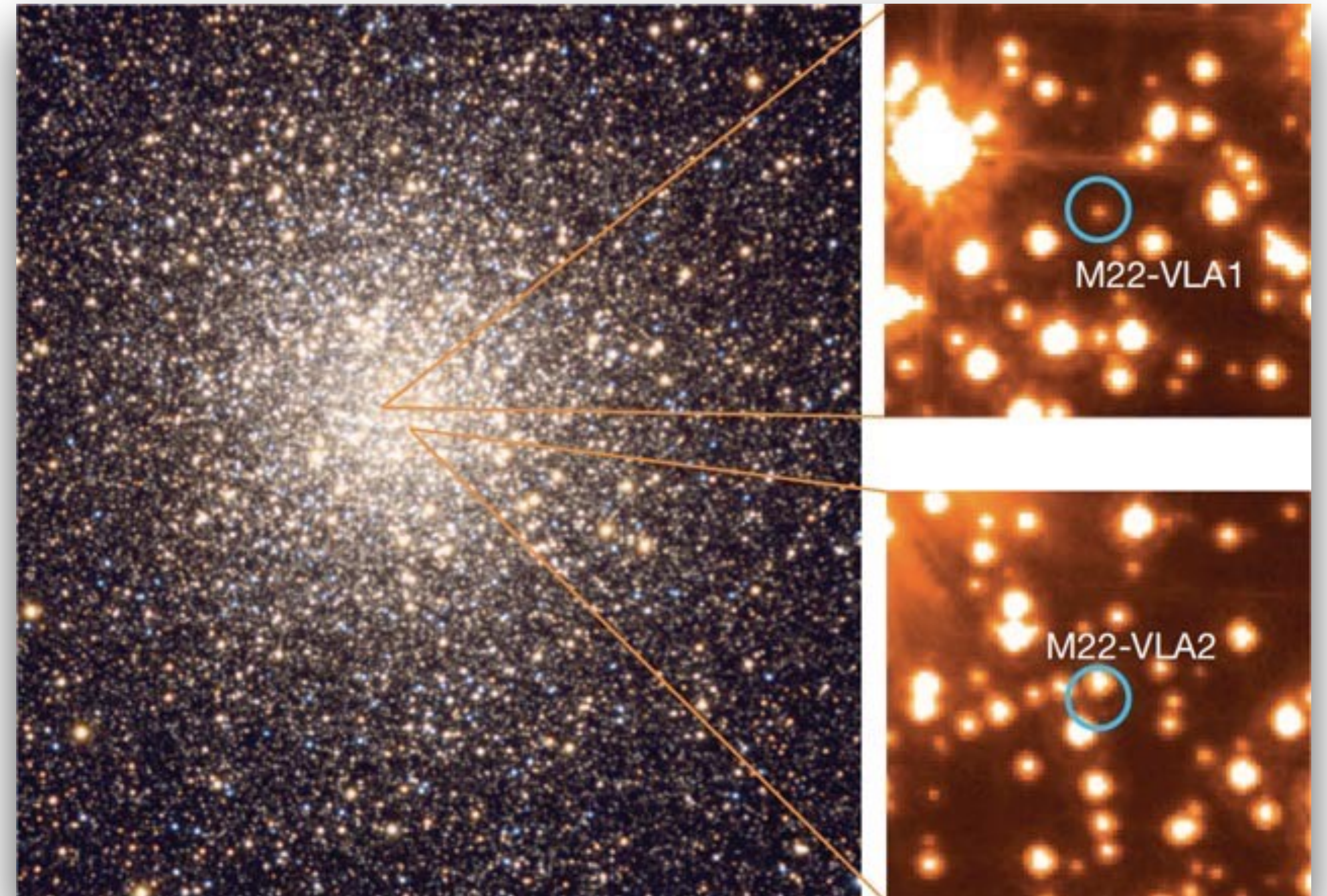
Neutron stars and black holes in dense stellar systems

Sambaran Banerjee
Helmholtz-Instituts für Strahlen- und Kernphysik (HISKP) and
Argelander-Institut für Astronomie (AIfA), University of Bonn

Bonn NS workshop 2017

Banerjee, S., 2017, MNRAS, 467, 524
Banerjee, S., 2018, MNRAS, 473, 909

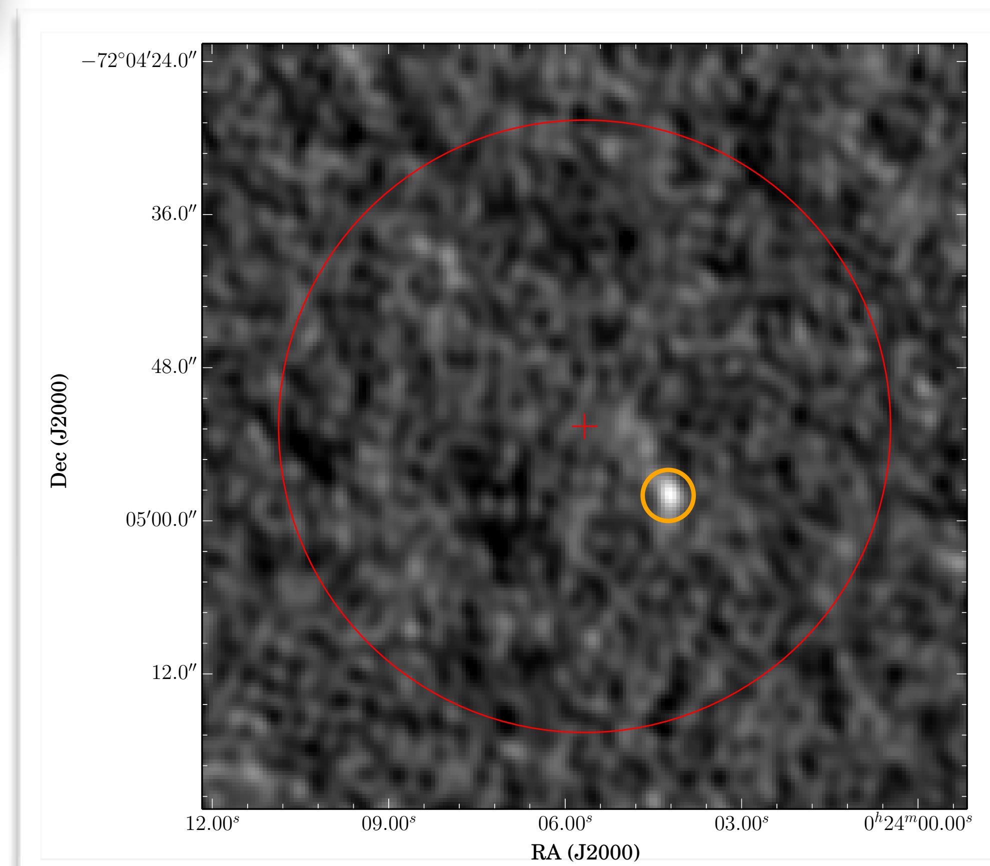


M22 BH candidates (Strader et al. 2012)

