Black holes and core expansion in massive star clusters

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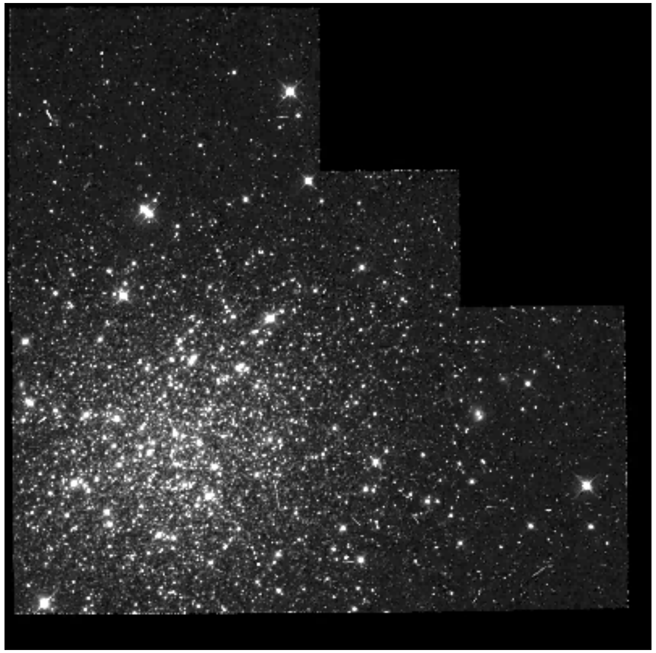
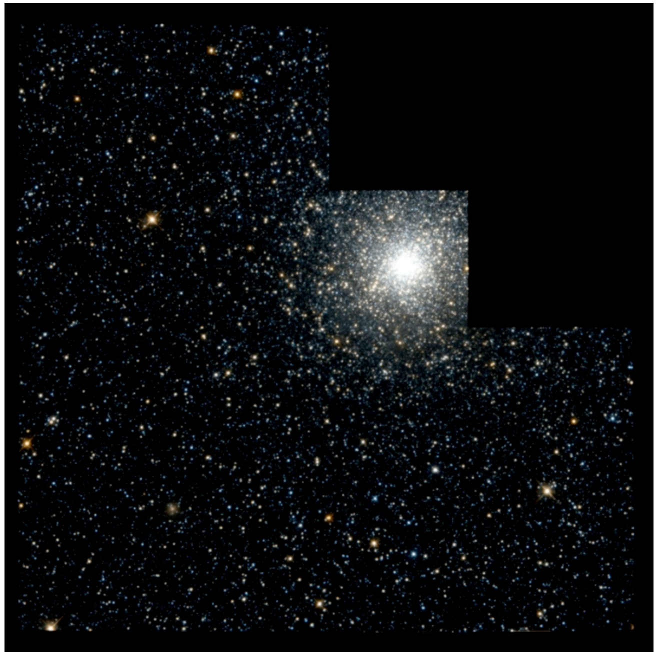
The LMC and SMC

Important point:

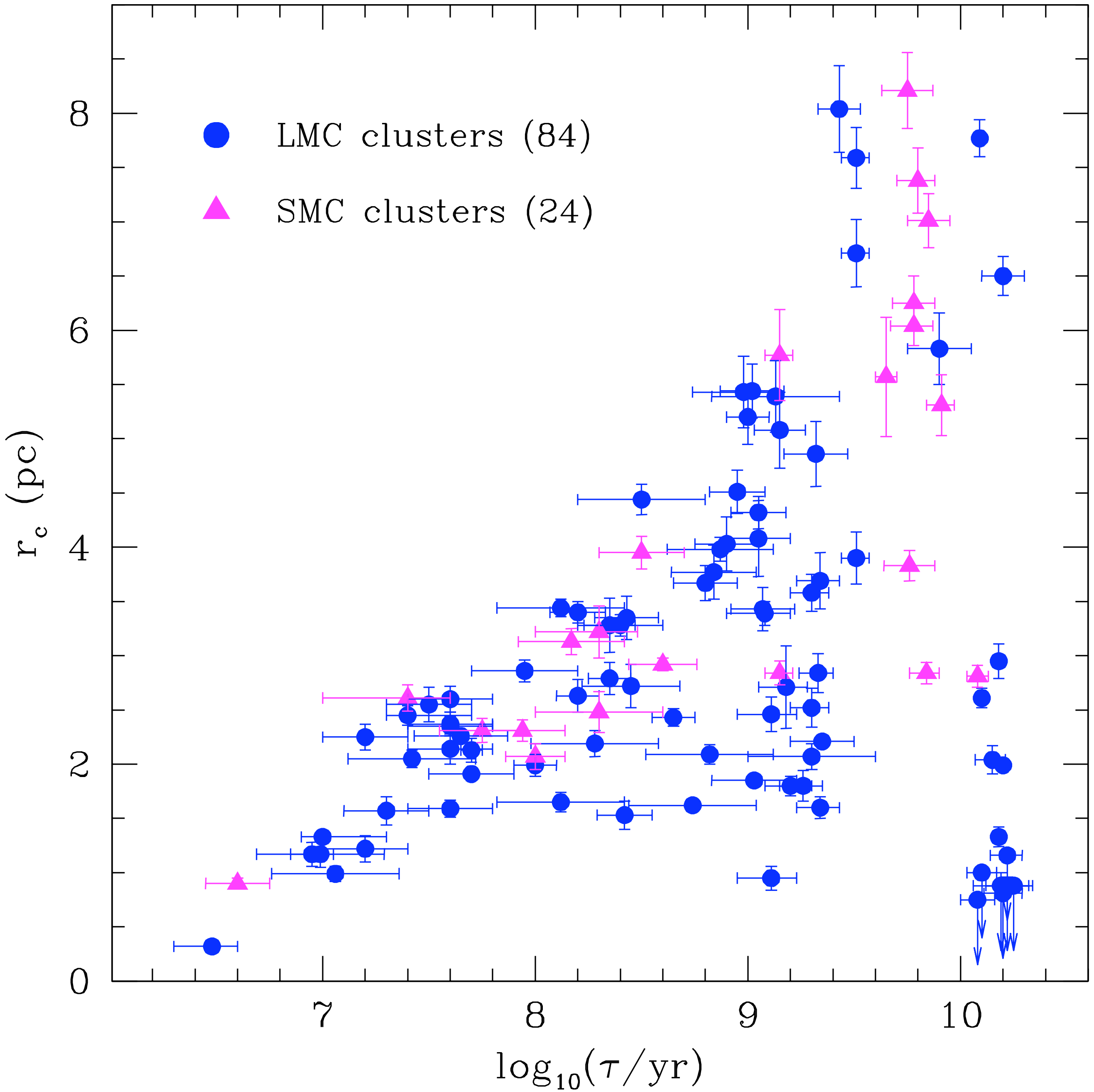
LMC and SMC contain rich stellar clusters having a range of ages.

