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Very Low Mass Stars in Binaries: a Theoretical Look

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Why do stars come in pairs?

Approx. 2 out of every 3 G stars are members of binaries

[e.g. Duquennoy & Mayor 1991, Halbwachs et al. 2003]

Multiplicity is even higher among pre-main sequence stars

[e.g. Duchene 1999, Reipurth 2000]

***** But what about K, M, L, T dwarfs? *****

Other questions:

- Substellar IMF
- Fraction of low-mass stars with discs
- Is formation mechanism of brown dwarfs different?

To address this issue: Series of simulations of low-mass SF in small (5M☉) clouds ...

- Many stars and BDs formed: allows direct comparison with observations of stellar multiplicity
- Test of dependence of SF on initial conditions
- Investigation of the small-N cluster/ejection hypothesis
- Study time evolution of multiplicity

Model for Fragmentation of small Turbulent clouds

Numerical scheme: Smoothed Particle Hydrodynamics (SPH)

Initial conditions ⇨

- ***Spherical cloud***
- ***M = 5 M⊙***
- ***R = 1E+4 AU (≈0.05 pc)***
- ***ρi ≈ 1E-18 g/cc (≈ 2E+5 H2/cc)***
- ***Ti =10 K***
- ***Mj = 0.5 M⊙***
- ***tff ≈ 1E+5 yr***

Initial turbulent velocity field:

- Power spectrum $P(k) \propto k^{\alpha}$; $\alpha=[-3, -5]$, $k = 2\pi/\lambda$

- Mach number = 3.75

Collapsing blobs replaced by point masses

10 calculations with these initial conditions.
5 of each α

[Performed at UK Astrophysical Fluids Supercomputer Facility, UKAFF]

- Include opacity limit for fragmentation via barotropic equation of state:
- *Isothermal at low densities*
- *Adiabatic at densities higher than 1E-13 g/cc*
- Mass resolution ≈ few $M_{Jupiter}$
- Minimum binary separation ≈ few AU

Time evolution of multiplicity:

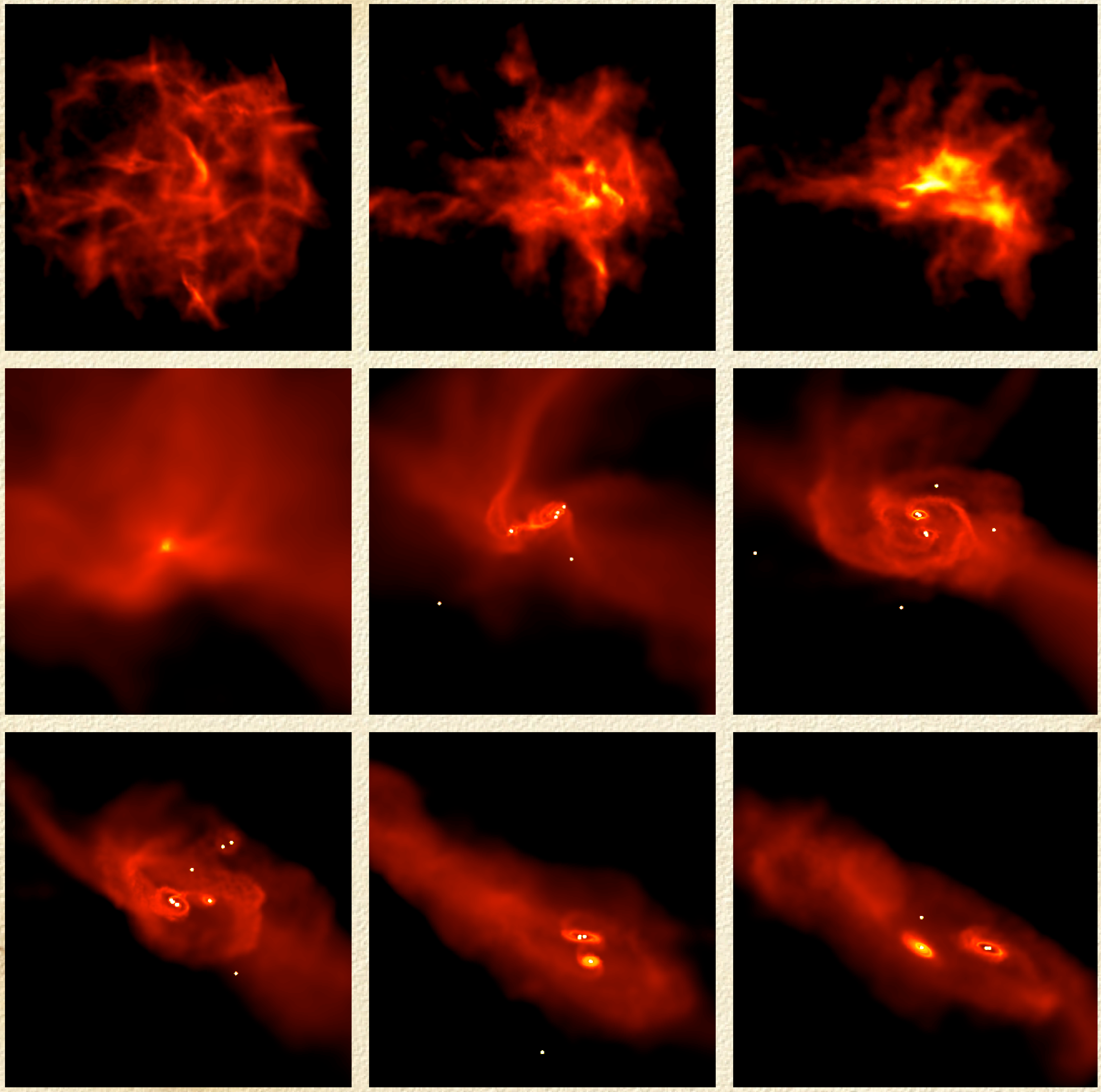
Hydro calculation for ≈ 0.5 Myr

- *Efficiency of ≈ 60%*
- *Star Formation has finished by then*
- *145 objects formed; ≈ 50% are BDs*

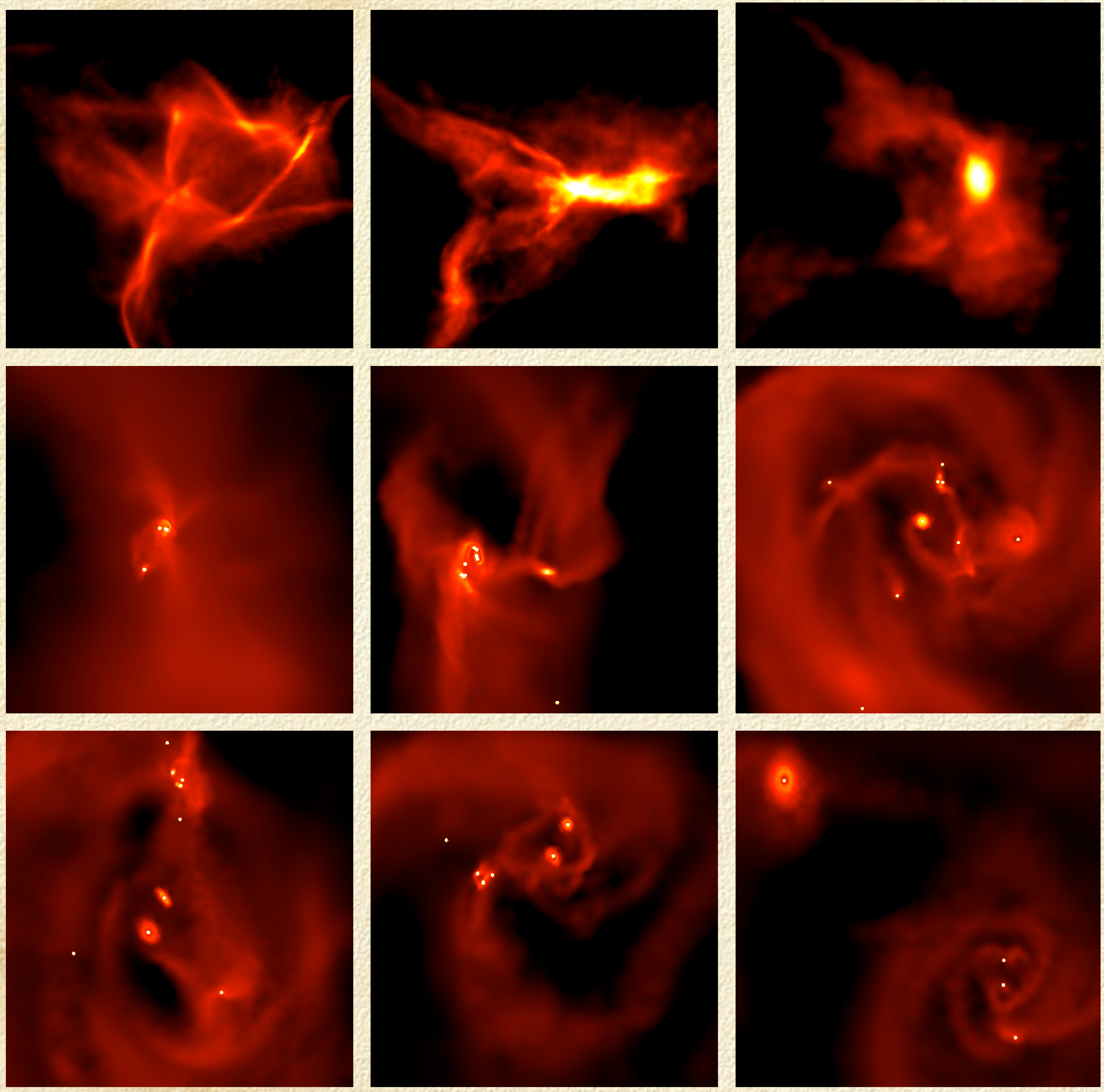
N-body follow-up of the stellar mini-cluster for 10 Myr

