Imaged companions: not as eccentric as they appear?

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Outline

- Direct imaging allows the detection of wide separation sub-stellar companions. Objects with periods of 100+ yrs may only have their orbital elements estimated from short orbital arcs
- An additional inner mass could be required to scatter the object out to such large distances. This unseen mass introduces an error on the derived orbital elements of the companion, in addition to any astrometric uncertainties
- If the companion actually orbits the star-inner mass barycentre then its elements derived relative to the star could differ significantly from those relative to the barycentre, particularly if only a fraction of its orbit is observed
- Many imaged companions may be susceptible to this uncertainty. For example a 10% eccentricity error, similar to that from astrometry, could be induced on Fomalhaut b by an observationally allowed 10 M_{Jupiter} mass at 10 AU

1. Could eccentric companions actually be circular?

- An unseen inner mass would induce a stellar motion. This would cause the companion elements derived in an astrocentric (star-centred) frame to vary over its orbit
- If it is on a circular barycentric orbit then it will *always* have an astrocentric eccentricity, with maximum a value of

$$e' \sim \frac{m_{\text{inner}}}{m_*}\sqrt{\frac{a_{\text{outer}}}{a_{\text{inner}}}} \qquad (1)$$

- So a circular companion could therefore *appear* eccentric if an inner mass were present

2. Orbital motion between observation epochs

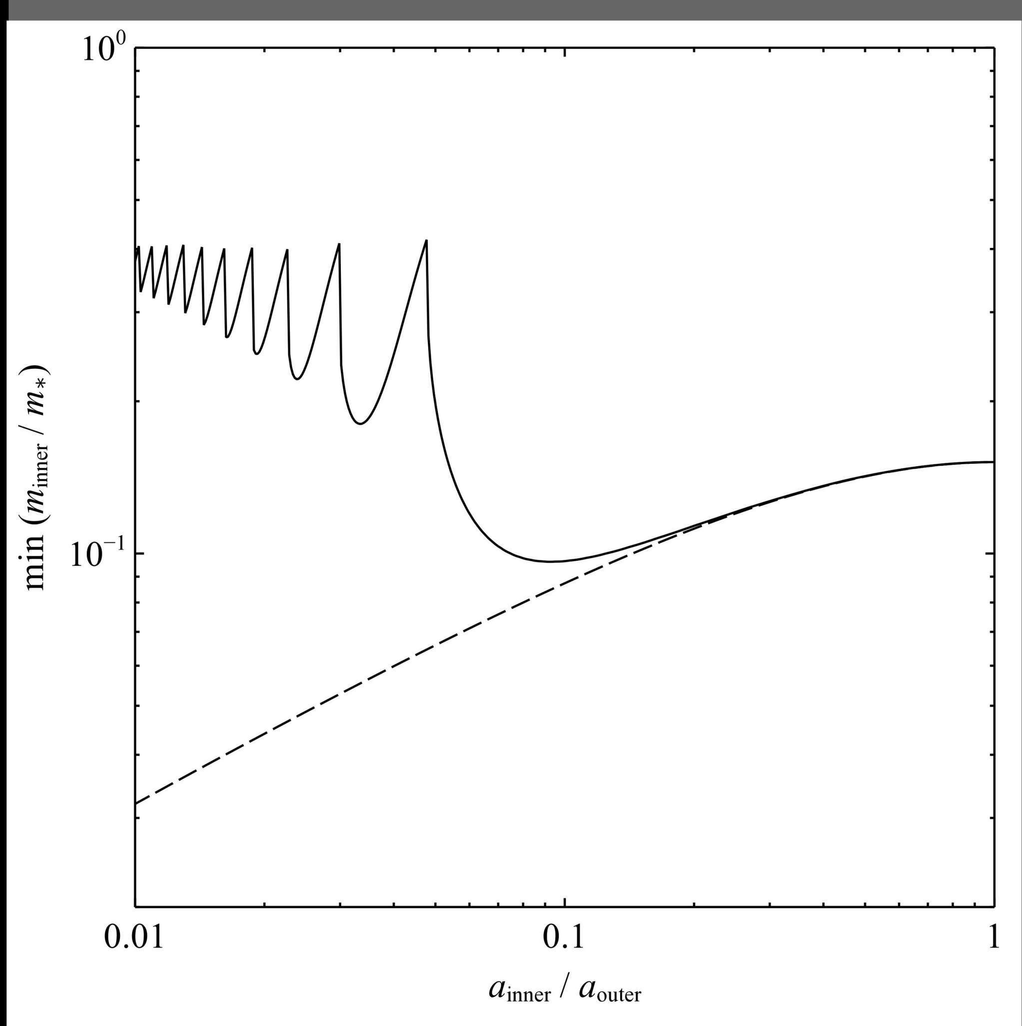

Fig. 1: Min. unseen mass giving a circular companion an astrocentric eccentricity of 0.8, if its velocity is derived from two observations. Dashed line is ~ Eqn. 1