NGC1841 (old/diffuse)





NGC 1818 (young/compact) NGC 1916 (old/compact)



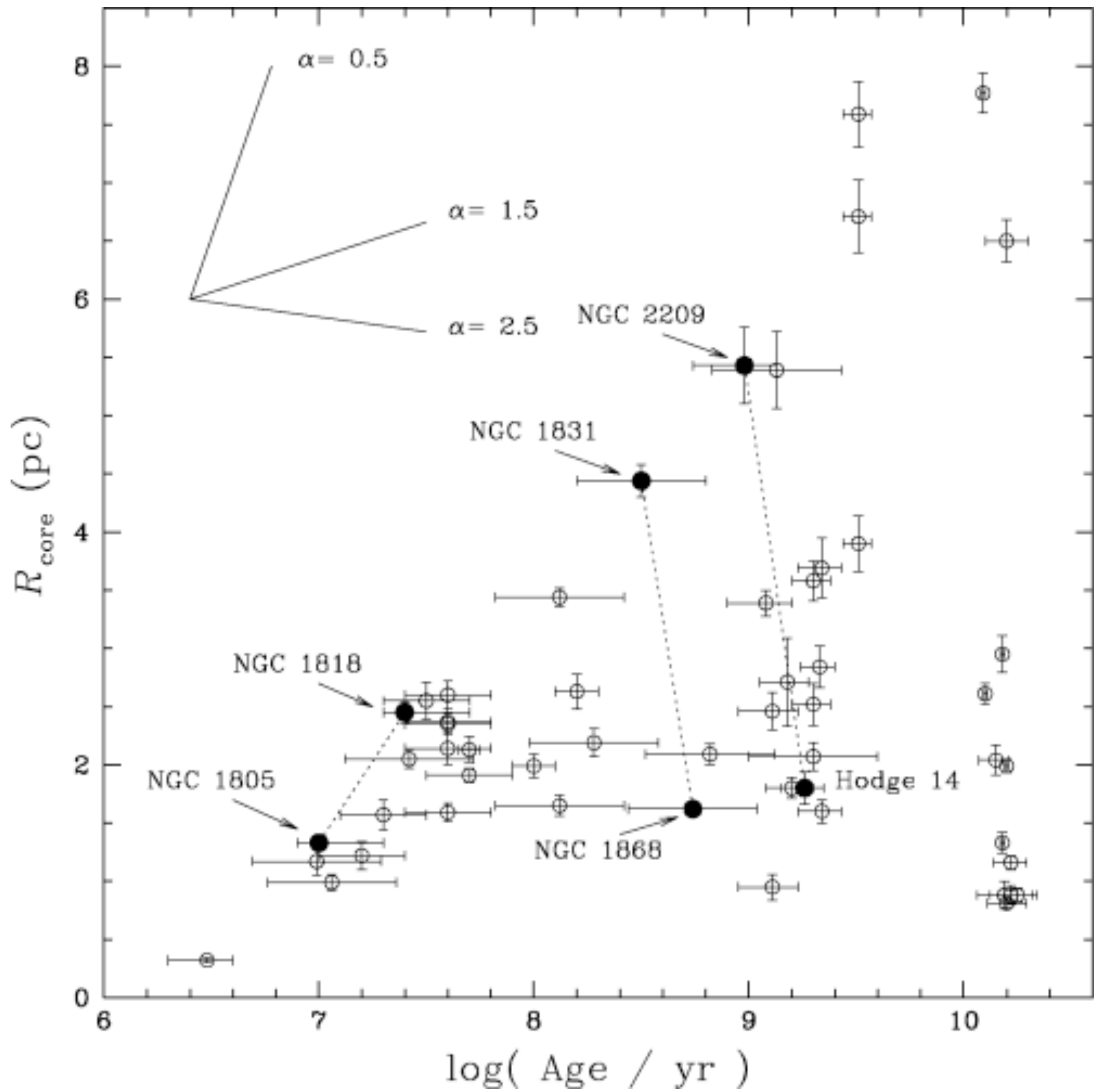
(Mackey & Gilmore 2003)

A QUESTION:

What makes some cluster cores expand at later times?

