Stellar mass black holes in young massive and open clusters and their role in gravitational-wave generation

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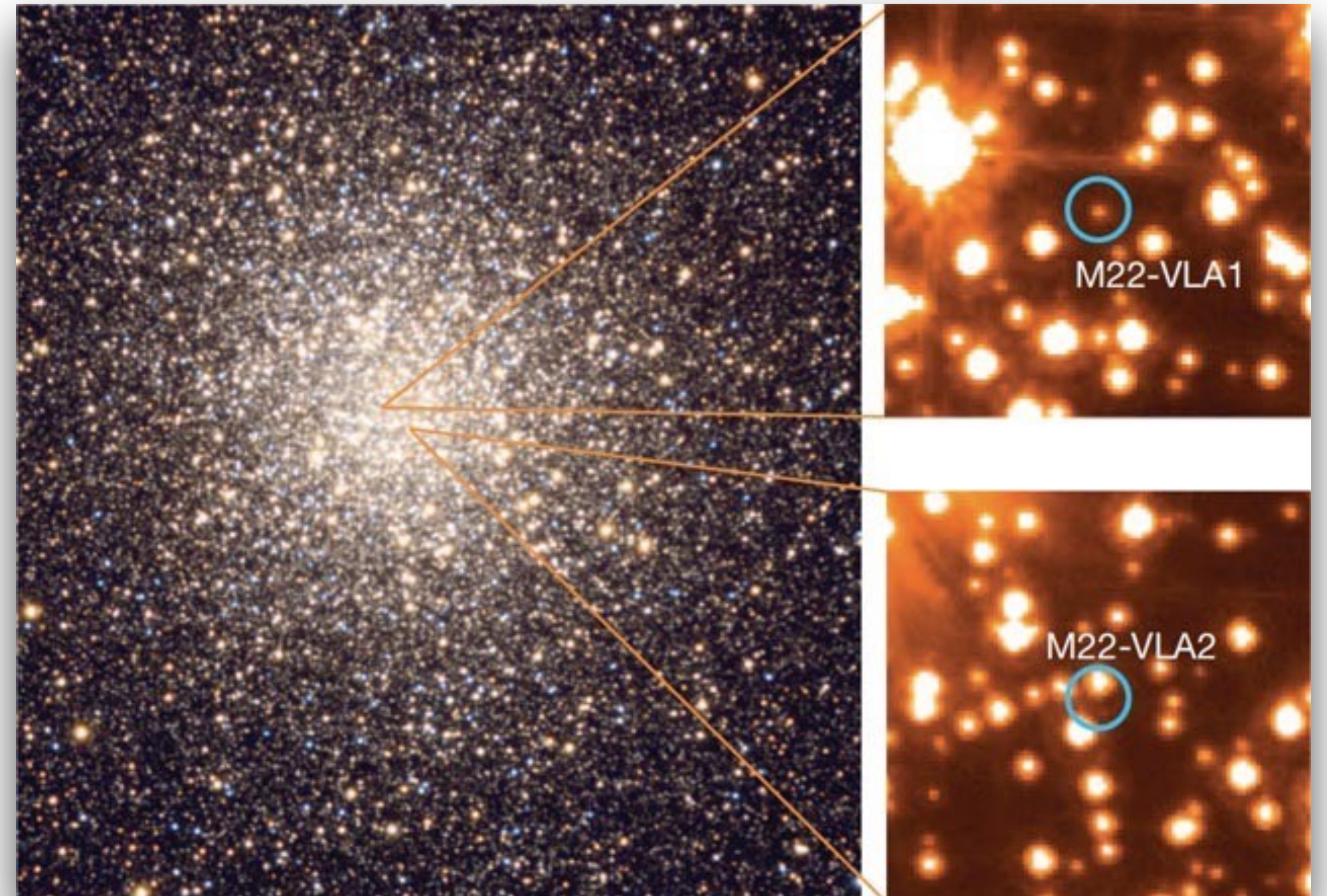
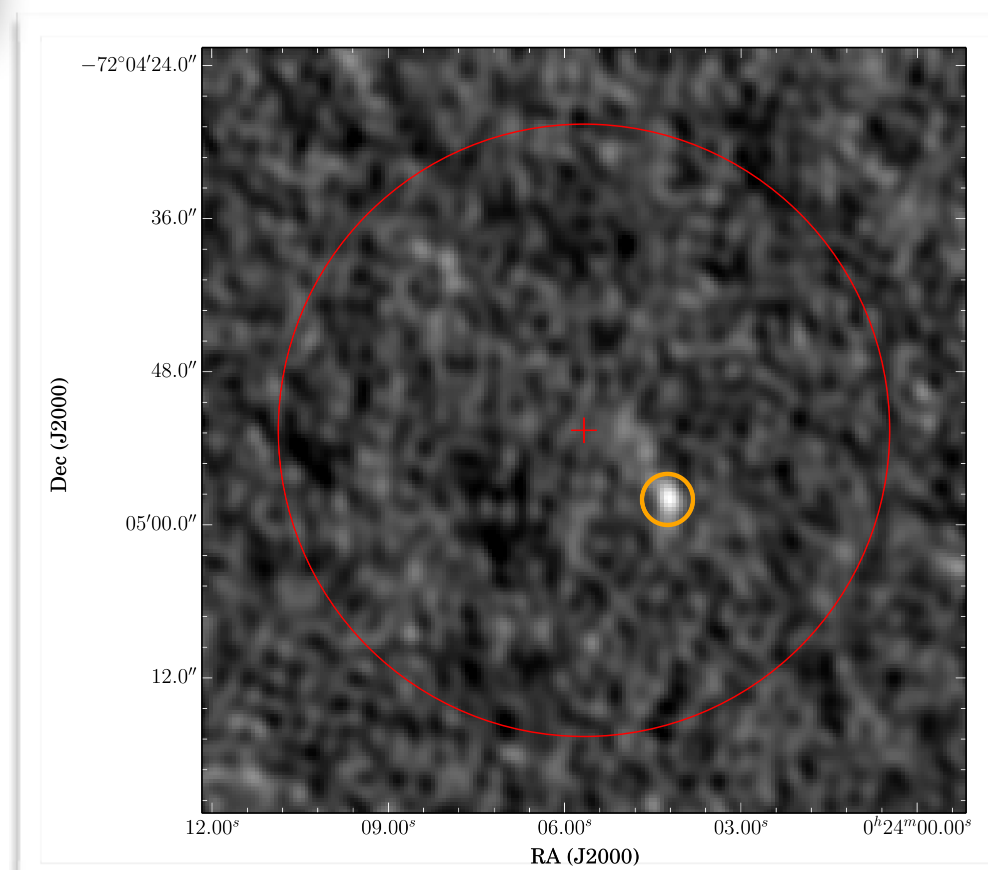
(arXiv: 1611.09357)



M22 BH candidates (Strader et al. 2012)

Promising source for LIGO-VIRGO gravitational-wave detector

Stellar-mass black holes in globular clusters

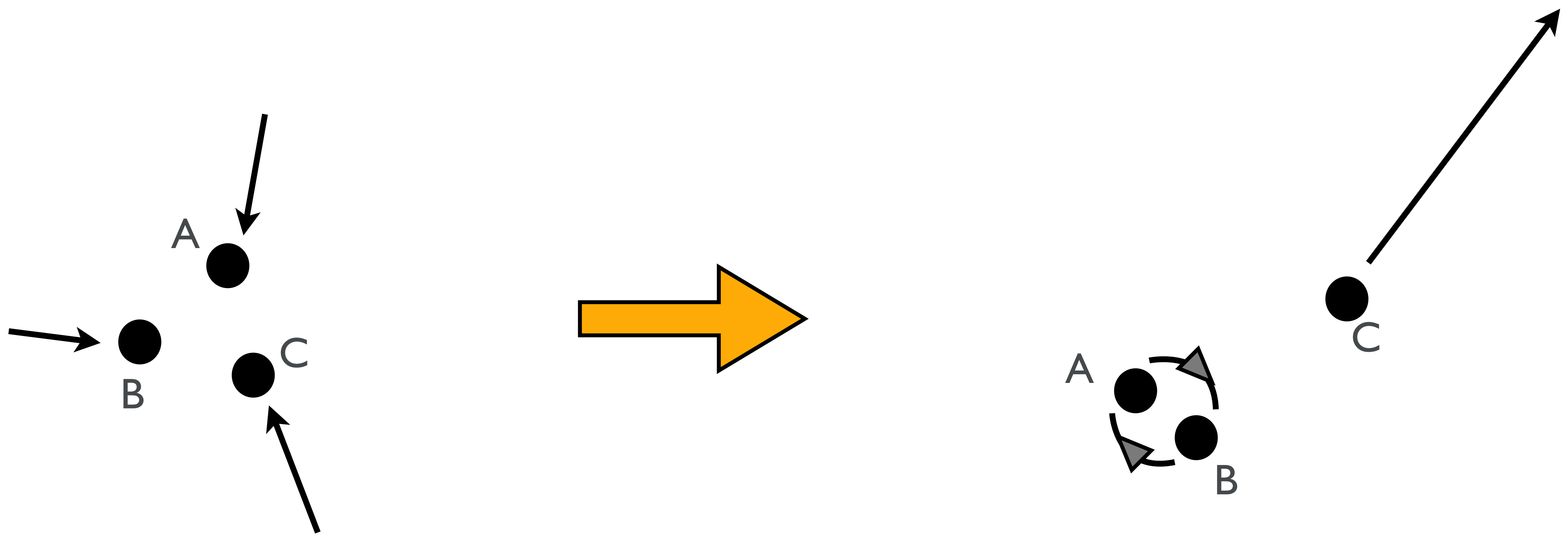


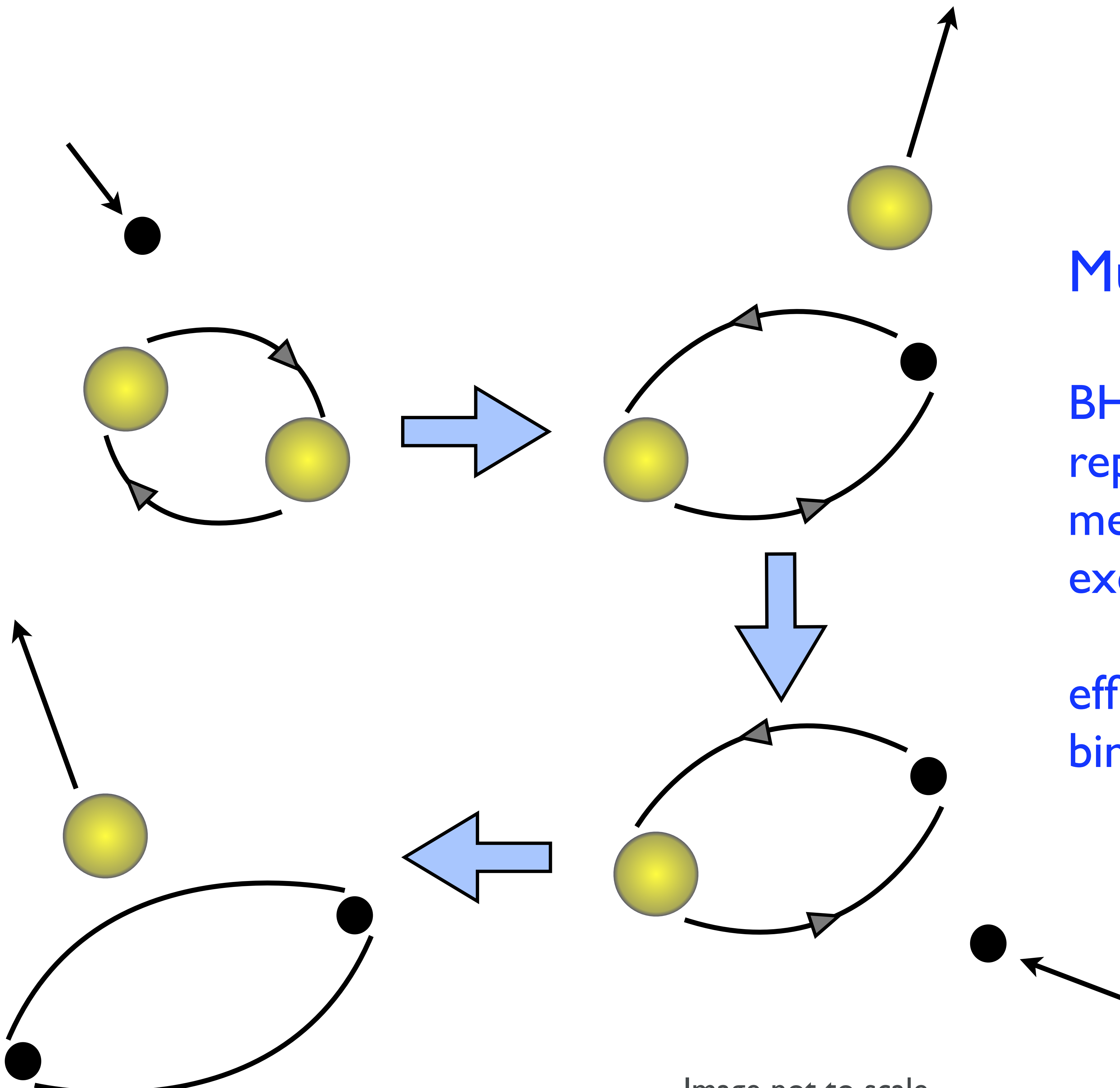
ACTA 5.5-Ghz image of 47 Tuc core (Miller-Jones et al. 2015)

Dynamical formation of BH-BH binaries

3-body binary formation in dense BH-core:

in close encounter among 3 BHs, two of them get bound while third escape with the excess K.E.



