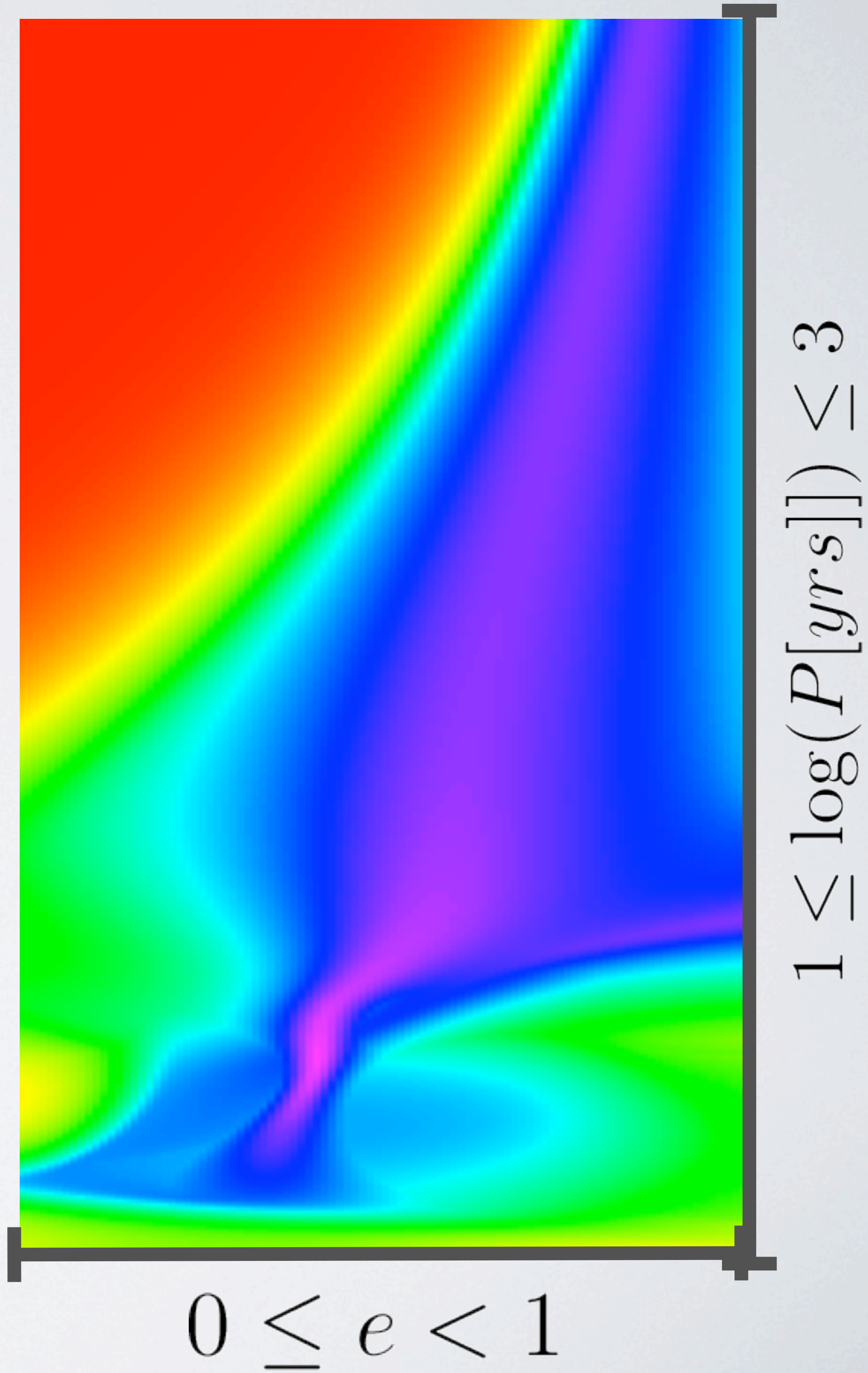




ORBIT DETERMINATION

- Not true for all systems...
- Need to ensure *global* minima reached





ORBIT REFINEMENT

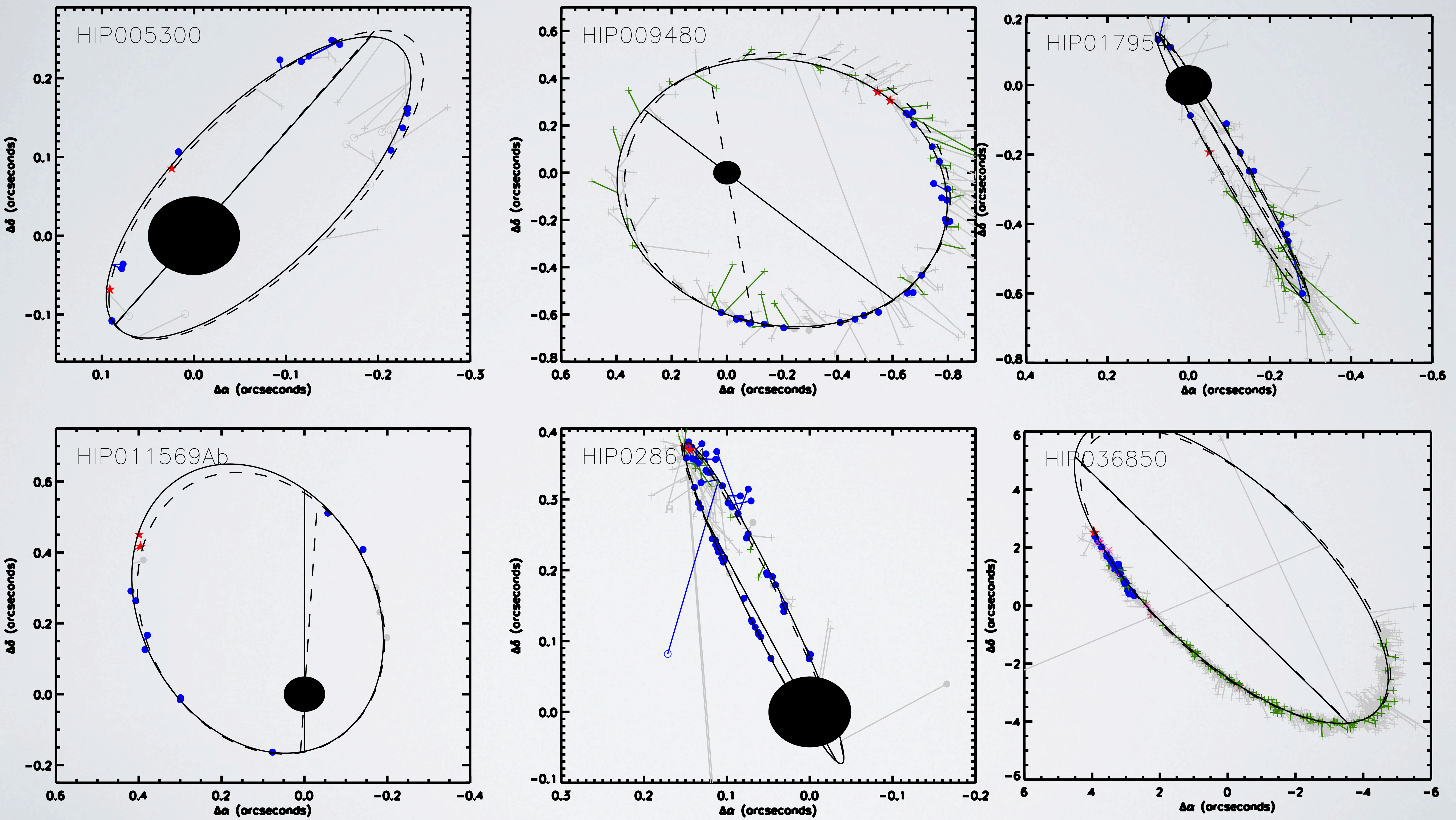
- Return to (P, e) grid, and at each position calculate (P, e, T_0, a, ω, Ω, i)
- Use these as a starting point for a Levenberg-Marquardt minimisation
- Ensures the global minima of the chi^2 distribution is found
- Implementation verified by comparison to 6th Orbit Catalogue members

