Dynamics of Binary Stars and their Planets

Eric Pfahl (KITP/UCSB)

with Matt Muterspaugh (Berkeley)

Multiplicity in Star Formation
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Planets are Common

- Nearly 10% of FGK stars have at least one Jovian planet within 10 AU (>200 detected).
- Tip of the iceberg? Saturn? Neptune? Earth?
- We will know much more in the next decade.

Binaries have Planets too

- 20-30% of stars with planets have a stellar companion (e.g., Raghavan et al. 2006).
- Most orbits have separations >100 AU.
- However, wide systems selected:

$$\text{D} = 10\text{–}50\,\text{pc}$$
$$\text{separation} < 10\text{–}50\,\text{AU} \Rightarrow \theta \lesssim 1''$$
$$\Rightarrow \text{Unresolved}$$

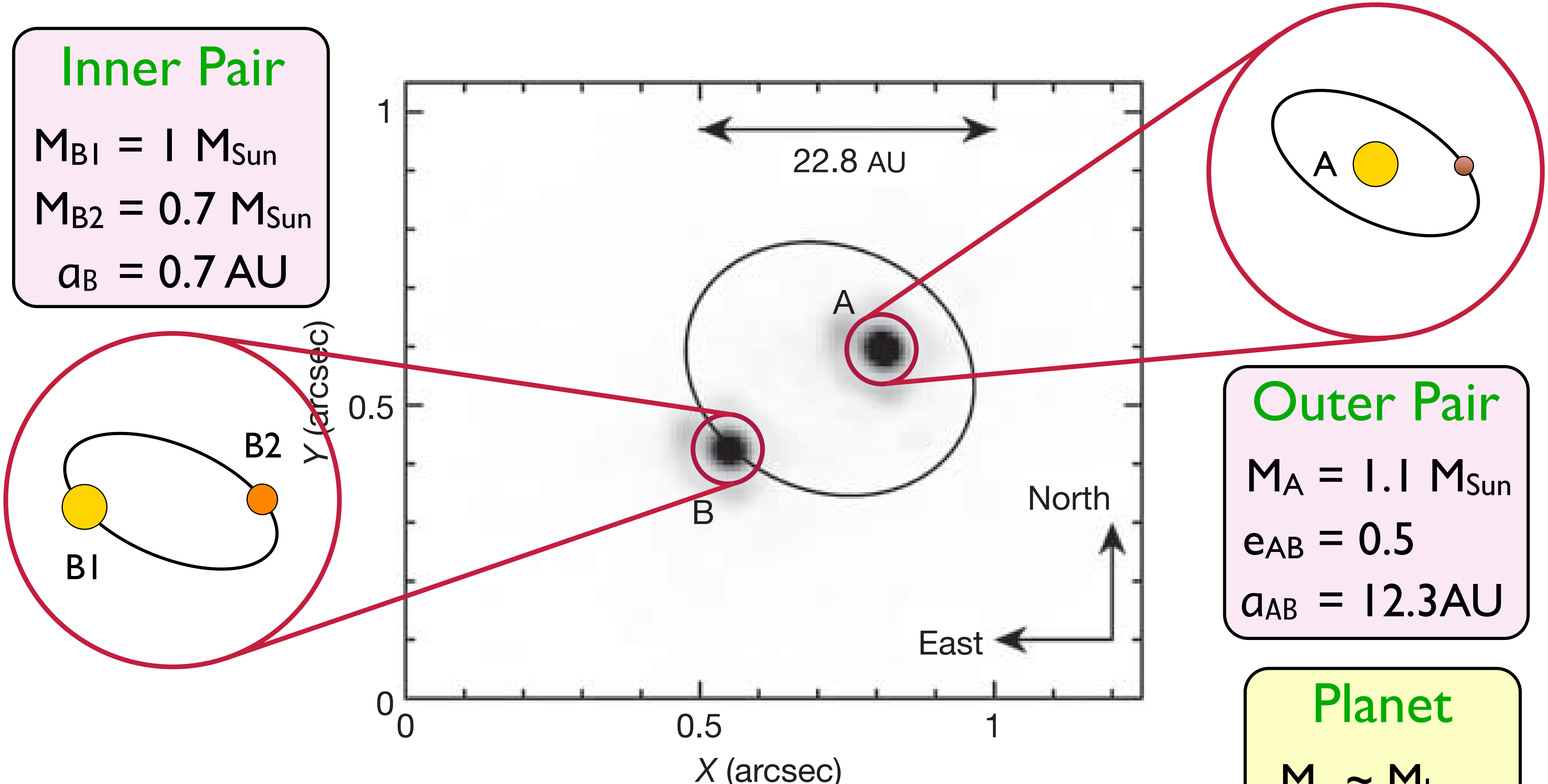
HD 188753

Inner Pair

$M_{B1} = 1\ M_{Sun}$

$M_{B2} = 0.7\ M_{Sun}$

$a_B = 0.7$ AU



(Konacki 2005)

Outer Pair

$M_A = 1.1\ M_{Sun}$

$e_{AB} = 0.5$

$a_{AB} = 12.3$AU

Planet

$M_p \sim M_{Jup}$

$P_{orb} = 3.35$ d

But...

Alas...

- Eggenberger et al. (2007) find no evidence for a planet in HD 188753.
- But same ideas apply.

