N-body simulations with BSSs: defining mass segregation indicators

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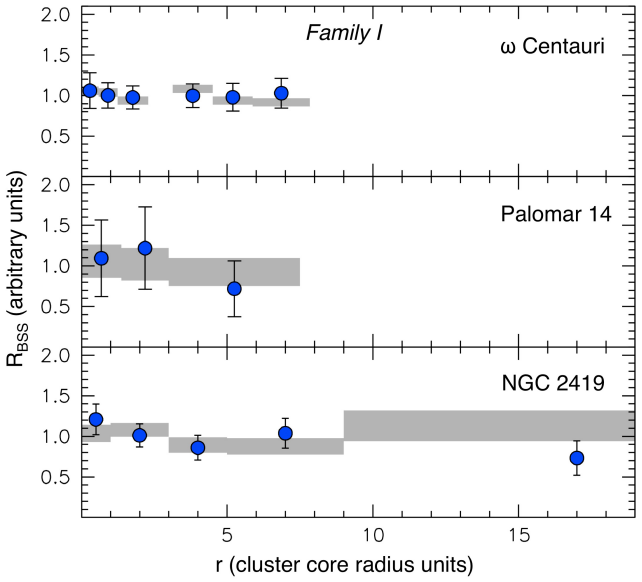
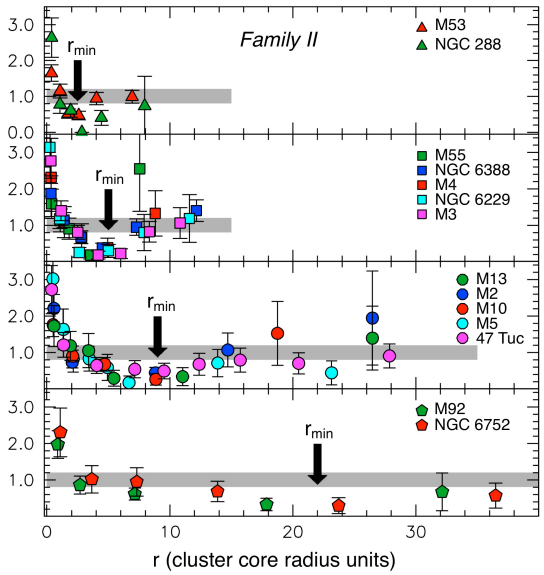
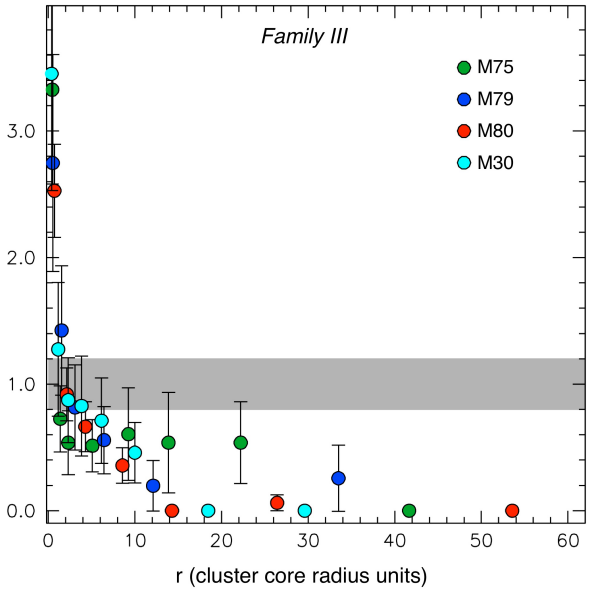
Context







(*Ferraro et al. 2012*)

Dynamical Friction (DF)

Question

Bimodality of BSS radial distribution: due to a non-monotonic radial behavior of the DF timescale in a segregated mass-spectrum?

Semi-analytical approach (1)
Alessandrini et al. 2014, Apj 795,169

DF time-scale in a multi-mass system (N_{pop} mass components)

$$\frac{1}{t_{DF}} = \sum_{i=1}^{N_{pop}} \frac{1}{{t_{DF}}^{(i)}}$$

Circular orbit approximation

$$t_{DF}{}^{(i)}(r) = \frac{v_t^3(r)}{4\pi G^2 n_i(r) m_i (m_i + m_t) \Xi_i(r) \ln \bar{\Lambda}}$$

