Influence of structural properties of clusters on the formation and evolution of black hole binaries

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Overview

Black hole-black hole (BH-BH) binaries are sources gravitational waves (GWs) during inspiral and merger events. With the advent of Advanced Virgo/LIGO it is important to estimate the demography of such promising sources of GWs. We have run N-body simulations of young dense star clusters, with stellar and binary evolution, to investigate the impact of dynamics and metallicity on the formation and evolution of BH-BH binaries (Ziosi et al. 2014). The simulated clusters are dense enough to provide a perfect environment to probe the effect of dynamics on short timescales, while their size makes them suitable for being simulated with direct N-body codes.

Methods

Grid of simulations to test our results against different types of cluster.
Five of the adopted combinations are shown below.
We use a modified version of the public code Starlab (Portegies Zwart et al. 2001) to include up-to-date stellar and binary evolution (Mapelli et al. 2013).

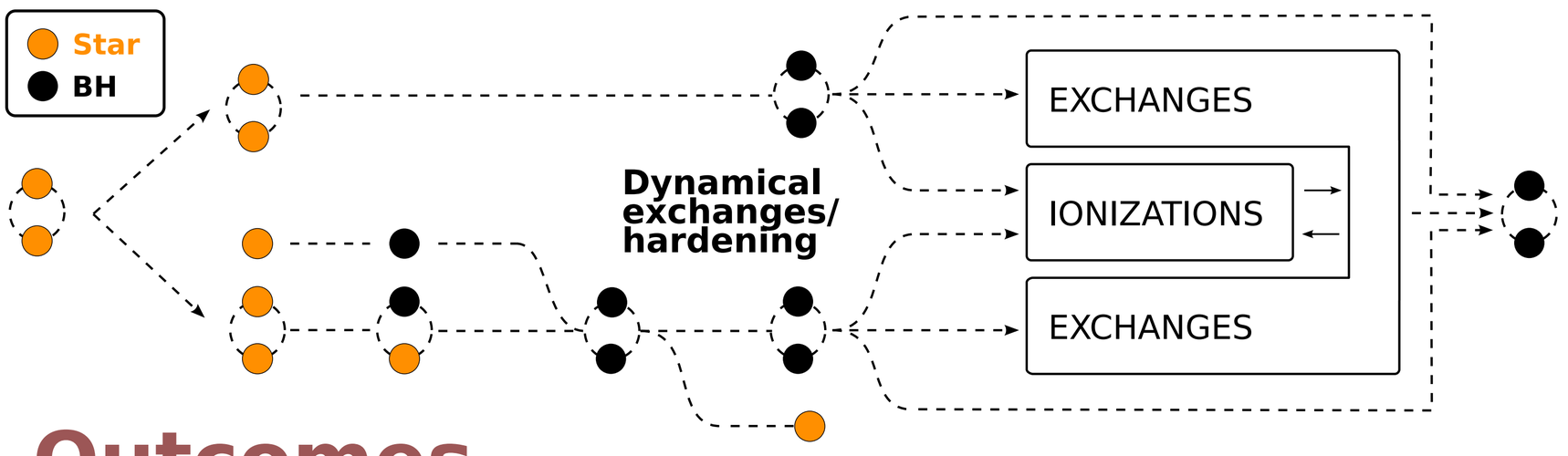
comb.	NCM	fPB	Rv [pc]	W	Z $Z_\odot$
c16	10^4	0.05	1	5	0.1
c19	10^4	0.05	1	9	0.1
c28	10^4	0.05	1	5	1
c56	10^4	0.05	3	9	0.1
c60	10^4	0.1	5	5	1

Details of the parameter combinations shown in the plots below.