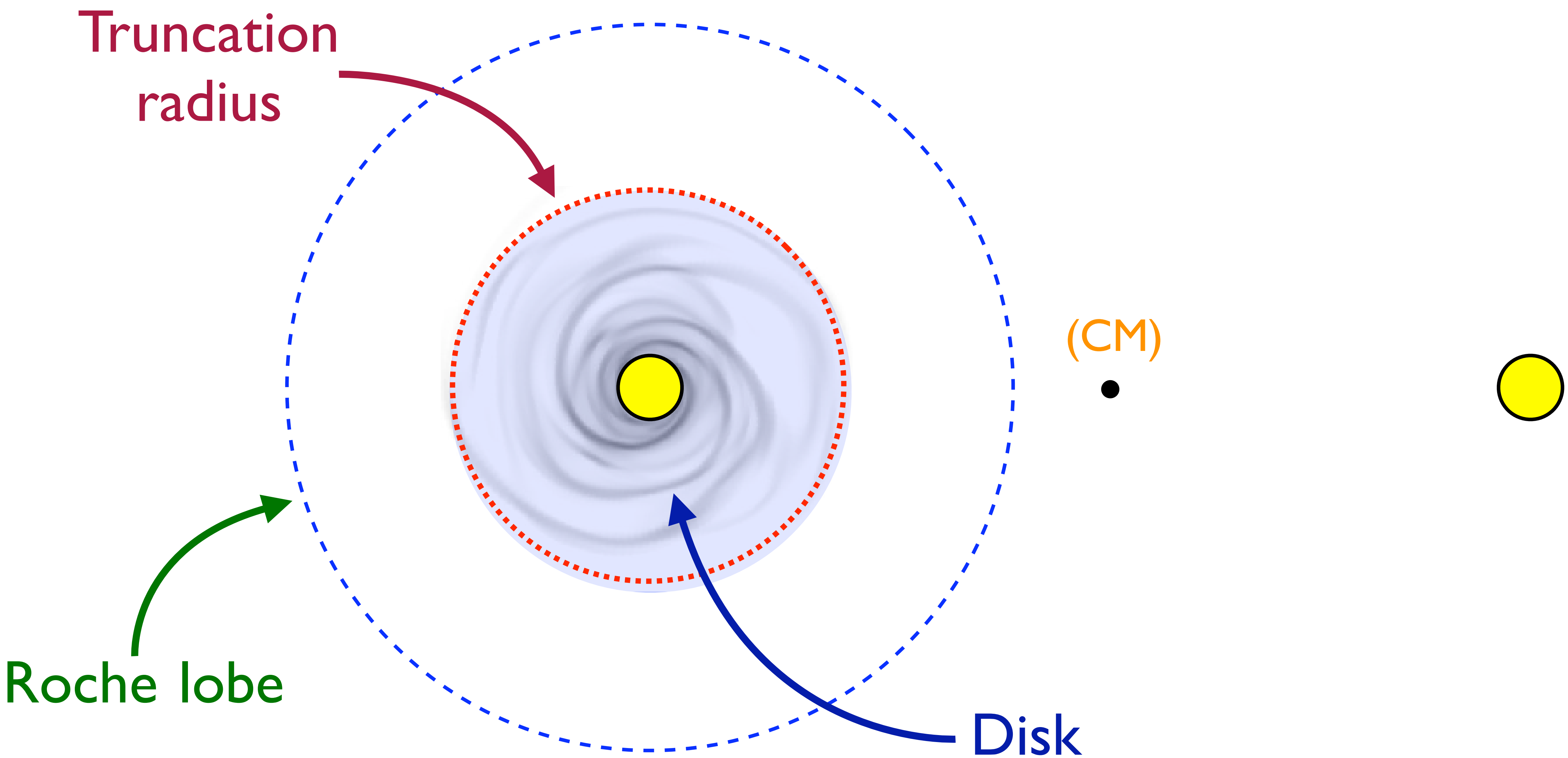
Influence of the Companion

Truncation Radius

$R_t \sim 0.3\, a(1\text{-}e)^{1.2}$

(Pichardo et al. 2005)

$R_t \sim 1$ AU in HD 188753



Binaries are Hostile to Planets

Tidal truncation inside ‘snow line’ at 1-3 AU.

(Hayashi 1981; Sasselov & Lecar 2000)

Insufficient mass/time within R_t.

(Jang-Condell 2007)

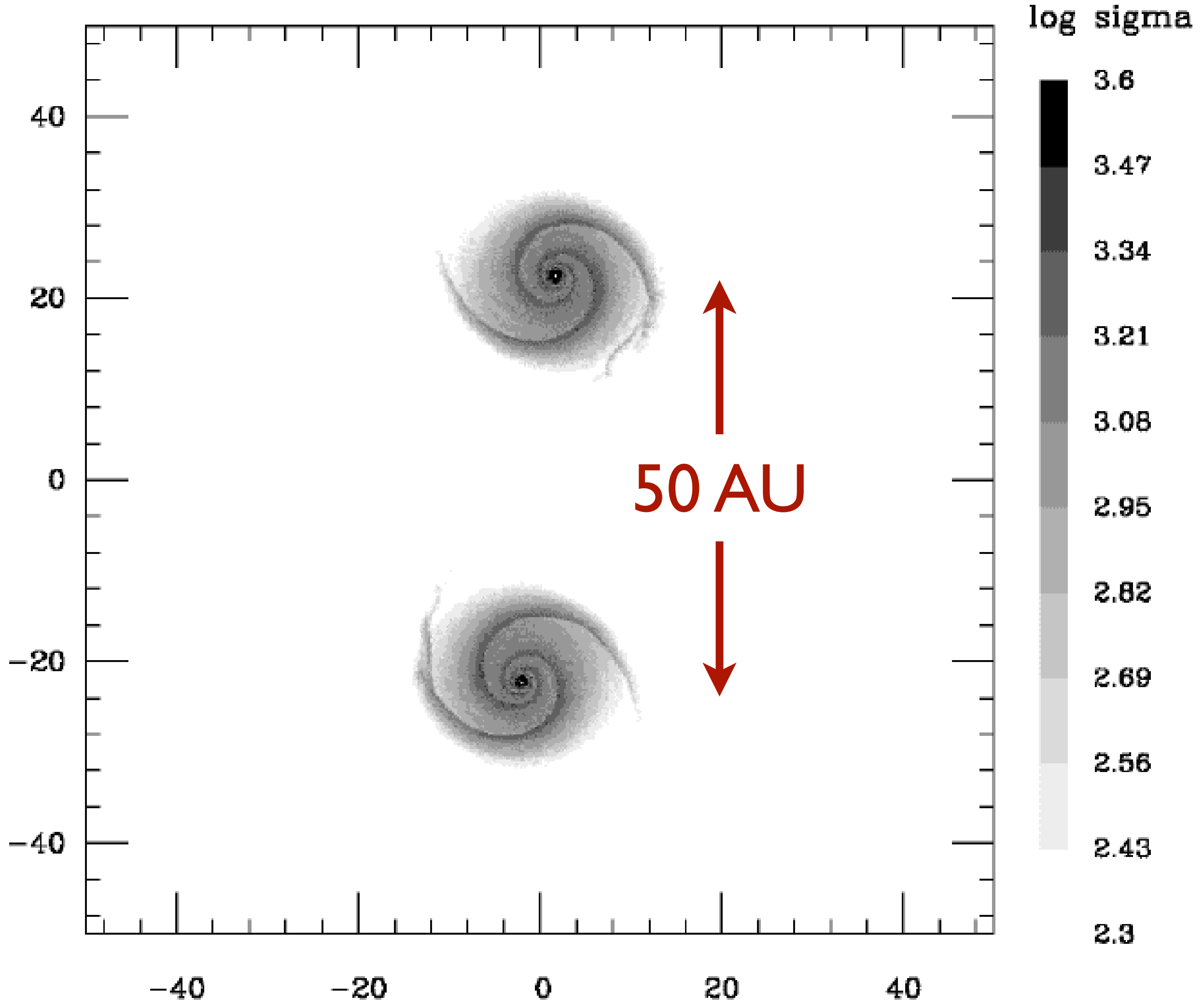
Stirring/Heating of the disk.

