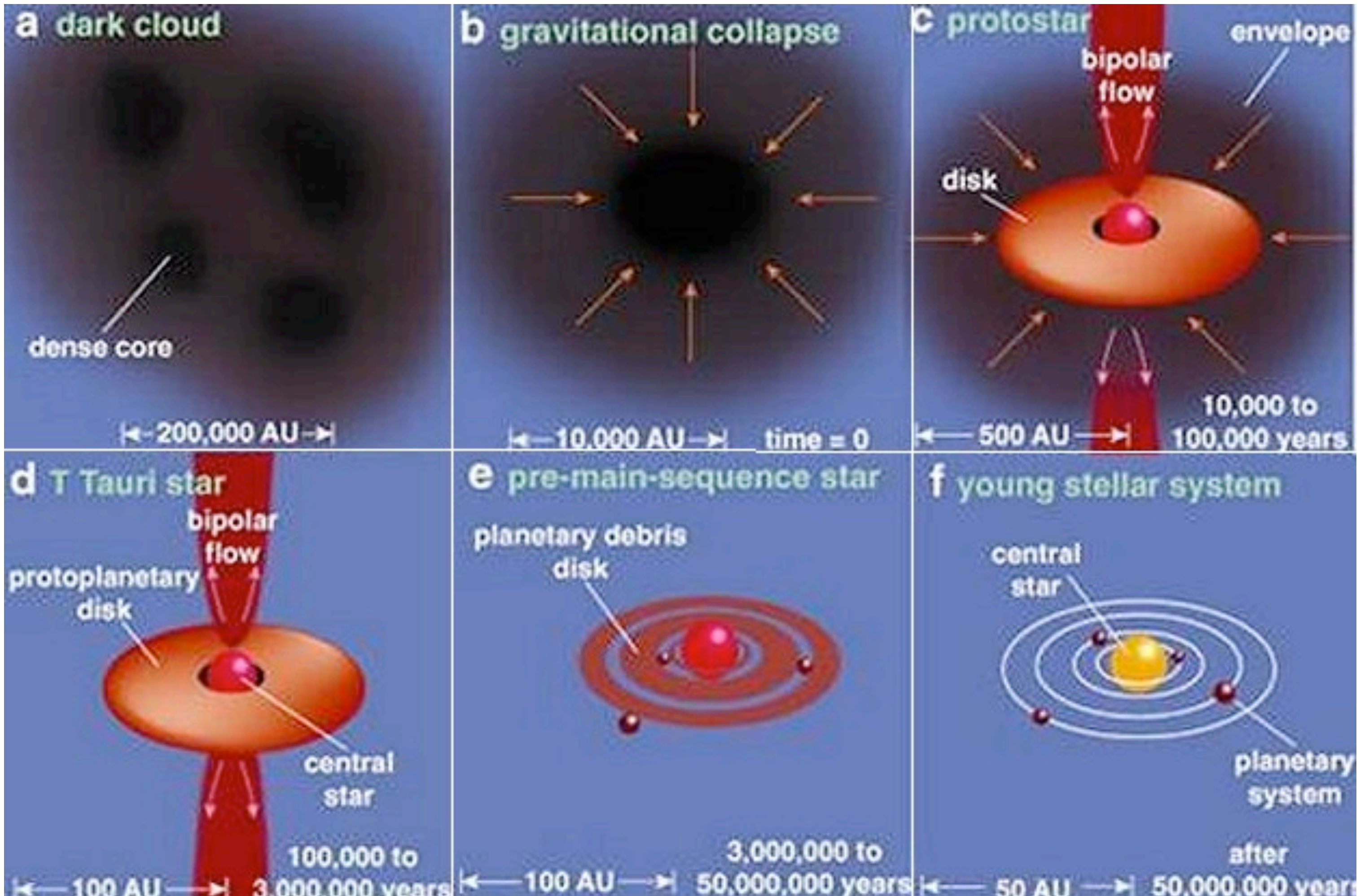
Binary Star Formation: Dynamical Evolution

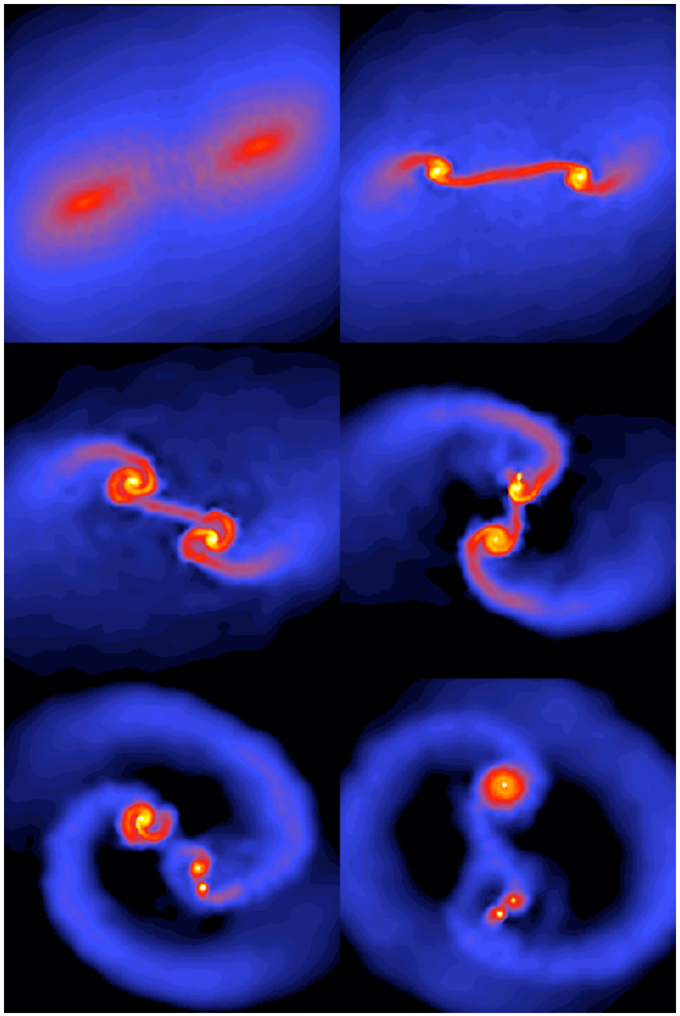
Alex Howe

Single Star Formation



Credit: Spitzer Science Center

Binary Star Formation



Bate, Bonnell, & Price (1995)

Stars collapse from pre-stellar cores.