Promising source for LIGO-VIRGO gravitational-wave detector

… as well for LISA

Stellar-mass black holes in globular clusters

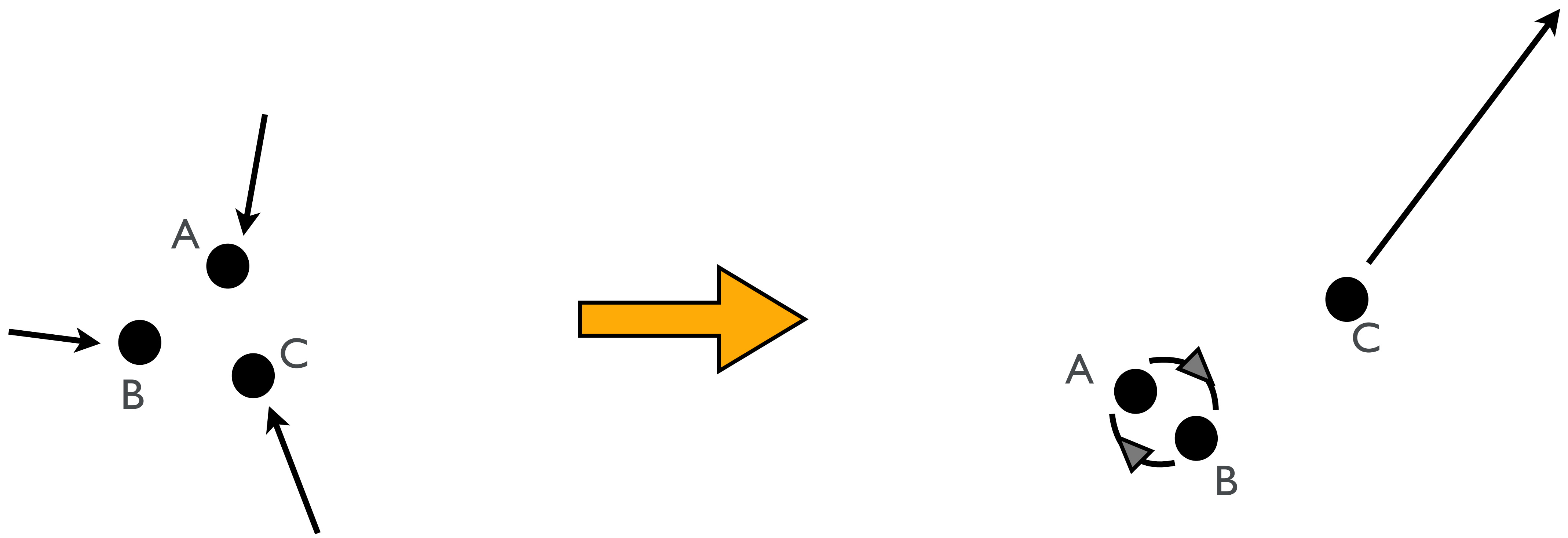


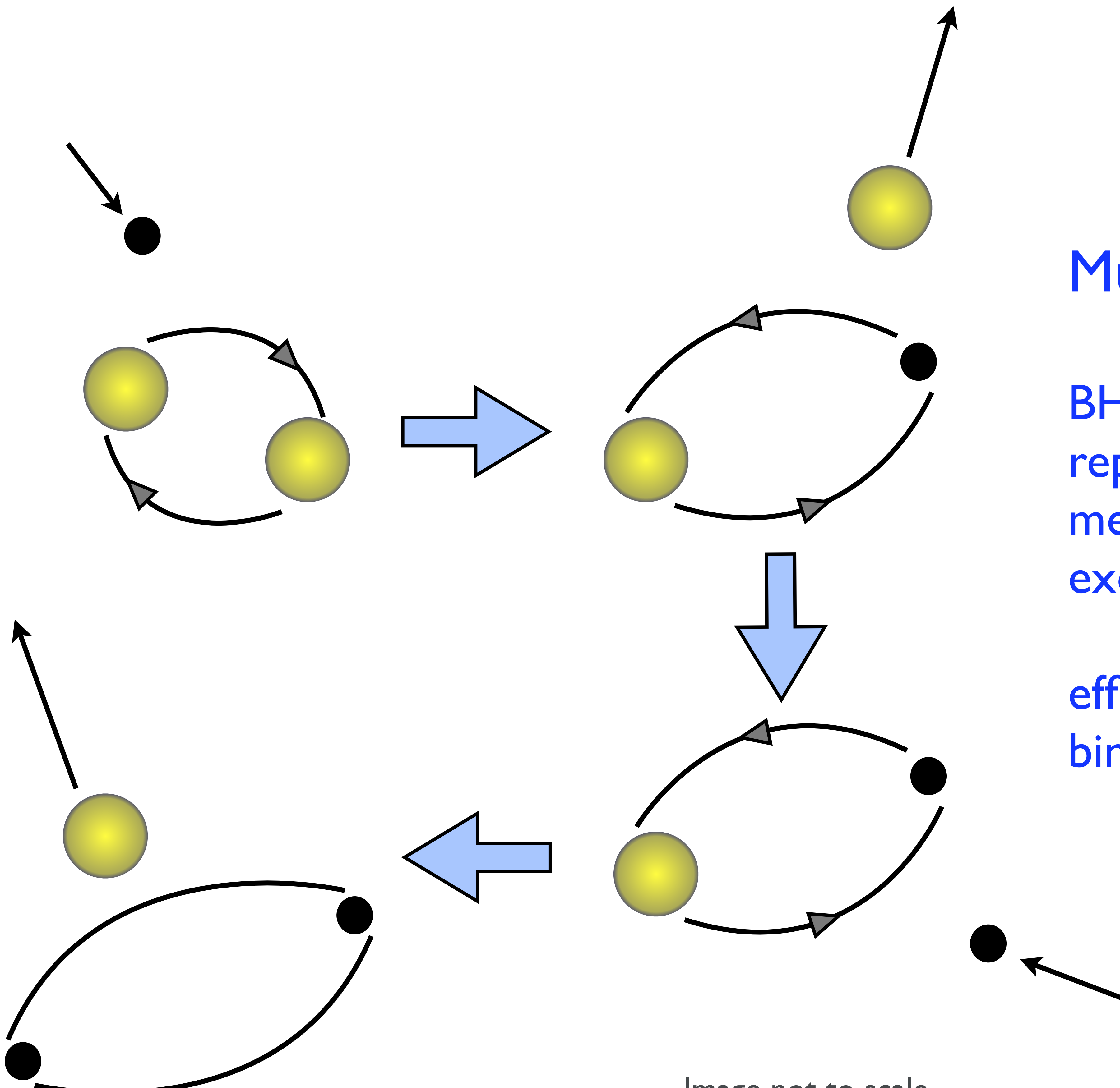
ACTA 5.5-Ghz image of 47 Tuc core (Miller-Jones et al. 2015)

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.