(Thébault et al. 2004, 2006)

Binaries are Hostile to Planets

- Spiral waves dissipate as thermal energy.
- Gas temperature, particle velocities increase.
- Collapse and core-accretion less likely.

(Nelson 2000)



Even binaries with a ~ 50 AU (R_t ~ 10 AU) are potentially hostile to giant planet formation.

‘Close’ Binary Defined

Binaries with $a/D < 2''$ tend to be cut.

$D \sim 20$-50 pc $\Rightarrow$ cut on $a < 40$-100 AU.

We expect that $R_t > 5$-10 AU a requirement.

$a/R_t \sim 3$-4 $\Rightarrow$ problems for $a < 20$-40 AU.

‘Close’ Binary $\rightarrow$ Binary $a < 50$ AU.

'Close' Binaries with Planets

(Pfahl & Muterspaugh 2006)

	Object	a(AU)	e	M_1/M_2	R_t(AU)
*	HD 188753	12.3	0.50	1.06/1.63	1.3
	γ Cephei	18.5	0.36	1.59/0.34	3.6
†	GJ 86	~20	···	0.7/1.0	~5
‡	HD 41004	~20	···	0.7/0.4	~6
	HD 196885	~25	···	1.3/0.6	~7

* Secondary a binary! (Konacki 2005; but see Eggenberger et al.)

† Secondary a white dwarf. (Mugrauer & Neuhauser)

‡ Secondary orbited by a brown dwarf in the desert. (Zucker et al. 2004)

4 of ~3000 stars surveyed
+
Selection Effects

$\Rightarrow$ $F_{cbp} \sim 1\%$
(Bonavita & Desidera 2007)

A Dynamical Backdoor

Maybe AB was much wider initially.

Perhaps A initially had a different companion in a wide orbit.

What if A was born single?

All require birth in a cluster!

