Stellar Clusters as Factories Producing Exotic Objects

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http://www.astro.lu.se/Research/OTA

Driving questions

- How unusual is our solar system?
- What powers gamma-ray bursts and supernovae?
- How do black holes form and grow?

Key ideas coming up today:

1) planetary systems are messed up in young clusters

2) compact binaries containing neutron stars and black holes are made dynamically in globular clusters

3) supermassive black holes form and grow in galactic nuclei

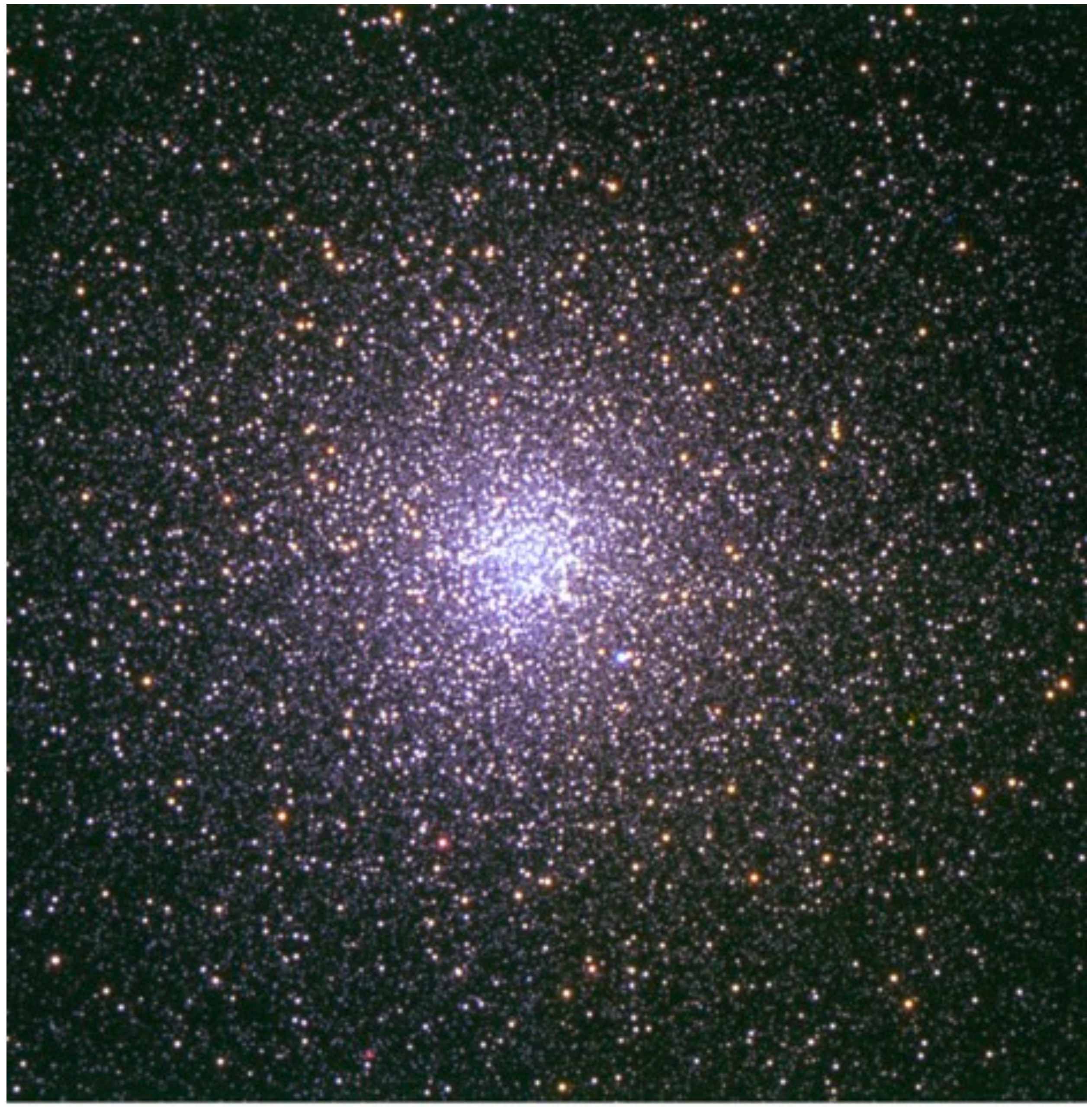
Spiral Galaxy NGC 1232

Young star-forming regions

Orion nebula and Trapezium cluster (IR image)

All stars are formed in some sort of group.

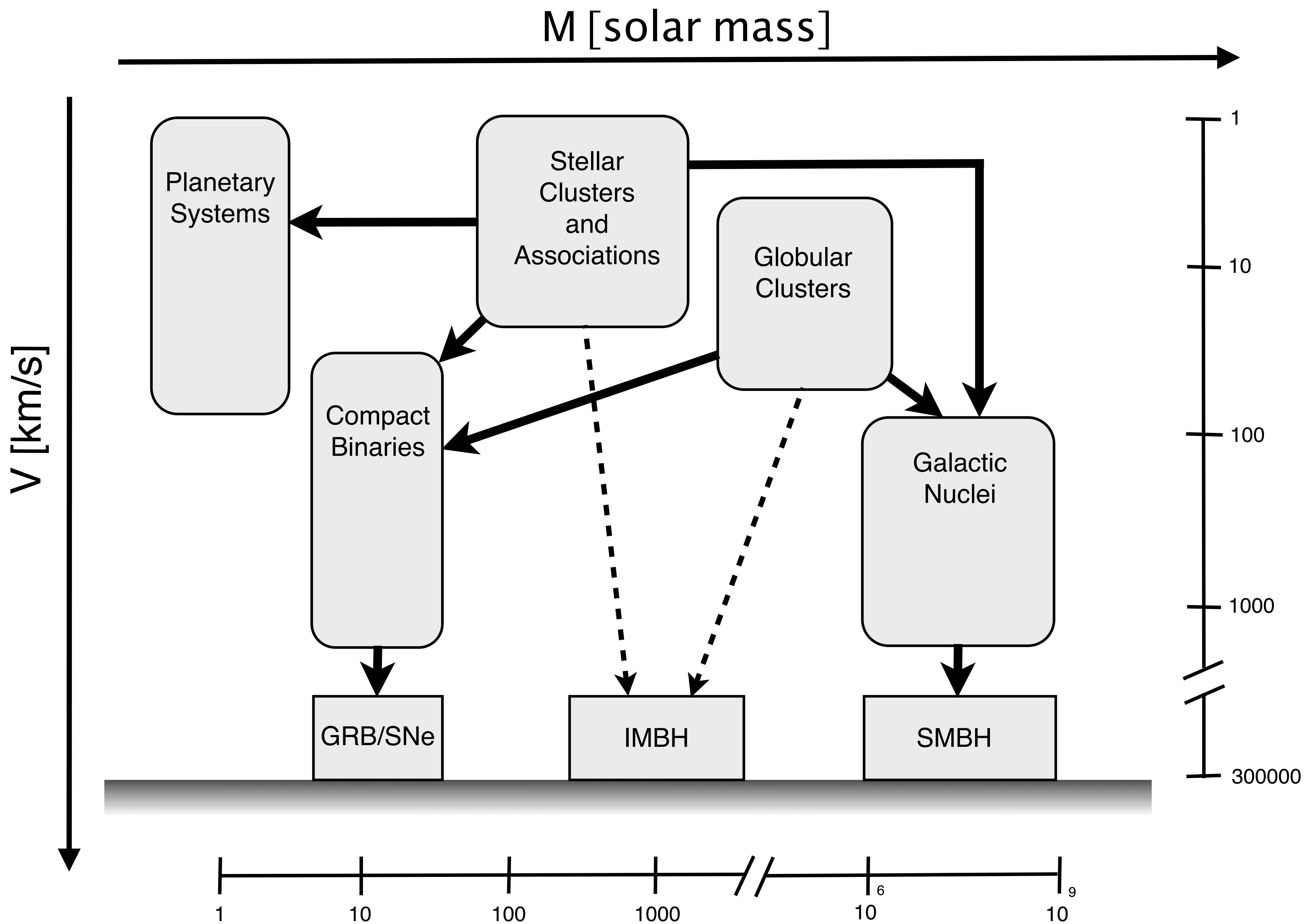
Globular Clusters



Globular Cluster 47 Tucanae
(FORS/VLT)

ESO PR Photo 20/06 (8 June 2006)

IR Image of the Galactic Centre


M [solar mass]
V [km/s]
Planetary Systems
Stellar Clusters and Associations
Globular Clusters
Compact Binaries
Galactic Nuclei
GRB/SNe
IMBH
SMBH
1
10
100
1000
300000
1
10
100
1000
10^6
10^9

Stellar 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 star to undergo an encounter is

$$\tau_{enc} \simeq 3.3 \times 10^7 yr \left(\frac{100\ pc^{-3}}{n}\right) \left(\frac{V_\infty}{1\ km/s}\right) \left(\frac{10^3\,AU}{R_{min}}\right) \left(\frac{M_\odot}{M_t}\right)$$

Encounters happen interestingly often.