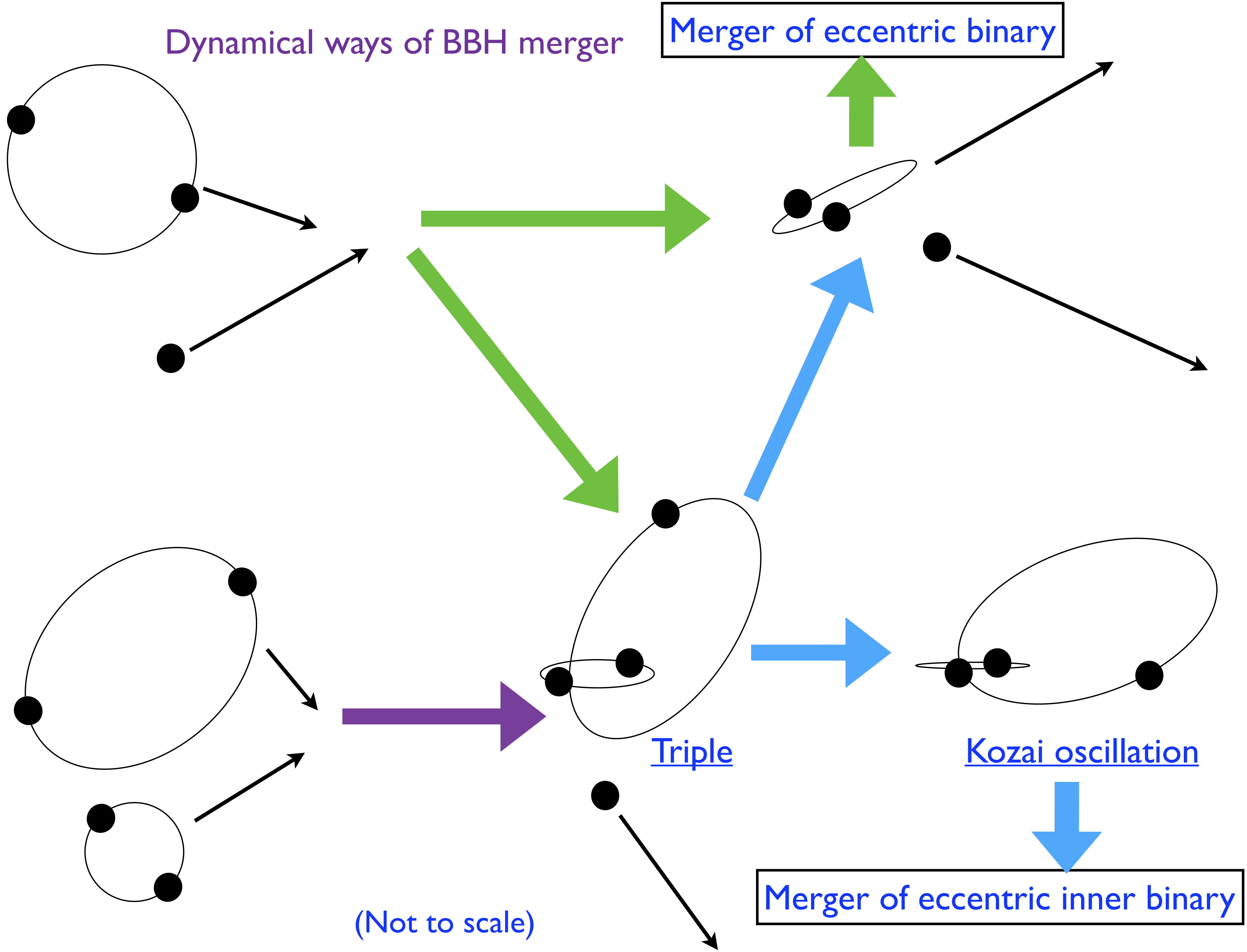


Multiple exchange:

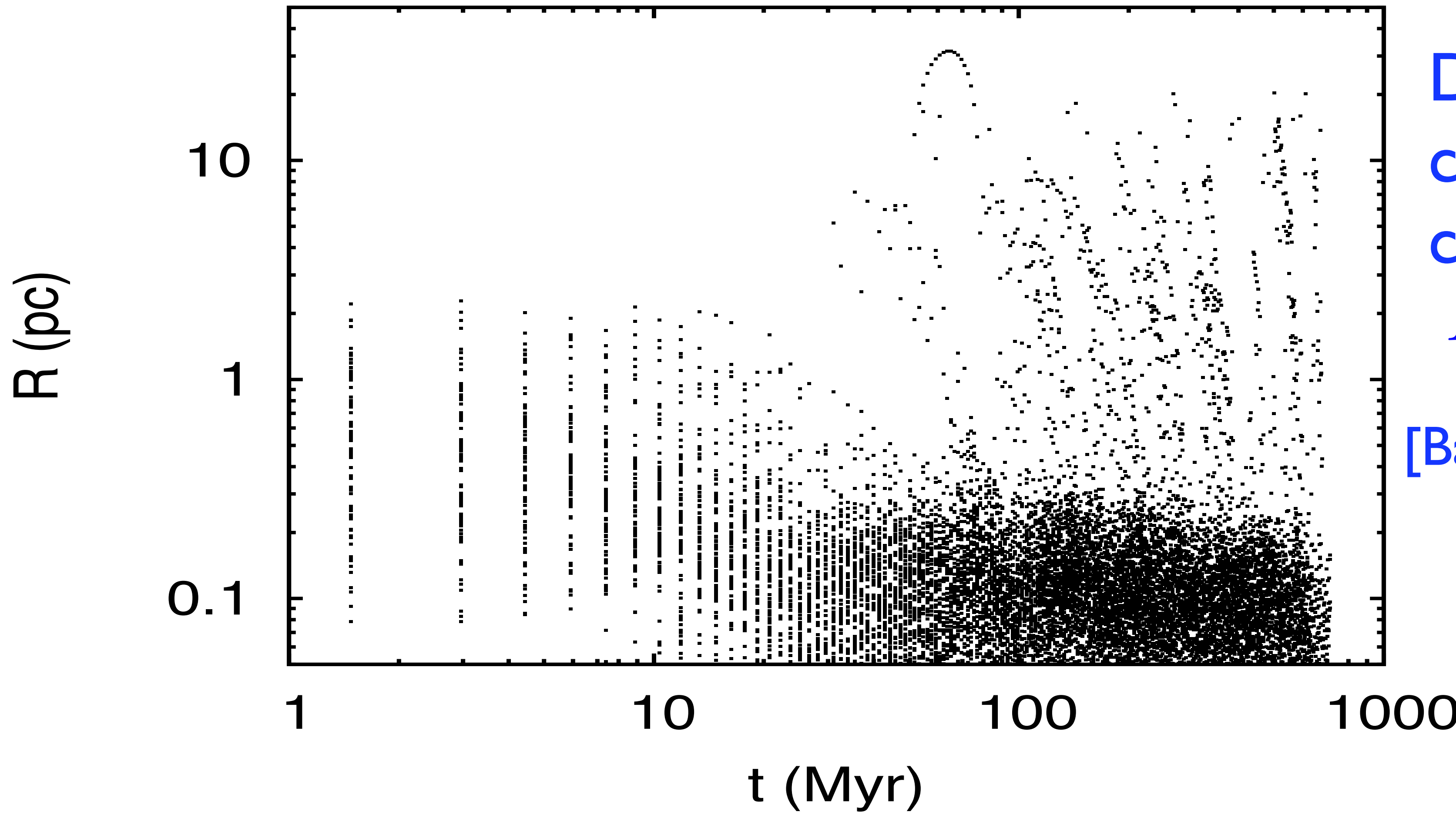
BHs being more massive replace stellar binary members in successive exchange encounters;

efficient with primordial binaries

Image not to scale

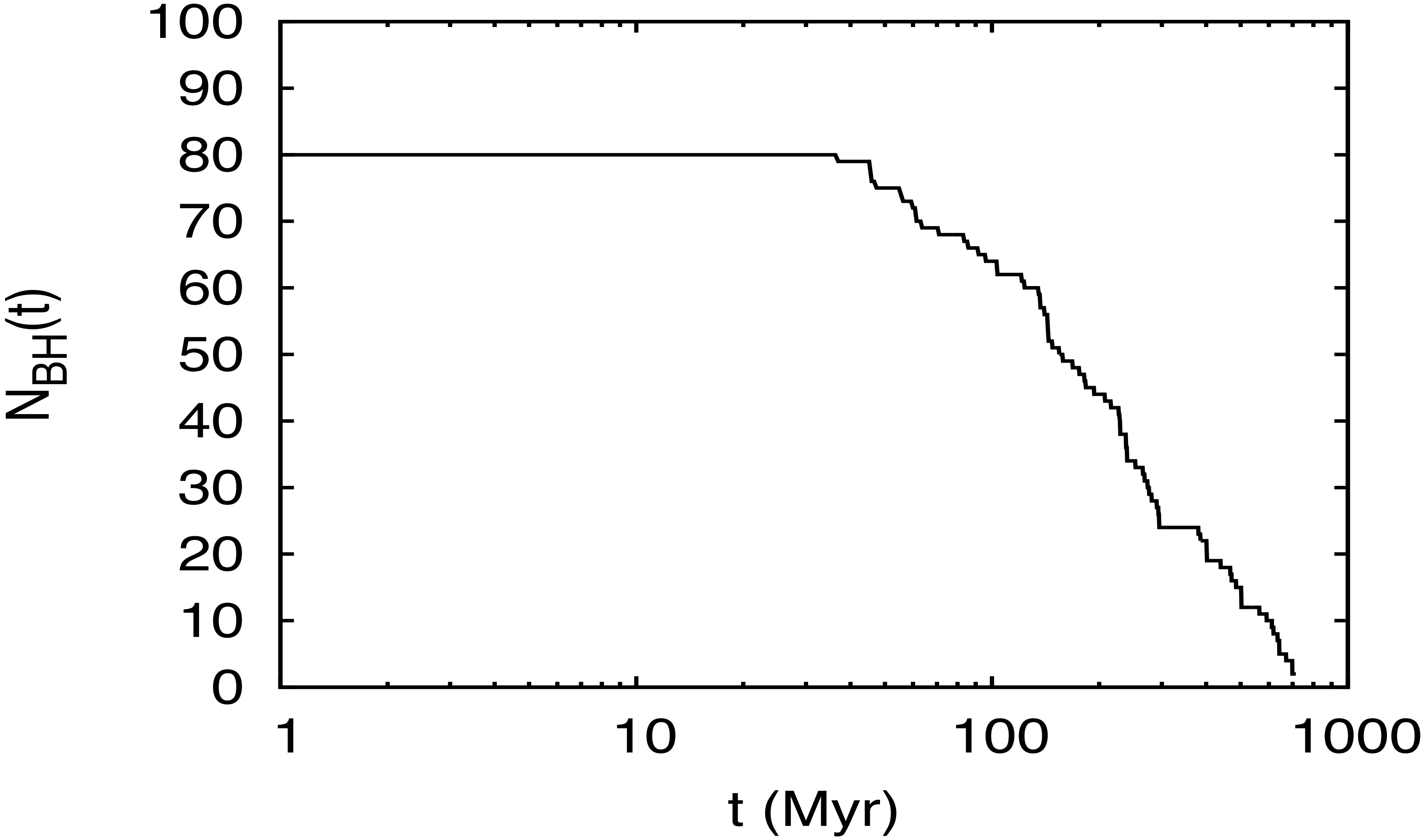


Dynamical ways of BBH merger
Merger of eccentric binary
Triple
Kozai oscillation
Merger of eccentric inner binary
(Not to scale)



Direct N-body computation of $N = 4.5 \times 10^4$ cluster, $r_h(0) = 1$ pc, $N_{BH} \approx 100$ (full retention).