Dynamical Pathways

The Players

A: Planet Host

B: *Binary* Companion

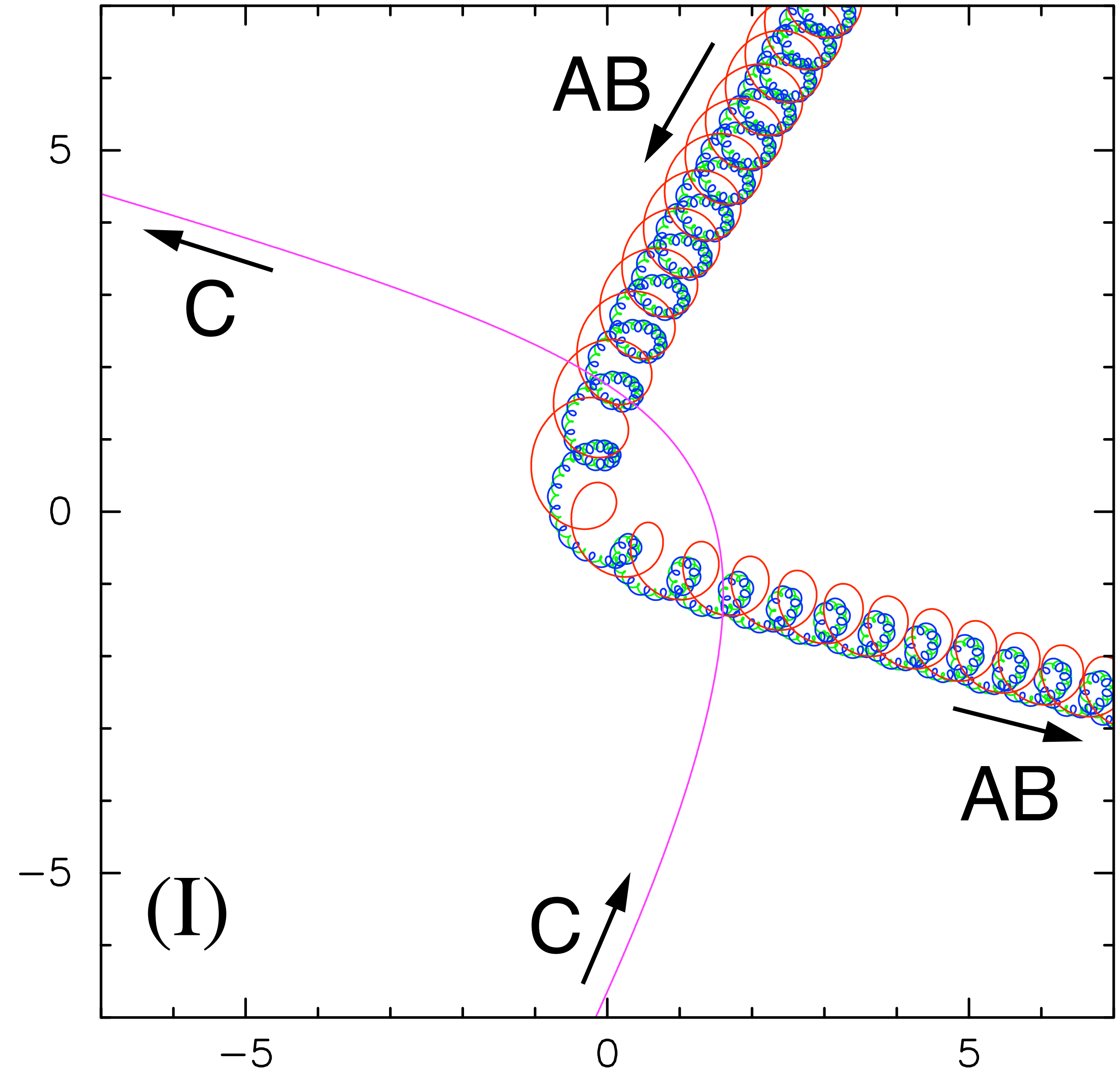
C: Catalyst Star

The Plays

I: AB+C → AB+C

II: AC+B → AB+C

III: A+BC → AB+C



(AB shrinks)

Dynamical Pathways

The Players

A: Planet Host

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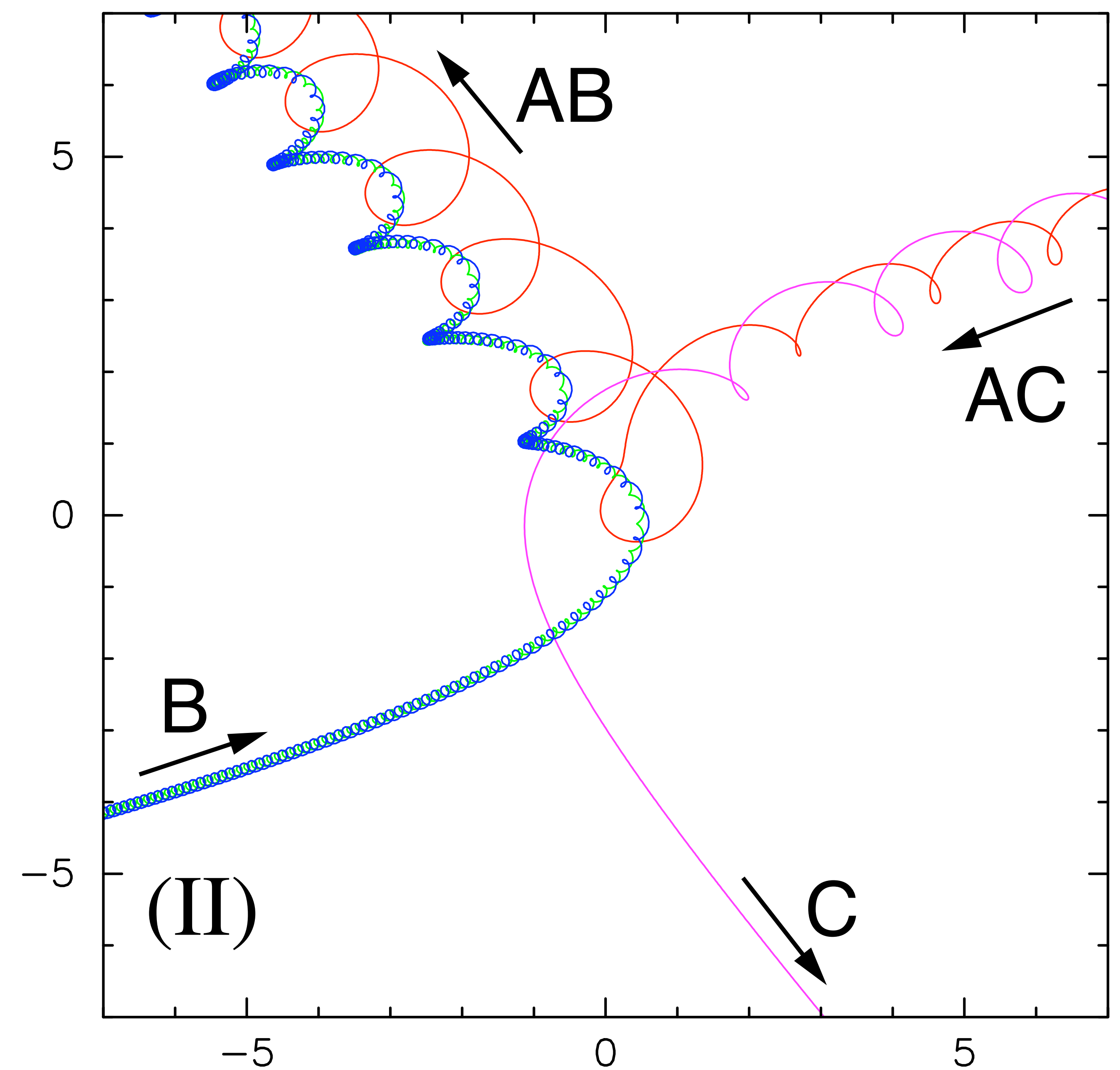

(B replaces C)