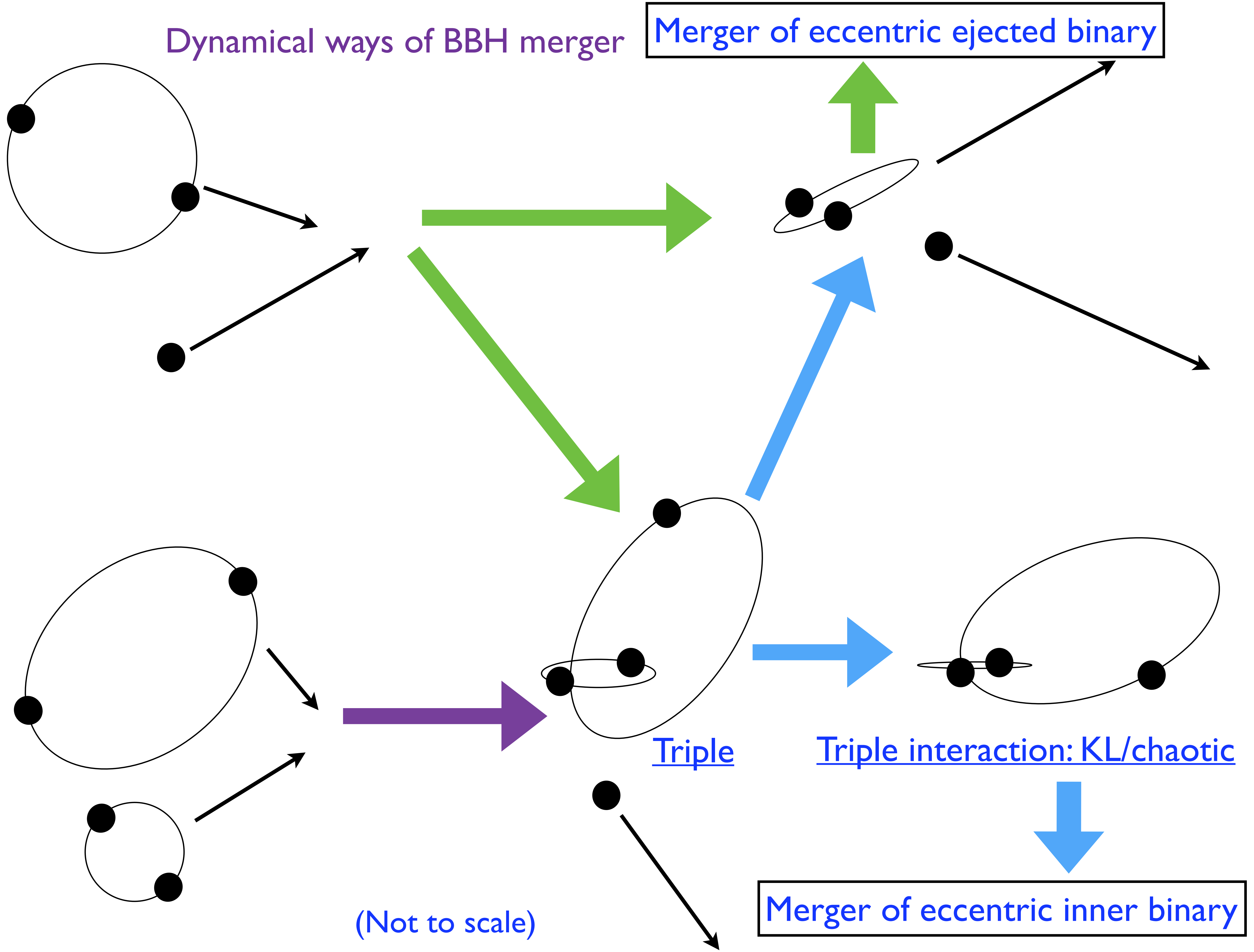


Multiple exchange:

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 ejected binary
Triple
Triple interaction: KL/chaotic
Merger of eccentric inner binary
(Not to scale)

Model calculations with NBODY7: from young age until >10 Gyr (Banerjee 2017)

Alternative (Belczynski et al. 2010) stellar wind, varying metallicity, solar neighbourhood-like external field, initial Plummer model, standard IMF

$M_{cl}(0)/M_{\odot}$	$r_h(0)/\mathrm{pc}$	$Z/Z_{\odot}$	f_{bin}	$T_{\mathrm{evol}}/\mathrm{Gyr}$	$N_{\mathrm{mrg,in}}$	$N_{\mathrm{mrg,out}}$
1.0×10^5	2.0	0.05	0.0	1	3 (57.7+28.0; 120.0), (53.1+32.9; 165.1), (40.3+55.4; 286.3)	0
1.0×10^5	2.0	0.25	0.0	1	4 (37.9+40.5; 102.9), (20.3+37.1; 179.3), (18.2+32.0; 188.6), (29.1+34.8; 246.6)	0
1.0×10^5	2.0	0.50	0.0	1	0	1 (24.8+19.0; 625.3)
7.5×10^4	2.0	0.05	0.0	10	7 (40.4+64.2; 56.8), (43.0+44.3; 200.4), (24.8+28.6; 543.9), (31.1+22.8; 909.2), (21.3+25.9; 1852.5), (24.4+26.0; 4417.1), (10.6+22.4; 10010.6)	0
7.5×10^4	2.0	0.25	0.0	10	2 (37.8+32.8; 76.5), (17.5+10.1; 10298.6)	1 (22.8+27.6; 508.3)
[1] 5.0×10^4	2.0	0.05	0.0	> 10	1 (24.3+17.7; 2466.1)	1 (26.0+42.8; 603.0)
[1] 5.0×10^4	2.0	0.25	0.0	> 10	1 (34.5+22.7; 151.5)	0
[1] 5.0×10^4	2.0	1.00	0.0	10	3 (9.0+7.5; 5210.1), (10.6+9.4; 7171.0), (9.1+9.0; 8117.7)	0
[1] 3.0×10^4	2.0	0.05	0.0	> 10	1 (38.1+25.9; 933.8)	2 (25.7+13.8; 1828.0), (23.6+22.3; 4464.1)
[1] 3.0×10^4	2.0	0.25	0.0	> 10	0	2 (35.3+20.3; 1787.1), (15.7+12.2; 12463.7)
[1] 3.0×10^4	2.0	1.00	0.0	> 10	1 (10.6+9.0; 3495.9)	0

