Star clusters in galactic cores

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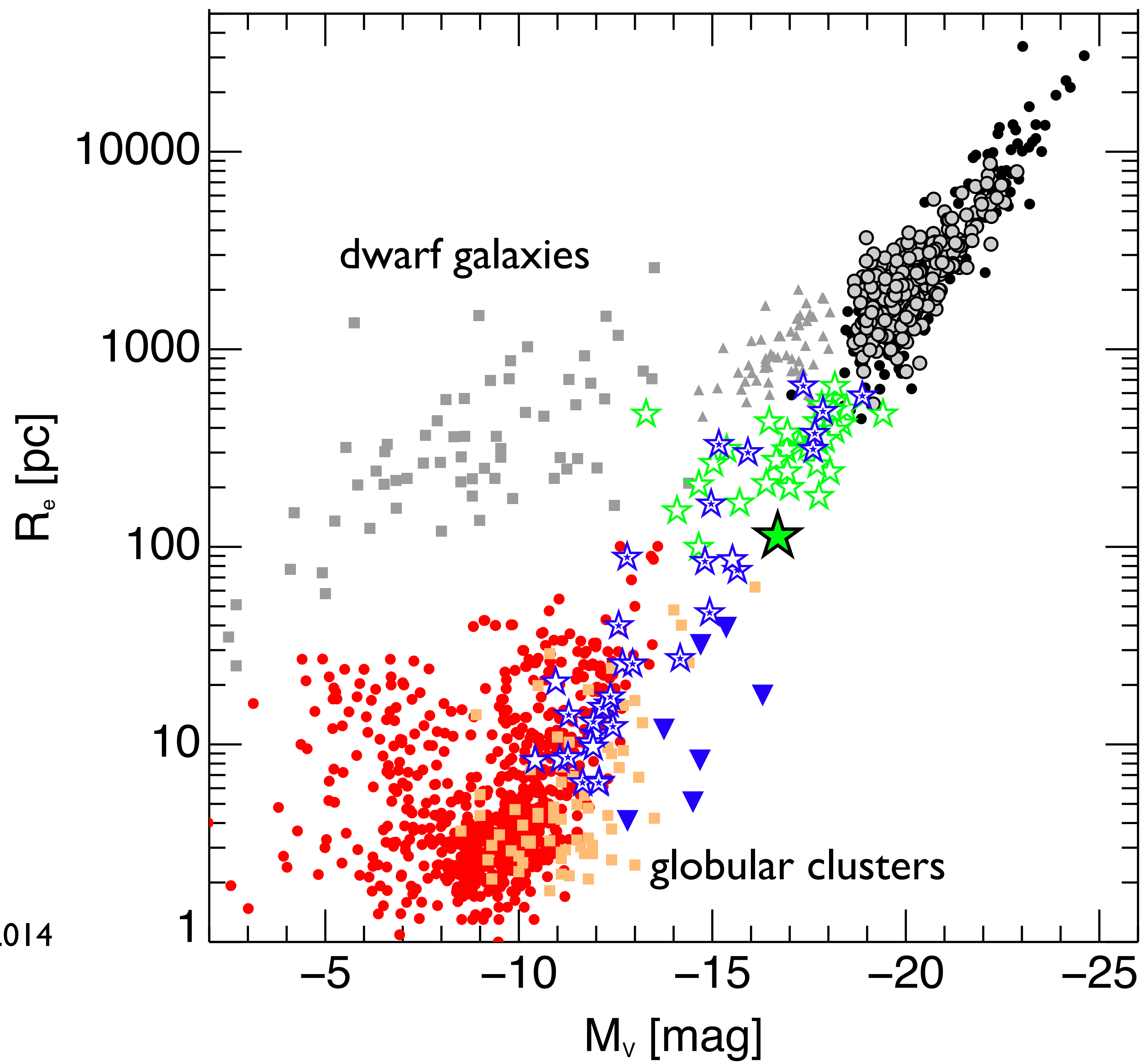
The zoo of small stellar systems



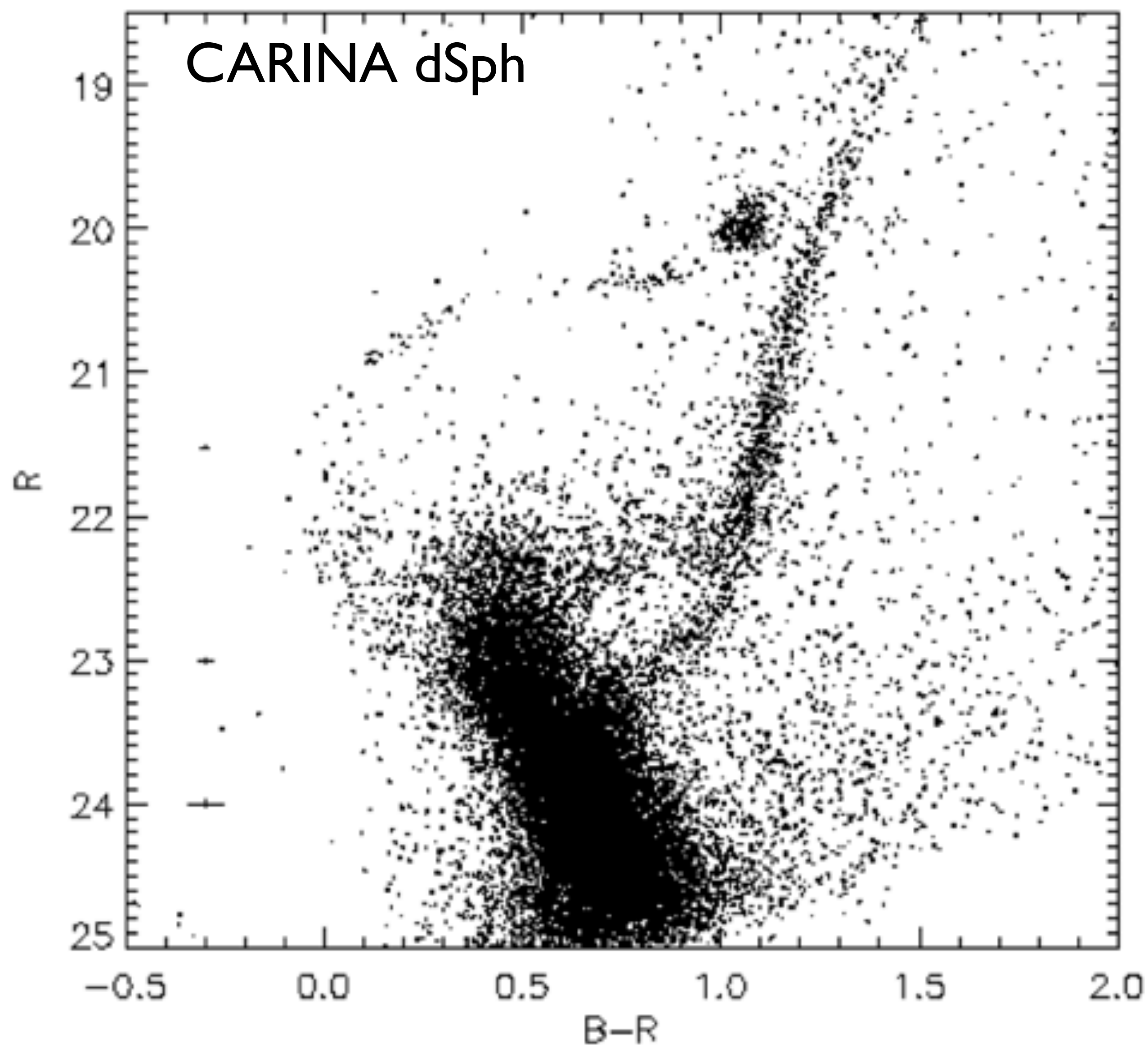
Norris et al. 2014

Dwarf galaxies vs. GCs

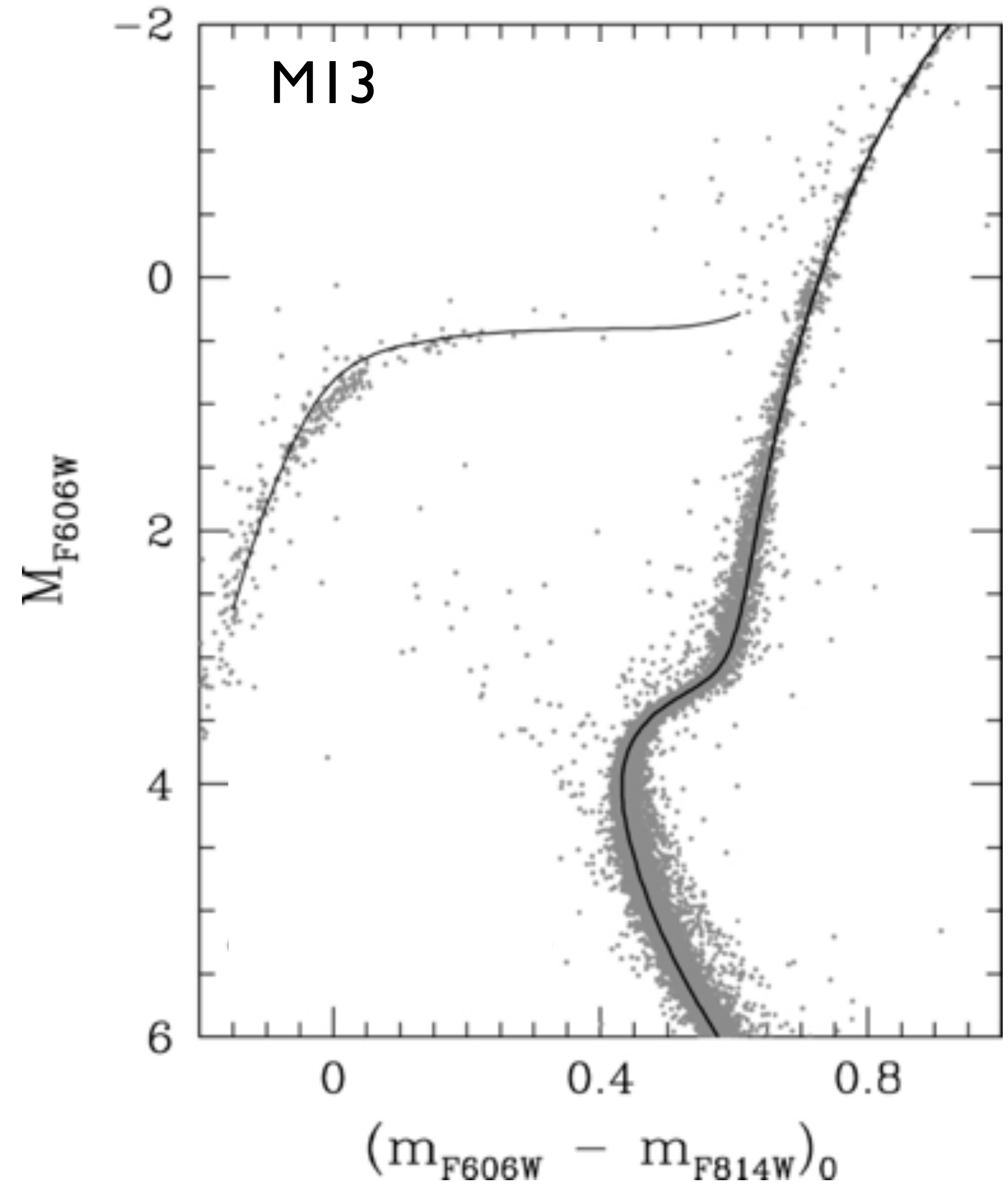
Fornax dSph ESO/Digitalized Sky Survey 2