Two things happen to planetary systems

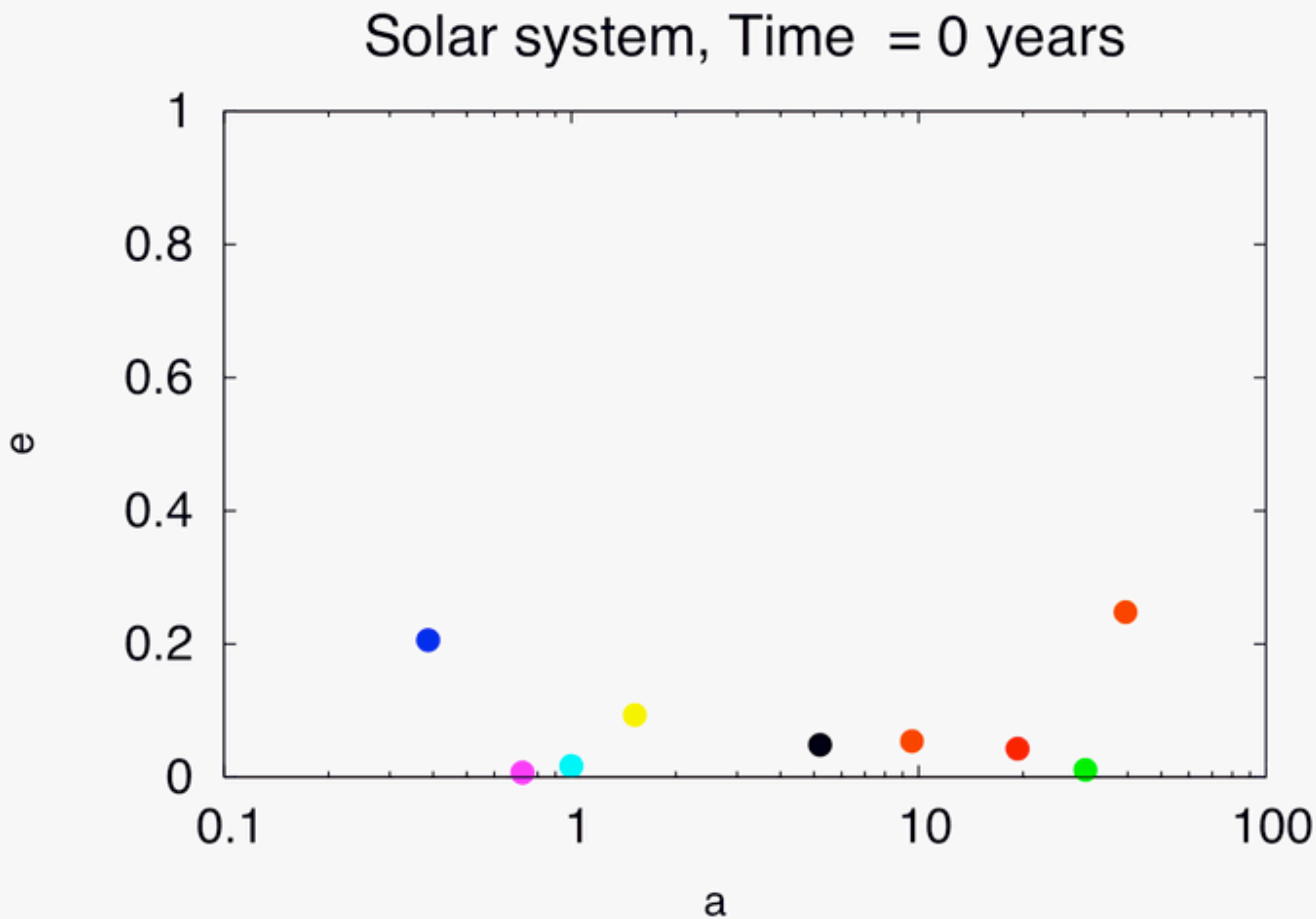
Either i) close encounters within young stellar groupings or ii) exchange encounters which leave planetary systems in binaries.

Strong planet-planet interactions within planetary systems sometimes follow.

Singletons are stars born single which don't have close encounters or exchange in to binaries.

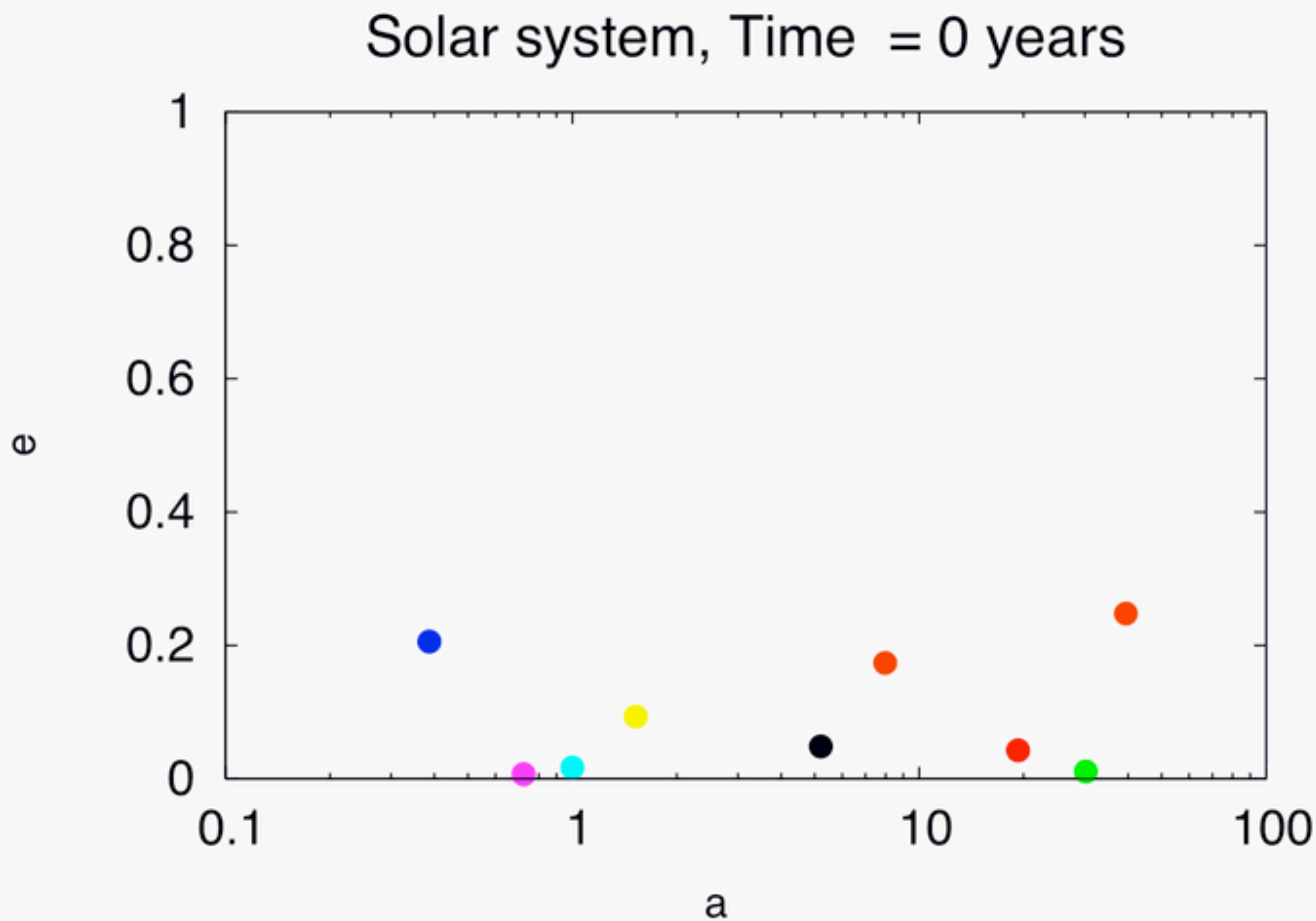
Unperturbed system:

Unperturbed system:

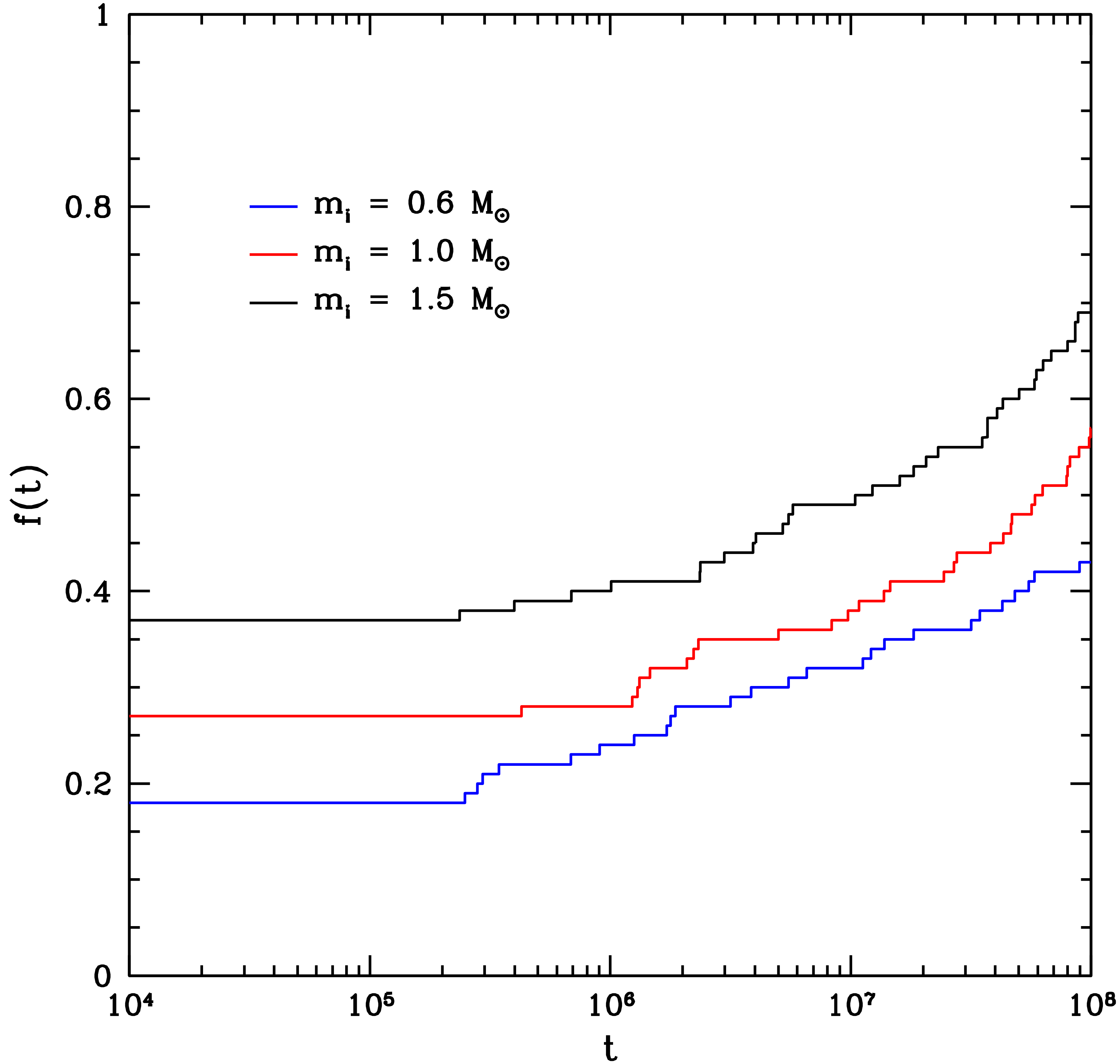


After a fly-by encounter:

After a fly-by encounter:



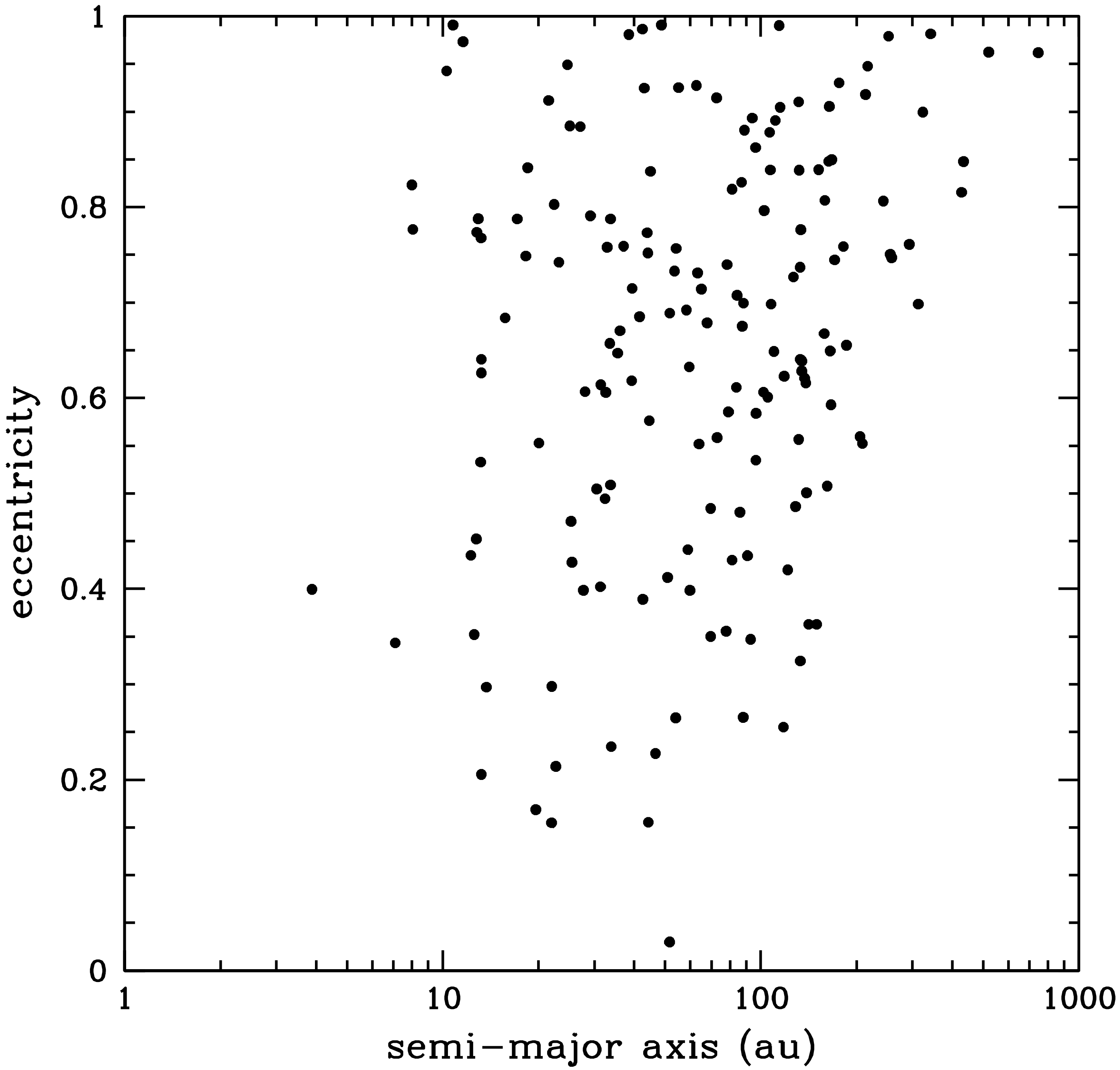
The long term effect of fly-bys (within 100 AU)



The fraction of solar-mass stars with four gas giants in a cluster of 700 stars that lose at least one planet within 100 million years of a close fly-by: 0.15

(Malmberg, Davies & Heggie, 2011)

Post fly-by systems consisting of a single planet bound to the intruder star immediately after the fly-by