ORBITS


2011
HIP 80628
HIP 82321
HIP 93506
HIP 36850
... a bit too wide
HIP 44127
HIP 47479
HIP 76952
HIP 5300
HIP 9480
HIP 11569
HIP 17954
HIP 28614

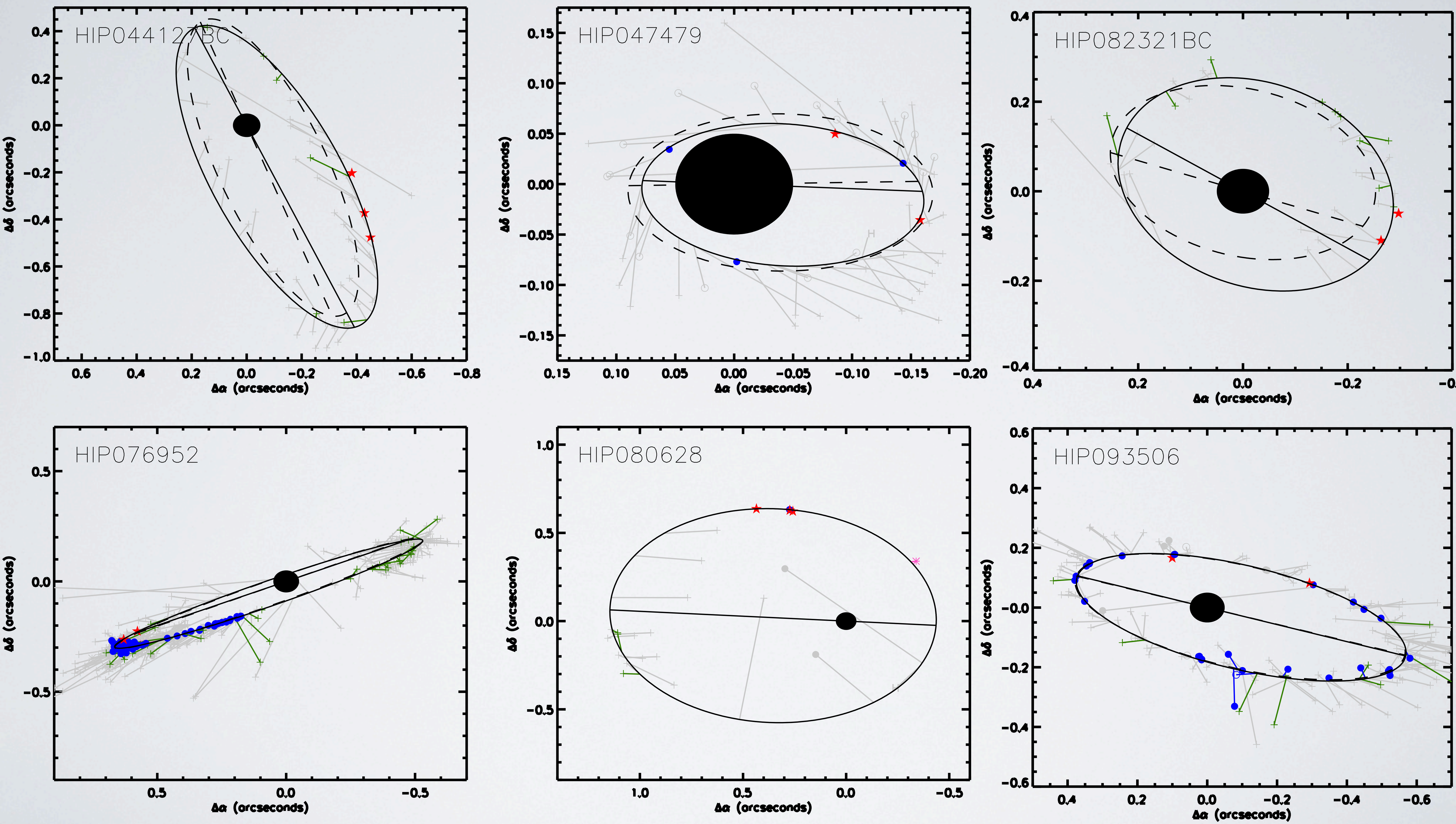
Interferometric/Speckle ★ Our Adaptive-optics data

