Resolved Binaries Among TNOs: Statistical Inversion

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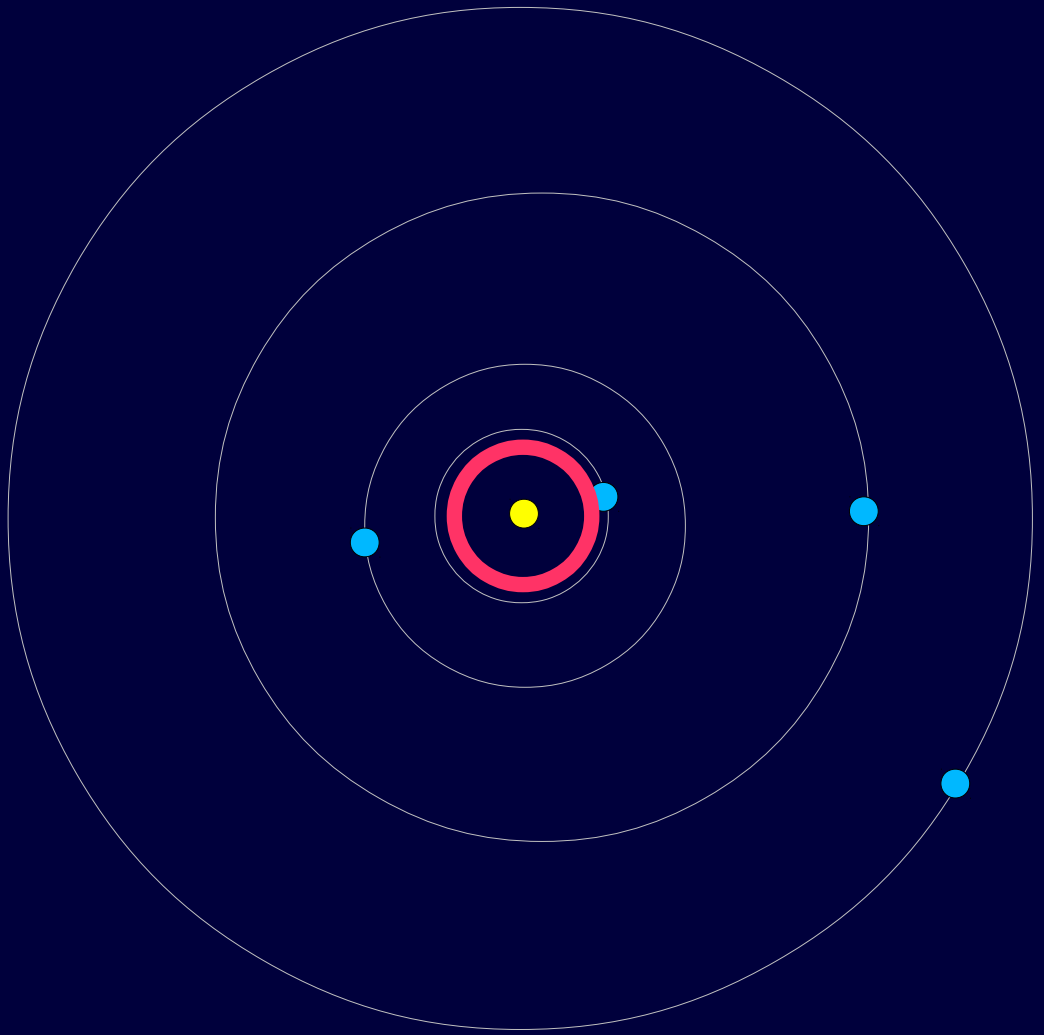
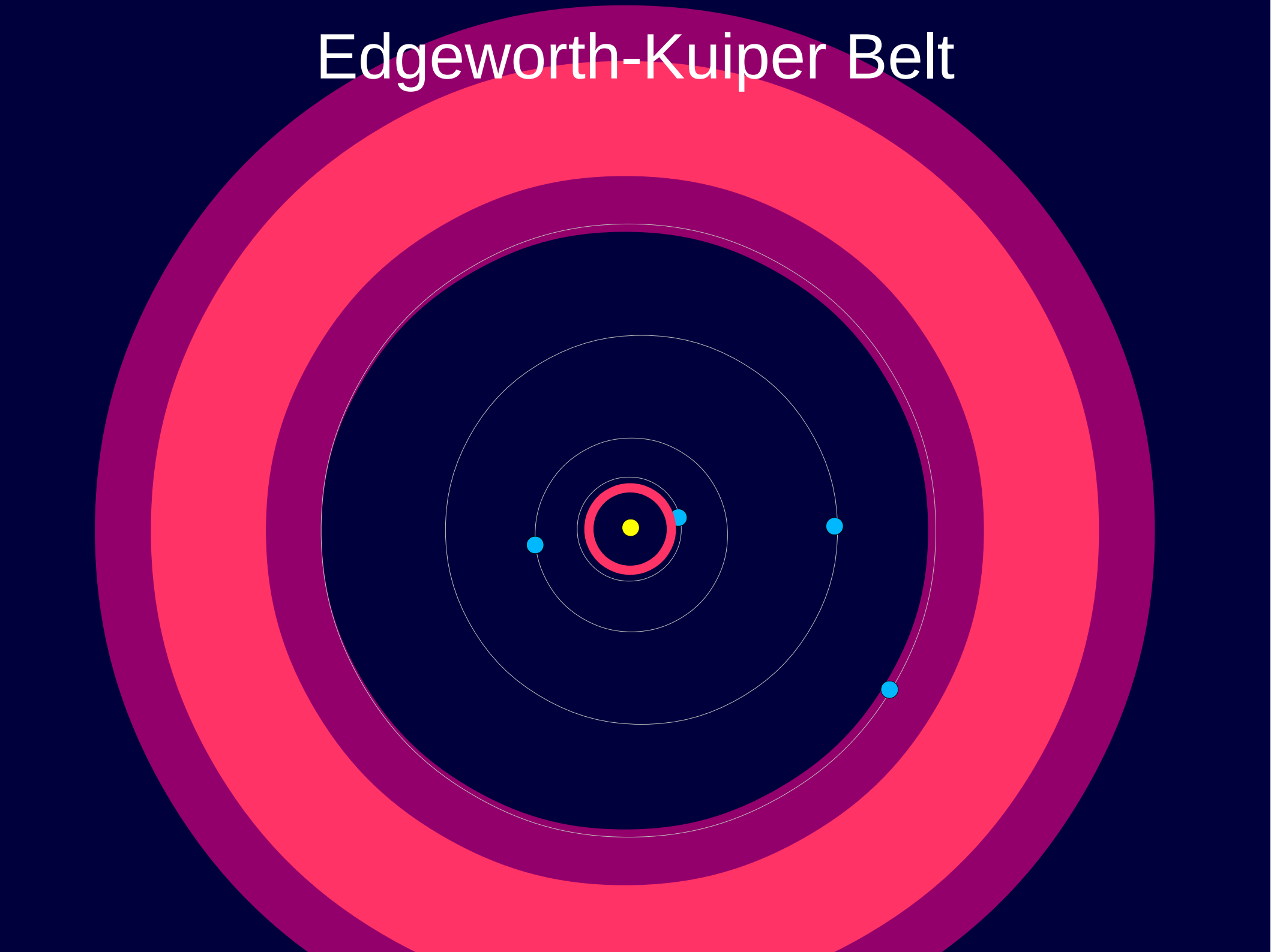
Asteroid Belt

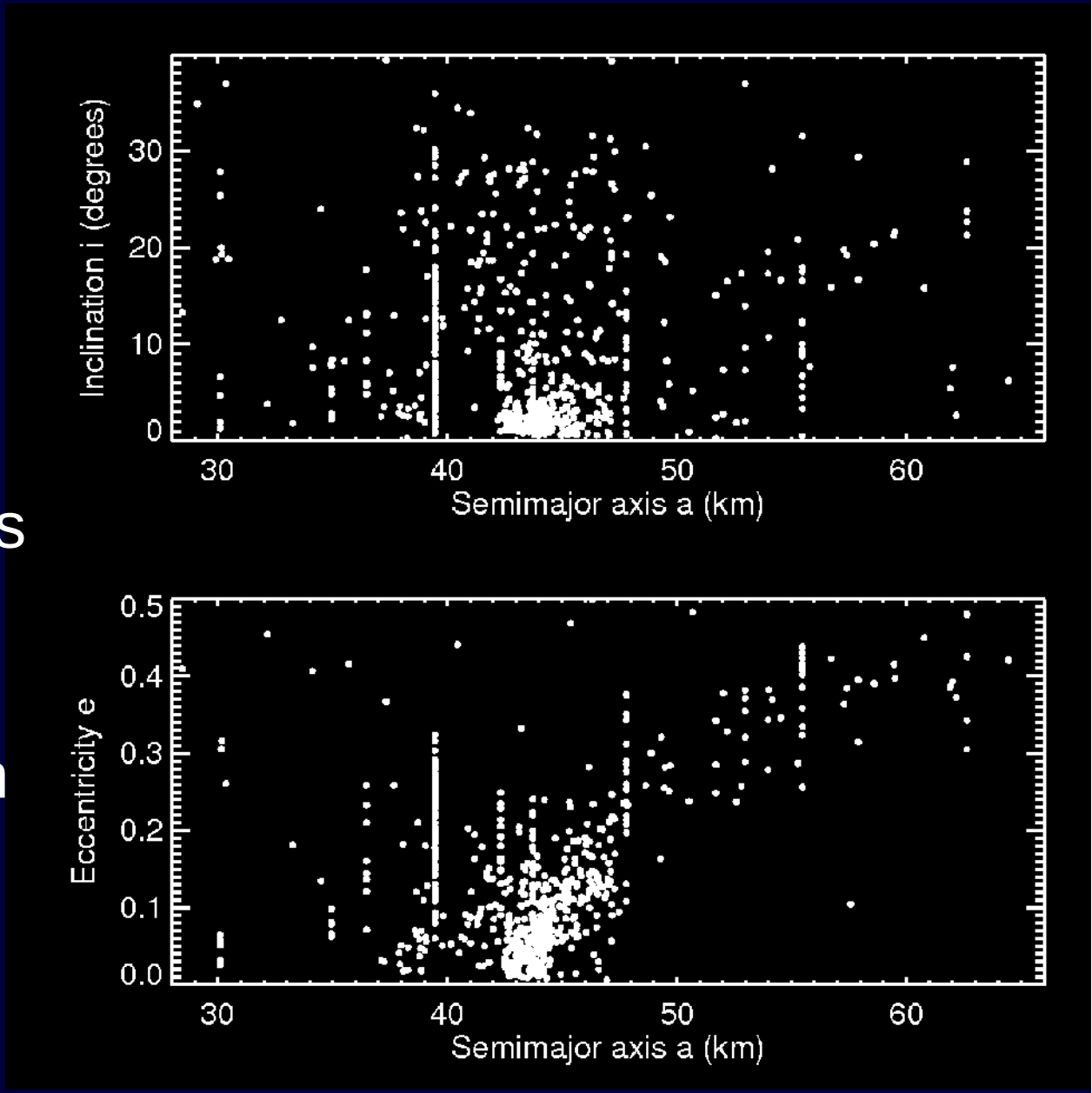


Edgeworth-Kuiper Belt

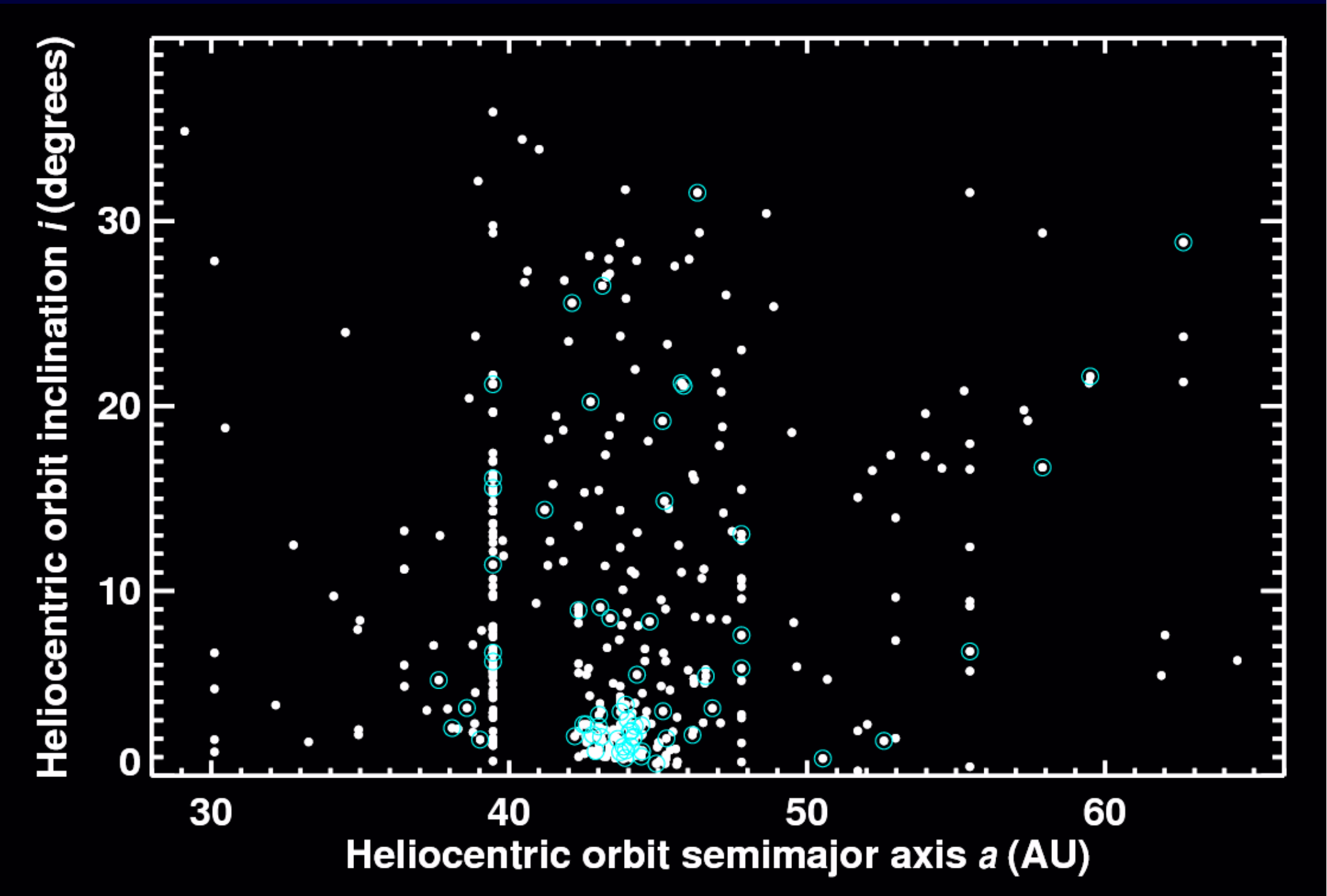


Kuiper Belt / Transneptunian Population

- Total mass <1 $M_{\oplus}$
- Distinct dynamical classes
- Diverse colors and compositions
- Binaries: P from 5 days to >10 years, masses from 10^{17} to 10^{22} kg
- Largest >2000 km with atmospheres, active surfaces, etc.
- More typically 100 km, cold, inert



