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Dynamical evolution of very low mass binaries in open clusters

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Why Open Star Clusters?

- Most stars form in clusters, or loose associations
- Dense clusters undergo dynamical evolution
- This affects stars & brown dwarfs
- Can cluster evolution significantly process very low mass binaries?

(M. McCaughrean/ESO 2001)

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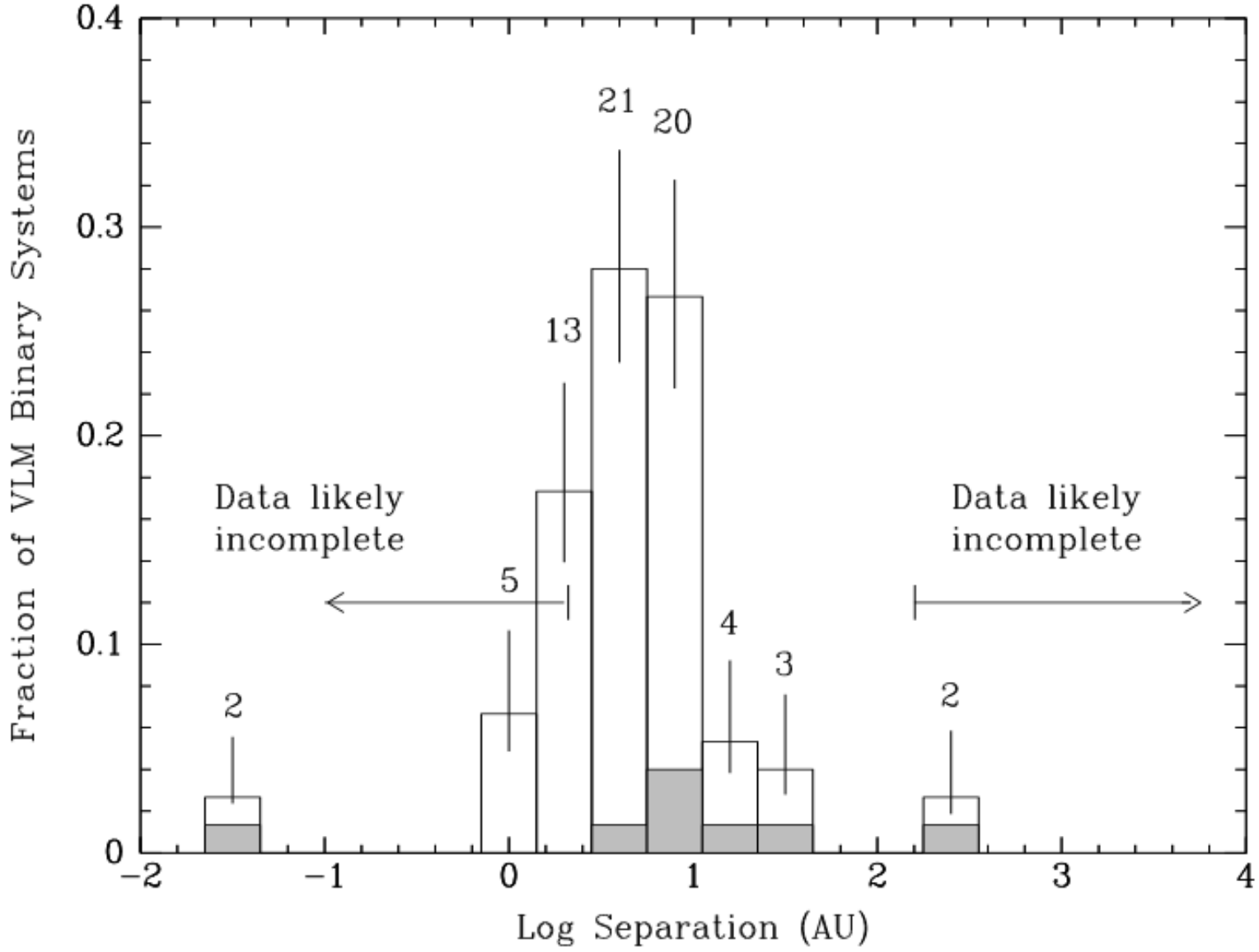
VLM/BD-BD Binaries



(Burgasser et al 2007, PPV)

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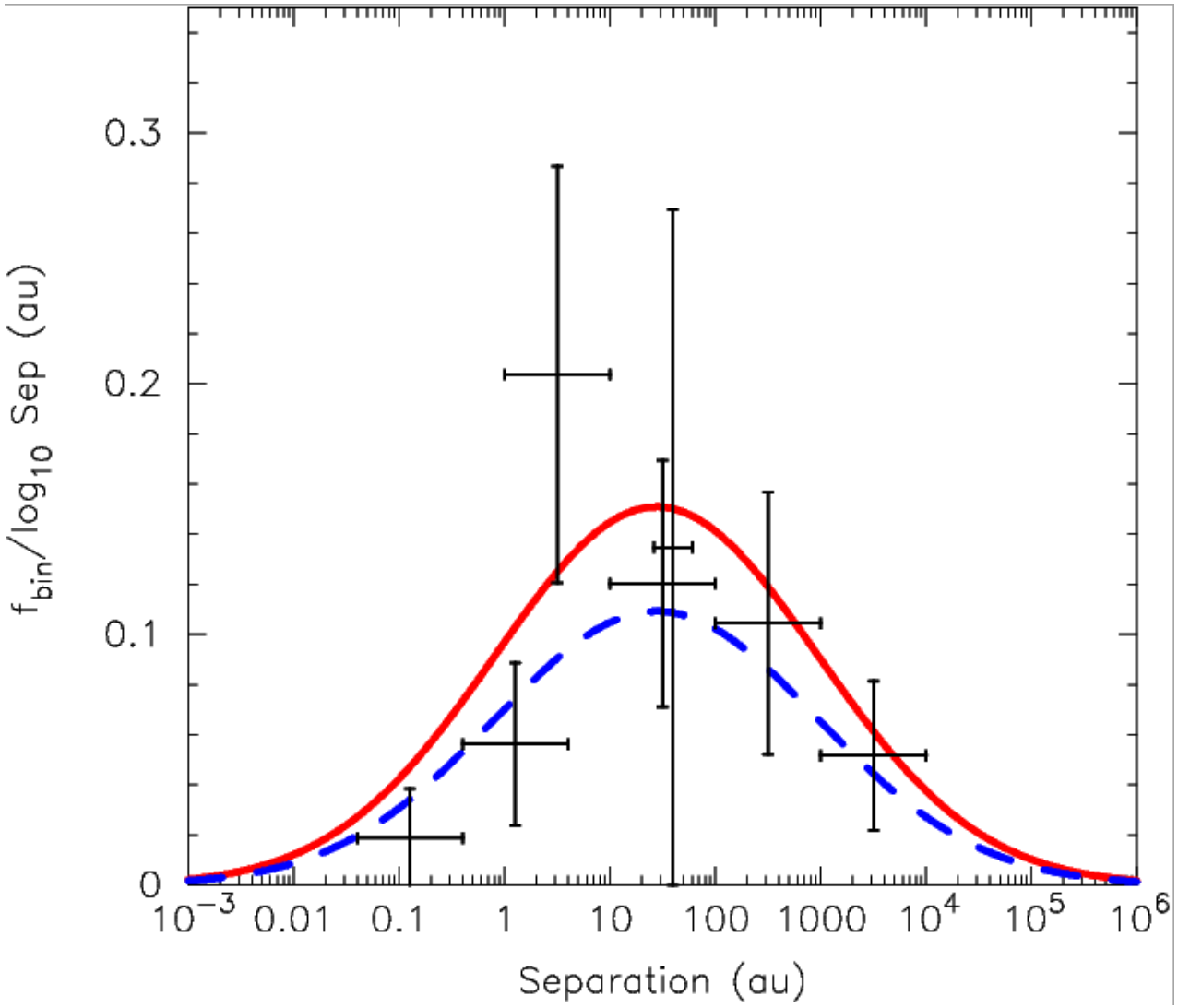
Binary Stars: the Field

- Fischer & Marcy (1992) collated data from several sources
- M-dwarfs binary fraction 40%
- Log-normal separation distribution???



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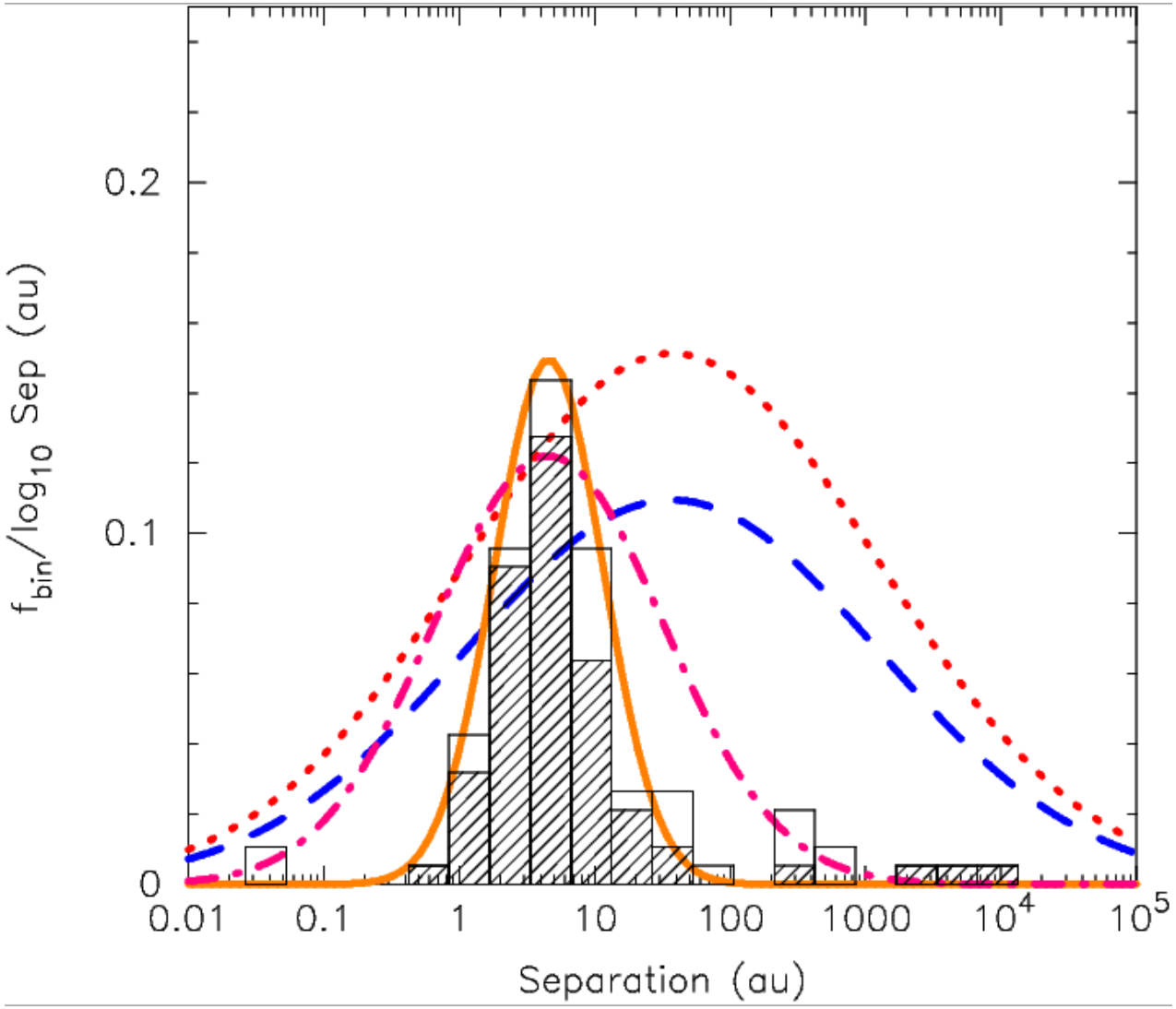
VLM/BD-BD Binaries

- Evidence of a discontinuity between stars & BDs (Thies & Kroupa 2007)?
- f_{bin} = 0.15, or 0.26?
- Two fits to the separation distribution: Basri & Reiners 2006, or Thies & Kroupa 2007
- Can an initial separation distribution be dynamically modified to match the observations?



