Open problems in compact object dynamics

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Key ideas and open questions in compact object dynamics

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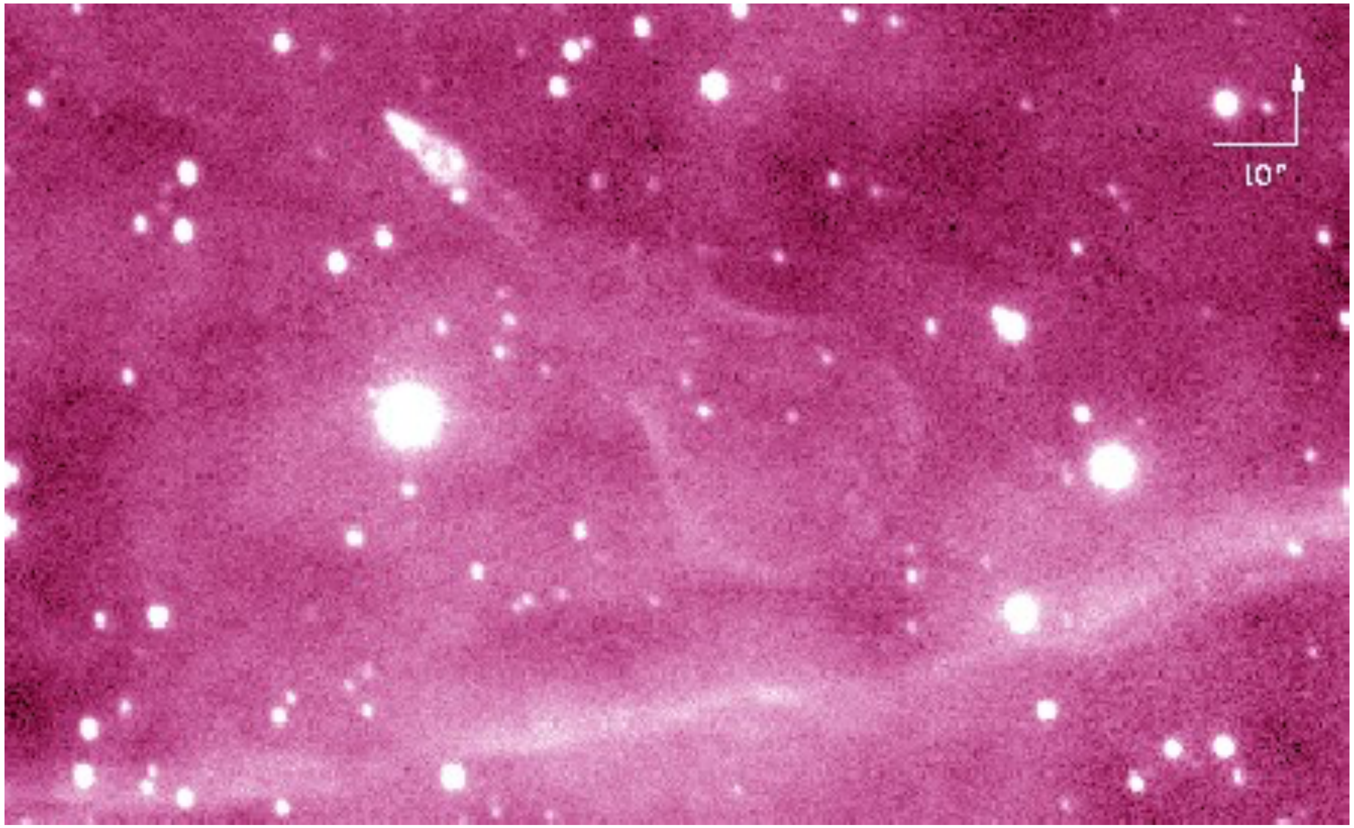
KEY IDEA #1

Natal kicks can keep binaries together.

Guitar Nebula

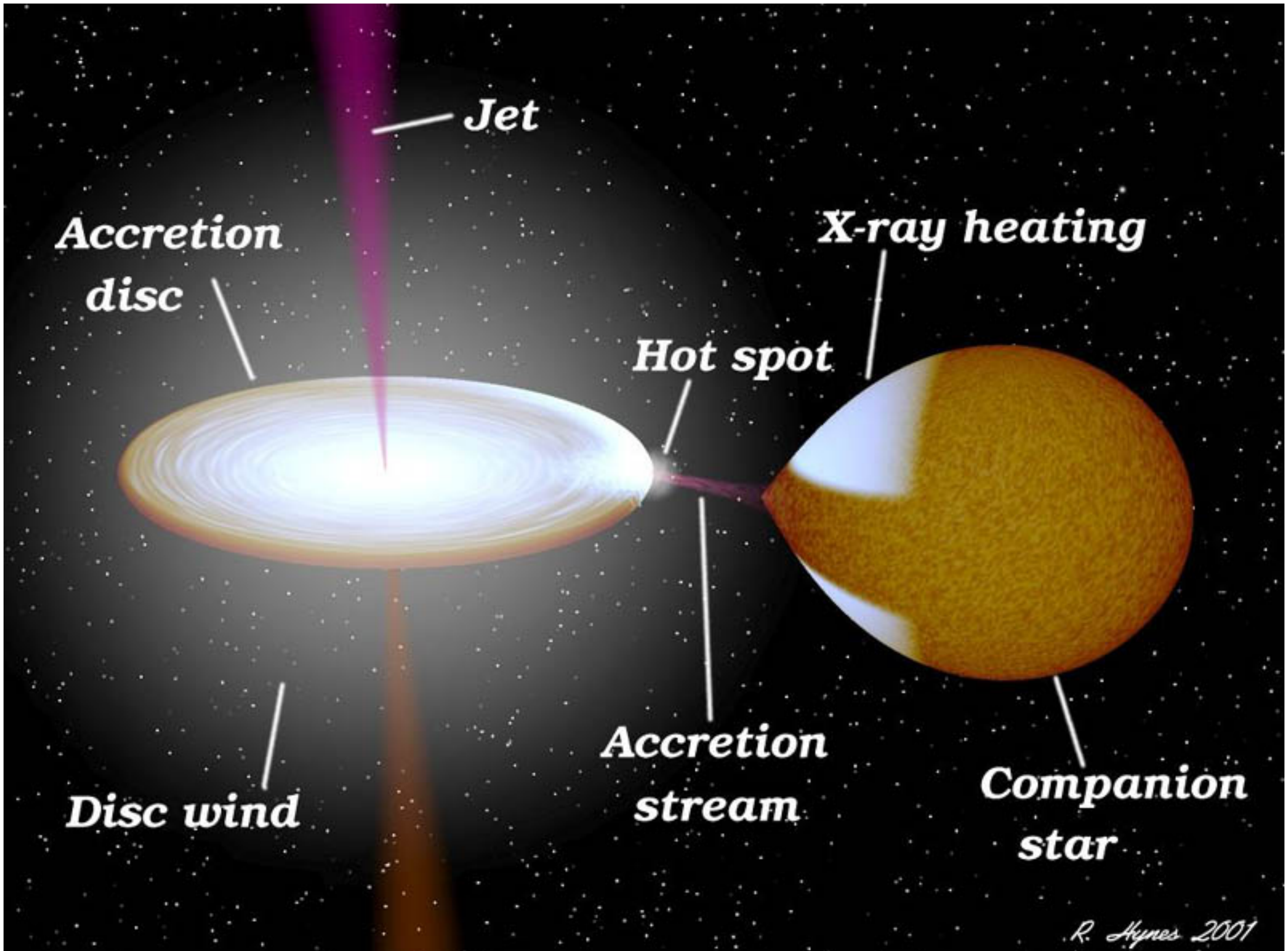


Palomar Observatory

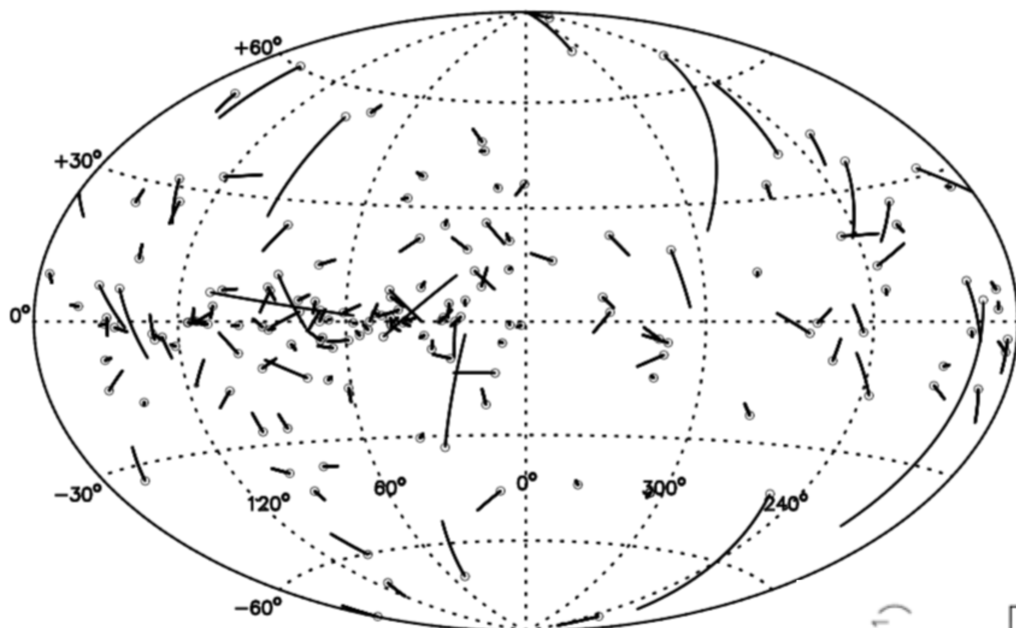
PSR 2224+65 transverse velocity of above 800 km/s