✚ Visual/Eyepiece ✚ Unused measurement due to lack of uncertainties



● Interferometric/Speckle ★ Our Adaptive-optics data

+ Visual/Eyepiece + Unused measurement due to lack of uncertainties



ORBITS

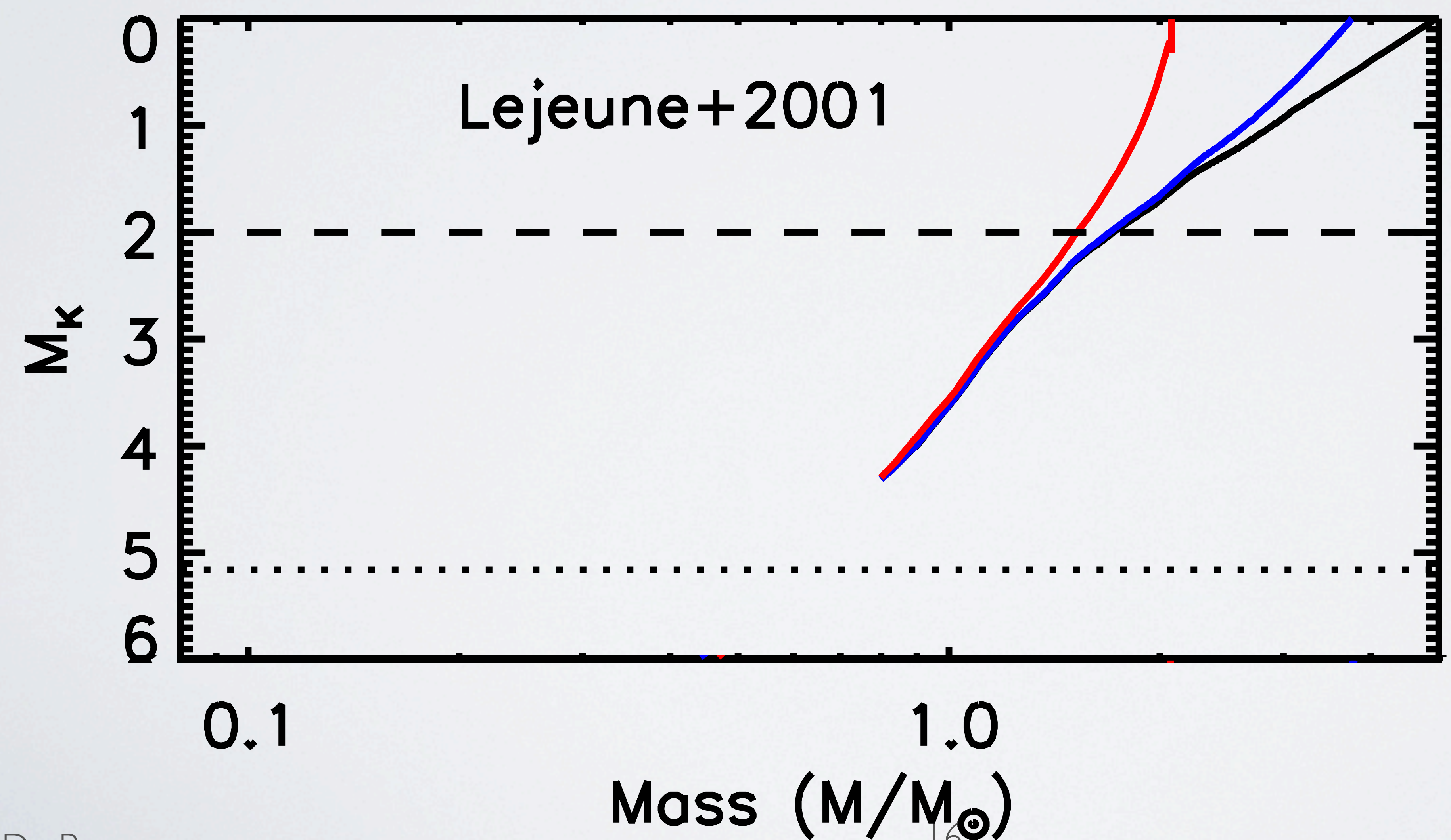
6th Orbit Catalogue

HIP	Old Mass	New Mass
5300	3.44	3.16±0.02
9480	2.97	2.72±0.03
11569	2.22	2.12±0.11
17954	3.37	4.15+0.12
28614	6.33	6.36±0.01
36850	5.50	5.42±0.12
44127	0.61	0.68±0.04
47479	7.49	5.83±0.08
76952	4.14	4.19±0.10
80628	n/a	4.99±0.48
82321	1.00	1.16±0.06
93506	5.22	5.26±0.04

- Orbits estimated ranging from 10 to 500 years (0.12" - 6.78")
- Dynamical mass estimated from Hipparcos parallax (van Leeuwen et al. 07), typically small difference between old and new
- While the majority have significant number of measurements, some pairs do require further observations during periastron/apastron passage.

THEORETICAL MODELS

- Obtained four theoretical model grids with solar metallicity, and constructed mass-magnitude relations at a range of ages.



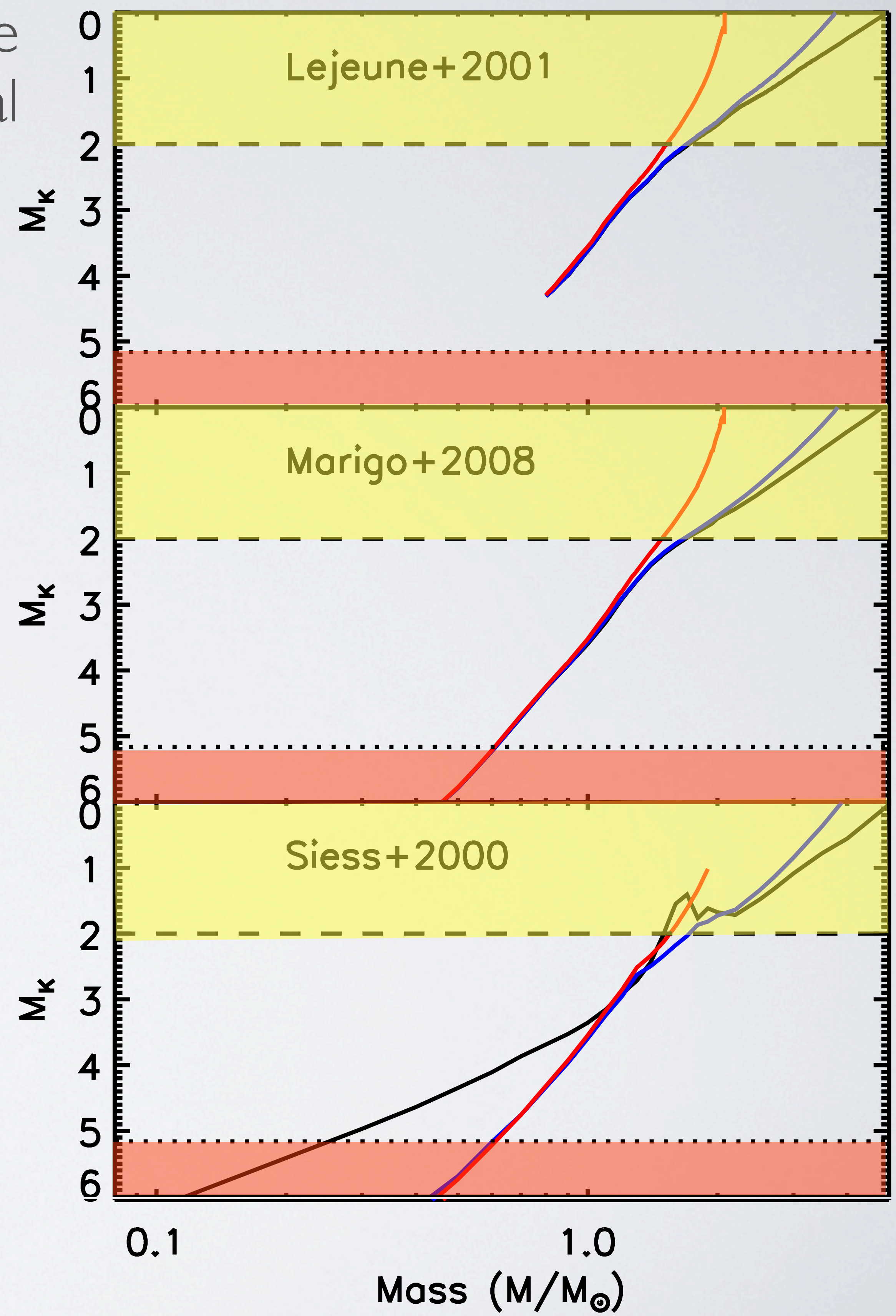
Red - 10 Myr
Blue - 100 Myr
Black - 1 Gyr

Mass-magnitude relations are dependant on age for stars with Mk < 2, corresponding to spectral type A and earlier. Caused by expansion of star away from the Main Sequence