Fragmentation causes each core to form several stars—observations suggest 2-3 for most cores (Goodwin & Kroupa, 2005).

Clustered Star Formation

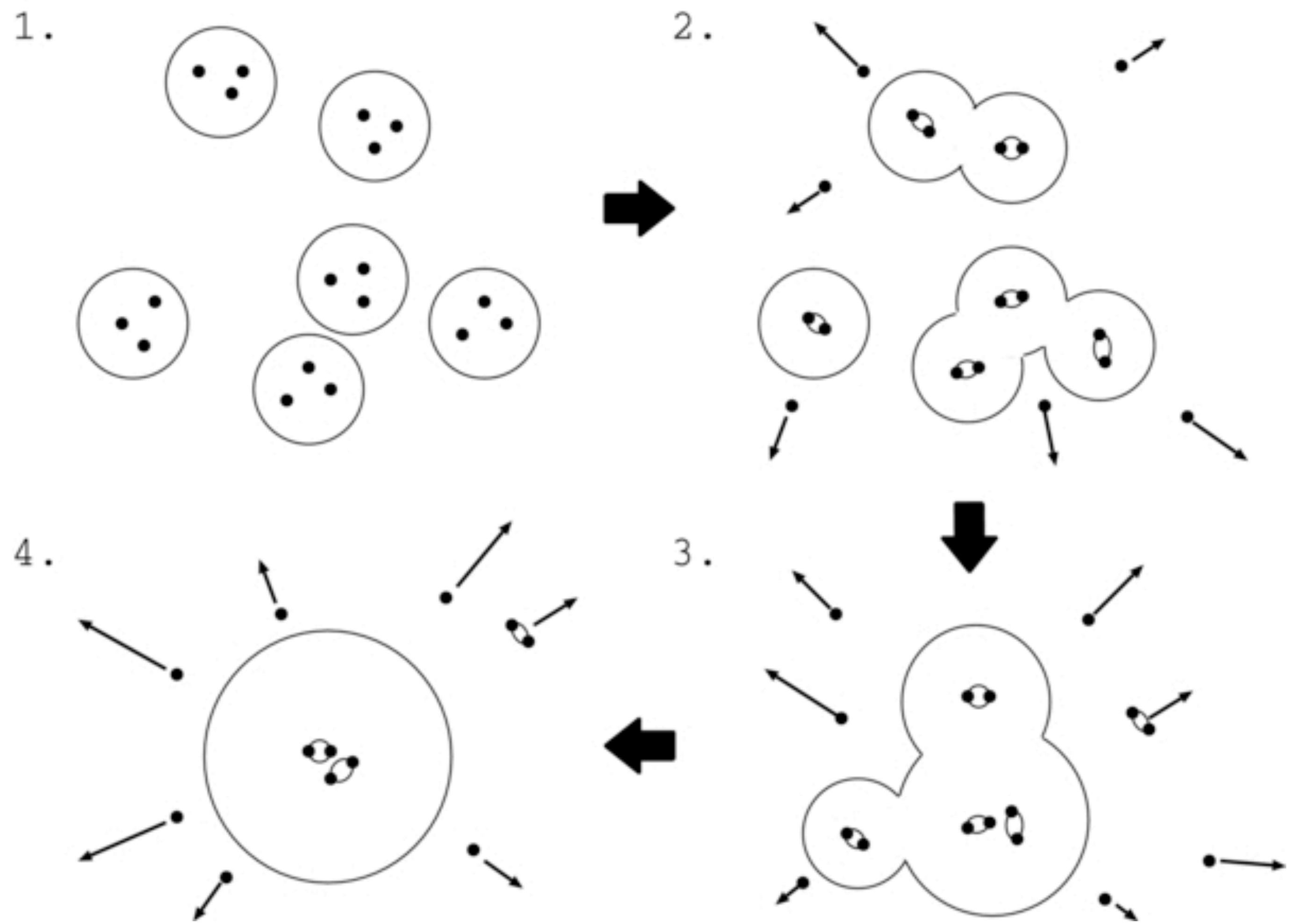
M17. Credit: ESO

NGC 290. Credit: ESA/NASA

Great Sagittarius Star Cloud
Credit: Hubble Heritage Team

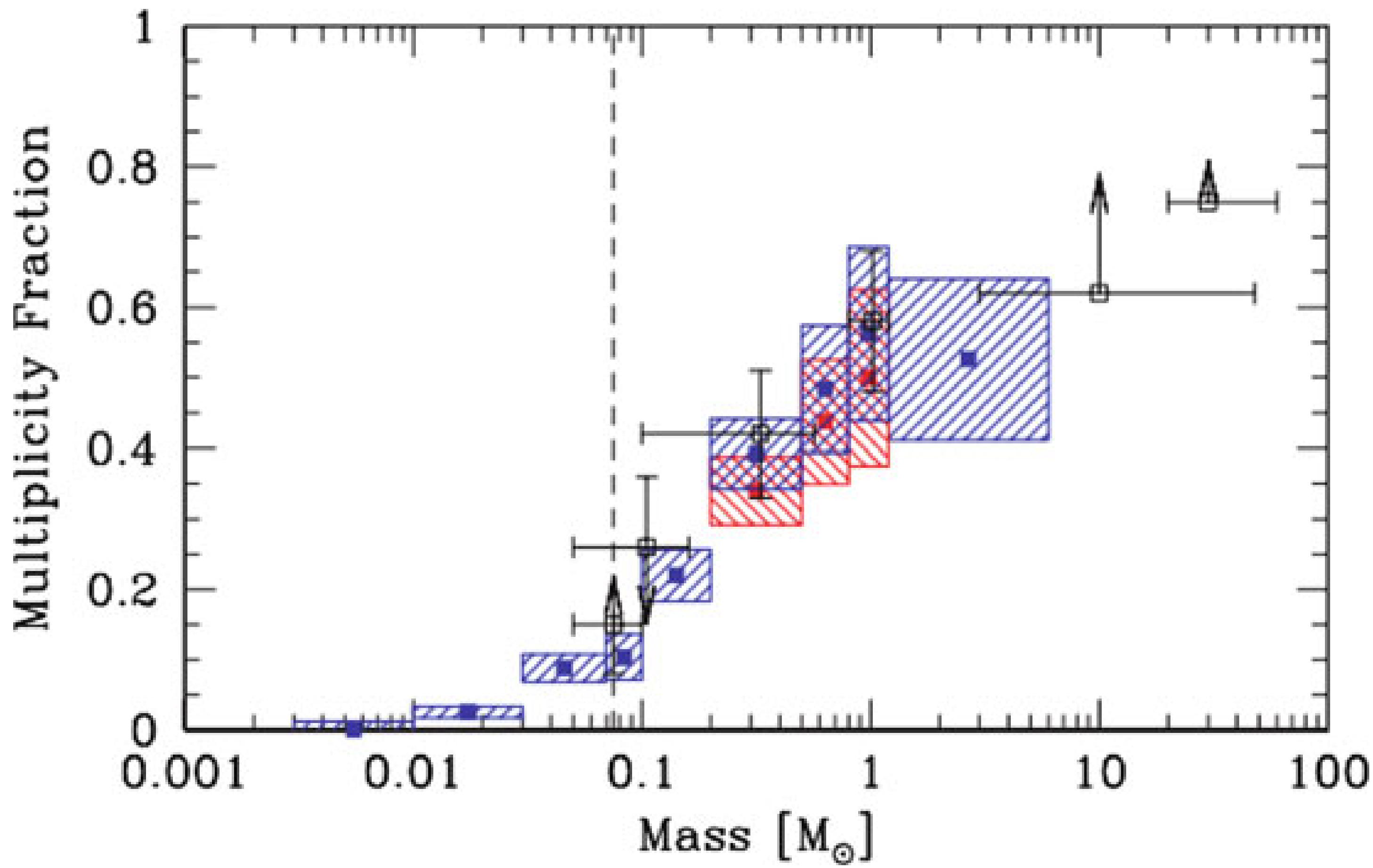
Stars are born in clusters that evolve dynamically over time.

What's going on?