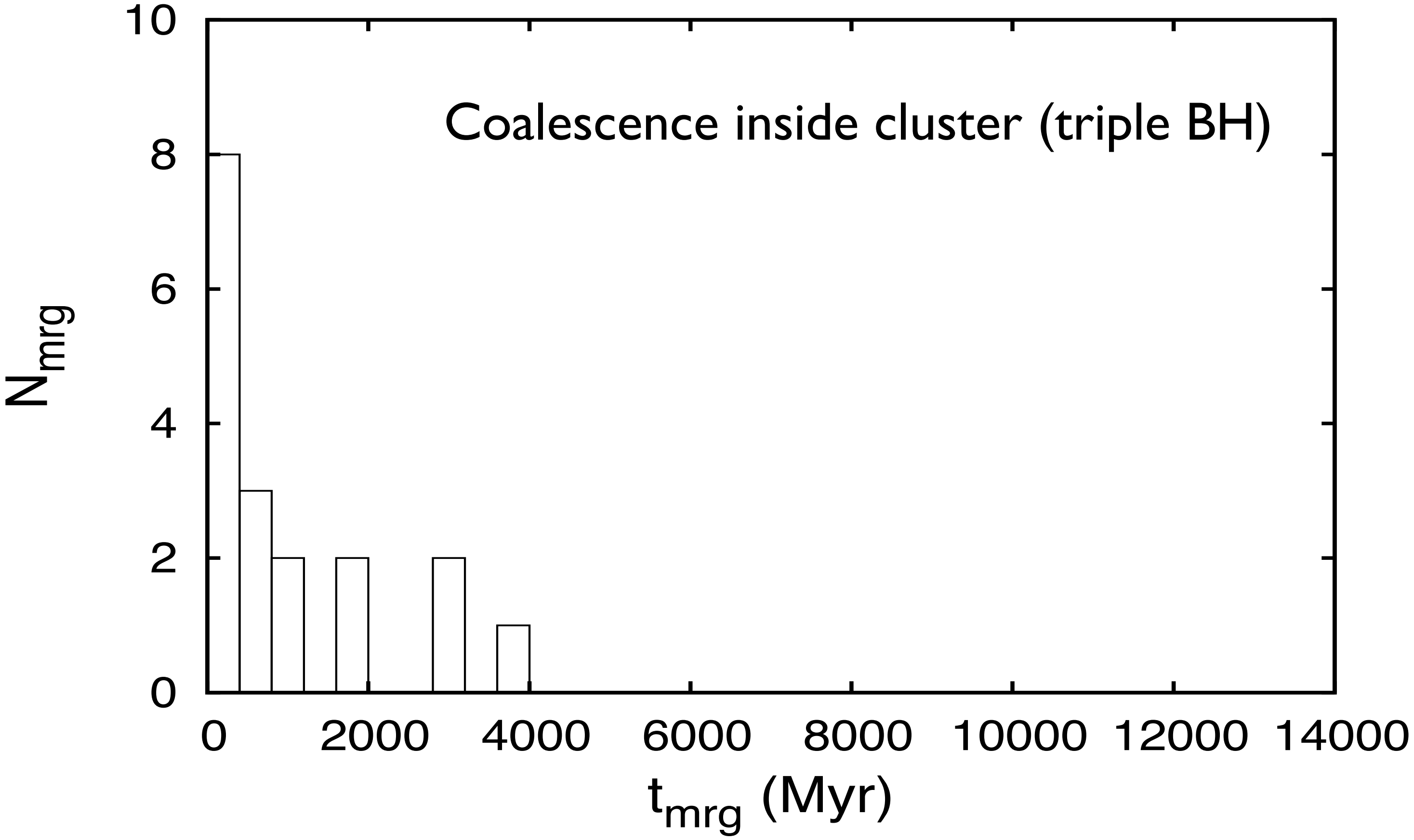
[Banerjee et al. (2010), MNRAS, 402, 371]

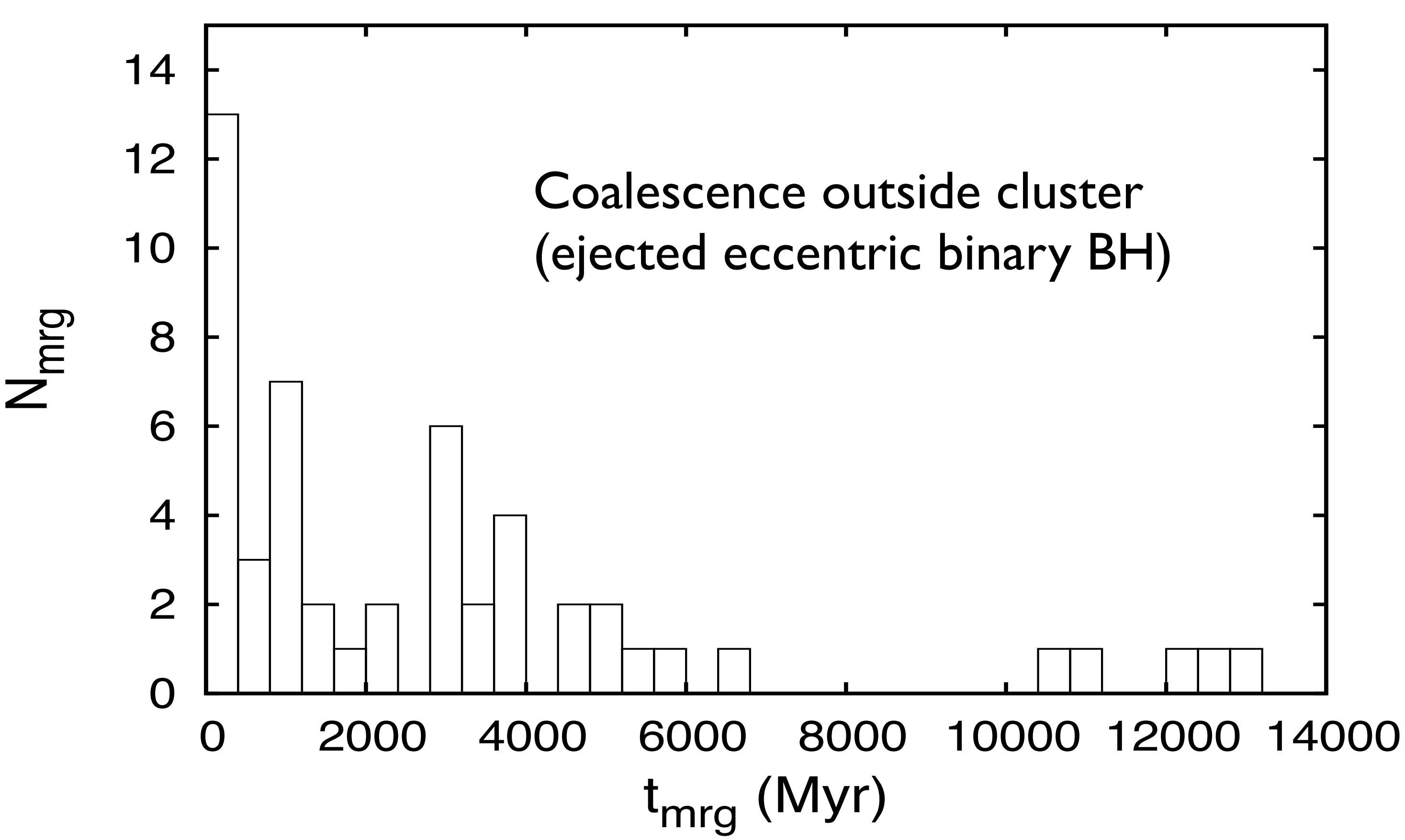


Two phases: (a) initial segregation: $N_{BH} \approx$ const (b) formation of BH-core: N_{BH} depletes due to super-elastic dynamical encounters.

BH-core (or "Dark core") phase have potential for a wide variety of physical phenomena

Merger-time distribution

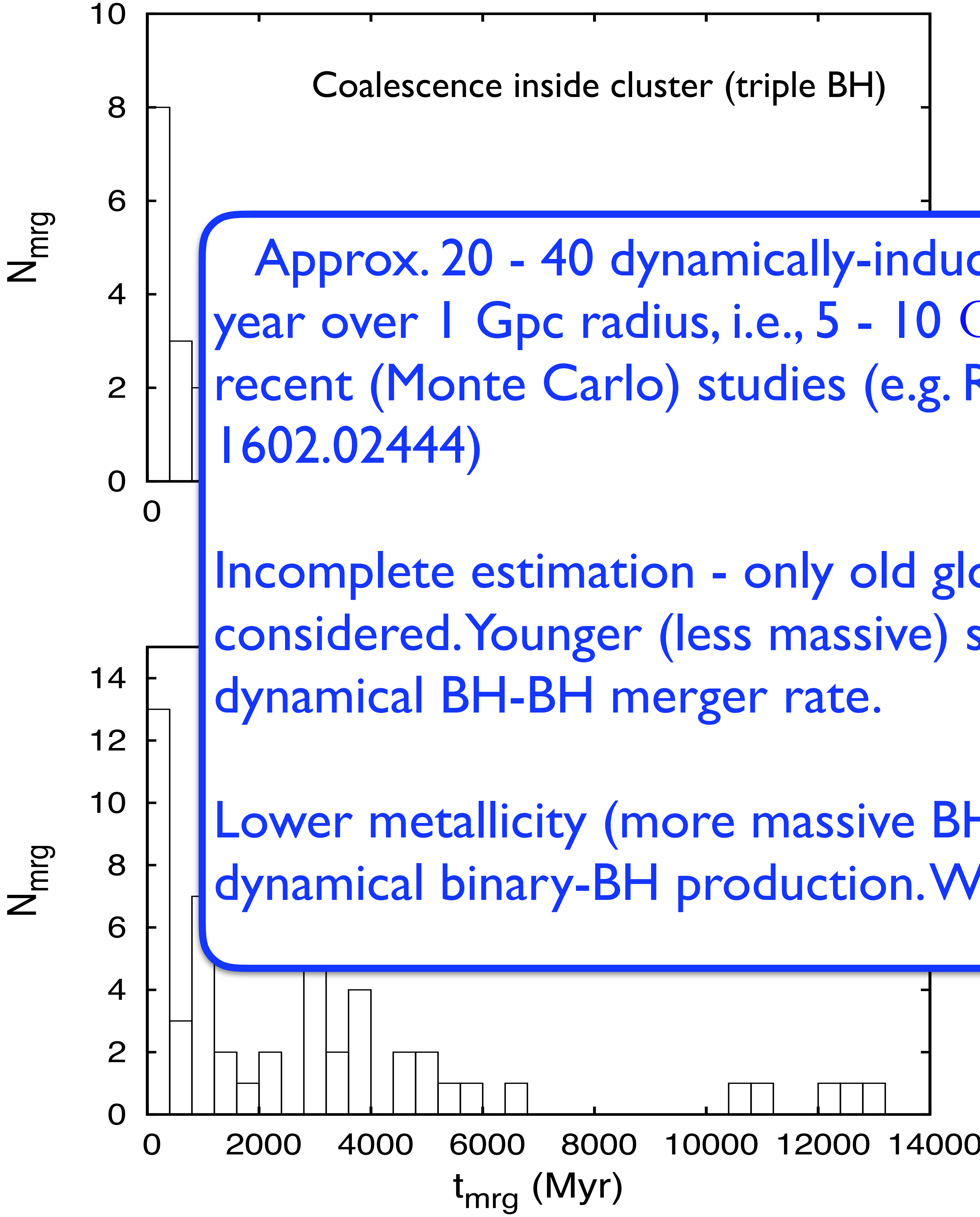




Most mergers happen within first few Gyr.