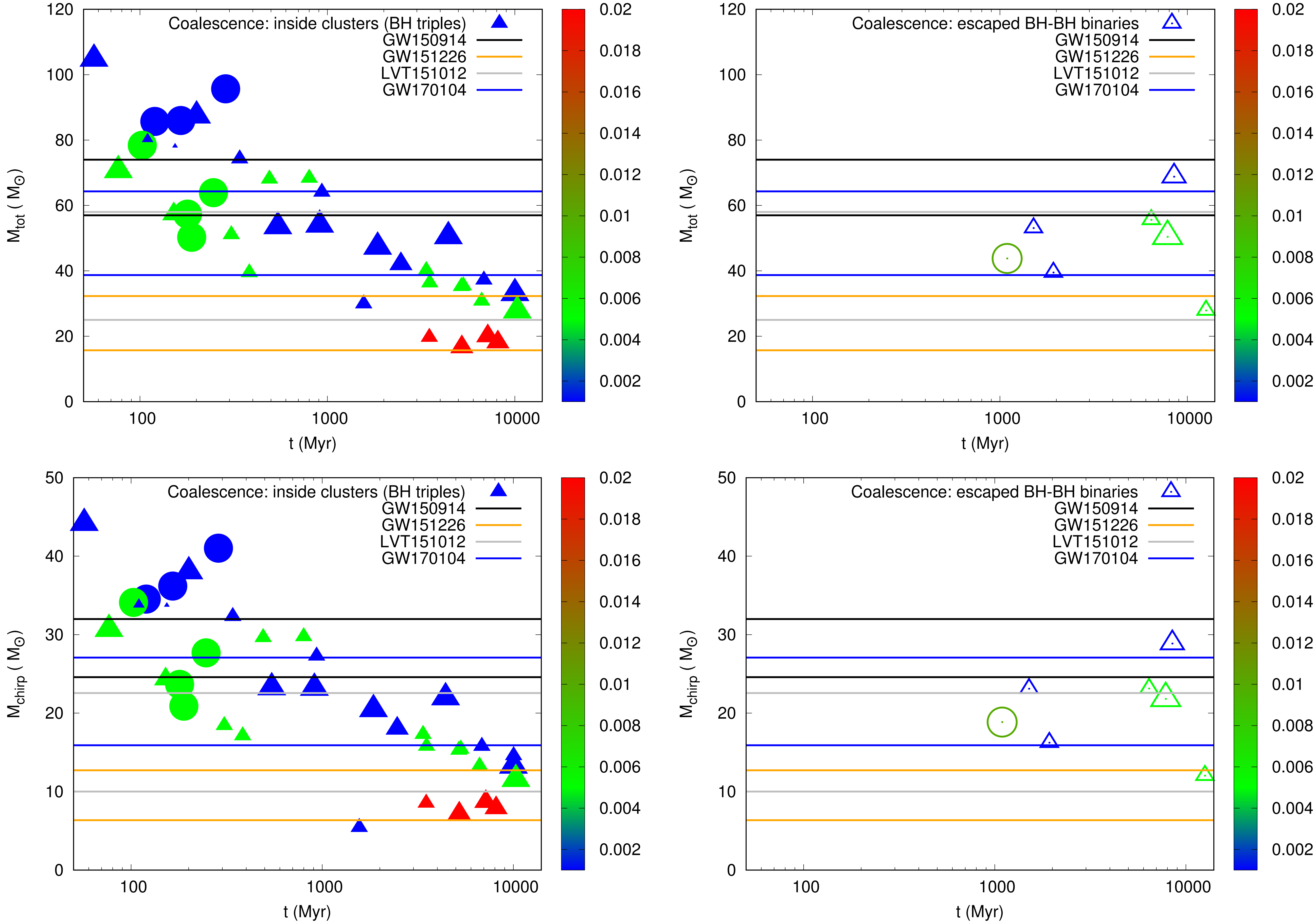
Model calculations with NBODY7: from young age until >10 Gyr (Banerjee 2018)

Alternative (*Belczynski et al. 2010*) stellar wind, varying metallicity, solar neighbourhood-like external field, initial Plummer model, standard IMF, **primordial binaries**