Fujii, Saitoh, & Portegies Zwart (2012)

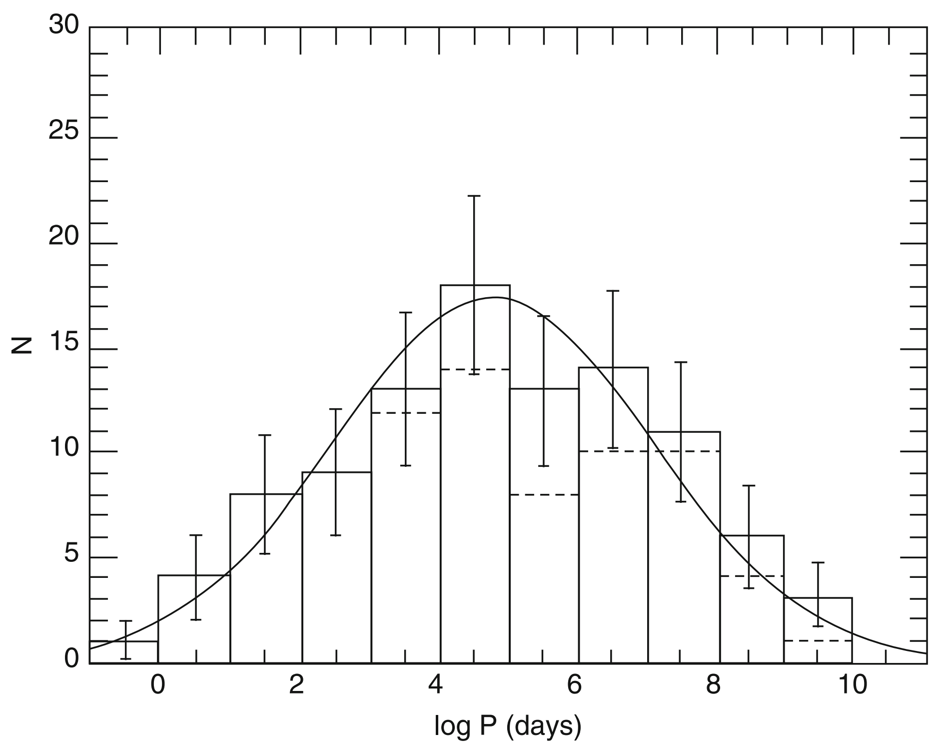
Properties of Binaries



Observed (black) versus simulated (blue and red) multiplicity of stars as a function of mass (Bate, 2009).

Properties of Binaries

- S:D:T:Q = 1.50 : 1.0 : 0.105 : 0.026
  (Duquennoy & Mayor, 1991)
- Eccentricities and mass ratios nearly random



Period distribution of G dwarf binaries (Bodenheimer, 2011).