Binaries Among TNOs



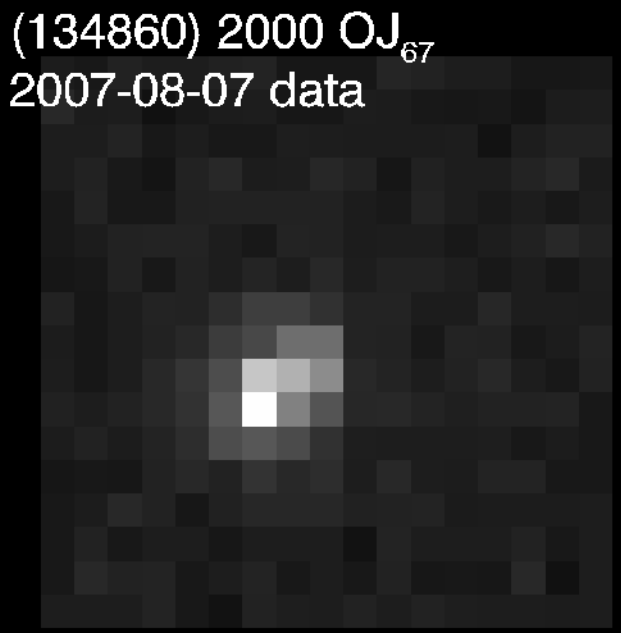
Current Data Sources

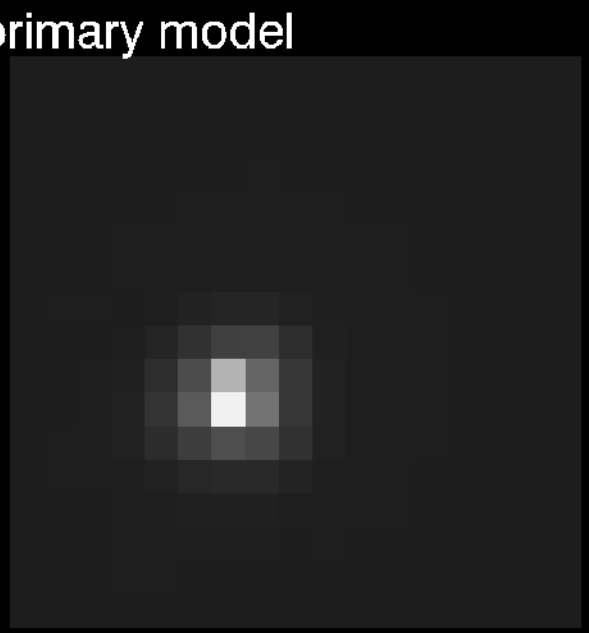
Gemini

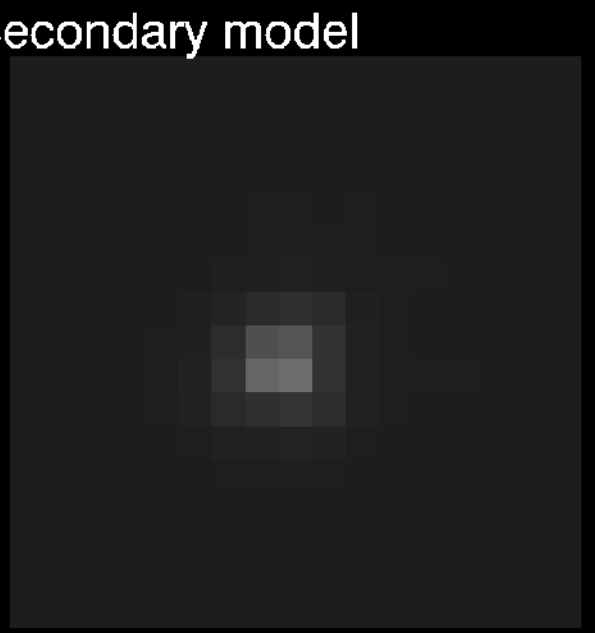
Keck

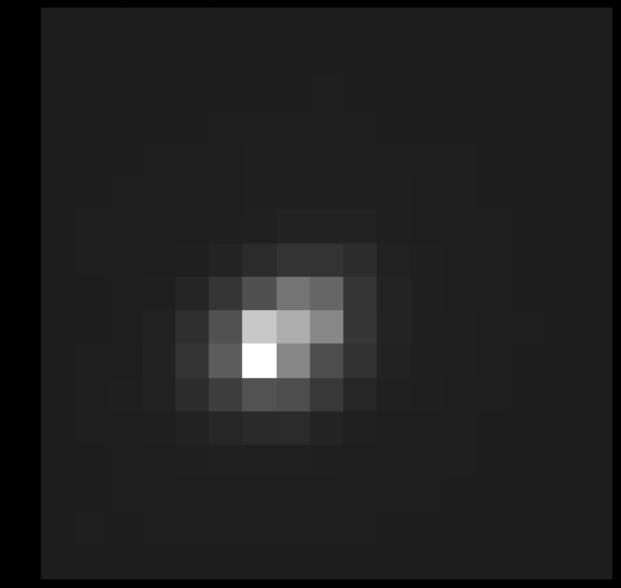
Hubble

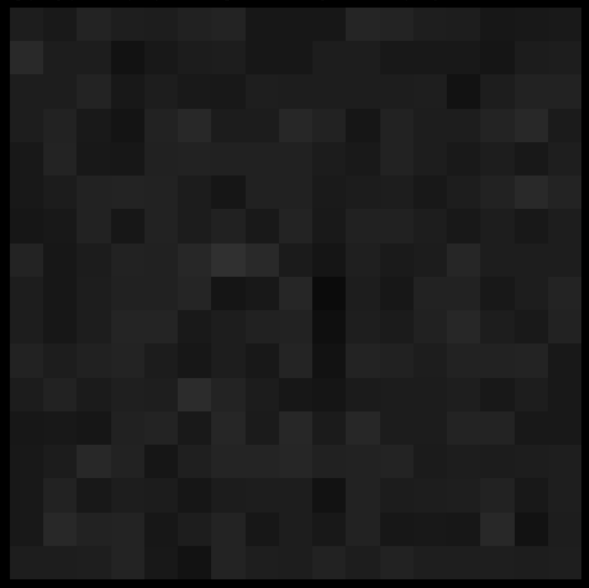
PSF-Fitting with Tiny Tim

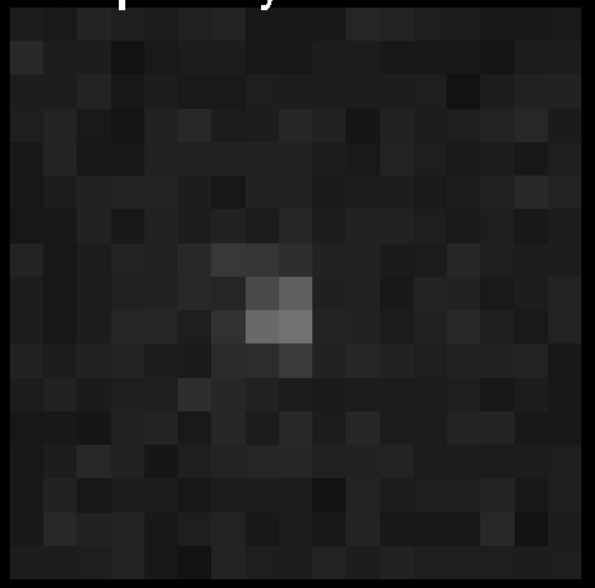






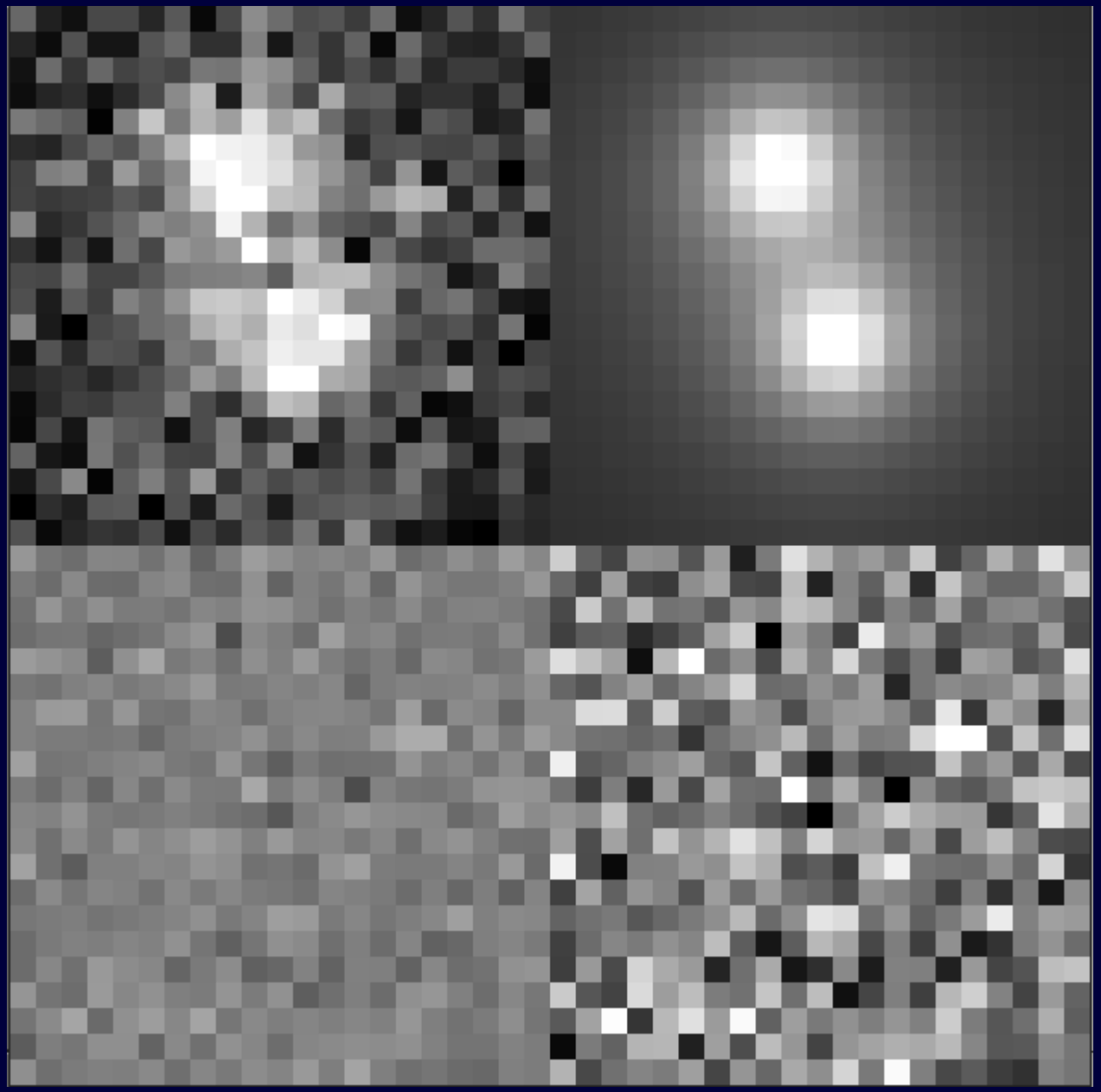






PSF-Fitting LGS AO Example

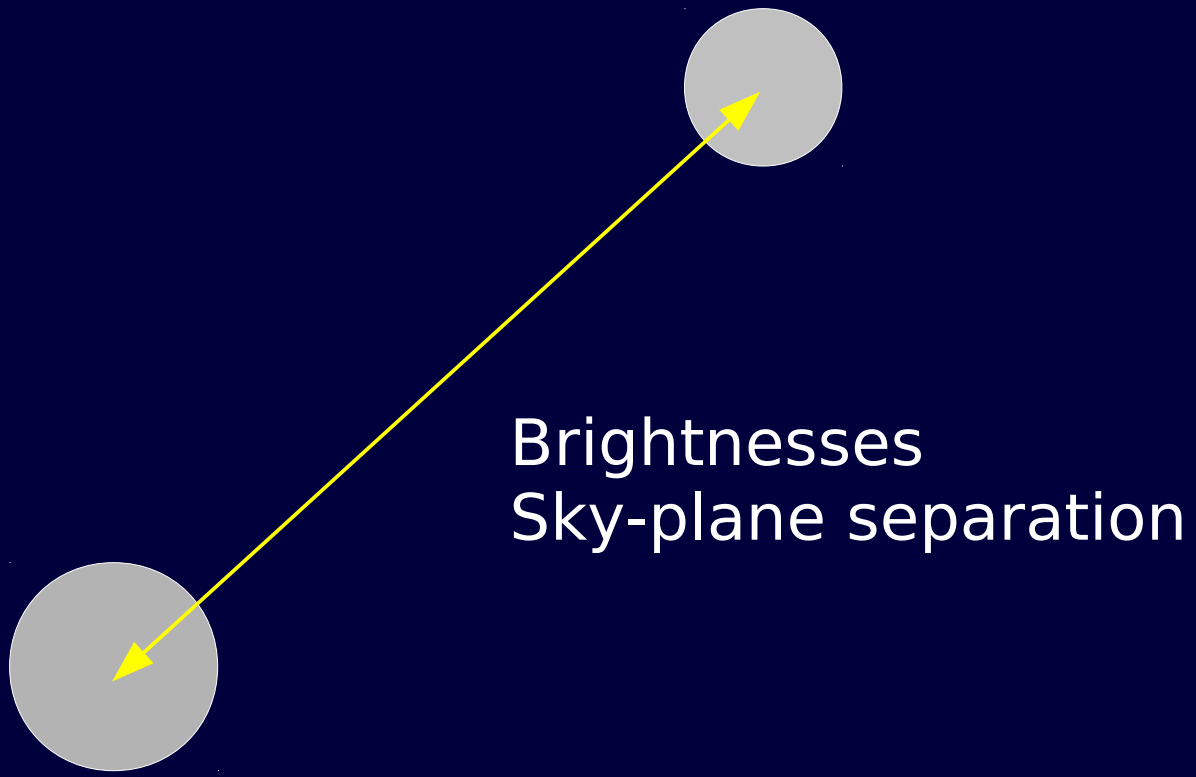
Data



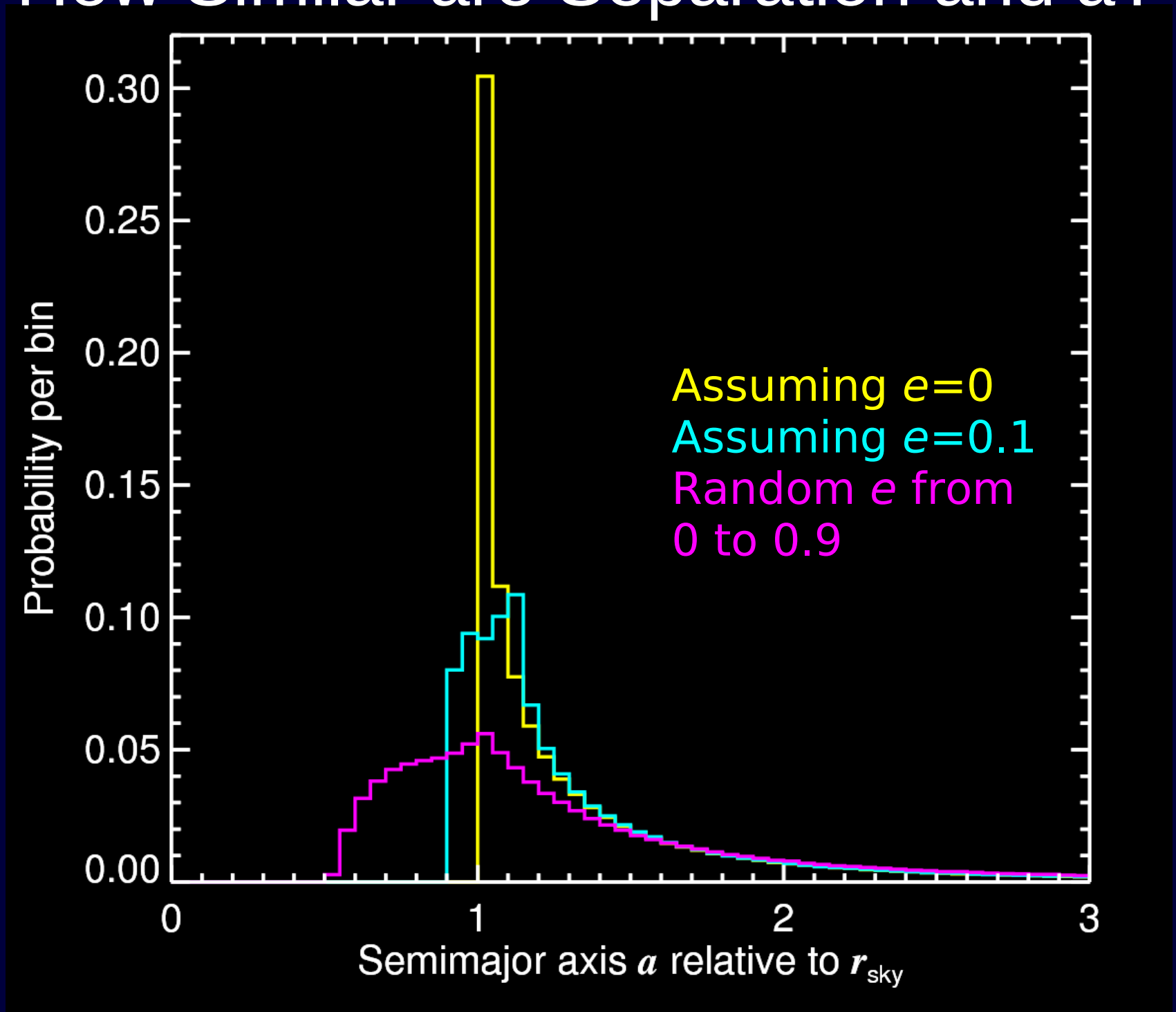
Model

Residuals (2 different stretches)

