Effects of Black Hole Mass Spectrum on Dynamics of Globular Clusters

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Introduction

- Hundreds of black holes (BHs) can be formed as a result of stellar evolution in each globular cluster (GC).
- We study the dynamical evolution of GC with BHs remained in the GC, and check the effect of initial BH mass function.
  - We focus on the formation and evolution of BH-BH binaries.
  - Investigate the ejection of BHs in the form of binary and single.
  - Estimate the BH-BH binary merger rate to be observed by advanced GW detectors.

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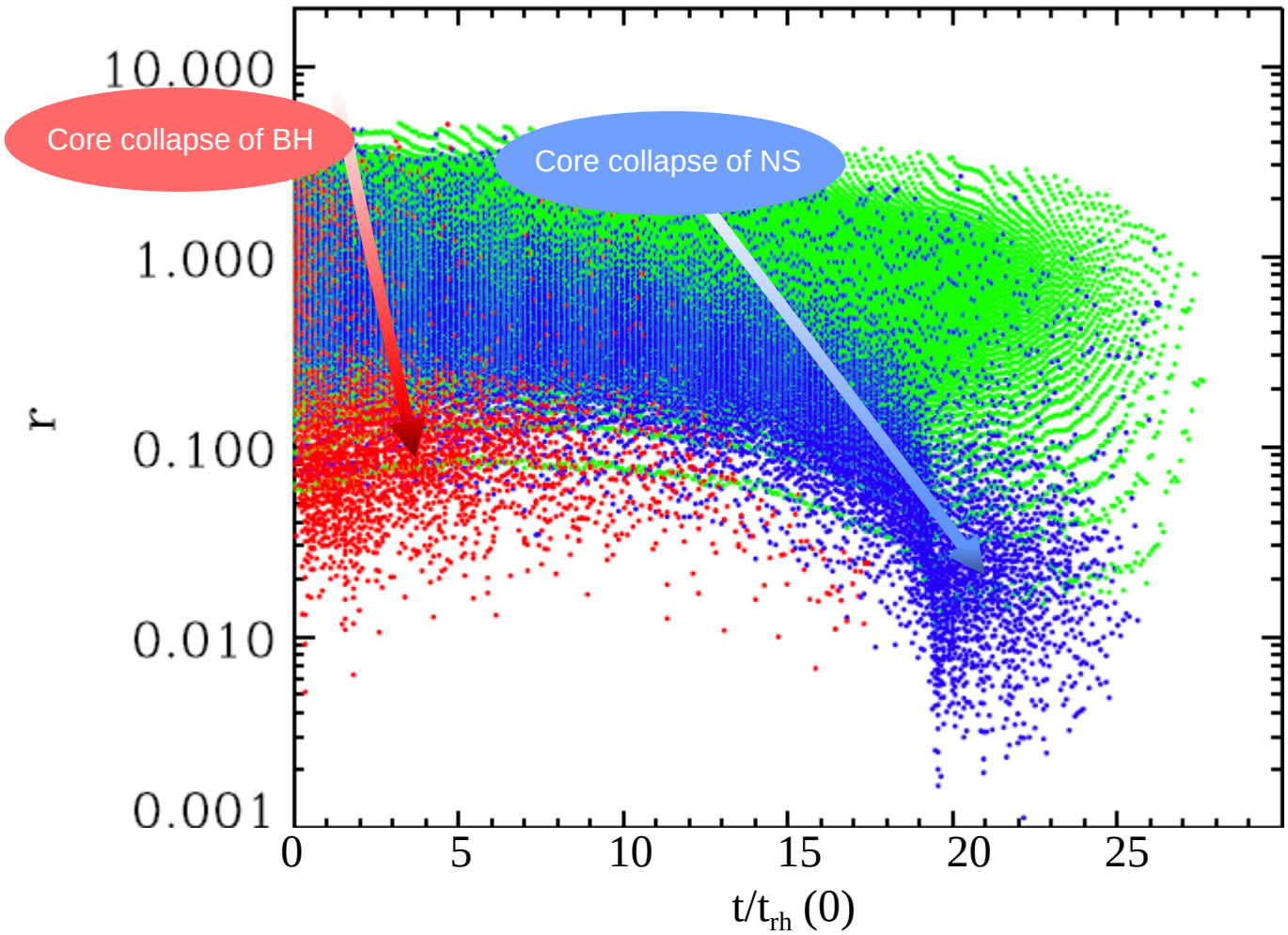
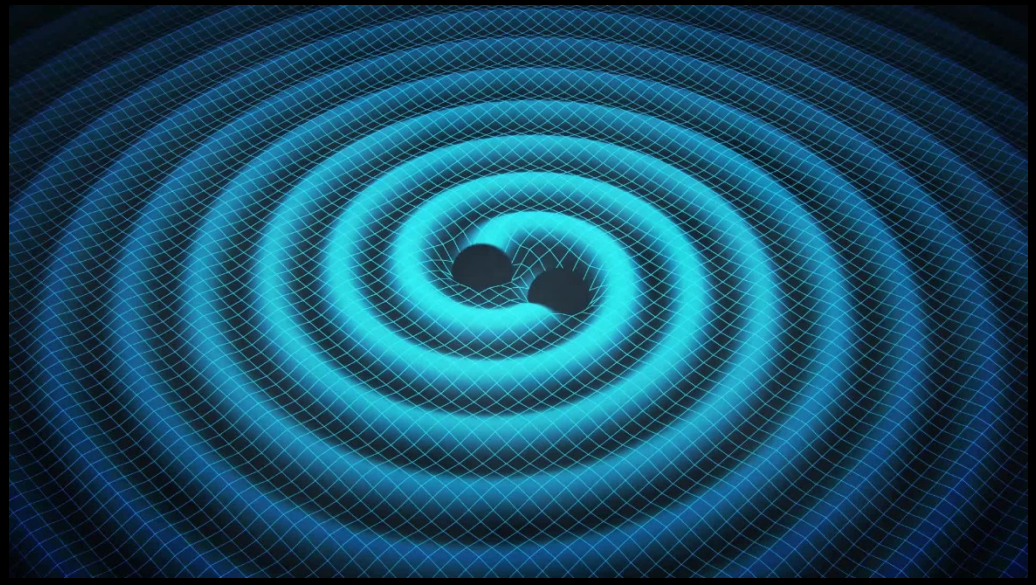