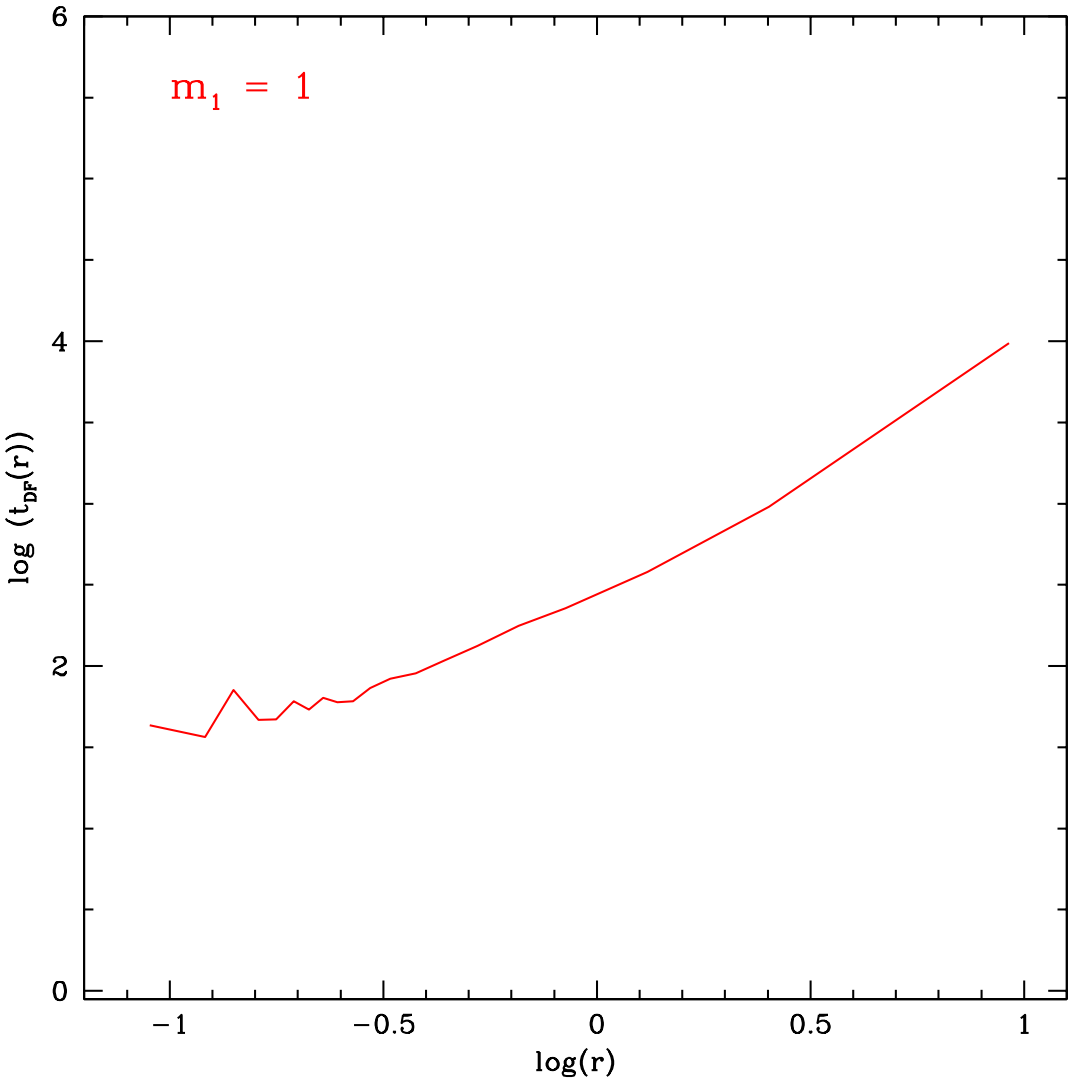
m_t (test particle): BSS

Semi-analytical approach (2)

N-body simulations (NBODY6, *Aarseth, 2003*)

- $N = 10^4$ field particles
- $N_{pop} = 3$
  $m_1 = 1$ (8500 particles) → 0.3 $M_\odot$
  $m_2 = 2$ (1200 particles)
  $m_3 = 3$ (300 particles)
- $m_t = 4$ (BSS) → 1.2 $M_\odot$
- $W_0 = 4$, 6 and 8

Semi-analytical approach (3)