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Simulation Set-Up

- N-body simulations (no gas); 10 Myr
- 2000 stars and VLM objects
- Distribute mass in a Plummer sphere with characteristic half-mass radius
- Plummer sphere is a good approximation for Orion today; however, many young clusters (e.g. Taurus-Auriga) appear to be very substructured
- Choose masses from VLMB archive
- Assume an initial binary fraction (50%, 25%, 15%)
- Assume a separation distribution (DM91, TK07, or VLMB archive)

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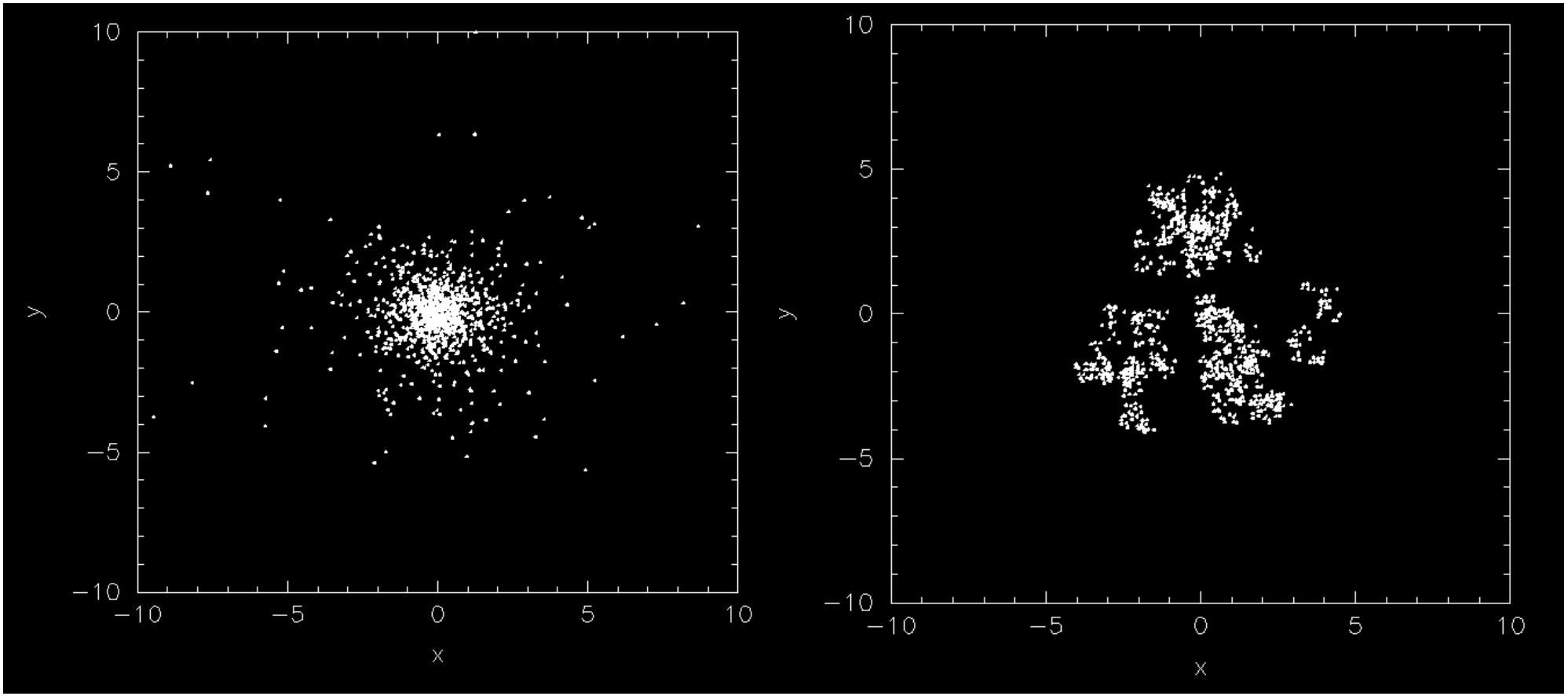
Simulation Set-Up



(a) Plummer

(b) fractal

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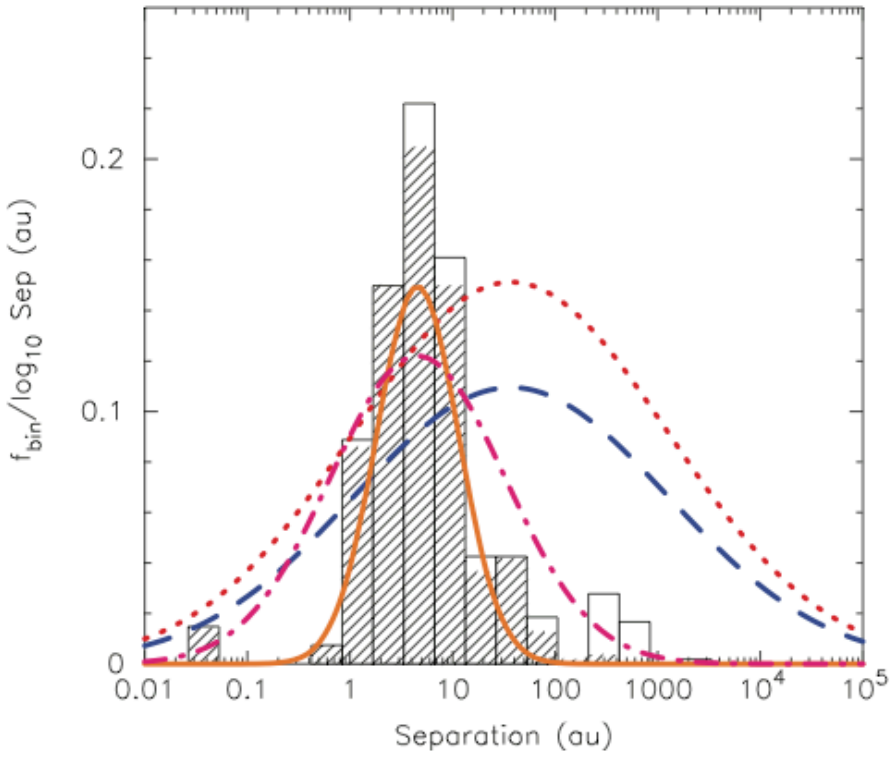
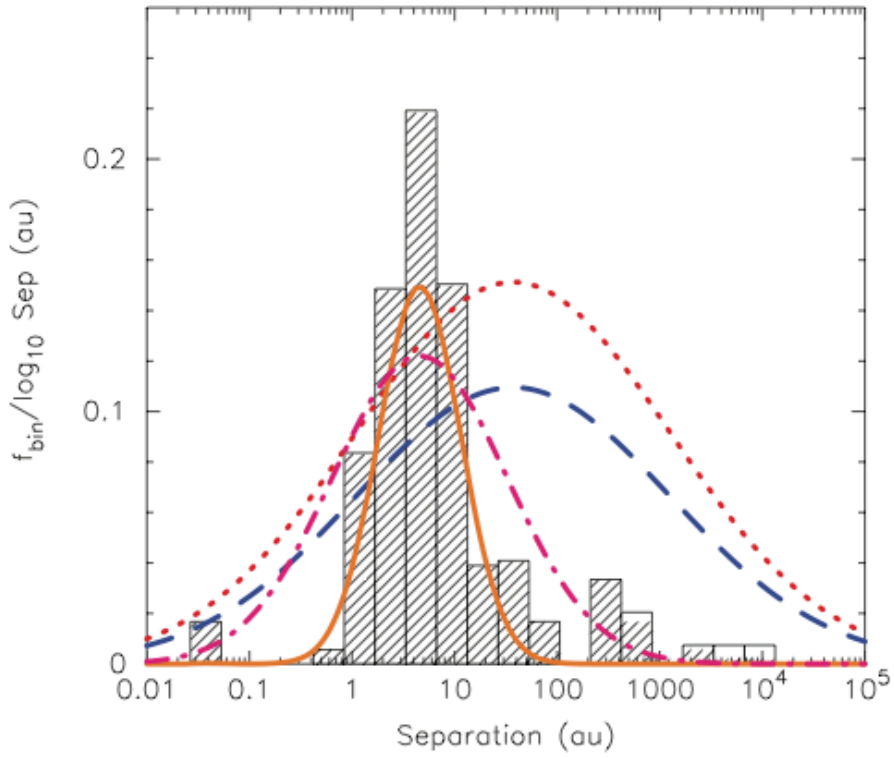
VLMB archive, f_{bin} = 25%