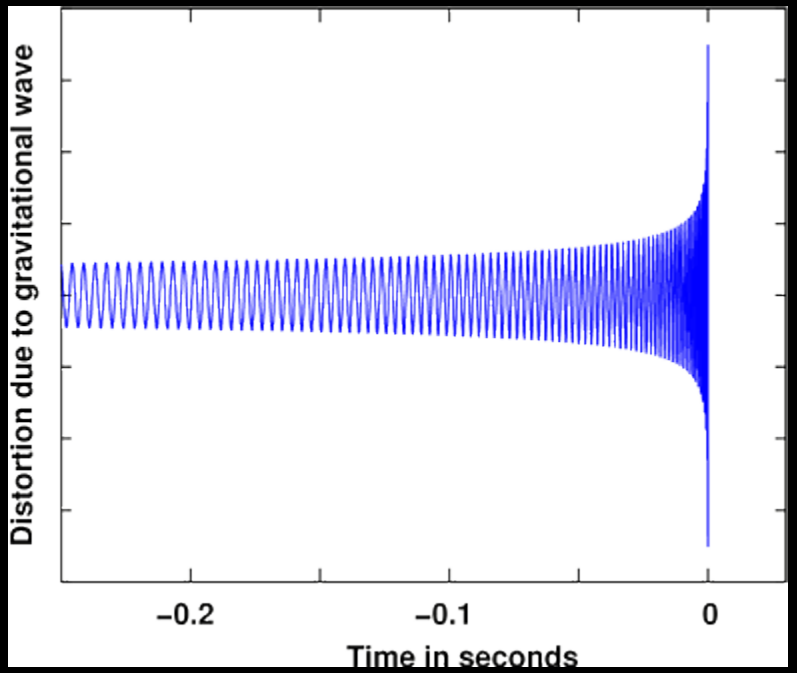
Bae et al. (2014)

Introduction

- Ejected BH binaries are also interesting as sources of gravitational waves (GWs).