- *95% of multiple systems stable by then*

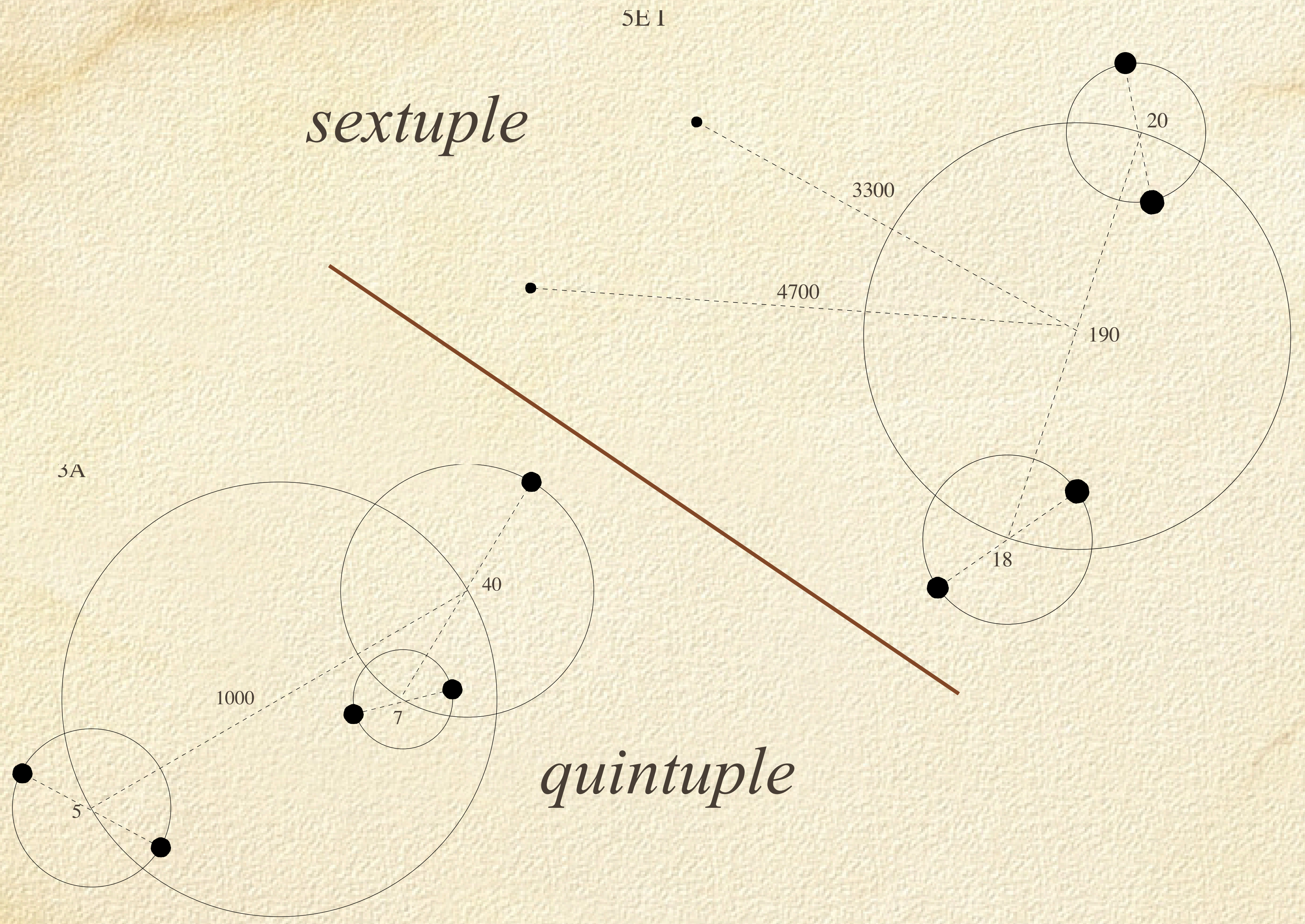
Evolution of typical α=-3 cloud



Evolution of typical α=-5 cloud



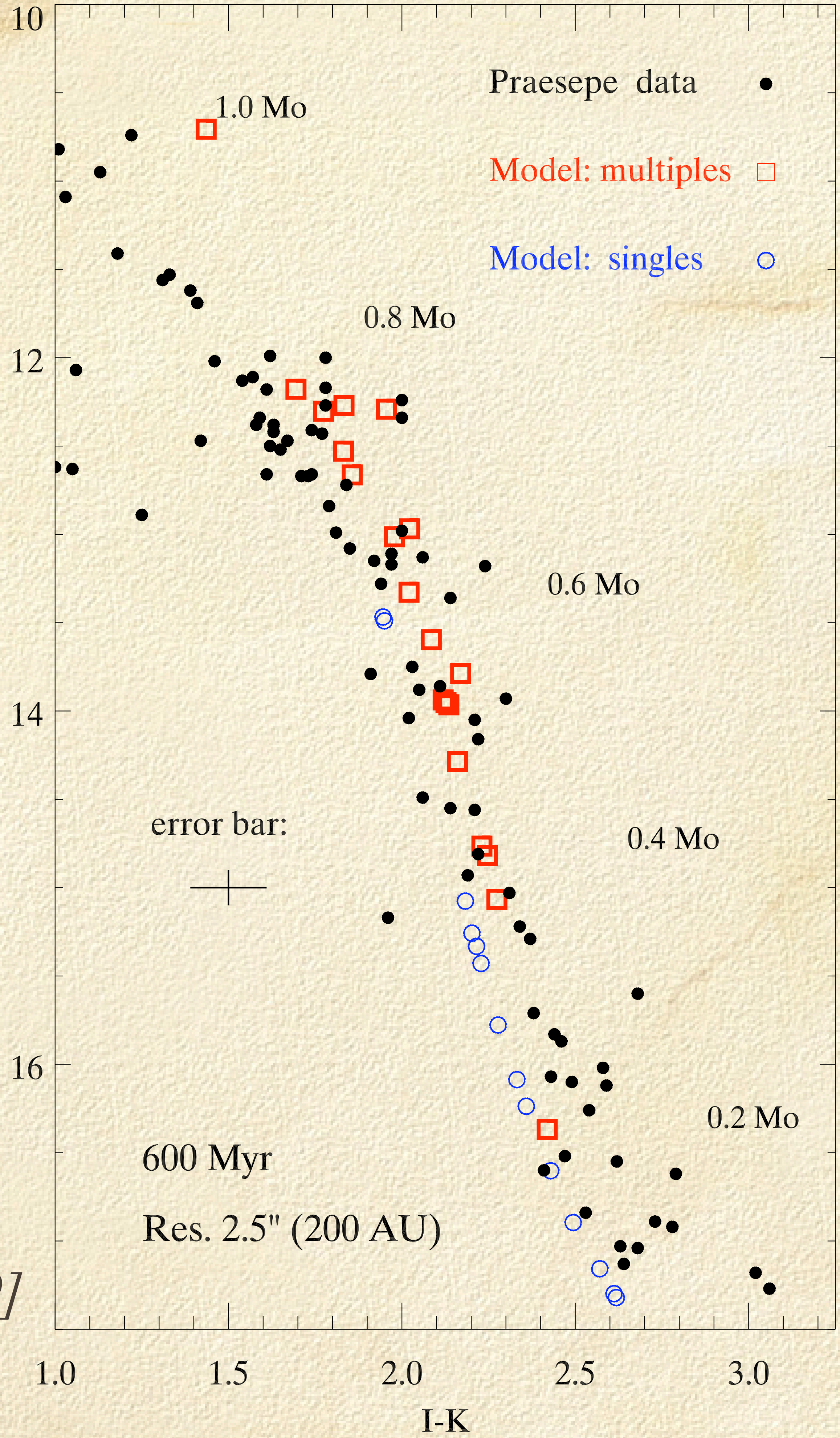
Results: Many high-order multiples initially



Multiple star formation major channel for SF in turbulent flows

Results: Comparison with real clusters

The width of predicted binary sequence ✓ with e.g. Praesepe, for masses above ≈ 0.3 Msun



[Præsepe data from Hodgkin et al. 1999]

Results: Time evolution of multiplicity

- First few 0.1 Myr $\Rightarrow$ 60% of stars and BDs in multiples

- After few Myr $\Rightarrow$ percentage down to 40%

- Companion frequency drops in time from ~1 to ~0.3:

    - *Internal decay of multiples*

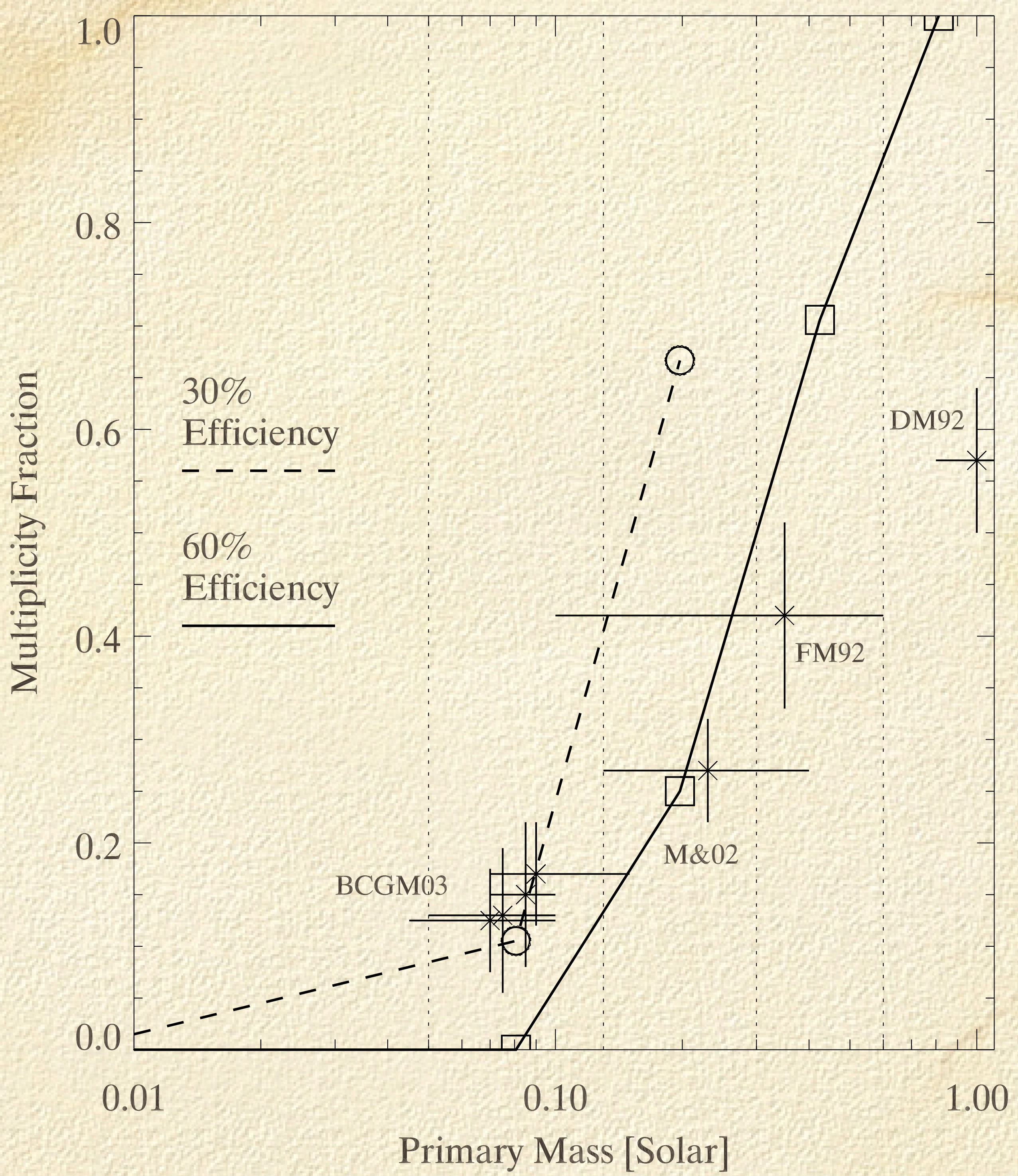
    - *Release of outliers to the field*

- This predicted trend in qualitative agreement with observations, e.g. Duchêne et al. 2004