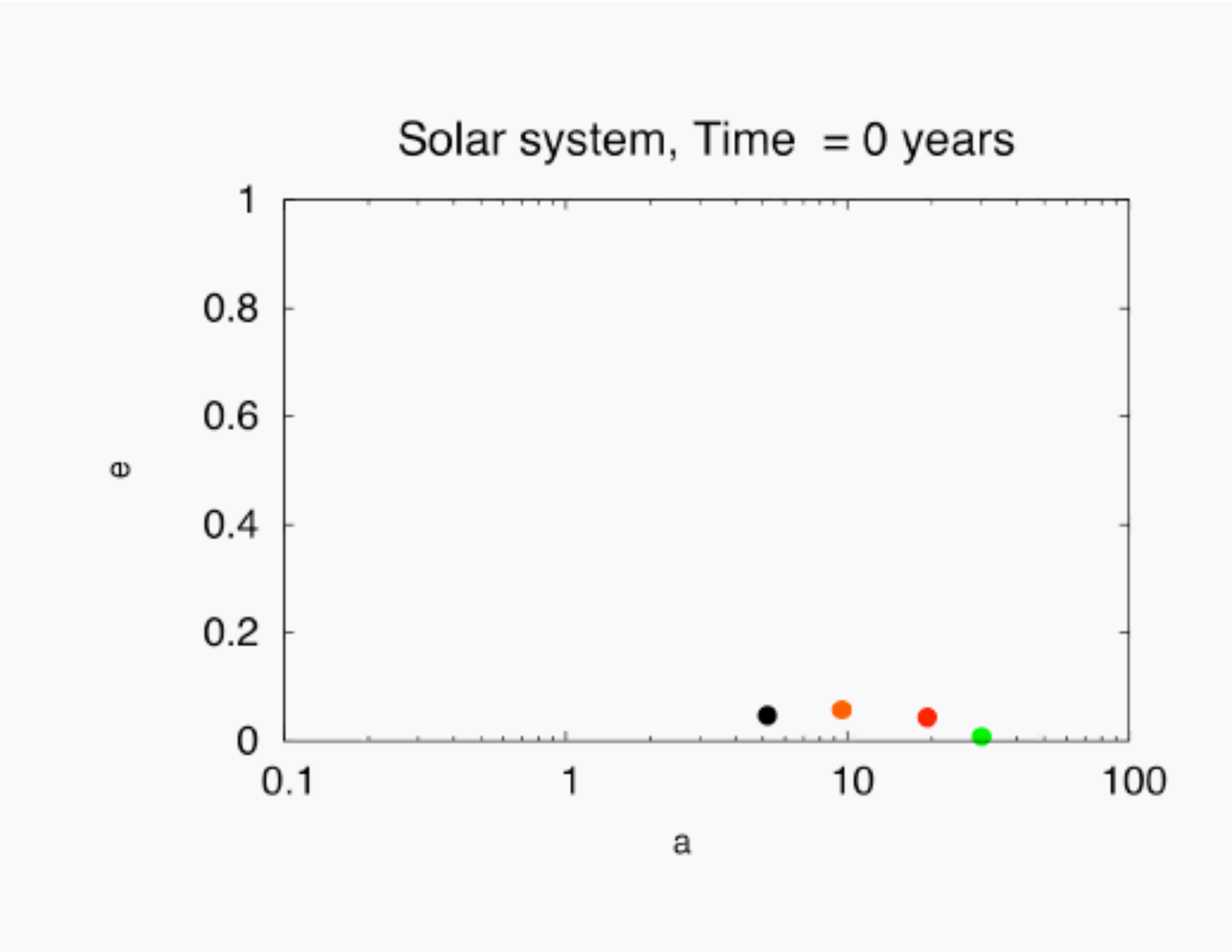


(Malmberg, Davies & Heggie, 2011)

Evolution of our solar system in a binary

(Malmberg, Davies & Chambers, 2007;
Malmberg & Davies 2009)

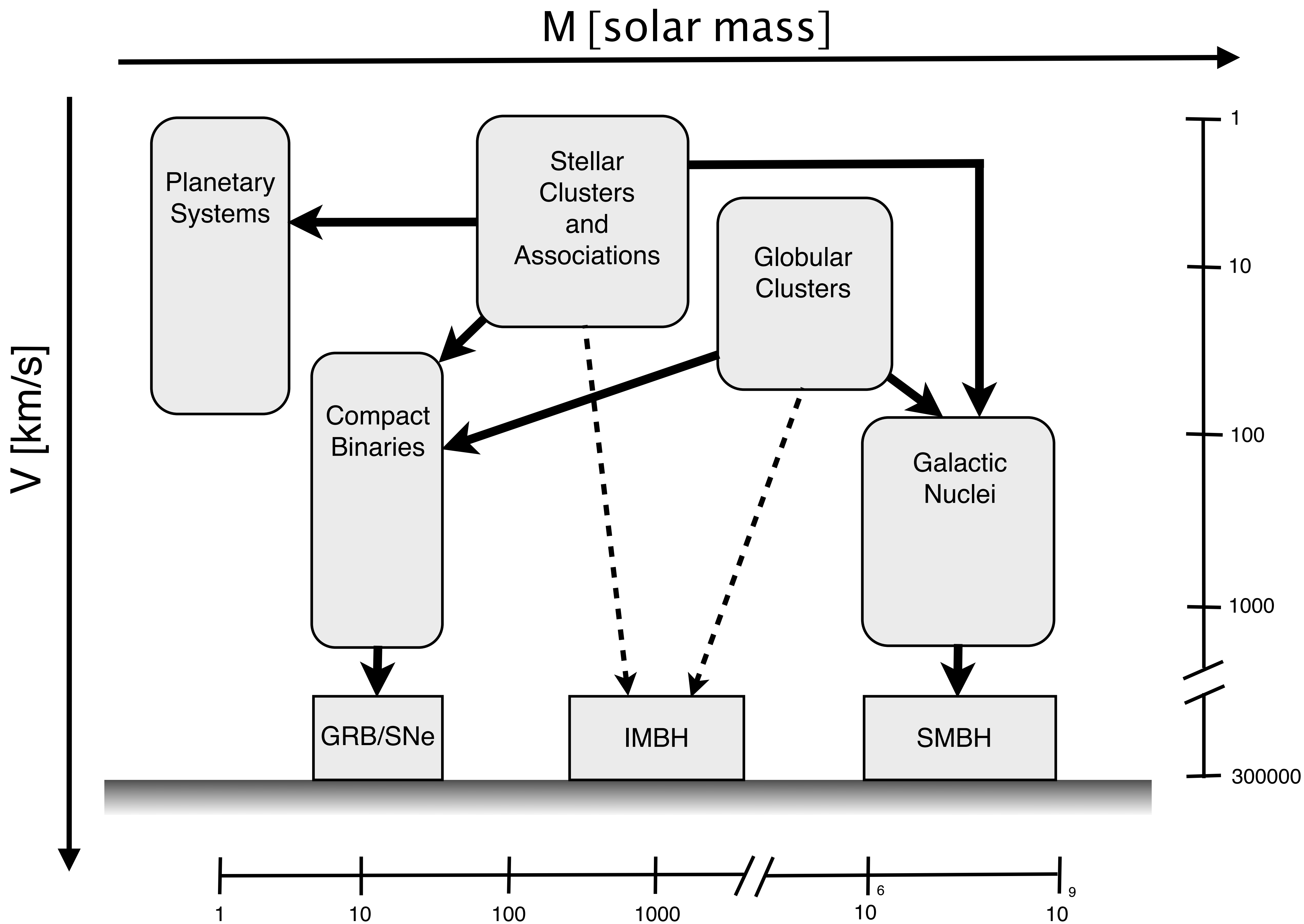
Evolution of our solar system in a binary



(Malmberg, Davies & Chambers, 2007; Malmberg & Davies 2009)

The bottom line:

Fly-bys and binary companions can make stable planetary systems unstable interestingly often.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Compact Binaries

Contain black holes, neutron stars or white dwarfs.

Compact binaries are a source of gravitational radiation.

Mergers may produce short gamma-ray bursts.

May also be sites for heavy element production.

They are rare: fewer than 1 in 1000 neutron stars are found in tight neutron-star binaries.