(Cordes et al. 1993)

Low-mass X-ray binaries

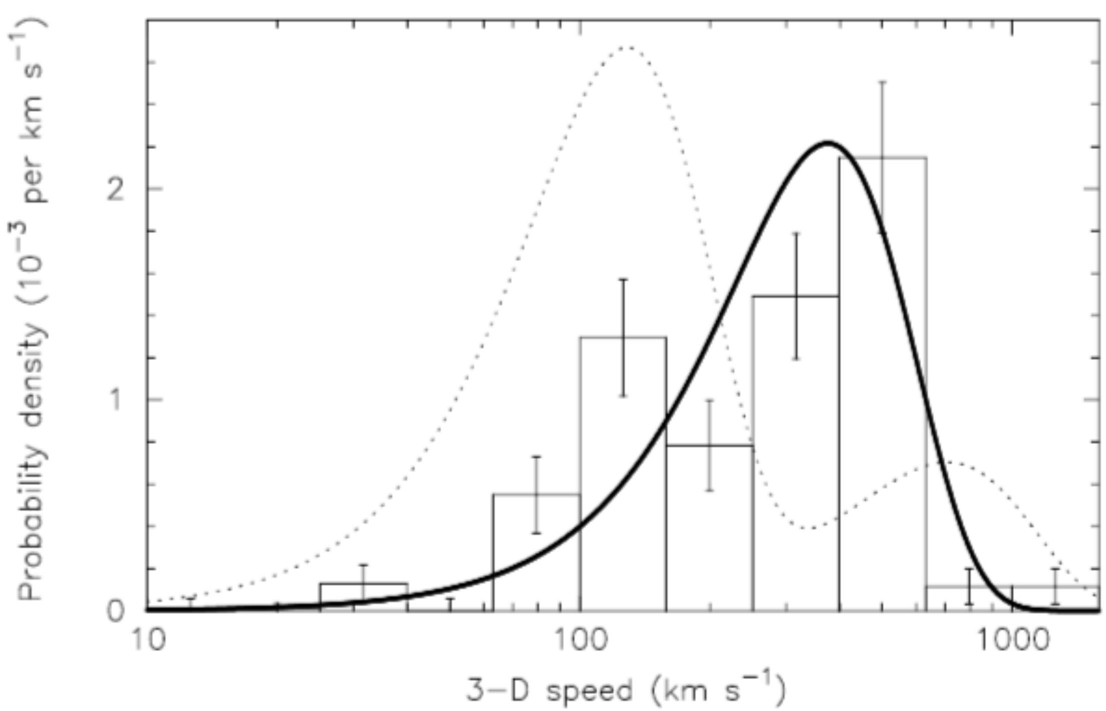


Neutron star kicks



(e.g. Hobbs et al. 2005)

Much discussion about the cause of the kicks e.g. Dong Lai et al.

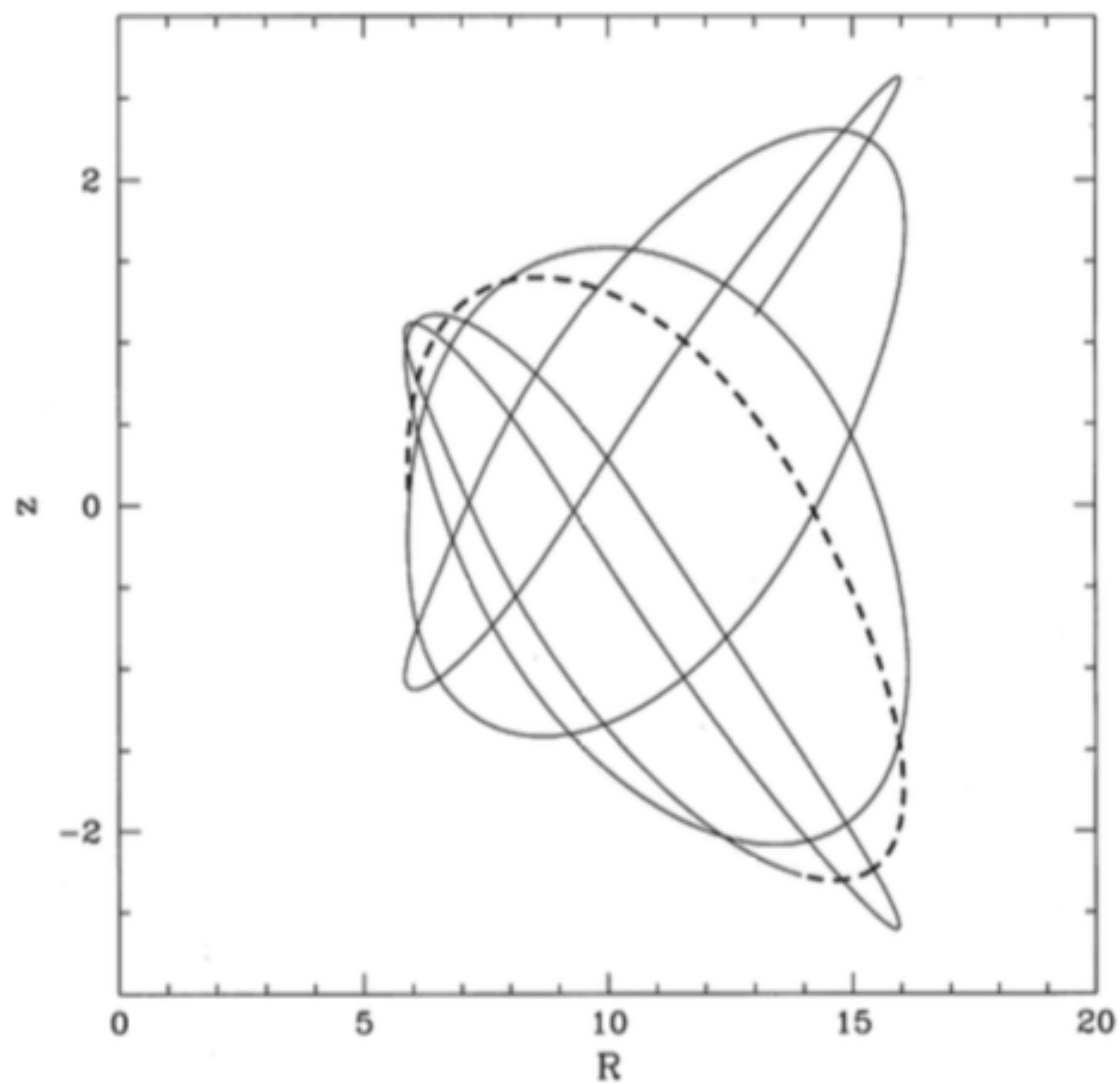


KEY IDEA #2

The *three Vs conspiracy* means that kicks make an observable impact.