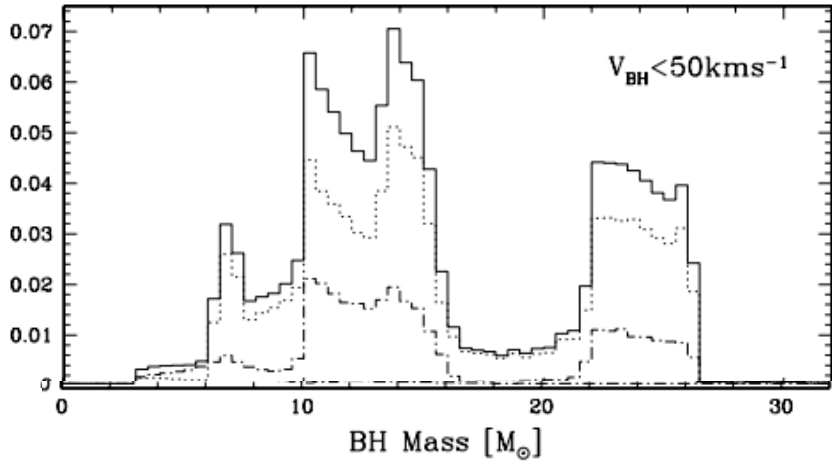


Credit : Swinburne Astronomy Productions

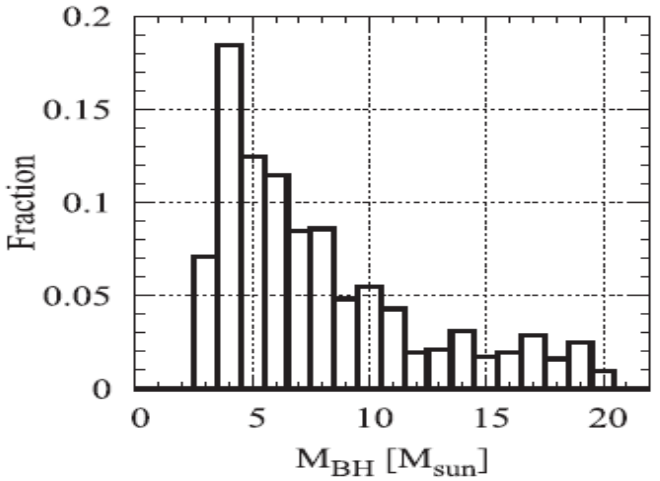


Credit : Marcus Pössel

Cluster models



Belczynski et al. (2006)



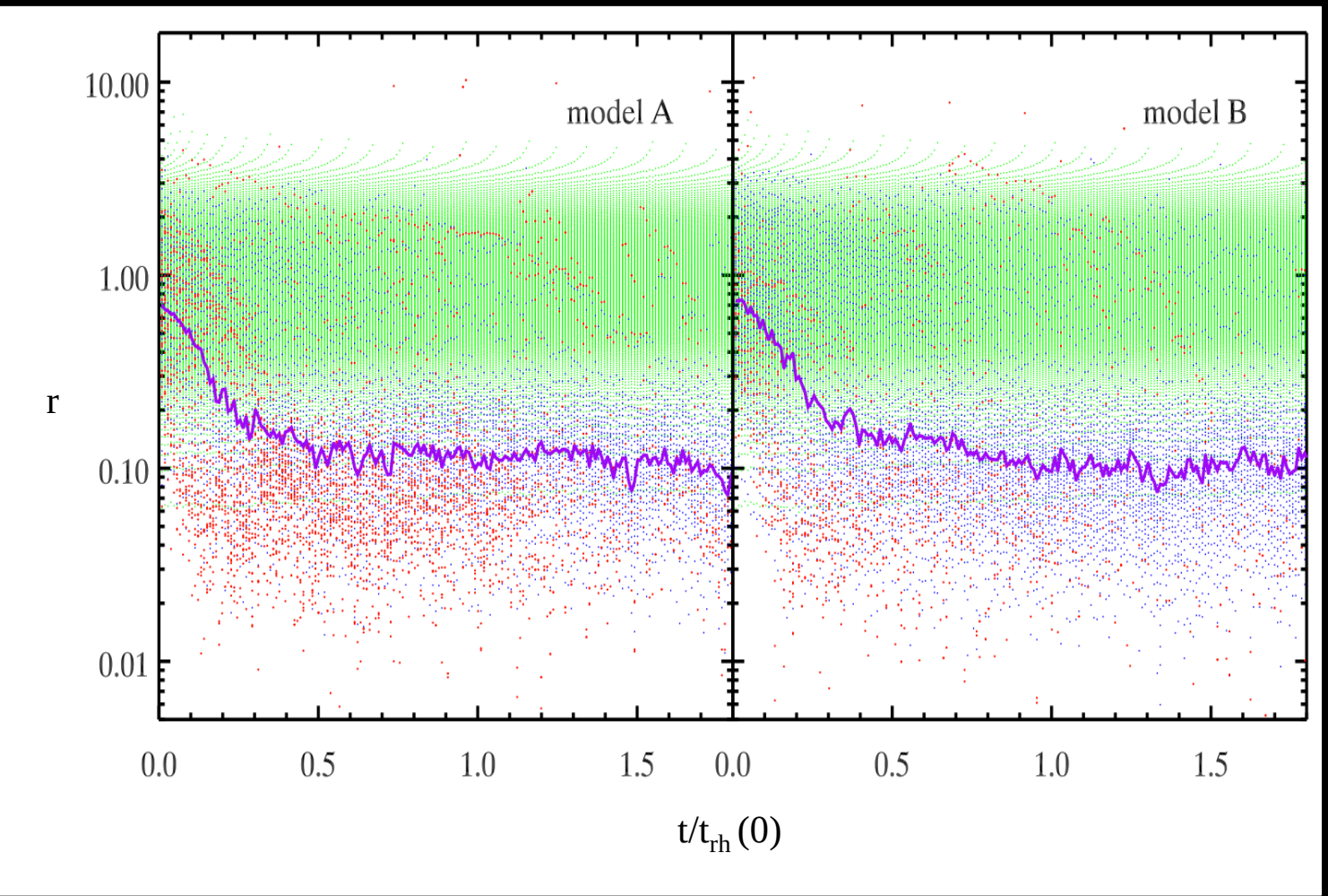
A. Tanikawa. 2013

- BH mass fraction : 2.5% of cluster masses

Model	N_{total} ($\times$ 10,000)	BH mass ratio 10 $M_\odot$ BHs : 20 $M_\odot$ BHs	# of runs
A	5 (10)	2:1	13 (1)
B	5 (10)	5:1	13 (1)
C	5 (10)	10 $M_\odot$ (fixed)	13 (1)