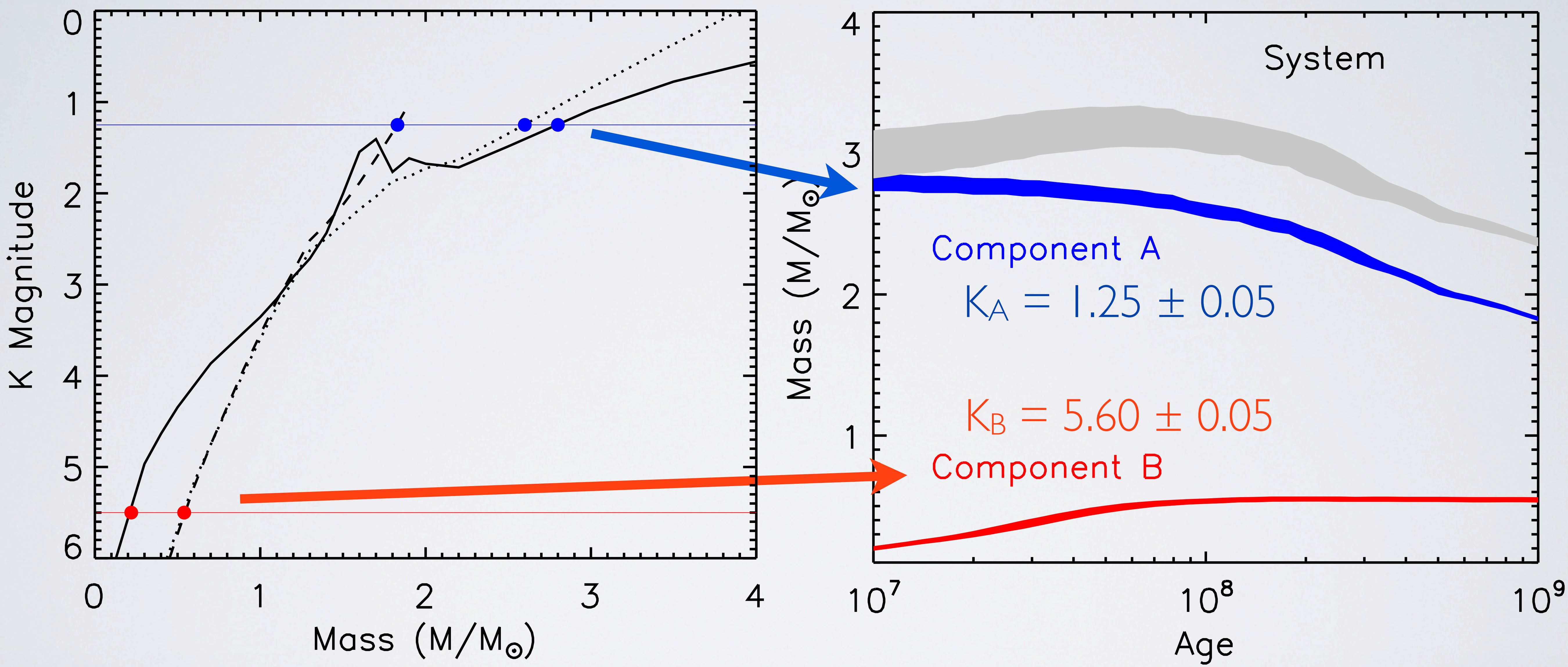
Similarly, for M-dwarfs due to their contraction onto the Main Sequence

The differences between the models within these two regimes is important to test with observations. Requires tight constraints on orbital parameters and photometry

More interested in what the models can tell us about the systems...



THEORETICAL MODELS



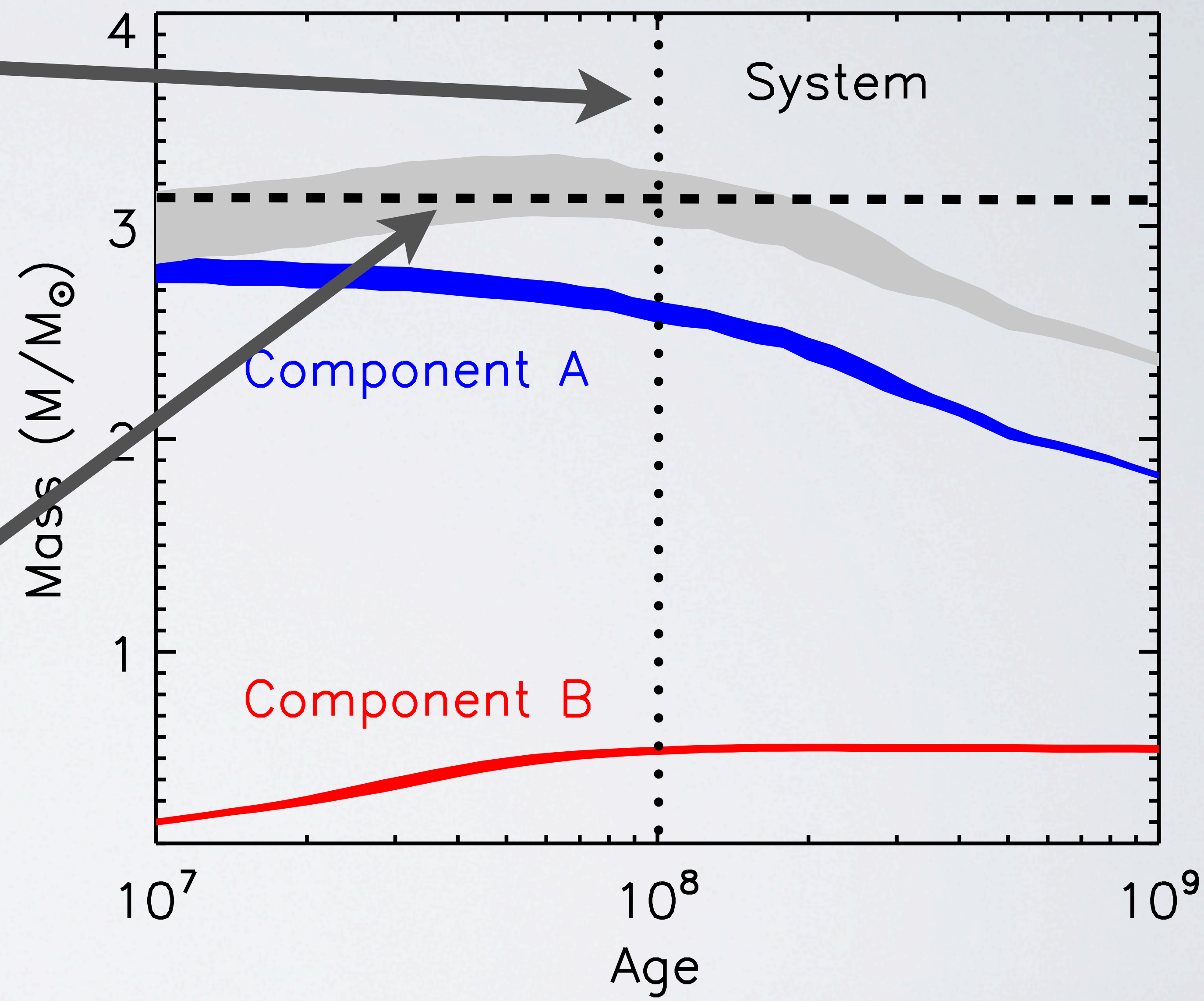
- A series of mass-magnitude relations at different ages
- A mass-age relation for components of given magnitudes