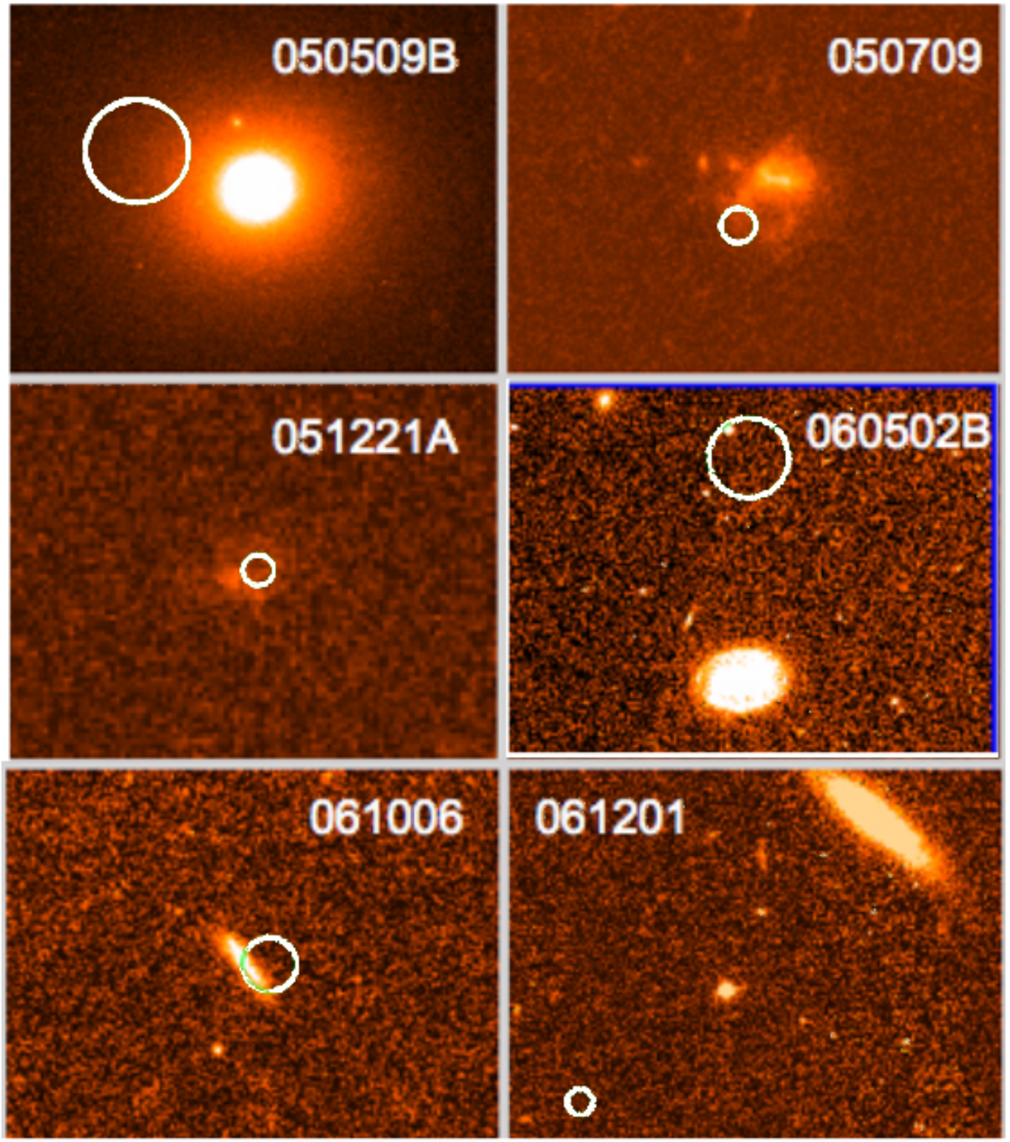
Cygnus X-2

Cyg X-2 is an X-ray binary containing a neutron star which has been ejected from the Galactic disc some time ago



(Kolb et al. 2000)

Locations of short gamma-ray bursts



SGRBs may originate from the merger of NS-NS binaries

See Tauris et al. 2017 for a review of the formation of NS-NS binaries

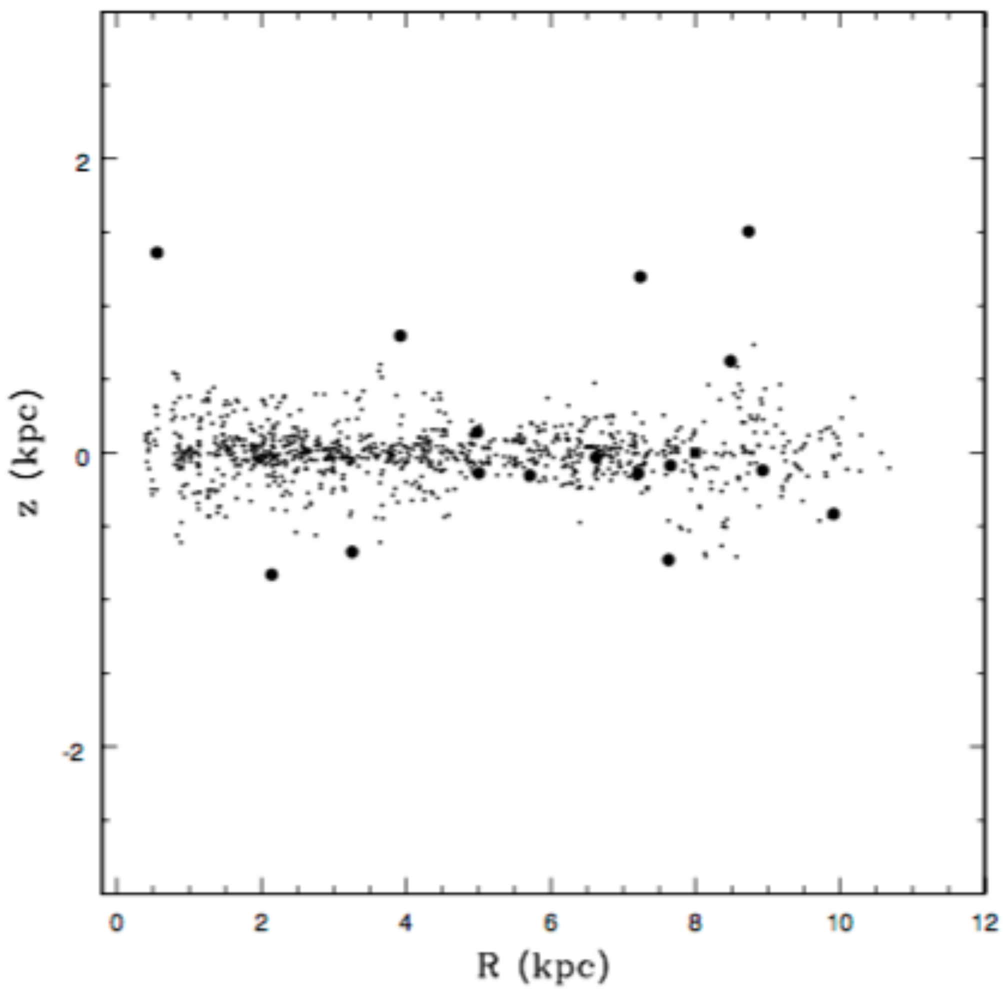
Localisations from the Swift satellite

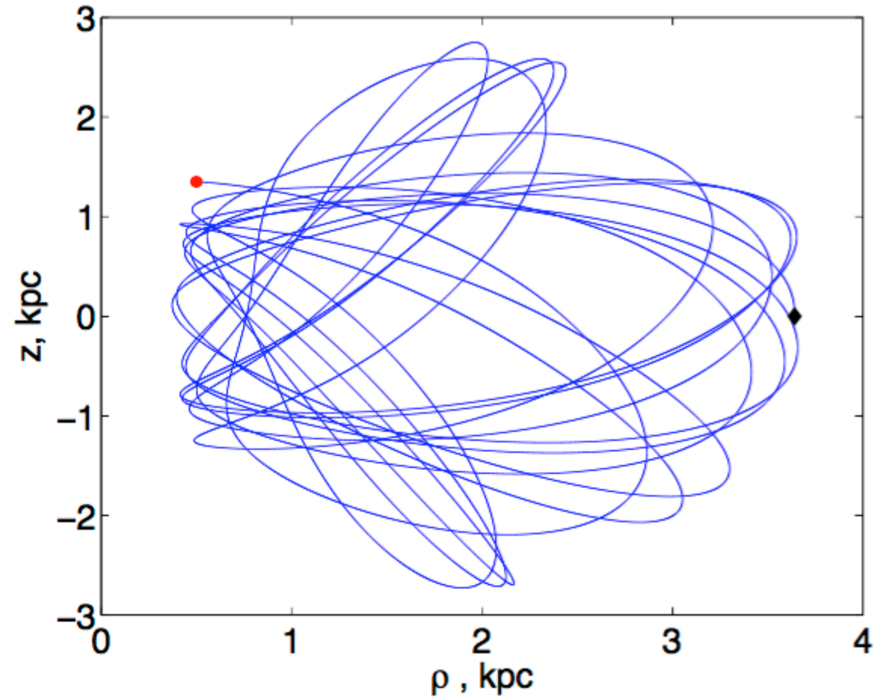
(Church et al. 2011)

KEY IDEA #3 (open question)

Do black holes receive kicks when they are formed in core-collapse supernovae?

Black hole kicks (?)





BHs without natal kicks

(Repetto et al. 2012)

Up-and-in better than up

(Mandel 2016)

KEY IDEA #4 (open question)

Binary evolution in the field compared
to evolution due to encounters in clusters.
Which one dominates (in terms of the
production of gravitational-wave sources)?

Producing compact binaries outside of clusters

Initial main-sequence - main-sequence binary

Most massive star evolves and transfers envelope

... leaving a helium-star - main-sequence star binary

Helium star explodes in the first supernova explosion

... to leave a neutron-star - main-sequence binary

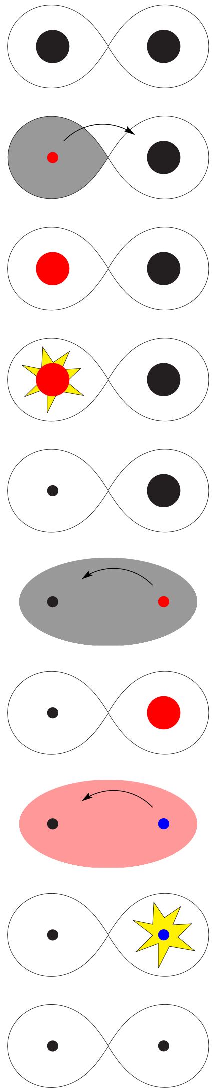
Second star evolves into a giant, and transfers mass unstably