(a) $r_{1/2} = 0.1\,\mathrm{pc}$



(b) $r_{1/2} = 0.8\,\mathrm{pc}$

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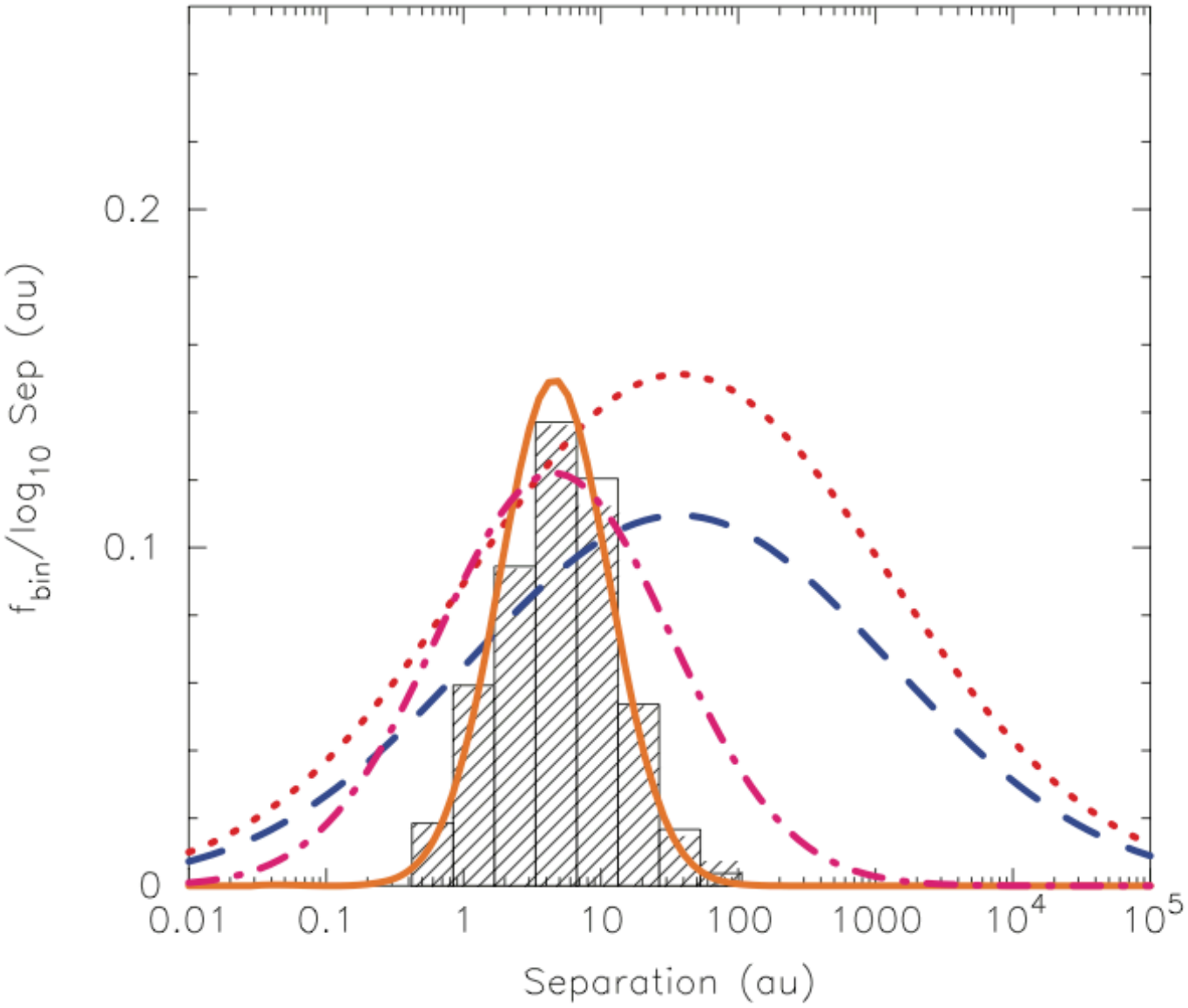
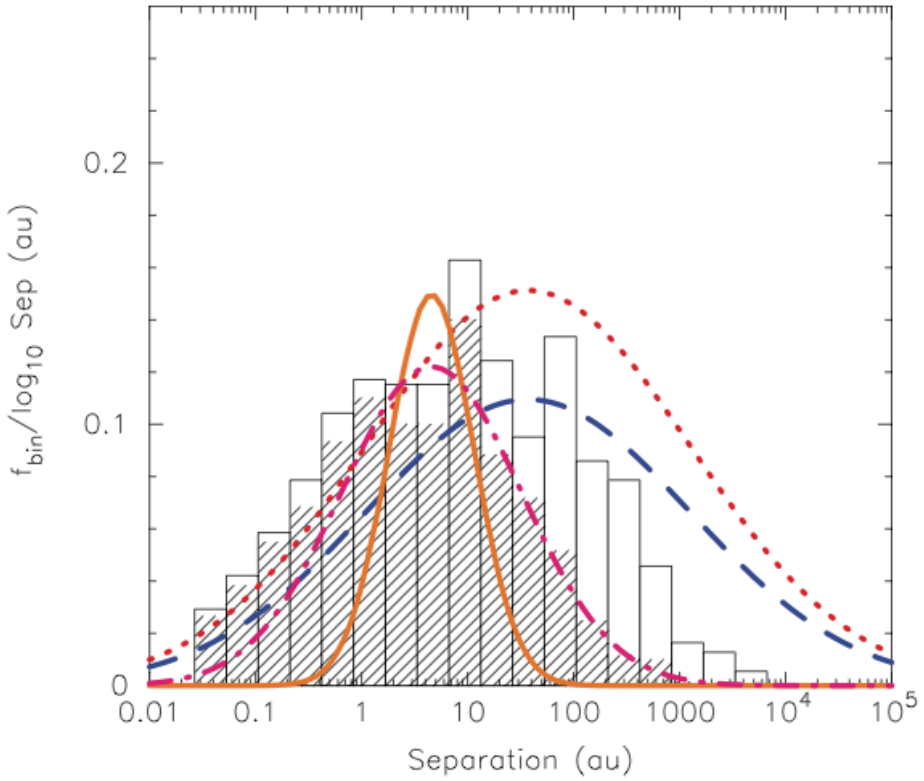
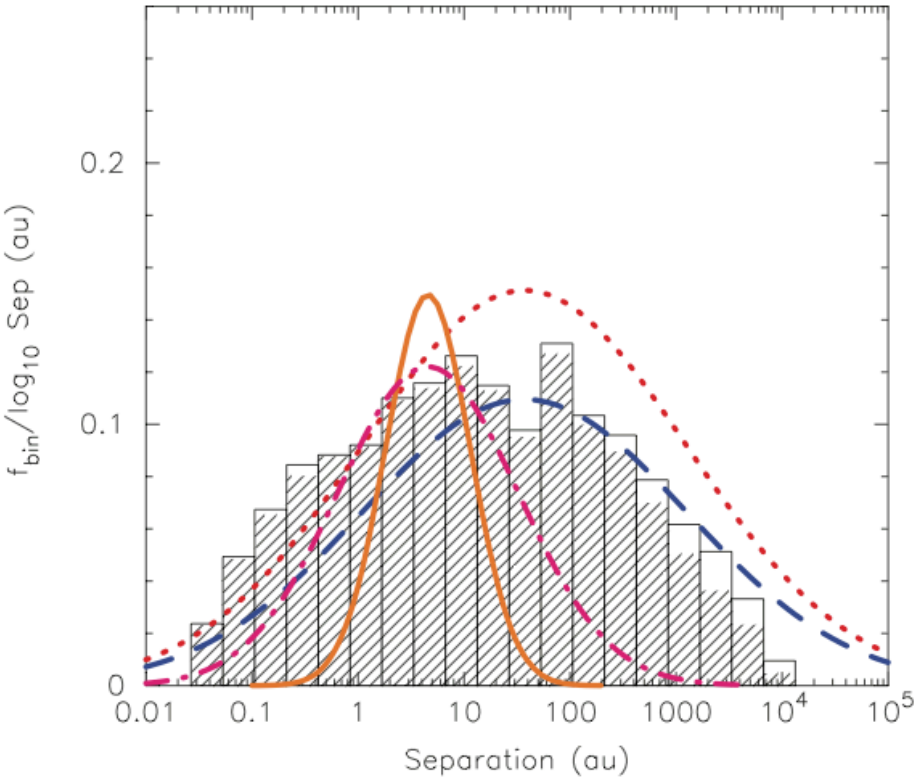
Thies & Kroupa 2007, f_{bin} = 15%



Duquennoy & Mayor 1991, f_{bin} = 50%



(a) $r_{1/2} = 0.1\,\mathrm{pc}$



(b) $r_{1/2} = 0.8\,\mathrm{pc}$

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Summary

- If all VLMBs form in dense clusters (unlikely – see Eli Bressert's talk), then a stellar-like population can be processed to the Basri & Reiners (2006) distribution
- Dynamics cant explain why VLMB separation distribution is different to that of stars
- However, recent observations (Bergfors et al 2010) seem to suggest the M-dwarf separation distribution sits somewhere between that for the G-dwarfs and the VLMBs
- Details in Parker & Goodwin 2011, MNRAS, 411, 891

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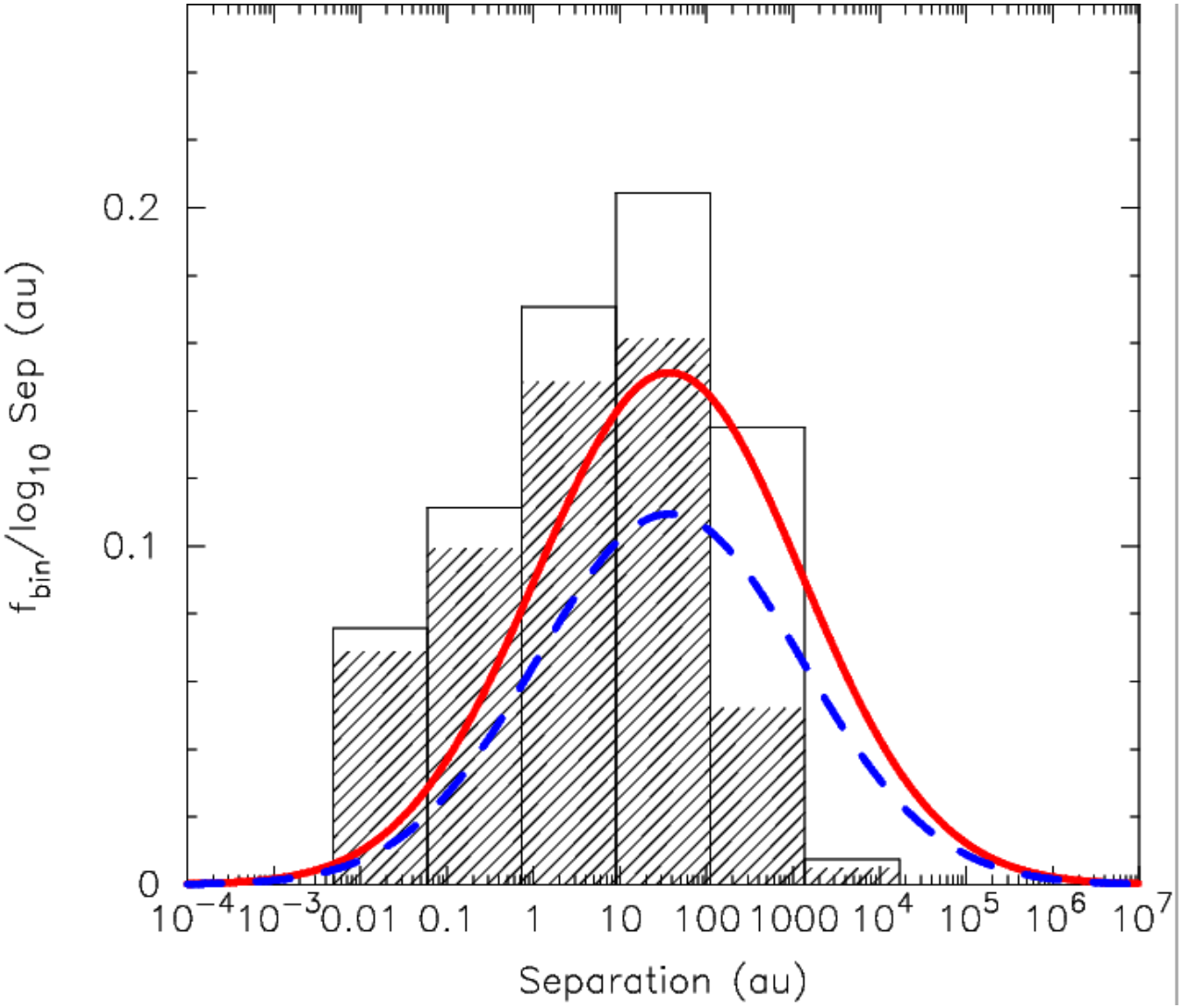
Separation Distribution