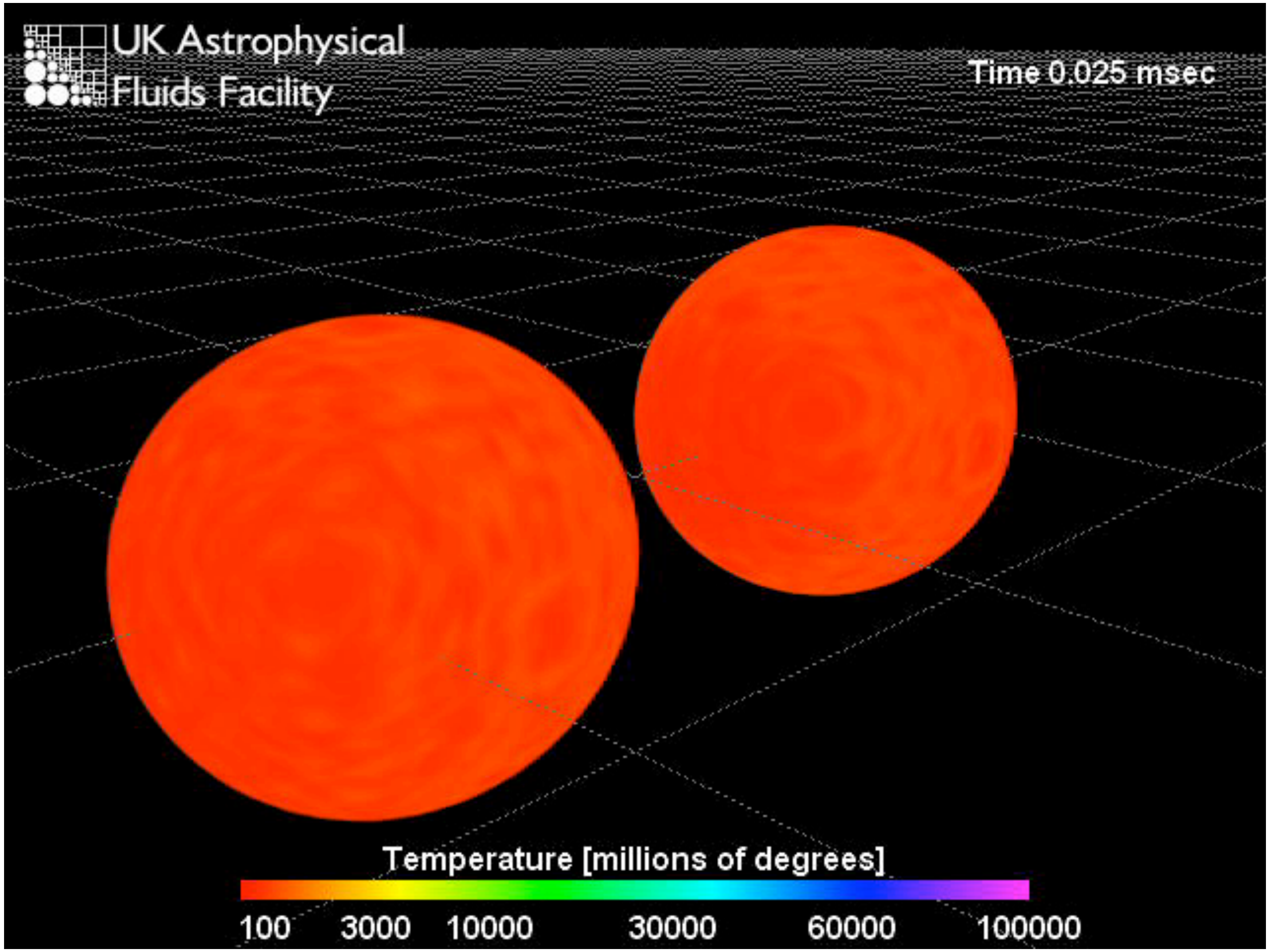
Inspiral timescale

Timescale for a circular binary of separation a to merge by gravitational radiation is

$$\tau_{gr} = 3 \times 10^8 \; yr \left(\frac{M_\odot}{M_1}\right)\left(\frac{M_\odot}{M_2}\right)\left(\frac{M_\odot}{M_1 + M_2}\right)\left(\frac{a}{R_\odot}\right)^4$$

Merging neutron stars

Merging neutron stars



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

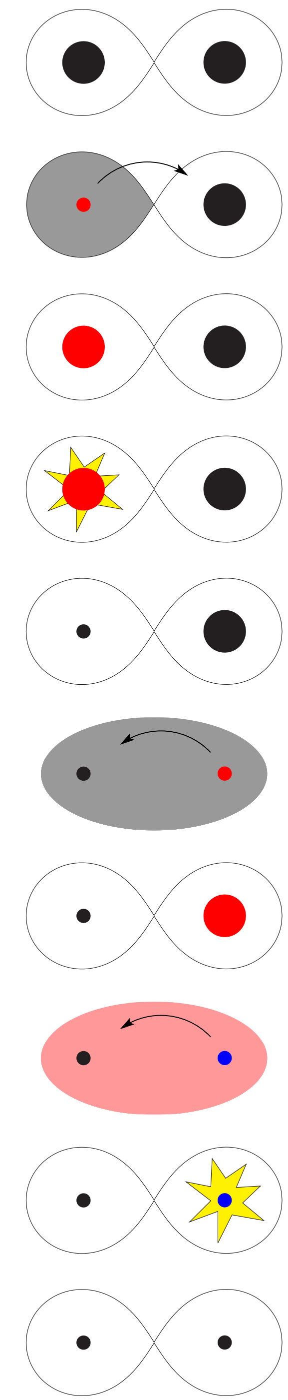
Second star evolves into a giant, and transfers mass unstably

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

Helium star transfers mass unstably, forming a very tight binary

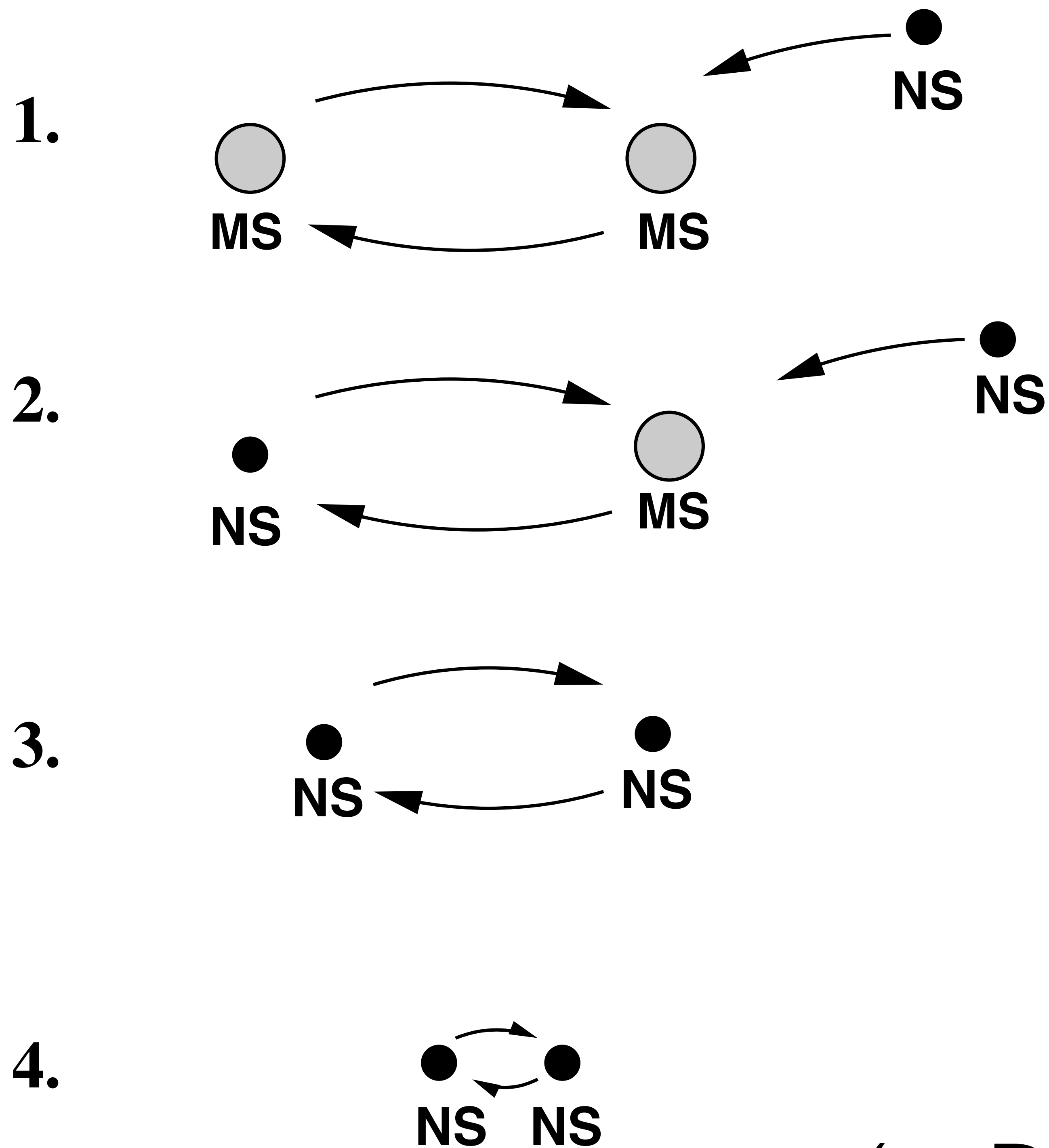
Finally the core explodes as a supernova,