... forming a tight helium-star - neutron-star binary

Helium star transfers mass unstably, forming a very tight binary

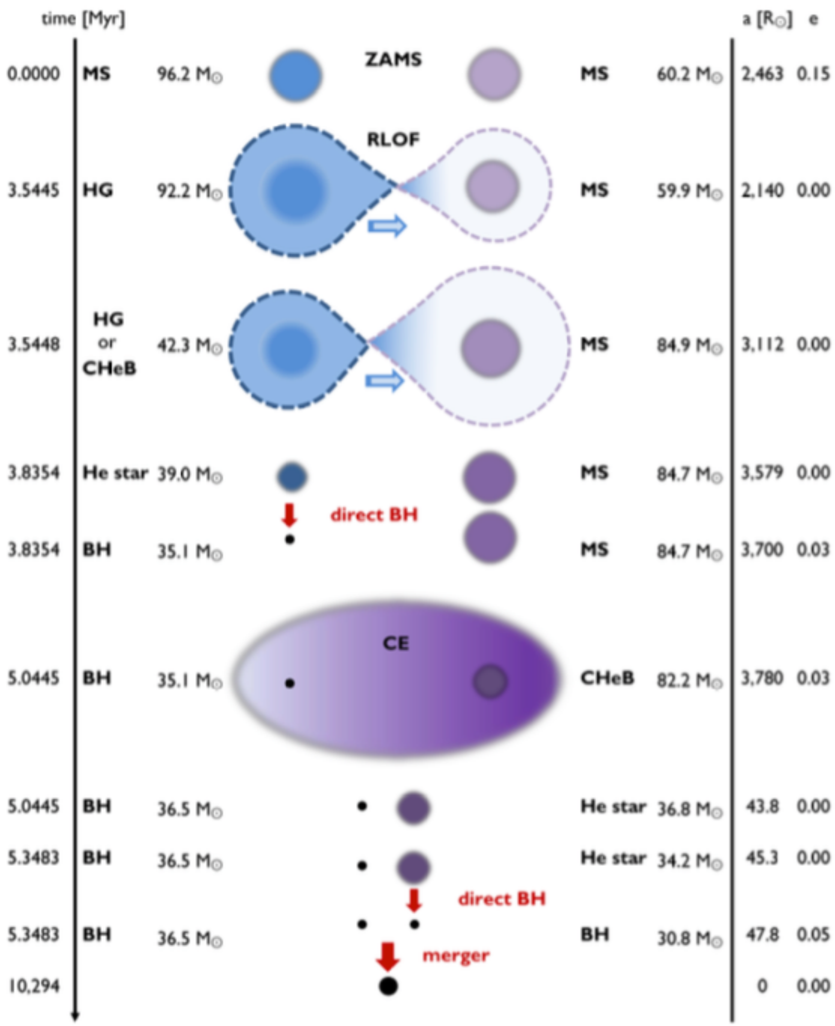
Finally the core explodes as a supernova,

... to leave an ultra-compact double neutron-star binary

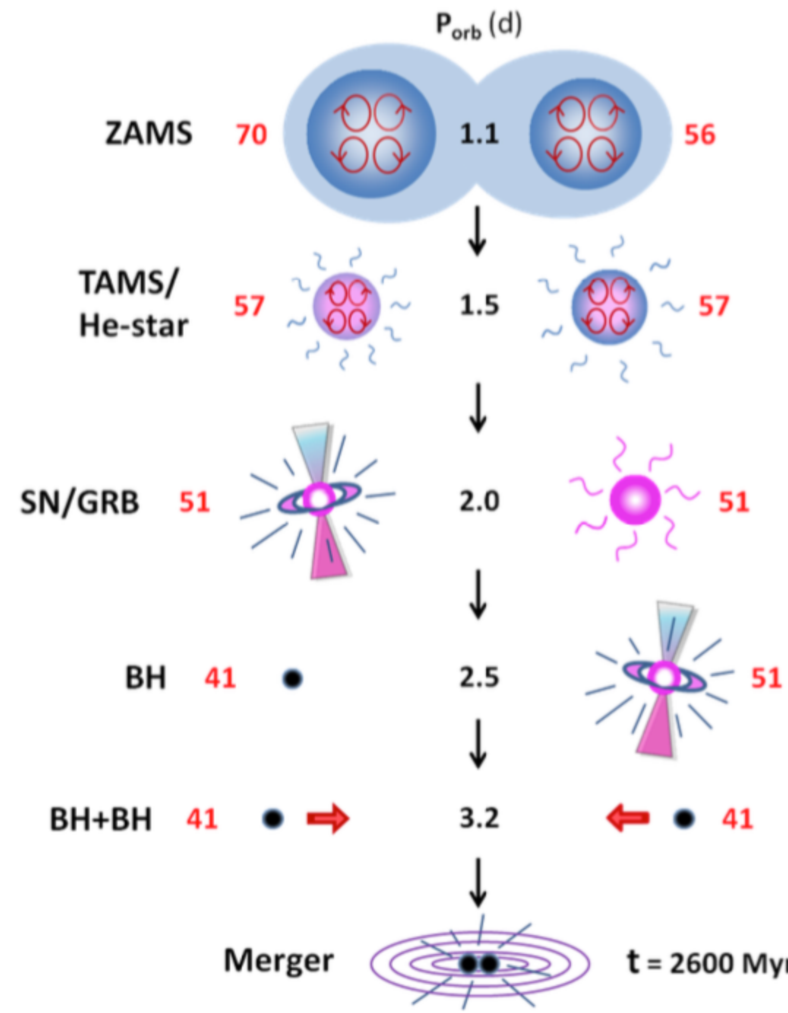


(Church et al. 2011)

Producing BH-BH binaries in the field

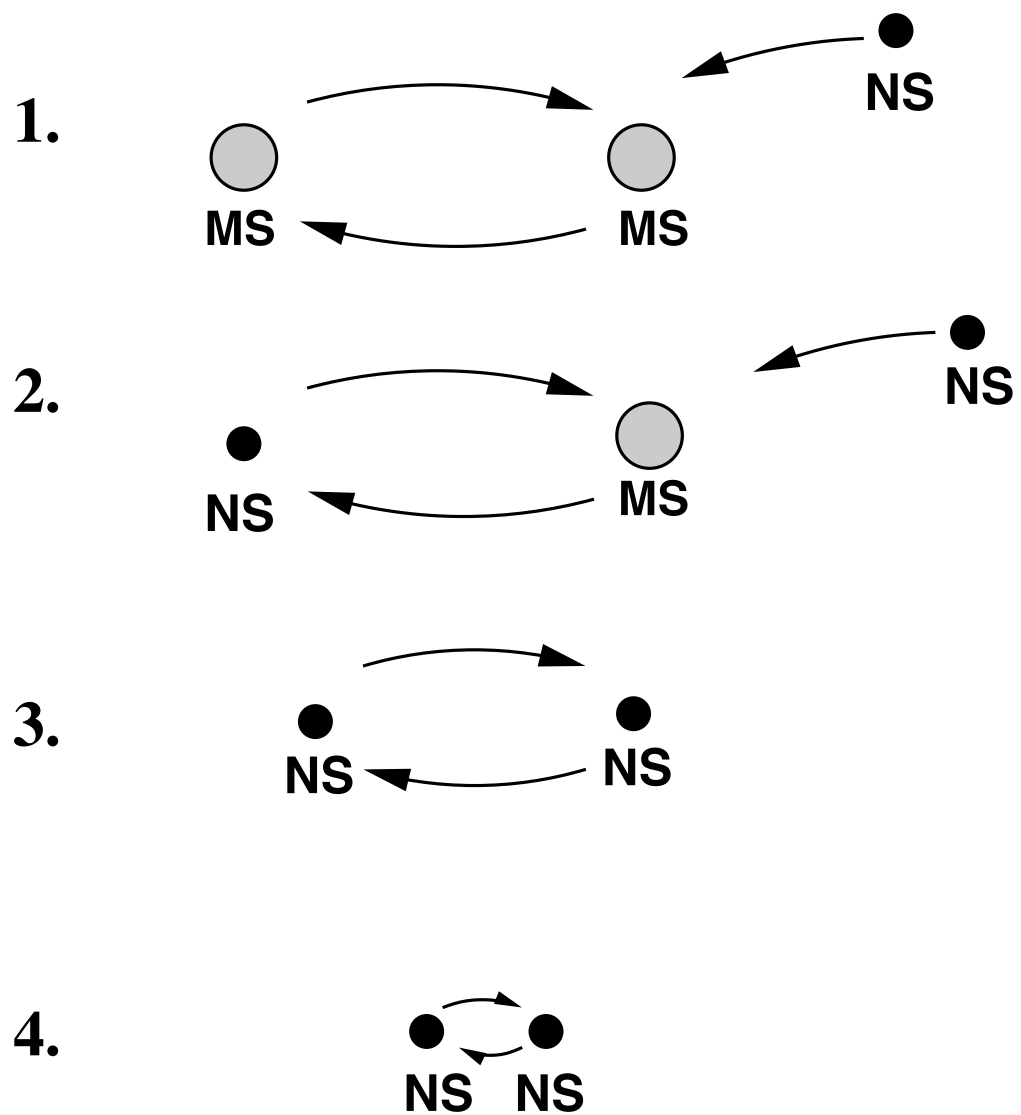


(Belczynski et al. 2016)



(De Mink et al. 2016; Marchant et al. 2016)

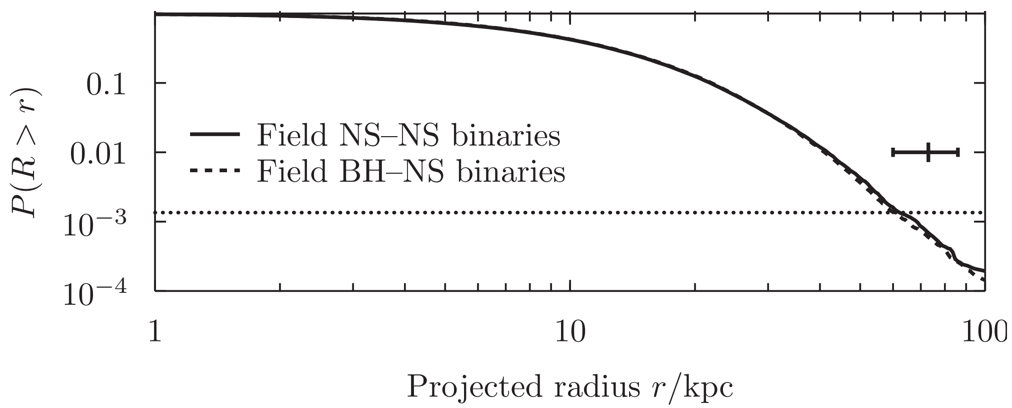
Producing compact binaries within clusters

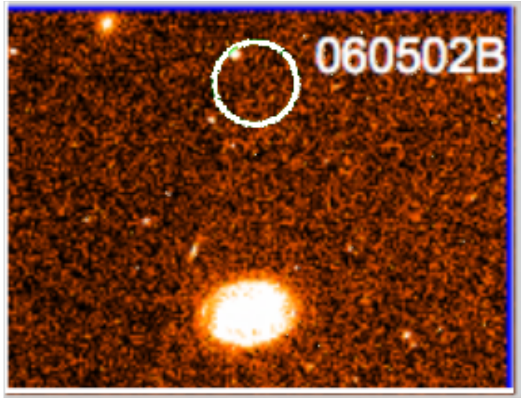


(eg. Davies 1995)

Offsets sometimes larger than expected

060502B - burst occurred outside host galaxy





It could be that the progenitor formed dynamically in a globular cluster.