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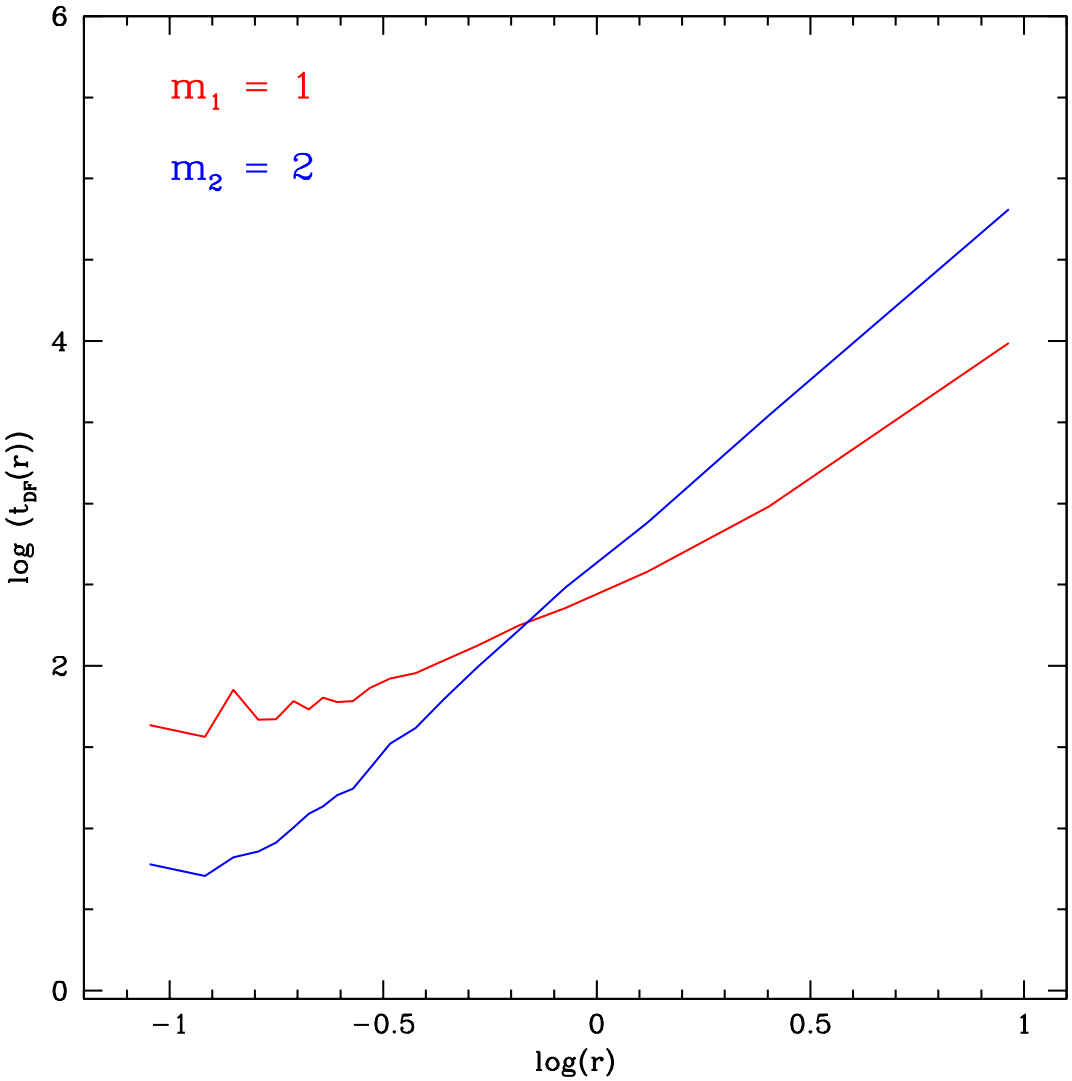
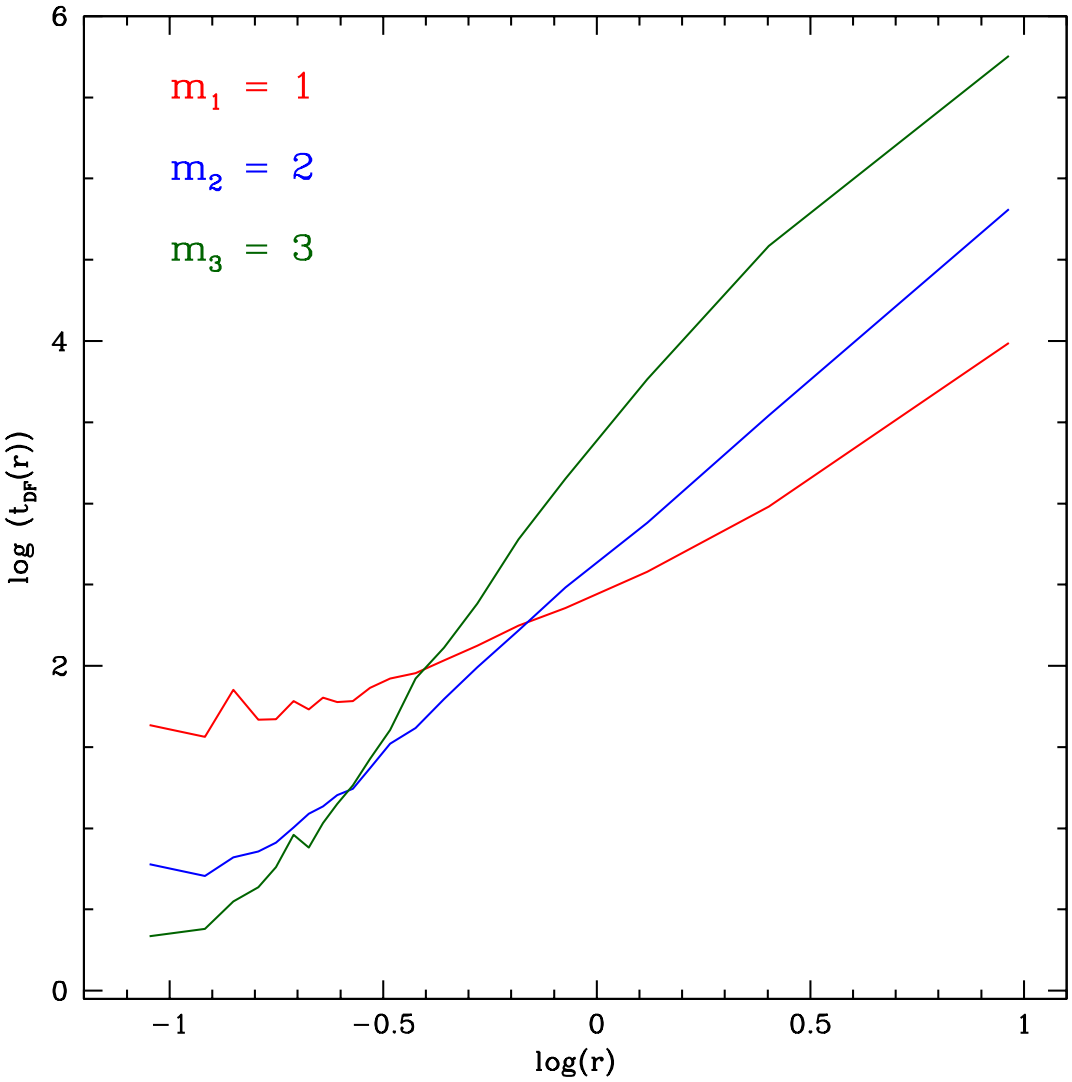
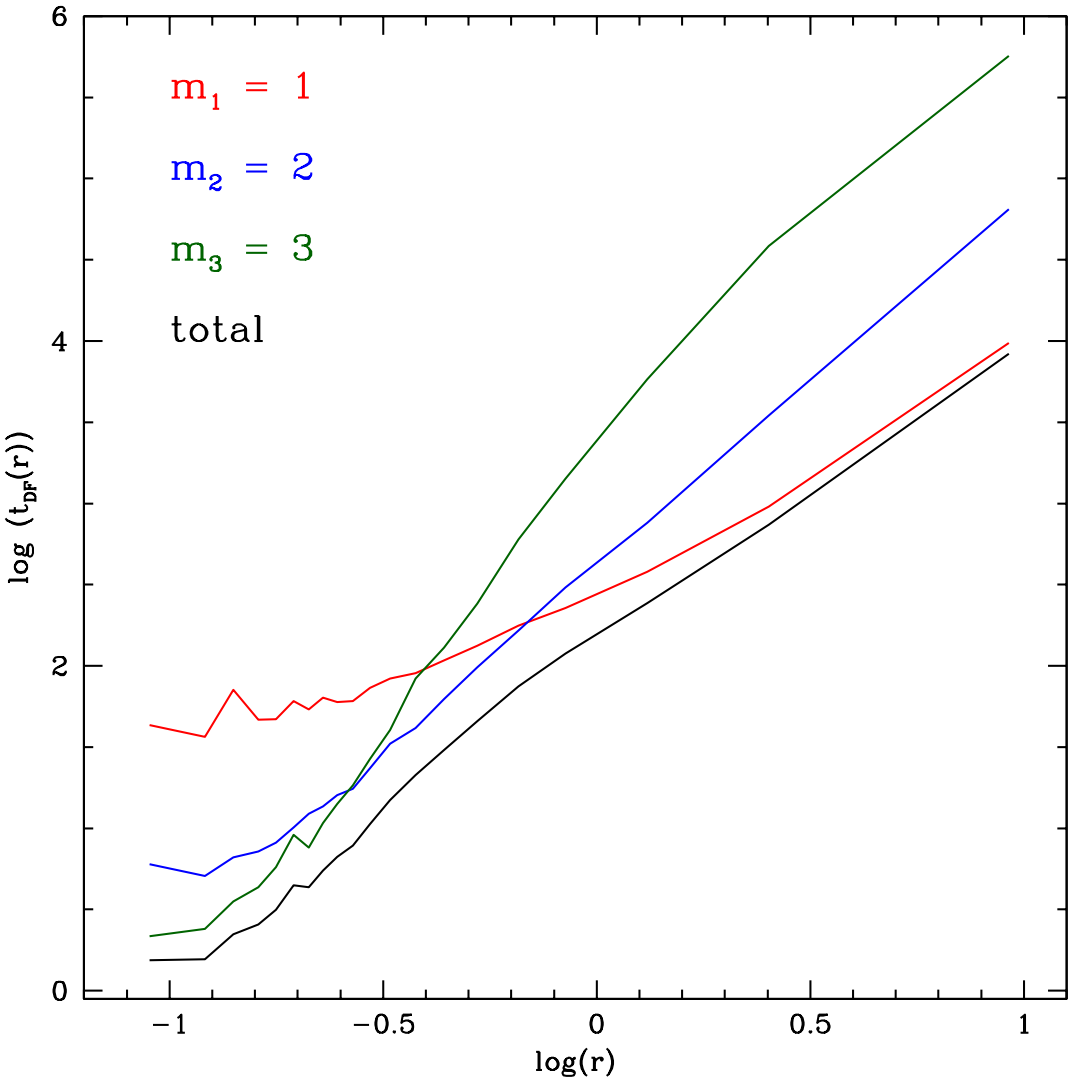