THEORETICAL MODELS

The position of the primary on the CMD is then used to estimate the age of the system (e.g. 100 Myr)

The system mass based on the mass-magnitude relations can then be determined

This is compared to the dynamical system mass obtained from the orbit



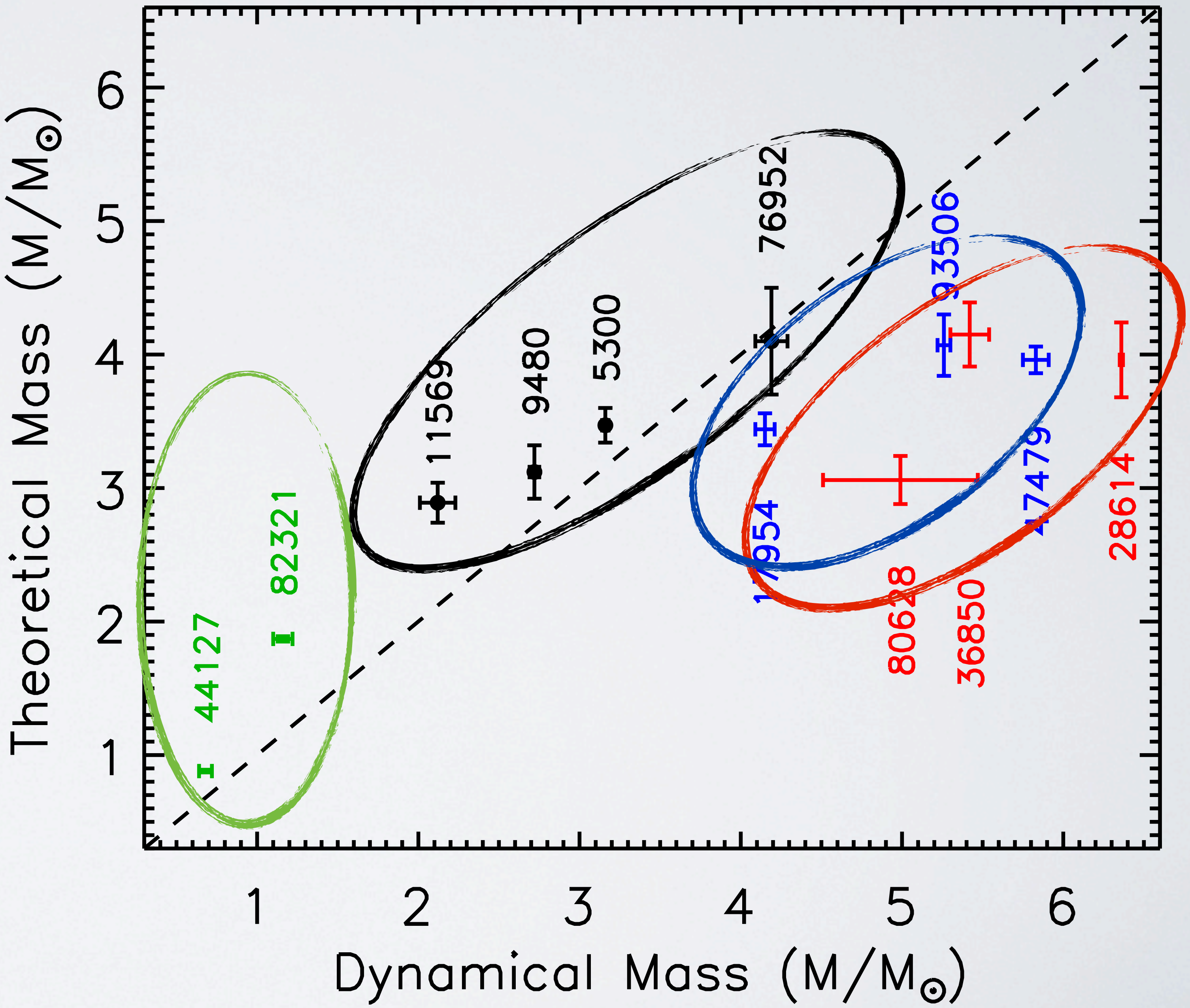
Mass Comparison

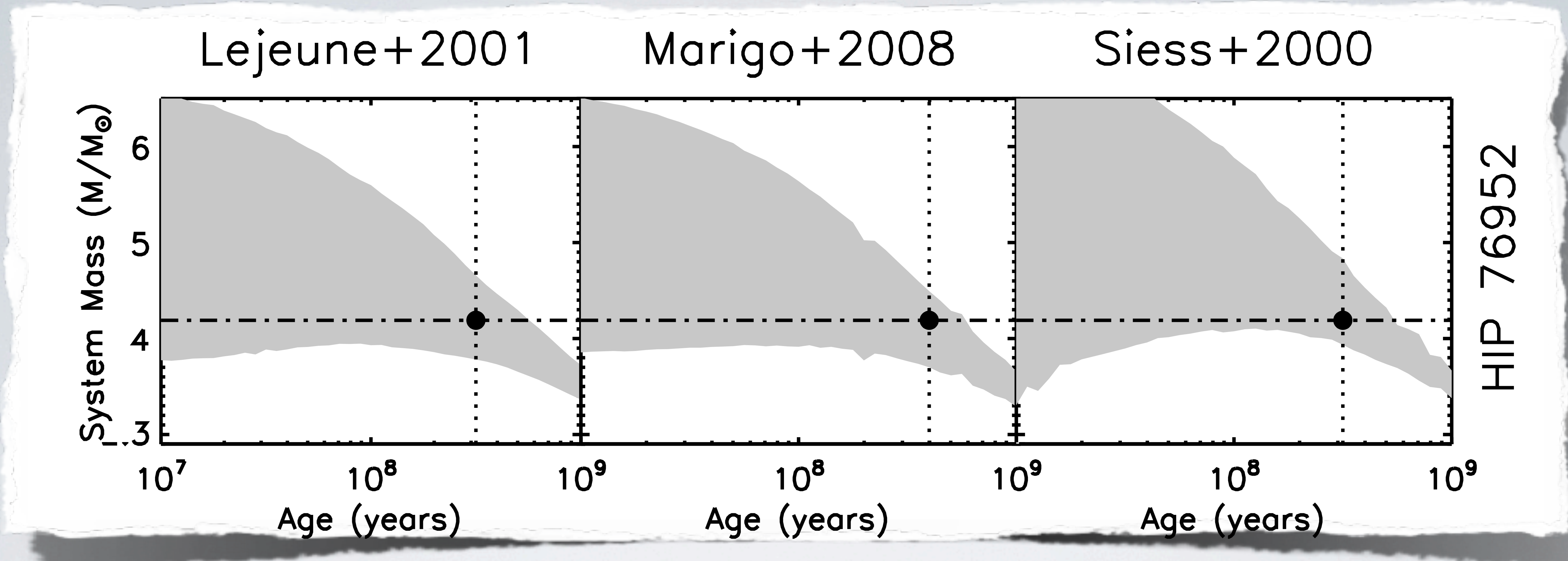
Binary stars

Hierarchical triples