(Church et al. 2011)

Also looking at offsets for WD-NS systems (Church et al. in prep.)

So which dominates, field or cluster?

$$\boxed{\text{Common} \times \text{Rare} \approx \text{Rare} \times \text{Common}}$$

KEY IDEA #5

Encounters break up wide binaries and mop up massive stars in to hard binaries which can be very eccentric.

Encounter timescales

Cross section is given by

$$\sigma = \pi R_{min}^2 \left(1 + \frac{2G(M_1 + M_2)}{R_{min} V_\infty^2} \right)$$

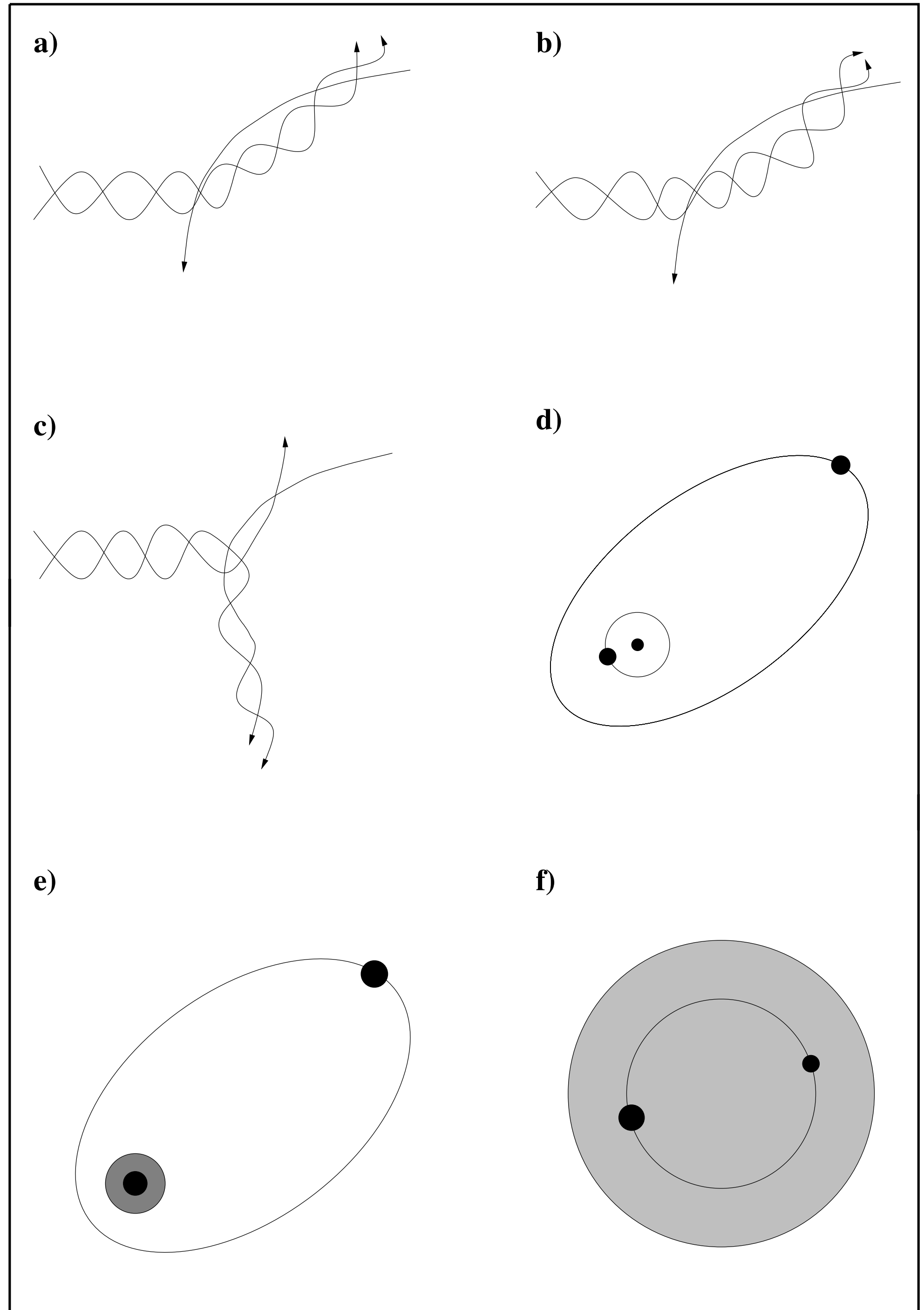
Timescale for a given object to undergo an encounter is

$$\tau_{enc} \sim 10^{11} yr \ \left(\frac{10^5/pc^3}{n} \right) \cdot \left(\frac{M_\odot}{M} \right) \cdot \left(\frac{R_\odot}{R_{min}} \right) \cdot \left(\frac{V_\infty}{10km/s} \right)$$

For 2+1 encounters, Rmin is roughly the size of the binary, which can be much larger than the radius of a star.

Can have situation where $\Gamma_{1+1} \simeq \Gamma_{2+1}$

Possible outcomes of encounters between a binary and a single star.



Concepts concerning binary-single encounters

- Hard-soft boundary

$$d_{\rm hs} \simeq 6{\rm AU}\left(\frac{V_\infty}{10{\rm km/s}}\right)^{-2}$$

- Soft binaries get broken up
- Hard binaries get harder
- Thermal distribution of eccentricities
- Clean exchanges: lowest-mass star ejected
- Stellar collisions occur during encounters

2+2 compared to 2+1

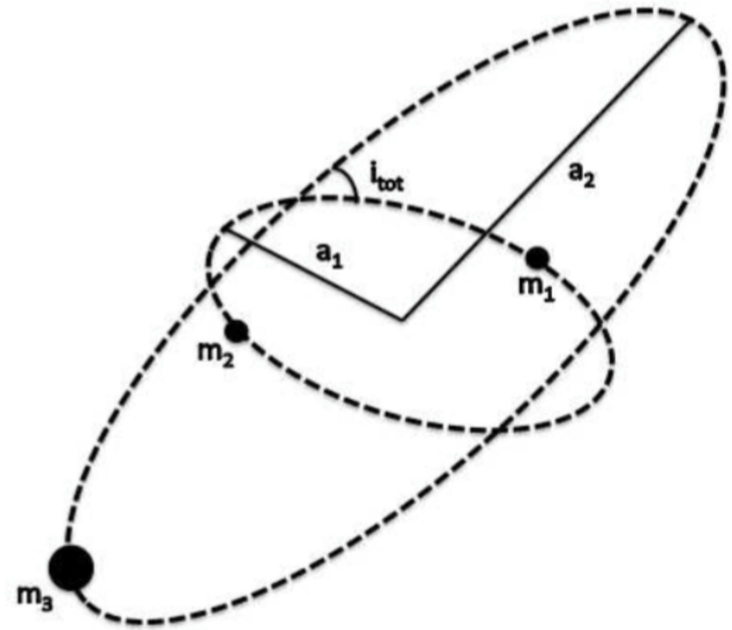
Cross section for some 2+2 interaction roughly same as for 2+1.

Physical collisions more common in wide binaries for 2+2 than for 2+1, as

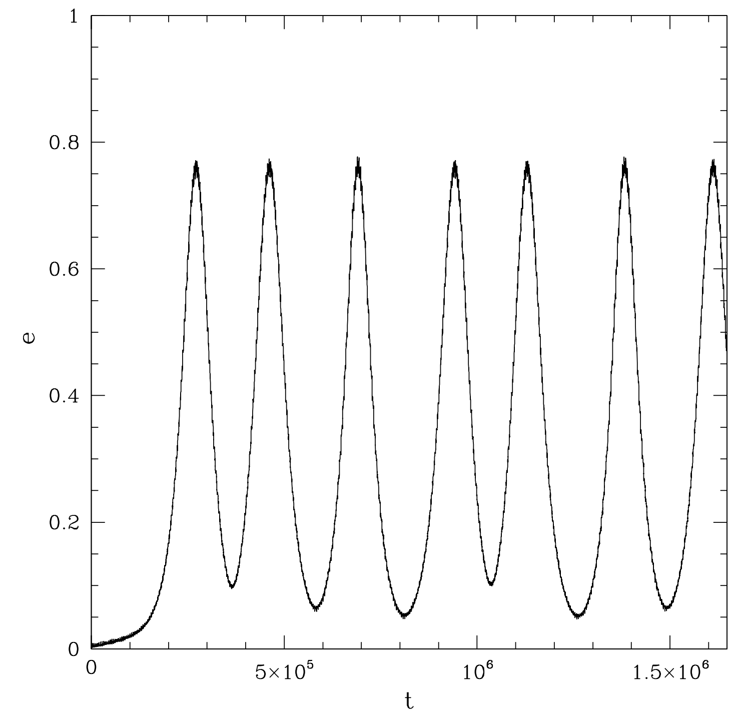
$$\boxed{\frac{4}{2}(4-1) > \frac{3}{2}(3-1)}$$

It is common for 2+2=2+1+1.