Dynamics of heavy components

N=100k models

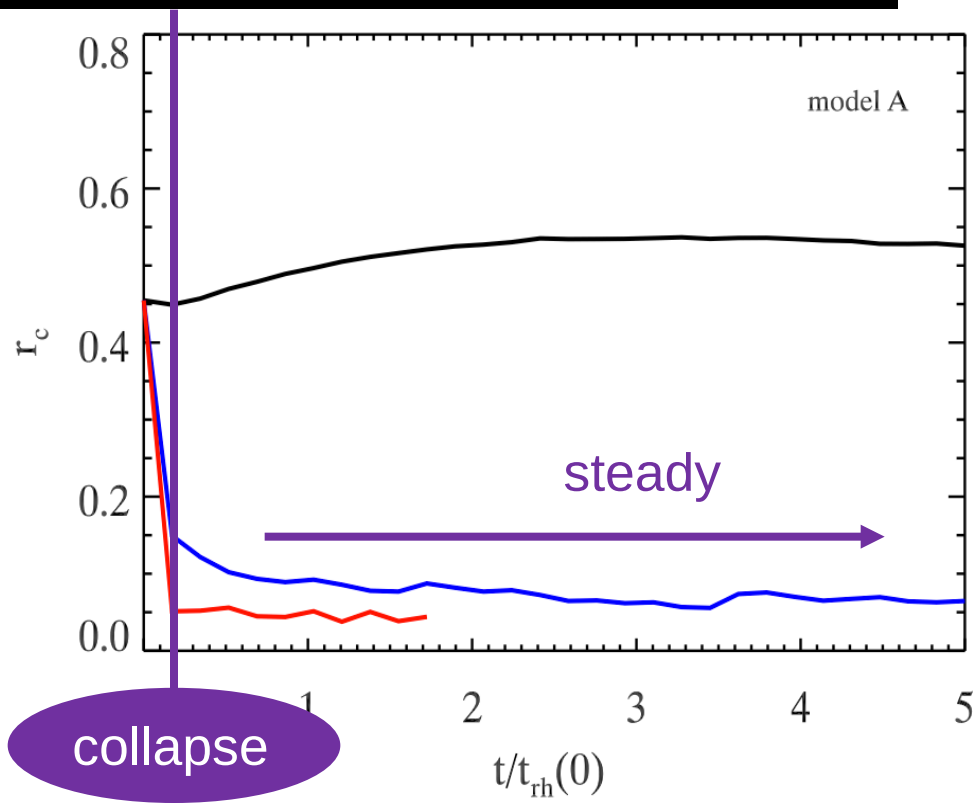


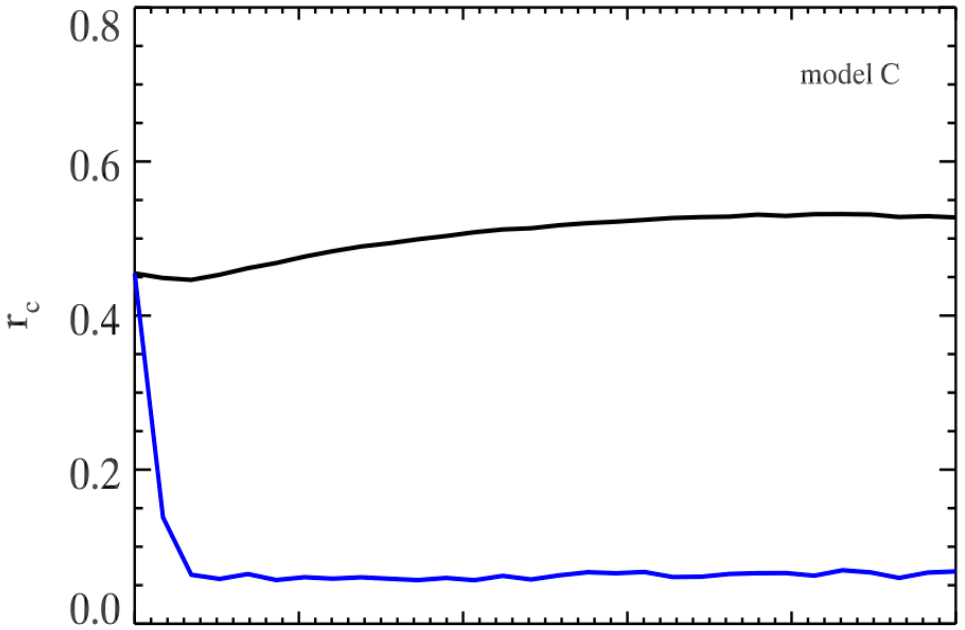
Purple : r_h of all BH

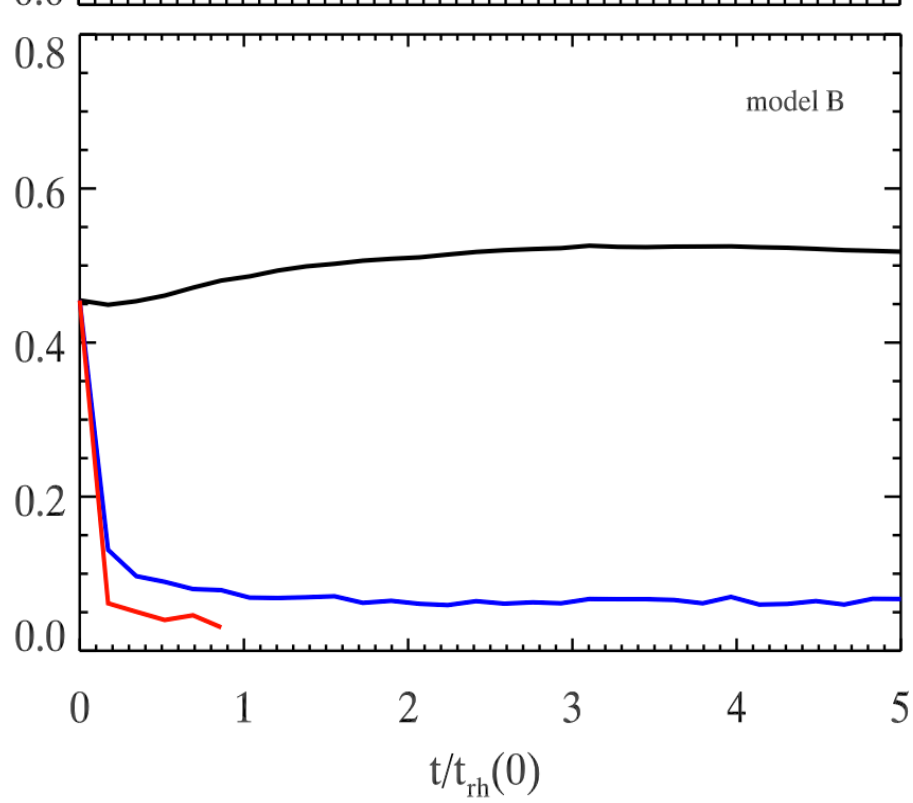
Green : stars
Red : 20 $M_\odot$ BHs
Blue : 10 $M_\odot$ BHs

Core radius (r_c) of all runs (stacked)