Semi-analytical approach (3)

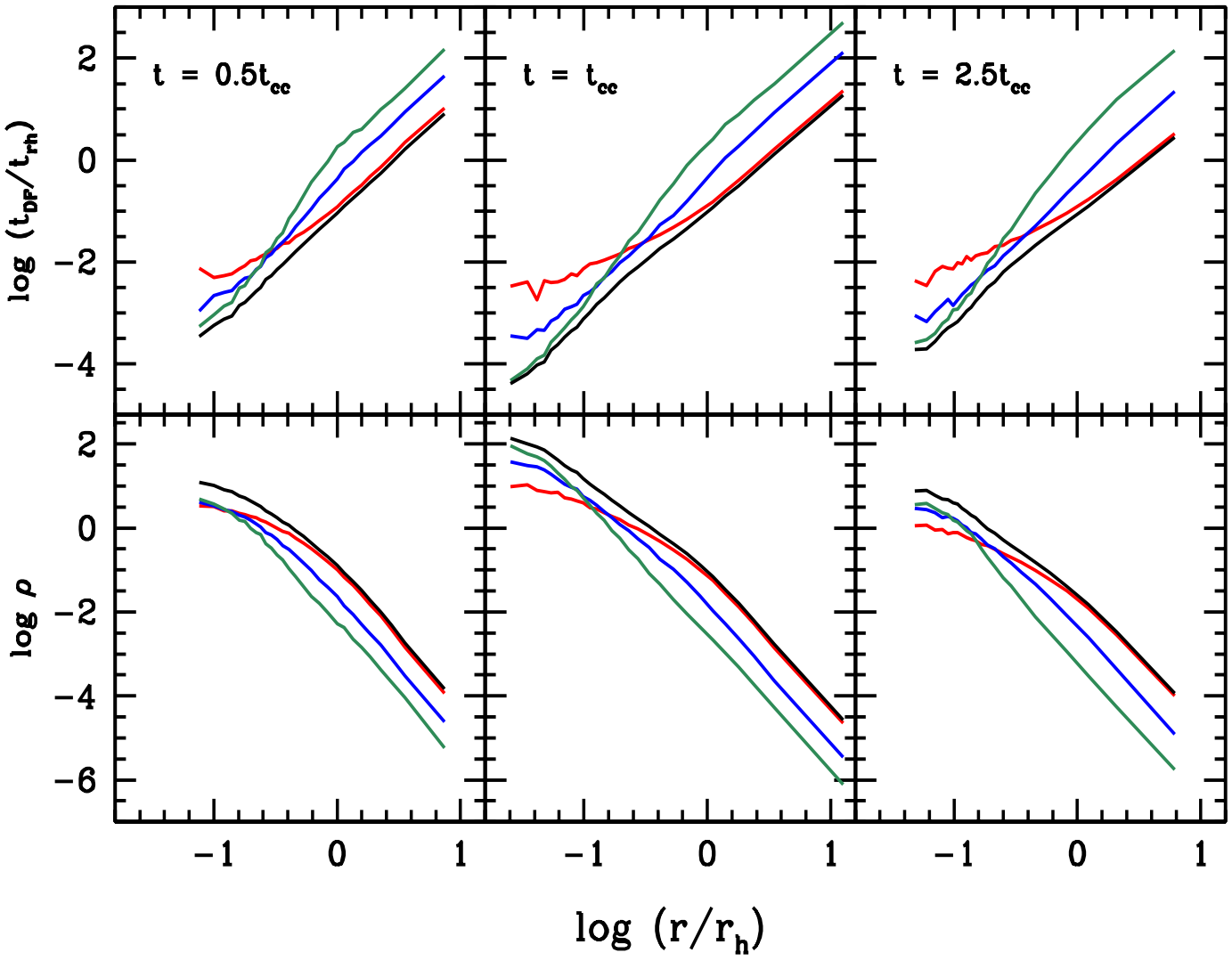


Semi-analytical approach (3)



The DF timescales of BSSs is a monotonic function of the radius also in multi-mass systems

Semi-analytical approach (4)