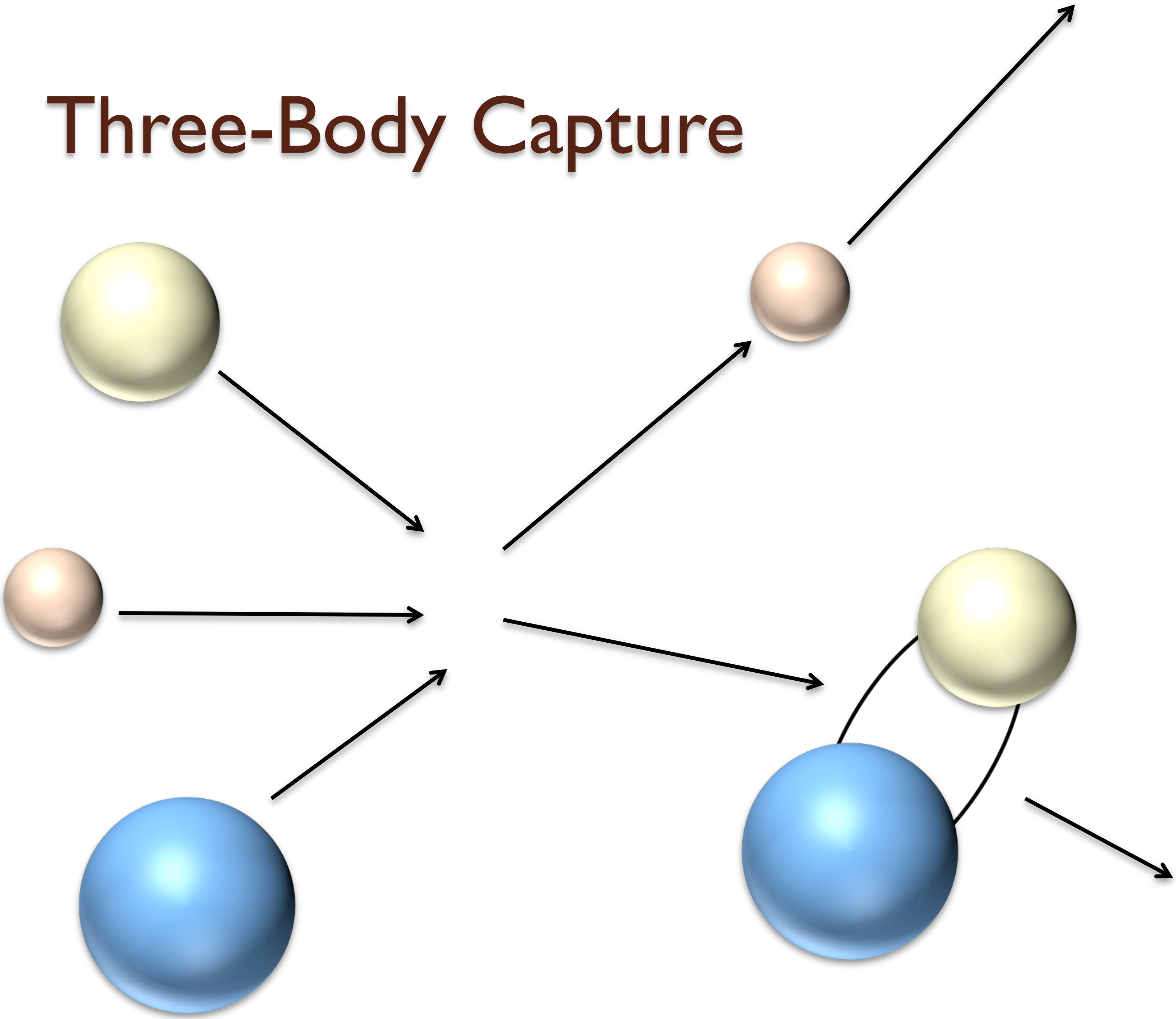
Wide range of periods and thus separations.

Broad peak at ~10^4 days or ~10s of AU.

How are Binaries Formed?

- Fragmentation
- ~~Fission~~
- Gravitational instabilities in disks
- Capture?
  - Three-body capture
  - Tidal capture
  - Dissipative capture