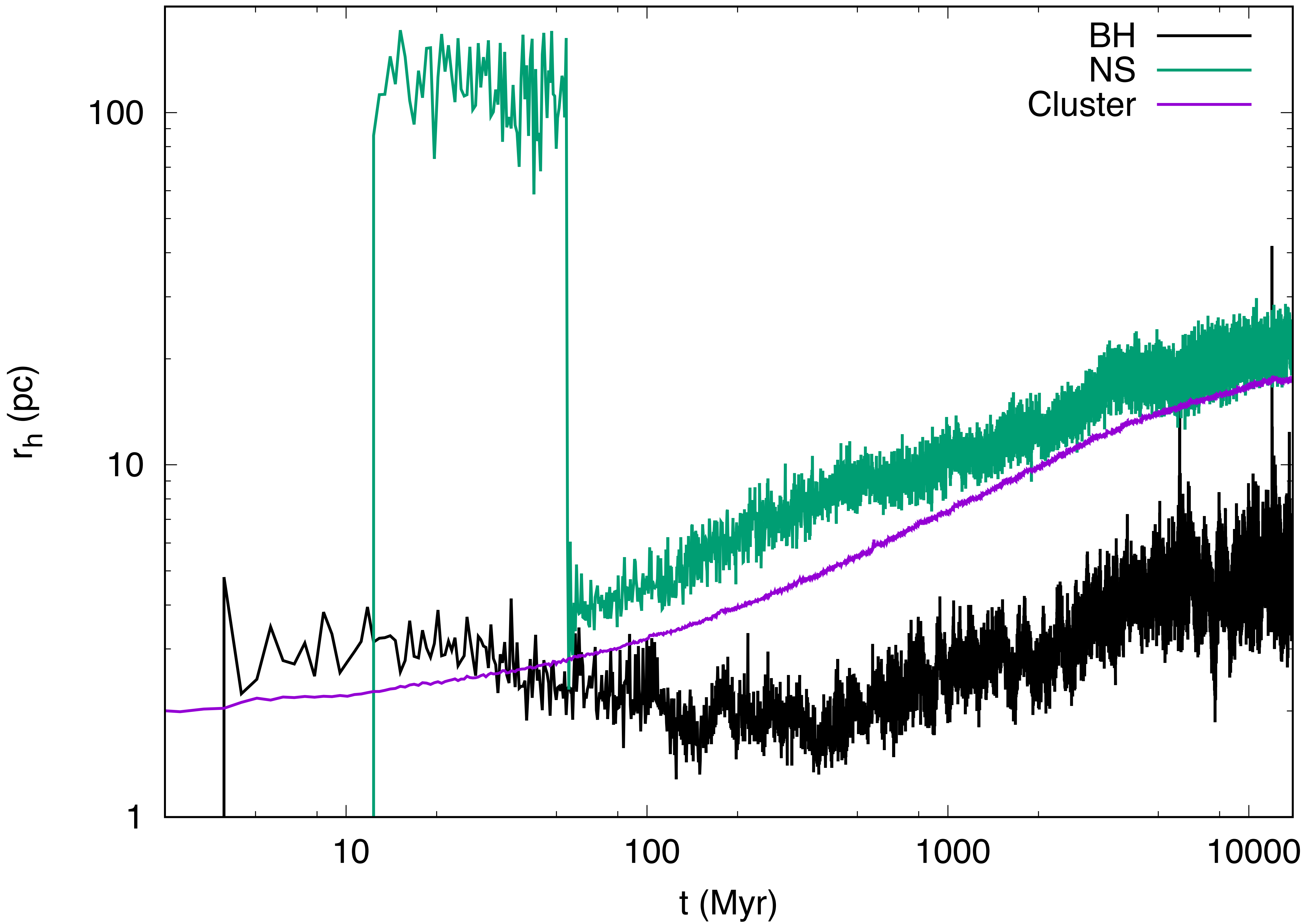
$M_{cl}(0)/M_{\odot}$	$r_h(0)/\mathrm{pc}$	$Z/Z_{\odot}$	f_{bin}	$T_{\mathrm{evol}}/\mathrm{Gyr}$	$N_{\mathrm{mrg,in}}$	$N_{\mathrm{mrg,out}}$
3.0×10^4	2.0	0.05	0.02	10	0	1 (25.9+27.2; 1410.9)
3.0×10^4	2.0	0.25	0.02	10	2 (19.0+17.2; 3513.1), (18.9+16.2; 5185.2)	0
3.0×10^4	2.0	0.05	0.05	10	1 (22.4+14.8; 6838.7)	0
3.0×10^4	2.0	0.25	0.05	10	4 (33.3+34.8; 490.3), (34.5+33.8; 799.8), (17.5+22.6; 3368.0), (17.2+13.5; 6649.7)	0
3.0×10^4	2.0	0.05	0.1	10	3 (37.9+36.3; 340.2), (28.0+1.85; 1561.0), (21.3+13.3; 10025.2)	0
3.0×10^4	2.0	0.25	0.1	6	3 (38.8+12.3; 307.0), (18.2+21.2; 383.2), (17.7+17.6; 5310.3)	0

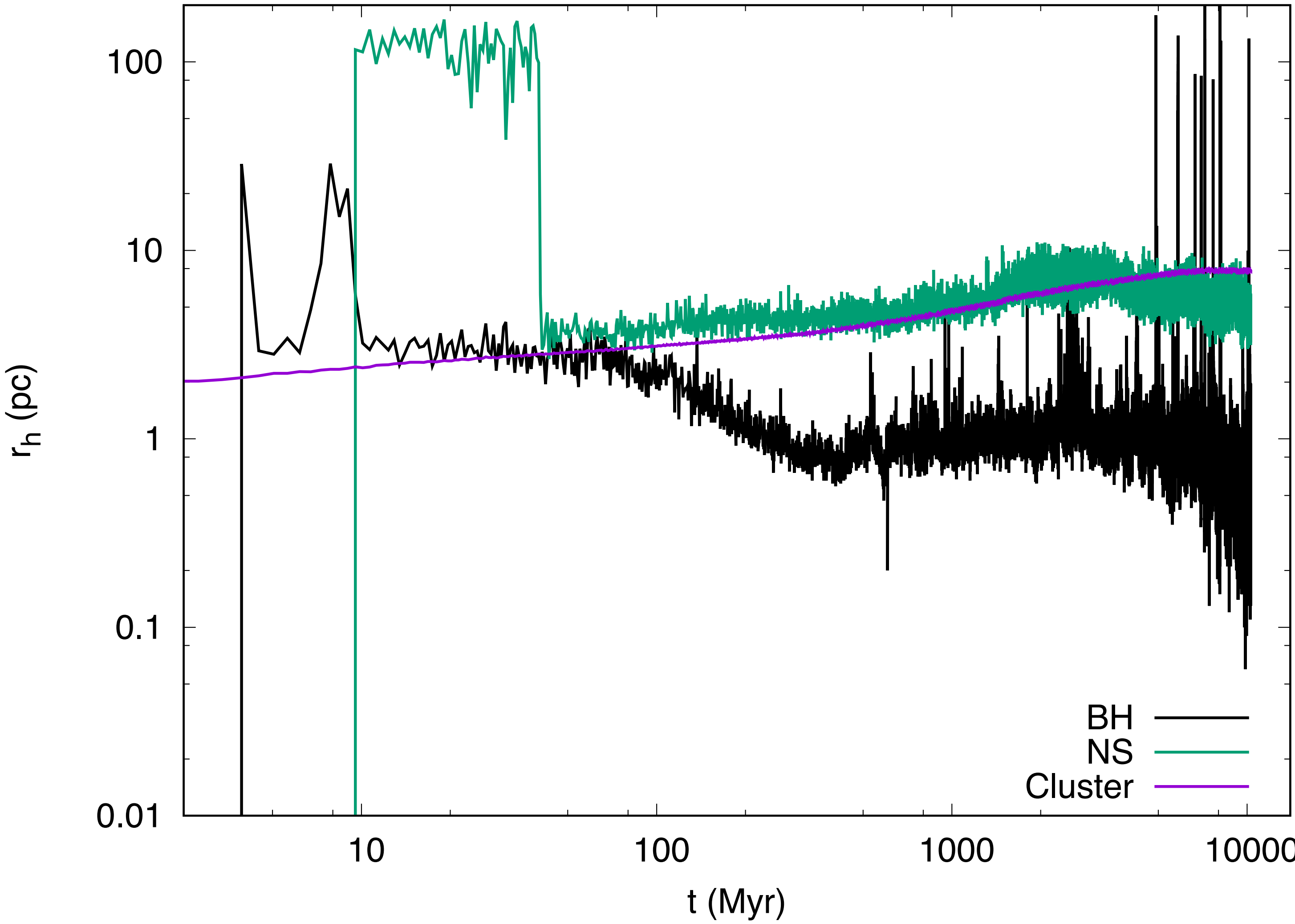
c.f. Ziosi et al. 2014, Mapelli 2016, Kimpson et al. 2016

Binary black hole (BBH) coalescences (colour bar: metallicity)