- Over-production of low separation binaries
- Wide field binaries not recovered



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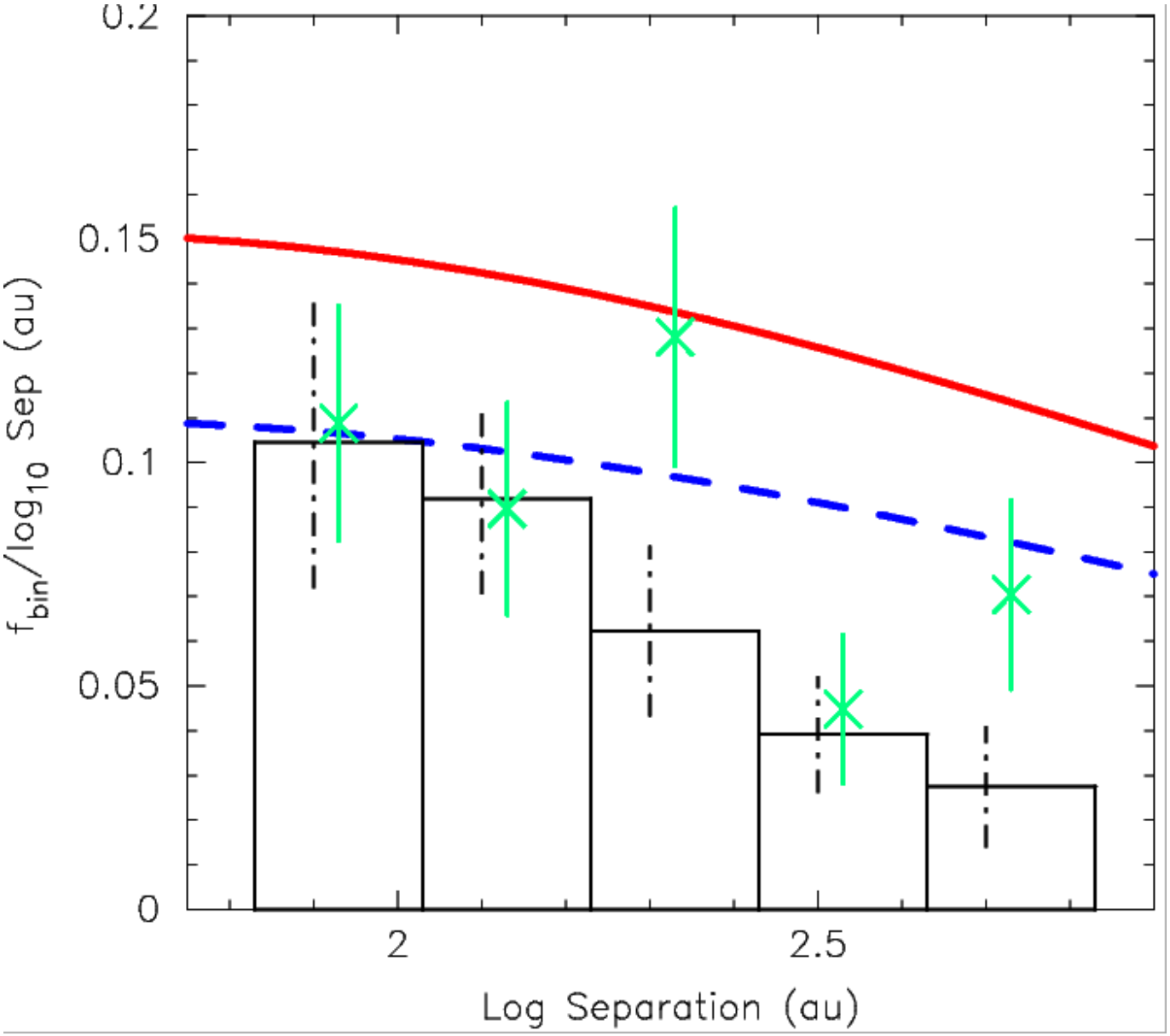
Comparison with Orion



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Alternative Hypothesis

"Star clusters are not dense enough to process an initial binary population. Orion formed with its current density ($r_{1/2}$ = 0.8pc), and the field population is the direct product of the star formation process"

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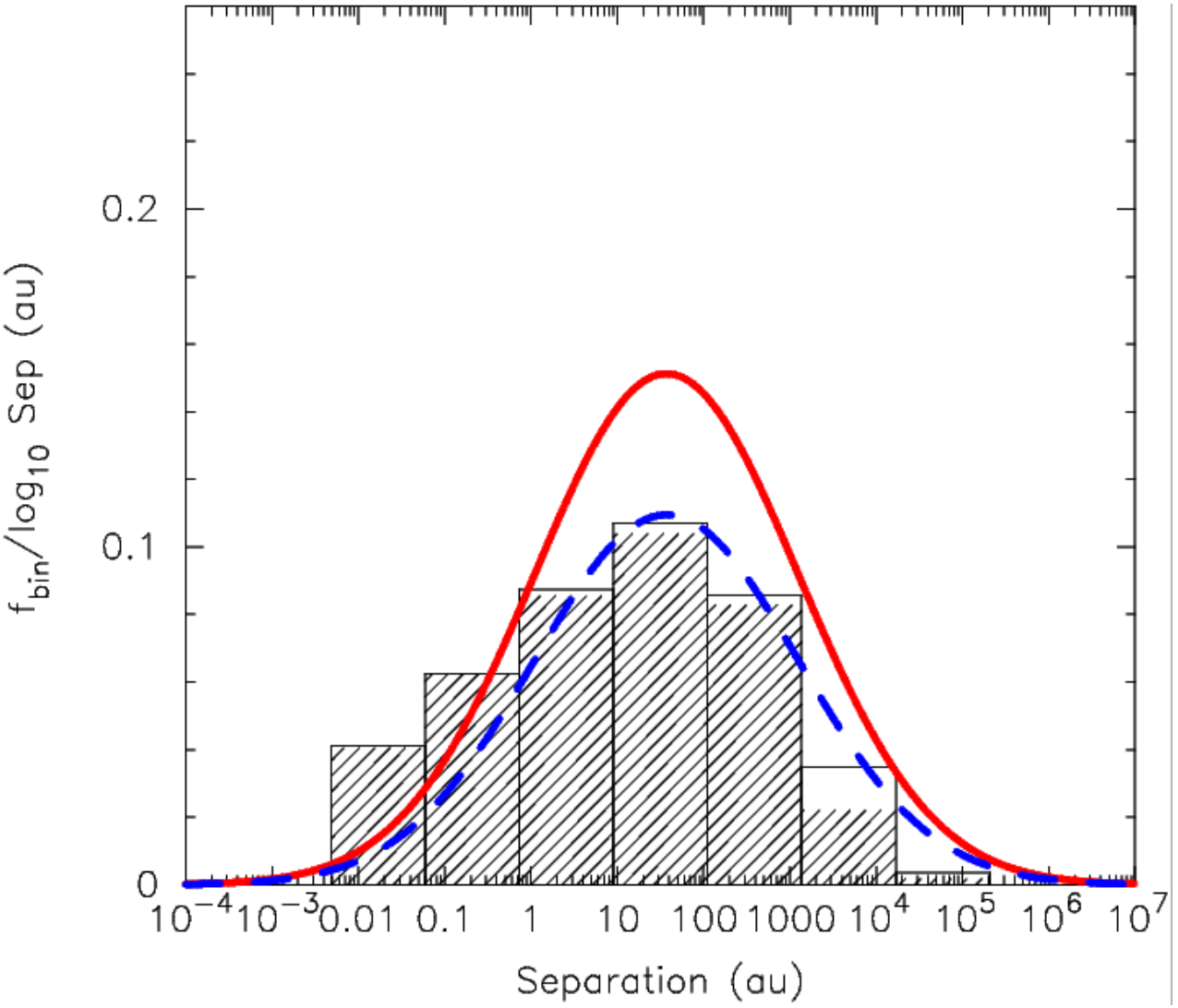
Initial distribution = Field

- Initial half-mass radius = 0.8pc
- Wide field binaries still not recovered



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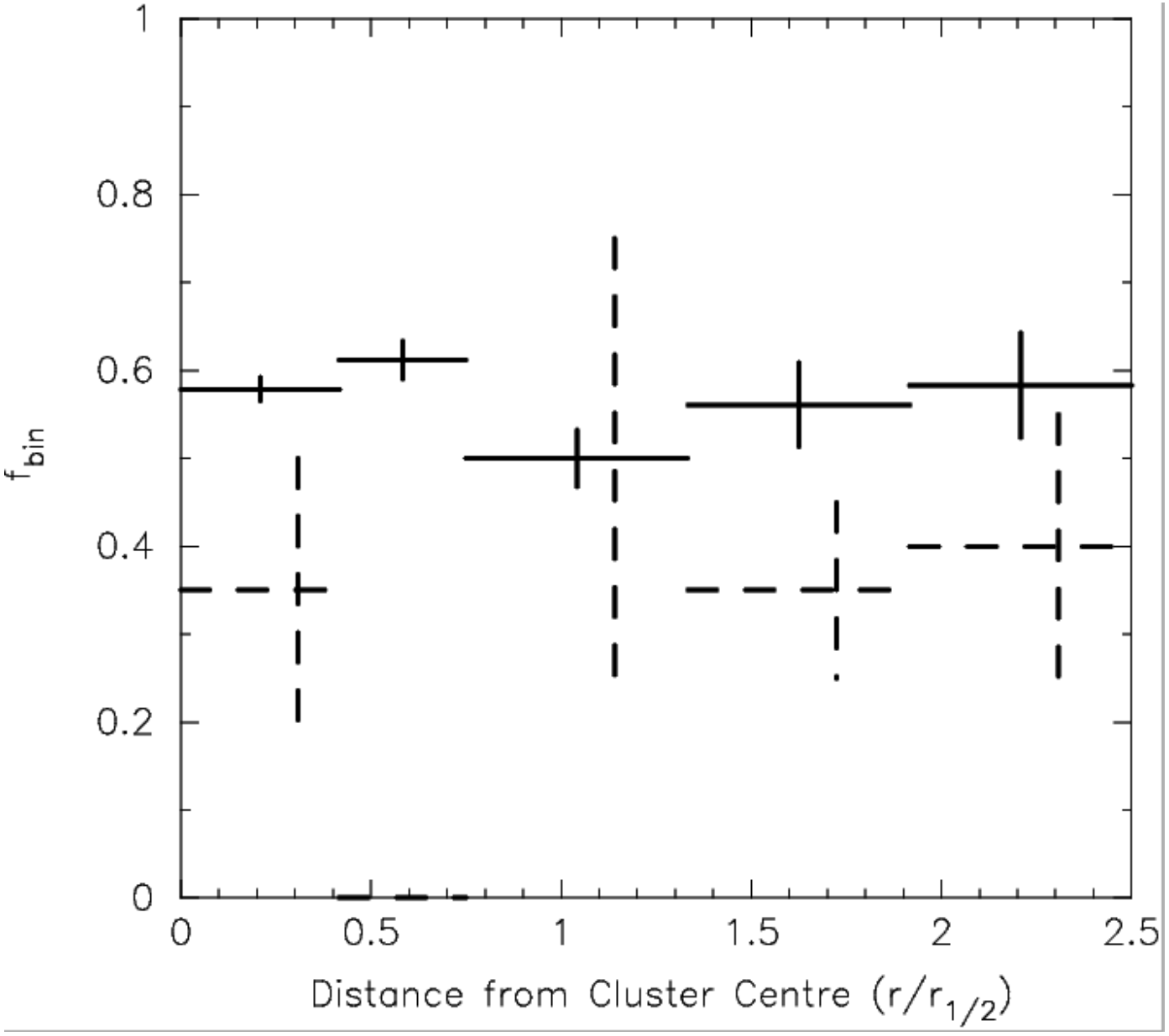
Dynamical Mixing