Dynamical Pathways

The Players

A: Planet Host

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C: Catalyst Star

The Plays

I: AB+C → AB+C

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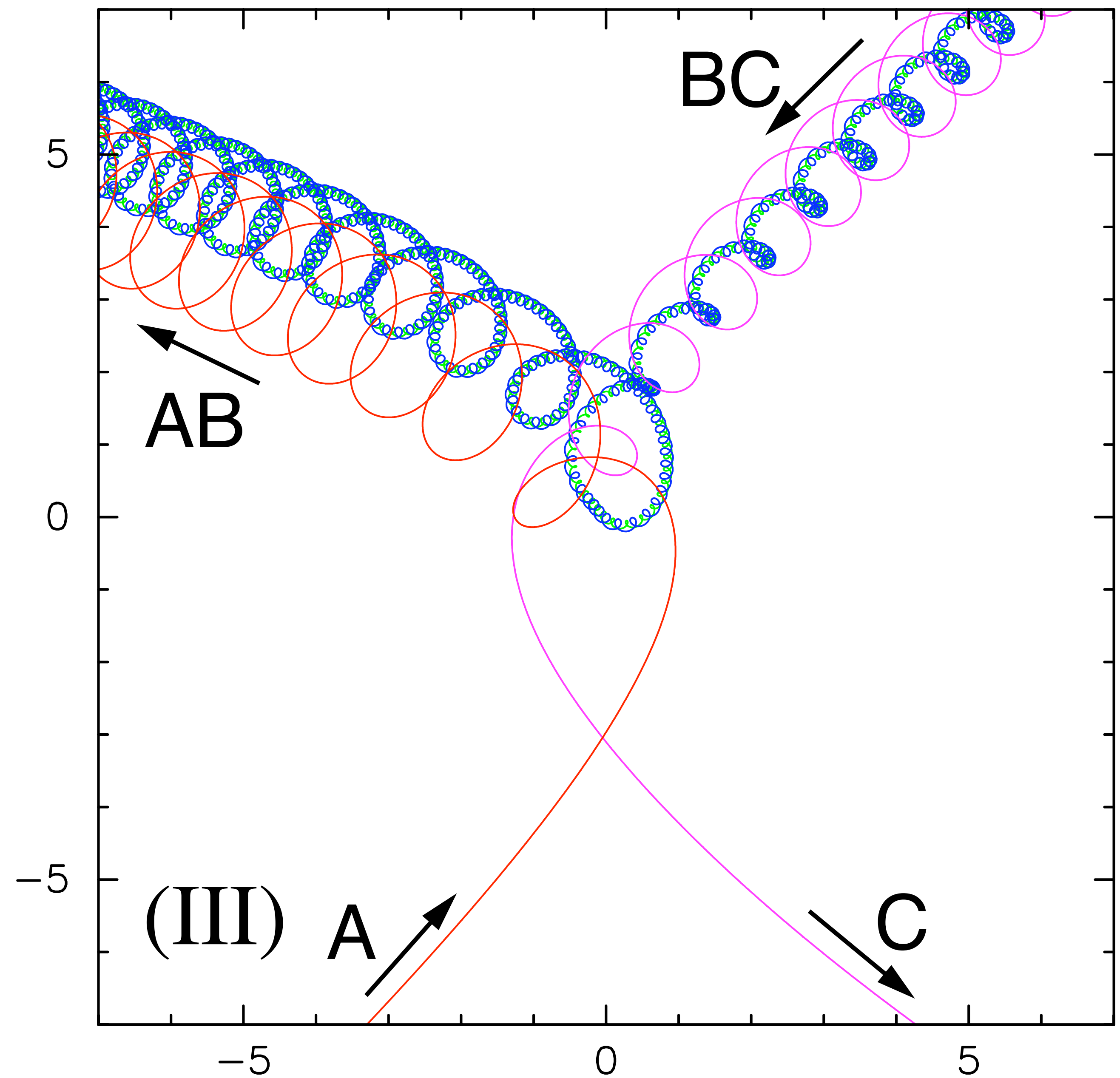


(A replaces C)

Stellar Birth Clusters

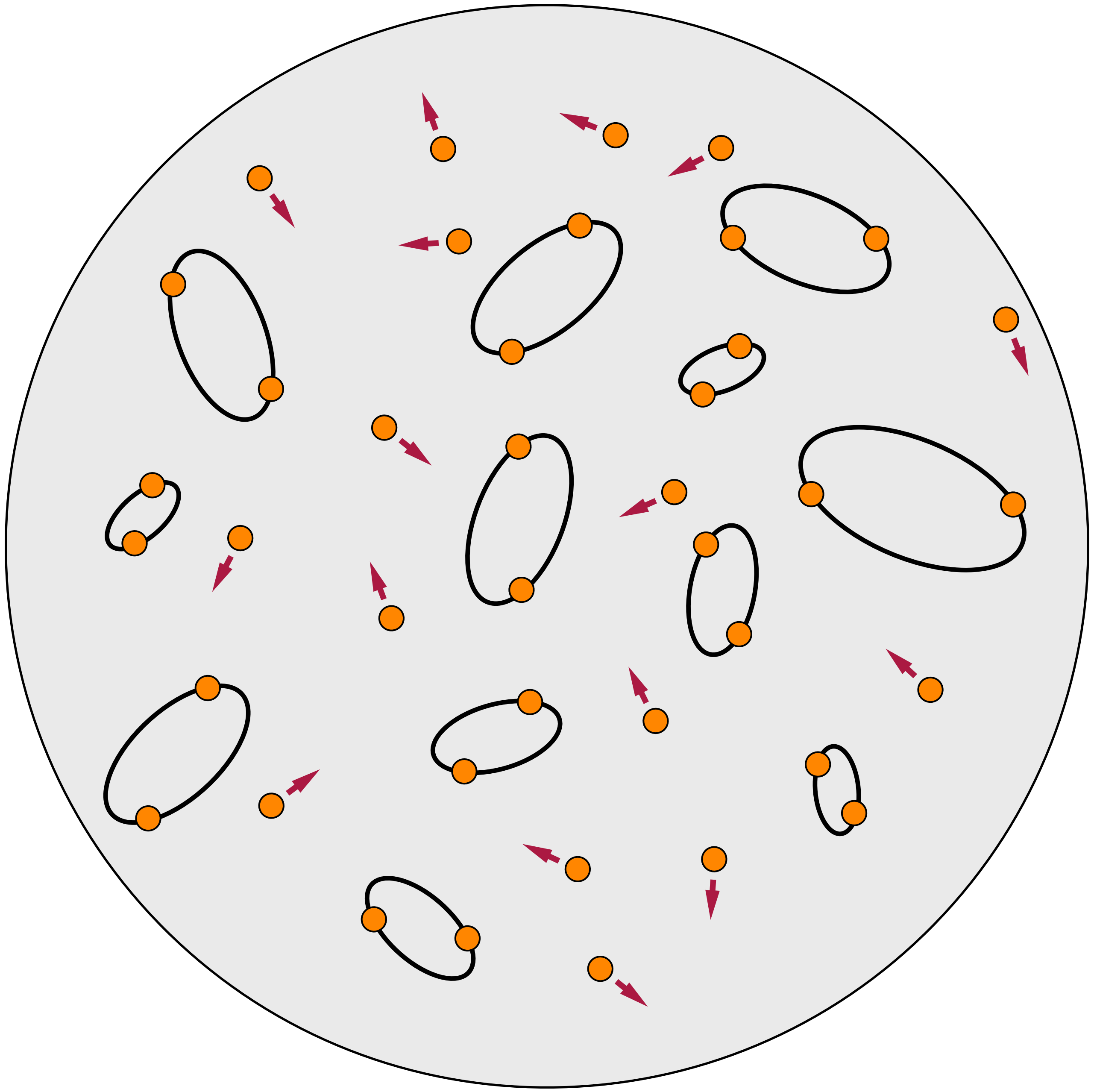
~90% of all stars form in clusters with 10^2-10^3 members.
(e.g., Lada & Lada 2003)