Possible answers include

- Effect of location
- Mass loss due to evolution
- Heating from stellar binaries
- Another way involving BHs



(de Grijs et al 2002, Wilkinson et al 2003)

Binary 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 binary to undergo an encounter is

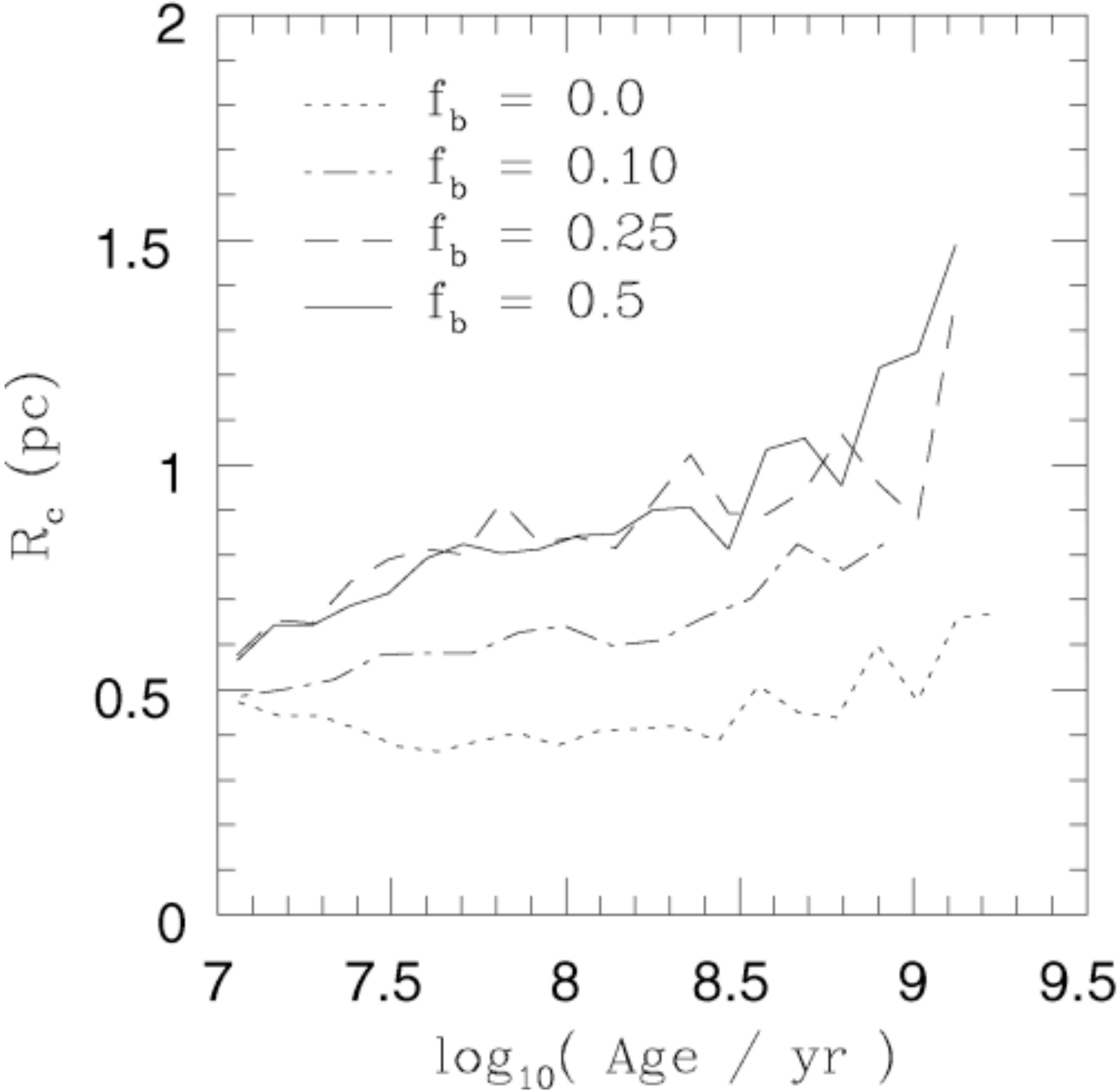
$$\tau_{enc} \simeq 3.3 \times 10^7 yr \left(\frac{100\ pc^{-3}}{n}\right) \left(\frac{V_\infty}{1\ km/s}\right) \left(\frac{10^3\,AU}{R_{min}}\right) \left(\frac{M_\odot}{M_t}\right)$$

Binary heating

Hard binaries get harder via encounters.

Binary-single encounters will thus heat clusters.

Wilkinson et al (2003) found that heating from stellar binaries could not lead to core expansion sufficient to explain the observed clusters.