M15 Nasa/ESA

Dwarf galaxies vs. GCs



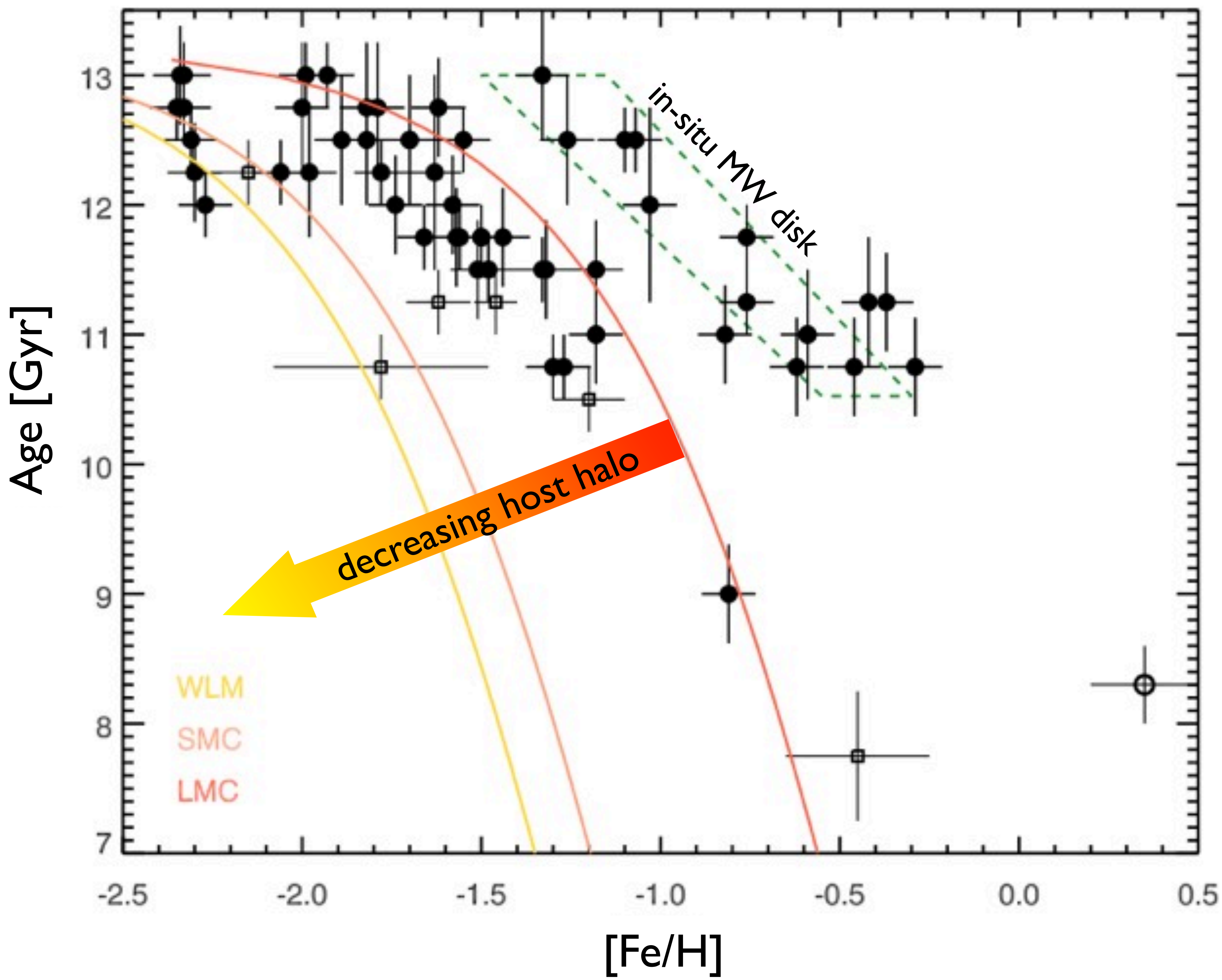
Smecker-Hane et al. 1996



VandenBerg et al. 2013

Origin of galactic GCs?

Leaman, VandenBerg & Mendel (2013)



In-situ GCs

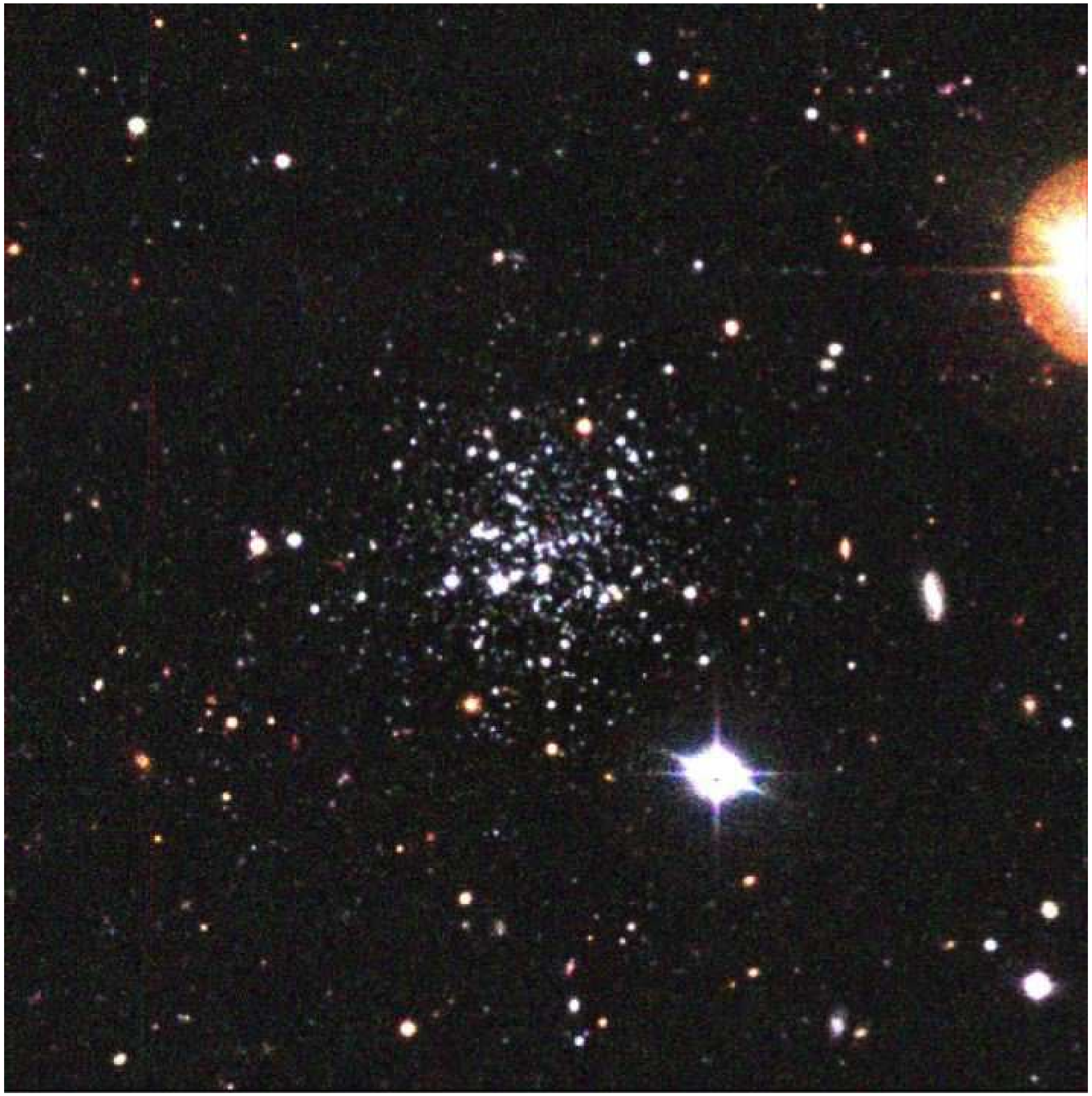
- GCs in disk-like orbits, consistent with age-metallicity of MW disk

Accreted GCs

- 2/3 of GCs in halo-like orbits
- accreted as part of 10^7-10^8 $M_\odot$ disrupted dwarf host galaxies

can we UNIQUELY distinguish between these two families of clusters?

GC or dwarf galaxy?