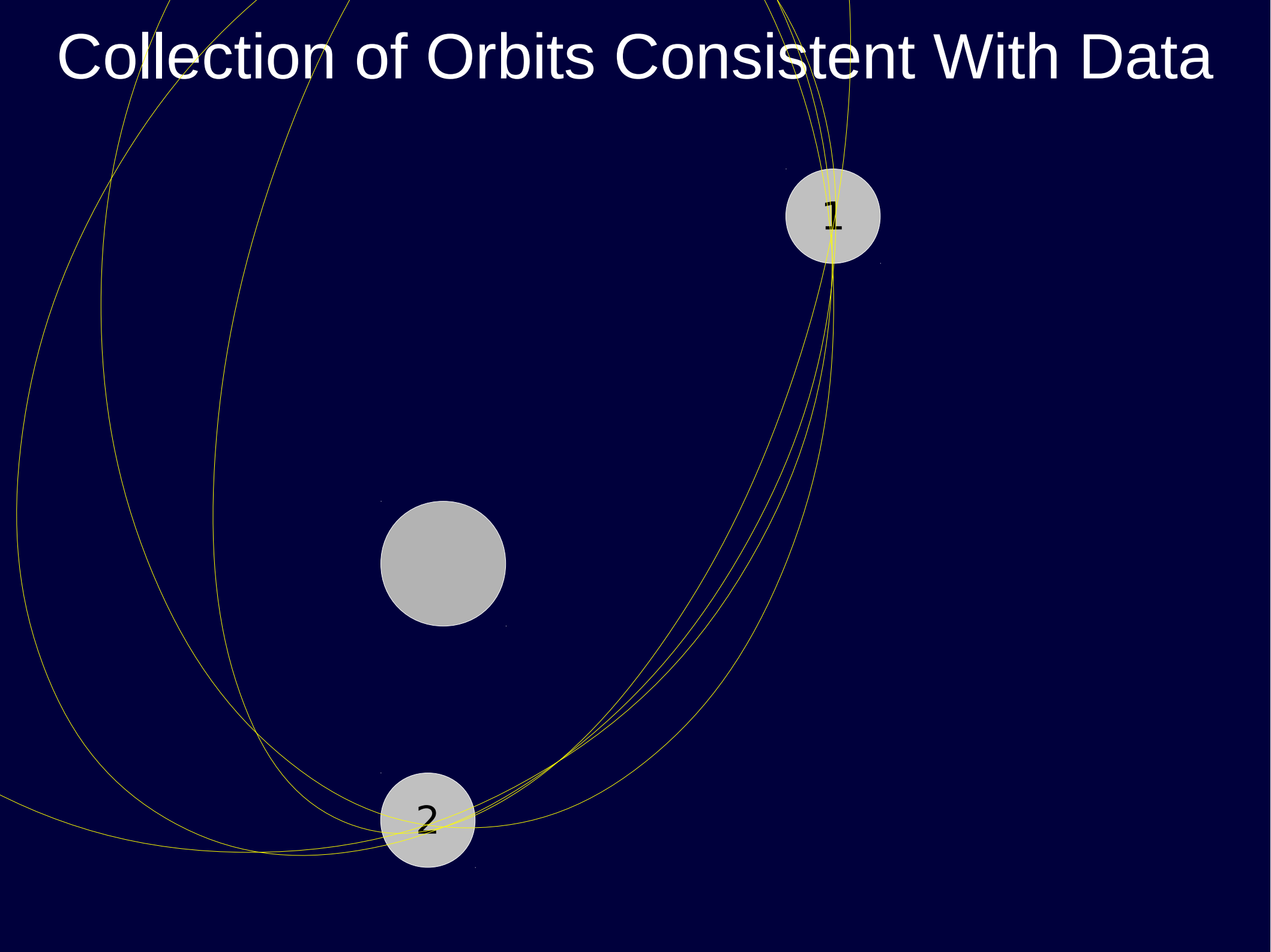
What Can We Learn From One Image?



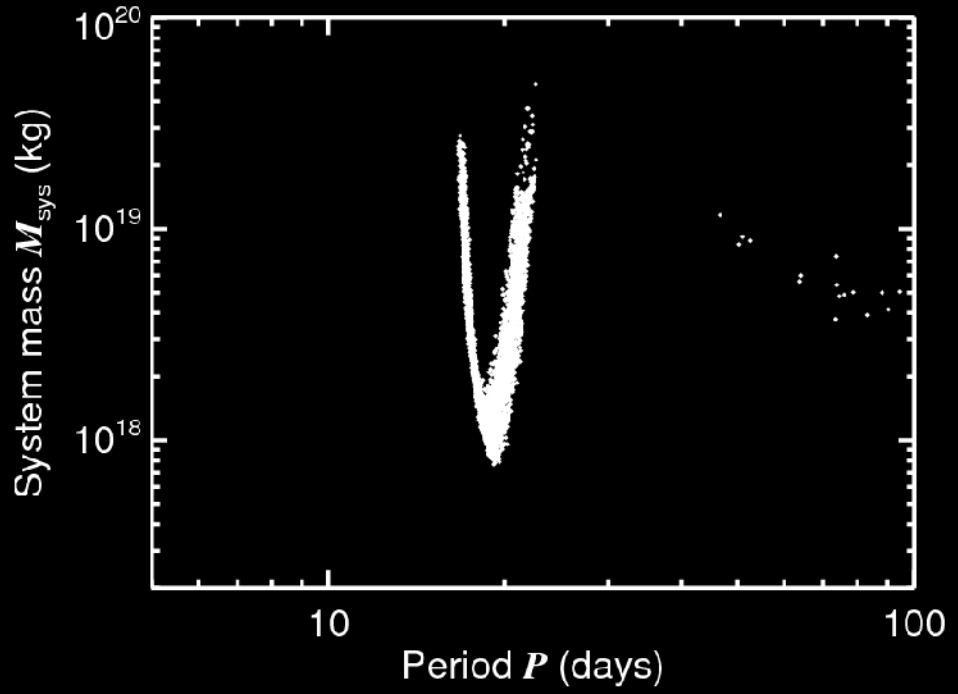
How Similar are Separation and *a*?

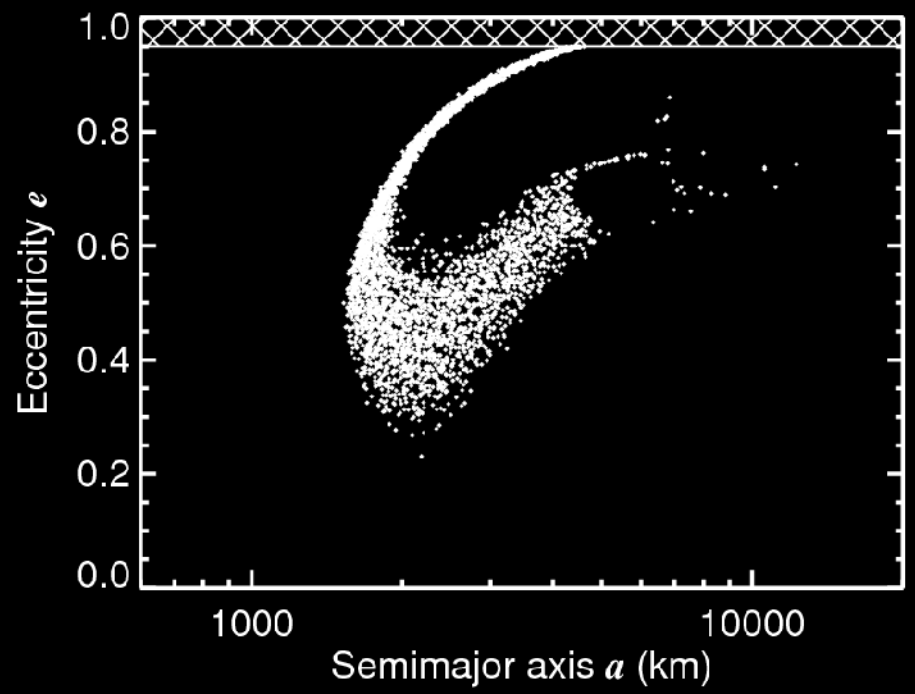


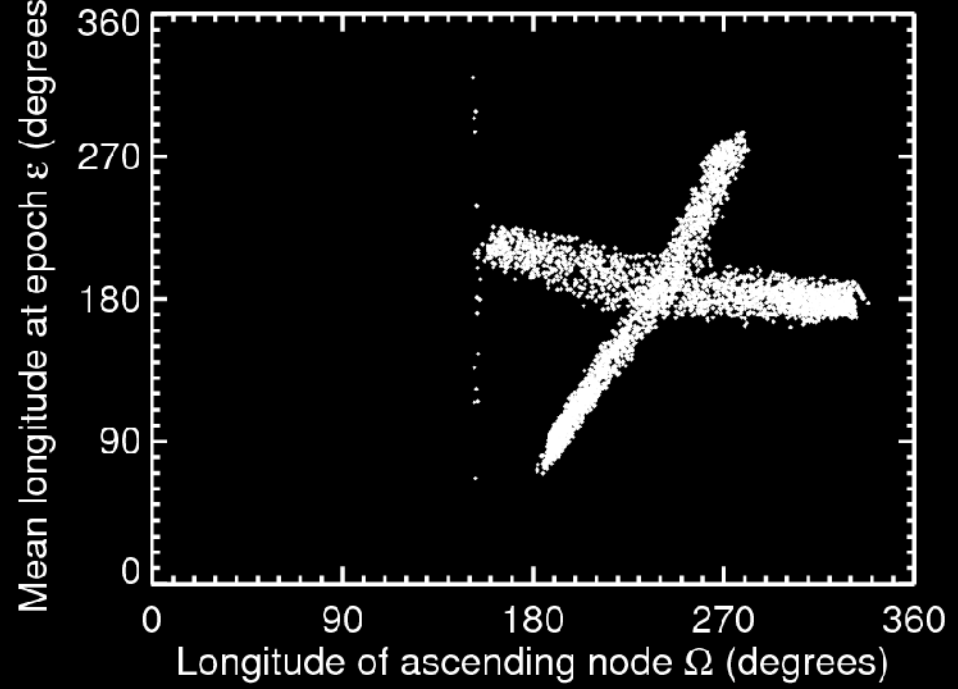
Collection of Orbits Consistent With Data