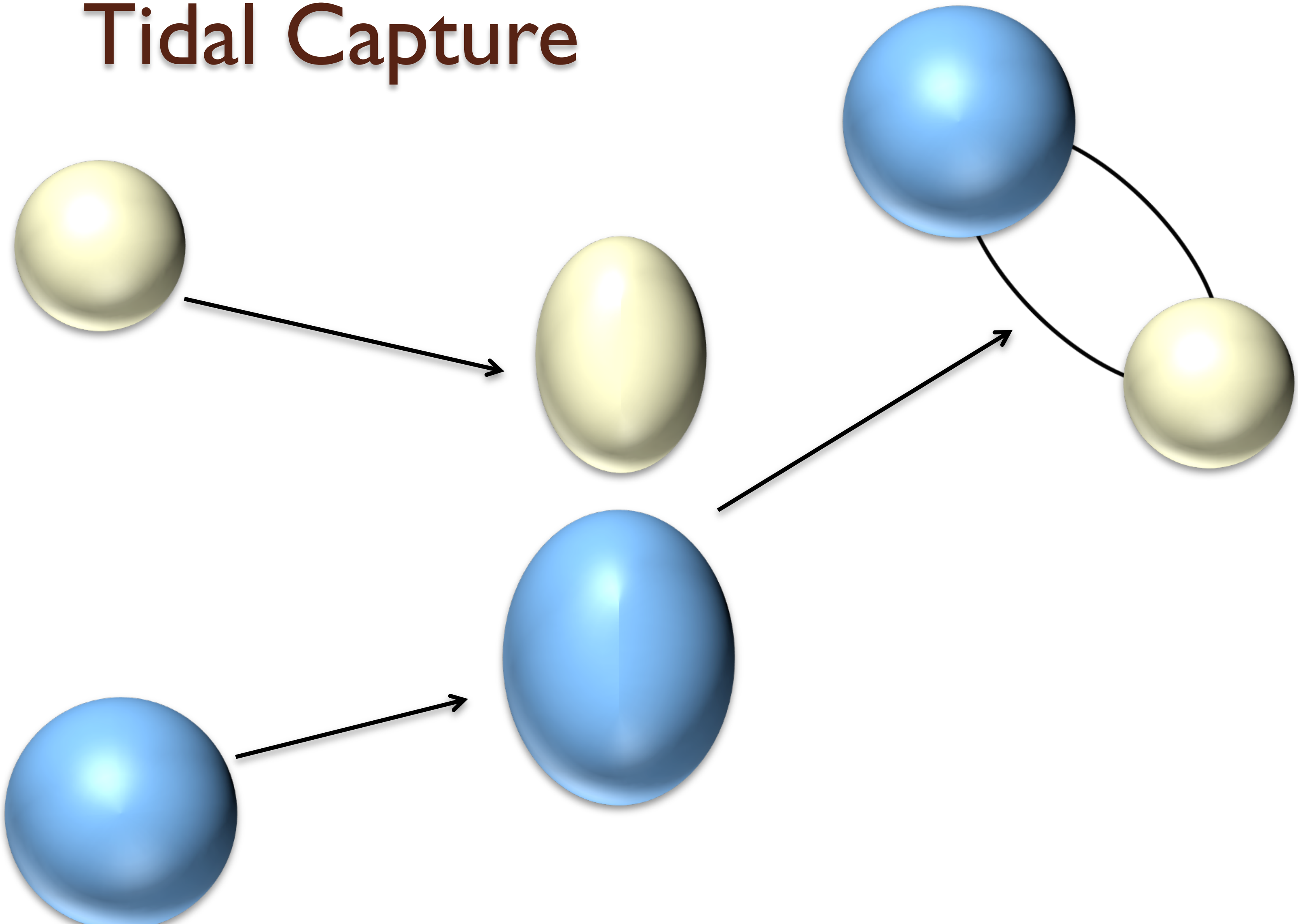
Three-Body Capture



Three-Body Capture

- Cross sections are far too low in the galactic disk.
- May be important in dense young clusters.
- Would produce wide binaries (Bodenheimer, 2011).

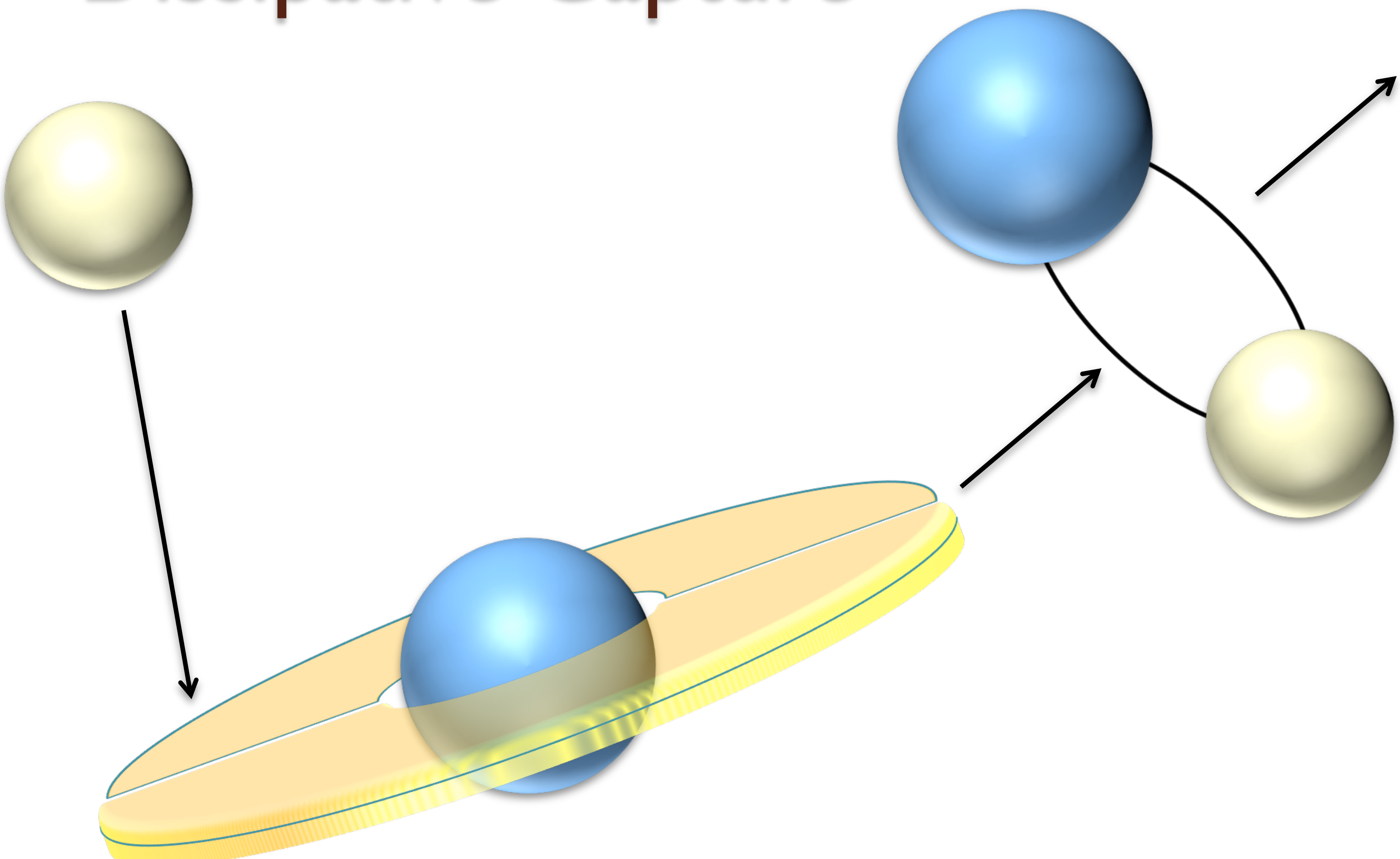
Tidal Capture



Tidal Capture

- Cross sections are far too low in the galactic disk (again).
- May be important in dense young clusters.
- Would produce very tight binaries (Bodenheimer, 2011).