Results: Multiplicity as function of primary mass

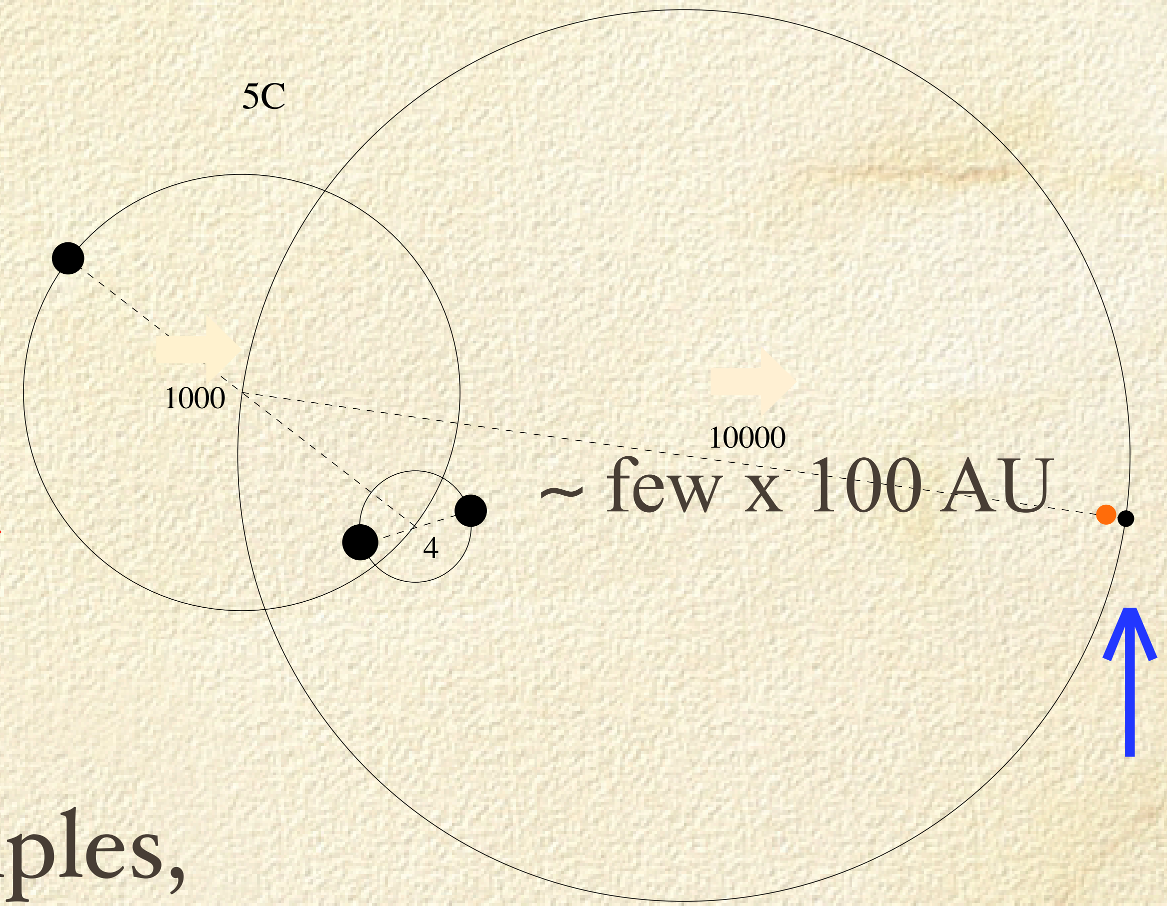
- Positive dependence of binarity on primary mass

- Problem forming binary VLMS and BDs



At least ~ 15% BF ; Martín et al. 03, Bouy et al. 03

Results: Where do we find brown dwarfs?



- First few 0.1 Myr, locked in unstable multiples

- After few Myr, large fraction released individually to field

- Few survivors in stable multiples, very often orbiting binaries/triples far away

- Thus, we expect that observed bound BDs at large separations are often orbiting a binary/triple, e.g. TWA 5AB (Brandeker et al. 2003)

Question: How to form systems with low binding energy?

- Simulations so far:
  * too much localised fragmentation
  * no SF in voids
  * a binary becomes dominant quickly
  * converging flows feed fast intersection zone