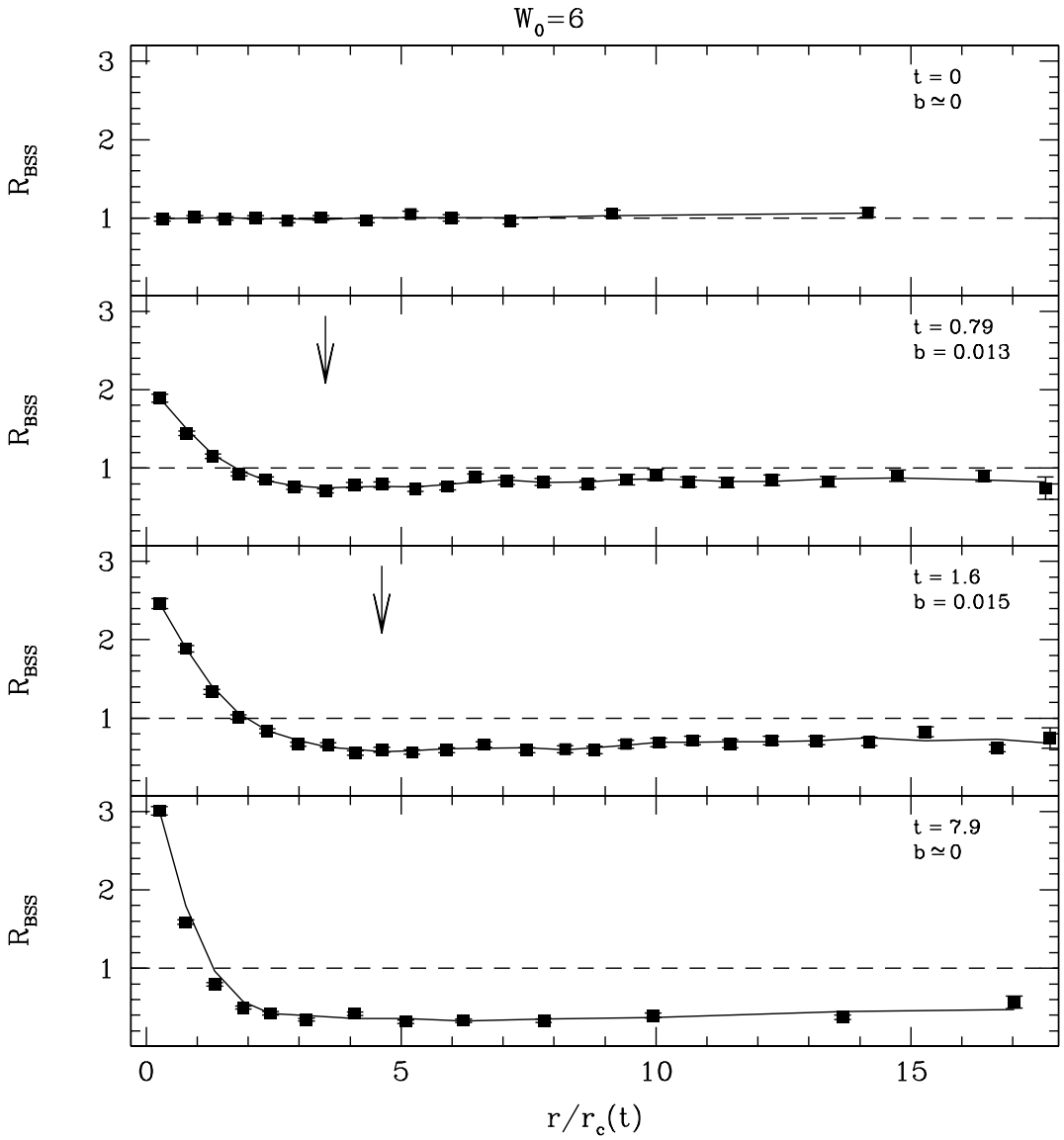
- t_{DF} always **monotonic**
- t_{DF} shaped by the **global mass density**

Semi-analytical approach (5)

The time (instead of the radial) dependence of t_{DF} remains the most likely explanation of the observed BSS bimodal distribution,
reinforcing the assumptions adopted in previous works

Alessandrini et al. 2014, Apj 795, 195

Numerical works (1)



Miocchi et al., 2015

- A central peak rapidly forms and grows with time (BSS segregation)
- A dip forms
- Minimum in R_{BSS} found only in few cases; noisy evolution
- Too fast overall evolution (CC at 1 t_{rh0})

Numerical works (2)

Problems: realism of the simulations

- Small particle number ($N=10^4$)
- Unrealistic mass-spectrum (3 discrete components)
- BSSs are the most massive objects in the system

New N-body simulations

Alessandrini et al. 2016, (in prep)