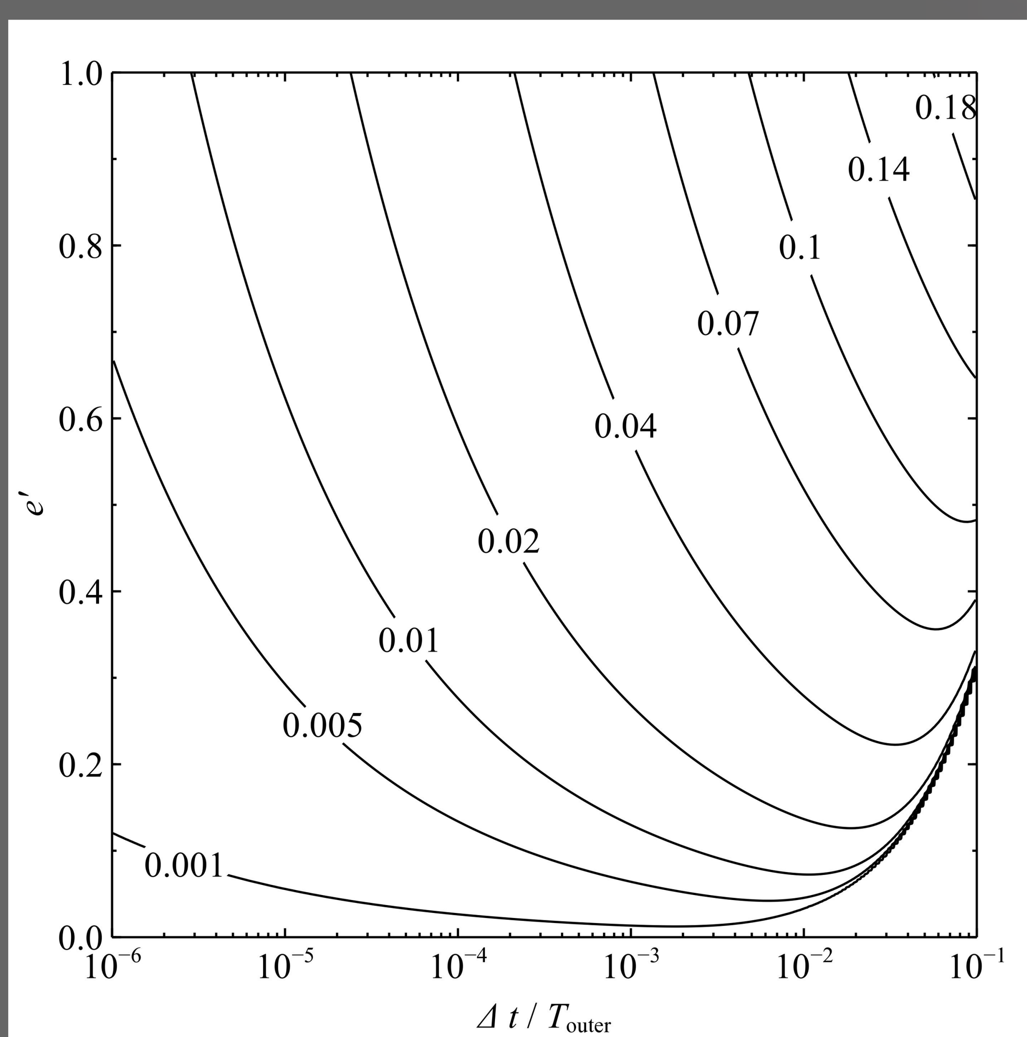

Fig. 2: Minimum m_{inner} / m_* (contours) required to give a circular companion an astrocentric eccentricity e'

- In direct imaging, velocity (which is needed to derive the companion's orbital elements) is derived from the change in position between (at least) two observation epochs
- The motion of an unseen inner mass in this time Δt would "average out" the star's barycentric velocity, and so reduce the effect of the unseen mass on the derived elements
- This leads to a minimum inner mass required to make a circular companion appear eccentric, which is a function of e' and $\Delta t / T_{\text{outer}}$. This mass will have the greatest effect if

$$\frac{a_{\text{inner}}}{a_{\text{outer}}} \approx 2.19 \left(\frac{\Delta t}{T_{\text{outer}}}\right)^{\frac{2}{3}} \qquad (2)$$

- We can estimate the companion period T_{outer} assuming its orbit is circular. Then we may use Fig. 2 to find the inner mass required to give the observed eccentricity, and find its location with Eqn. 2. We can then establish whether this mass is observationally allowed

3. If the companion really is eccentric?

- An unseen mass could make the companion appear more eccentric than it really is
- The error is maximised if the companion is at pericentre, which gives us T_{outer}. We can find the required inner mass with plots analogous to Fig. 2., and can still find its location with Eqn. 2