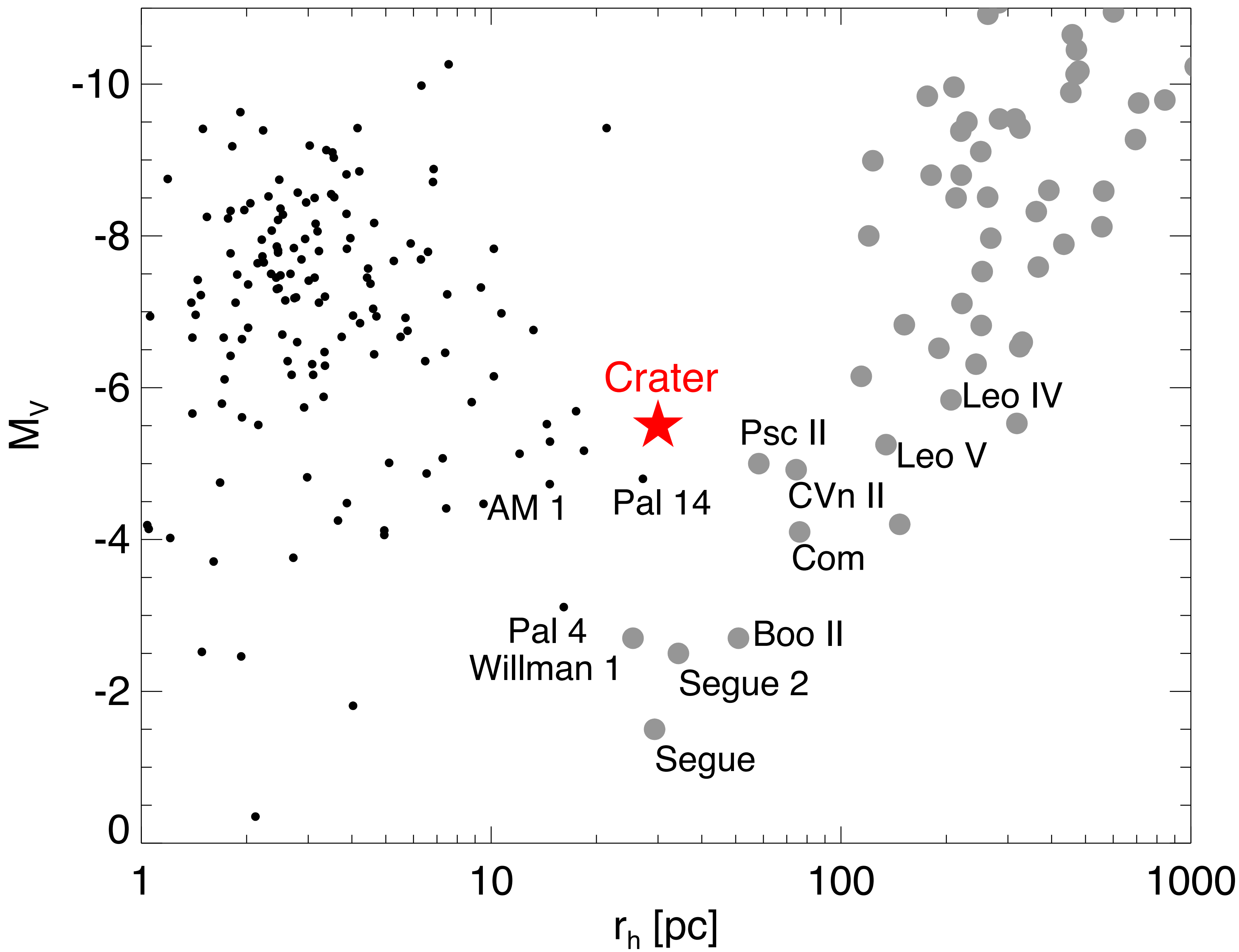
Laevens et al. 2014

Crater / Laev 1

Laevens et al. 2014:
- “most distant MW cluster”

Belokurov et al. 2014:
- “dwarf galaxy with unusual properties”

The zoo of small stellar systems



Belokurov et al. 2014

Pal 14, Pal 4, AM 1, NGC 2419, Crater

- more extended than "normal" GCs

Rh≈20pc vs. Rh≈3pc

- preferentially in the outer MW halo

HOW DID THEY FORM?

Formation of extended clusters

Originally formed as compact ("normal") clusters
+ mechanism that allows an expansion of the clusters:

- tidal shocks (require very eccentric orbits, hard!)
- accreted stellar systems (originally born in dwarf galaxies)

see Frank, Grebel & Küpper 2014

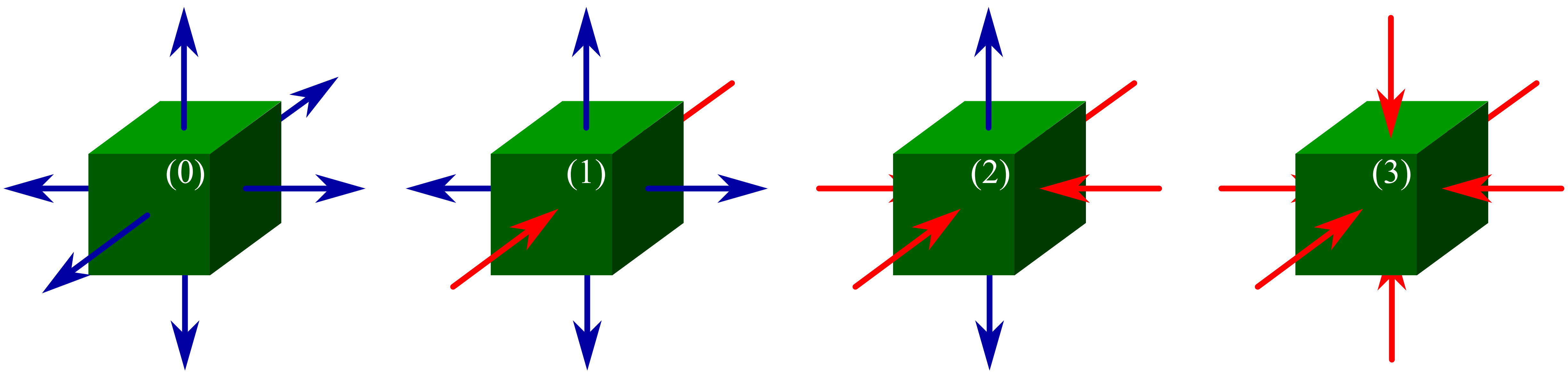
We test the following idea:

- cluster is born "normal" in the core of dwarf-like system
- it experiences COMPRESSIVE TIDES
- it is later accreted into the Milky Way and it expands

Compressive tides

$$T^{ji} = -\partial^j \partial^i \phi_{ext}$$

$$T^{ji} = \begin{vmatrix} \lambda_1 & & \\ & \lambda_2 & \\ & & \lambda_3 \end{vmatrix}$$



$0 < \lambda_1 < \lambda_2 < \lambda_3$ | $\lambda_1 < 0 < \lambda_2 < \lambda_3$ | $\lambda_1 < \lambda_2 < 0 < \lambda_3$ | $\lambda_1 < \lambda_2 < \lambda_3 < 0$

FULLY COMPRESSIVE TIDES

Renaud 2010

Compressive tides

where do we find these tides? example:

$$\phi(r) = -\frac{GM}{\sqrt{r_0^2 + r^2}}$$

Plummer (1911) potential

$$T^{ij} = -GM\frac{\delta^{ij}\left(r_0^2 + r^2\right) - 3x_i x_j}{\left(r_0^2 + r^2\right)^{5/2}}$$

associated tidal tensor

Compressive

$$\lambda_1, \lambda_2, \lambda_3 < 0$$

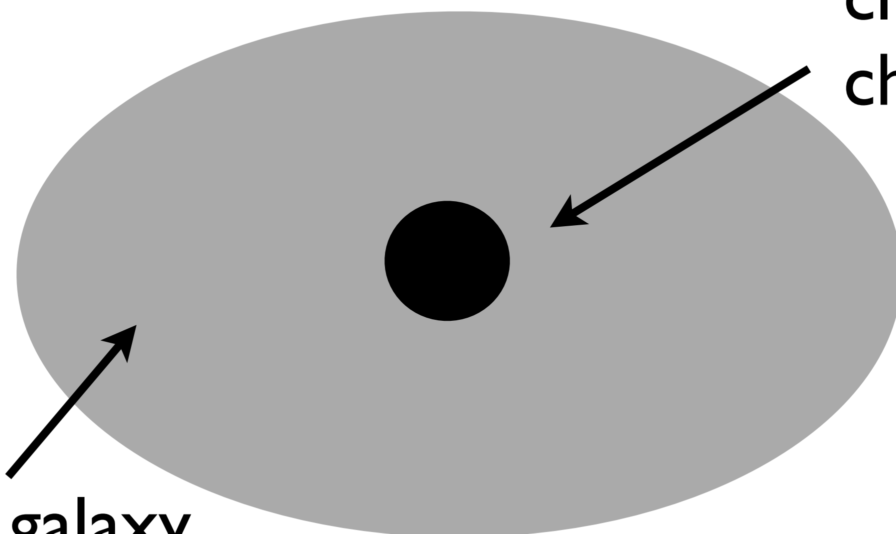
if

core region

$$r < \frac{r_0}{\sqrt{2}}$$

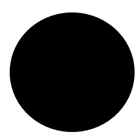
(simple) analytical description

1)



$$E_0 = \frac{1}{2}M\sigma^2 - \frac{GM^2}{2r_v} - \frac{1}{2}\lambda\alpha M R_t^2$$

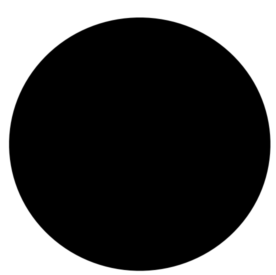
2)



compressive tides
are turned off

$$E_1 = \frac{1}{2}M\sigma^2 - \frac{GM^2}{2r_v}$$

3)