Most clusters dissolve in <100 Myr.
(e.g., Wielen 1985)

Within 100 pc, there are ~10^5 binaries from thousands of clusters.

Star Cluster Basics

Cluster of Stars
(and Gas and Dust)



$M_c \sim 3N\langle m \rangle$

Mean Properties

Number of stars
- N -

Radius containing half of the mass
- r_h -

Velocity Dispersion
- $\sigma = (GM_c/r_h)^{1/2}$ -

Mean density within r_h
- $n_h = 3N/(8\pi r_h^3)$ -

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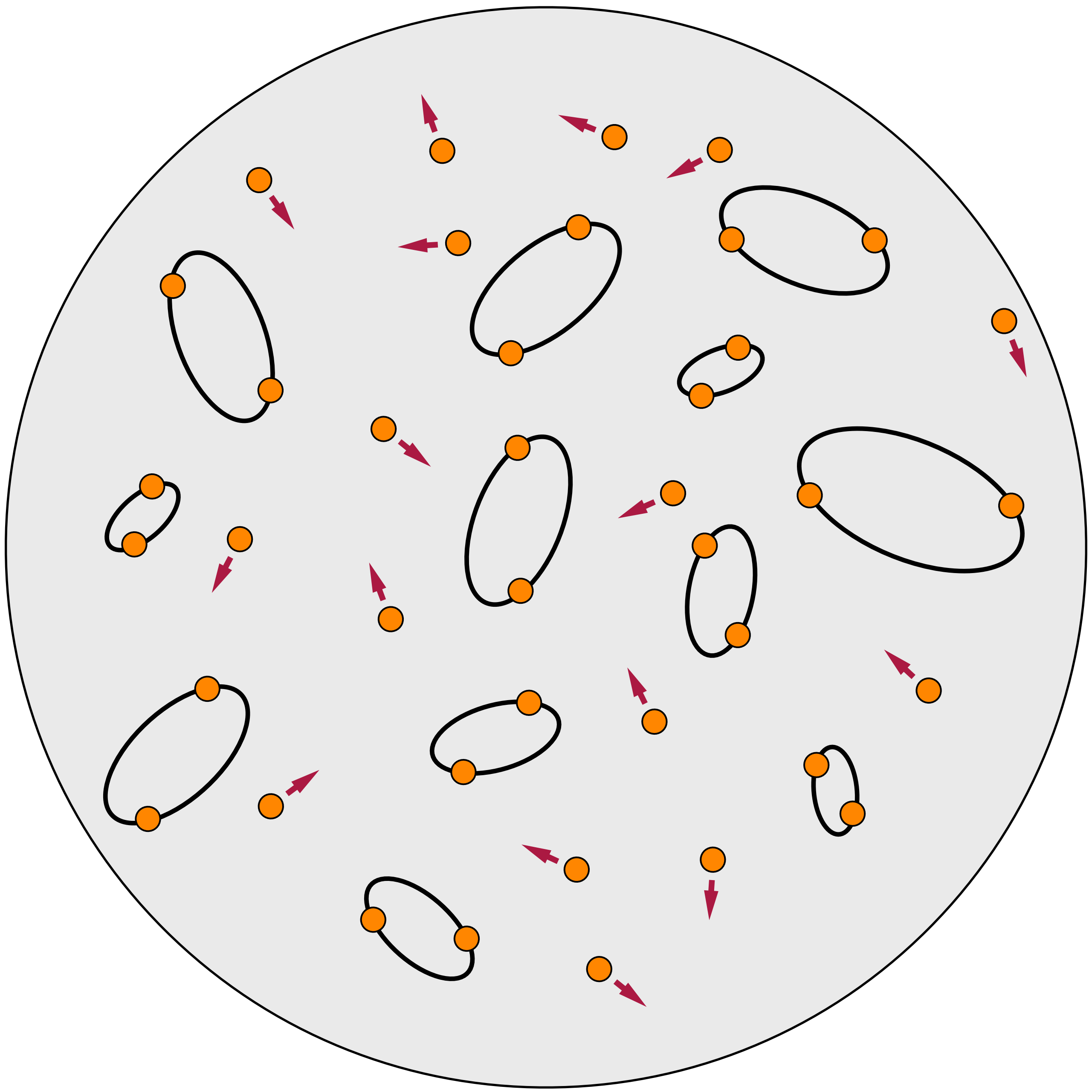
(and Gas and Dust)