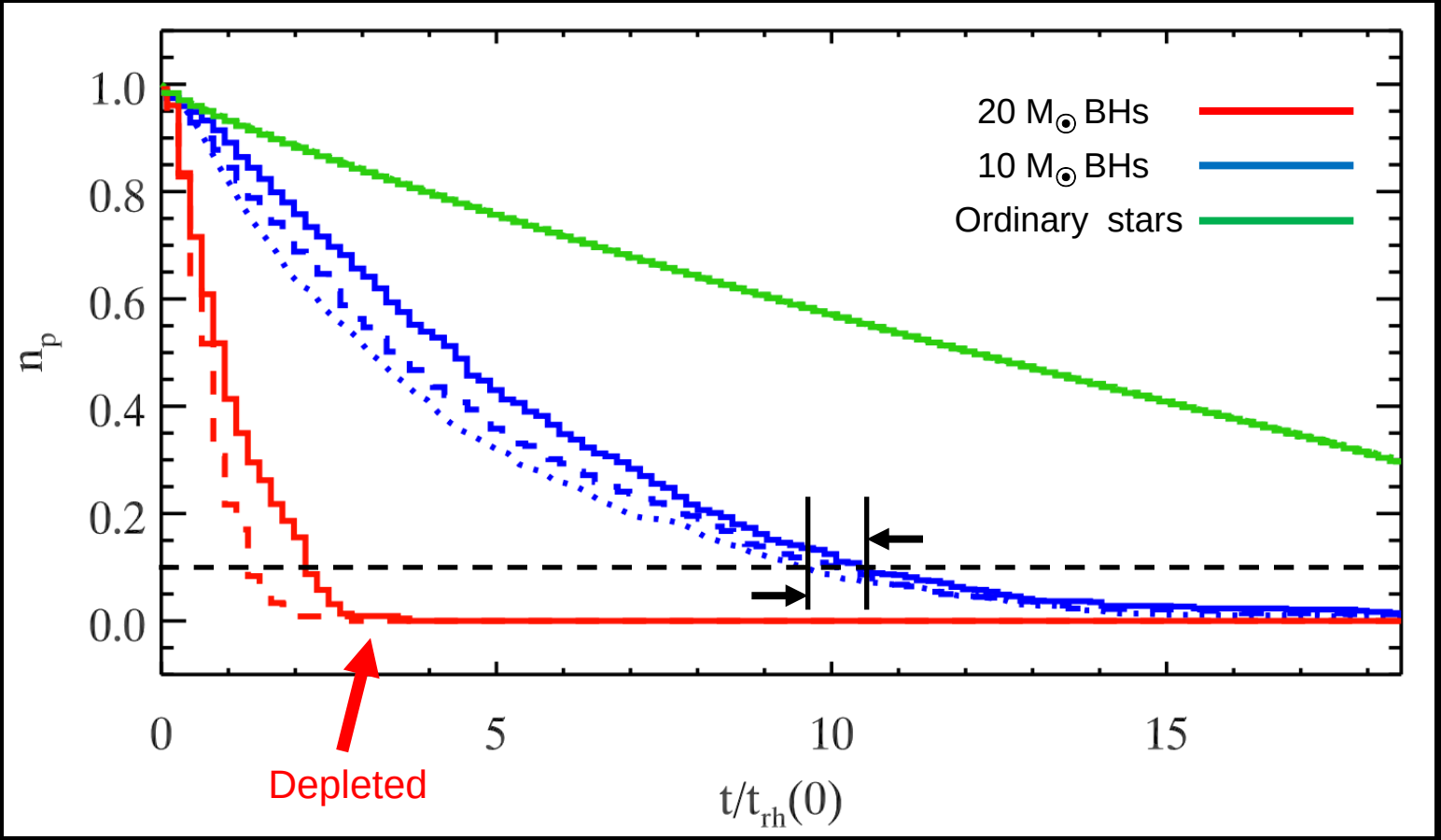
Black : cluster
Red : 20 $M_\odot$ BHs
Blue : 10 $M_\odot$ BHs