[Banerjee et al. (2010), MNRAS, 402, 371]

Merger-time distribution



Most mergers happen within first few Gyr.

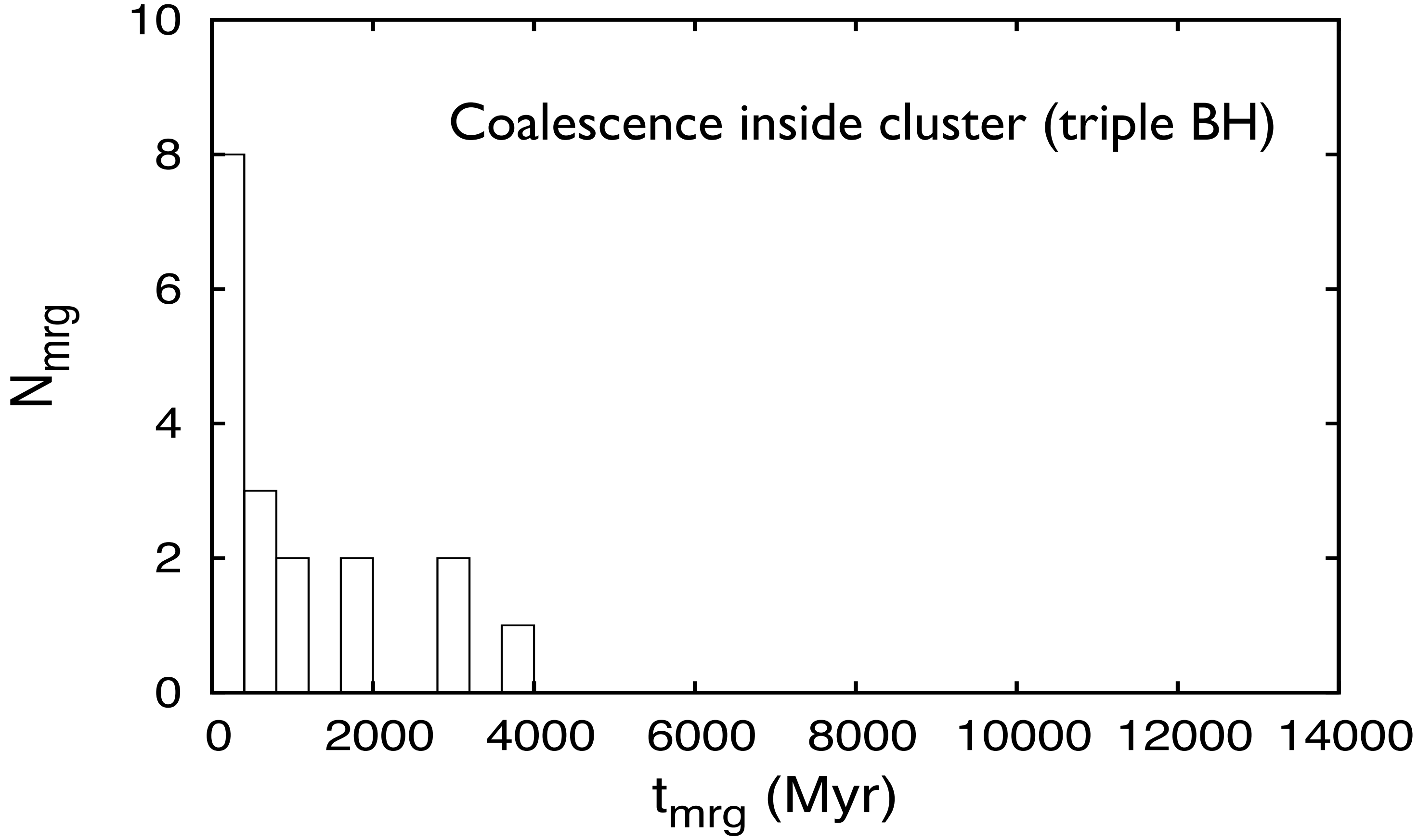
Approx. 20 - 40 dynamically-induced BH-BH mergers per year over 1 Gpc radius, i.e., 5 - 10 $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ - consistent with recent (Monte Carlo) studies (e.g. Rodriguez et al. arXiv: 1602.02444)

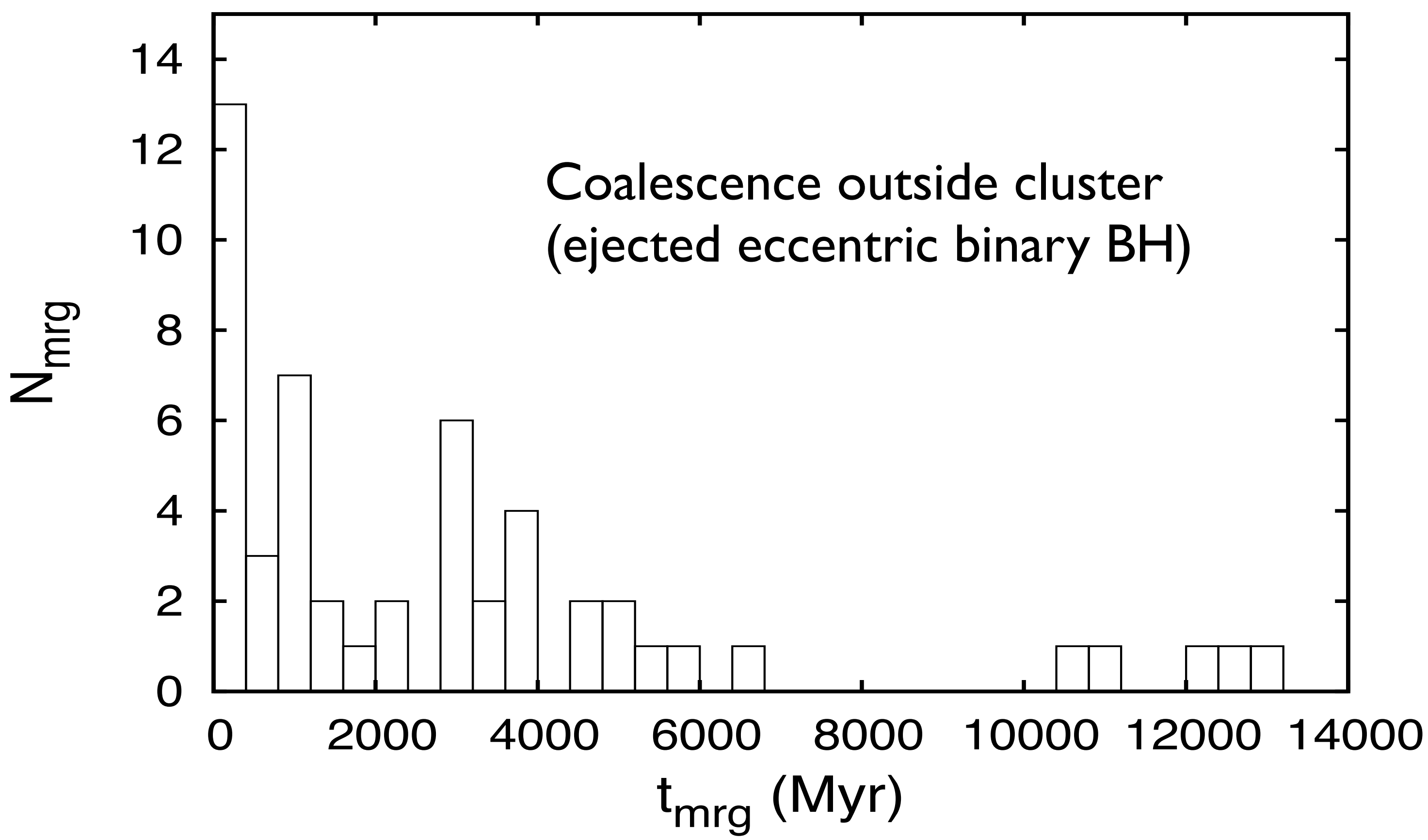
Incomplete estimation - only old globular cluster type systems considered. Younger (less massive) systems can potentially boost dynamical BH-BH merger rate.

Lower metallicity (more massive BH) would also boost dynamical binary-BH production. Work in progress…

[Banerjee et al. (2010), MNRAS, 402, 371]

Merger-time distribution





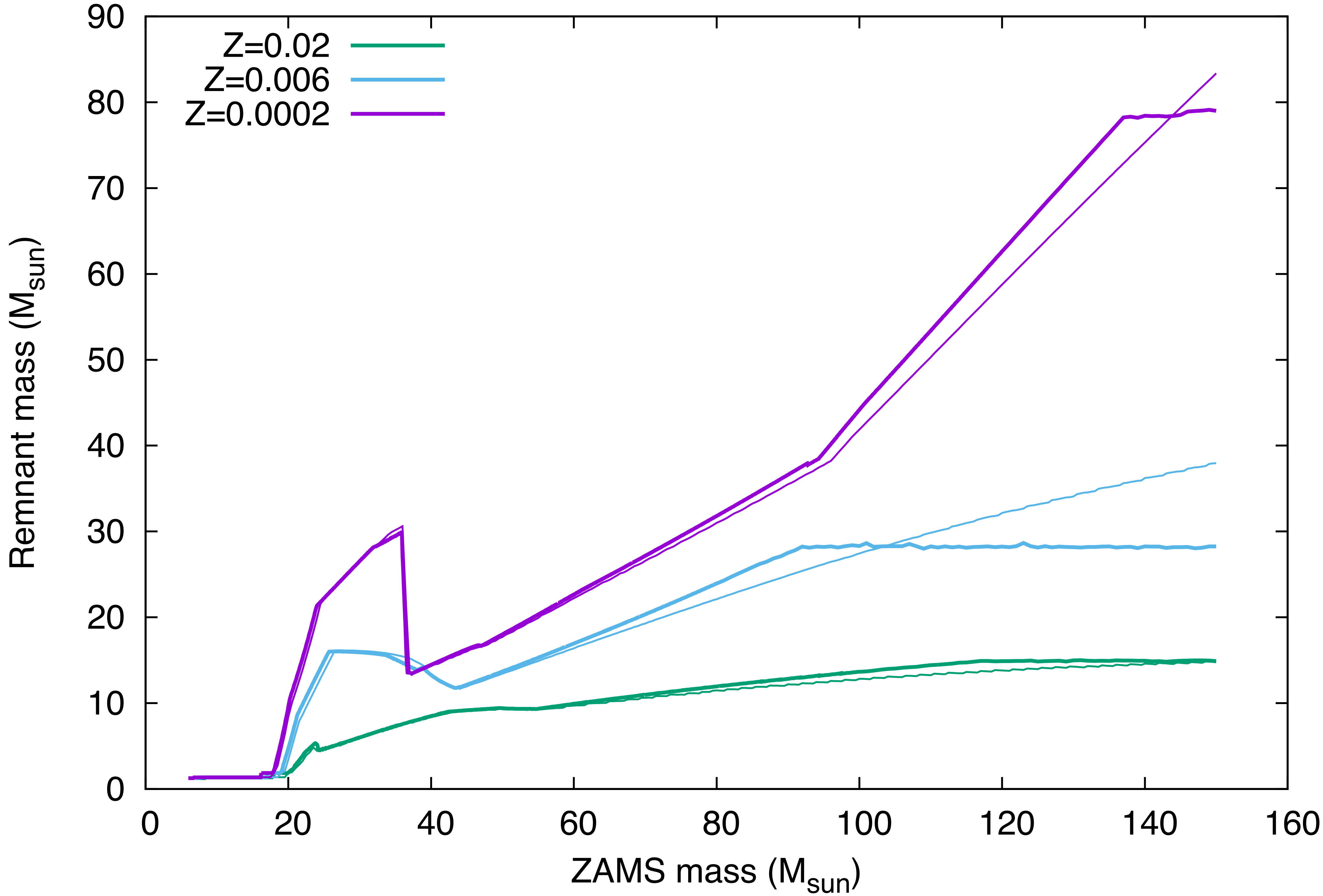
Most mergers happen within first few Gyr.