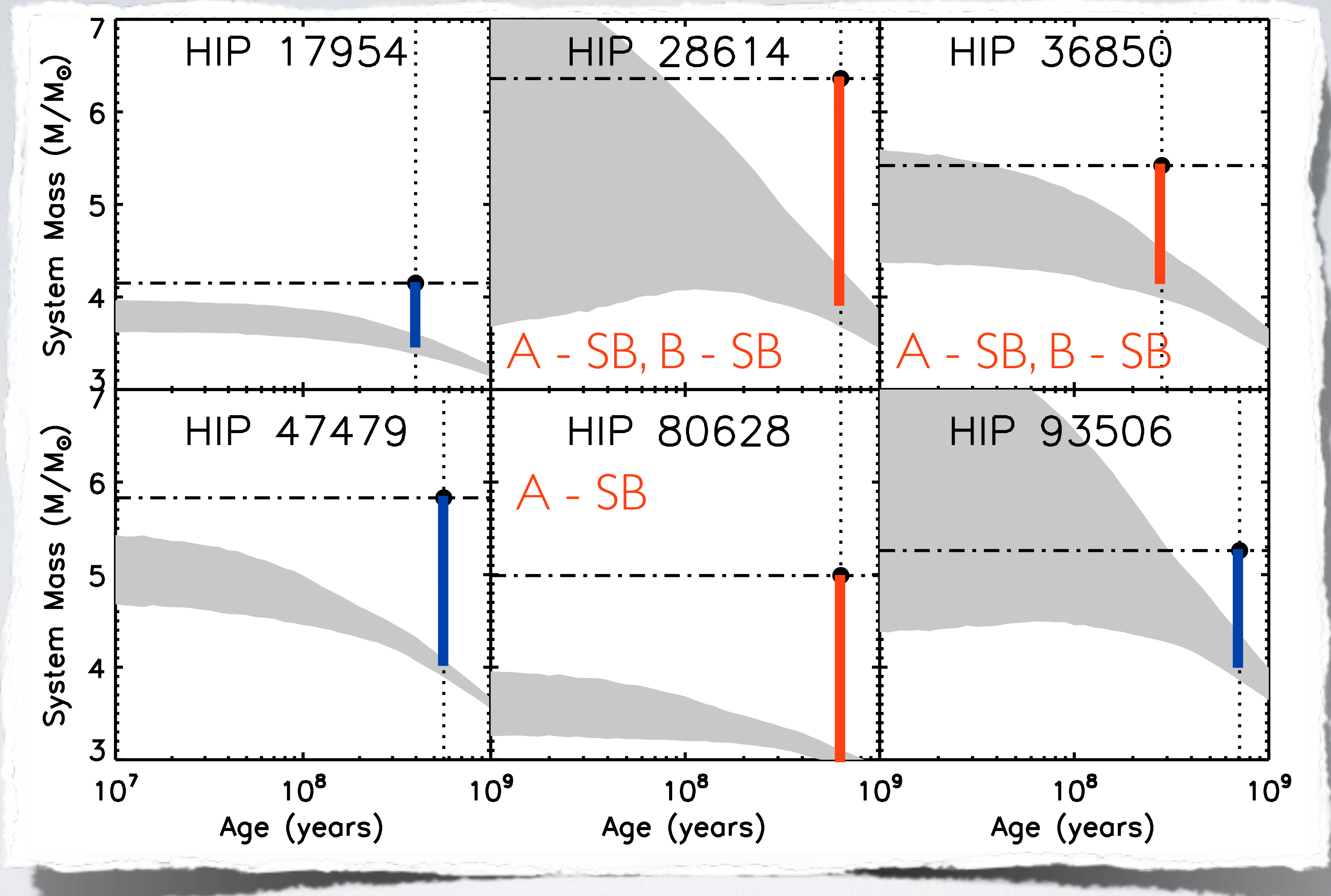
Known spectroscopic components

Significant dynamical mass excess
- suspected unresolved SB?





- Surprisingly, only one system had dynamical mass consistent with mass-mag relations
- Poor constraints on 2MASS K-band magnitude (σ_K=0.226) leads to large uncertainty in the mass-age relation.
- B-V colour consistent with age of ~350 Myr
- Dynamical mass ± 0.1 M_{sol}