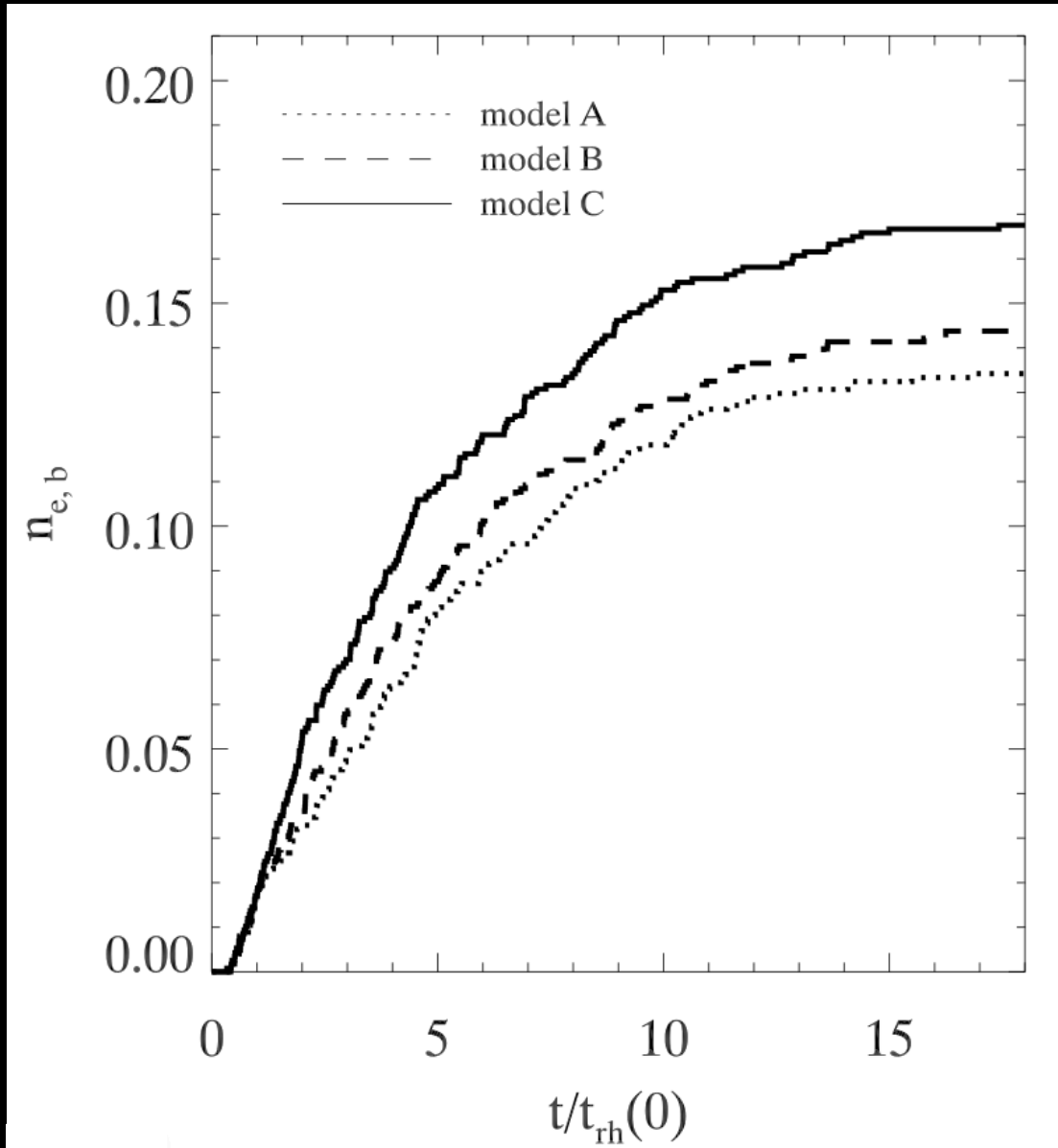
Retention of BH



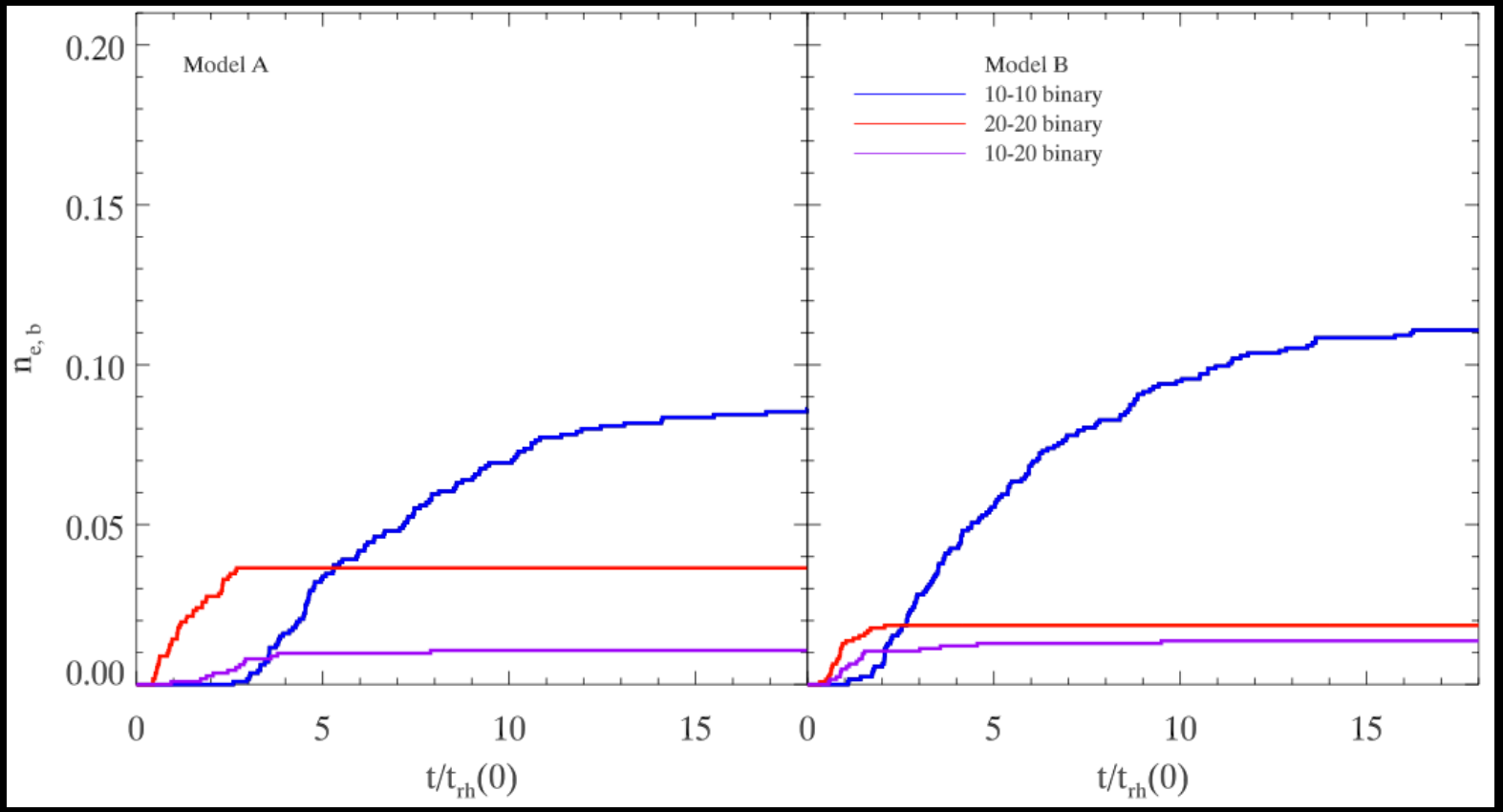
- Shows a number of particles retained in a cluster (normalized).
- 20 $M_\odot$ BHs are quickly depleted
- About ~10% of 10 $M_\odot$ BHs can be retained after $t/t_{rh}(0)$ ~10