4. Susceptible systems

- All imaged companions could be susceptible to this, but for some the required inner mass may be observationally ruled out
- RV and spectroscopy are the primary means to rule out inner masses. Masses may not be excluded if these have not been applied, the system is unsuitable (e.g. an A star) or ***the system is face on***. This configuration also favours companion imaging
- The effect is greatest if Δt / $T_{\text{outer}} < 10^{-2}$, which has an upper limit from the centroiding accuracy and Δt. Suitable systems are thus ***nearby*** with a ***wide separation companion*** (Fig. 3)
- Many imaged exoplanets and companion BDs fulfil these criteria, but have not yet had their orbital elements derived. Future attempts to do so may be susceptible to this error

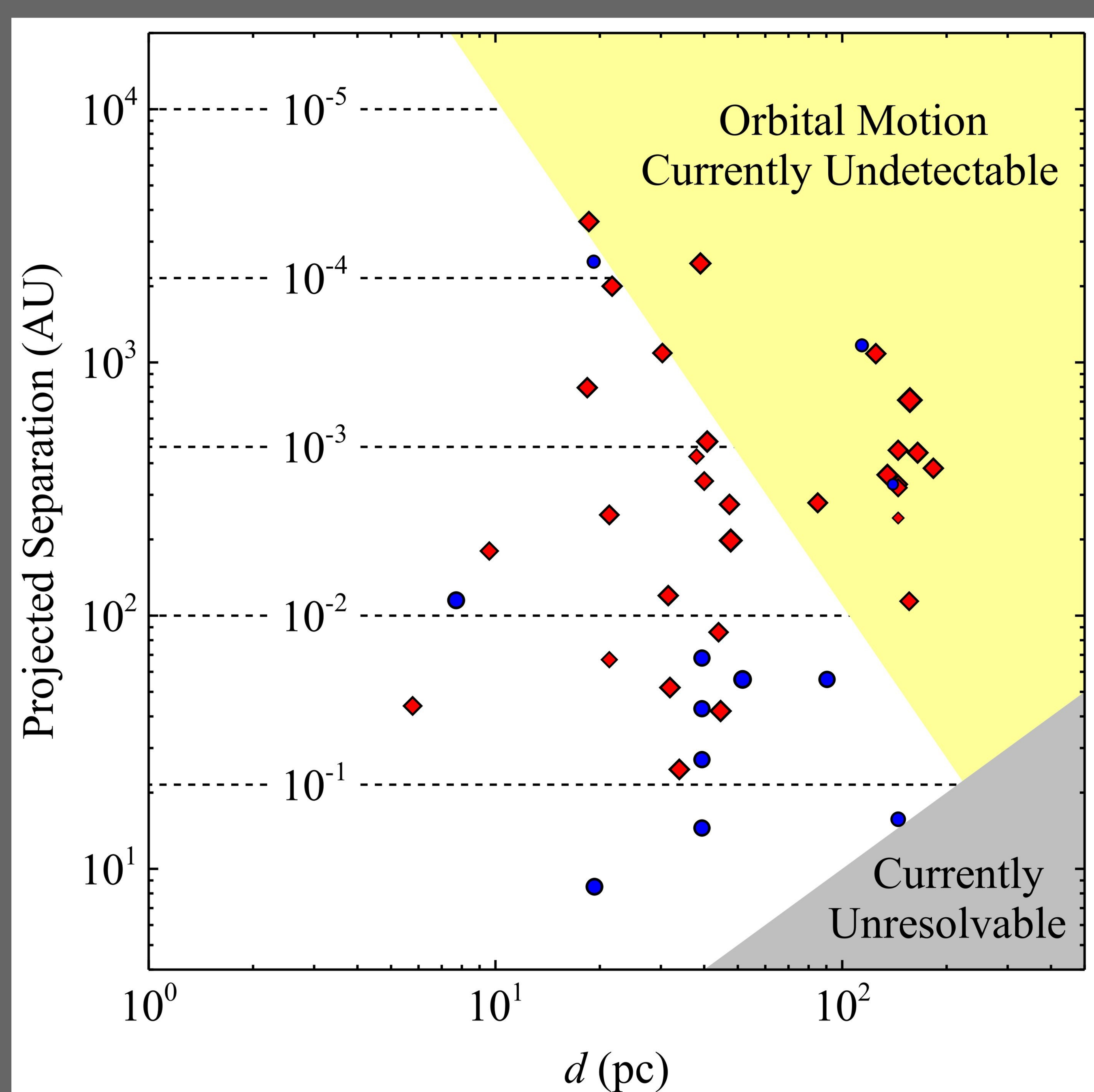

Fig. 3: Maximum Δt / T_{outer} (dashes), derived for circular orbits about Sun like stars. Circles (diamonds) show imaged planets (BDs) scaled by their host star masses

Kalas et al. 2013, in press
Exoplanet.eu, 2013, accessed 1st July 2013
Metchev S. A. & Hillenbrand L. A., 2004, ApJ, 617, 1330
Reid I. N. et al., 2001, ApJ, 121, 489 (+ references)
Zuckerman B. & Song I., 2009, A&A, 493, 1149 (+ references)

Background image: Haven Giguere / Yale