Triples



(VanLandingham et al. 2016)

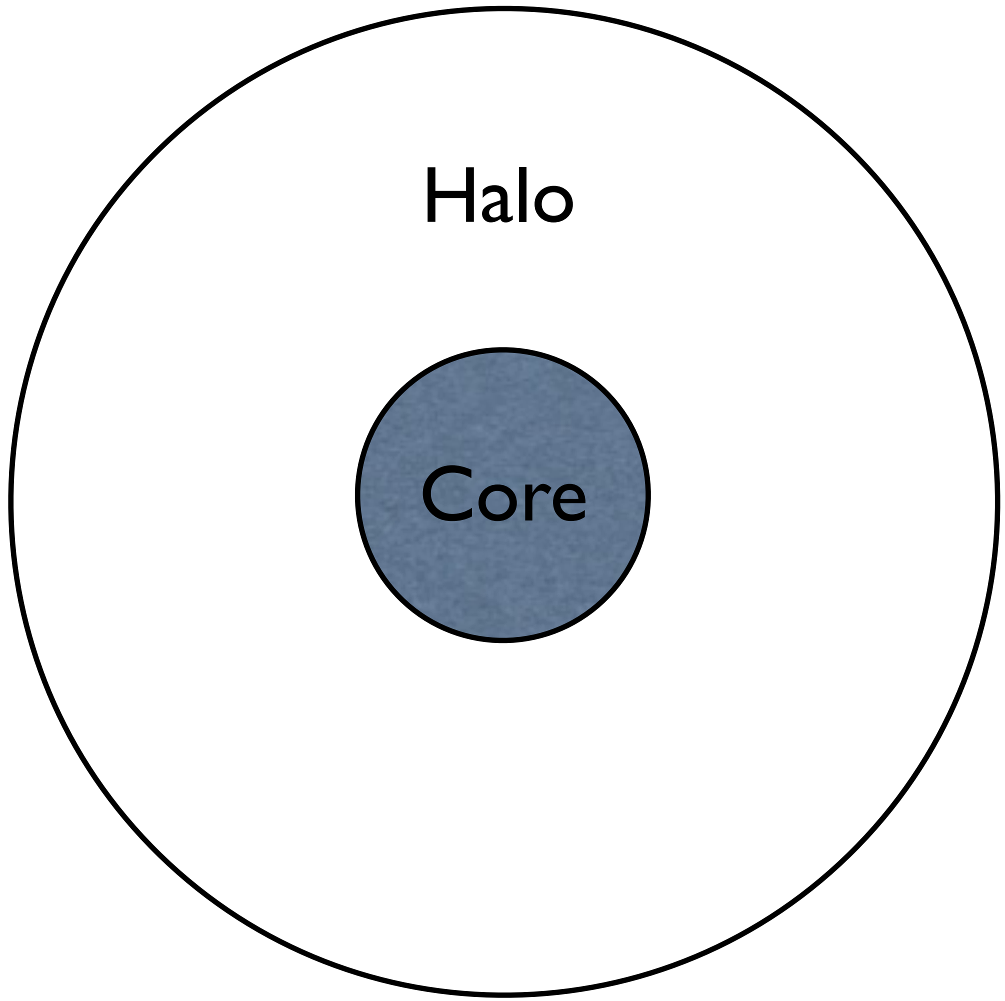


(Malmberg et al. 2007)

KEY IDEA #6

Two-body relaxation drives the dynamical evolution of stellar clusters. Core collapse may be prevented by sources of heating. Cluster evolution matters: properties determine encounter rates and retention.

A model stellar cluster

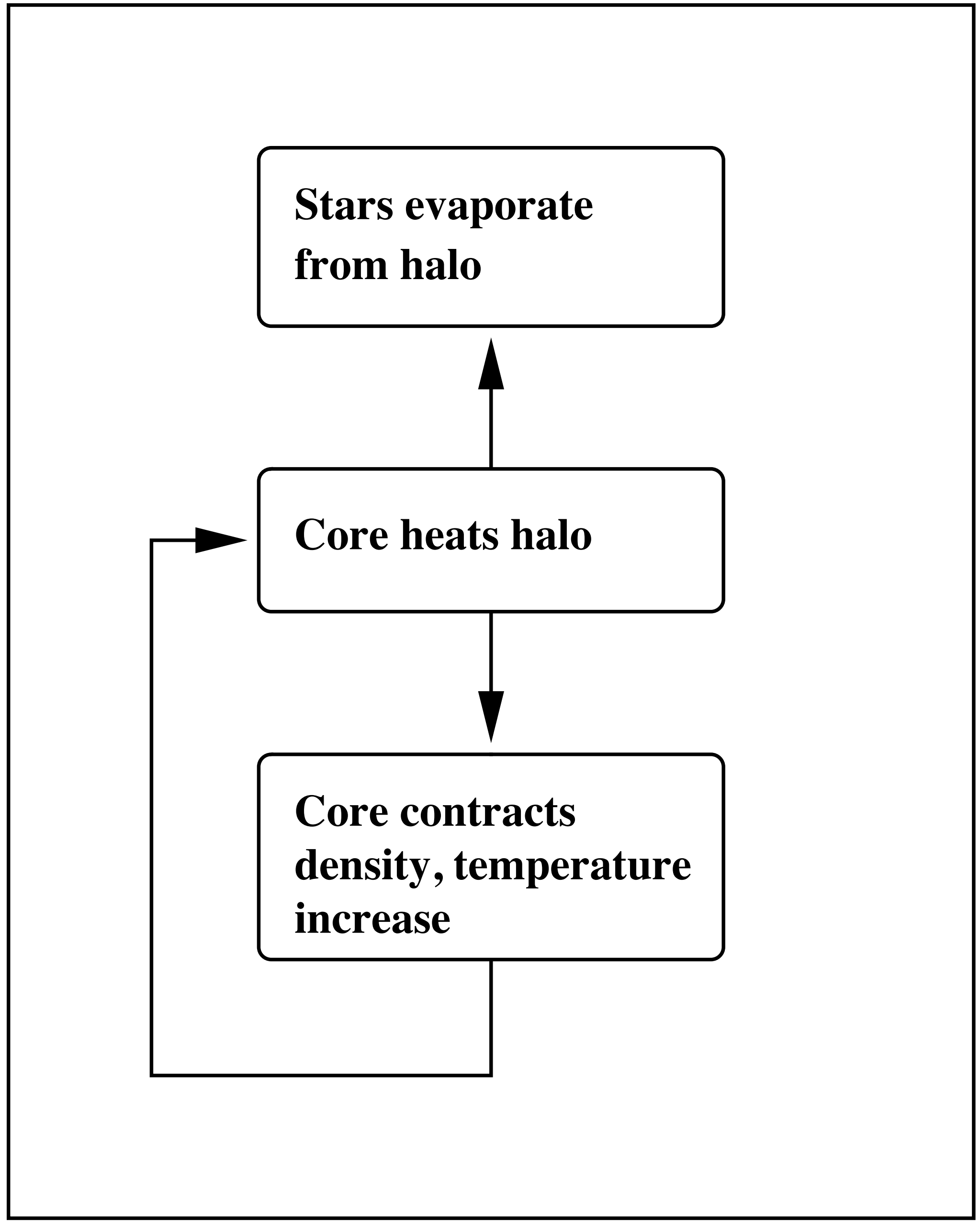


Key ideas:

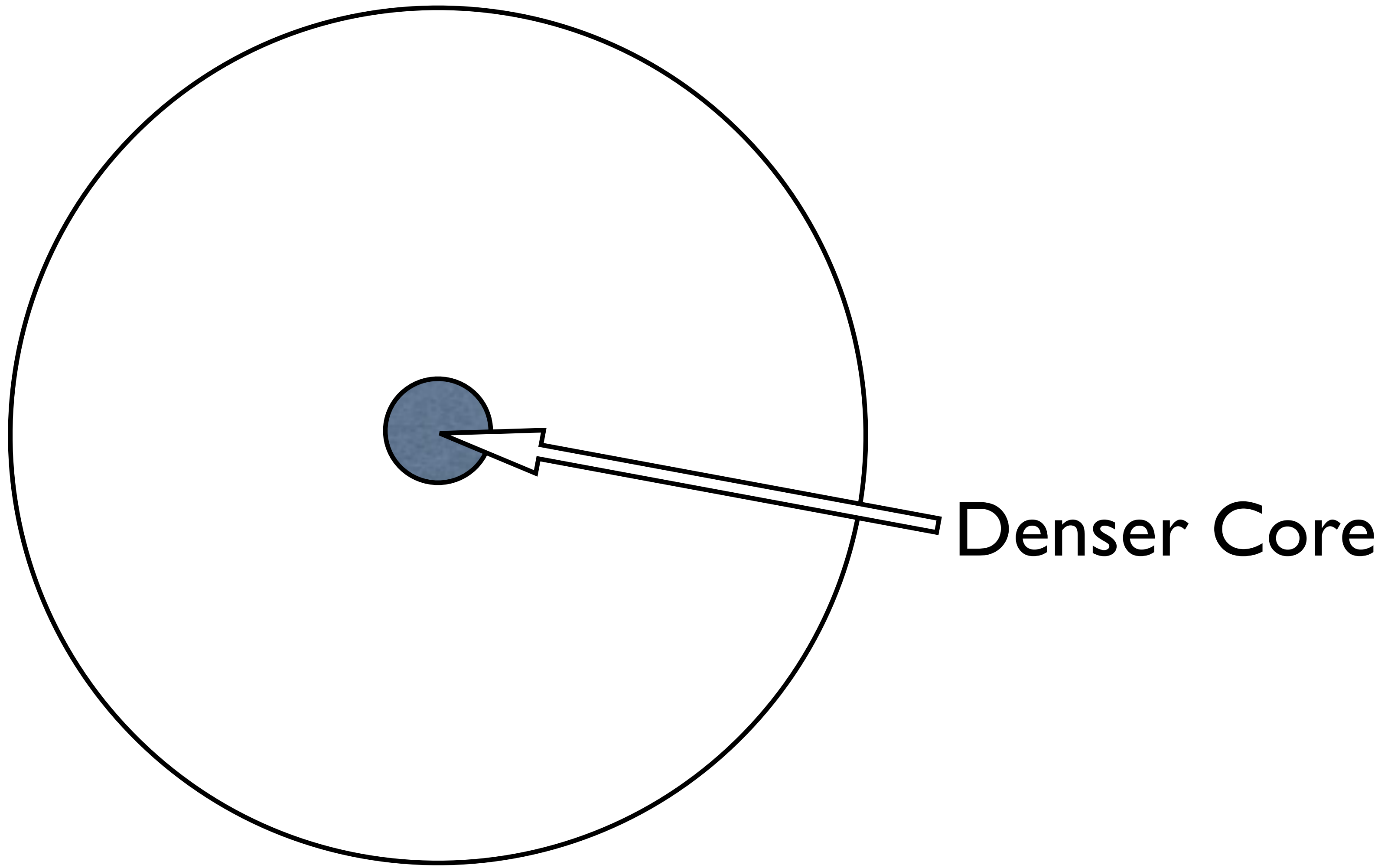
Scattering between stars transports energy within a cluster (two-body relaxation).

Self-gravitating systems have a negative heat capacity.

The dynamical evolution of a cluster



An evolved stellar cluster



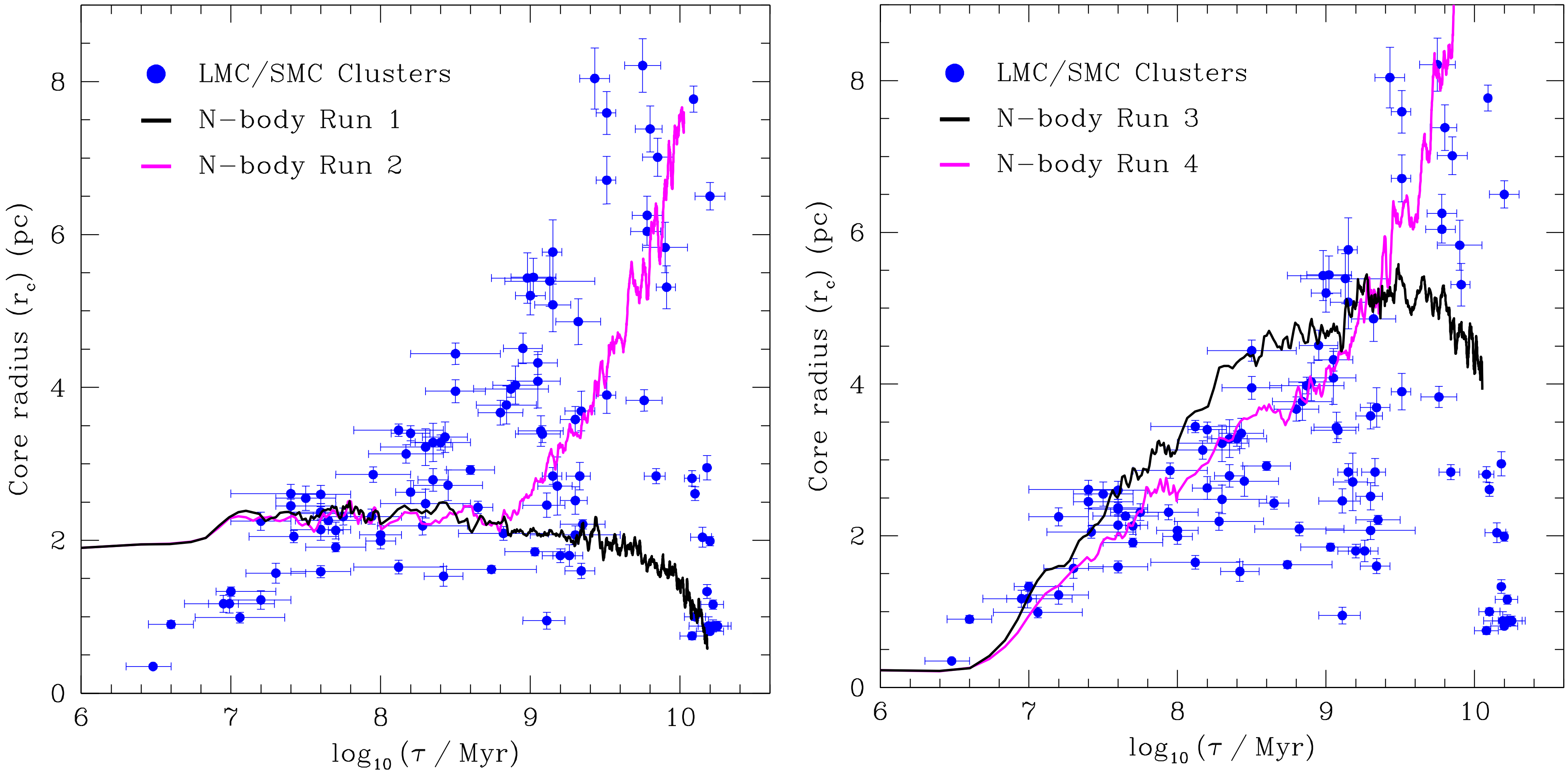
A competition between two processes:

Energy loss via two-body scattering from cluster core leading to core collapse.

Heating via binary-single encounters which could prevent or delay core collapse.

If binaries are tight enough they will spiral together and merge before they can heat the cluster.

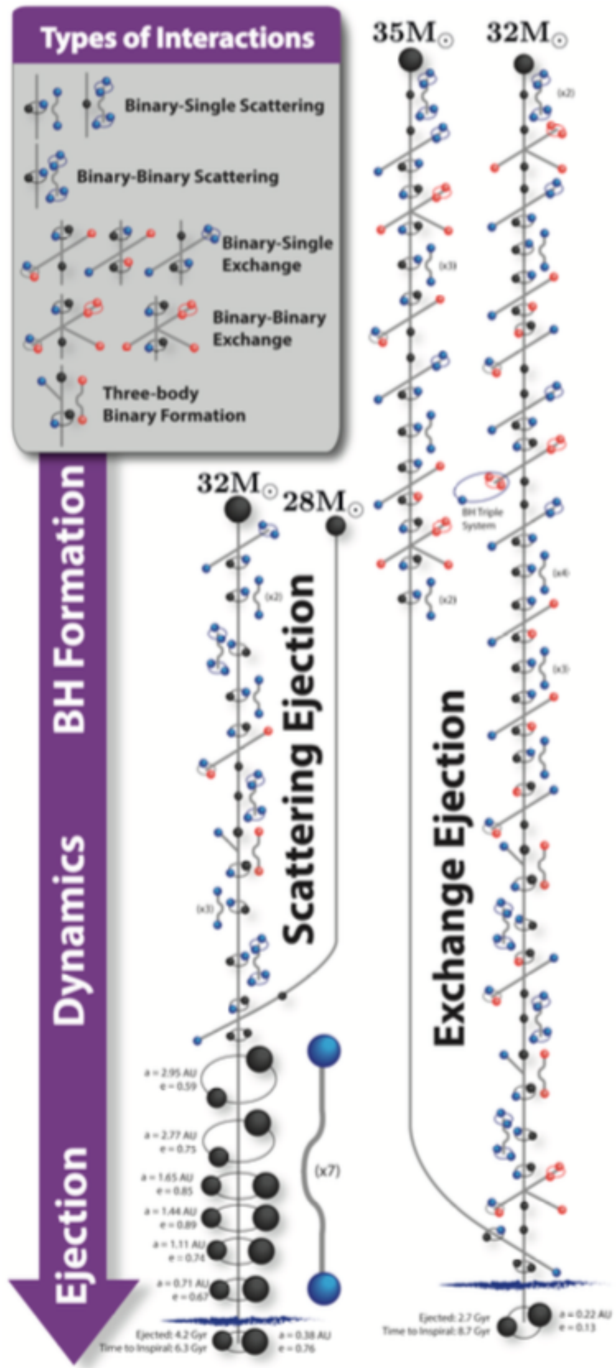
BHs can *heat* a cluster



(Mackey et al. 2007; 2008)

KEY IDEA #7

Exotica production in stellar clusters is a complex business.