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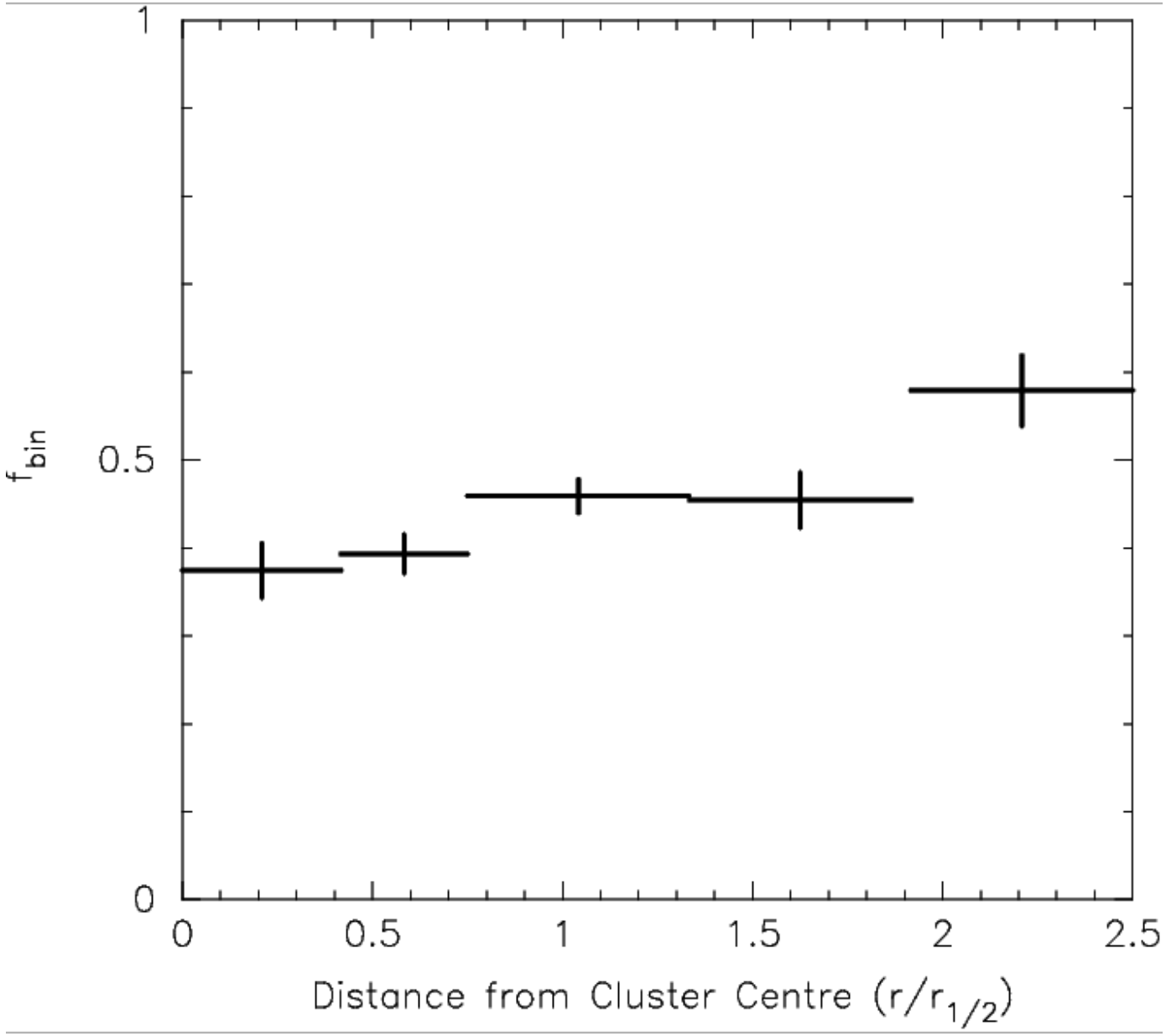

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Star Formation Constraints

- Not possible for stars to form from a single population
- Clusters with different densities process populations differently
- Field population is the sum of various star forming modes and regions (c.f. Brandner & Köhler 1998)
- See Parker, Goodwin, Kroupa & Kouwenhoven (2009, MNRAS, 397, 1577)
  - Also see Kouwenhoven, Goodwin, Parker, Davies, Malmberg & Kroupa (2010, MNRAS, 404, 1835)

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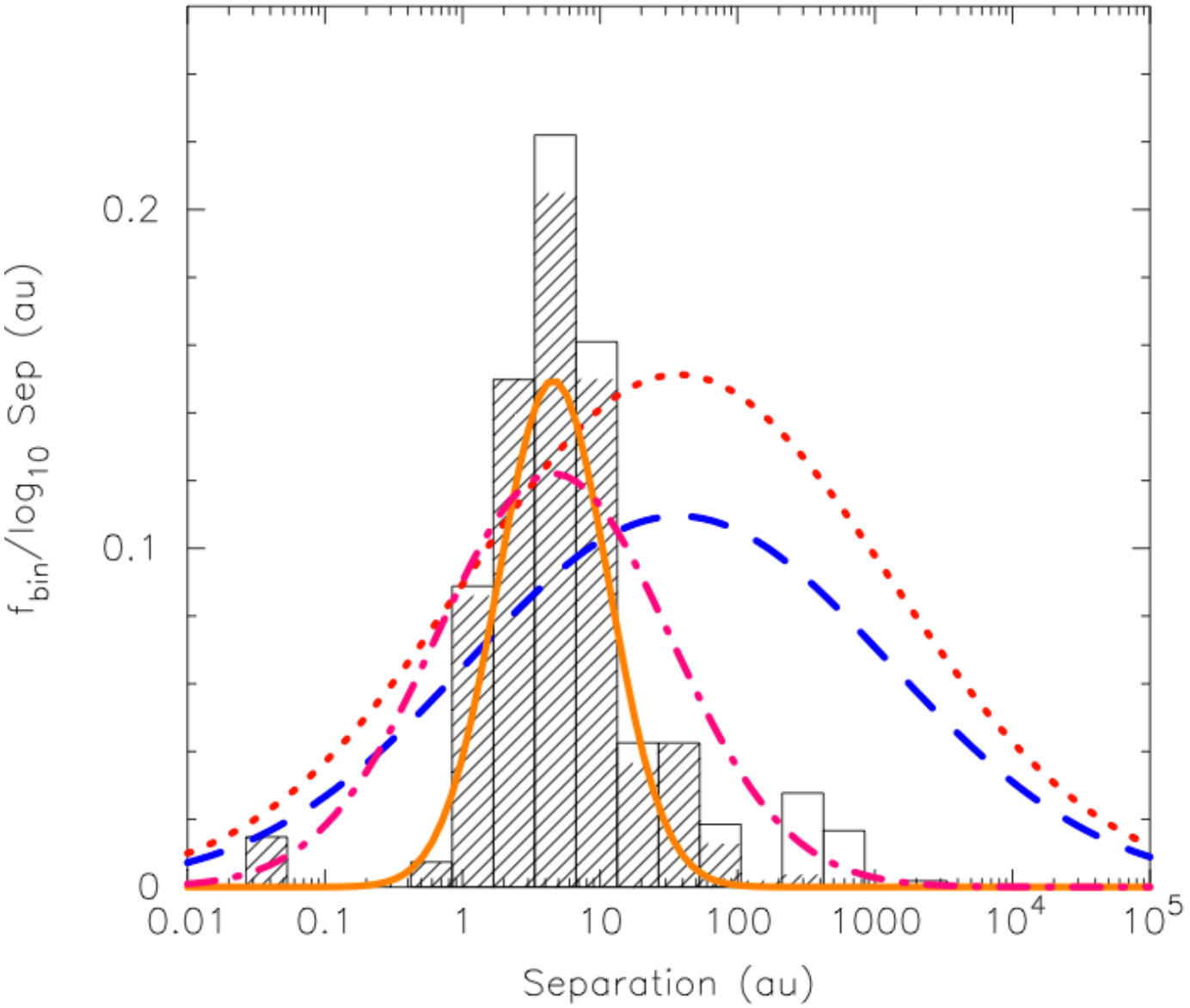

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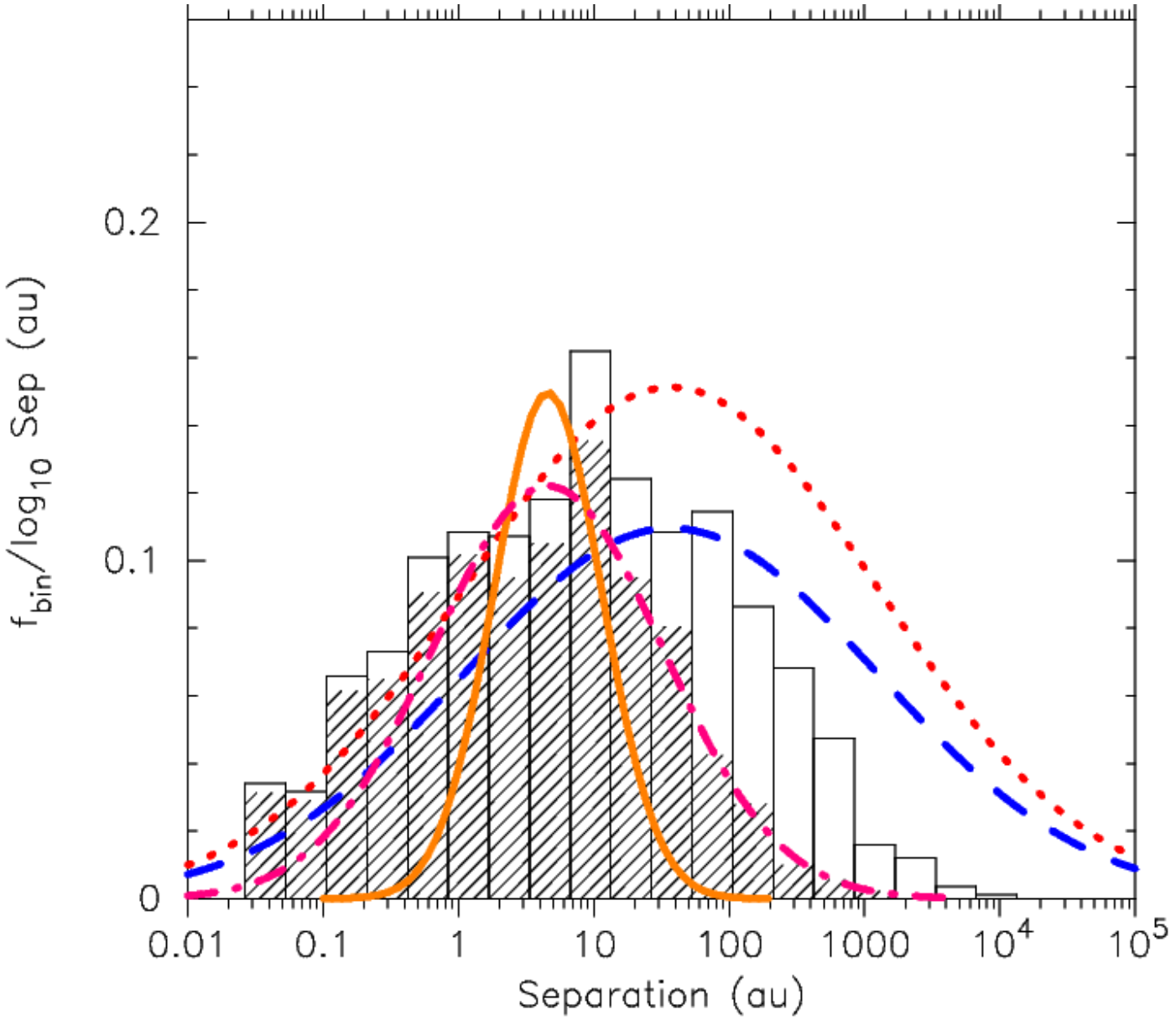