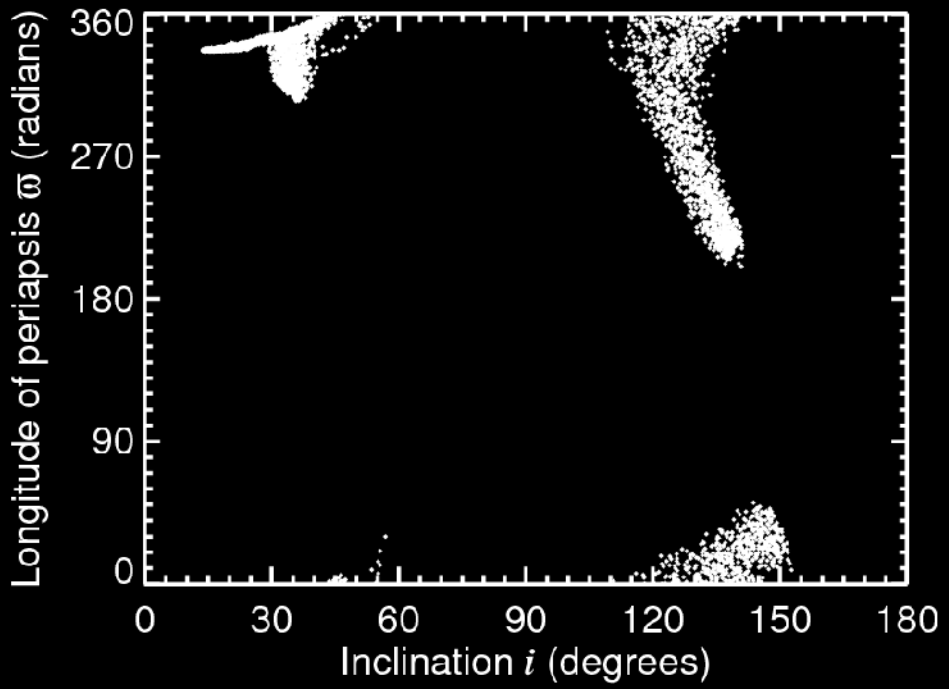


Monte Carlo Cloud of Orbits

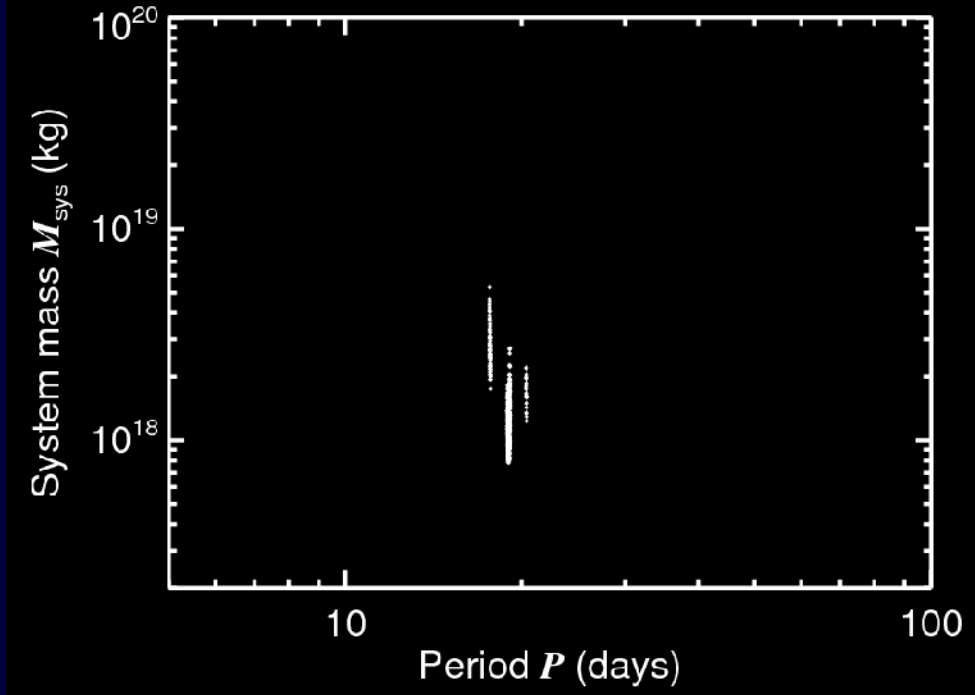


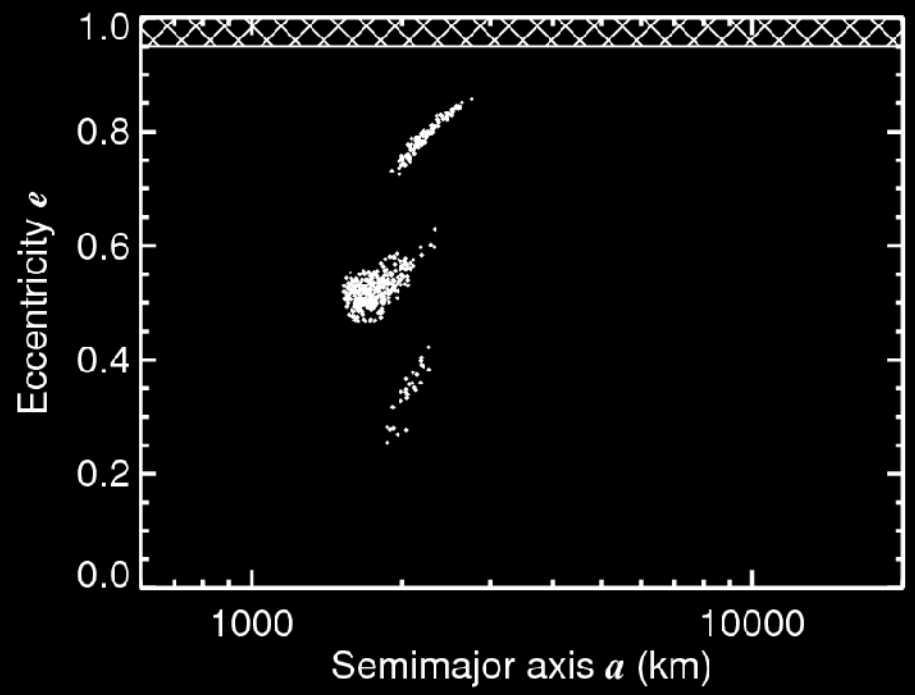


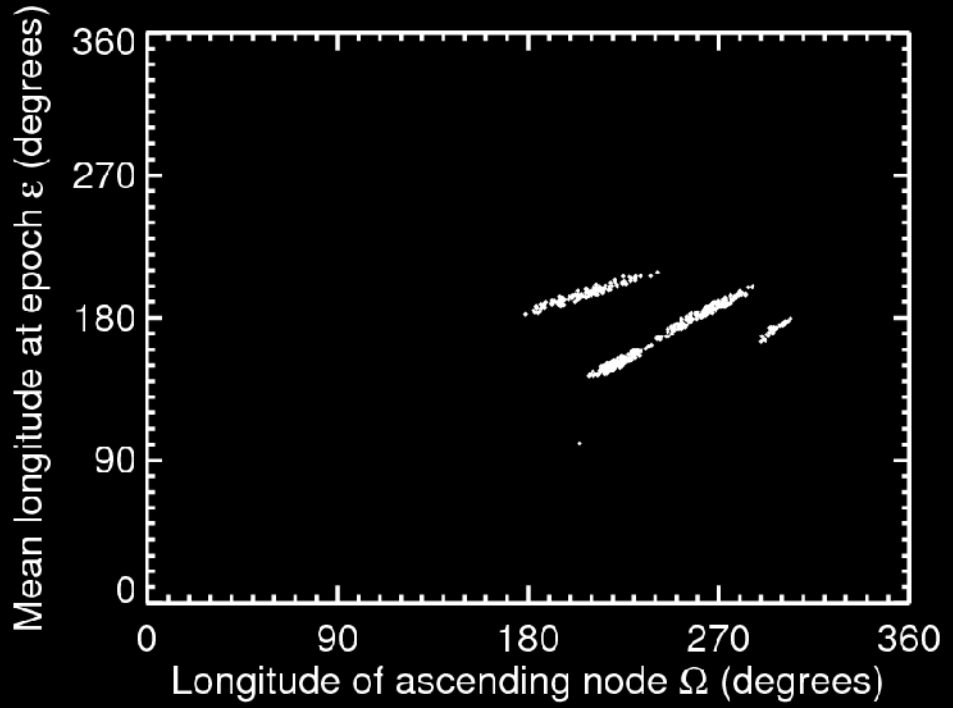


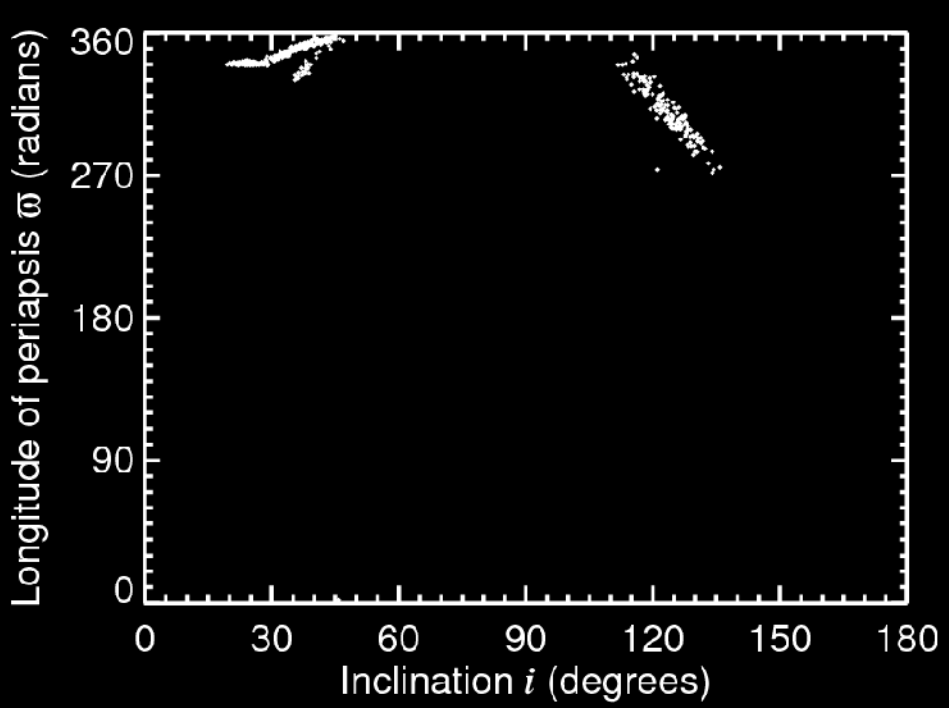


Monte Carlo Cloud of Orbits

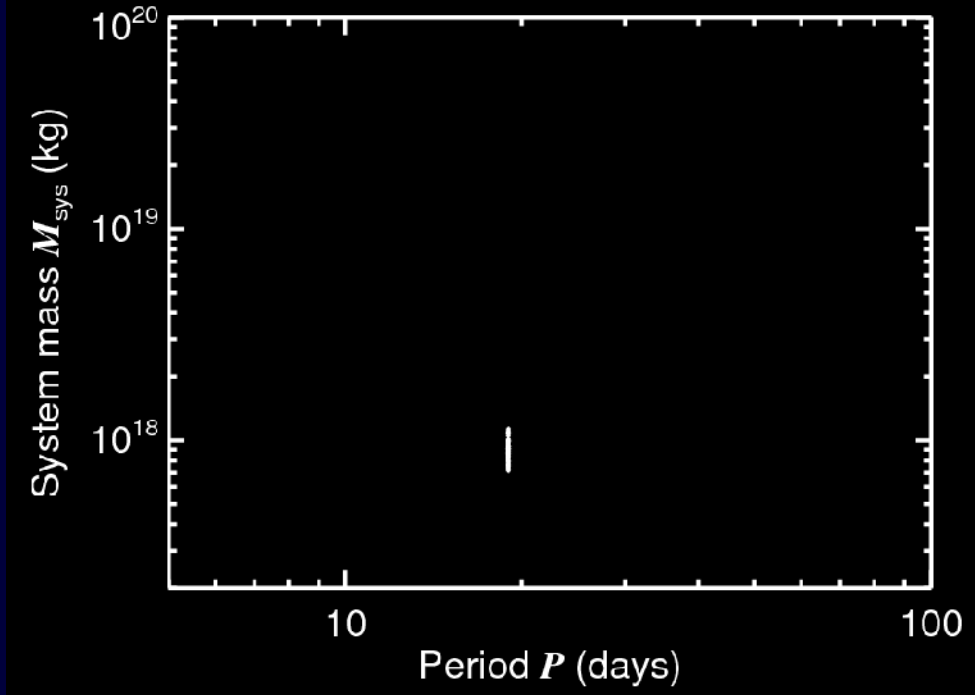


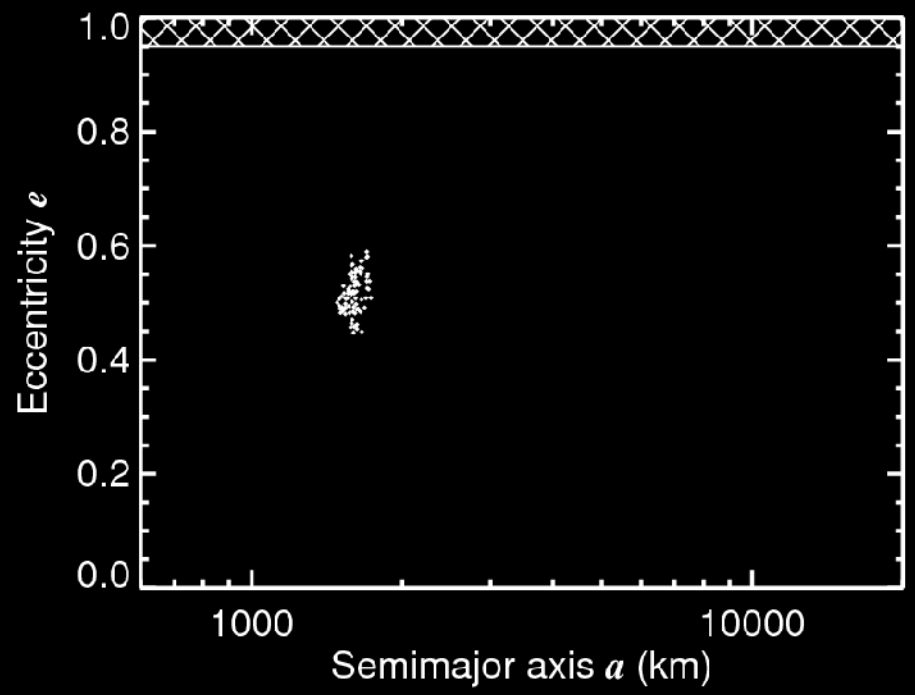


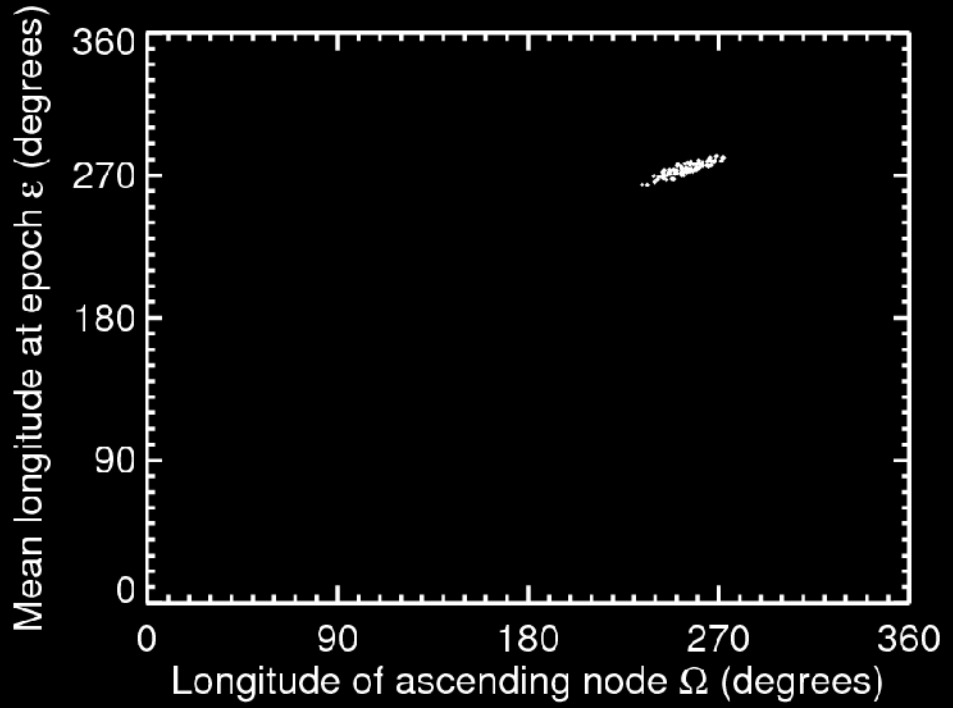


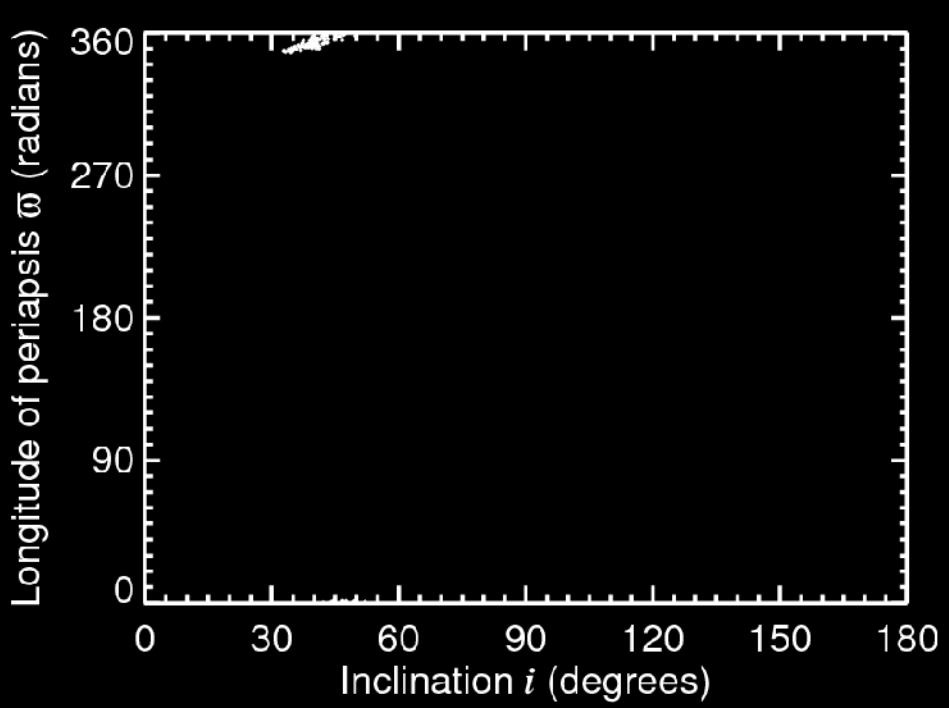


Monte Carlo Cloud of Orbits



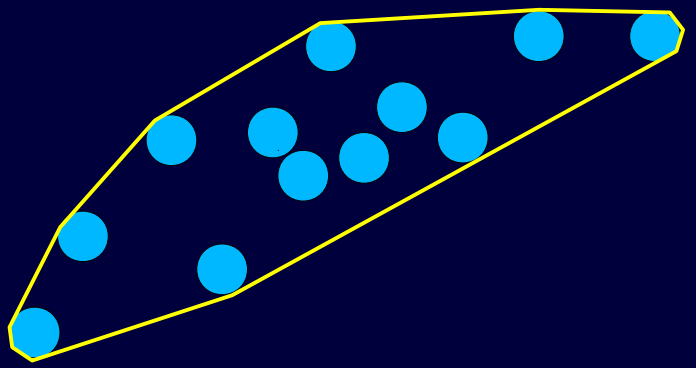






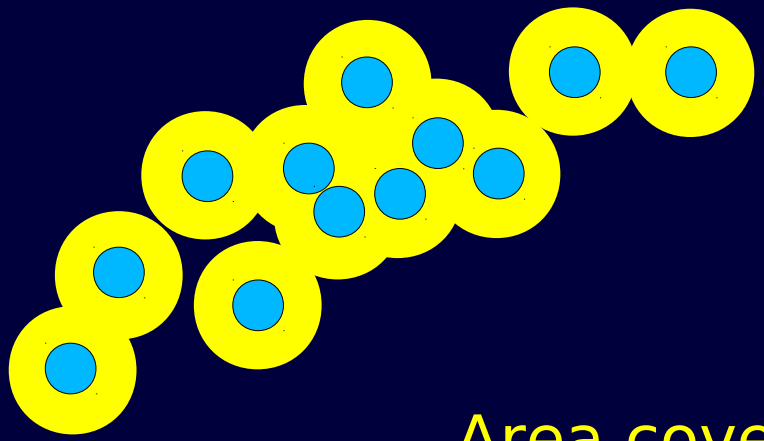
Project To Sky Plane at Time T

Observation Timing Figure of Merit



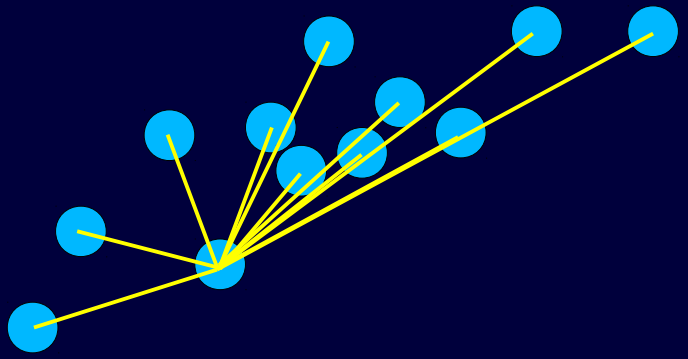