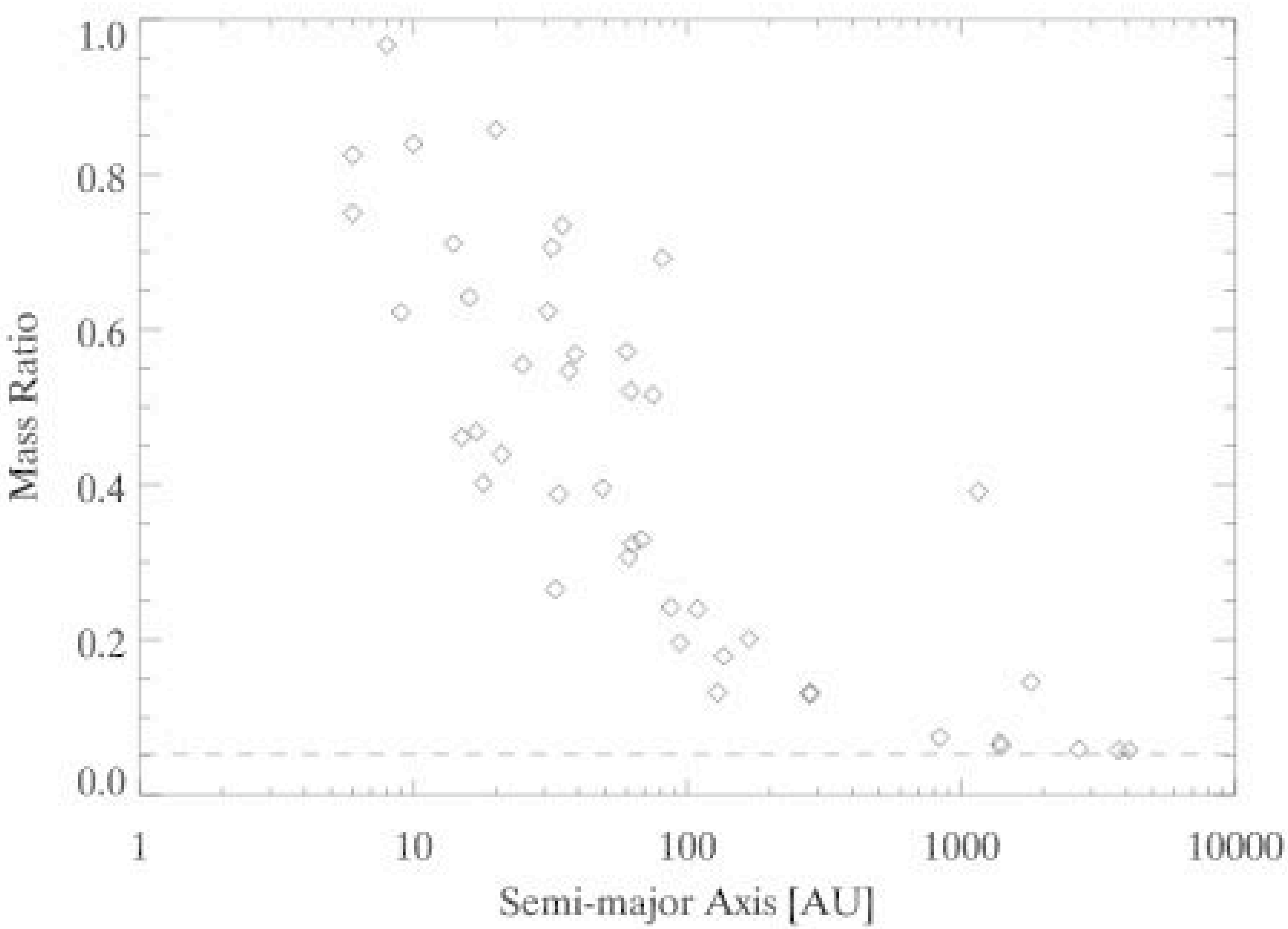
As a result:

- 3-body dynamics always present: many ejections

- low survival probability for systems with low binding energy

- problem of numerical scheme?
  "new" physics? eos?
  initial conditions? proper account of larger scales?

Some simple calculations are able to produce the desired `q' vs `a' relation, but how to get this with realistic initial conditions?



Conclusions

- `Turbulent' fragmentation results in formation of many binaries and higher-order multiples.

- Companion frequency decreases during first few Myr.

- BDs bound at large separations likely to orbit binaries

[Delgado-Donate, Clarke, Bate & Hodgkin, 2004, MNRAS, 351, 617]