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BD Formation Constraints

- Unclear from dynamical simulations whether they are a different population
- In order to match the observed separation distributions, would probably have to form with a binary fraction of 50%
- Details in Parker & Goodwin (2010, MNRAS accepted, arXiv: 1009.3110)

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The Kozai Mechanism

- Kozai (1962) quantified how the orbits of inclined asteroids were affected by Jupiter
- If the orbit is inclined by more than 39.23º, a cyclical exchange of angular momentum to the asteroid occurs
- Causes eccentricity of the orbit to vary periodically
- Same effect predicted for planetary systems orbiting a binary component

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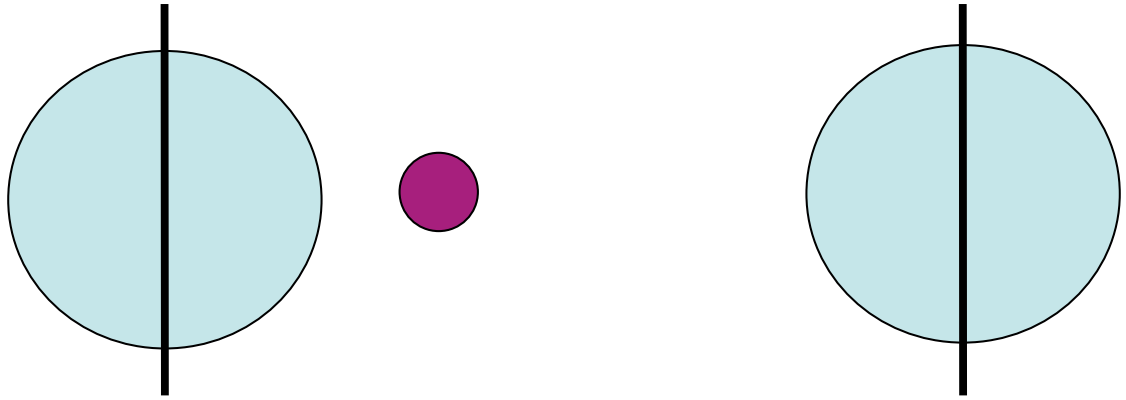
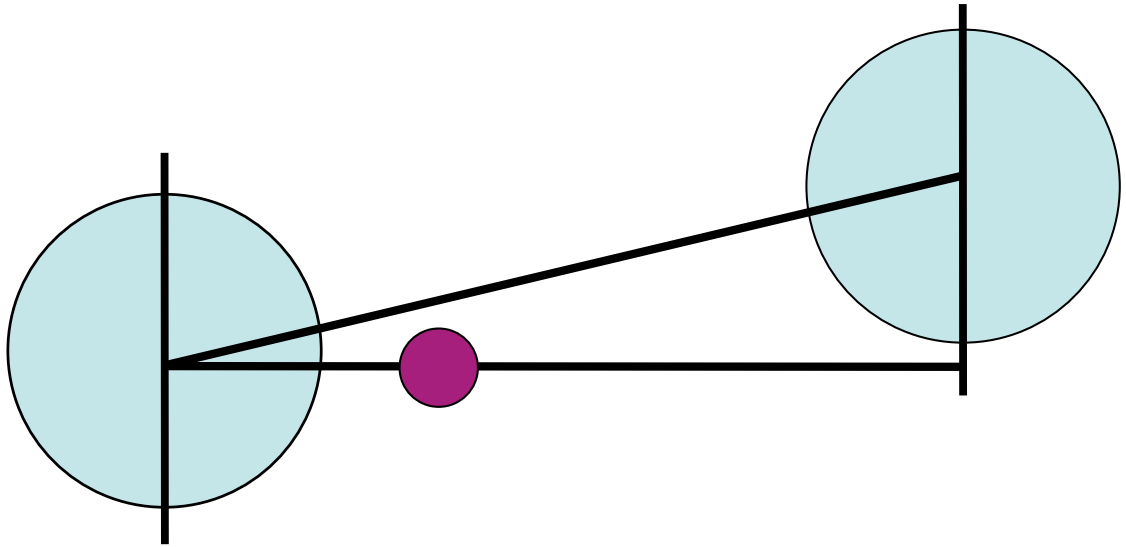
The Kozai Mechanism

Assume stars form in same plane:



If inclination angle exceeds 39.23°,
Kozai mechanism can be invoked



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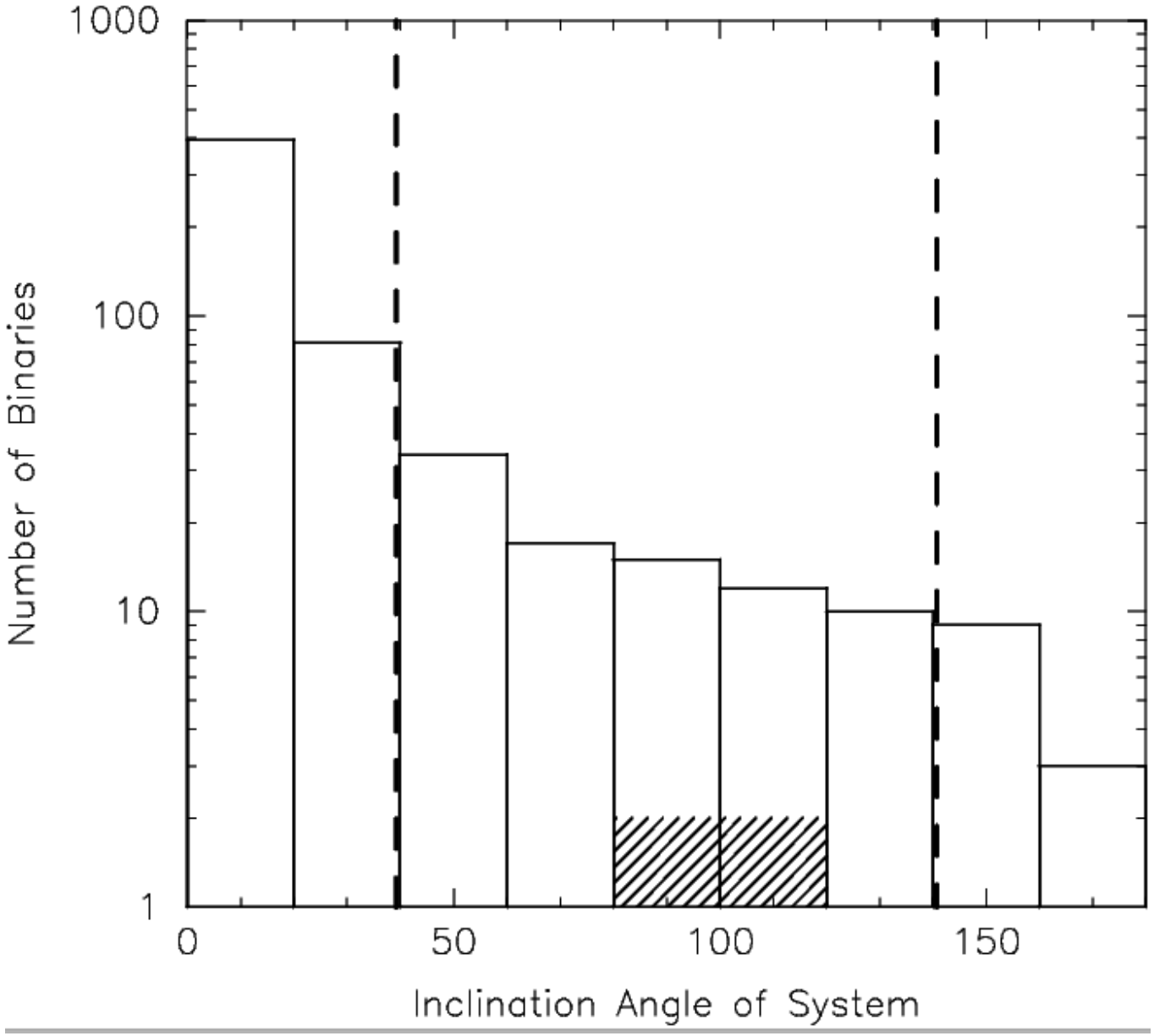
The Kozai Mechanism