[Banerjee et al. (2010), MNRAS, 402, 371]

Belczynski et al. 2010, ApJ, 714, 1217 wind …

- Vink et al. (2010) main-sequence winds for O-type stars — depends on metallicity, weak for low-Z stars
- Weaker LBV winds
- Implosion (failed supernova) to black hole for $\gtrsim 7.3 M_\odot$ Fe-core => low (zero) BH natal kicks
- NSs formed from electron-capture supernovae (of $\approx 1.26 M_\odot$) have low (zero) natal kicks
- Recently implemented in NBODY6/7

Initial-final mass relation in (modified) BSE/NBODY6(7)



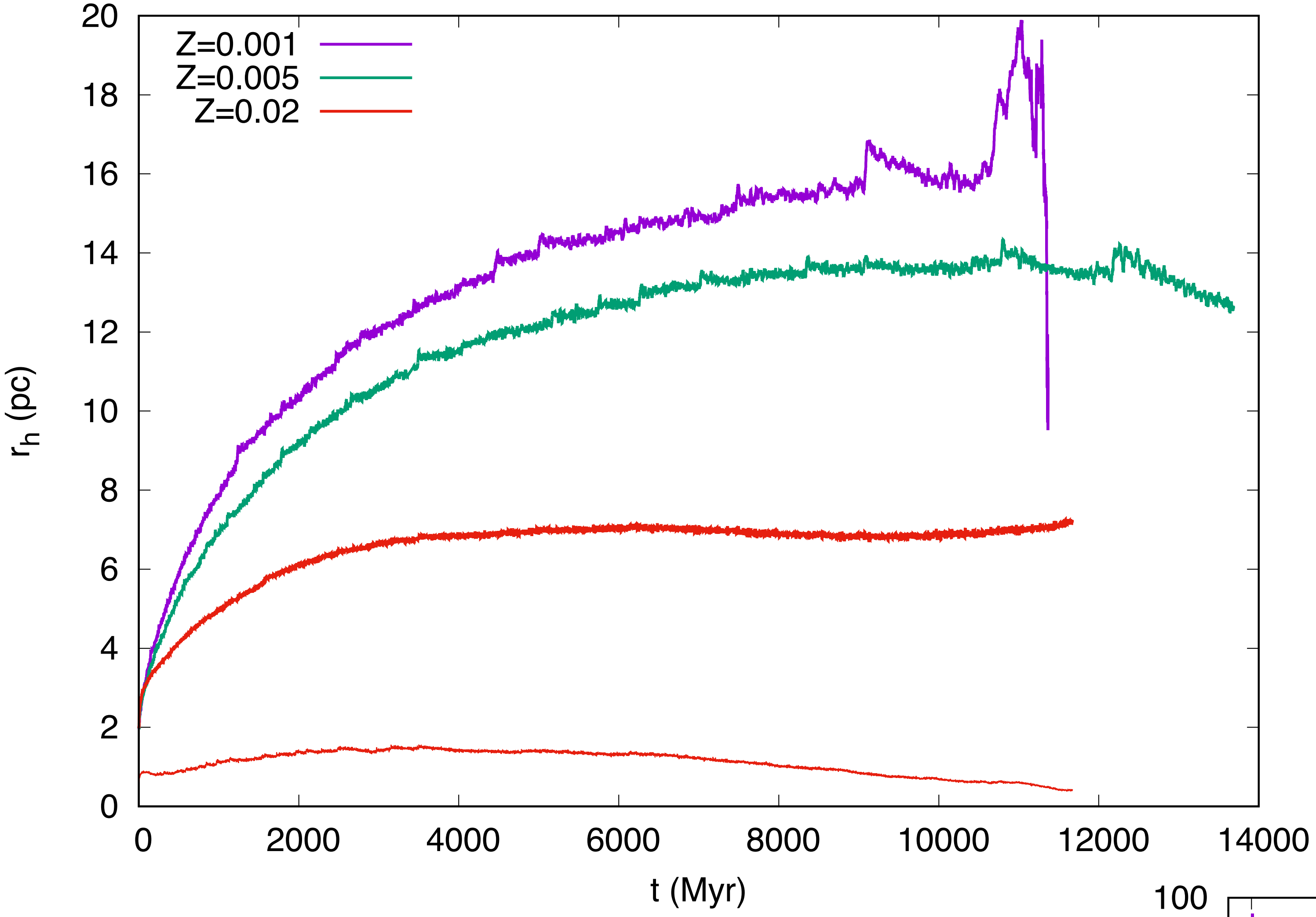
c.f. Spera, Mapelli & Bressan 2015, MNRAS, 451, 4086

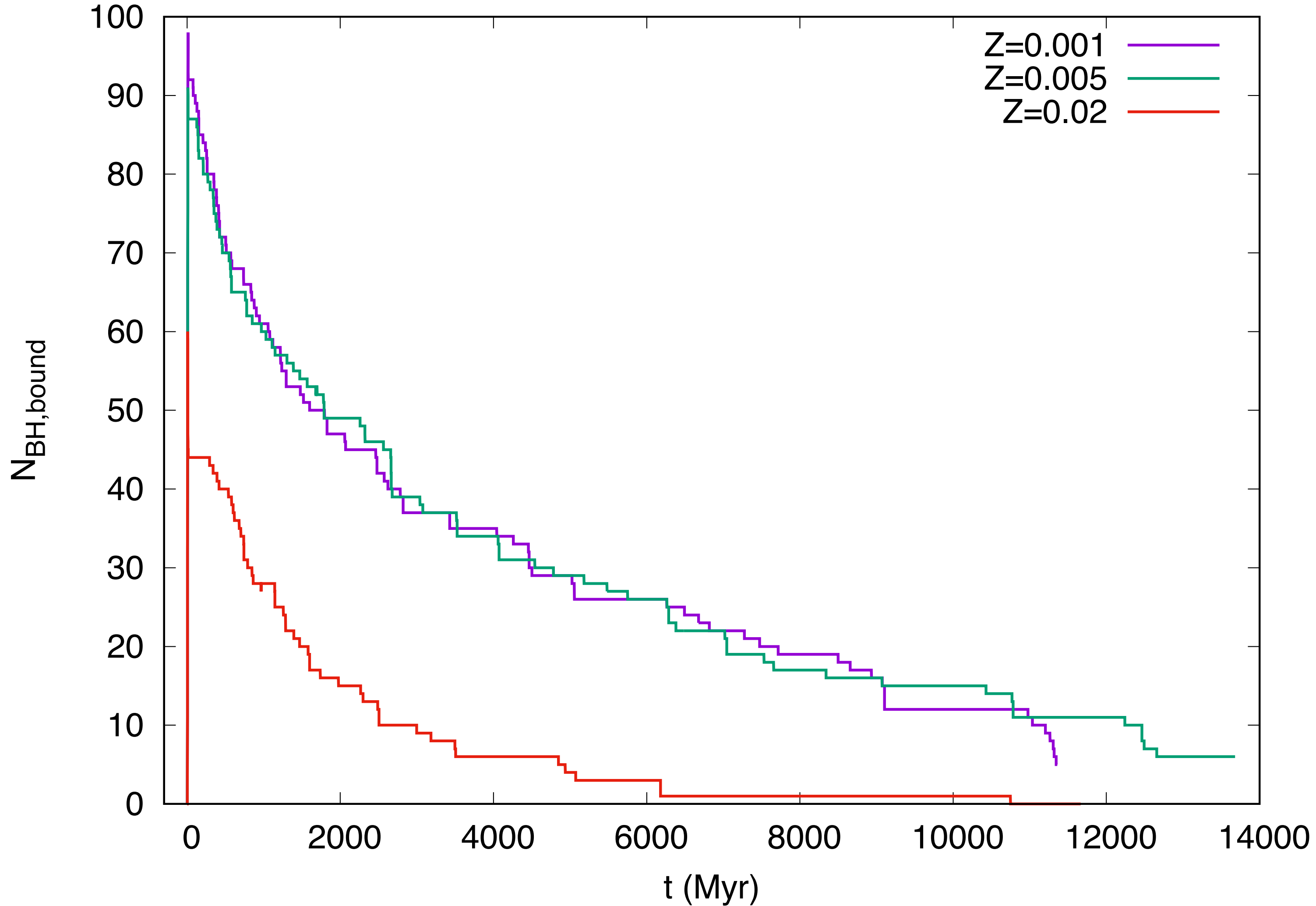
New model calculations: from young age until Hubble time

Varying metallicity, solar-neighbourhood-like external field

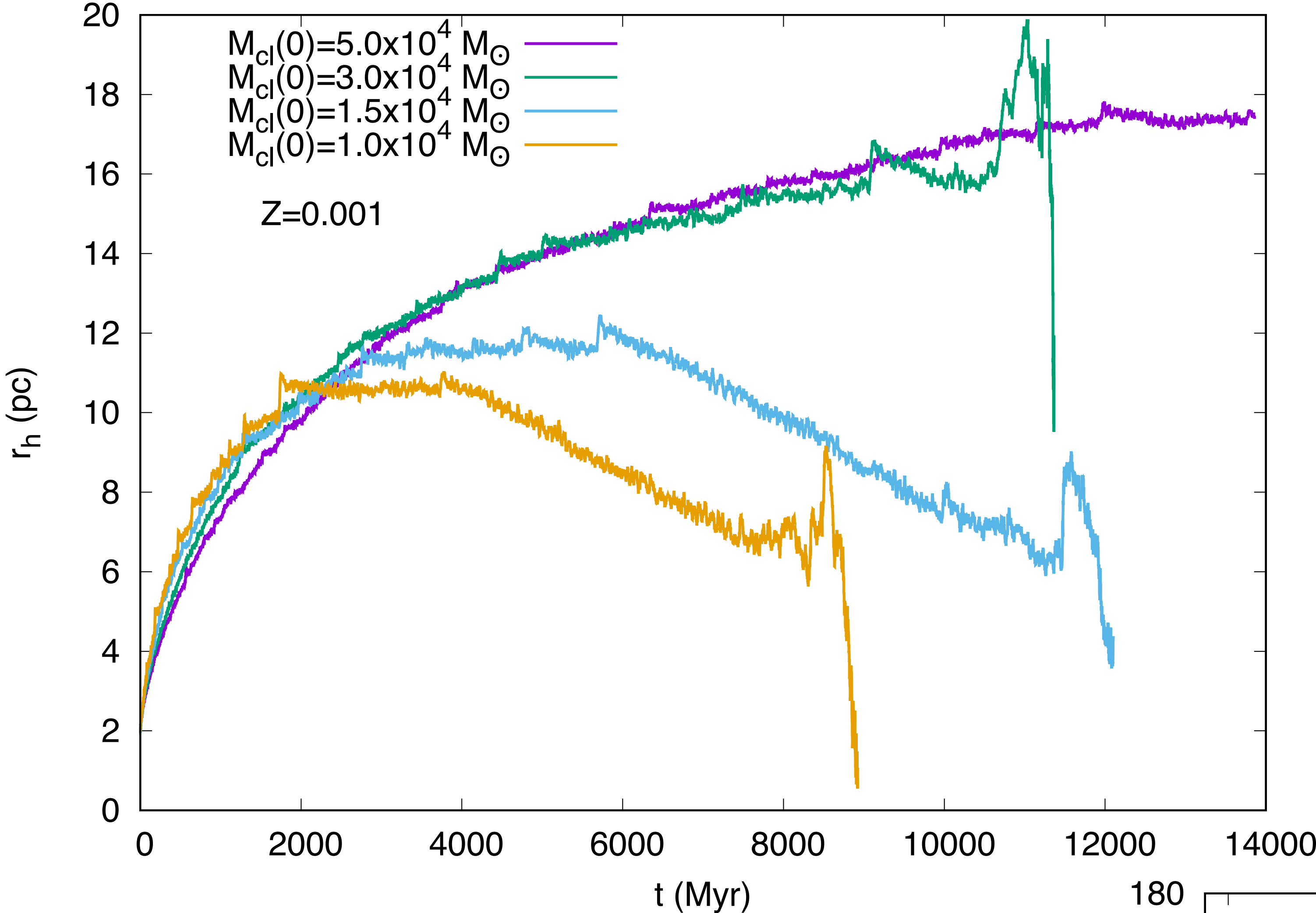
Table 1: Summary of new calculations with NBODY7.