(Wilkinson et al 2003)

Heating from BH binaries

Timescale for a given binary to undergo an encounter is

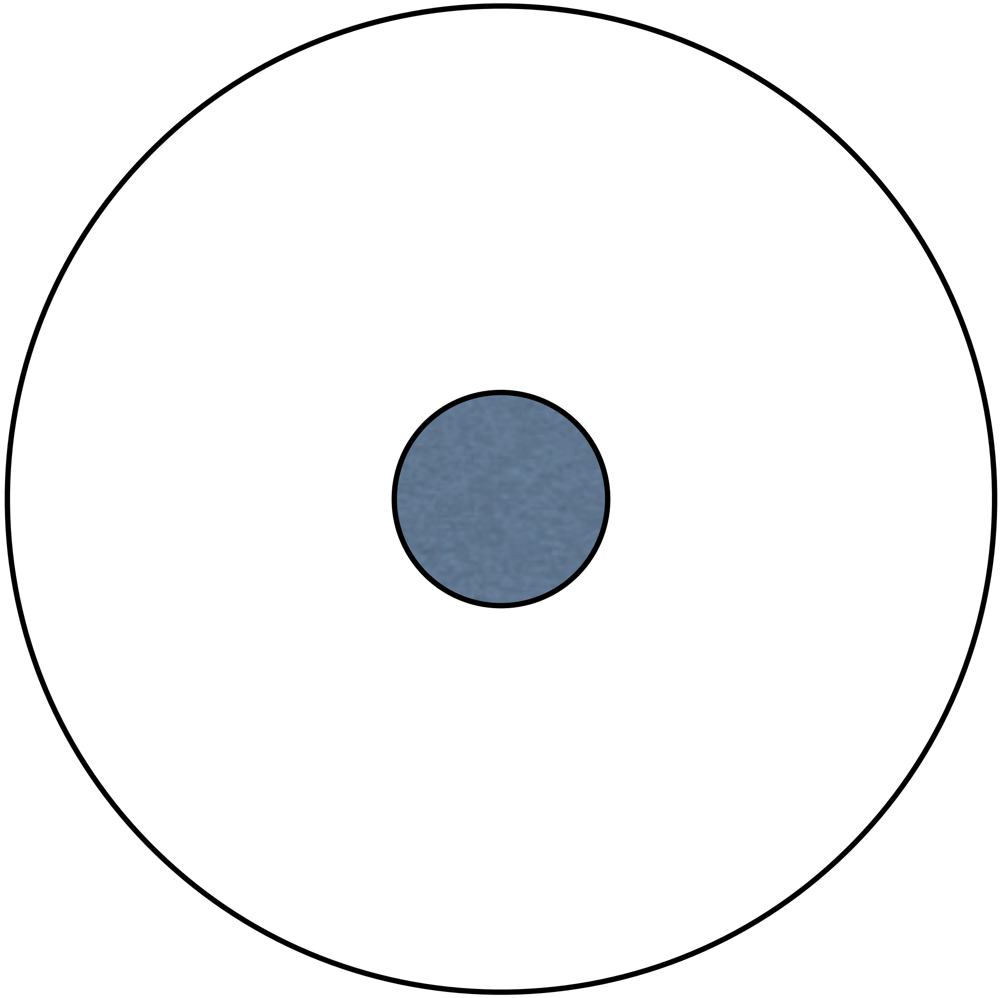
$$\tau_{enc} \simeq 3.3 \times 10^7 yr \left(\frac{100\ pc^{-3}}{n} \right) \left(\frac{V_\infty}{1\ km/s} \right) \left(\frac{10^3\, AU}{R_{min}} \right) \left(\frac{M_\odot}{M_t} \right)$$

For massive binary of given hardness (binding energy)