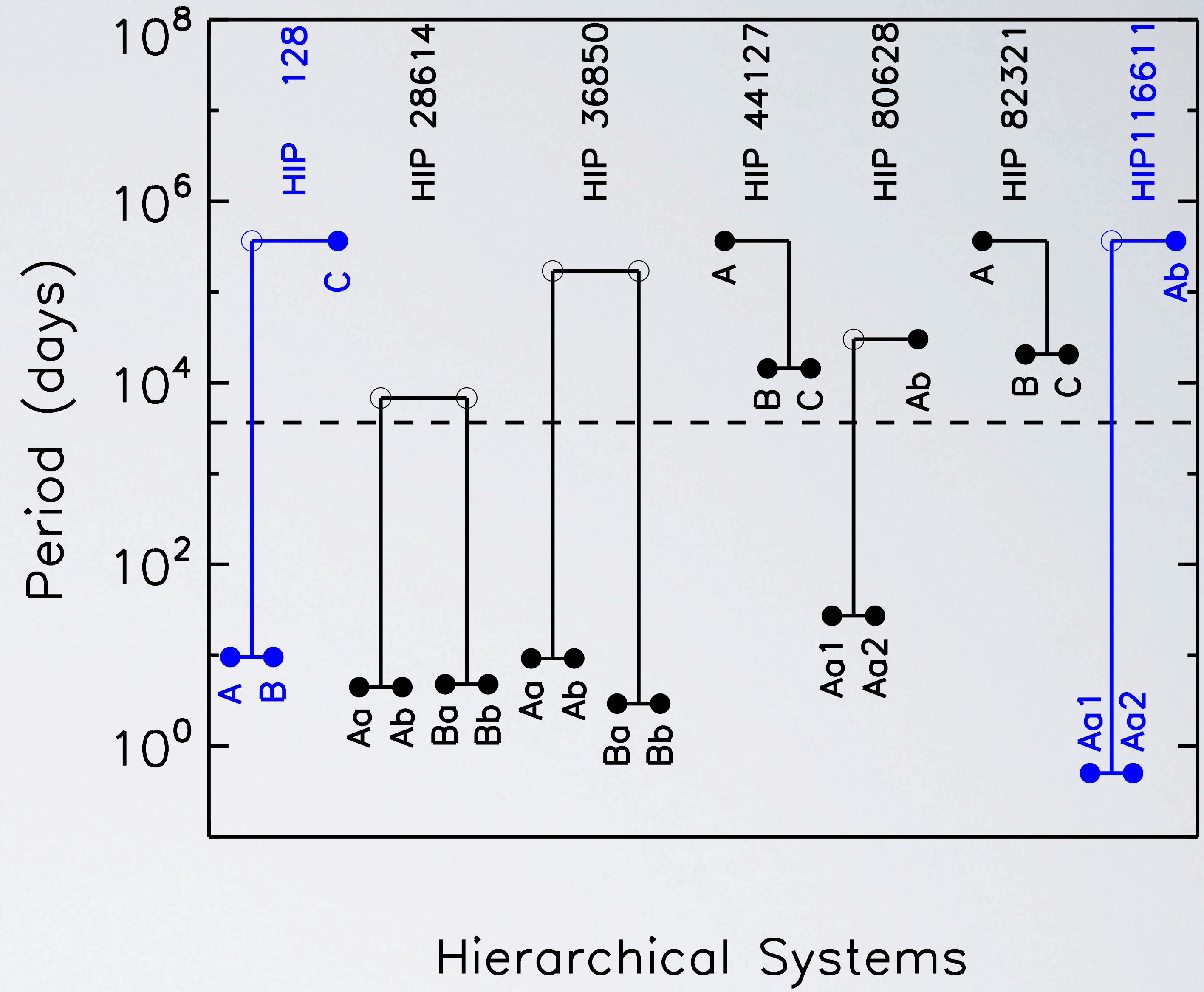


- 3 systems with known spectroscopic sub-components have significant dynamical mass excesses

- 3 systems showing the same excess have no known spectroscopic sub-components.

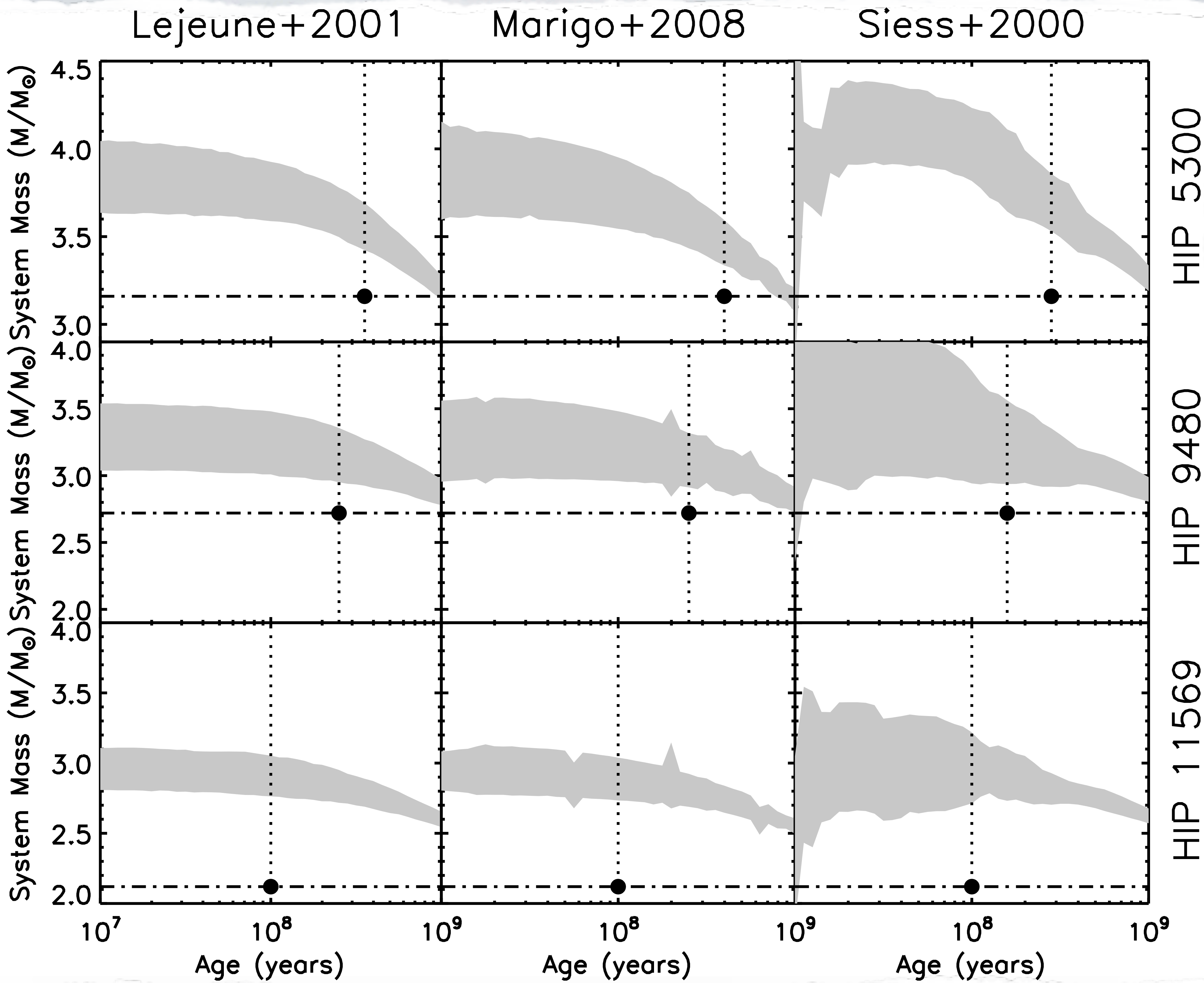
- Can use this information to estimate higher order multiplicity