system reaches
new virial
equilibrium

$$r'_v = r_v \left(\frac{1}{1 + \frac{2\lambda\alpha R_t^2 r_v}{GM}} \right)$$

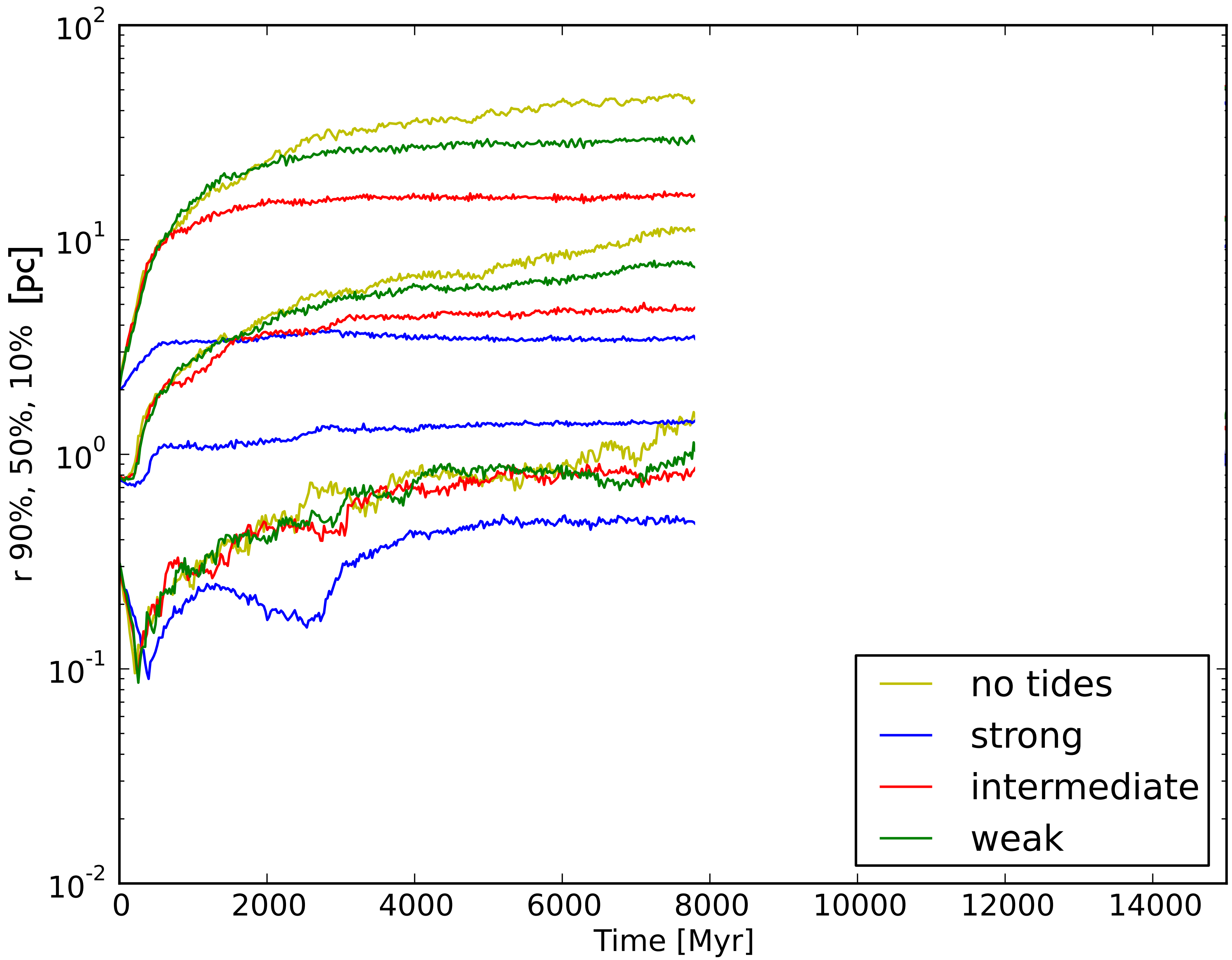
N-body simulations

- nbody6tt (Renaud, Gieles & Boily 2011)
- initial conditions: 4k/8k particles from plummer models
(no initial mass function)
- compressive tides given by the core of a Plummer potential
- switch-off the compressive tides, cluster back to isolation
- long term evolution simulations (≈13 Gyr)

Different test cases to understand the dependence on:

- strength of the tidal field
- the transition between compressive tides and no tides
- density
- spatial extent of cluster (roche-lobe filling)
- orbit of the cluster in the compressive potential

a) tidal field strength



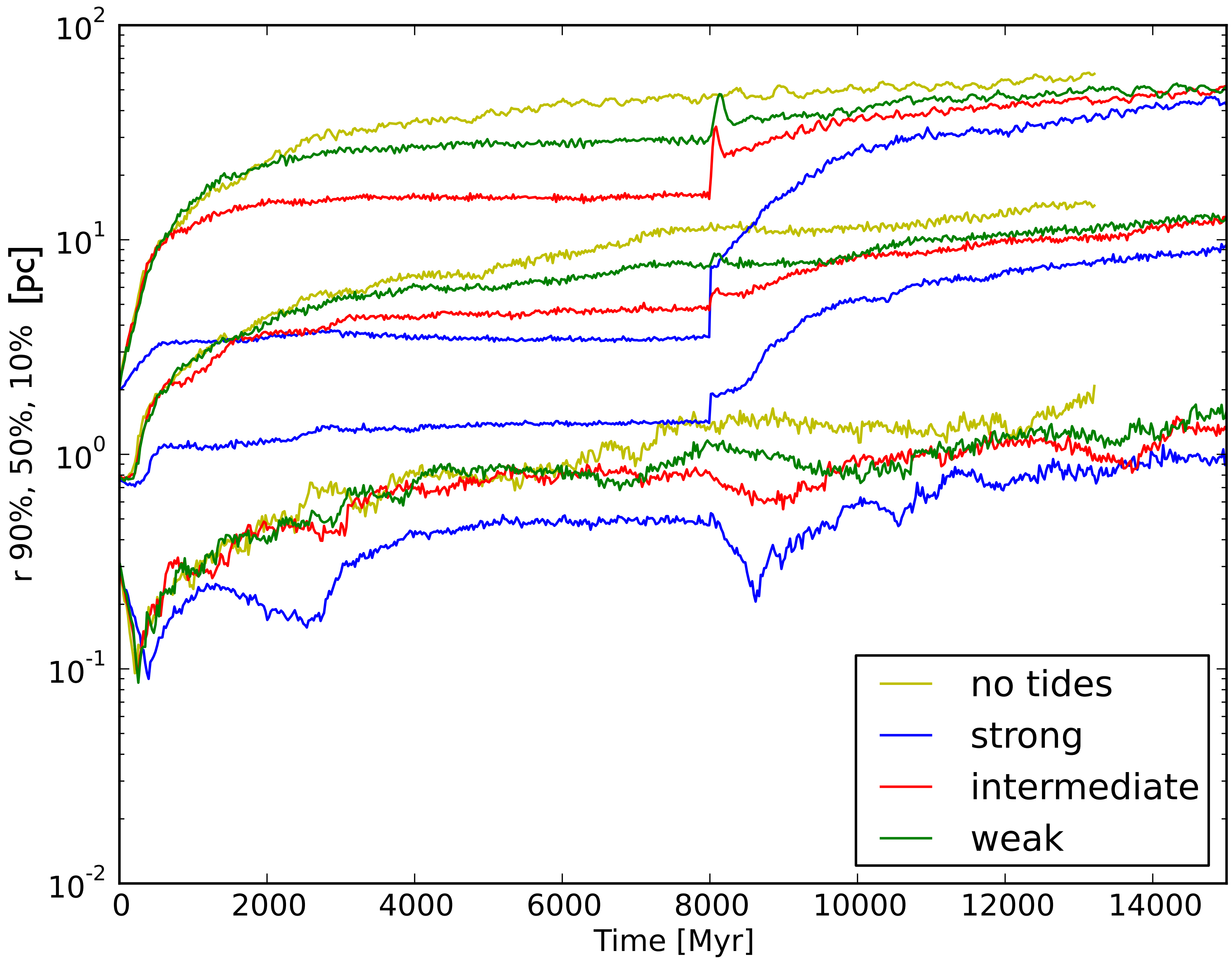
GC in the center of a Plummer potential with:

strong
- R=100 pc, M=10^8 M$_\odot$

intermediate
- R=500 pc, M=10^8 M$_\odot$

weak
- R=1000 pc, M=10^8 M$_\odot$

a) tidal field strength



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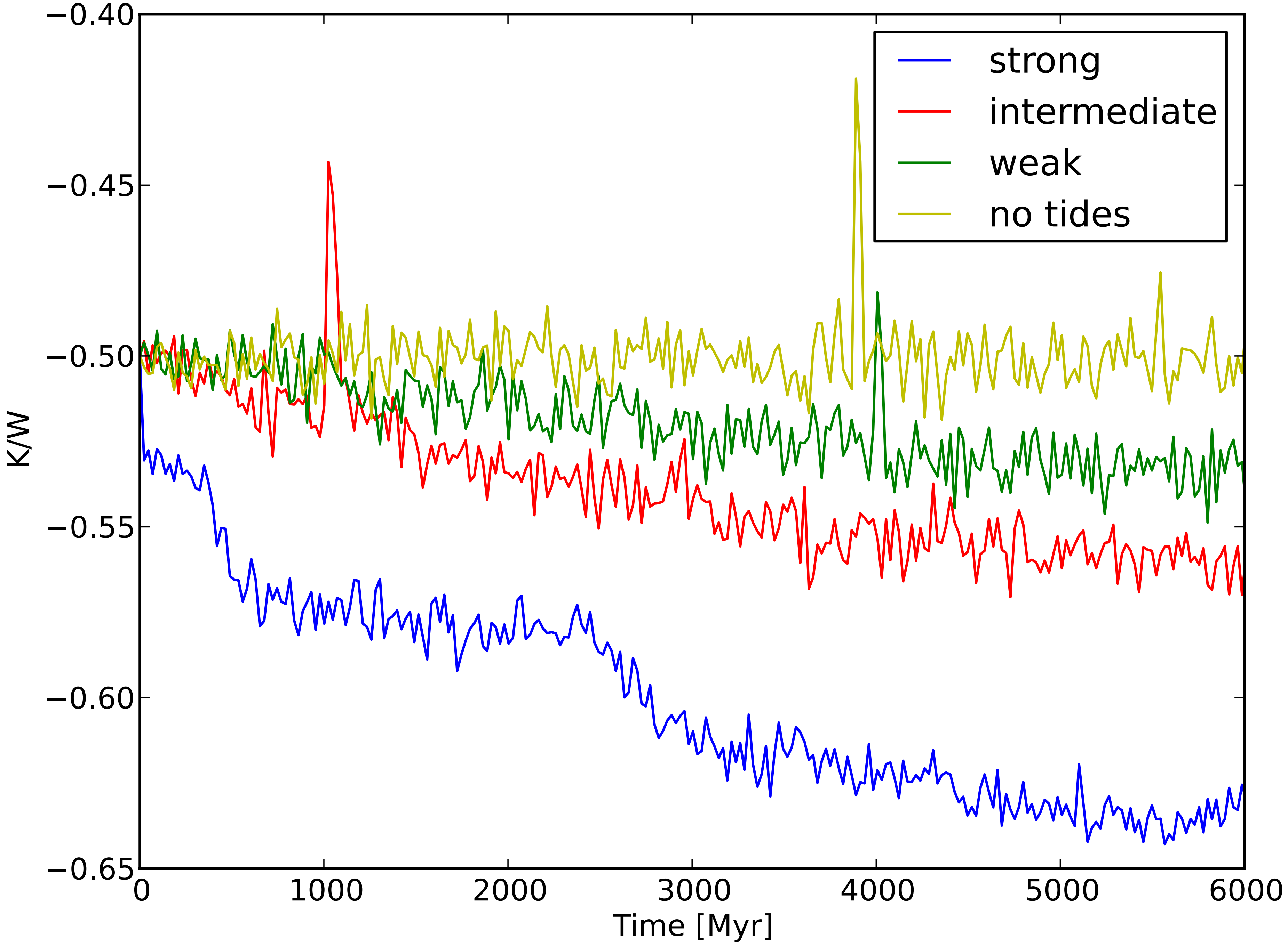
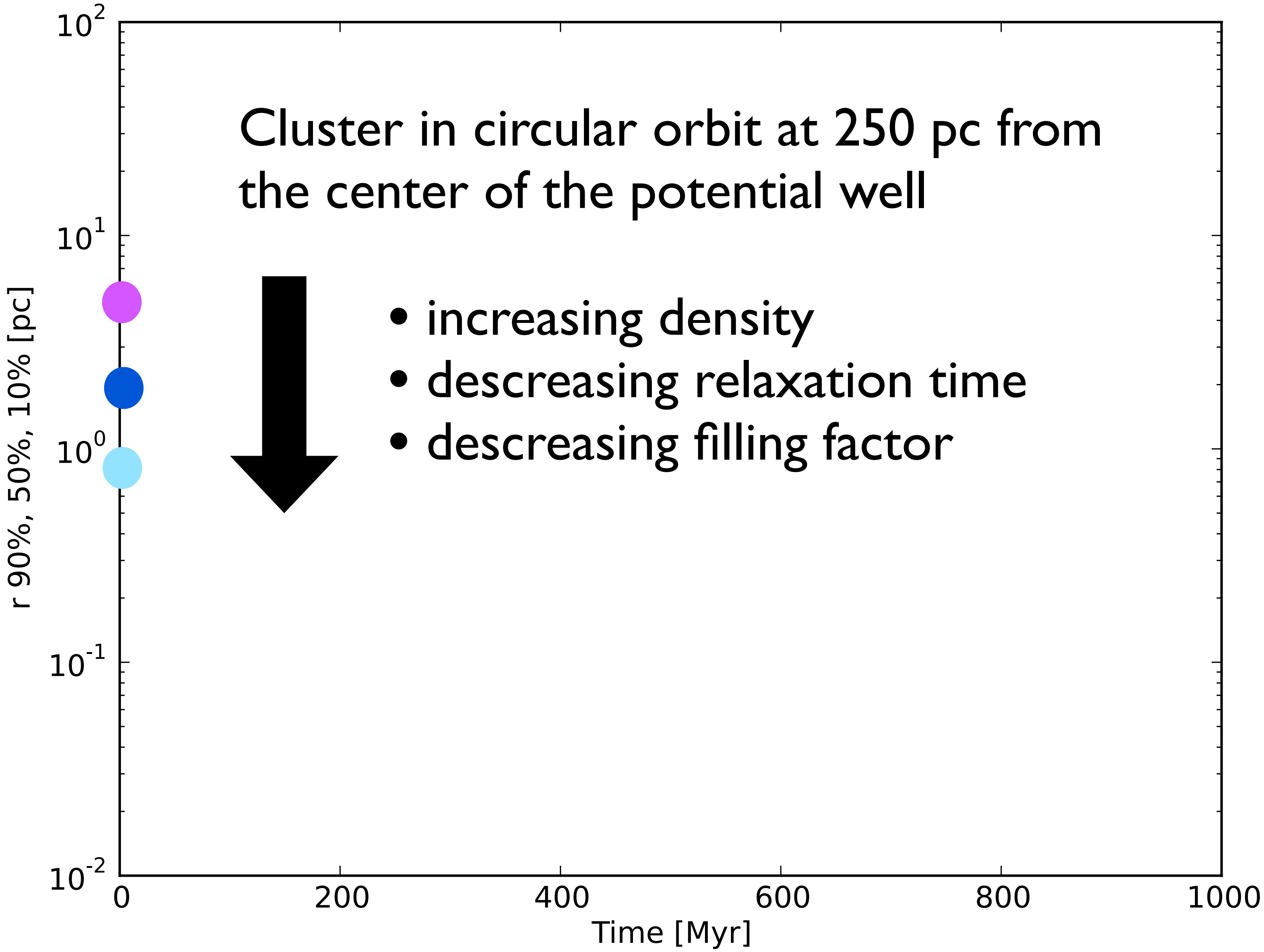
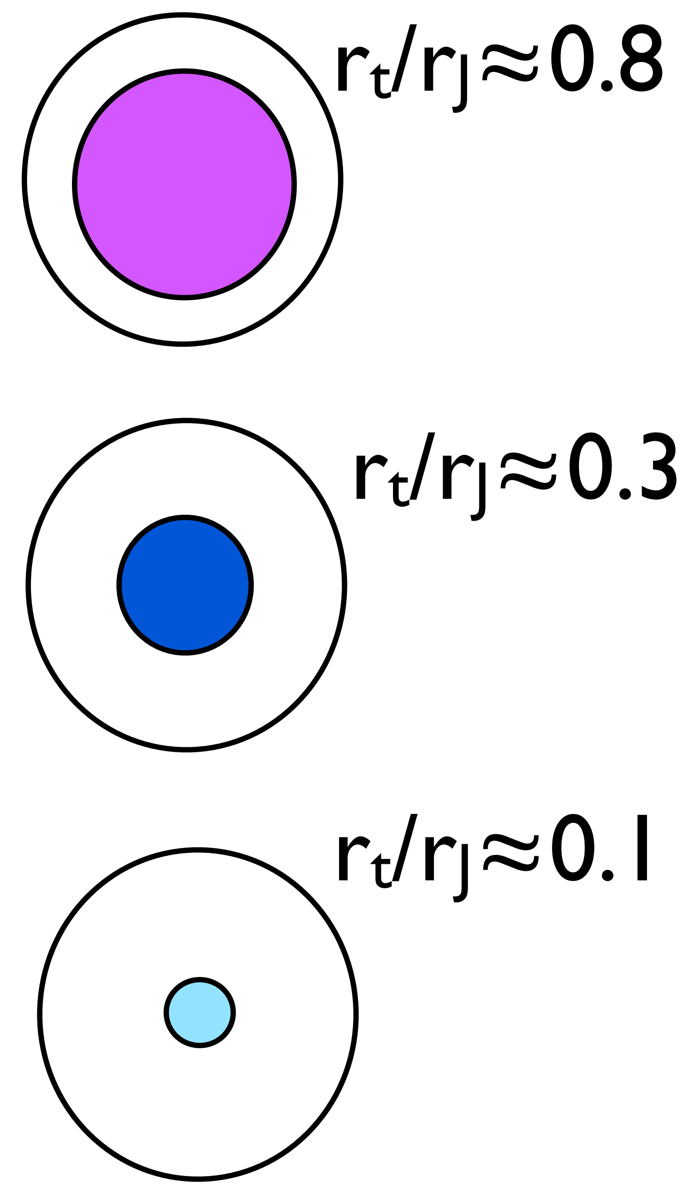


b) circular orbit



Filling factor



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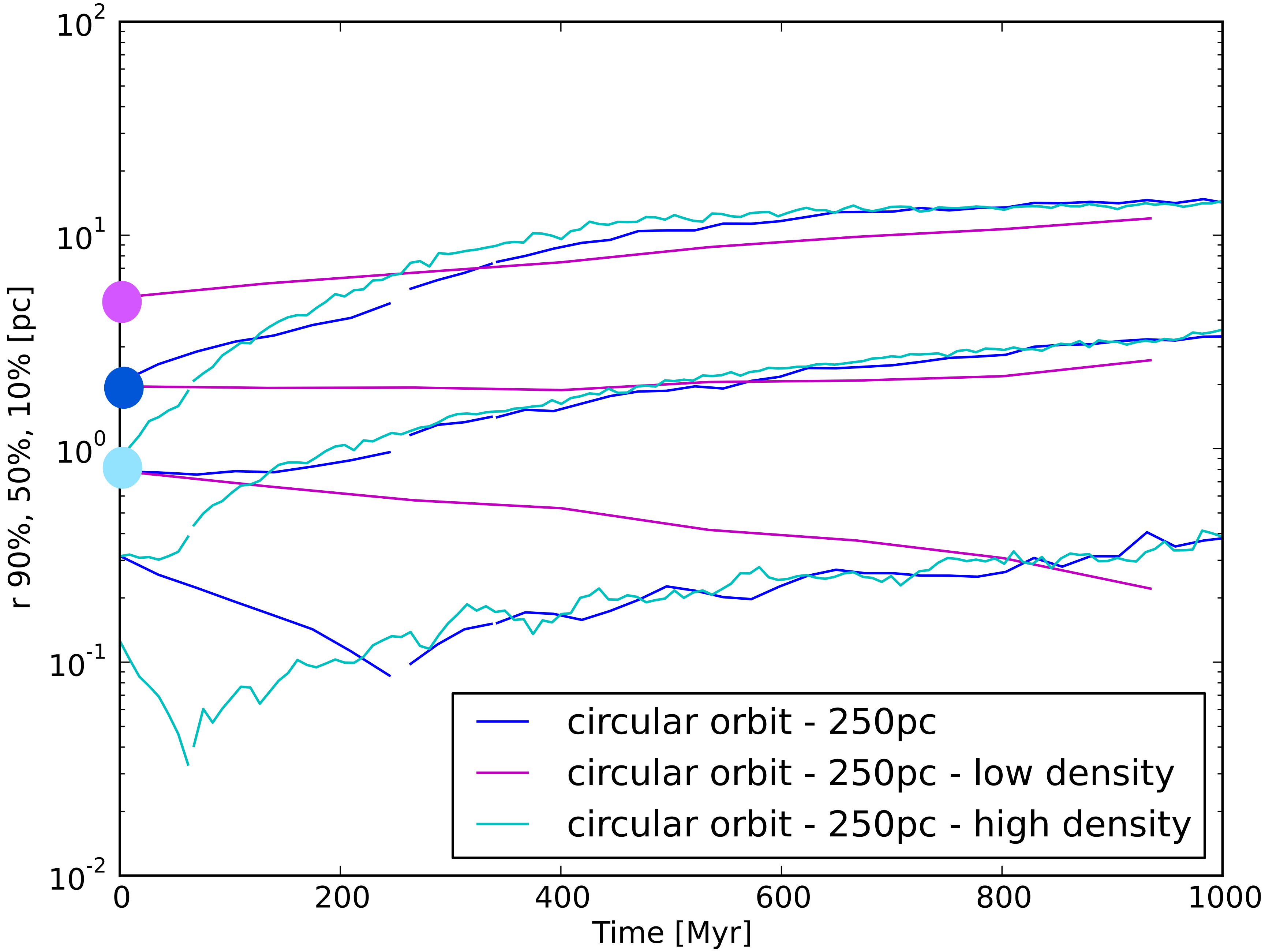