Area of convex hull?

Observation Timing Figure of Merit



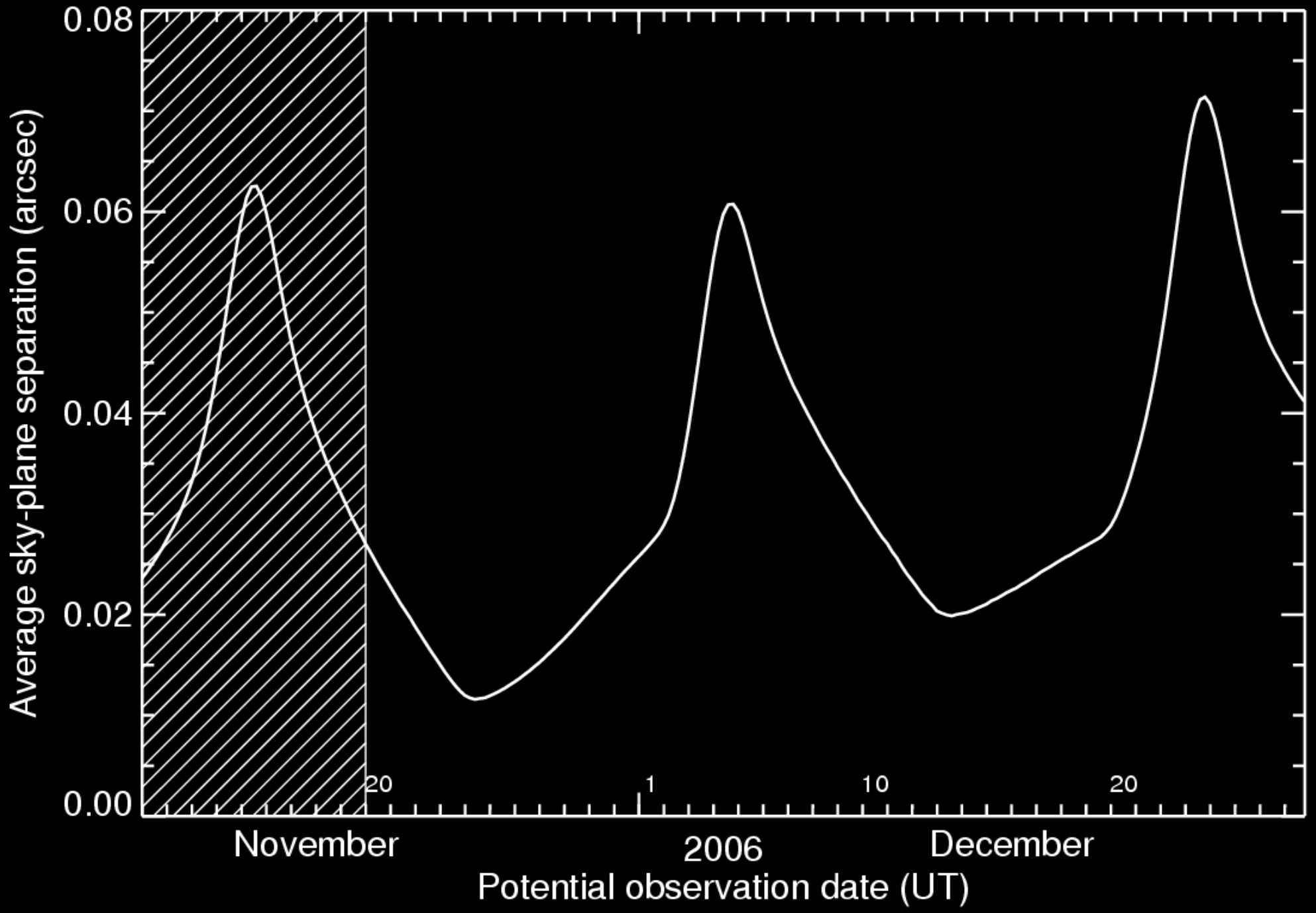
Area covered by points sized by typical astrometric precision?

Observation Timing Figure of Merit



Mean distance between points

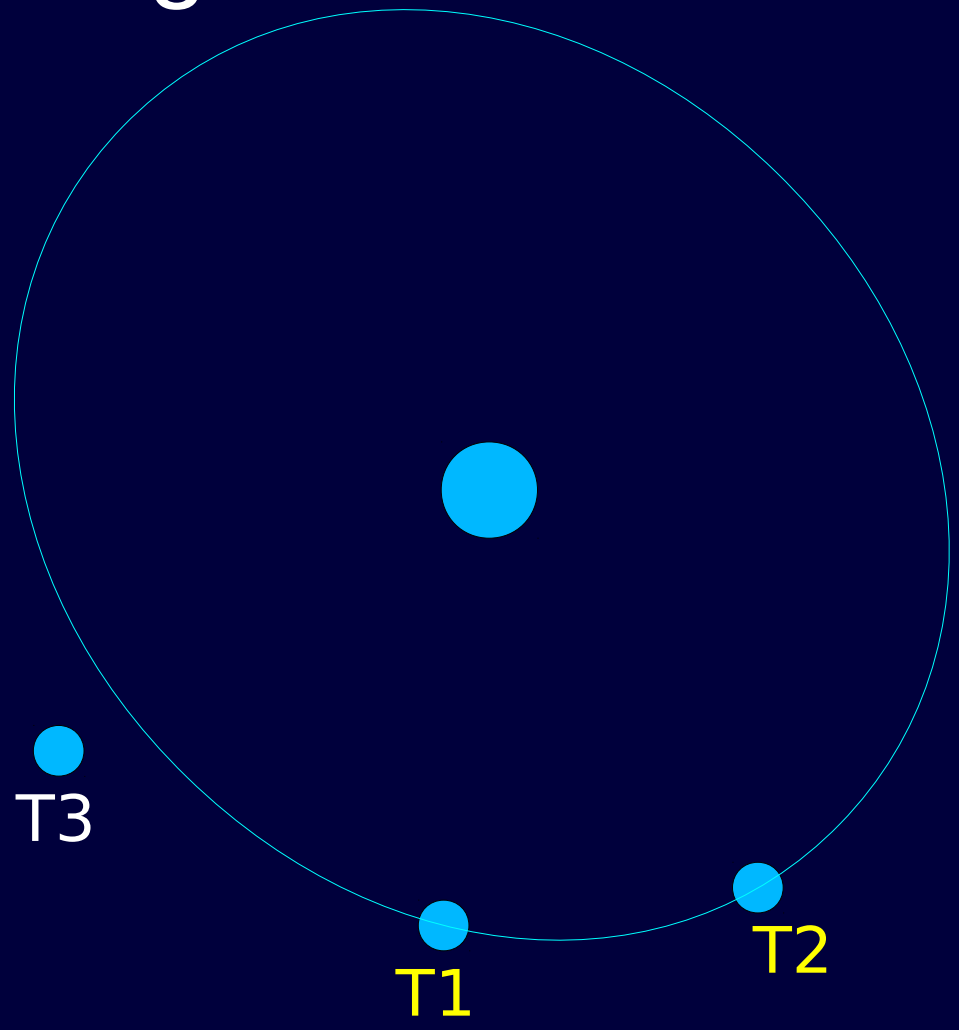
Optimal Scheduling



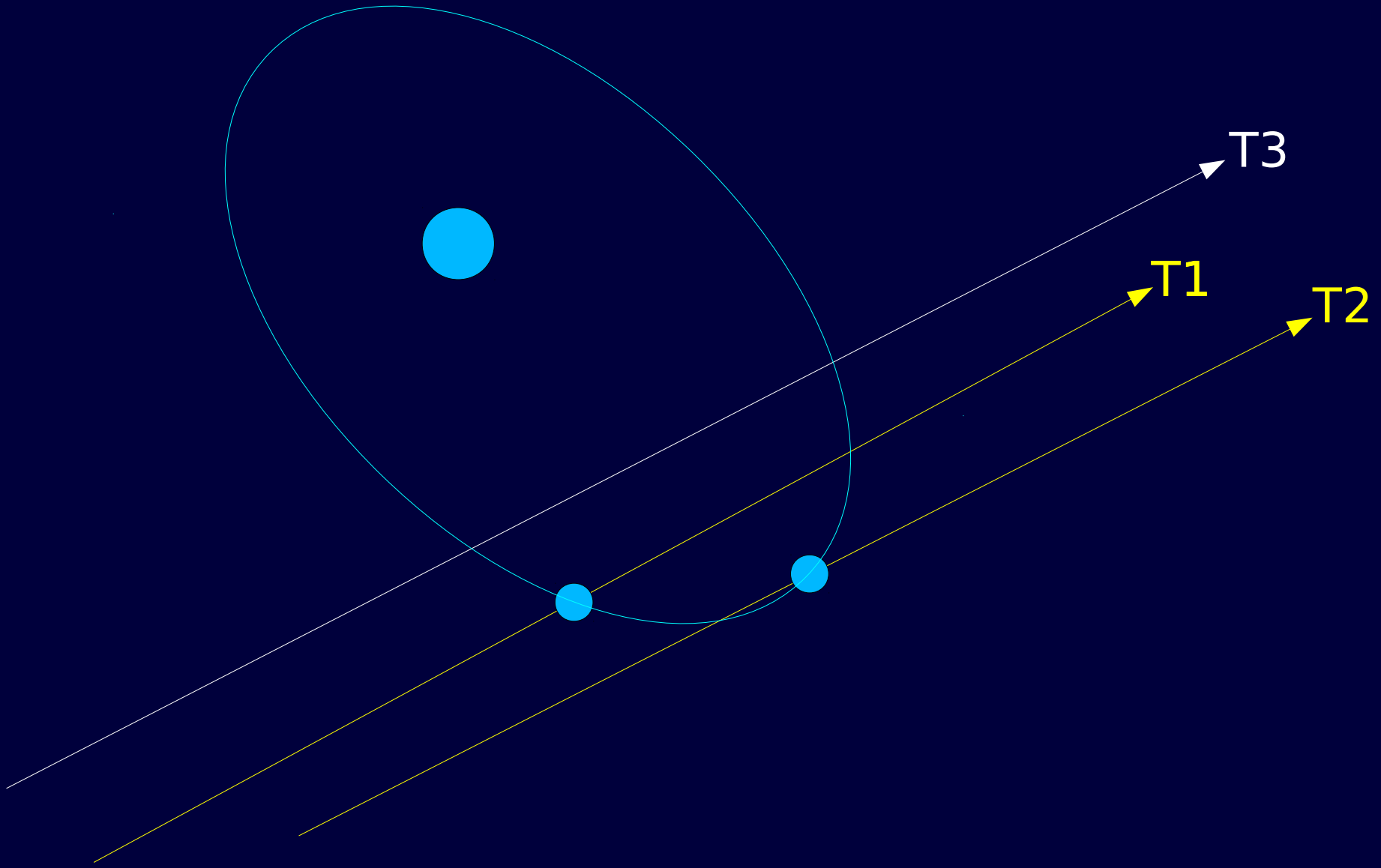
Generating Random Orbits

- Simplest: try orbital element values at random (or grid search), keep only those with small χ^2
- Choose 2 “anchor” observations, generate random points along those lines of sight, solve 2 point boundary value problem for orbital elements, keep those with small χ^2
- Use 3 observations and Thiele-Innes method
- Other...