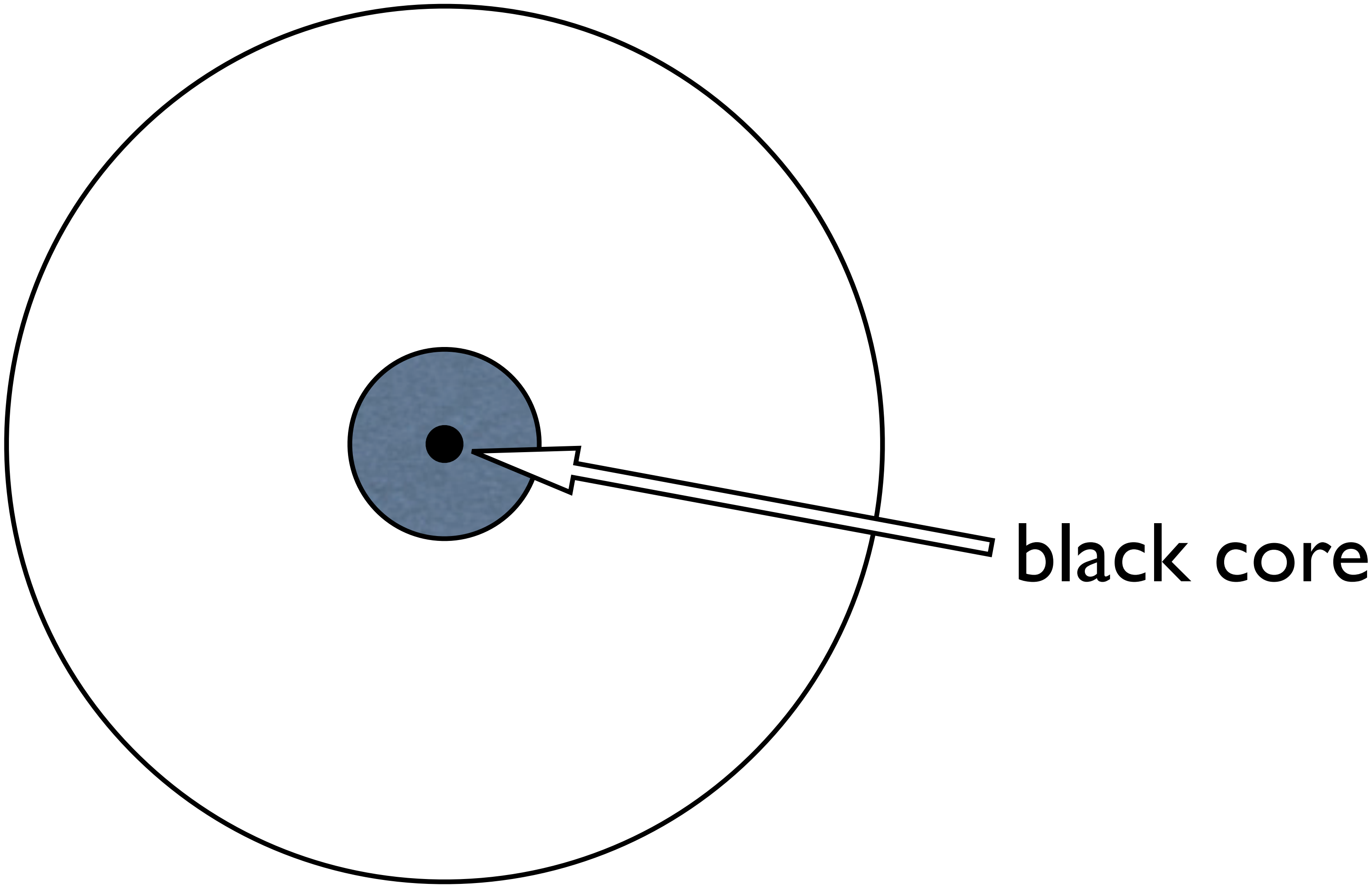
$$\tau_{enc} \propto M_{bh}^{-3}$$

Also, for sub-population of sufficiently massive objects, get mass segregation instability (Spitzer 1987) forming a separate, inner core.

A Model Stellar Cluster



A Model Stellar Cluster



What happens in the black core?

Three-body BH binaries will form.

Some BH binaries will merge via GR.

Heating of cluster via binary-single encounters.

BHs will be ejected from the cluster.

Holley-Bockelmann et al (2008)

Portegies Zwart & McMillan (2000, 2002)

O'Leary et al (2006) Moody & Sigurdsson (2009)

N-body simulations of clusters

Used nbody4 program and grape-6 hardware.

Modelled cluster with about 10^5 particles.

Model from Elson, Fall & Freeman (1987)

Used Kroupa IMF (stellar masses 0.1-100).

Assume BHs produced for stars >20 solar masses.

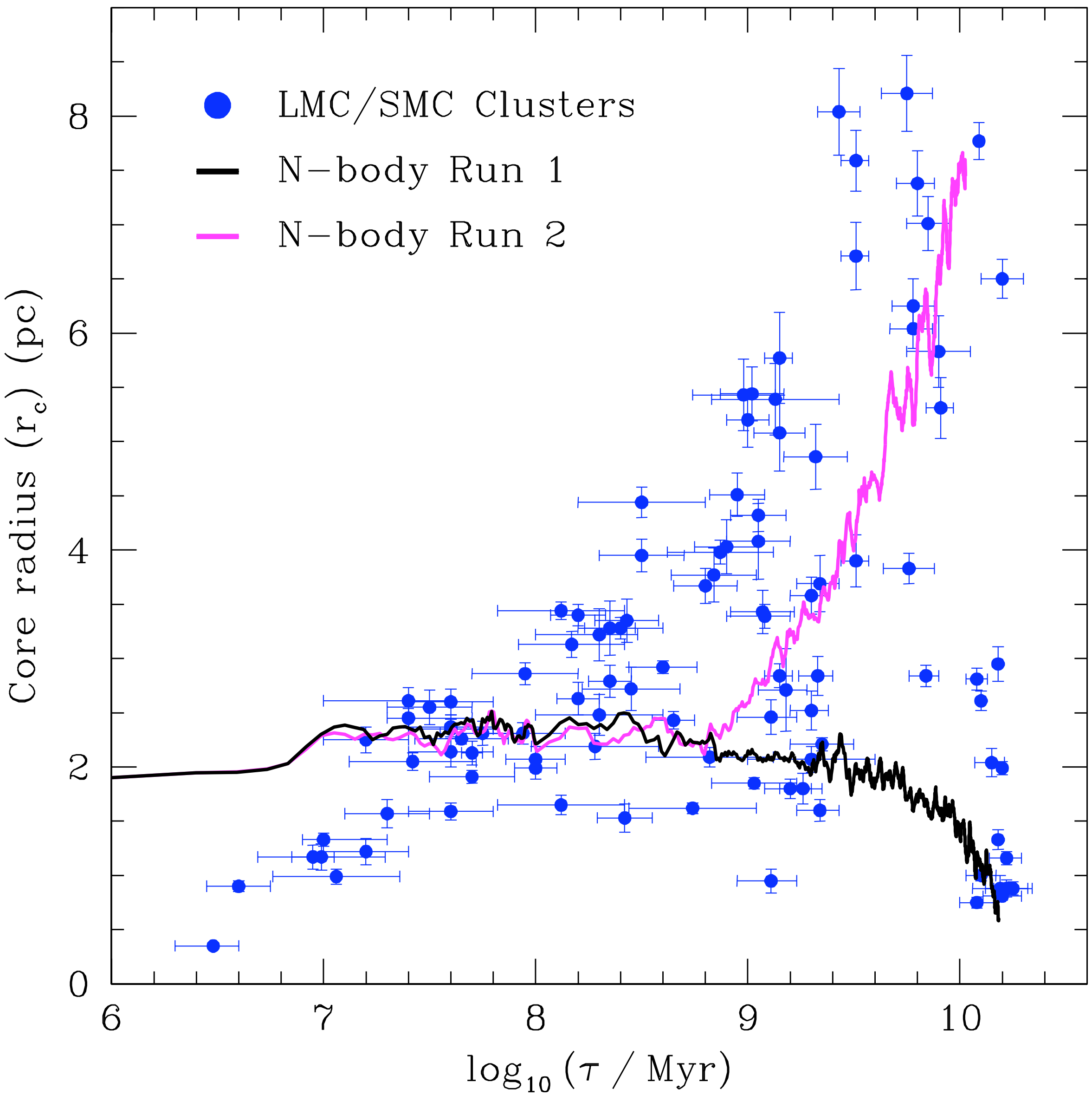
Mackey et al (2007, 2008)