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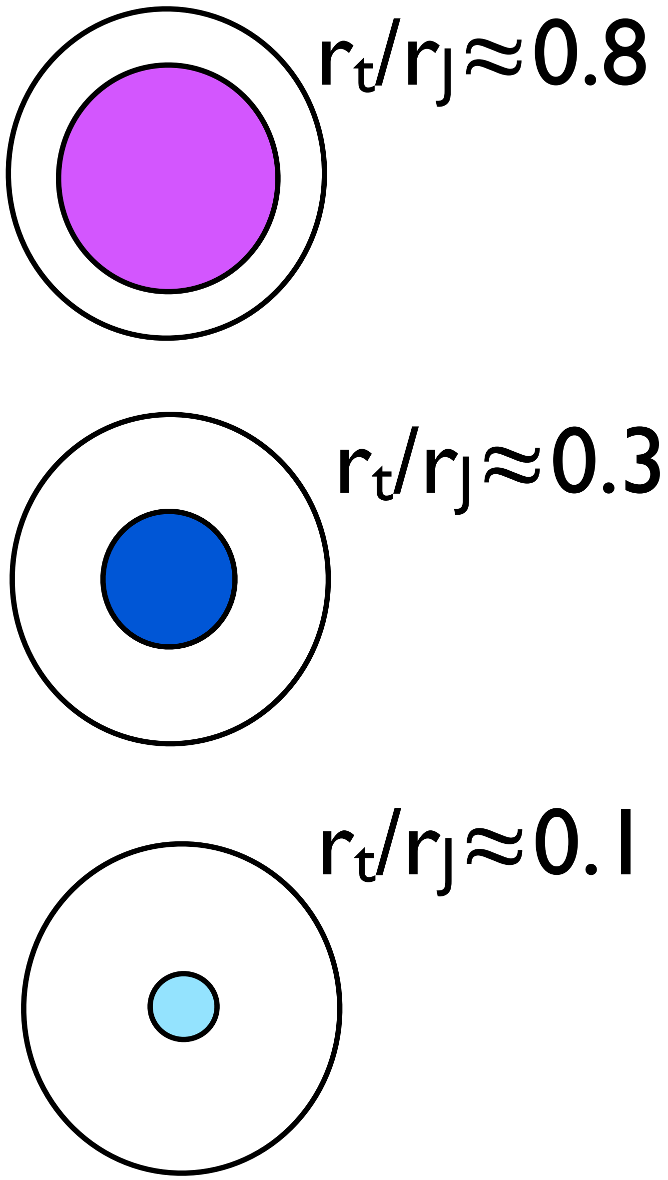

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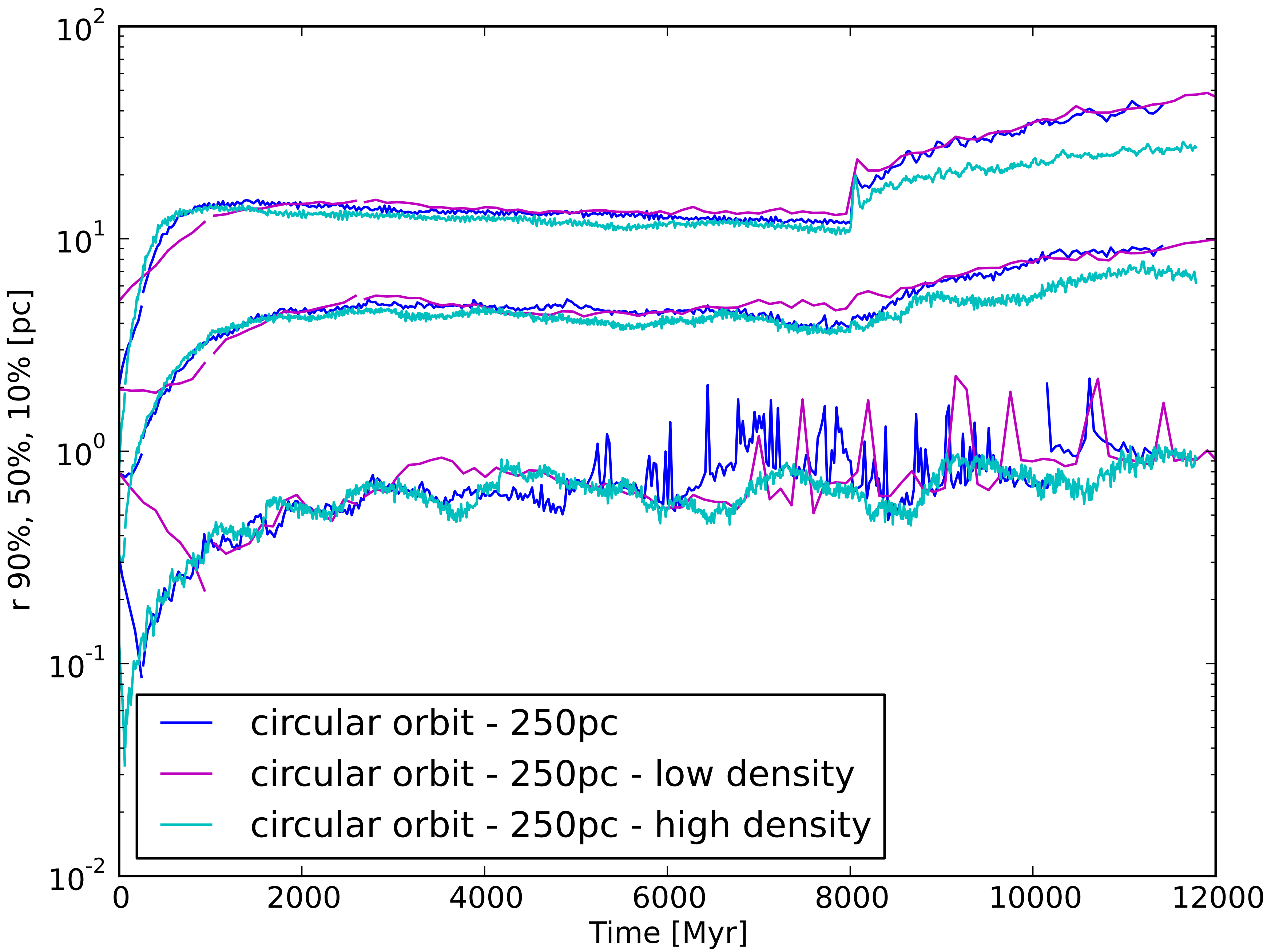

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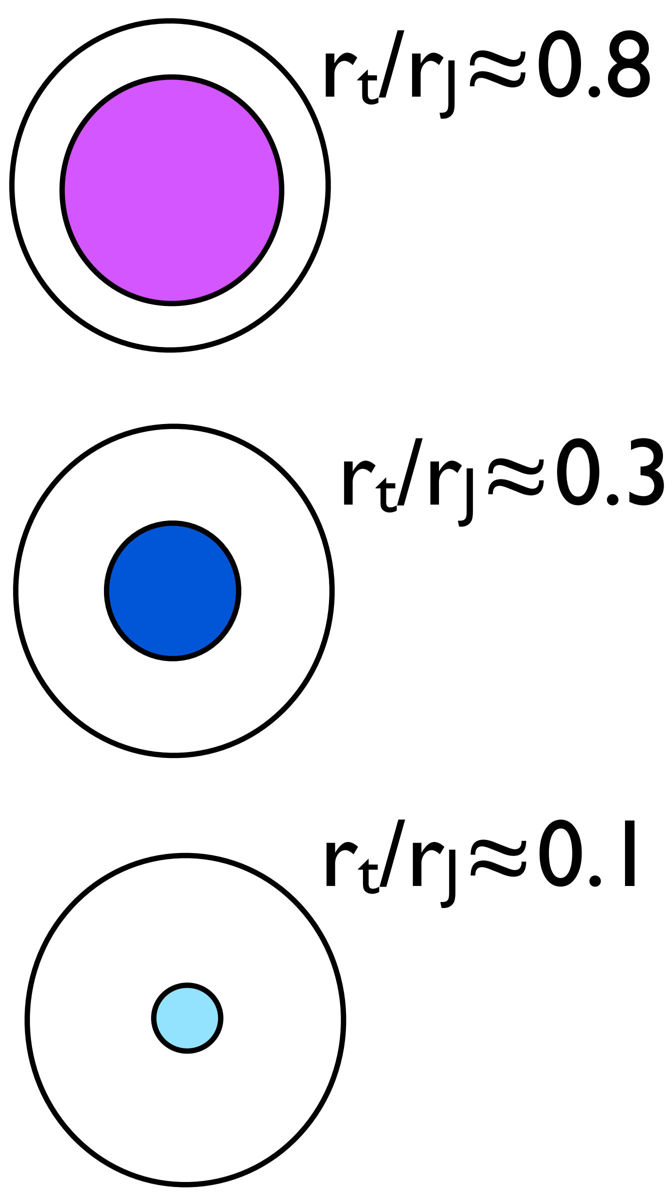