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



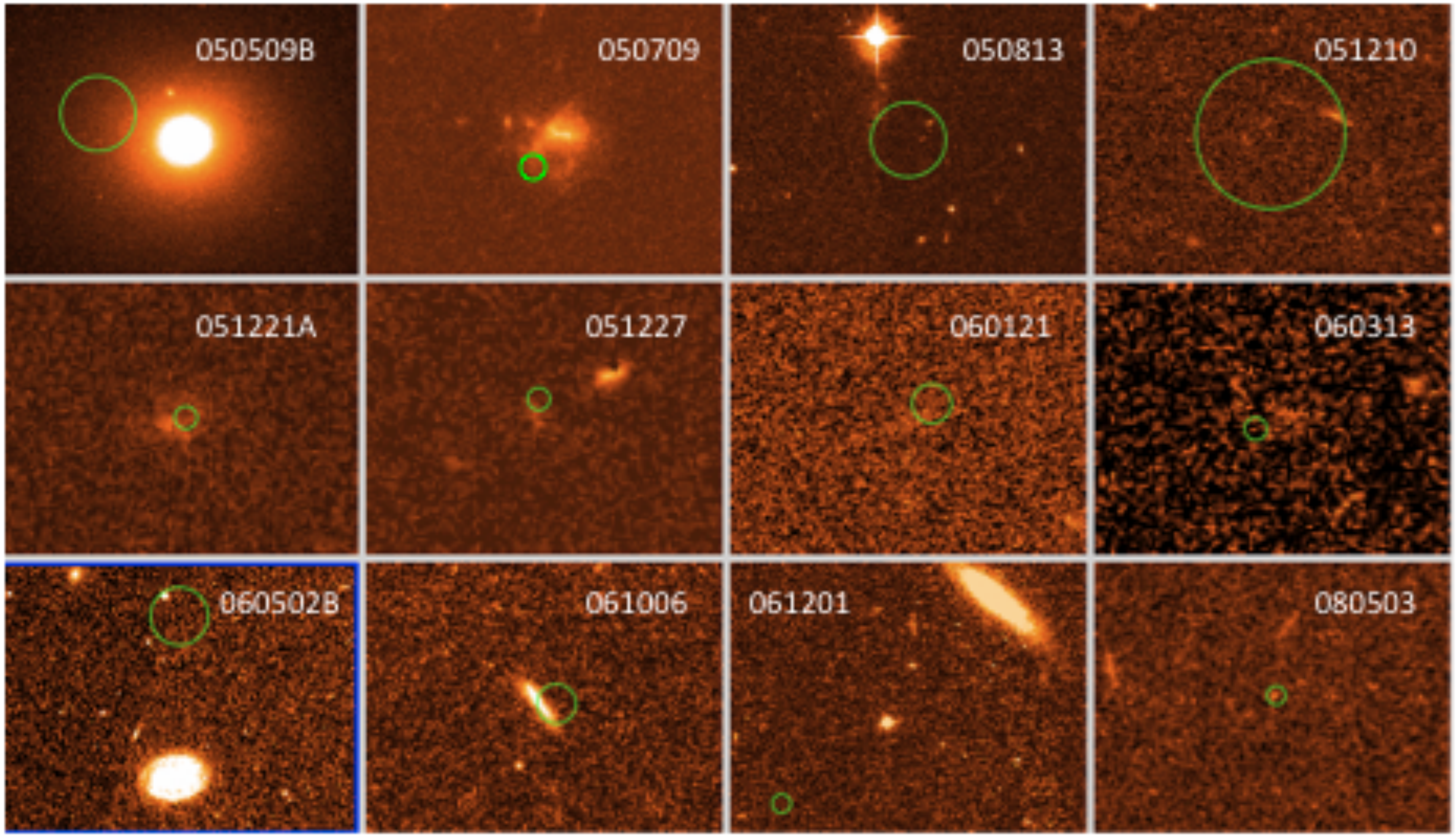
(Church et al., 2011)

Producing compact binaries within clusters



(eg Davies 1995)

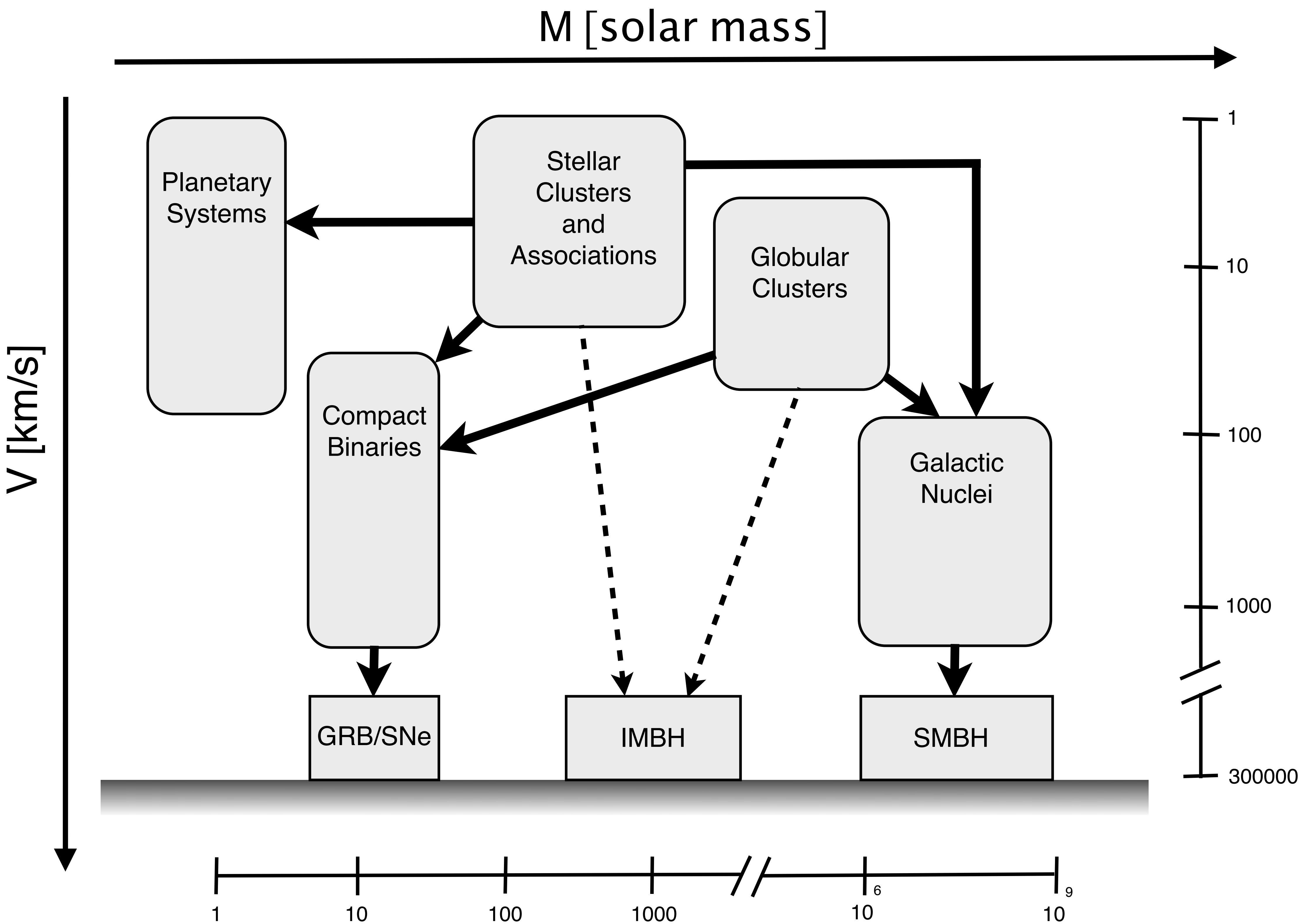
SHORT GRBS


050509B
050709
050813
051210
051221A
051227
060121
060313
060502B
061006
061201
080503

The bottom line:

An interesting fraction of gamma-ray bursts may occur in globular clusters.