Cluster simulations including BHs

Name of run	Initial mass segregation	Black hole kicks
Run1	No	Large
Run 2	No	Zero
Run 3	Yes	Large
Run 4	Yes	Zero

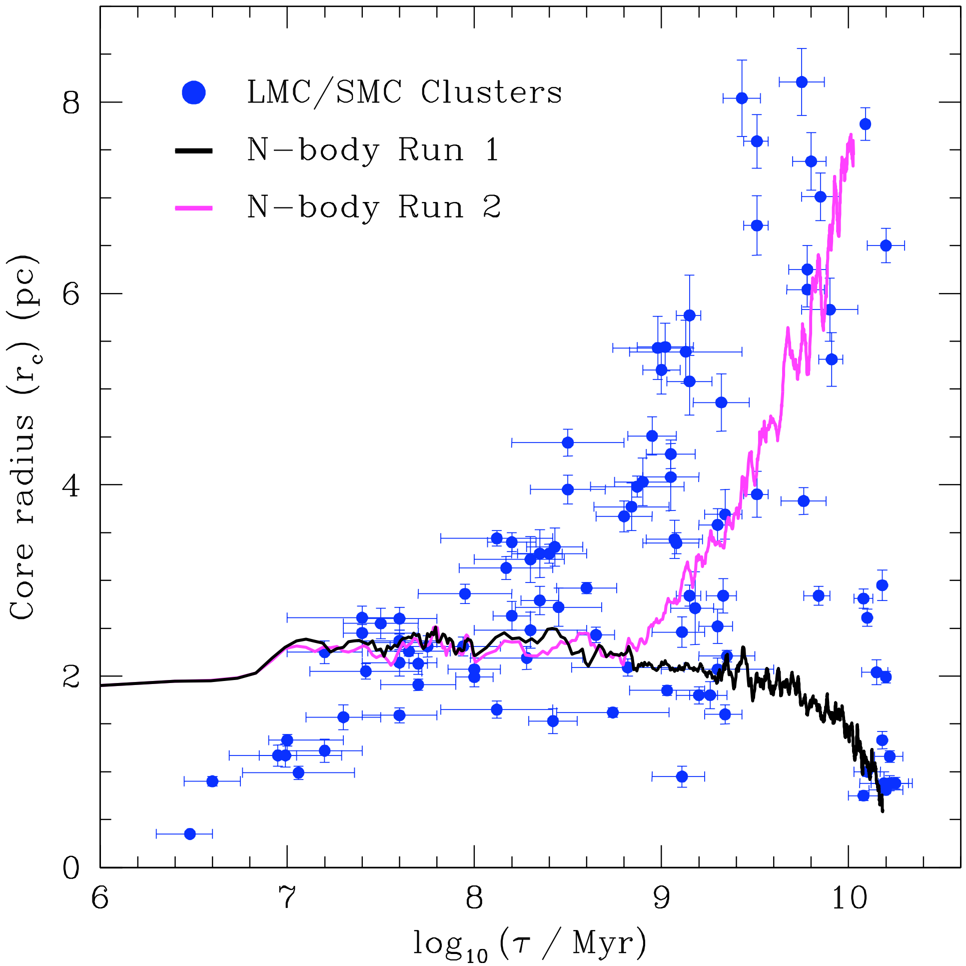
(Mackey et al 2007)