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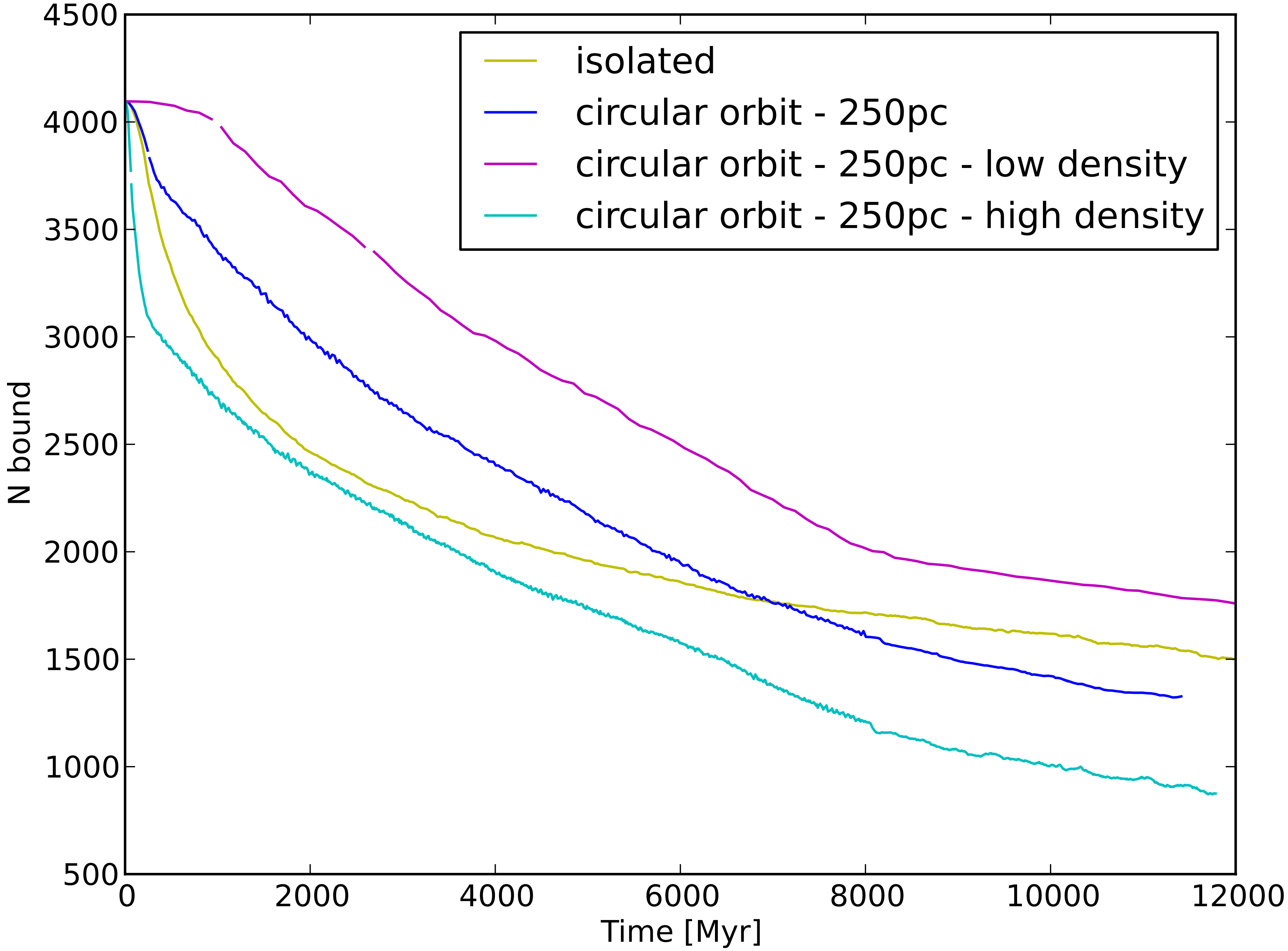

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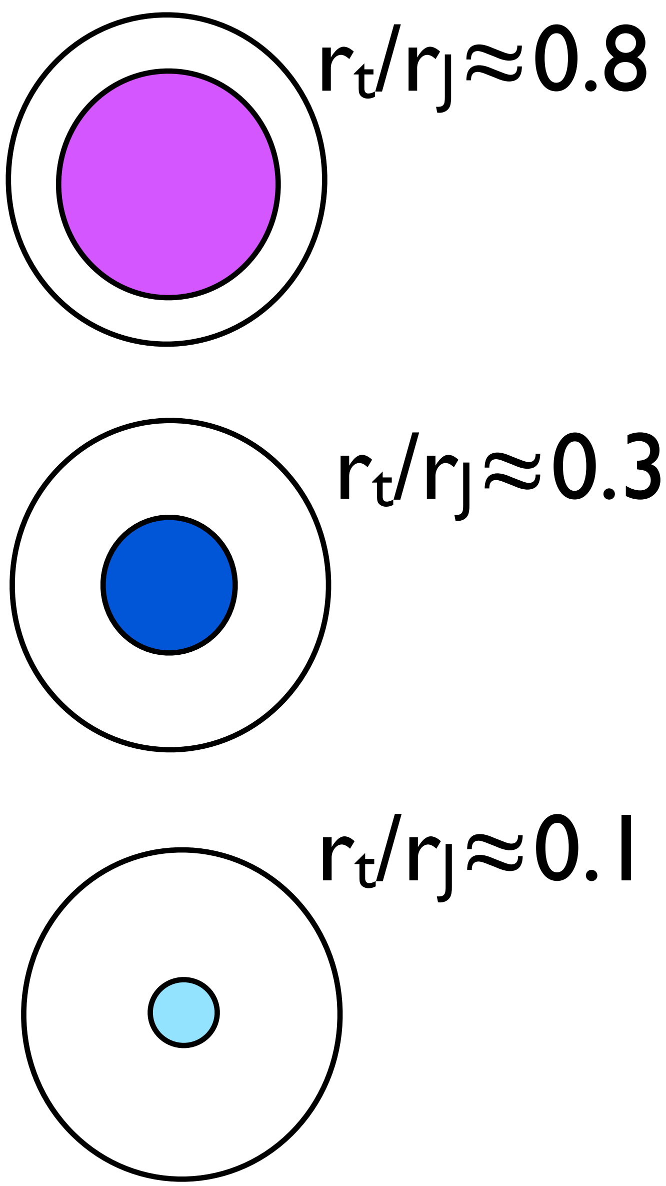
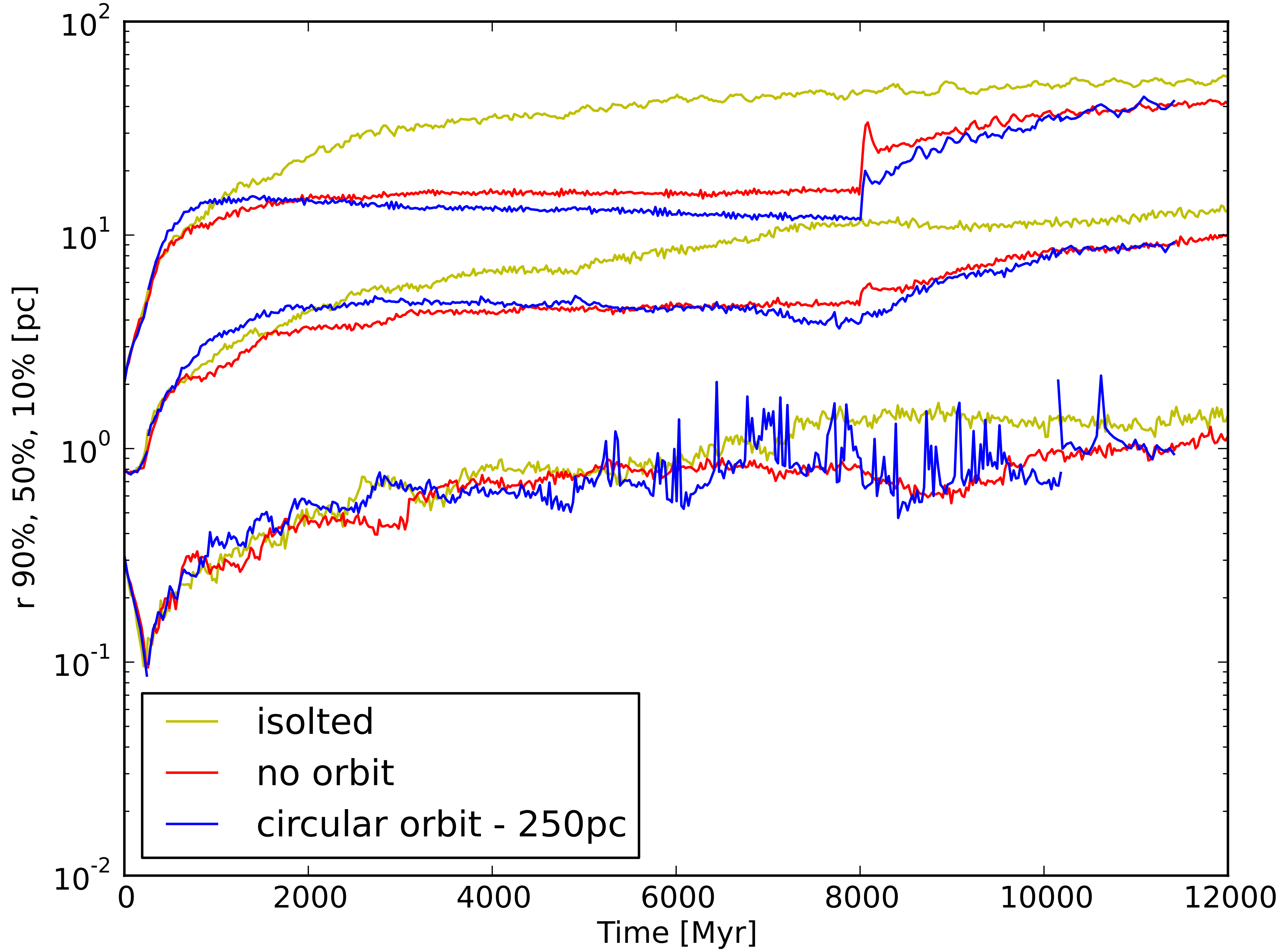
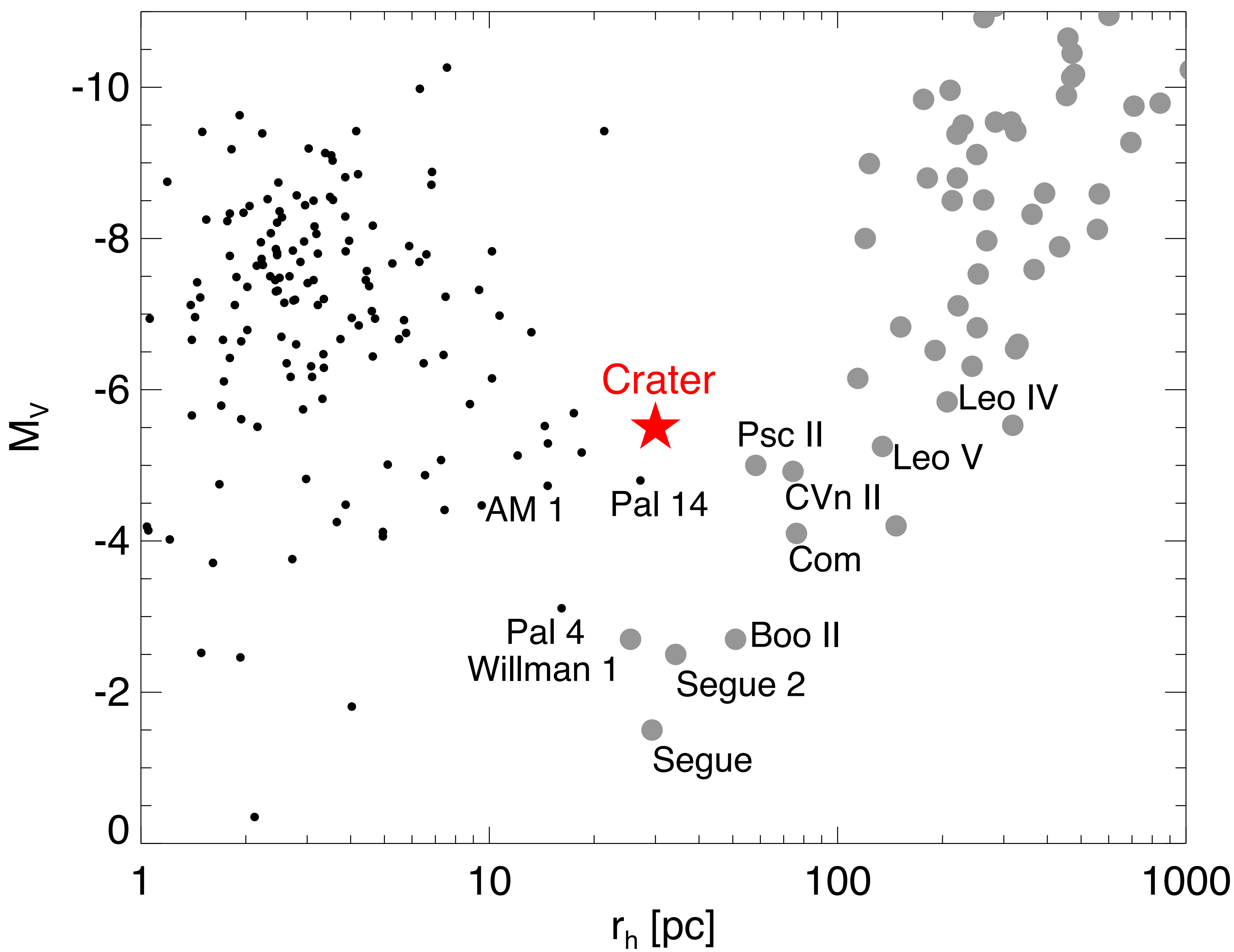