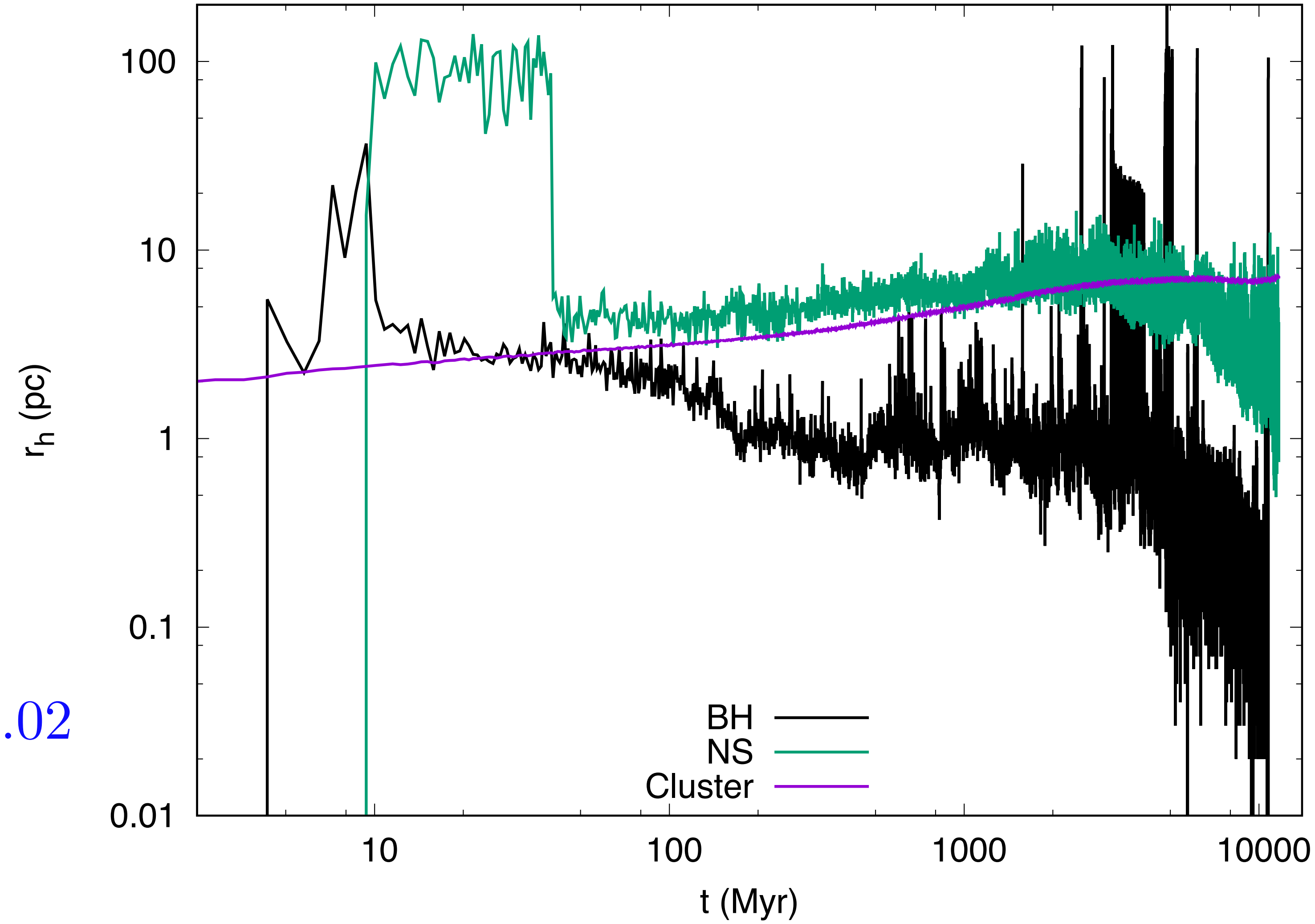
$M_{cl}(0) \approx 5 \times 10^4 M_\odot; r_h(0) \approx 2$ pc; $Z = 0.001$