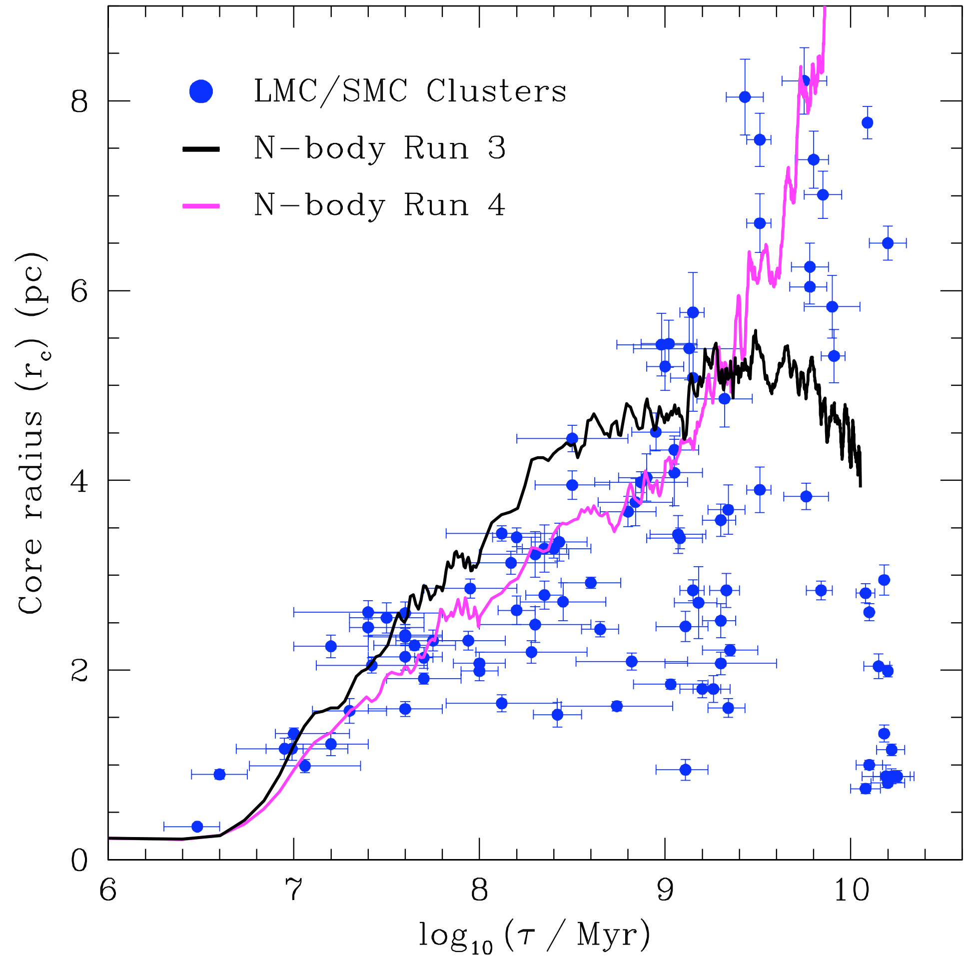
Results for runs 1 and 2



(Mackey et al 2007)