Dissipative Capture



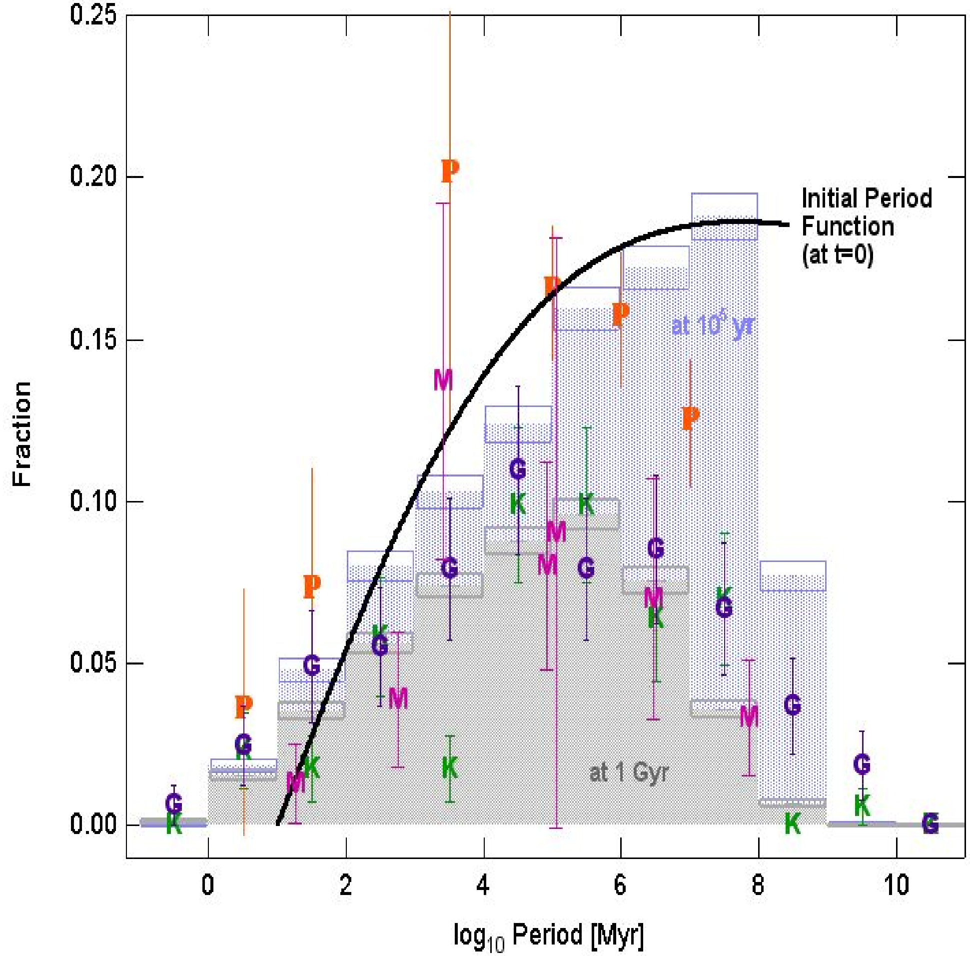
Dissipative Capture

- More distant encounters can cause capture than for tidal capture.
- Only occurs in young clusters that are still forming stars (Bodenheimer, 2011).

Numerical Simulations

- Need full hydrodynamic N-body simulations to account for fragmentation and all types of capture.
- Very sensitive to input parameters.
- Delgado-Donate et al. (2004) produce 80% binary fraction.
- Bate (2009) produces a 56% binary fraction for solar-type stars, consistent with observations.

Subsequent Evolution



Binary fraction by period at 100 kyr and 1 Gyr (Goodwin et al., 2006).

Binary fraction decreases after cluster formation.

Very wide binaries are separated.