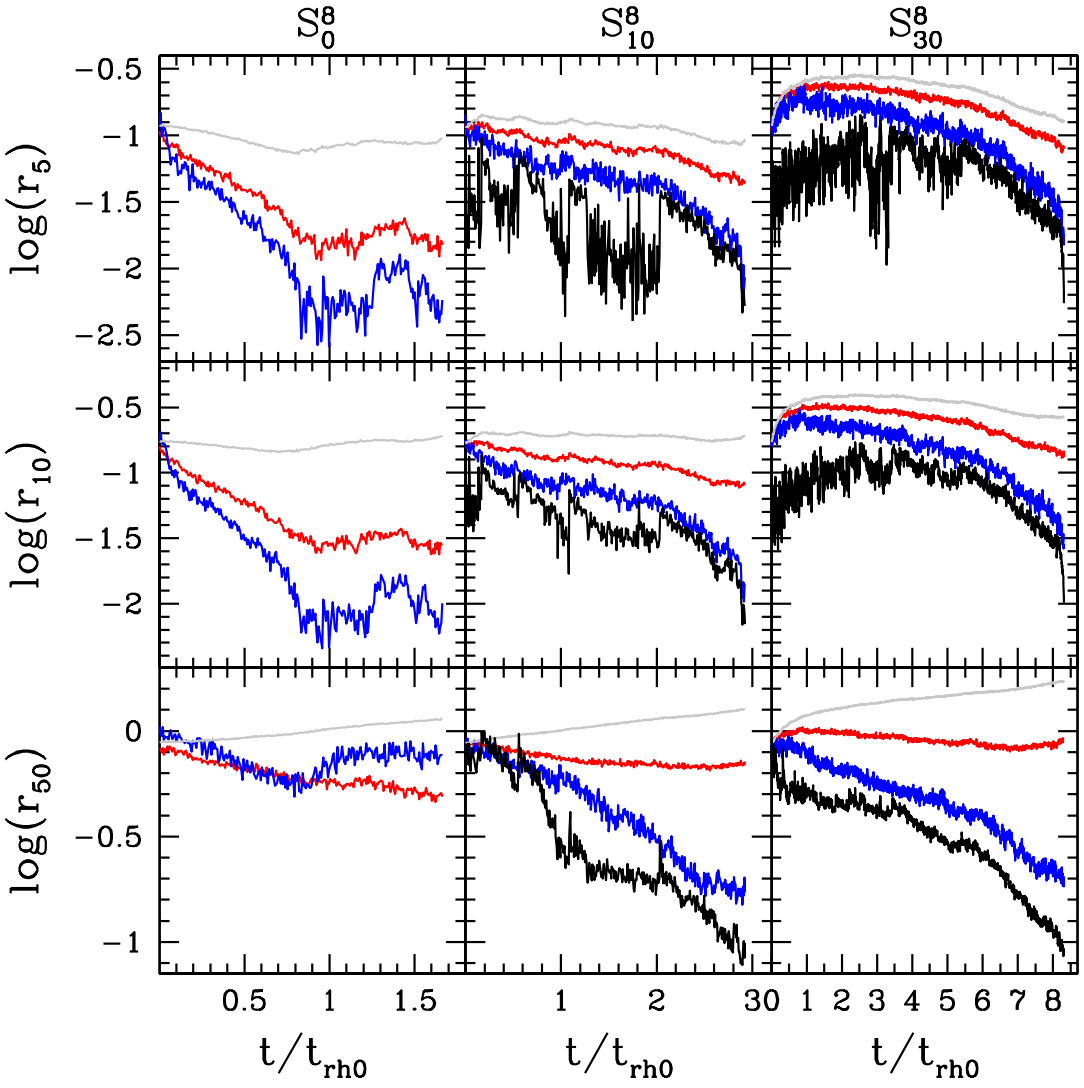
Initial conditions

- $N = 10^5$
- Kroupa 2001 IMF evolved at t=12 Gyr:
  - Reference population (REF) → 0.8 $M_\odot$
  - Blue Stragglers (BSS) → 1.2 $M_\odot$
  - Dark Remnants (DR: WD,NS,BH) → > 1.2 $M_\odot$
- f_{DR} = 0%, 10% and 30% (N_{DR}/N_{DR0})
- $W_0 = 5$ and $W_0 = 8$

Results

Evolution of the Lagrangian radii (W_0=8)

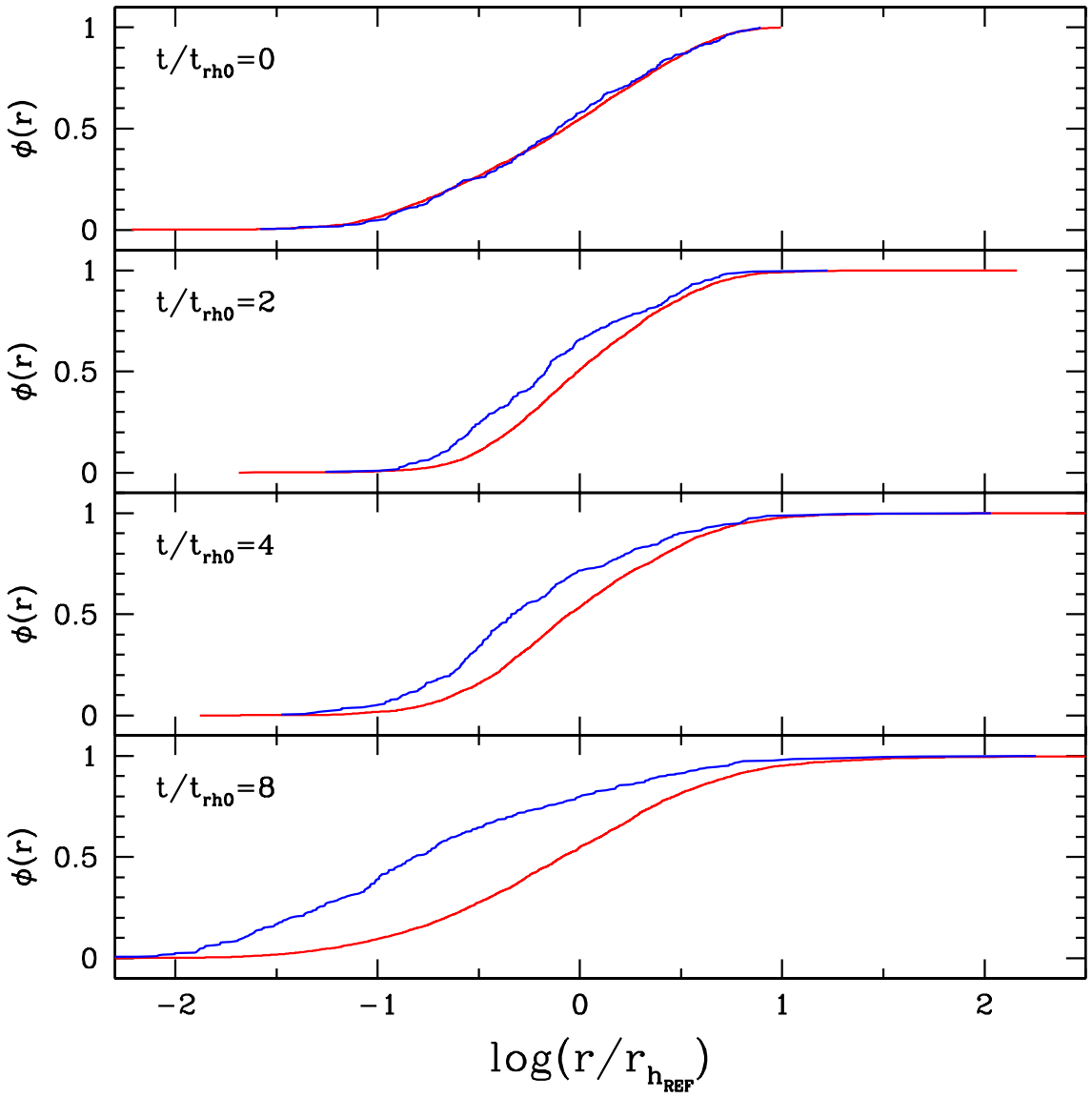
(REF, BSS, DR, global)



- If f_{DR}=0, unrealistic dynamics
- DRs form a sub-system, rapidly collapsing
- DRs slow down the evolution

DR fraction is crucial for the global evolution

Evolution of cumulative distributions (1)