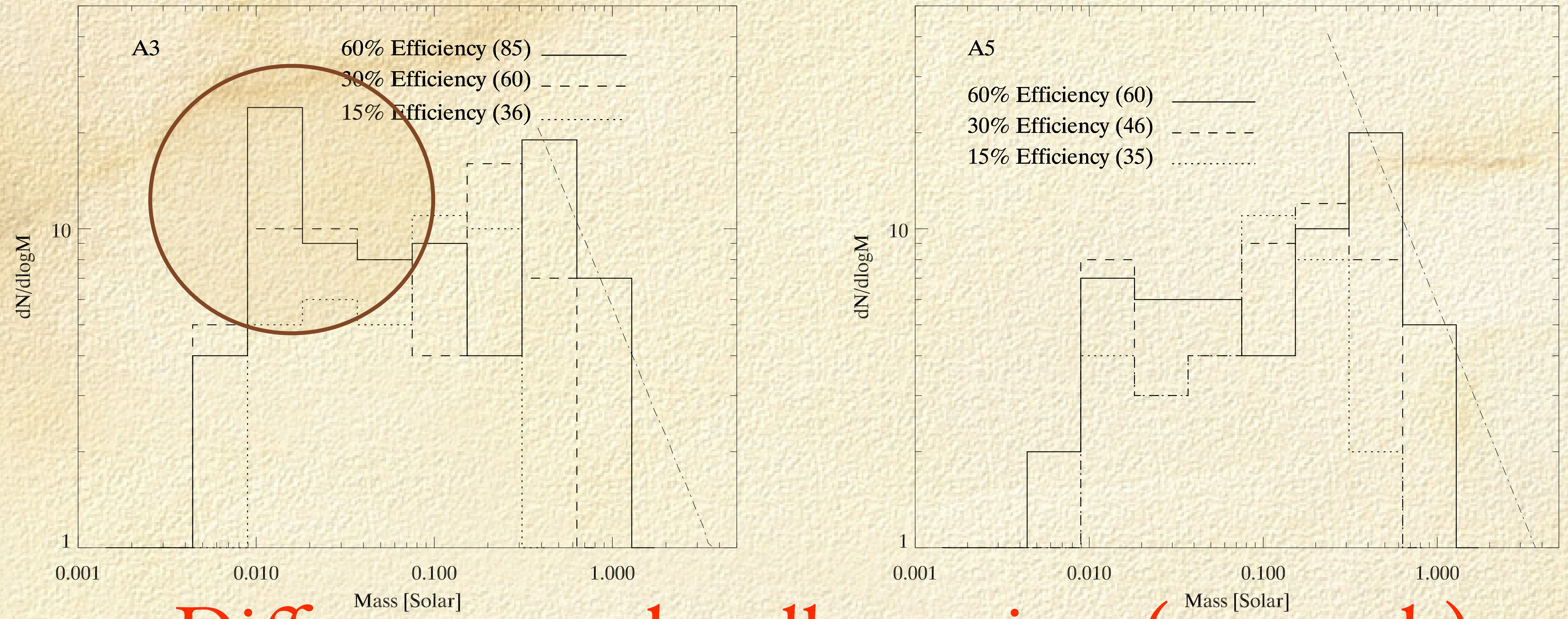
- Caveats: too few low-mass and wide binaries

[Clarke & Delgado-Donate, 2005, MNRAS, in prep.]

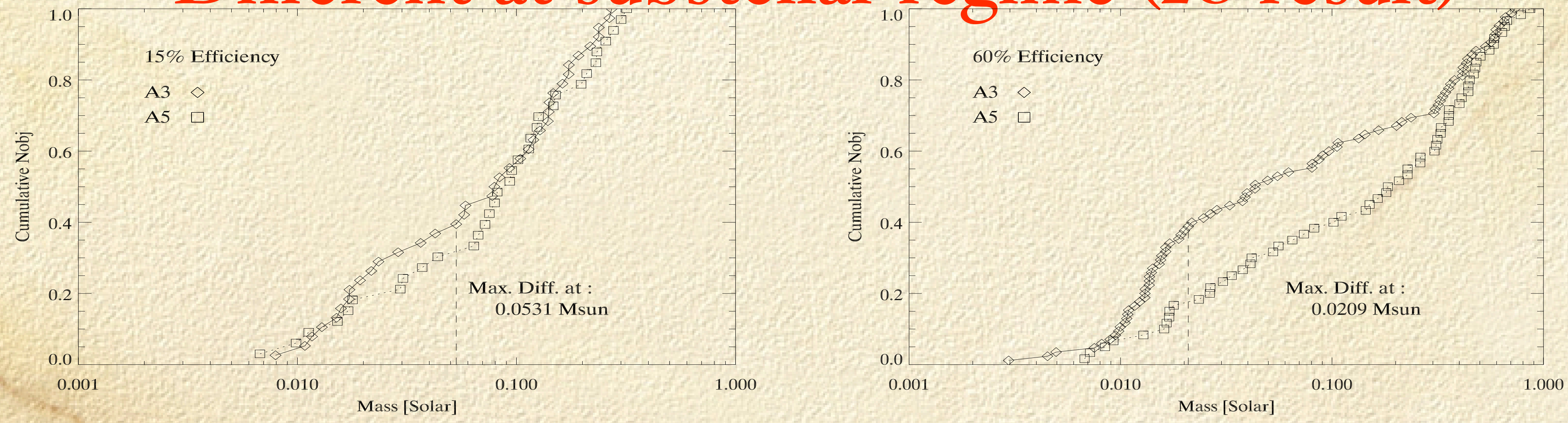
- Possible variations of SubStellar IMF with environment

[Delgado-Donate, Clarke & Bate, 2004, MNRAS, 347, 759]

Results: IMFs



Different at substellar regime (2σ result)



Observational hints to this? Taurus, IC348 vs Orion, Pleiades

[e.g. Briceño et al. 02, Preibisch et al. 03, Barrado y Navascués et al. 02]