Ejected BH-BH binaries

- Ejected BH-BH binaries, normalized by initial BH number
- About 30 % of BHs are ejected in the form of binary



Ejected BH-BH binaries



- 10-10$M_\odot$ binaries start to be ejected after the depletion of 20 $M_\odot$ BHs
- Small number of unequal mass binaries was also formed

Estimating merging binaries

- Because of a gap between our models and real GC, we need some extrapolation to determine binary merging rate per GC
  - We gather orbital information of ejected binaries (n-body scale semi-major axis, and eccentricity) from our model.
  - We calculate scale factor between n-body model and GCs with given velocity dispersion ($\sigma_i(0)$)
  - We then calculate merging time of each binary along $\sigma_i(0)$, and determine whether the binary will merge within cosmic time.

$$t_{mg} = \frac{5}{64}\frac{c^5 a^4}{G^3 m_1 m_2 (m_1 + m_2) f(e)}$$

$$where\ f(e) = (1-e^2)^{-\frac{2}{7}}\left(1 + \frac{73}{24}e^2 + \frac{37}{96}e^4\right)$$

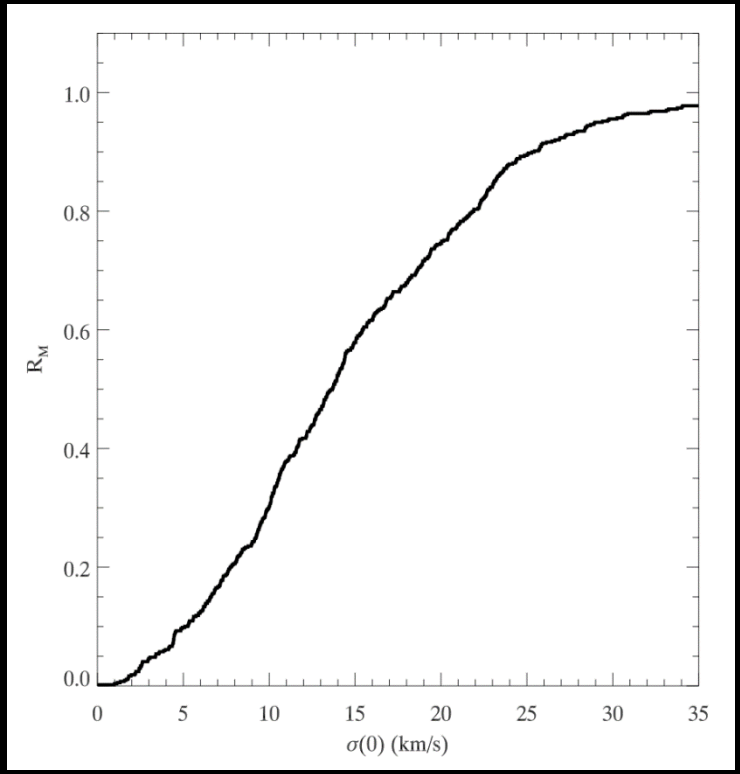
Number of merging binaries

- So we can find a merging binary fraction as a function of cluster velocity dispersion, then a number of merging BH-BH binaries of cluster can be written as follows

$$R_{GC} = N\, f_{bh} f_b R_M(\sigma_{GC}(0))$$

- Although we still have to adapt some assumption (N, f_{bh}), we calculate R_{GC} with a help of the Milky Way GC catalog (Gnedin et al. 2002).

R_{GC} = 9.85 (GC^{-1} Gyr^{-1})



Summary

- We performed N-body simulations with three different BH mass population, then studied dynamics of BHs and ejected BH-BH binaries.
- After the core-collapse of BH population, heavier BHs are quickly depleted, while lighter BHs can be retained long time.
- About ~30 % of ejected BHs are in binaries, and some of ejected binaries can be merge within cosmic time. Estimated merging rate is ~10 merging binaries per cluster per Gyr
- We found that the BH mass function does not affect our result significantly.