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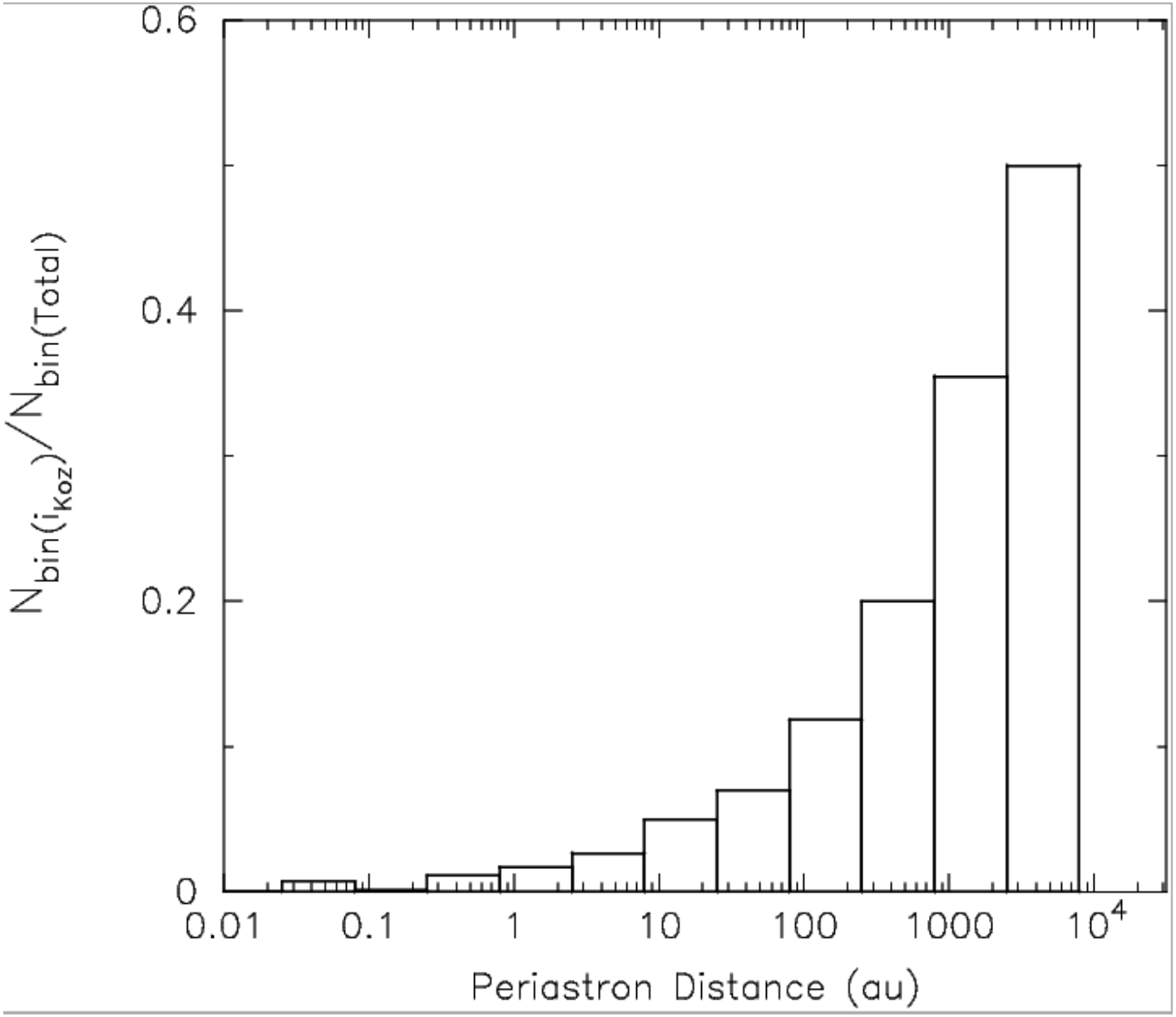

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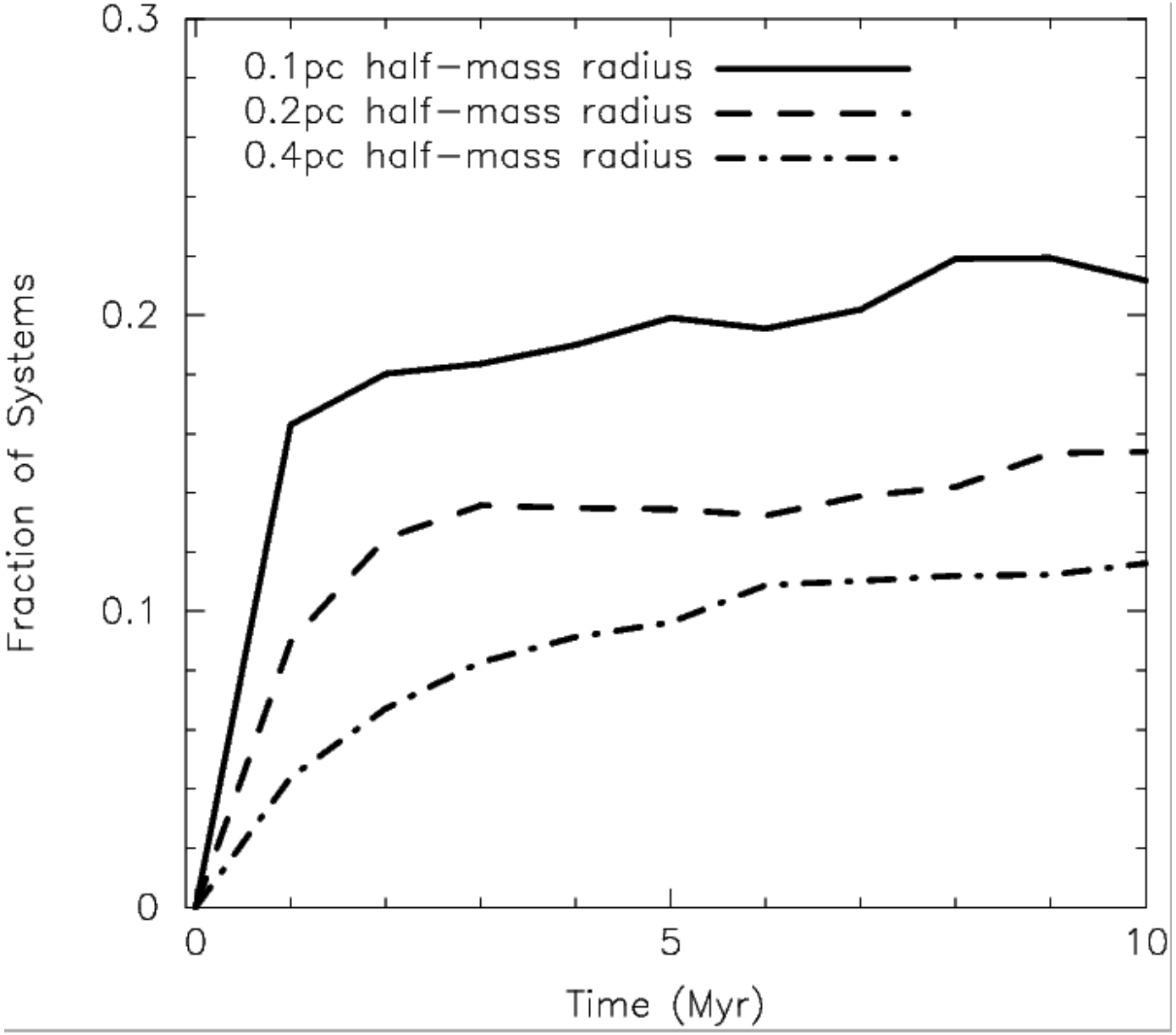
The Kozai Mechanism



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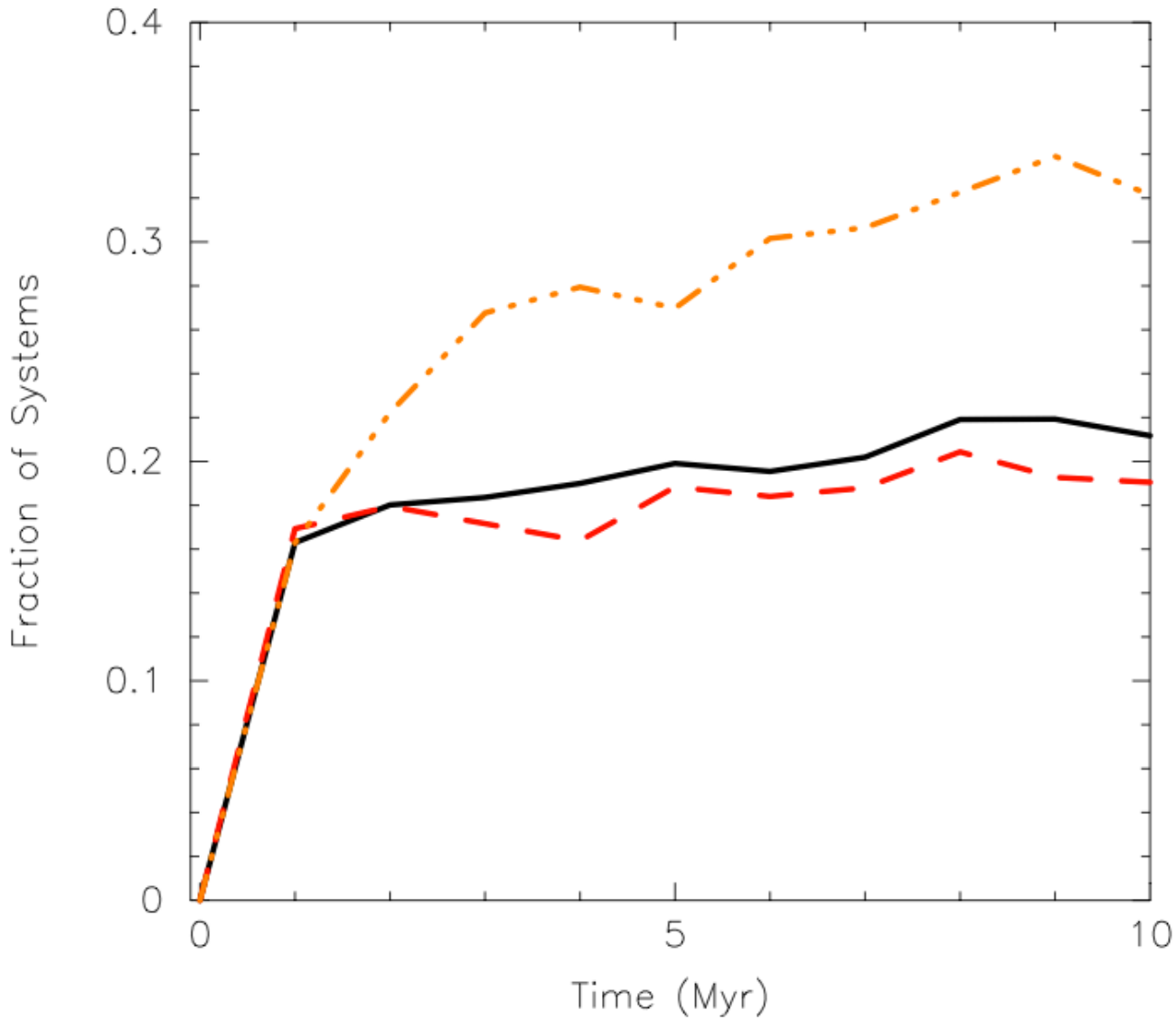
The Kozai Mechanism