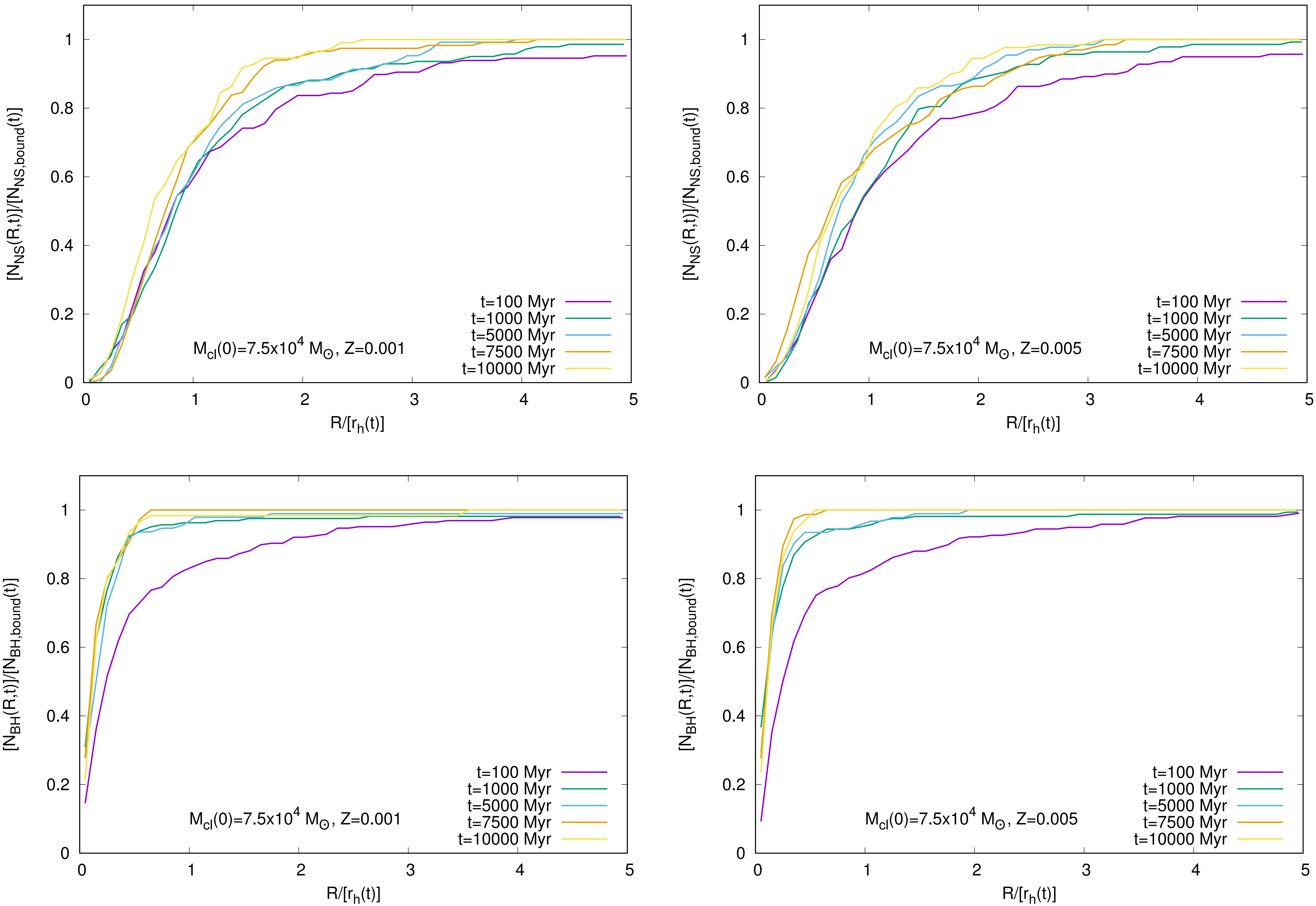


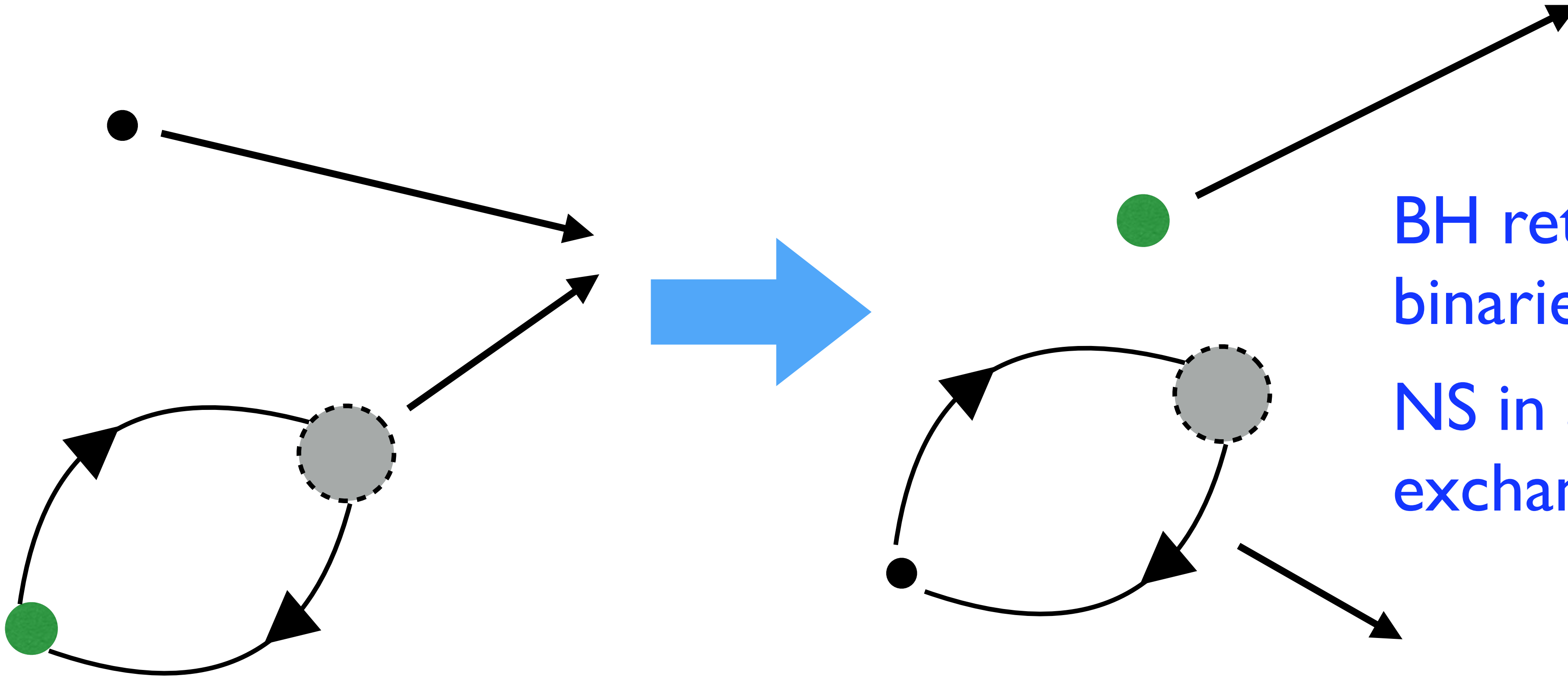
$M_{cl}(0) \approx 5 \times 10^4 M_\odot; r_h(0) \approx 2$ pc; $Z = 0.02$

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



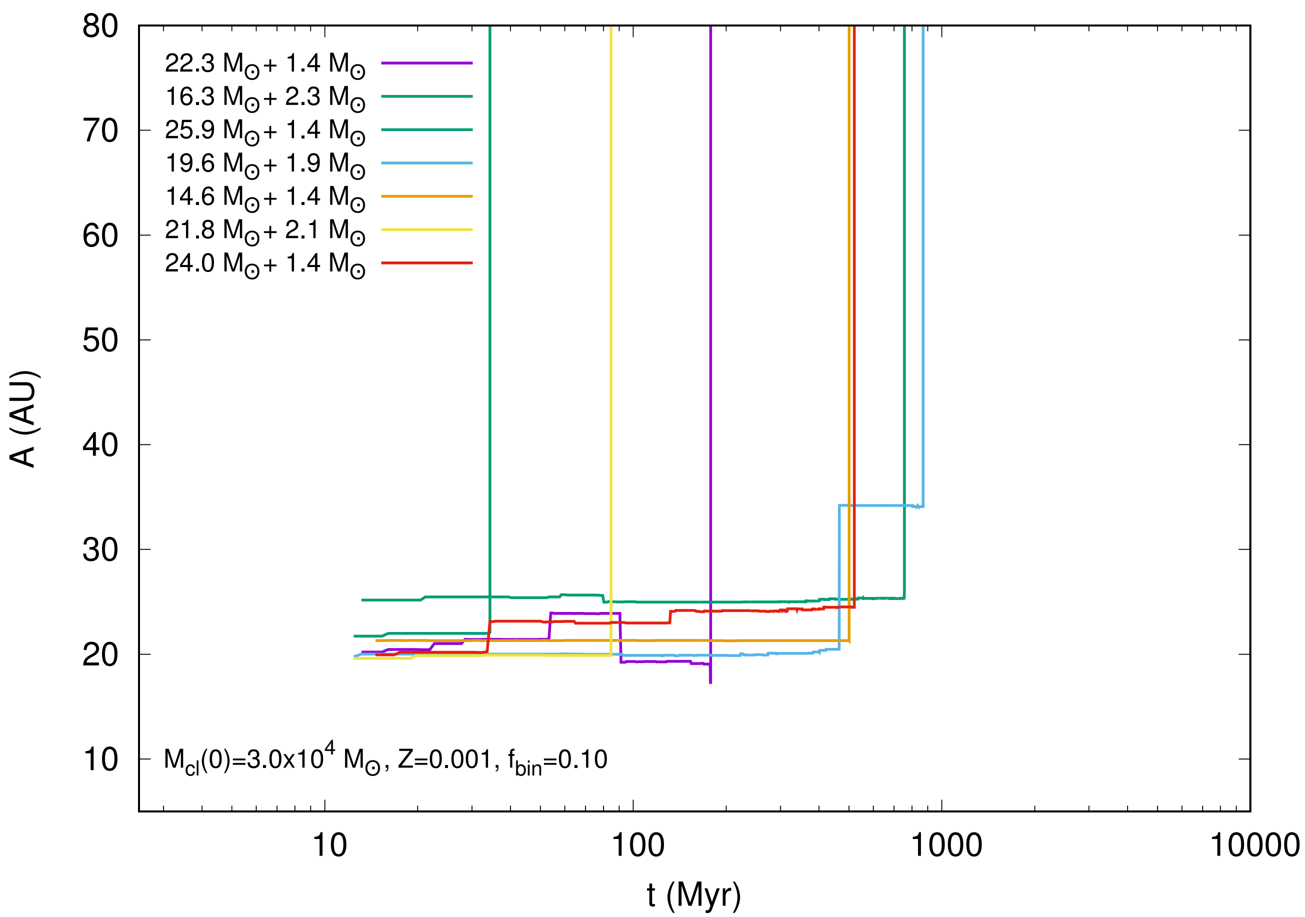
BH retention prevents mass segregation of NSs