Summary



- a cluster expands when the compressive tidal field is switched off
- we tested this conclusion with different test cases (different densities, filling factors, circular orbit)
- the cluster DOES NOT expand more than the corresponding cluster evolved in isolation

Is the expansion enough?



Belokurov et al. 2014

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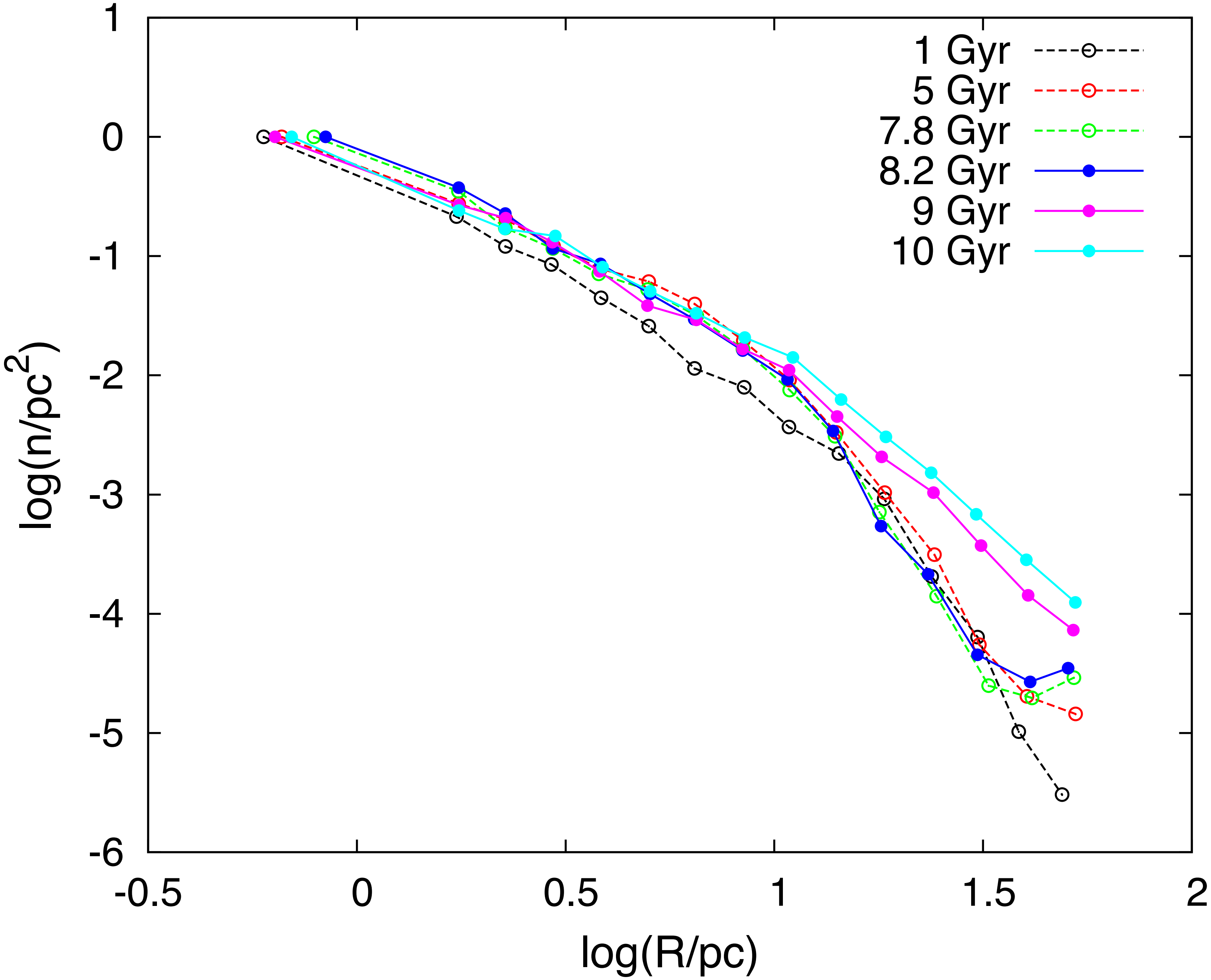

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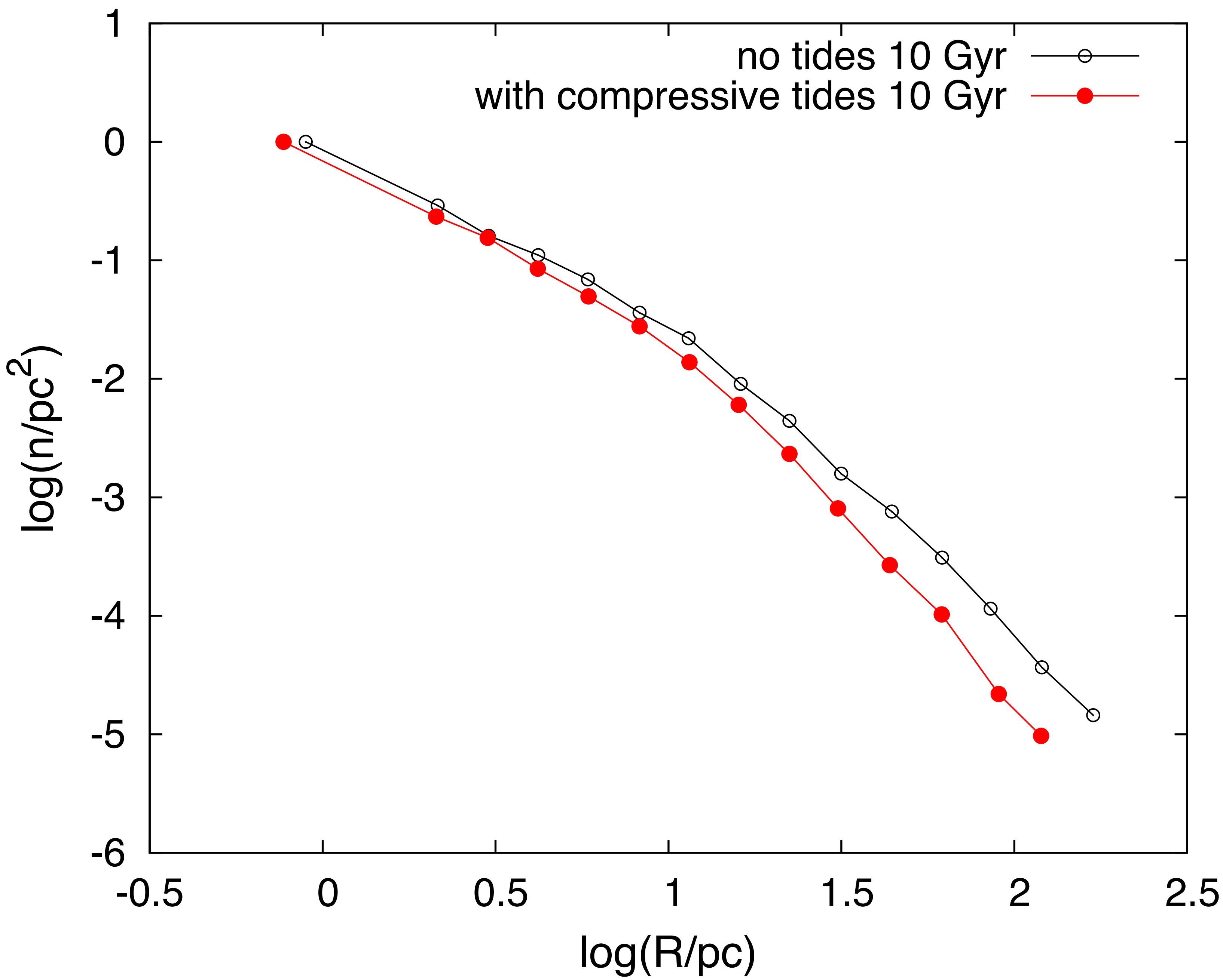

- We DO NOT obtain clusters with density profiles more extended than the corresponding isolated case

Conclusions and prospectives

- we showed that an accreated origin of clusters cannot explain the extended structure of MW outer halo GCs
- we tested an extreme case (transition from compressive tides to isolation)

What are we missing?

- initial mass function, stellar evolution
- realistic accreation and dissolution of the host-dwarf galaxy

What can we still learn?

- unique signatures imprinted by compressive tides
    - photometry
    - kinematics (velocity dispersion, anisotropy)
    - mass segregation/energy equipartition