(Church et al., 2011)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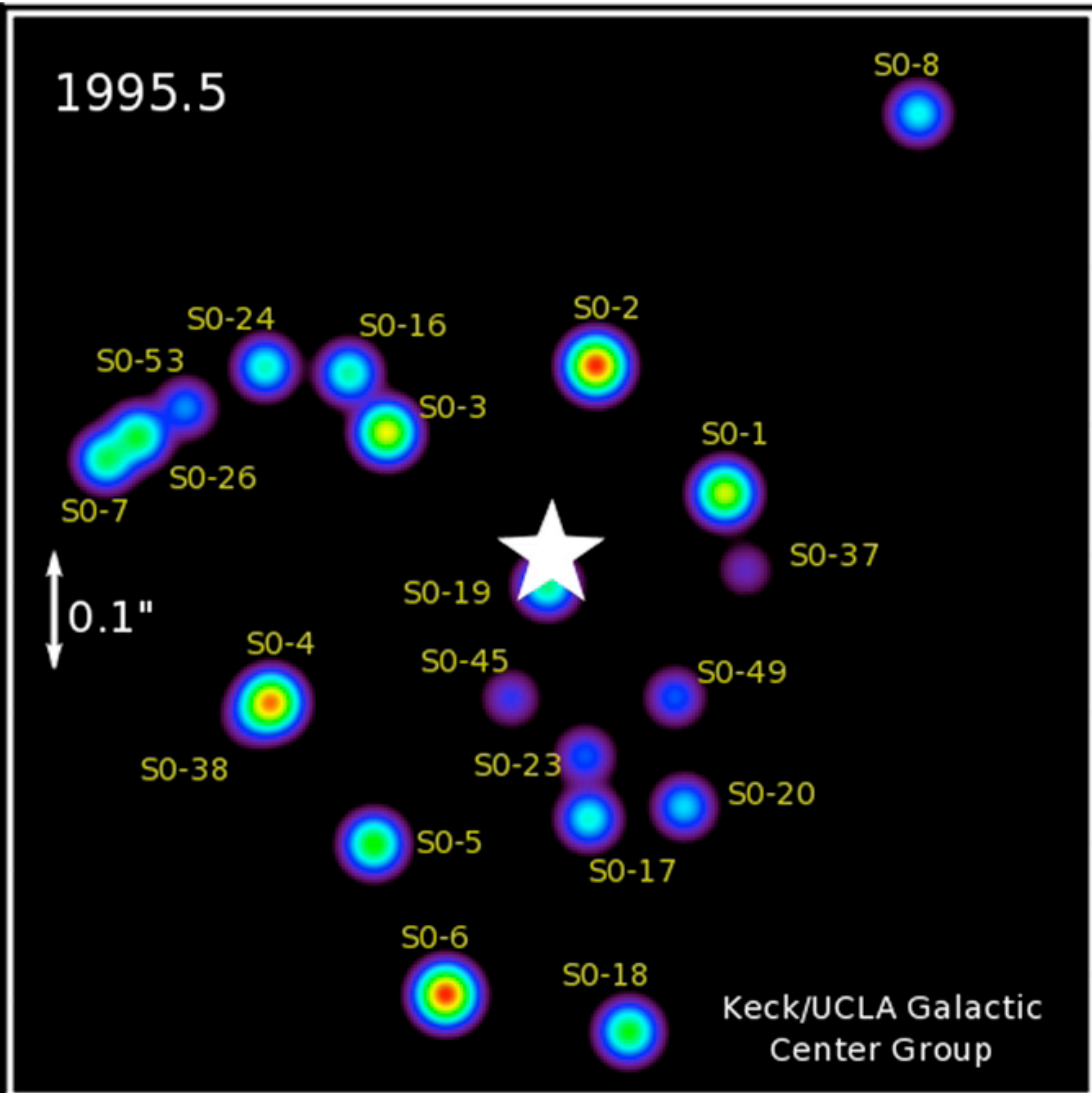
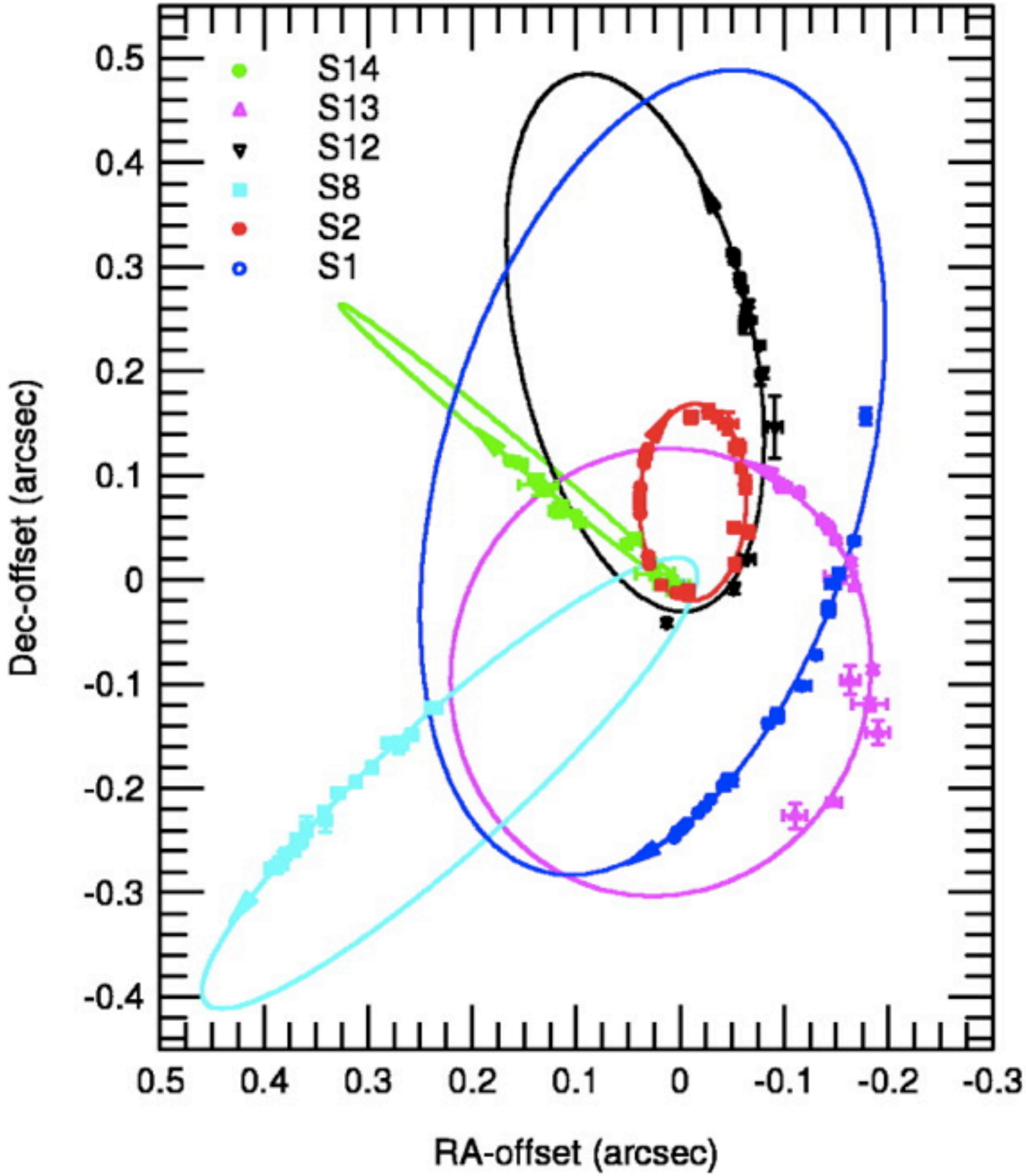

1995.5
S0-8
S0-24
S0-16
S0-2
S0-53
S0-3
S0-1
S0-26
S0-7
S0-37
S0-19
0.1"
S0-4
S0-45
S0-49
S0-38
S0-23
S0-20
S0-5
S0-17
S0-6
S0-18
Keck/UCLA Galactic
Center Group



1 arcsec

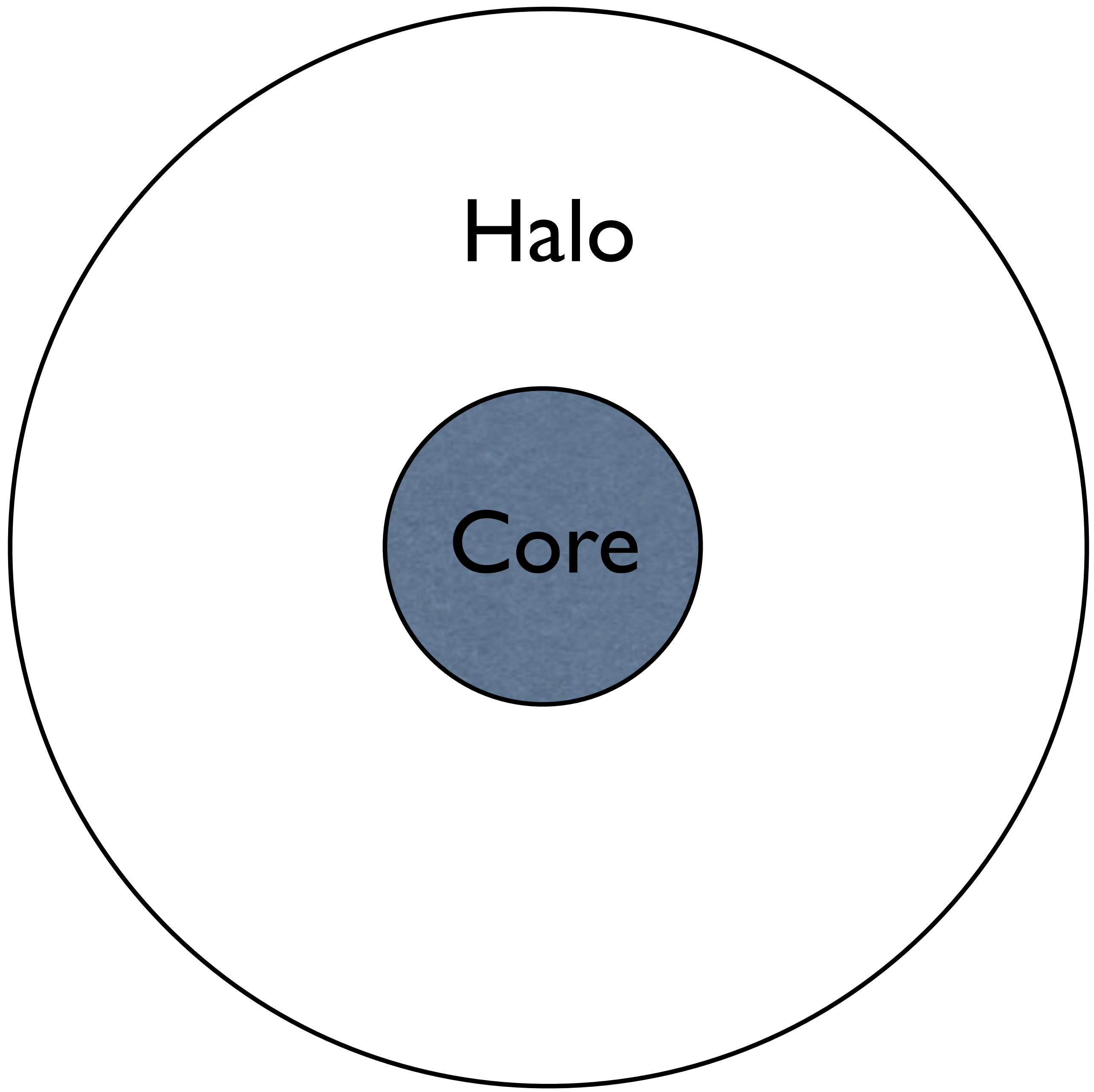
= 0.13 light years

From stellar orbits, we know mass of central object is about 4 million solar masses.