$M_c \sim 3N\langle m \rangle$

Embedded Phase

$r_h \sim (N/100)^{1/2}$ pc

$\Downarrow$

$n_h \sim 10(N/100)^{-1/2}$ pc^{-3}

$\sigma \sim (N/100)^{1/4}$ km s^{-1}

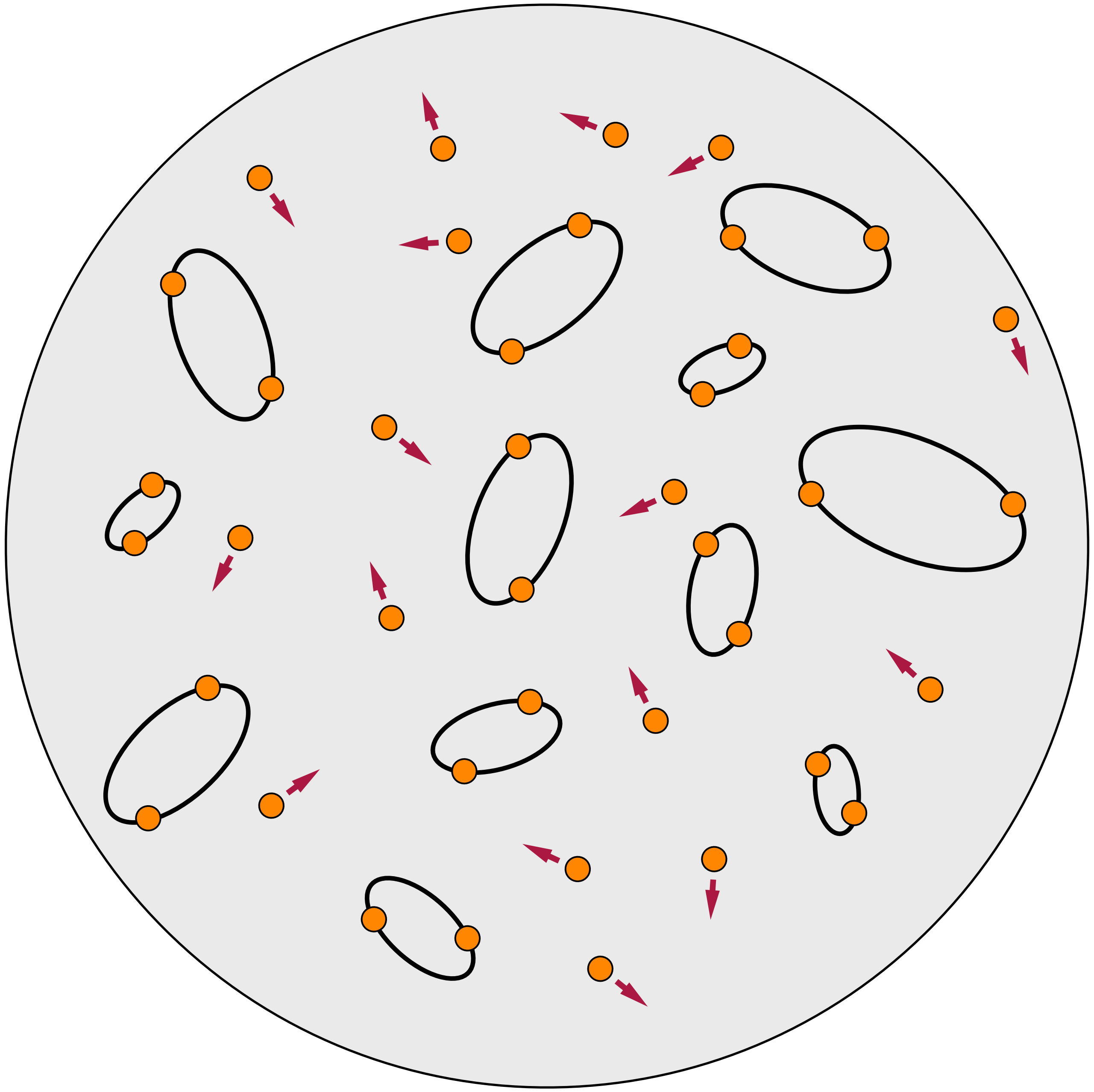
Lifetimes < 5-10 Myr.

Set by gas/dust expulsion.

Only ~10% of clusters survive.

Star Cluster Basics

Cluster of Stars
(and Gas and Dust)



$M_c \sim 3N\langle m \rangle$

Open Clusters

$r_h \sim 1$ pc

$\Downarrow$

$n_h \sim 10(N/100)$ pc^{-3}

$\sigma \sim (N/100)^{1/2}$ km s^{-1}

Lifetimes set by dynamics.