An example of how binary-single scattering can produce a tight BH-BH binary which then spirals in due to the emission of gravitational radiation

(Rodriguez et al. 2016)

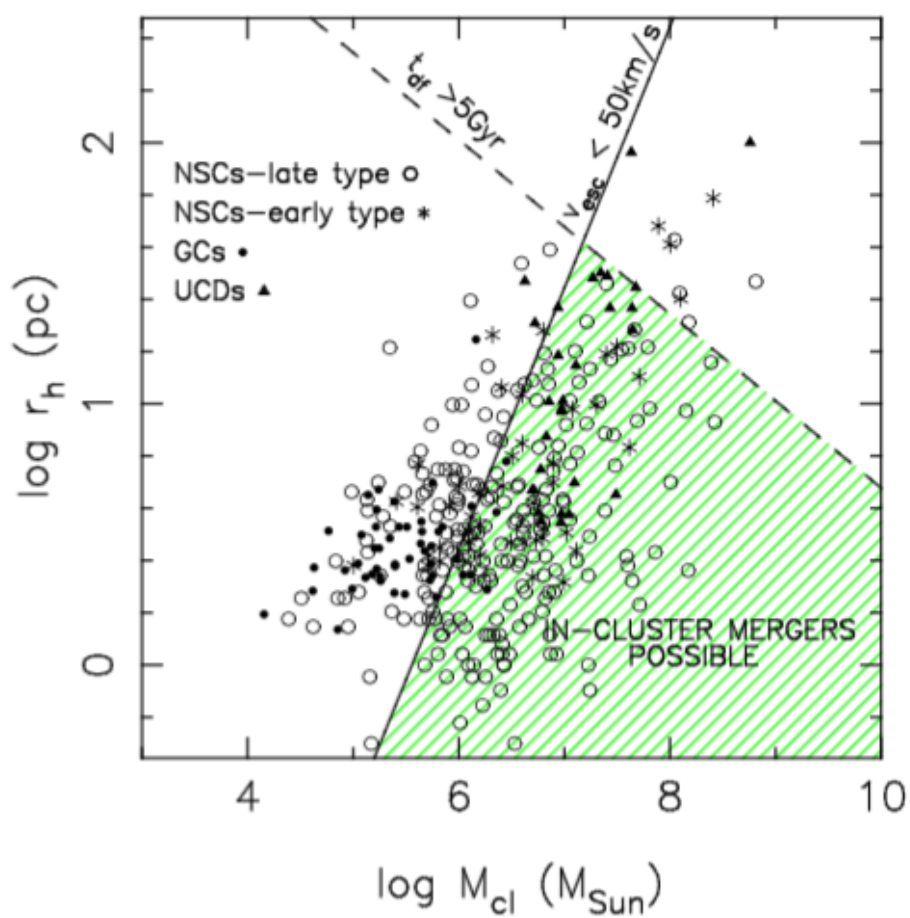
The three kicks

1) Natal black hole kicks

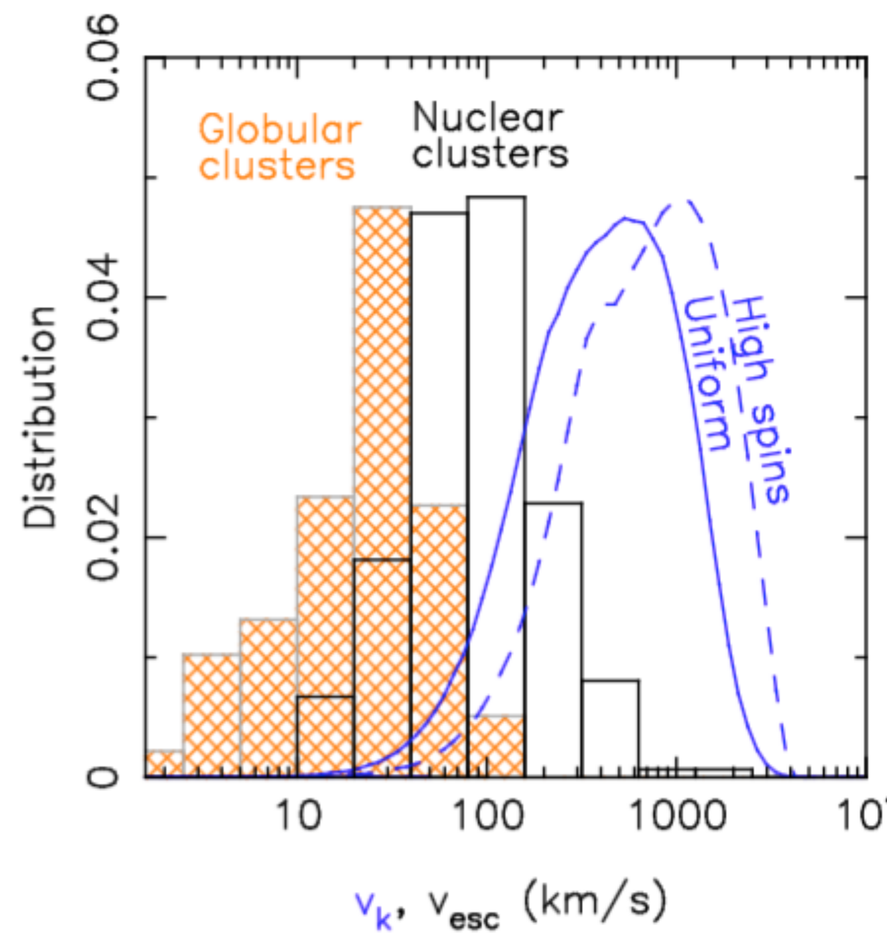
2) Scattering kicks

3) GR merger kicks

Not too heavy, not too light

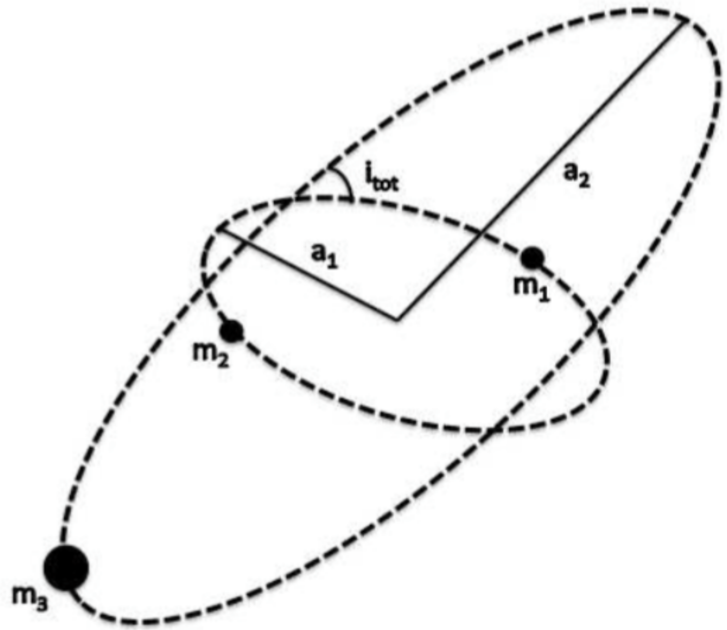


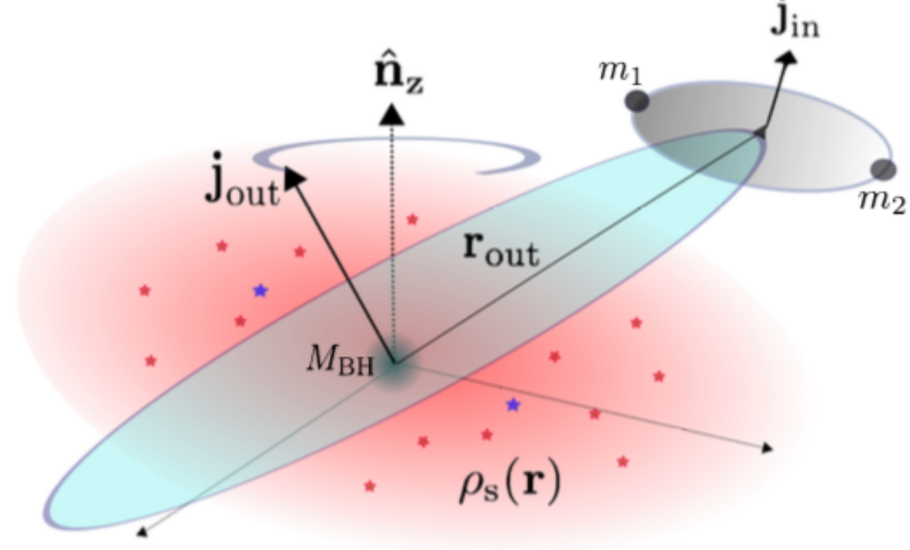
Timescales!



(Antonini & Rasio 2016)

Triples again





(VanLandingham et al. 2016) (Petrovich & Antonini 2017)

Summary:

1) natal kicks can be helpful (e.g. LMXBs)

2) three Vs conspiracy (kick, orbital, orbital)

3) do BHs receive natal kicks?

4) binary evolution vs cluster engine?

5) encounters: break up, harden, make eccentric

6) cluster evolution: core collapse vs. heating

7) clusters can create compact-object coalescences