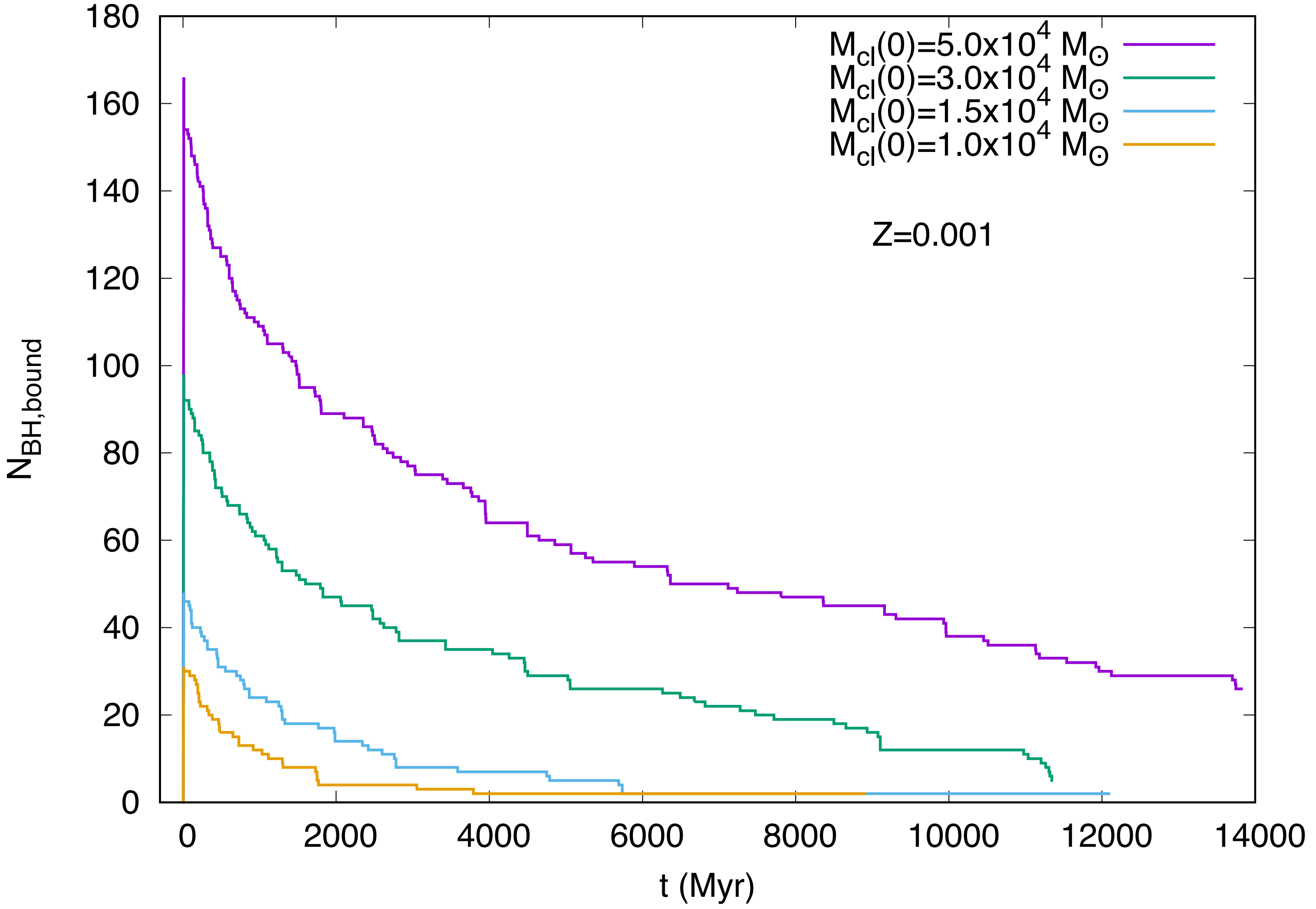
$M_{cl}(0)/M_\odot$	$r_h(0)/\mathrm{pc}$	$Z/Z_\odot$	$N_{\mathrm{mrg,in}}$	$N_{\mathrm{mrg,out}}$
5.0×10^4	2.0	0.05	1 $(24.3M_\odot + 17.7M_\odot)$	1 $(26.0M_\odot + 42.8M_\odot)$
5.0×10^4	2.0	0.25	1 $(34.5M_\odot + 22.7M_\odot)$	0
5.0×10^4	2.0	1.00	3 $(9.0M_\odot + 7.5M_\odot)$ $(10.6M_\odot + 9.4M_\odot)$ $(9.1M_\odot + 9.0M_\odot)$	0
3.0×10^4	2.0	0.05	1 $(38.1M_\odot + 25.9M_\odot)$	2 $(25.7M_\odot + 13.8M_\odot)$ $(23.6M_\odot + 22.3M_\odot)$
3.0×10^4	2.0	0.25	0	2 $(35.2M_\odot + 20.3M_\odot)$ $(15.7M_\odot + 12.2M_\odot)$
3.0×10^4	2.0	1.00	1 $(10.6M_\odot + 9.0M_\odot)$	0
1.5×10^4	2.0	0.05	1 $(49.4M_\odot + 30.9M_\odot)$	0
1.5×10^4	1.0	0.25	0	0
1.0×10^4	2.0	0.05	0	0
1.0×10^4	1.0	0.05	1 $(43.6M_\odot + 34.5M_\odot)$	0
1.0×10^4	1.0	0.25	0	0
0.7×10^4	1.0	0.05	0	0





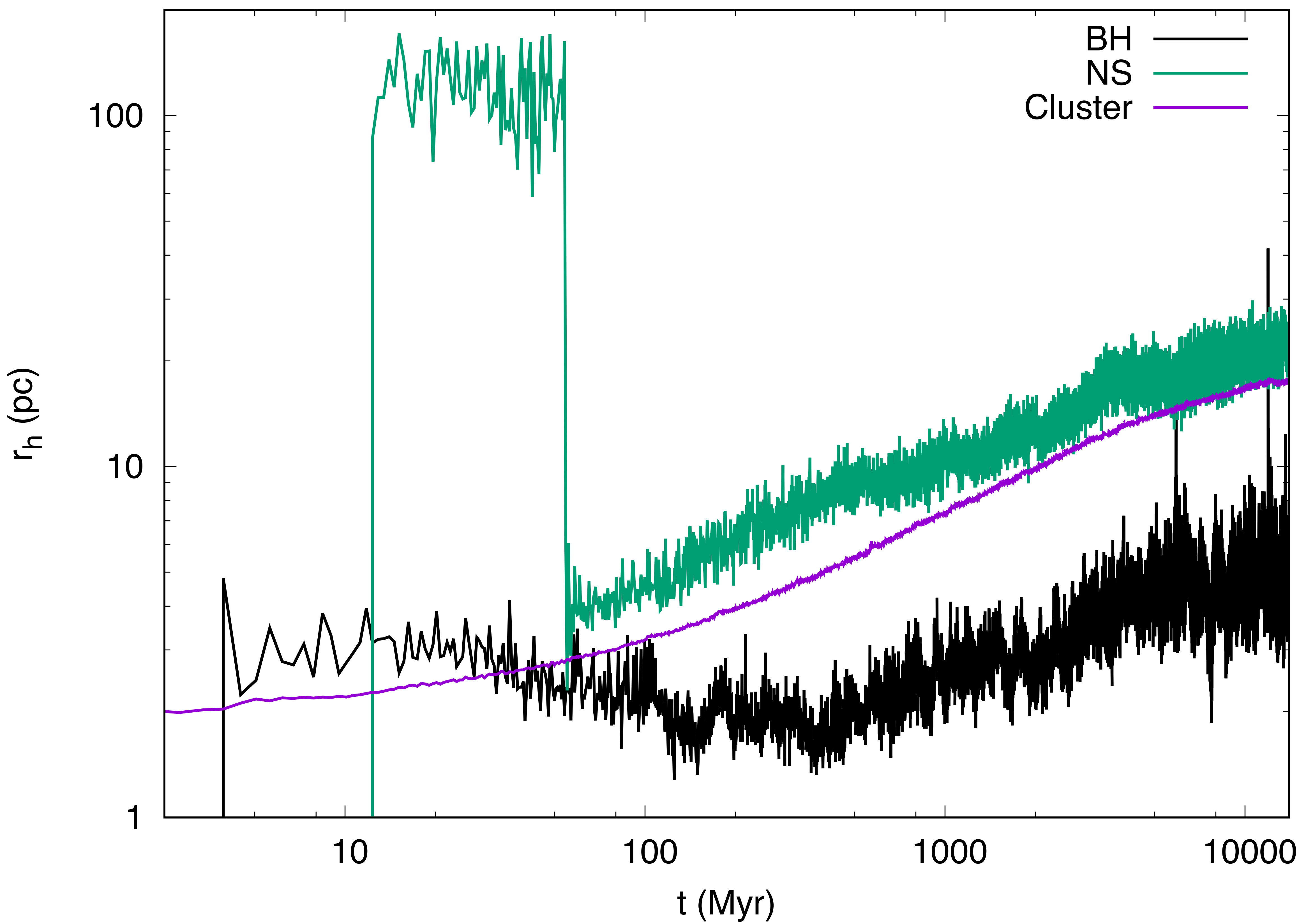
$$M_{cl}(0) \approx 3 \times 10^4; r_h(0) \approx 2 \text{ pc}$$