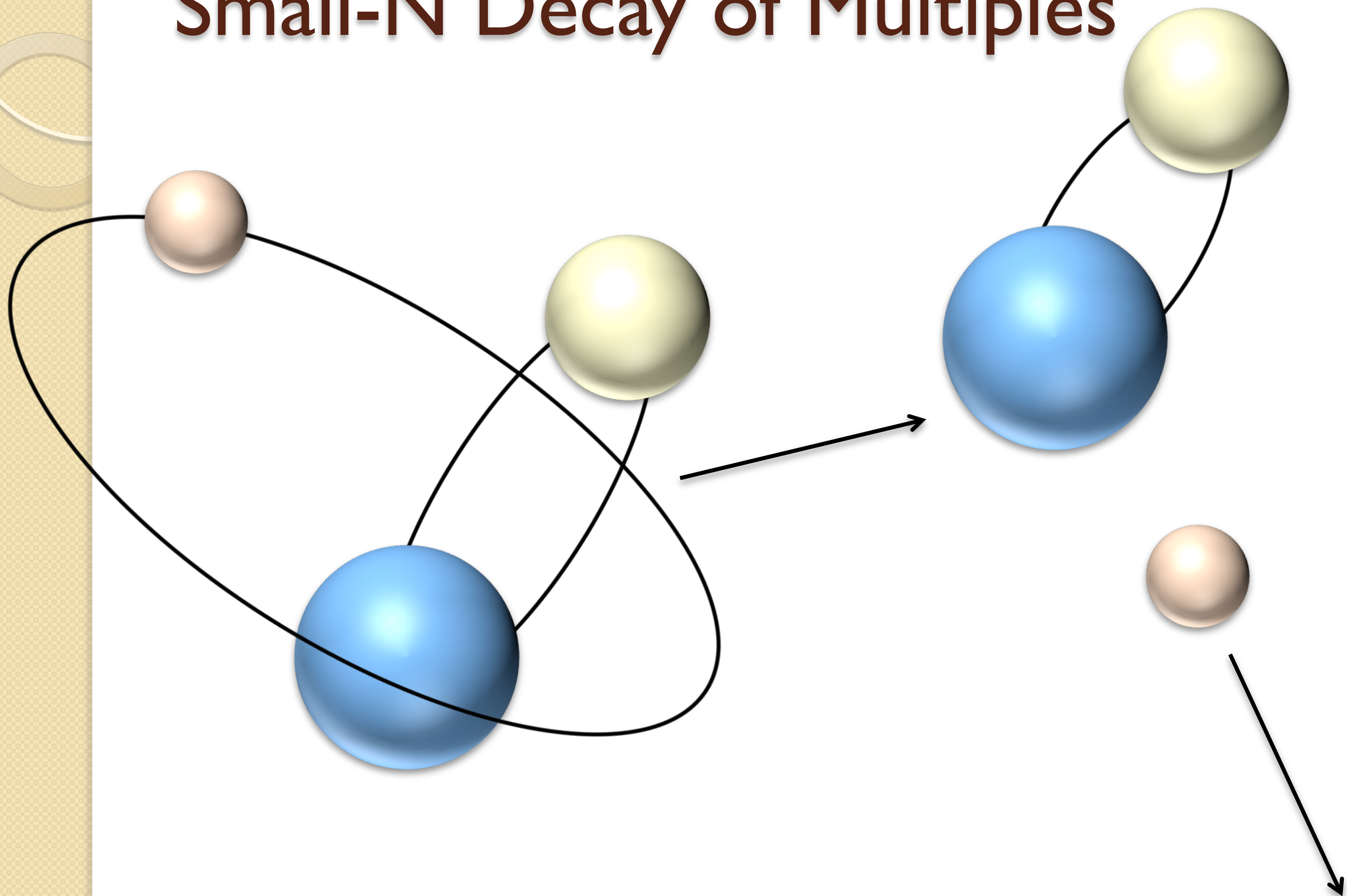
Subsequent Evolution

- Binaries and multiple systems continue to evolve as the cluster evaporates.
- Initial multiplicity fraction may be as high as 100%.
- Much higher than in field stars for wide binaries.
- (Goodwin et al., 2006)

Hard and Soft Binaries

- Hard binaries: $v_{orb} >> \sigma_{cl}$, very resistant to disruption.
- Soft binaries: $v_{orb} << \sigma_{cl}$, easily disrupted by encounters with other stars.
- Heggie-Hills Law: "Soft binaries soften, and hard binaries harden."
- Active binaries: $v_{orb} \sim \sigma_{cl}$, need N-body simulations to study.
- (Goodwin et al., 2006)

Small-N Decay of Multiples



Small-N Decay of Multiples

Triple stars and higher order multiples are unstable on a timescale of:

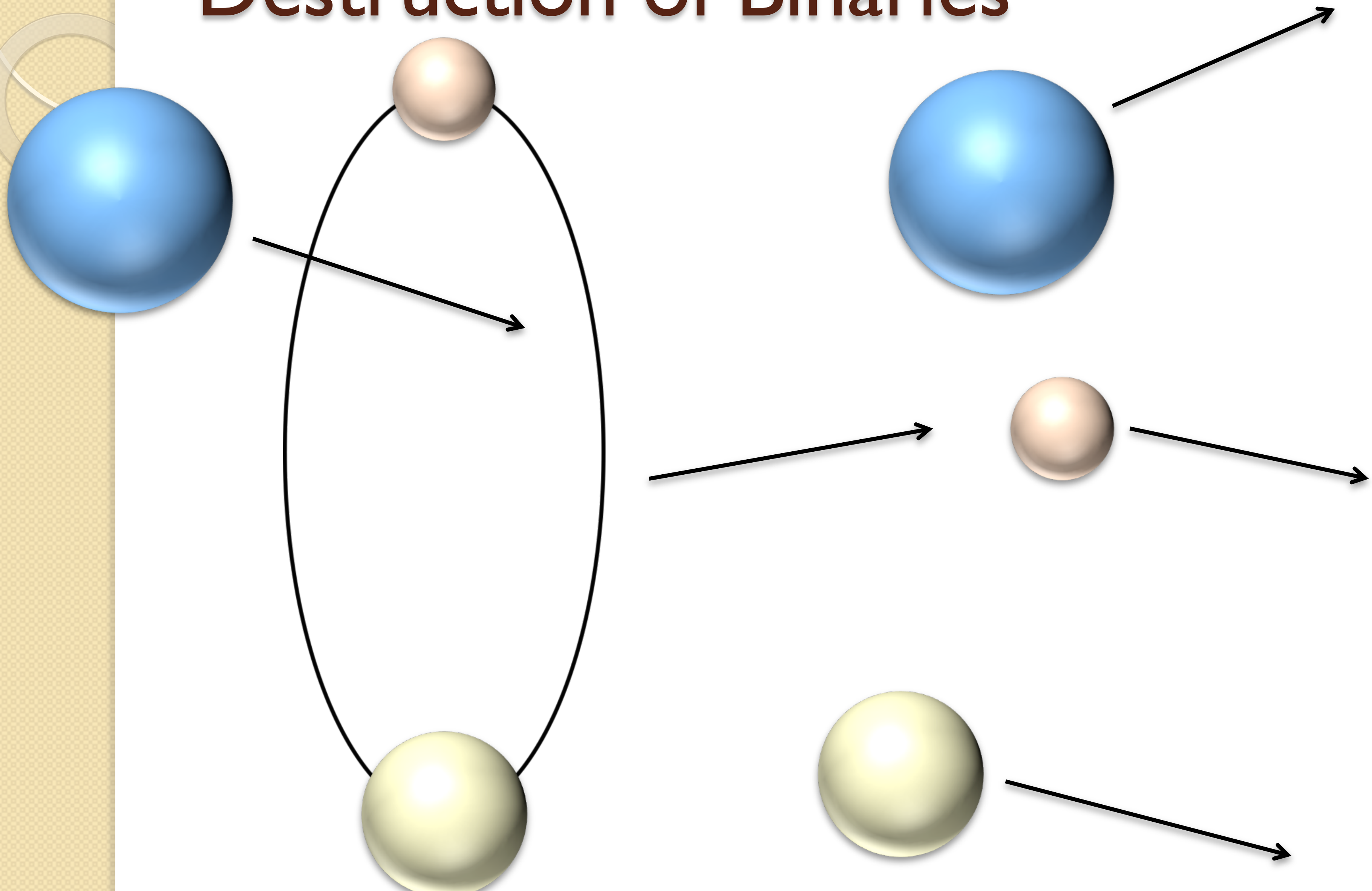
$$t_{\rm decay} = 14 \left(\frac{R}{\rm AU}\right)^{3/2} \left(\frac{M_{\rm stars}}{M_\odot}\right)^{-1/2} \quad {\rm yrs}$$

Typical decay takes 10^5 years.