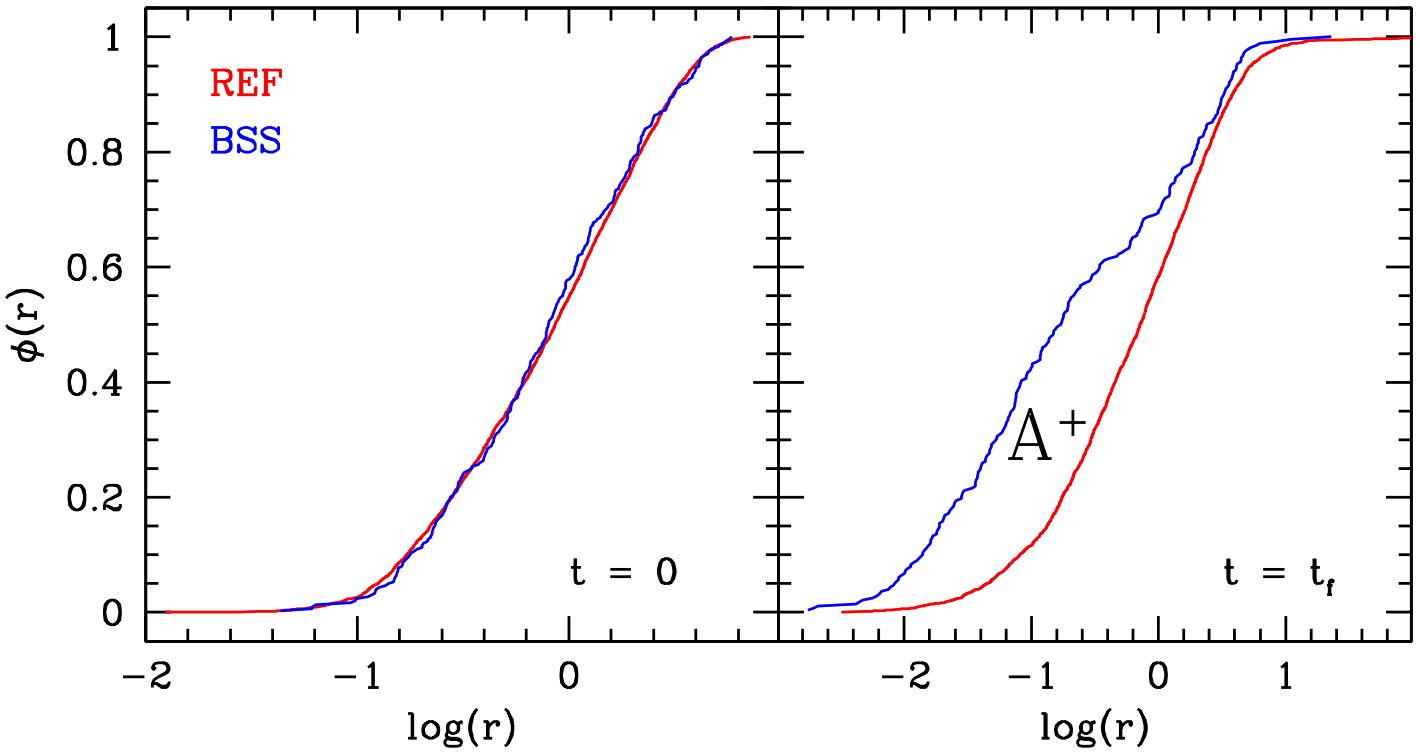


REFs (m=0.8 Msol)
BSSs (m=1.2 Msol)

- BSS segregation progressively separates the two cumulatives during the evolution

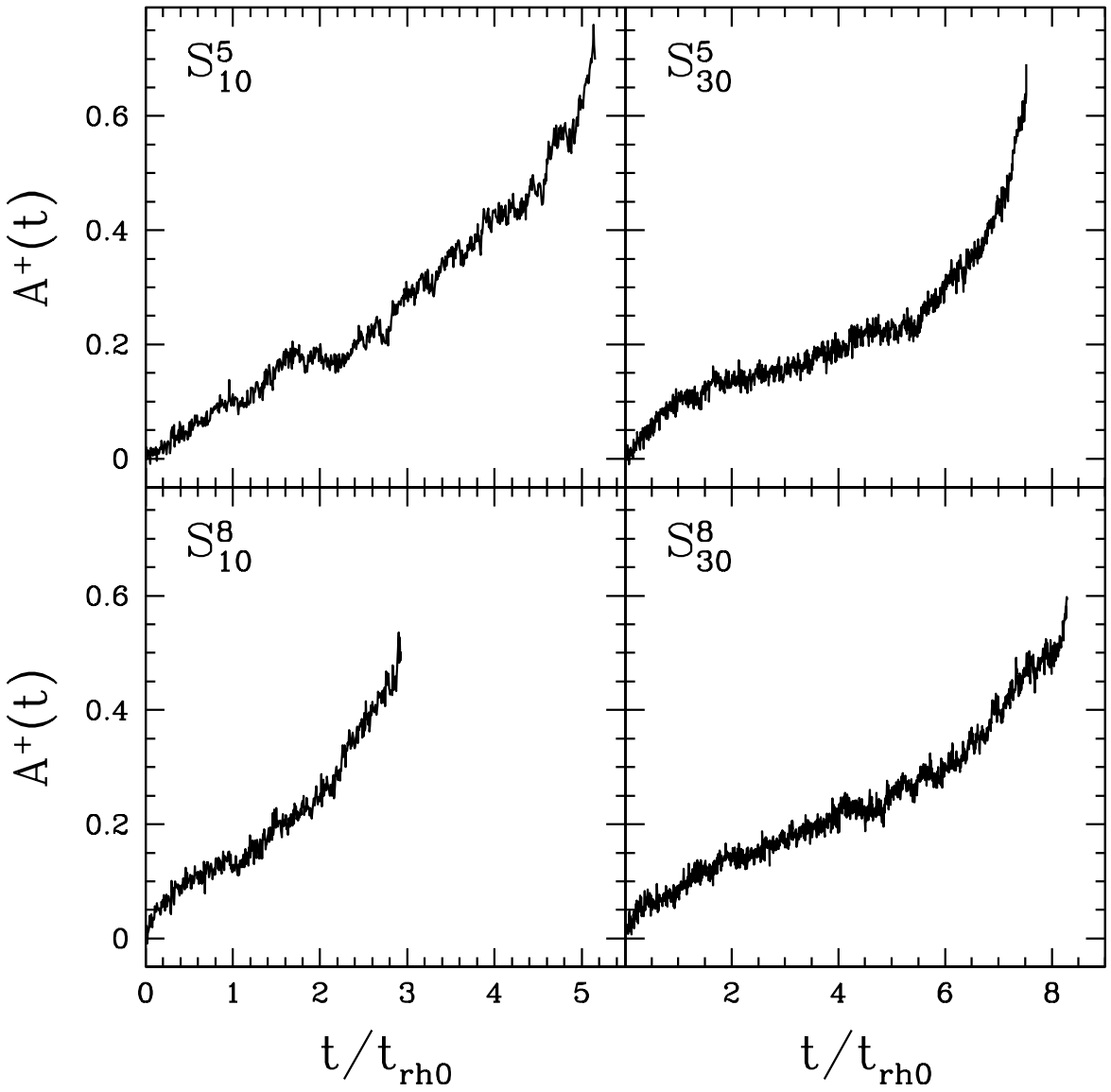
The area between the two curves grows with time