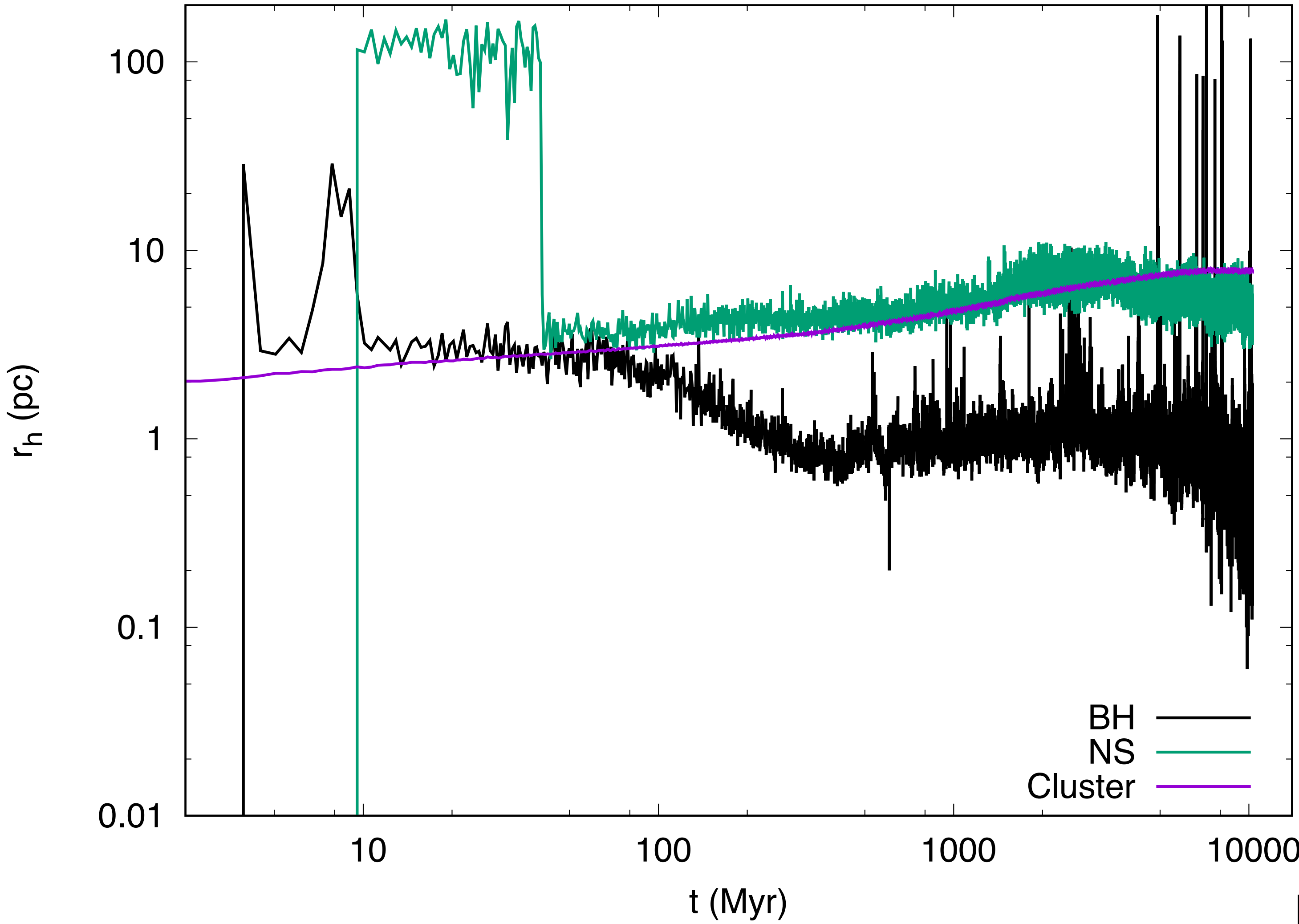




$Z = 0.001; r_h(0) \approx 2$ pc

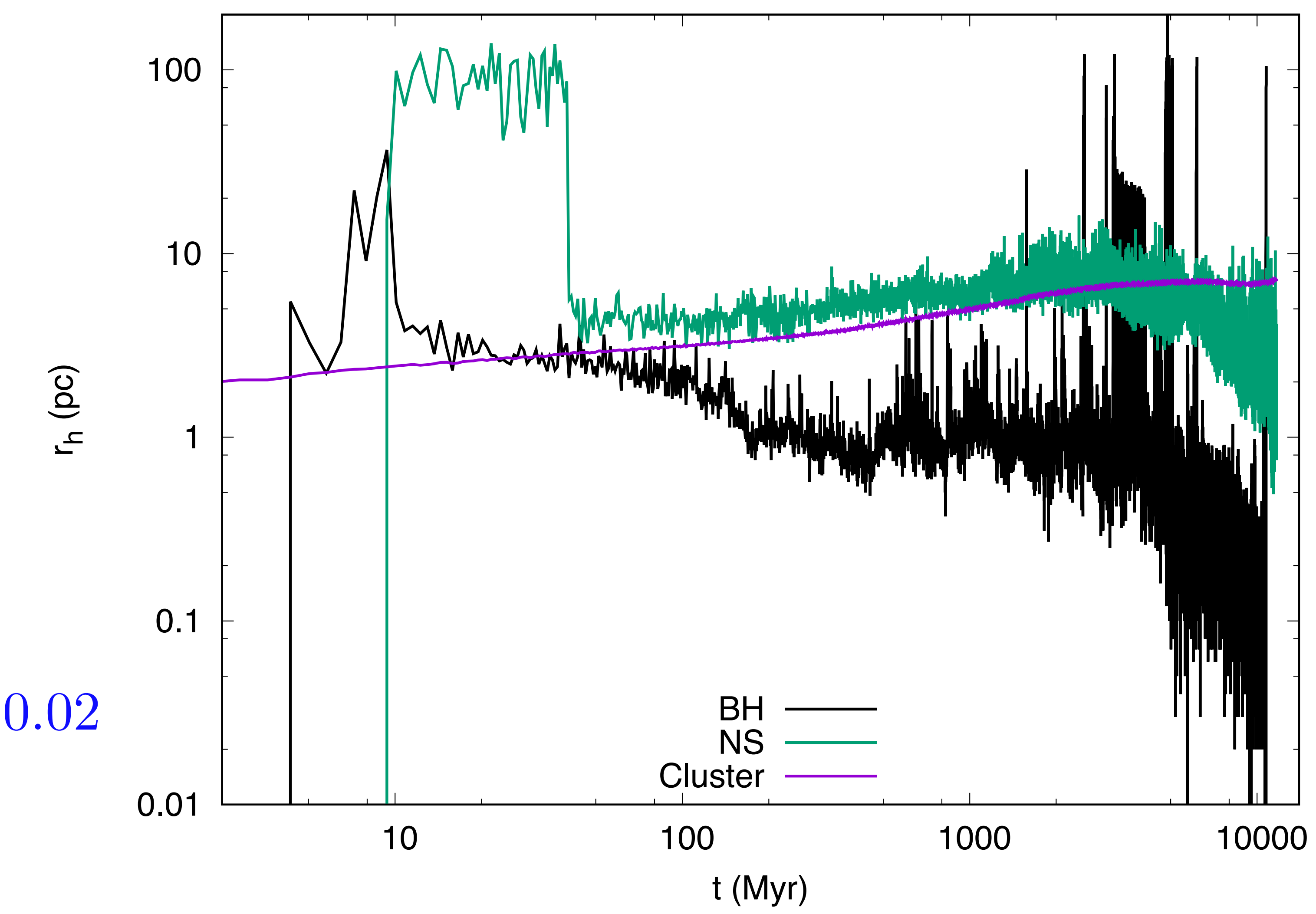
$$M_{cl}(0) \approx 5 \times 10^4 M_{\odot}; r_h(0) \approx 2 \text{ pc}; Z = 0.001$$



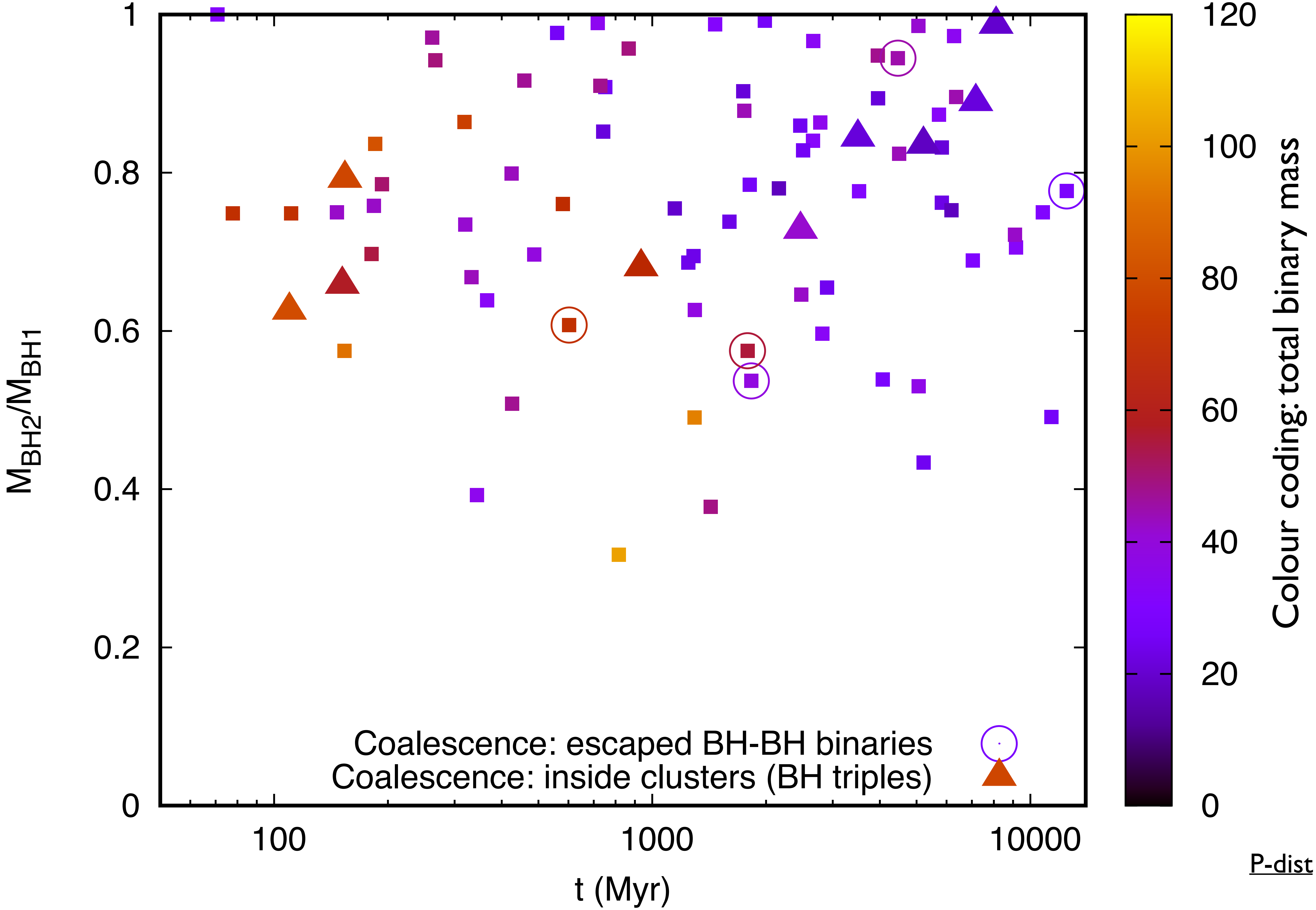


$M_{cl}(0) \approx 5 \times 10^4 M_{\odot}; r_h(0) \approx 2$ pc; $Z = 0.02$

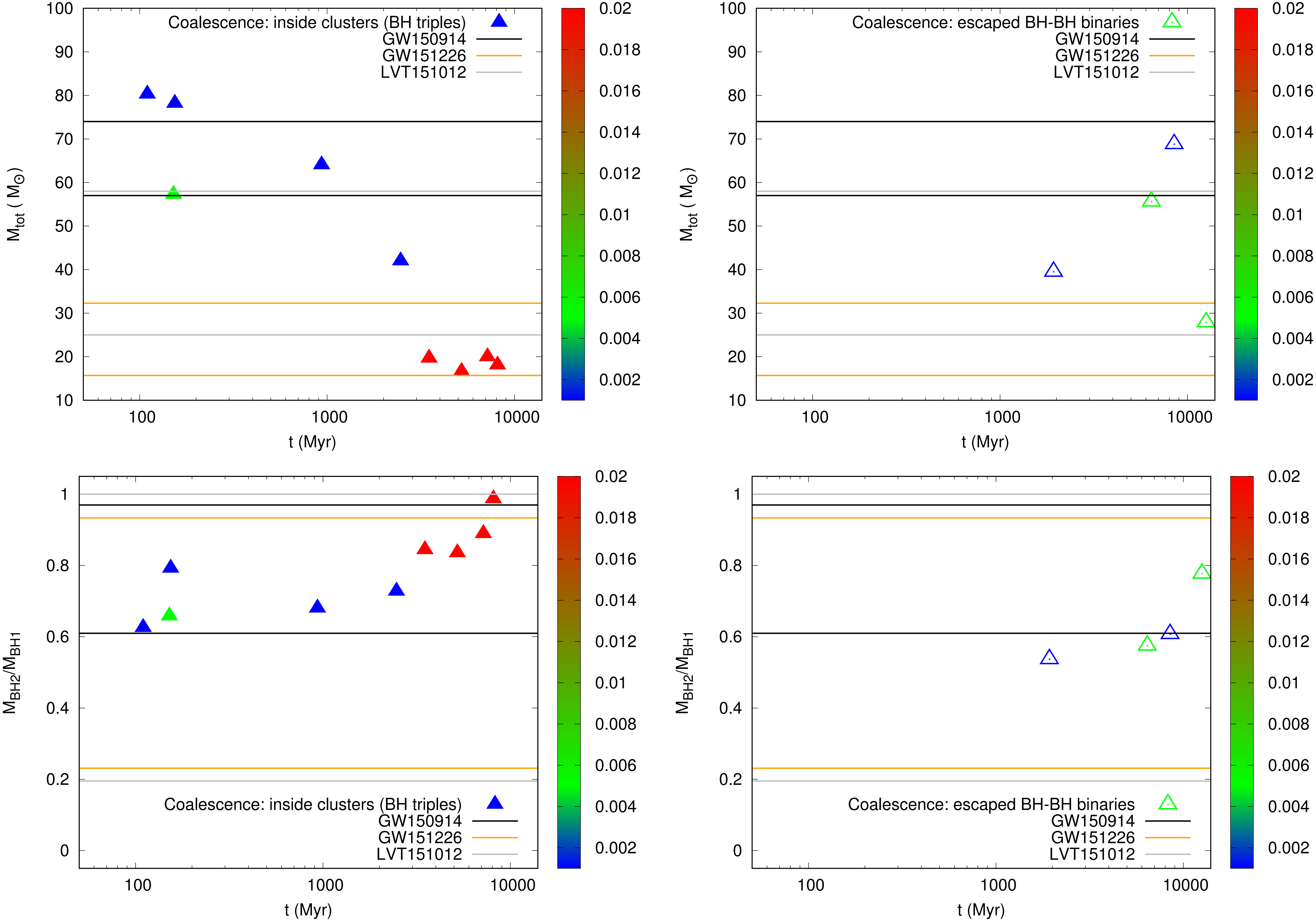
$M_{cl}(0) \approx 3 \times 10^4 M_{\odot}; r_h(0) \approx 2$ pc; $Z = 0.02$