Results in free low-mass stars plus hard binaries with low mass ratios.

Must be rare to maintain low single star fraction (Goodwin et al., 2006)

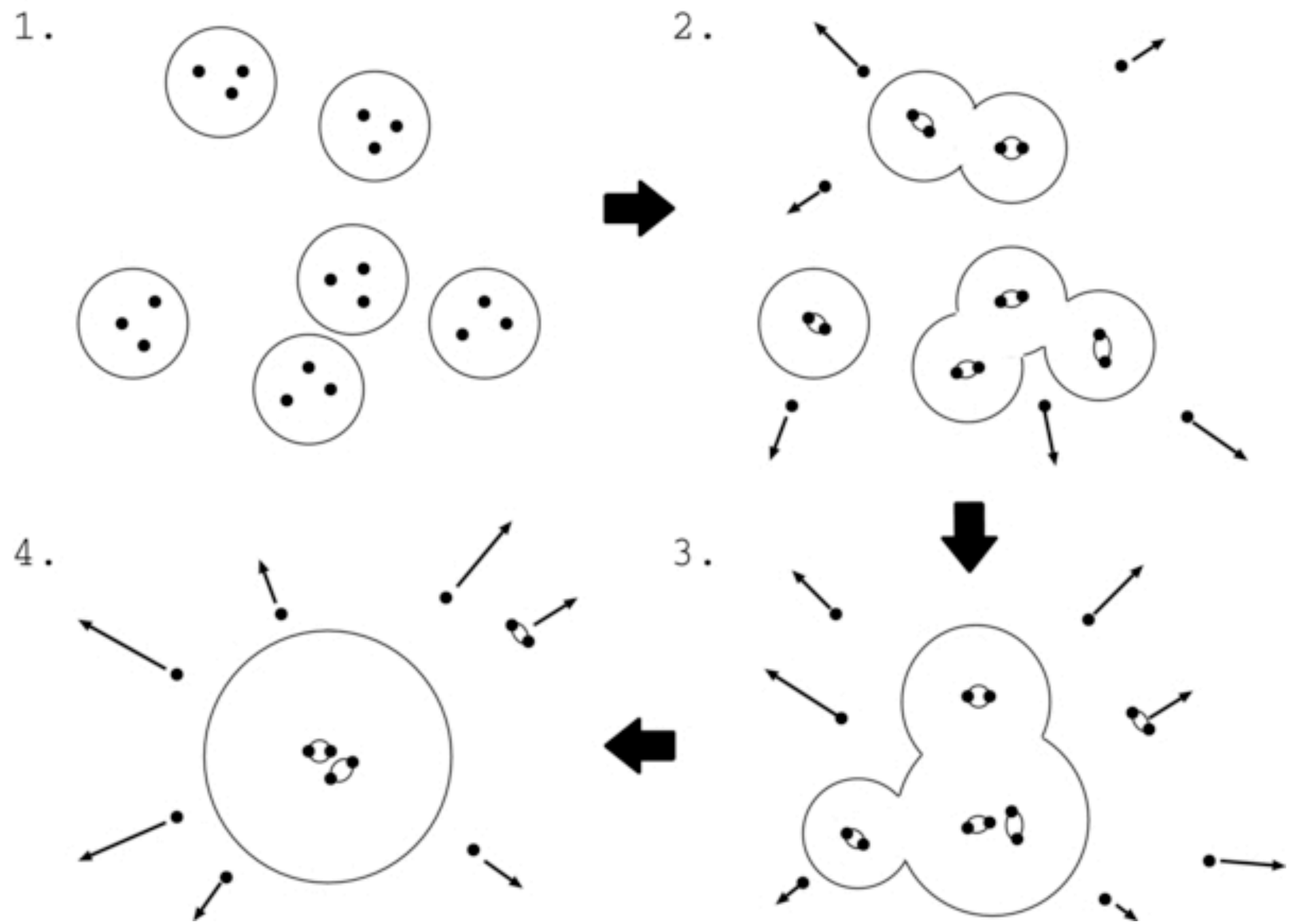
Destruction of Binaries



Destruction of Binaries

- Clusters tend toward equipartition of energy.
- Wide binaries have low energy, and adding energy disrupts them.
- Tight binaries have high energy, and removing energy hardens them.
- Runaway release of orbital energy could unbind the entire cluster (Goodwin, et al., 2006)

Destruction of Binaries



Fujii, Saitoh, & Portegies Zwart (2012)

N-Body Simulations

- Active binaries often exchange partners and eject the least massive member (Goodwin et al., 2012).
- Correctly reproduce the evolution from cluster to field binary distribution (Kroupa, Aarseth, & Hurley, 2001).
- But cannot dynamically generate many binaries and cannot dynamically harden many binaries (Kroupa & Burkert, 2001).

Conclusions

- Most binaries arise by fragmentation with a very high initial binary fraction.
- Stars can be captured into binaries by several processes, but none can produce large numbers of binaries in clusters.
- Very wide binaries are strongly disrupted by gravitational encounters.
- Cluster evaporation leaves hard binaries mostly unchanged.

Sources

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