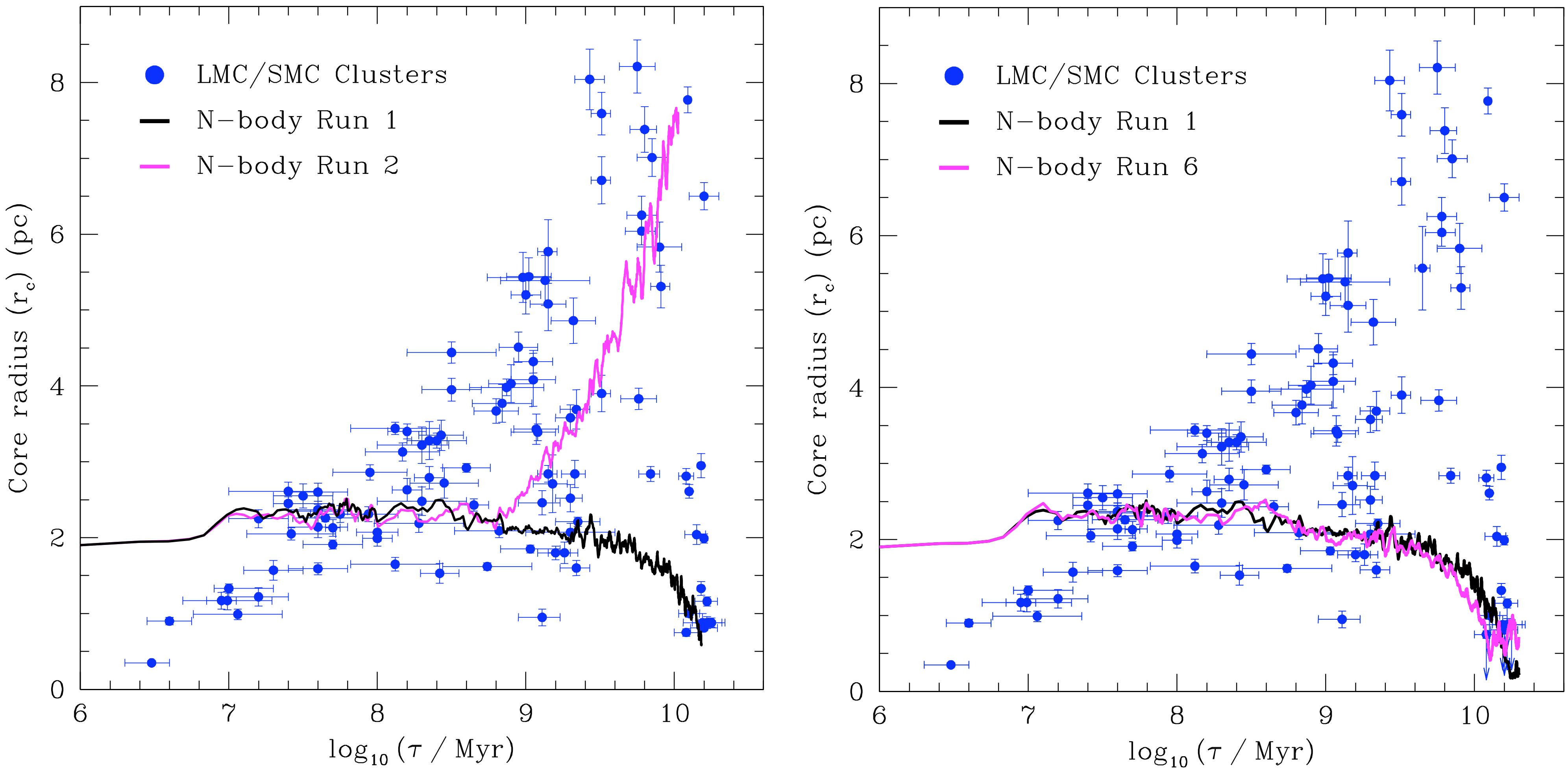
Results for runs a) 1 and 2, b) 3 and 4





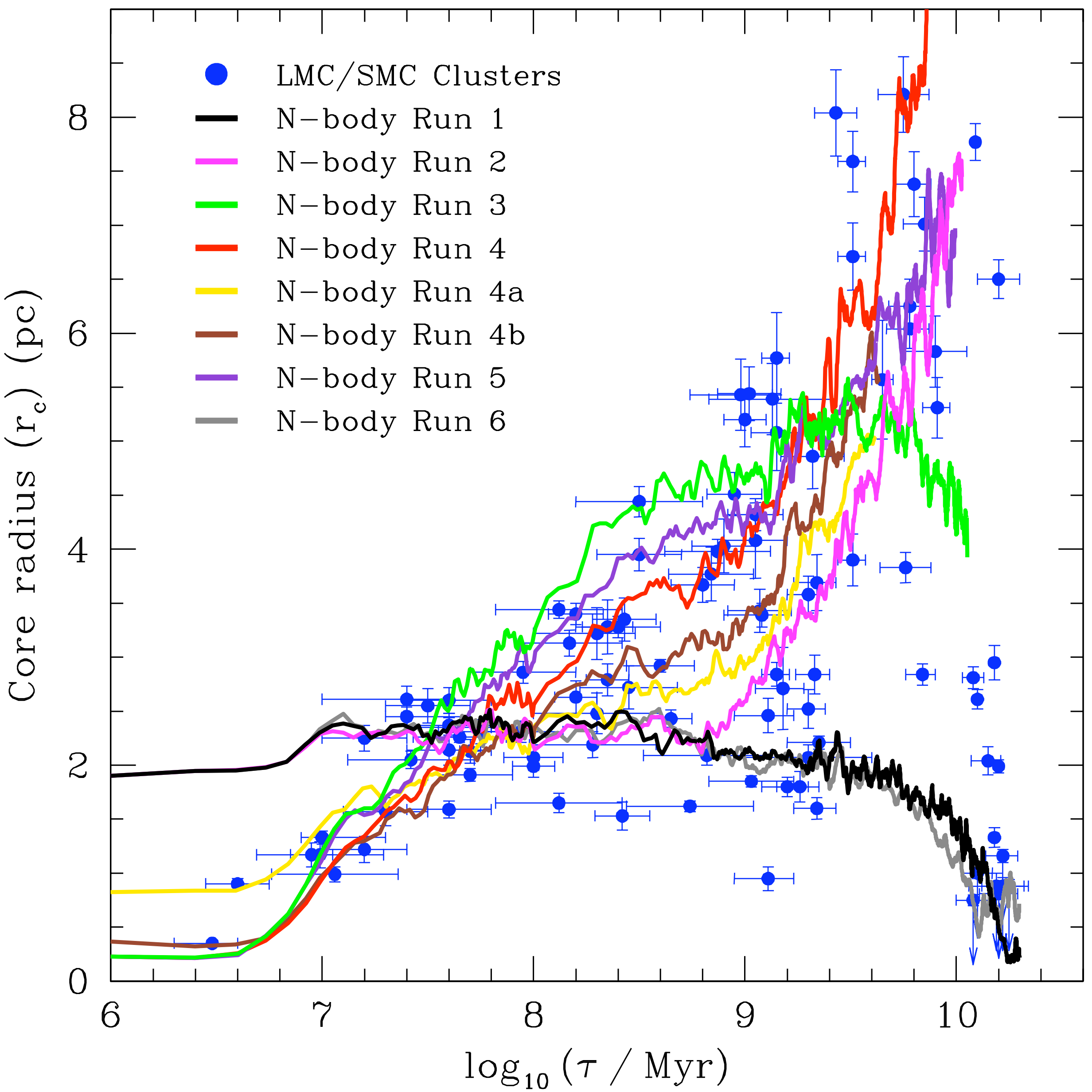
(Mackey et al 2007)

Black holes vs neutron stars



(Mackey et al 2008)

Results for all runs



(Mackey et al 2008)

Summary

LMC and SMC contain rich clusters having a range of ages.

Older clusters are observed to have a broad spread in core radii.

This spread seems not to be caused by stellar binaries or different IMFs.

Stellar-mass BHs may do something interesting.

BH binaries can form within dark cores and heat clusters causing core expansion.