Using 2 Anchor Observations

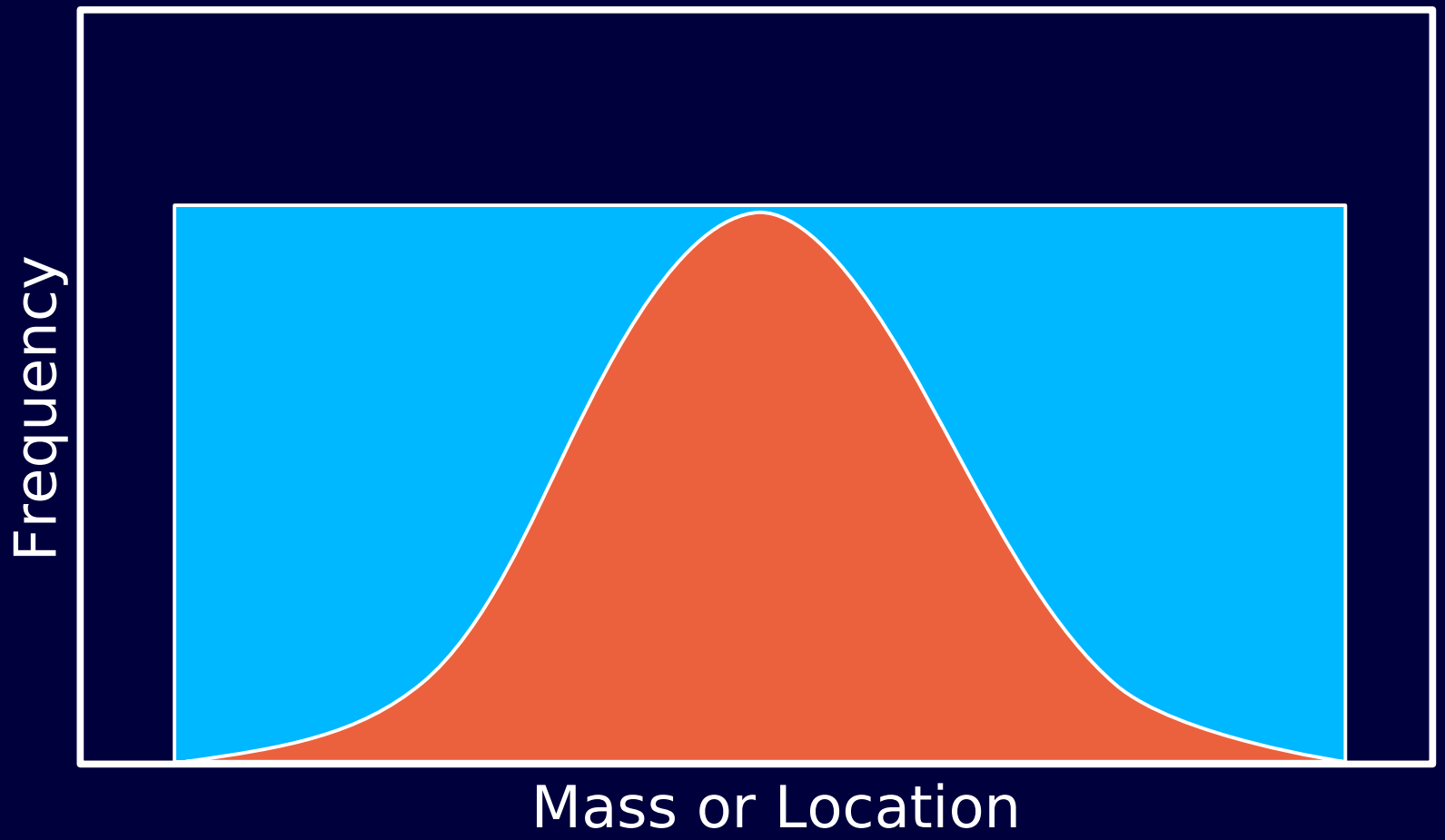


Using 2 Anchor Observations



Not All Orbits Are Equally Valuable

→ Need To Weight Them

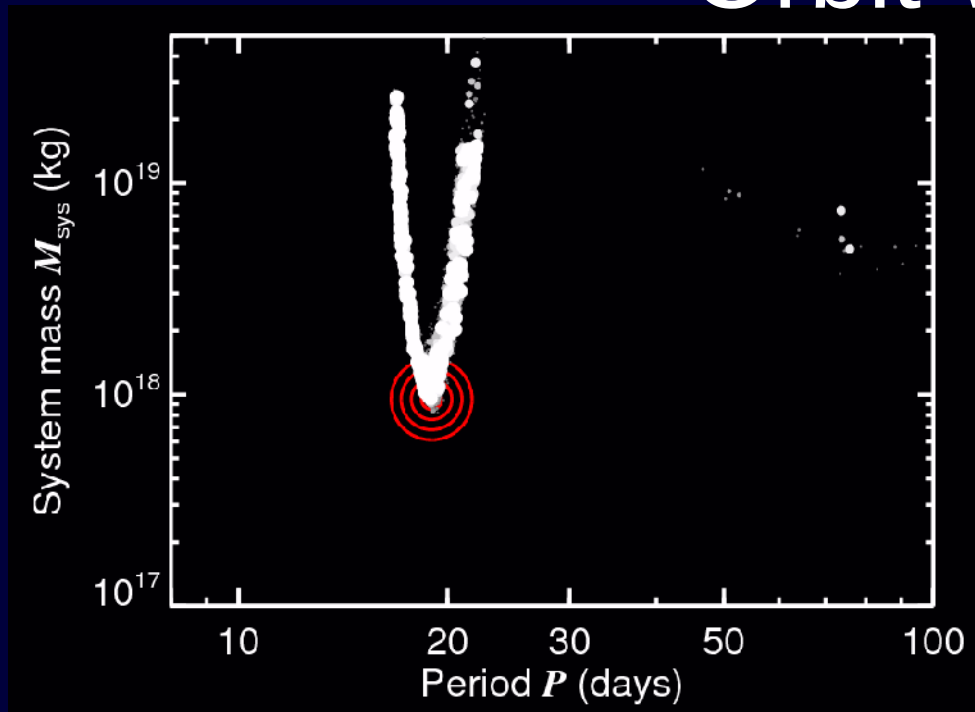


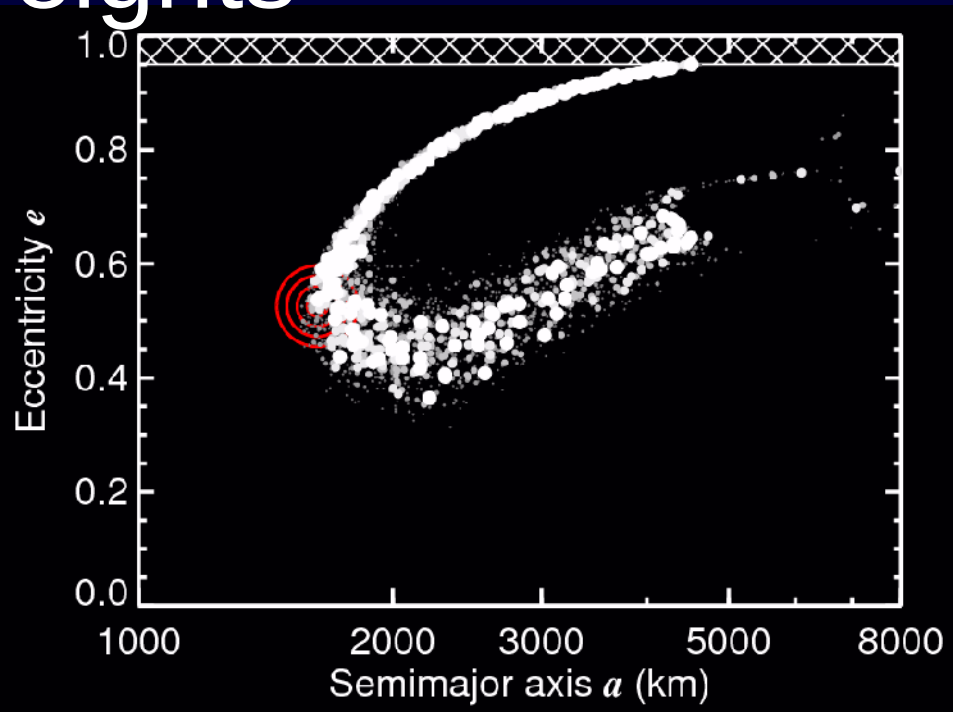
See:

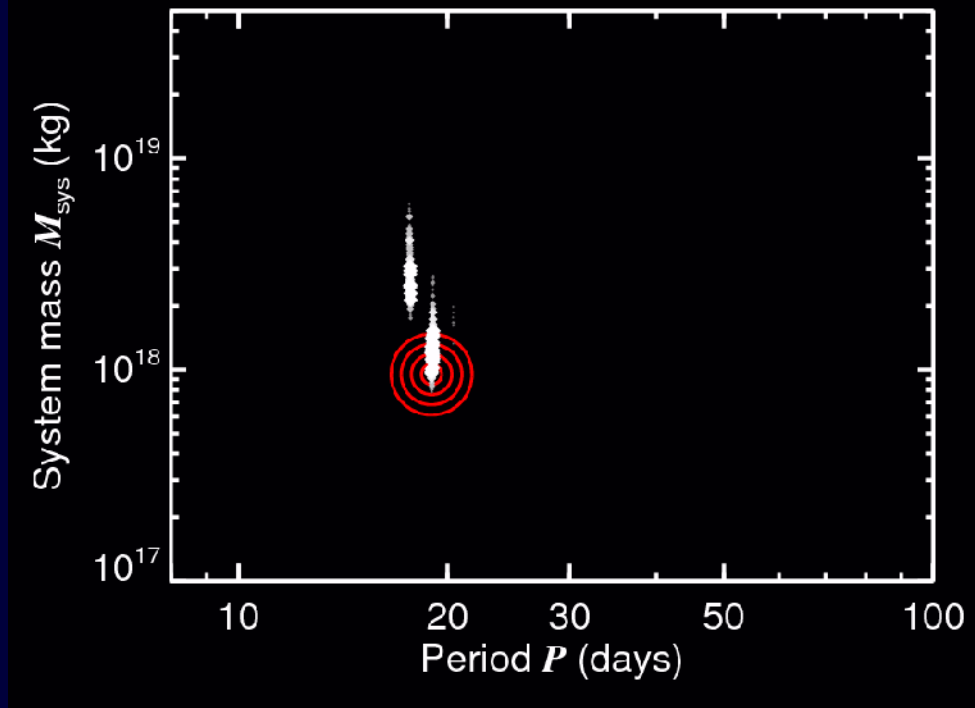
Virtanen et al. 2001, 2003, 2008

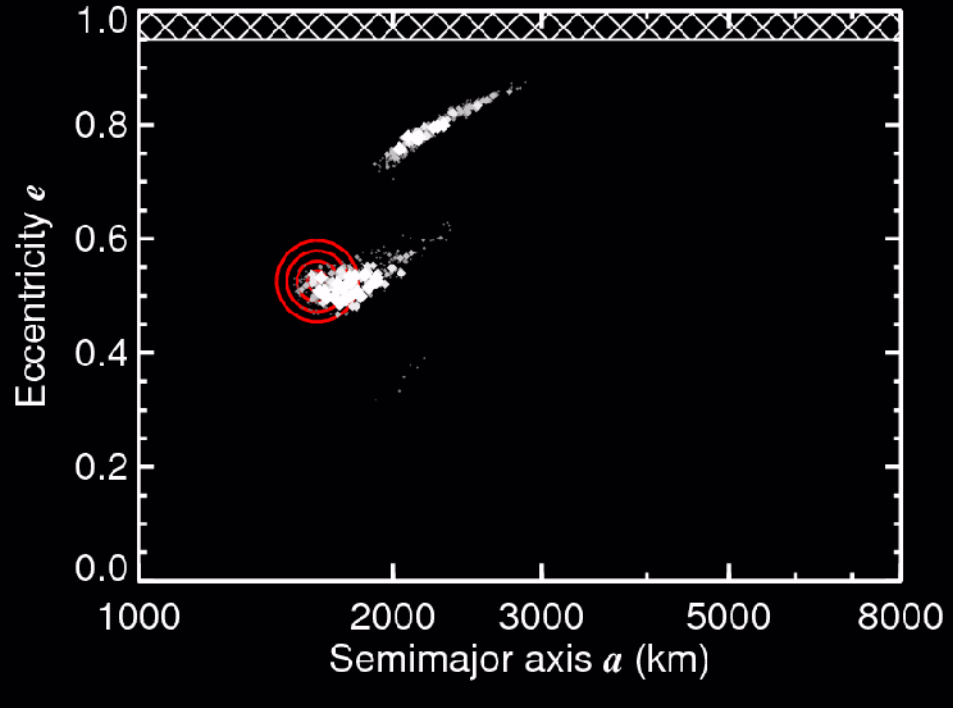
Virtanen & Muinonen 2006

Orbit Weights



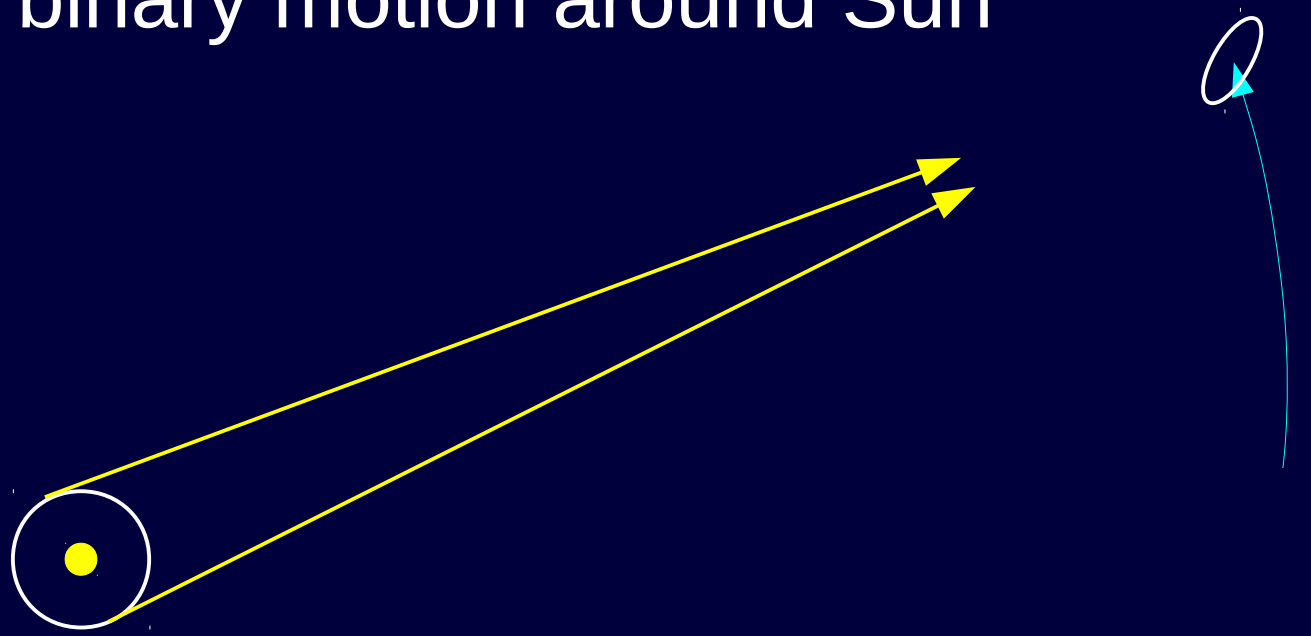




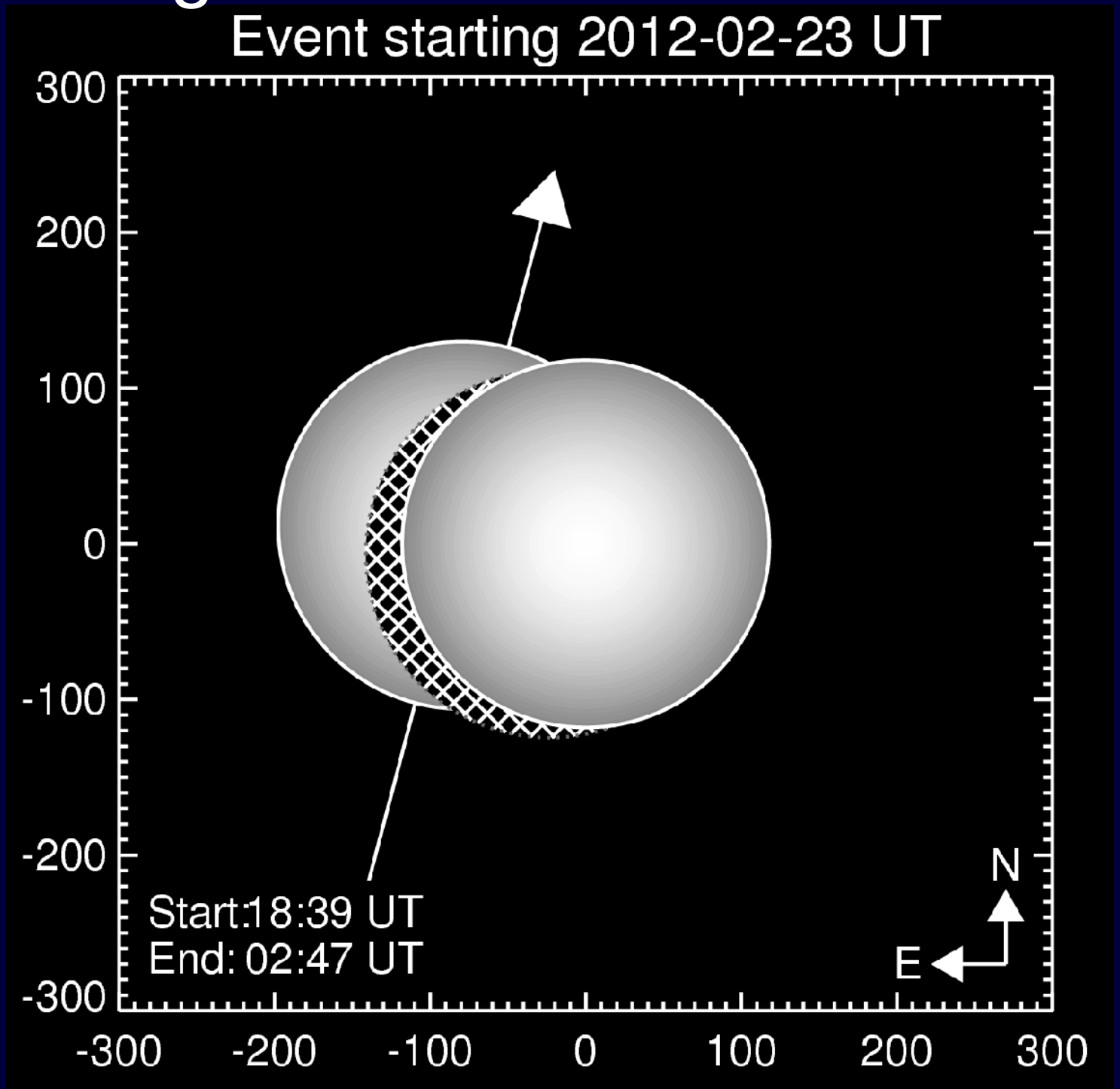


Complications: Parallax

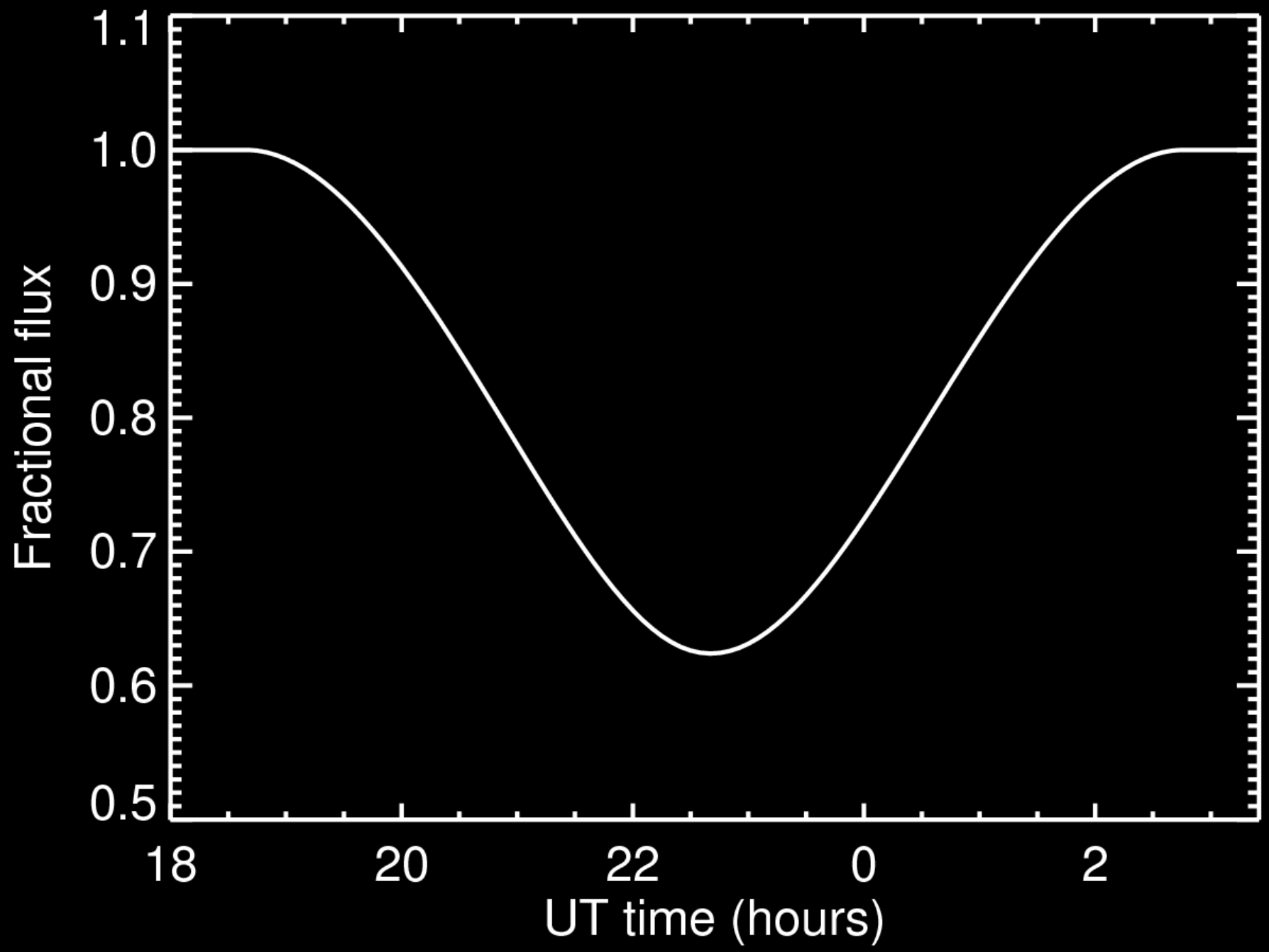
- From Earth motion
- Also binary motion around Sun



Digression: Mutual Events



Digression: Mutual Events

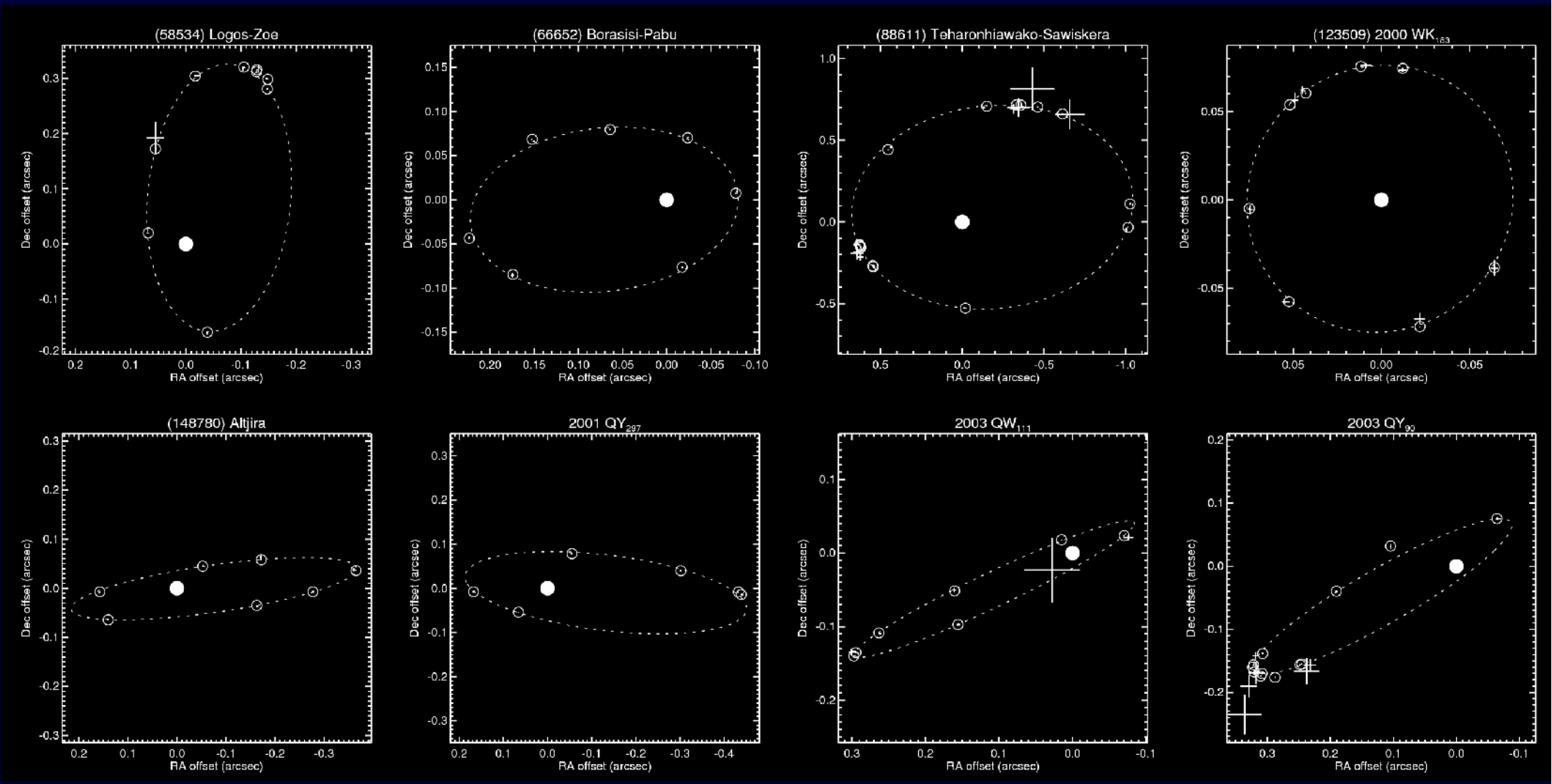


Summary

- Partial knowledge can be used to optimize scheduling of follow-up observations
- A Monte Carlo cloud of possible orbits is a useful tool for this
- Our method of generating and weighting the orbits requires knowledge of astrometric uncertainties and an anchor pair from a single orbit

Backup Slides

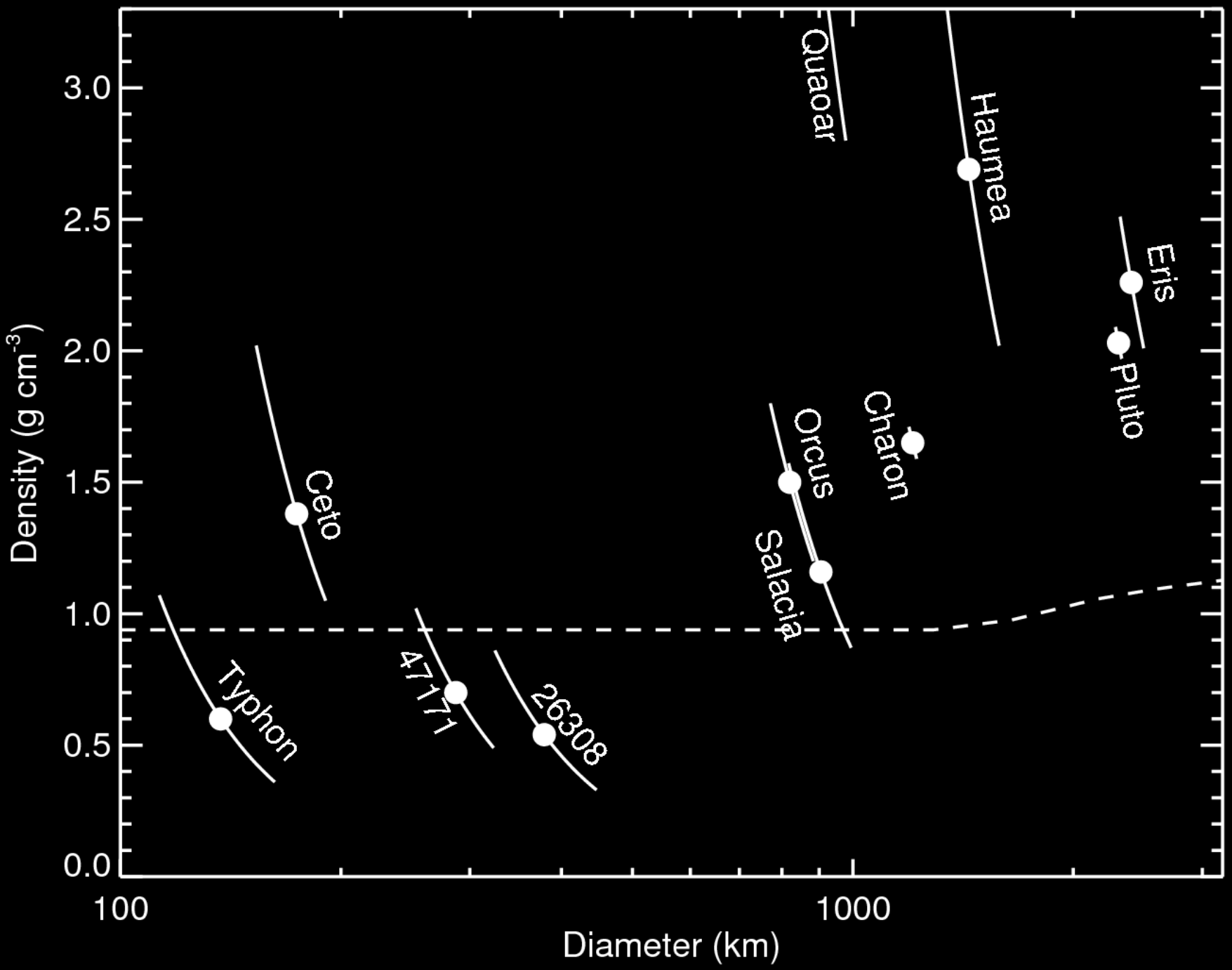
Orbits...