- R_H = 0.1pc
- G, A and F stars affected more than M-dwarfs



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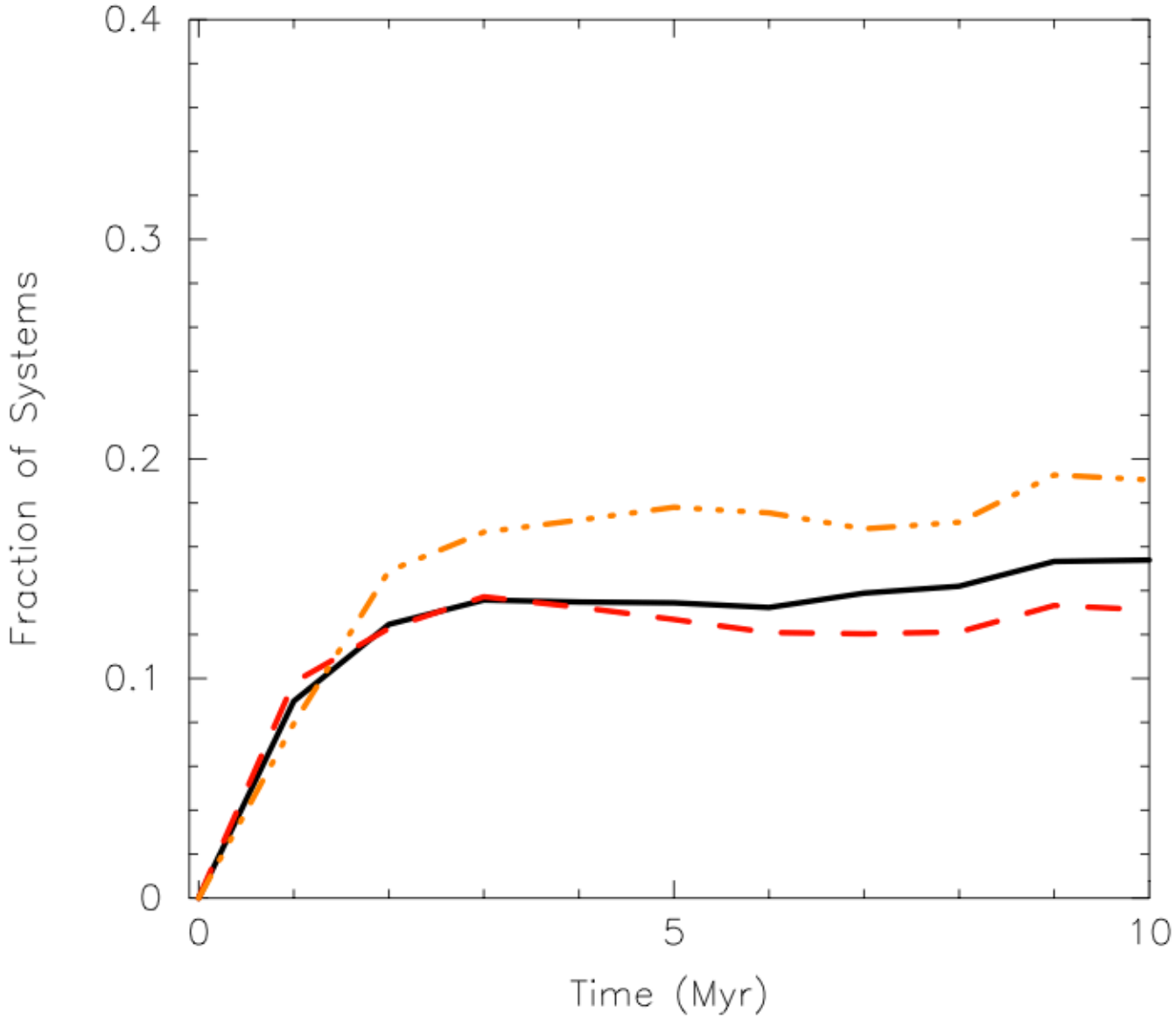
The Kozai Mechanism

- R_H = 0.2pc
- G, A and F stars affected more than M-dwarfs



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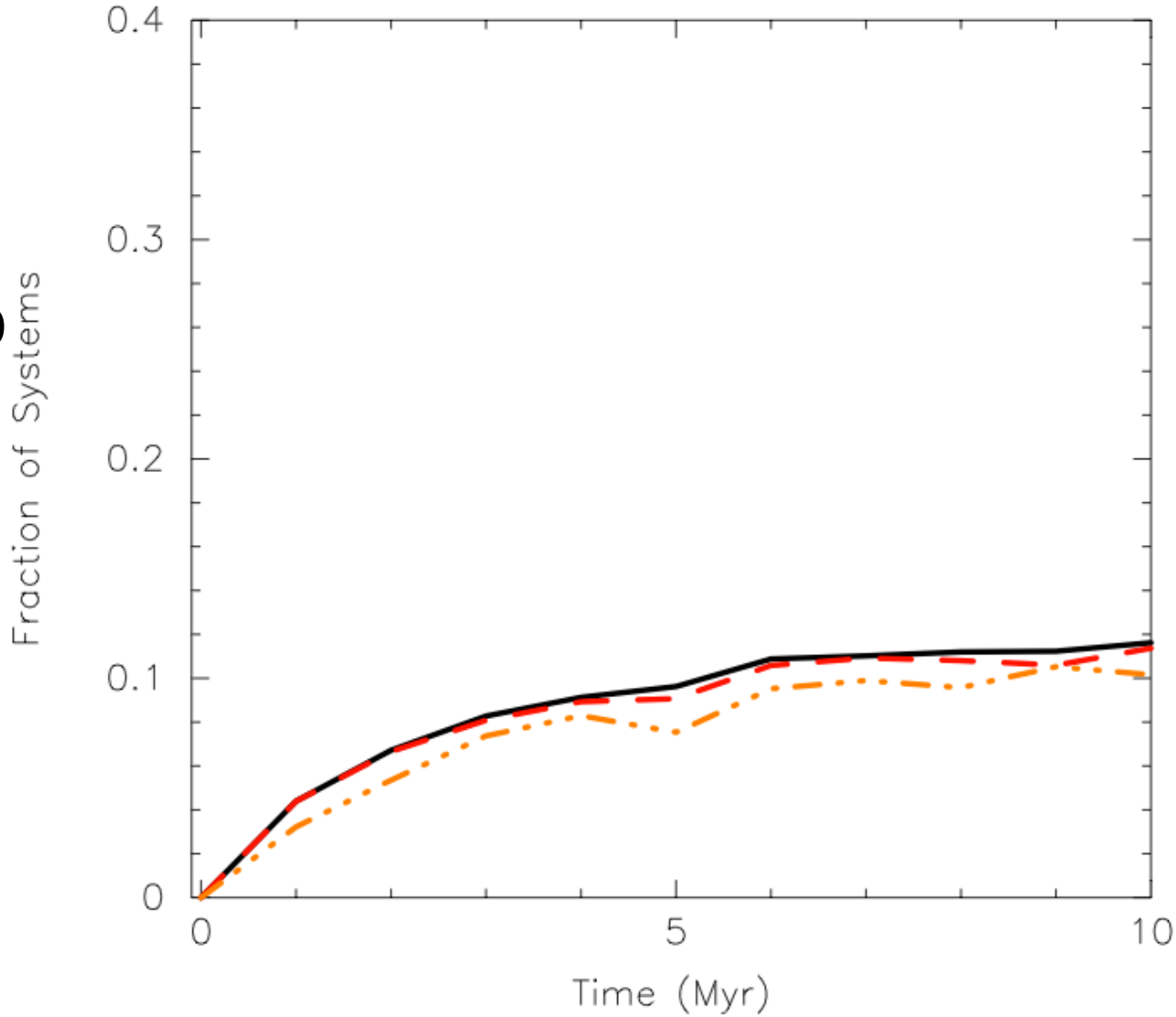
The Kozai Mechanism

- R_H = 0.4pc
- Mass dependence no longer there



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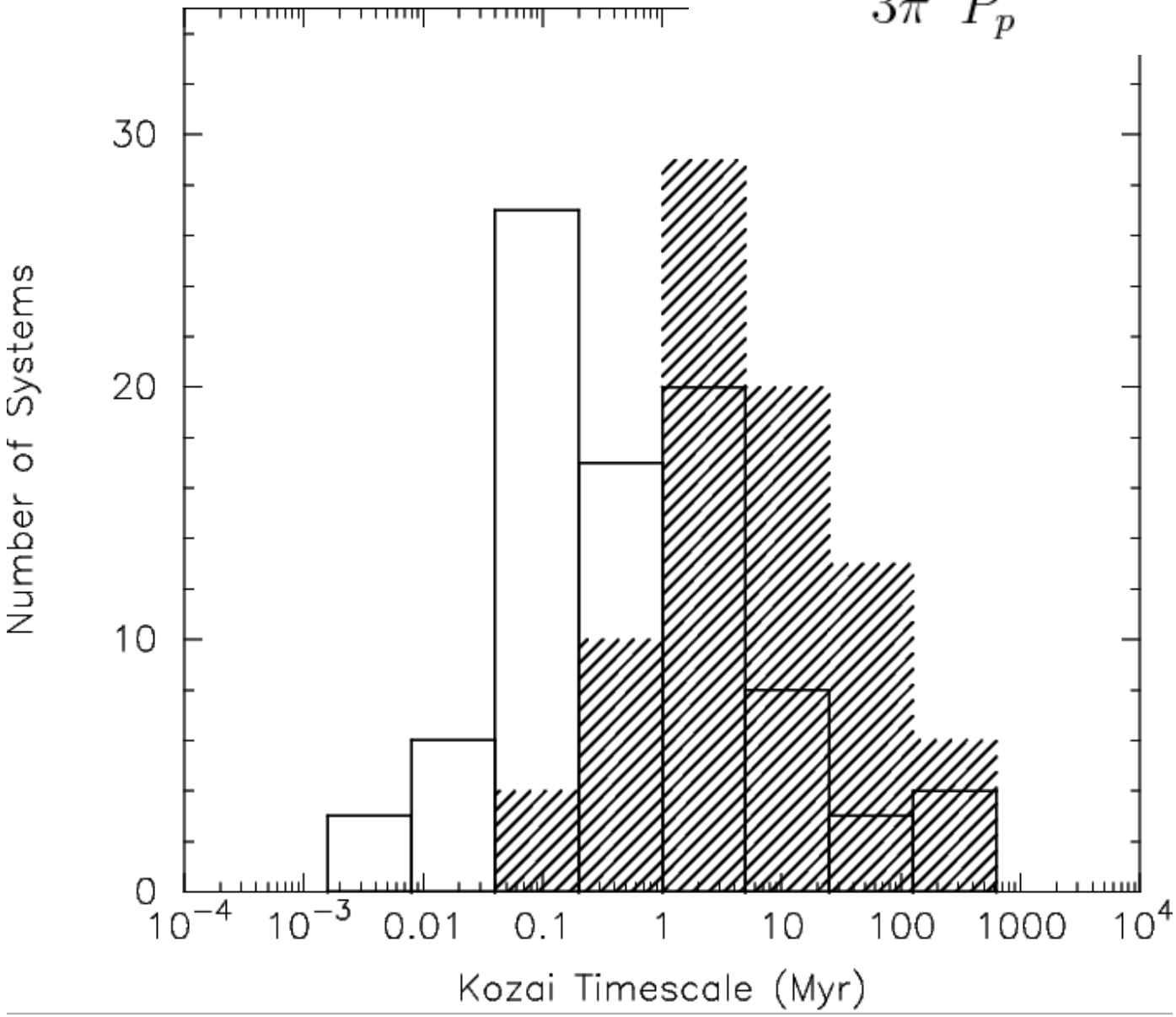
The Kozai Timescale

$$\tau_{\rm Koz} \simeq \frac{2}{3\pi}\frac{P_{\rm bin}^2}{P_p}(1-e_{\rm bin}^2)^{3/2}\frac{m_1+m_2+m_p}{m_2}$$



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Planet Formation Constraints

- Kozai mechanism likely to occur in young planetary systems orbiting binary stars
- Mechanism leads to eccentricity fluctuations in orbit (Malmberg, Davies & Chambers 2007; Malmberg & Davies 2009, Malmberg, Davies & Heggie 2010)
- Planets in 100au+ binary systems most susceptible
- See Parker & Goodwin (2009, MNRAS, 397, 1041) for further info

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Summary

- Studying the dynamical interactions in star clusters places strong constraints on the star formation process
- Most stars form in clusters - therefore, dynamical evolution will also affect young planetary systems
- Future work:
  - include gas potential in simulations
  - model mass distribution as a fractal
  - model wider mass range of clusters (e.g. R136/ Westerlund 1) on GPUs
  - Add planets directly to simulations