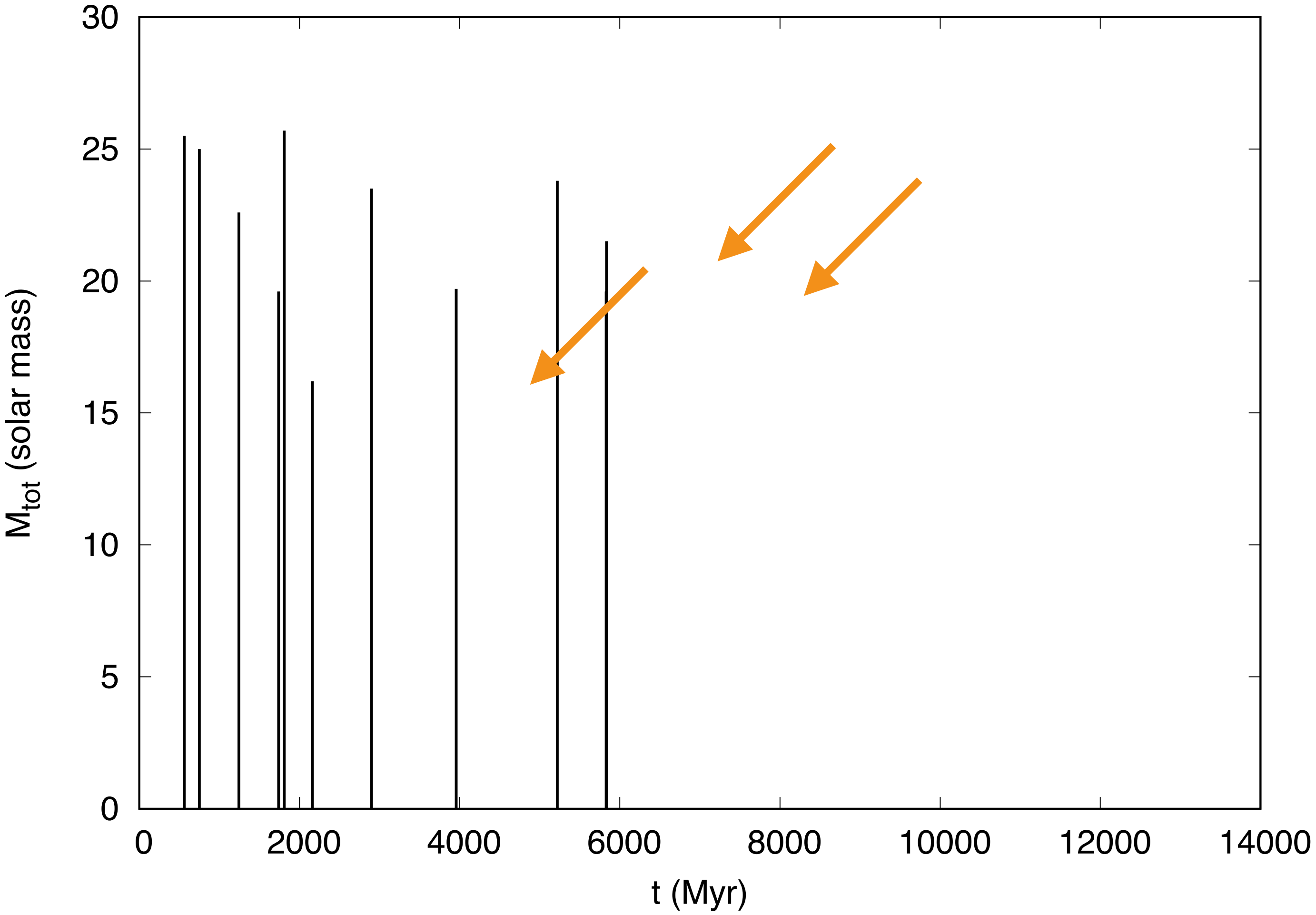
Escaped BH-BH binaries: all models



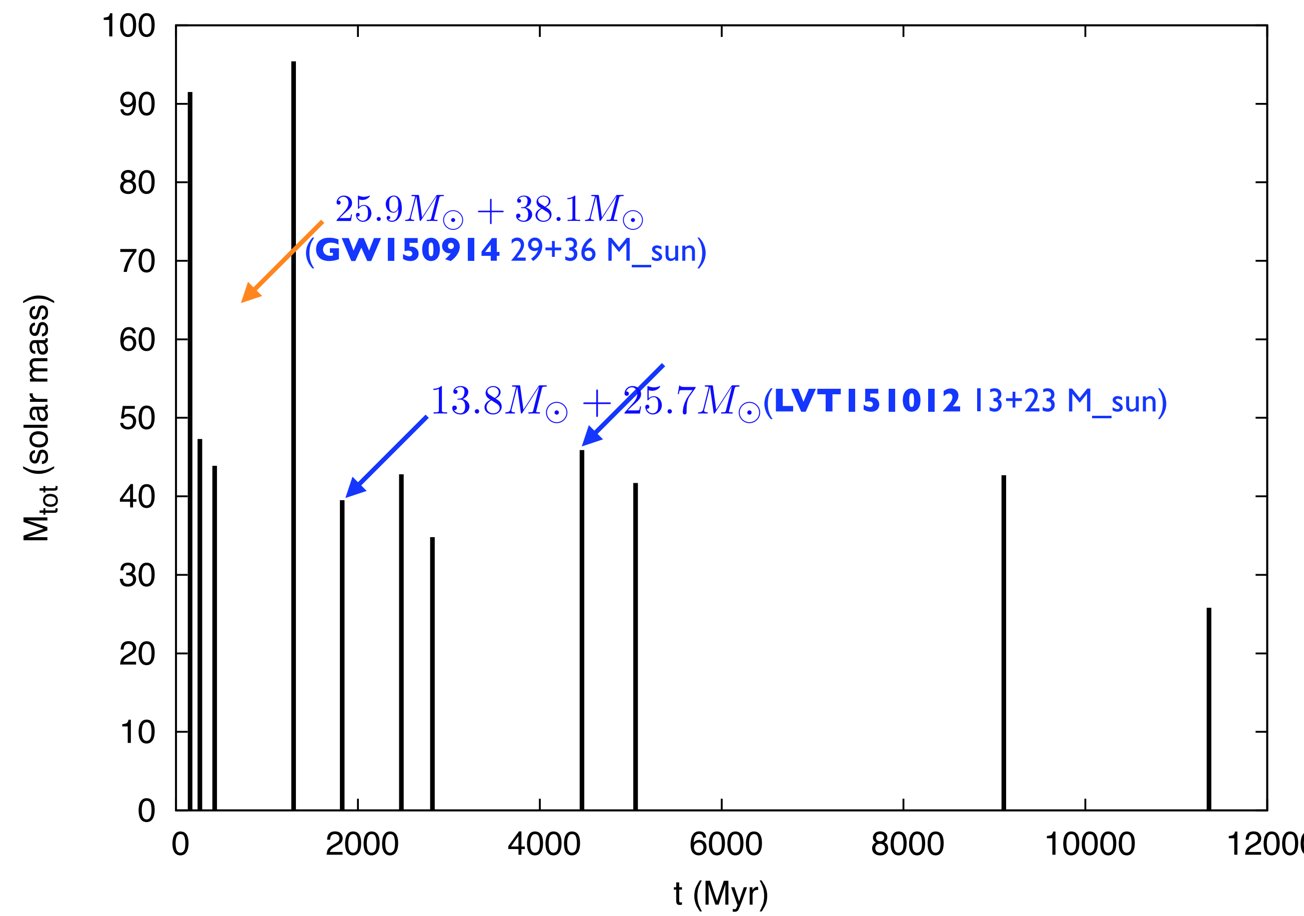
P-dist



Coalescence: inside clusters (BH triples)
Coalescence: escaped BH-BH binaries
GW150914
GW151226
LVT151012
M_{tot} ($M_\odot$)
M_{BH2}/M_{BH1}
t (Myr)
100
1000
10000
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02



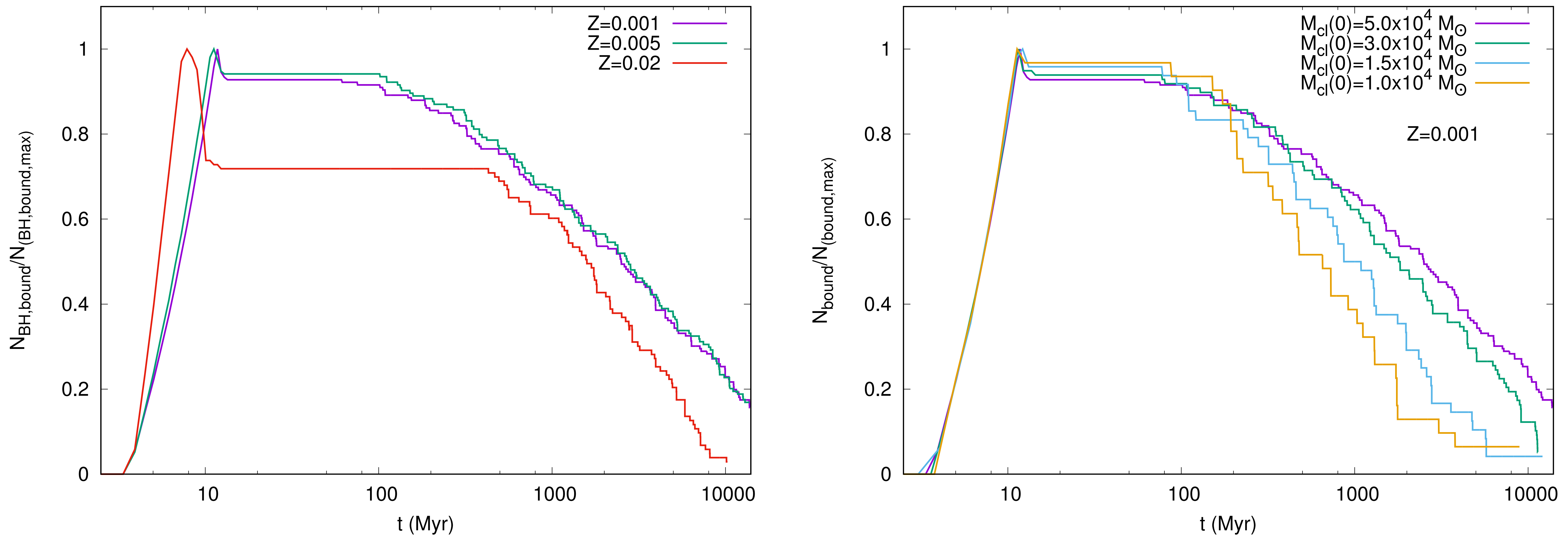
$M_{cl}(0) \approx 5 \times 10^4 M_\odot; r_h(0) \approx 2$ pc; $Z = 0.02$



$M_{cl}(0) \approx 3 \times 10^4; r_h(0) \approx 2$ pc; $Z = 0.001$

coalescence inside cluster

coalescence outside cluster



Z=0.001
Z=0.005
Z=0.02
$N_{BH,bound}/N_{(BH,bound,max)}$
t (Myr)
$M_{cl}(0)=5.0x10^4 M_\odot$
$M_{cl}(0)=3.0x10^4 M_\odot$
$M_{cl}(0)=1.5x10^4 M_\odot$
$M_{cl}(0)=1.0x10^4 M_\odot$
Z=0.001
$N_{bound}/N_{(bound,max)}$
t (Myr)