$t_{rel} \sim (r_h^3/GM_c)^{1/2}\ (0.1N/\ln N)$

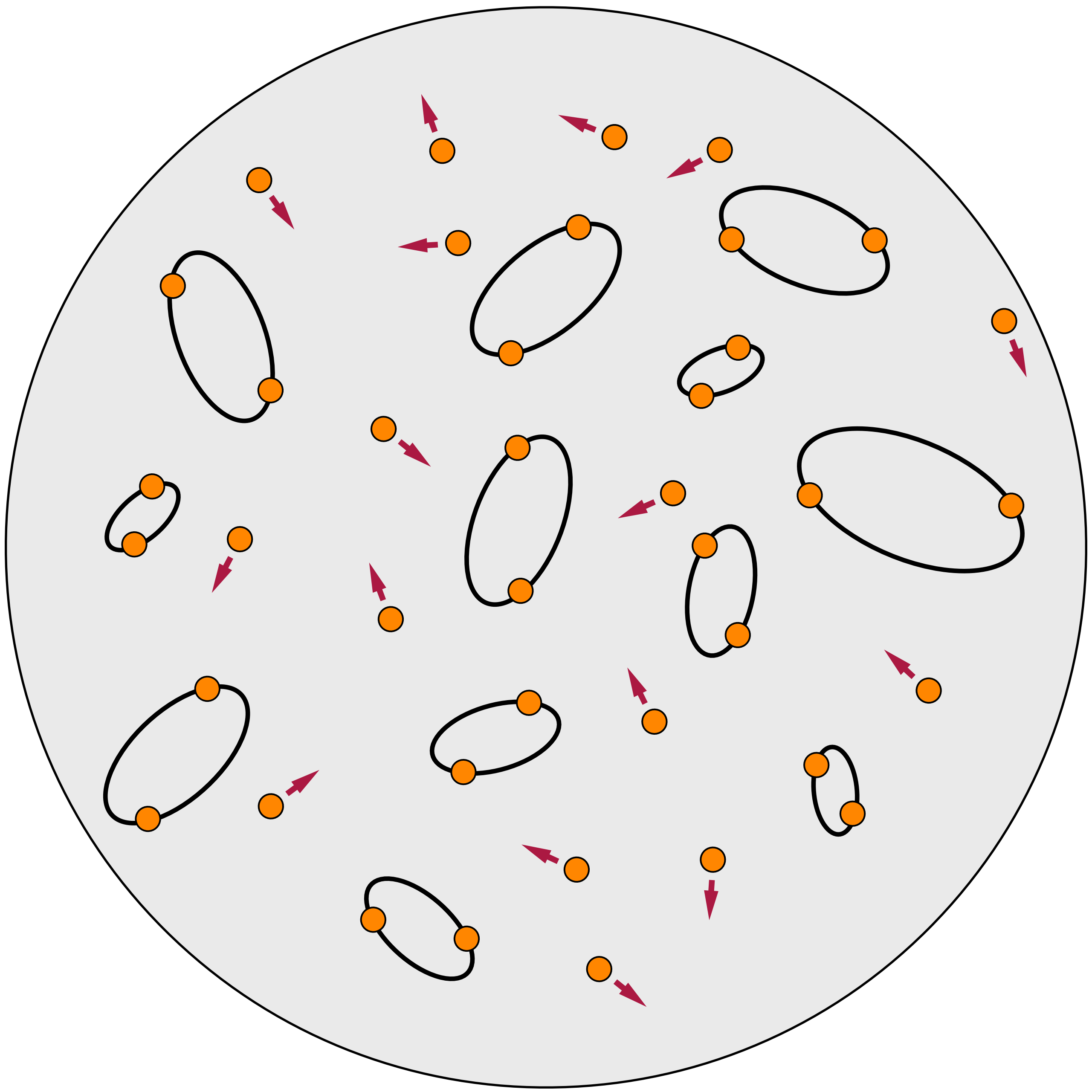
$\sim$ few $(N/100)^{1/2}$ Myr

N drops with

$T_{1/2} \sim 100\ (N/100)^{1/2}$ Myr

Star Cluster Basics

Cluster of Stars
(and Gas and Dust)



$M_c \sim 3N\langle m \rangle$

All Clusters

$p(N) \propto N^{-2}$

$p(a) \propto a^{-1}$

$f_b \sim f_s \sim 0.5$

$f_{cb} \sim 0.5$

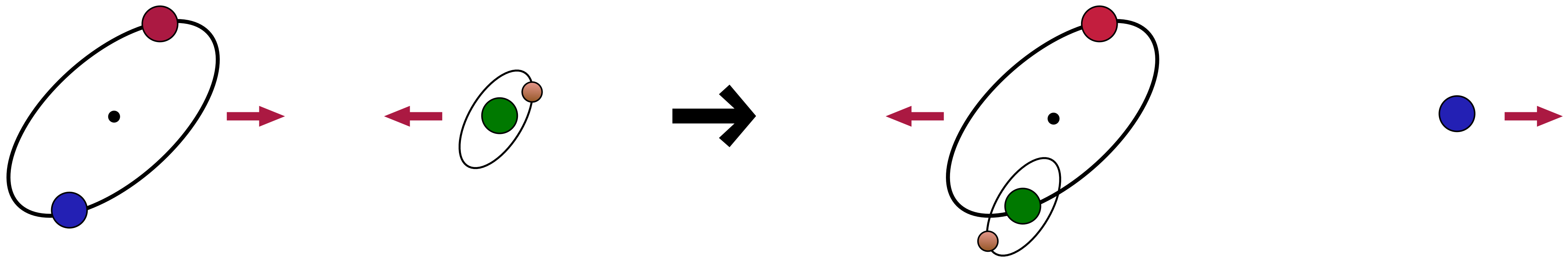
Scattering Dynamics

Cross Section: $\Sigma \sim \pi[a^2 + 2aGM_{123}/u^2]$ $(u \sim \sigma)$

For close binaries: $GM_{12}/[a\sigma^2] >> 1$

$$\Rightarrow \Sigma \sim 2\pi a GM_{123}/\sigma^2$$

(Approximate exchange cross section.)



Scattering Statistics

Rate per binary: $f_p\, n_s\, \langle \Sigma\sigma \rangle$

(average over singles)

Number per cluster: $\int dt \int dV\, n_b\, f_p\, n_s\, \langle\langle \Sigma\sigma \rangle\rangle$

(average over singles and close binaries)

$\boxed{\sim 0.003\ (N/100)^2}$

Sum over clusters:

$\boxed{F_{cbp}(\text{theory}) \sim 0.001}$

Result

$$F_{cbp}(\text{theory}) \sim 0.1\ F_{cbp}(\text{obs})$$

Maybe nature knows how to make giant planets in close binaries.

???

What's Next?

- More observations.

  (Konacki; Eggenberger et al.; Lane, Muterspaugh, et al.)

- Census of stellar birth clusters.

  (Taurus or Orion?)

- Better calibration of dynamics.

  (few-body; full N-body models)