The question:

How do supermassive black holes form and grow in galactic nuclei?

A Model Stellar Cluster

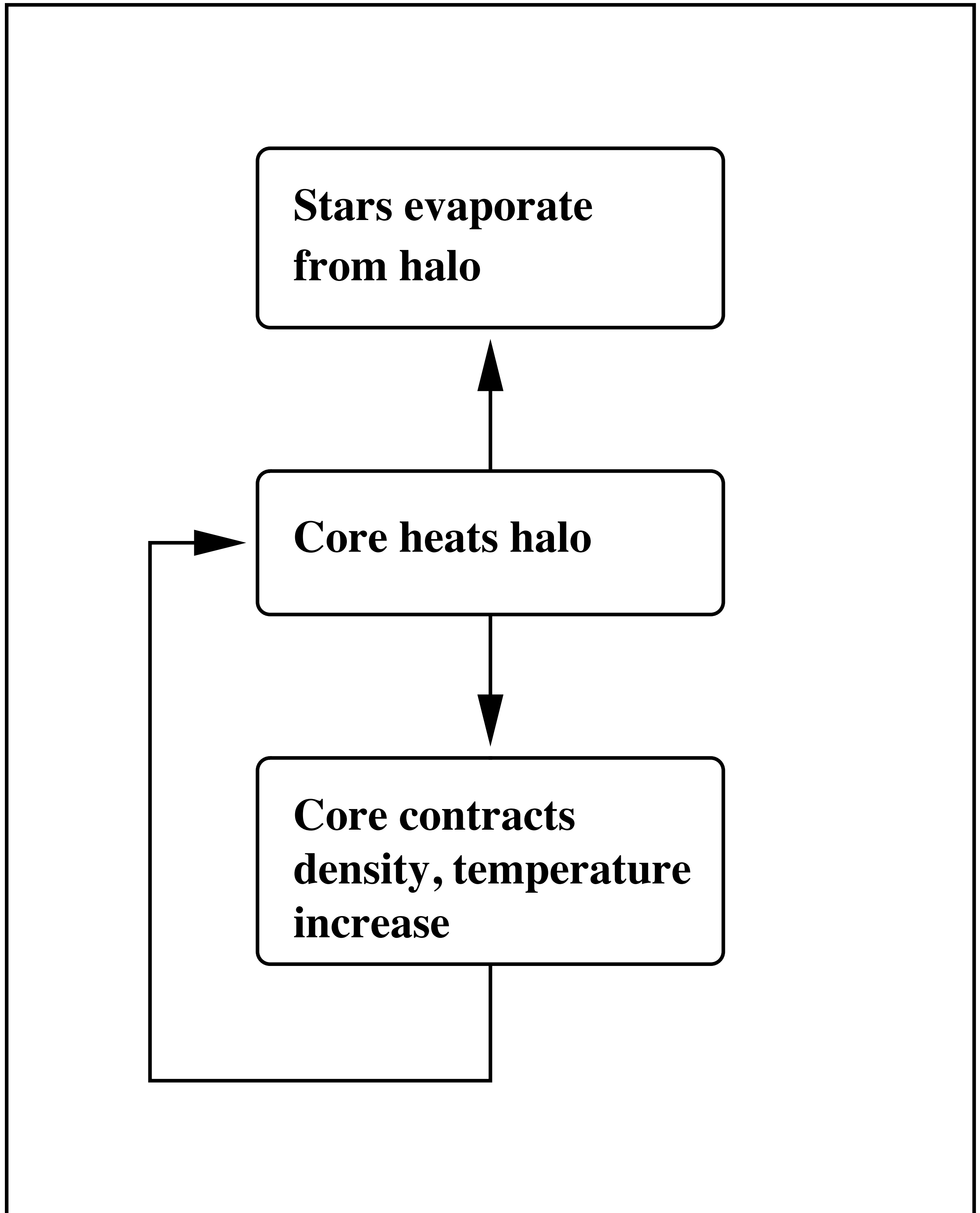


Key ideas:

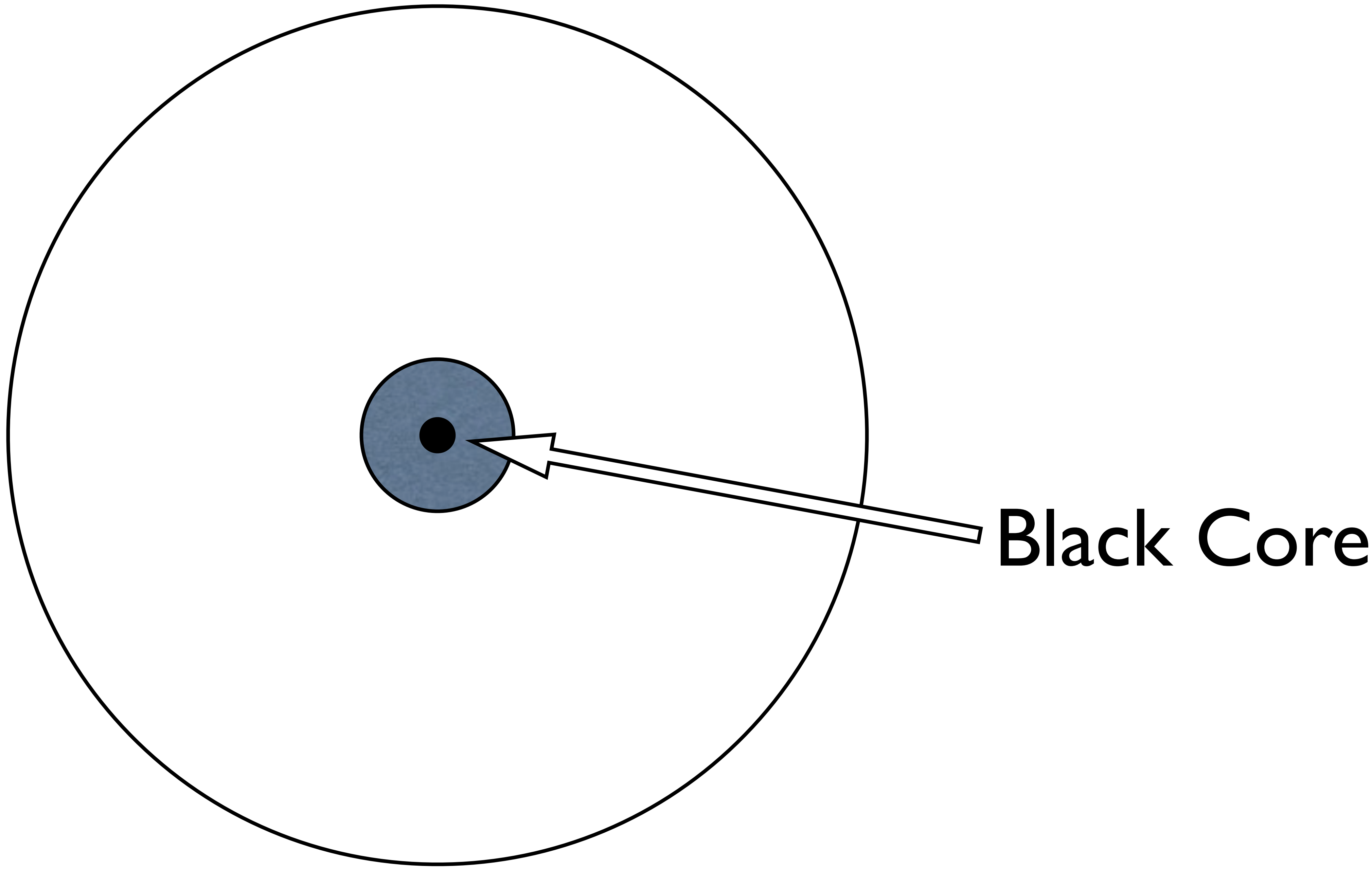
Scattering between stars transports energy within a cluster (two-body relaxation).

Self-gravitating systems have a negative heat capacity.

The dynamical evolution of a cluster



An Evolved Stellar Cluster



Evolution within the black core:

Compact black-hole binaries form which spiral together and merge via gravitational radiation.

These black holes then merge with other merger products.

Get a run-away merger process building up a massive seed black hole.

(Davies, Miller & Bellovary, 2011)

The bottom line:

Seeds for supermassive black holes form as a natural (dynamical) consequence within the cores of sufficiently-massive stellar clusters.

(Miller & Davies, submitted)

Key ideas you heard today:

0) stellar clusters are factories producing exotic objects

1) planetary systems are messed up in young clusters

2) compact binaries containing neutron stars and black holes are made dynamically in globular clusters

3) supermassive black holes form and grow in galactic nuclei