- Combine with known spectroscopic components of the 26 systems



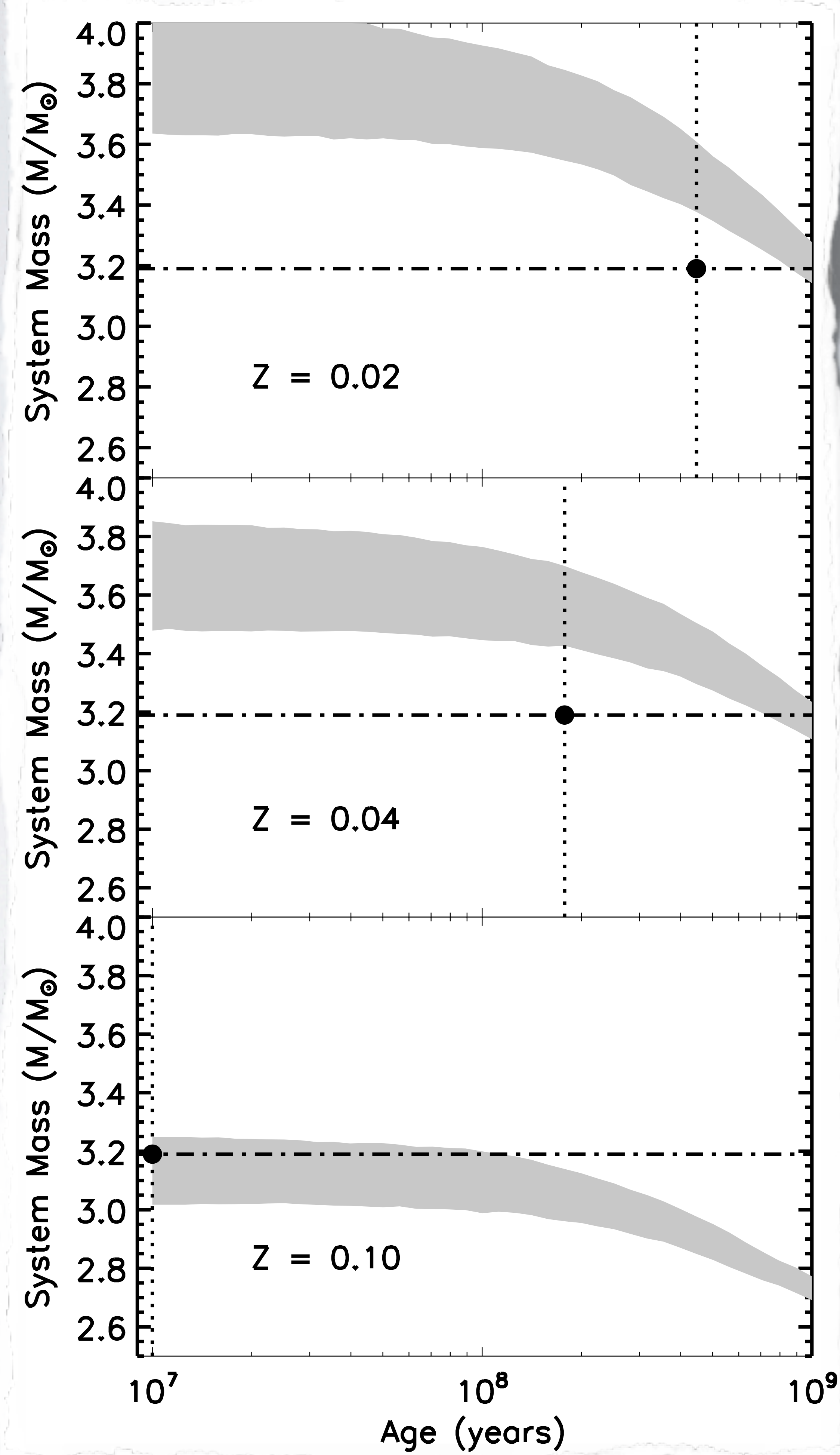
For binaries with projected separations < 100AU

Double	:	**Triple**	:	**Quadruple**
62%		**31%**		**8%**
Solar (Raghavan+10) (75%		18%		7%)

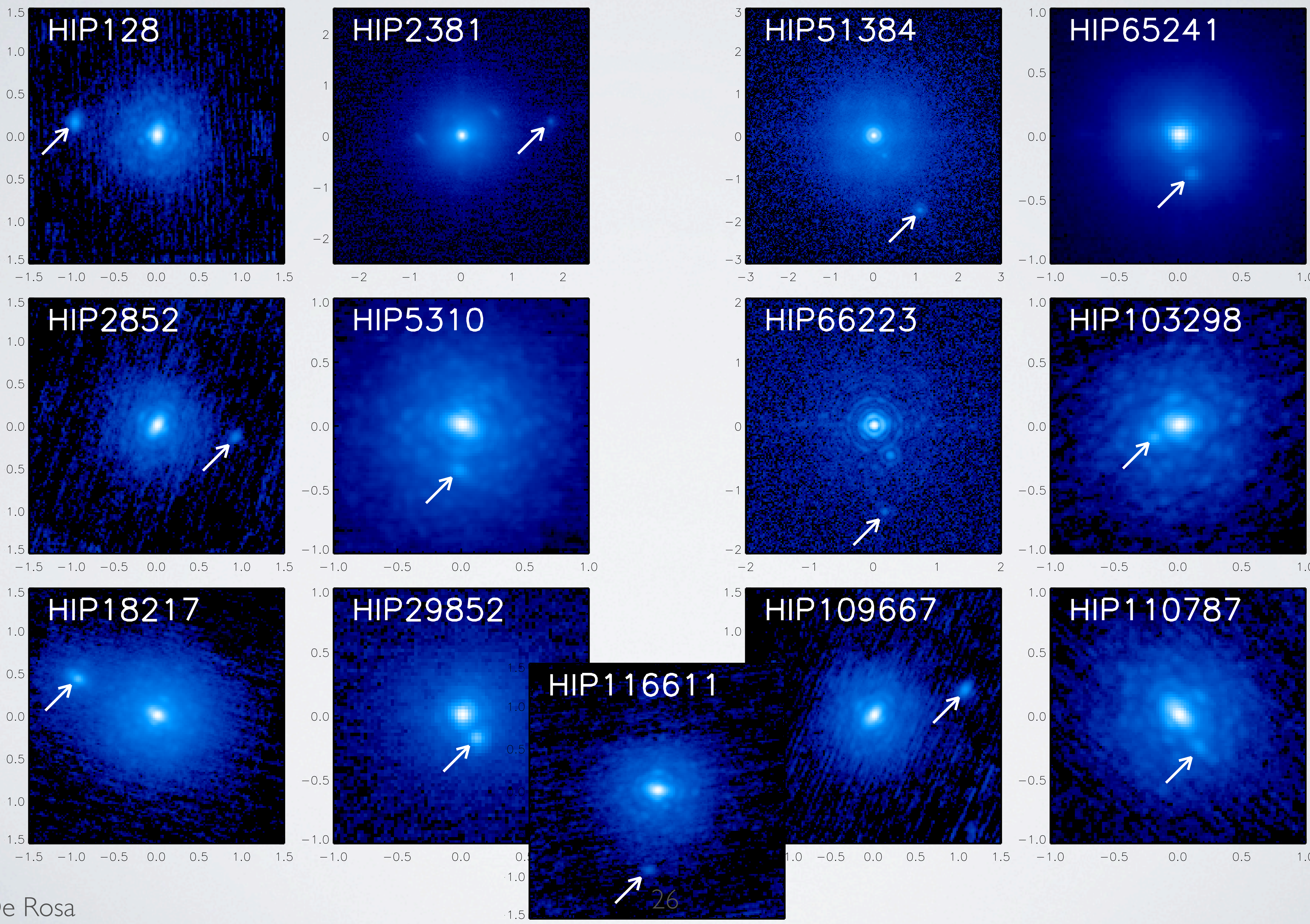


- Three binary systems show a significant dynamical mass defect

- A possible explanation for this mass defect is an incorrect assumption of the metallicity.
- Due to lack of published estimates, we have assumed solar metallicity for each target
- By increasing metallicity relative to Solar, this adjusts both the age estimate from the CMD, and the mass-age relation.



Newly Resolved Systems



Summary

- Estimated orbital parameters for 12 systems, including dynamical mass
- Comparison to theoretical mass-magnitude relations:
    - Evidence of potential spectroscopic components for 3 systems
    - Lower-limit of higher-order multiplicity within 100 AU
    - Complications due to lack of metallicity measurements - perhaps Strömgren photometry would help us here?
    - ΔV would help us place companion on CMD - speckle interferometry?
    - Potential for this technique to be applied to all high-quality orbits from the WDS catalogue with measured Δm.
- 13 newly resolved systems - typically fainter, so perhaps more challenging for speckle measurements?