Evolution of cumulative distributions (2)



A^+ seems to be a promising indicator of BSS segregation

Evolution of cumulative distributions (3)



A^+ always grows with time

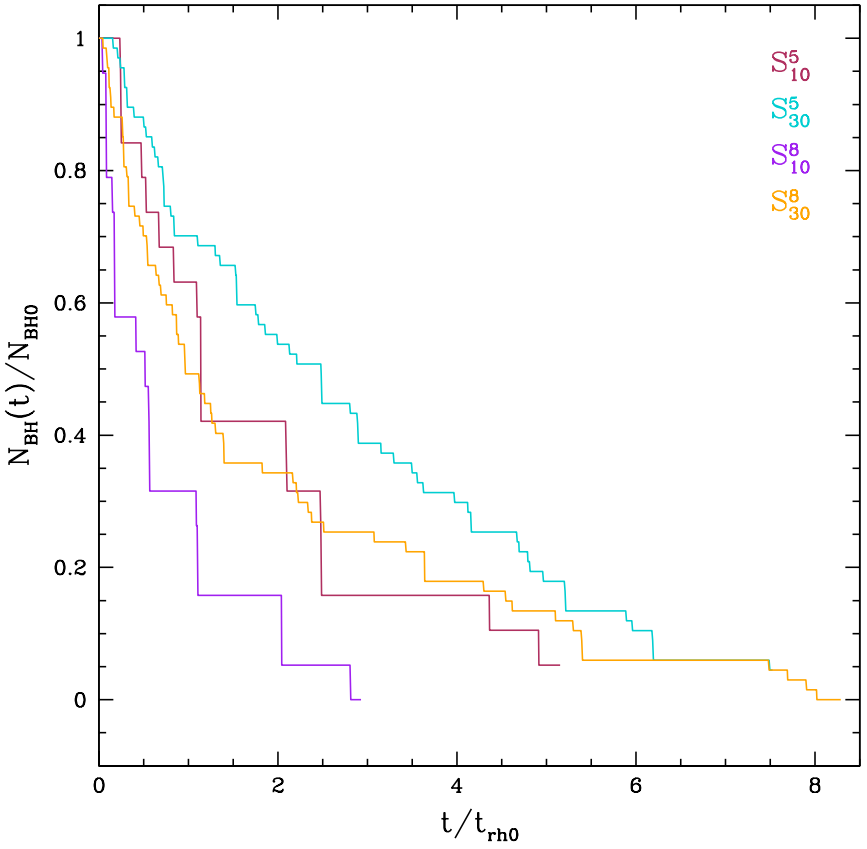
Two regimes

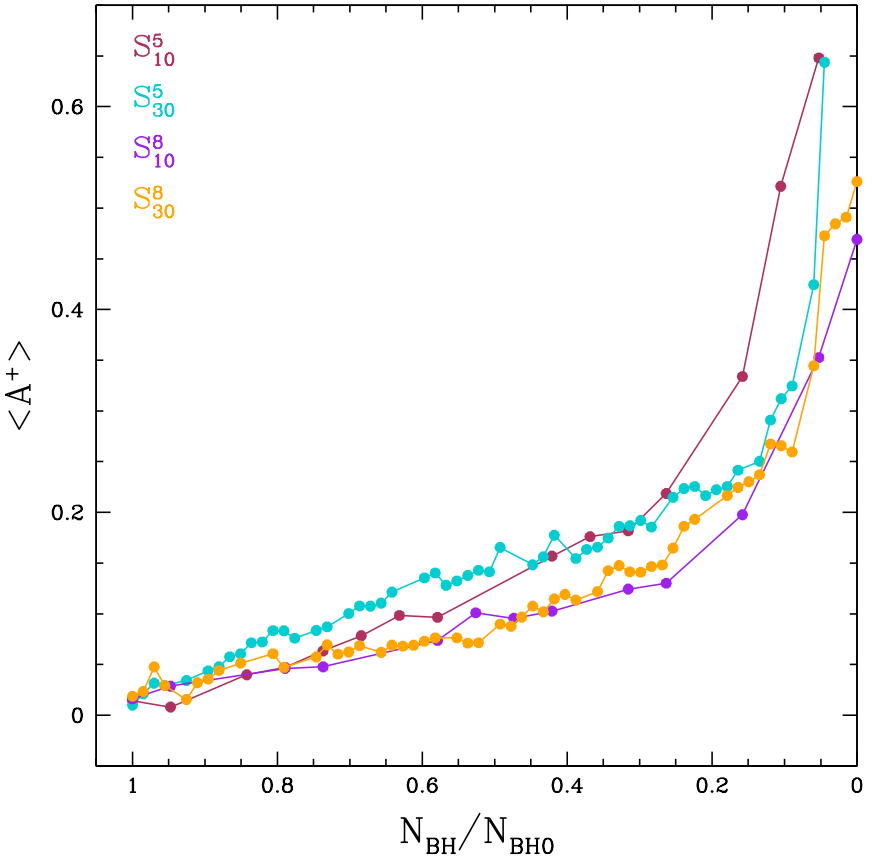
Slow: Initial Fast: Pre-CC

A^+ is a tracer of the whole dynamical evolution

Reaching the same value (~0.5-0.6) near CC:
CC signature?

Another virtue of A^+





Promising link between the value of A^+ and BH retention fraction

Summary

- **Semi-analytical approach:** t_{DF} is a monotonic function of r also in mass-segregated system. Hence a non monotonic behavior of $t_{DF}(r)$ is not the explanation for the observed BSS radial distributions

- **N-body simulations with 10^4 particle BSSs as the heaviest population**: formation of a central peak, and a dip that progressively moves (at least in a few cases) toward the external regions. However, noisy behavior and too fast evolution

- **N-body simulations with 10^5 particles, evolved Kroupa IMF, a population of heavy dark remnants**: much more realistic and slower evolution; definition of new mass-segregation indicator (as A^+)

- **Future plans**: improve the realism of simulations (primordial binaries, external tidal field). Explore a larger parameter space (W_0, f_{DR}, etc) to better understand the process of BSS segregation and its dependence on the properties of the host cluster