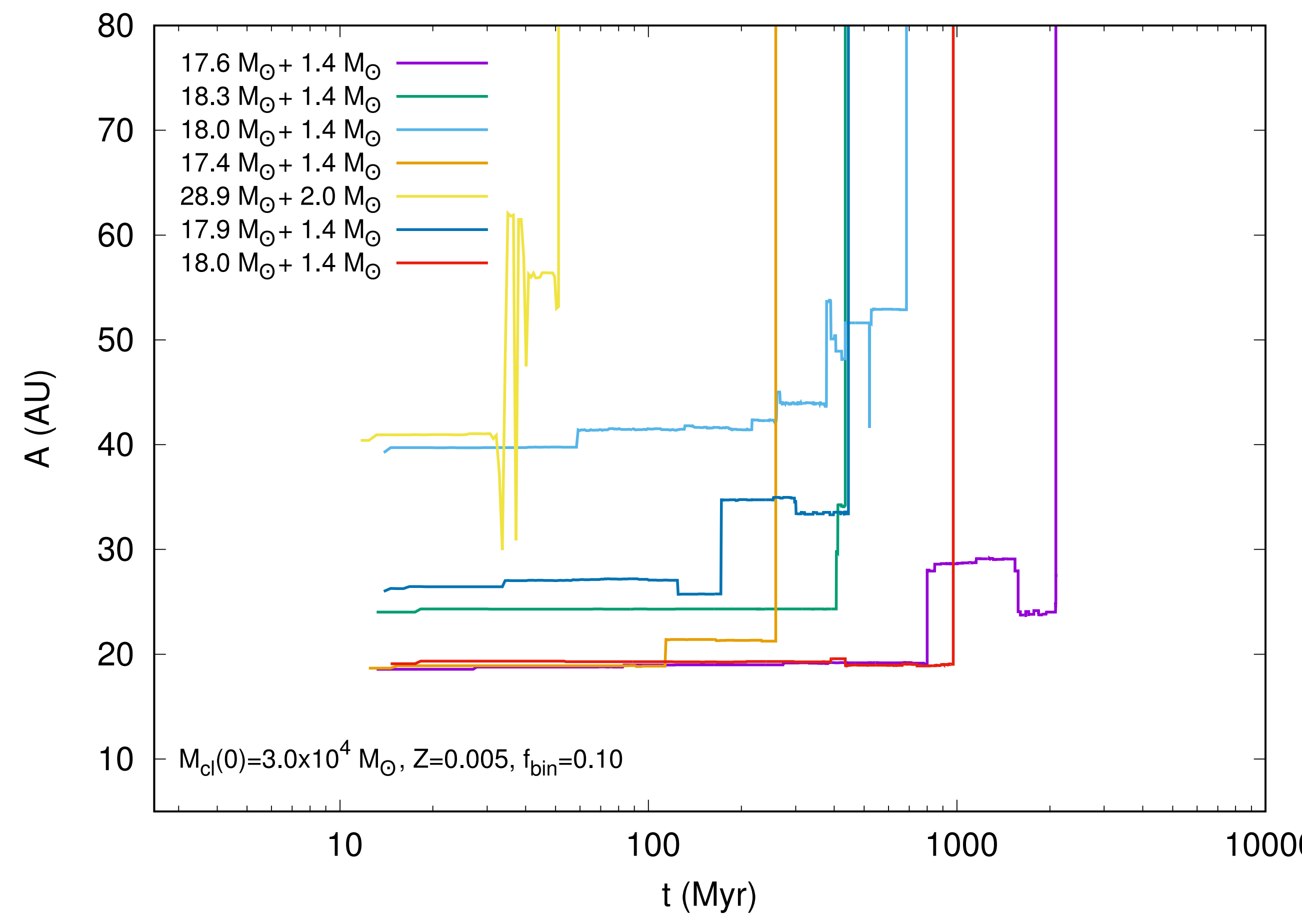




BH retention lifetimes of NS binaries:

NS in a binary gets exchanged by BH in < 1 Gyr





Summary

- In YMCs and open clusters, dynamical BBH coalescences predominantly take place in situ, mediated by triples, rather than among ejected BBHs
- All the coalescing BBHs have been assembled, via exchange interactions, with independently-born BHs (despite massive primordial binaries being present) - given non-zero BH spins, they would be spin-orbit misaligned
- **YMCs and open clusters potentially contribute to the BBH coalescence rate to a similar extent as globular clusters**
- **Energy injection by the BHs into the parent cluster stalls mass segregation, as well of the NSs. NSs are kept from effectively participating in exchange interactions, as long as a dynamically-dominant BH population is present.**
- NS member(s) in a binary would get exchanged with an intruder BH in < 1 Gyr
- **These concern how effective the dynamical formation of NS-containing binaries (e.g., DNS, NS-NS mergers, accreting NS systems) would be as long as a population of BHs exists in a dense stellar system**