(58534) Logos-Zoe
(66652) Borasisi-Pabu
(88611) Teharonhiawako-Sawiskera
(123509) 2000 WK183
(148780) Altjira
2001 QY297
2003 QW111
2003 QY90
Dec offset (arcsec)
RA offset (arcsec)

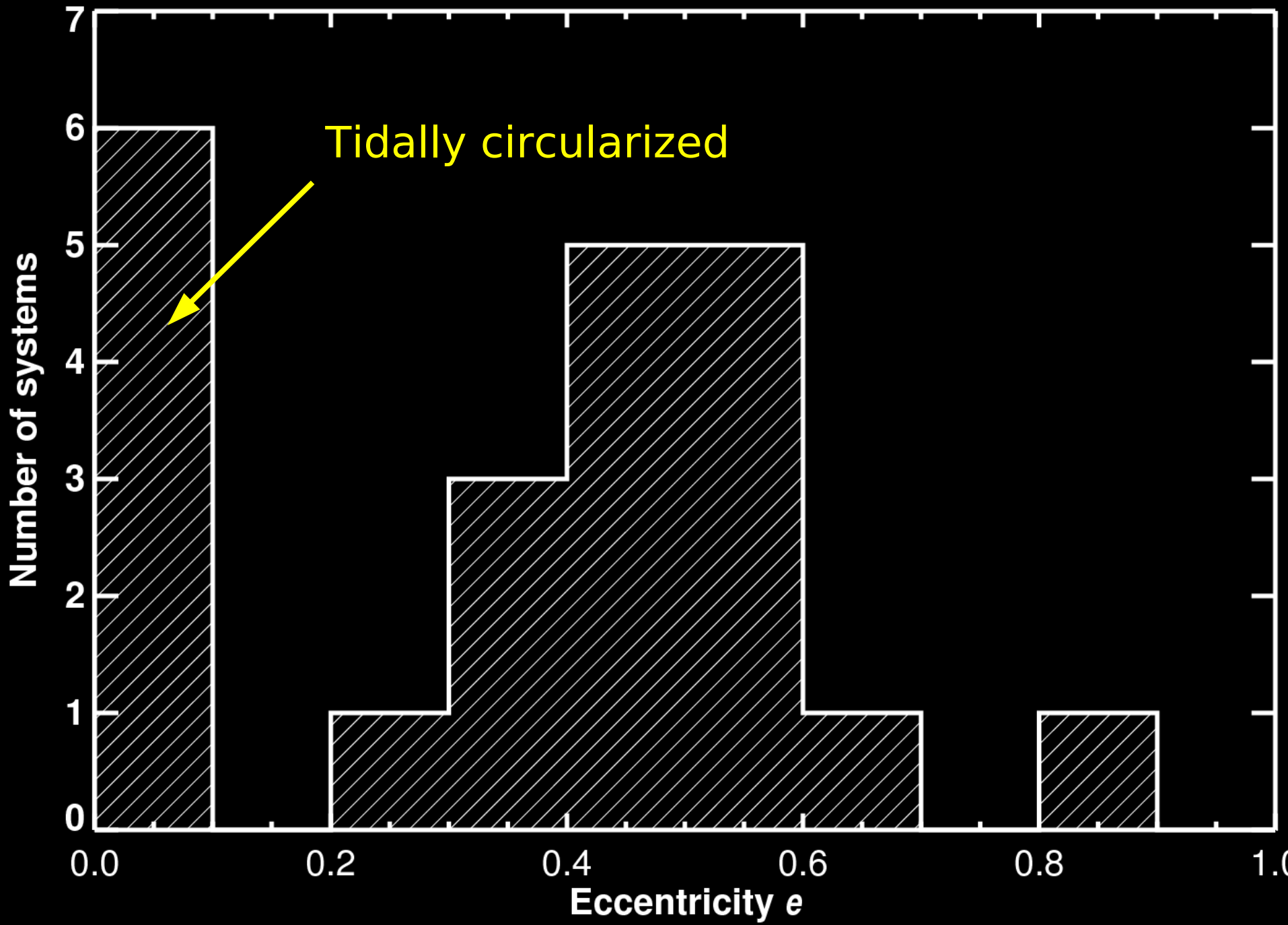
Triple System with Keck LGS AO
47171 1999 TC_{36}

(see Benecchi et al. Icarus 2010 207, 978-991)

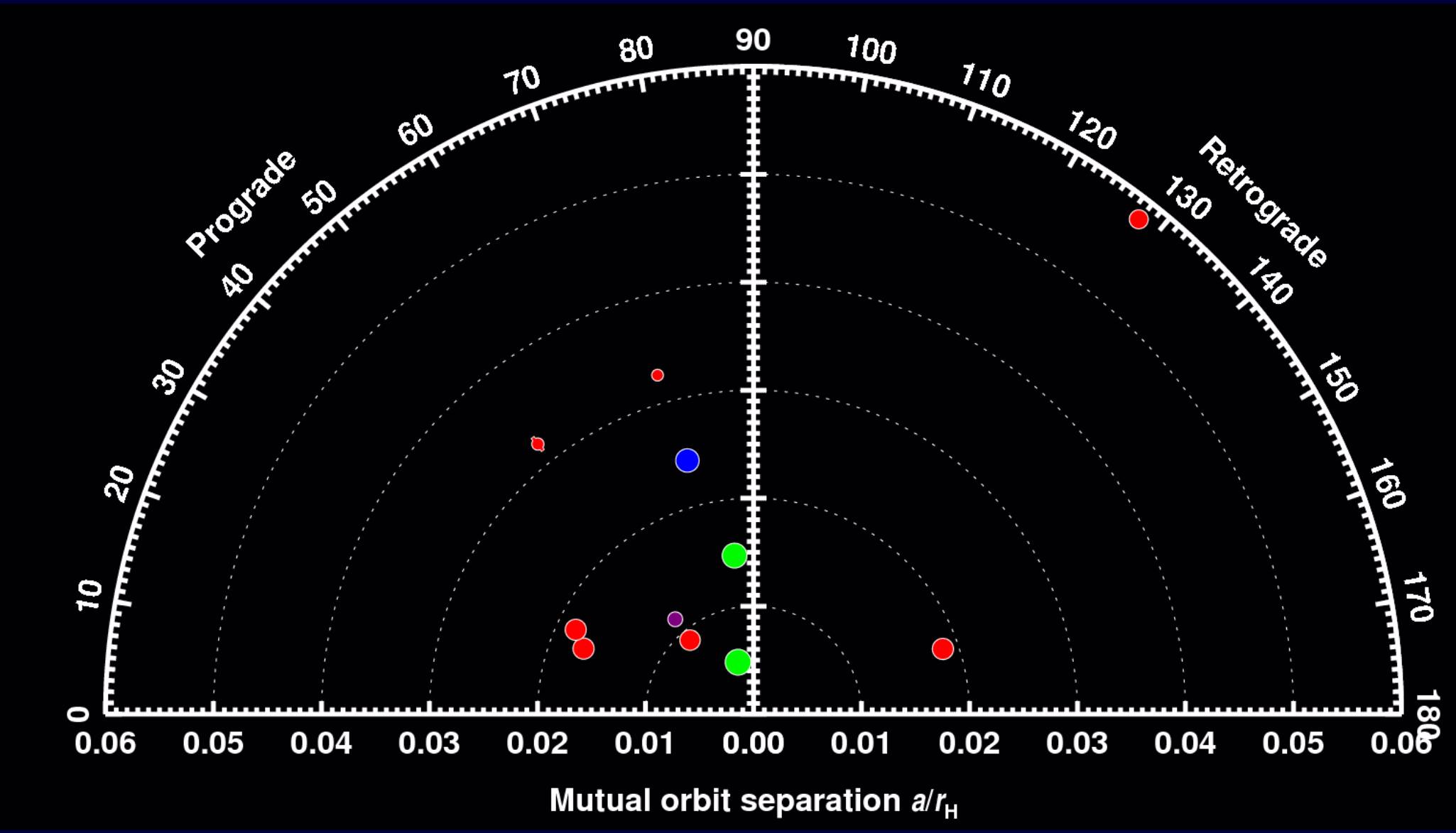
Densities From Mass + Size



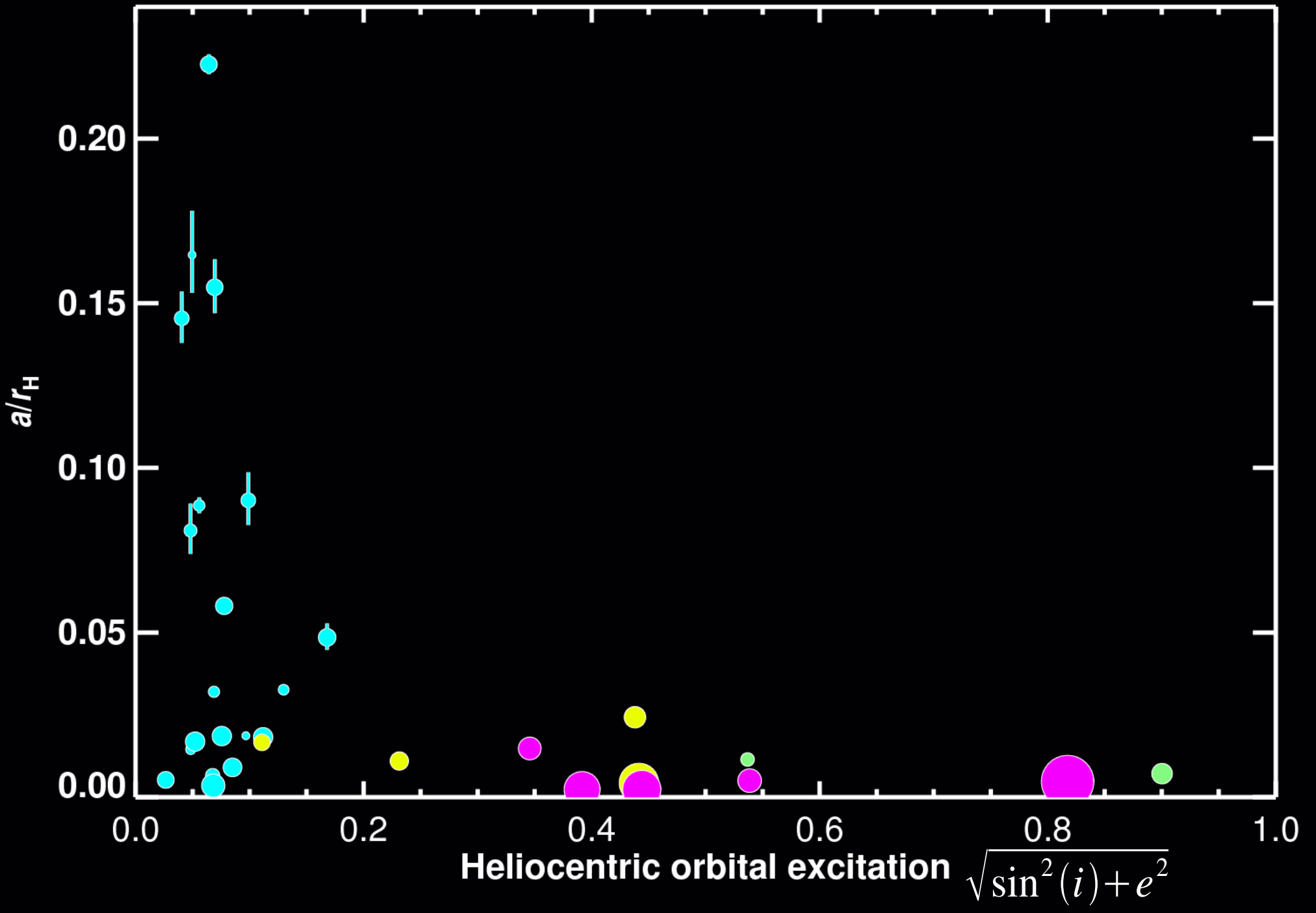
Eccentricity Distribution



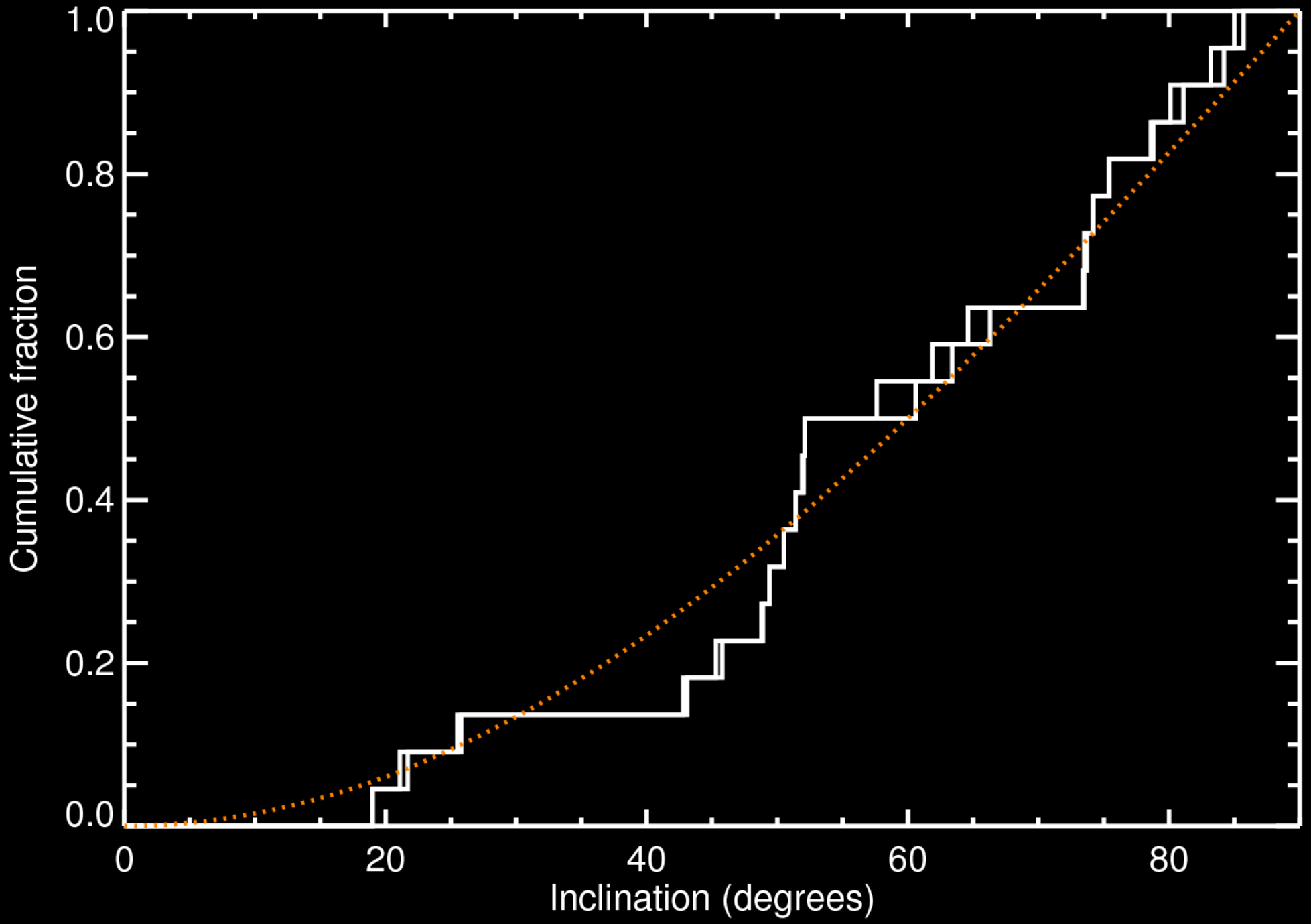
Tightness -vs- Inclination



Tightness -vs- Excitation



Inclination Distribution



Sky-Plane Mirror Ambiguity
2 orbit solutions: same P, a, e, but different i, ε, Ω, ϖ