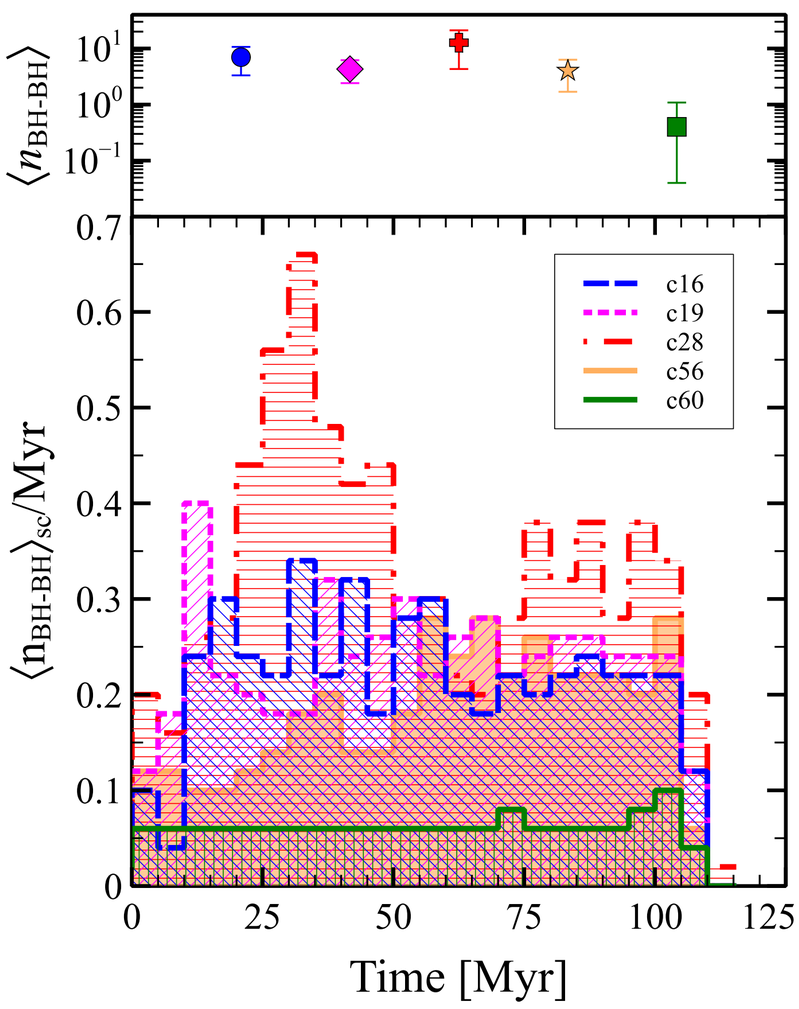
Parameter	Values
W_0	3, 5, 9
N_*	$1\times10^4, 5\times10^4, 1\times10^5, 5\times10^5$
r_v (pc)	1, 3, 5
IMF	Kroupa (2001)
$m_{min} - m_{max}$ ($M_\odot$)	0.1 - 150
Z ($Z_\odot$)	0.1, 1
t_{max} (Myr)	100
f_{PB}	0.05, 0.1, 0.2

Values for the structural parameters we investigate in our grid of simulations (Ziosi et al., in preparation).

Schematic representation of the main formation and evolution pathways of BH-BH binaries in our simulations.



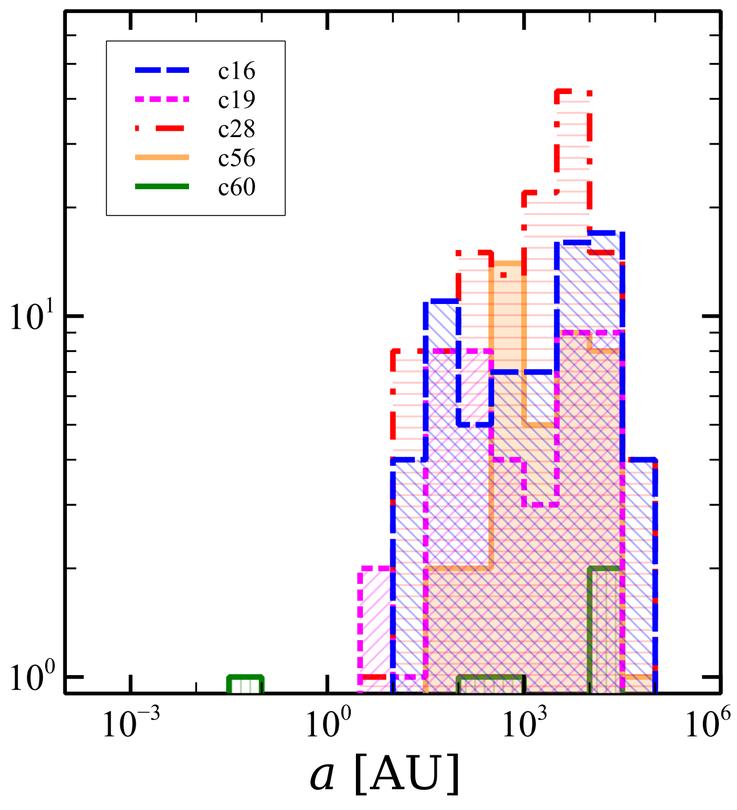
BH-BH population



- **Upper panel**: average number of BH-BH binaries per cluster for different sets of initial structural parameters, integrated over the ~100 Myr duration of the simulations
- **Bottom panel:** averge number of BH-BH binaries per cluster per Myr
- c28 shows a peak PROBABLY due to and intense exchange activity at ~ 25 Myr
- In both the panels c60, the loosest cluster type, has the lowest number of BH-BH binaries

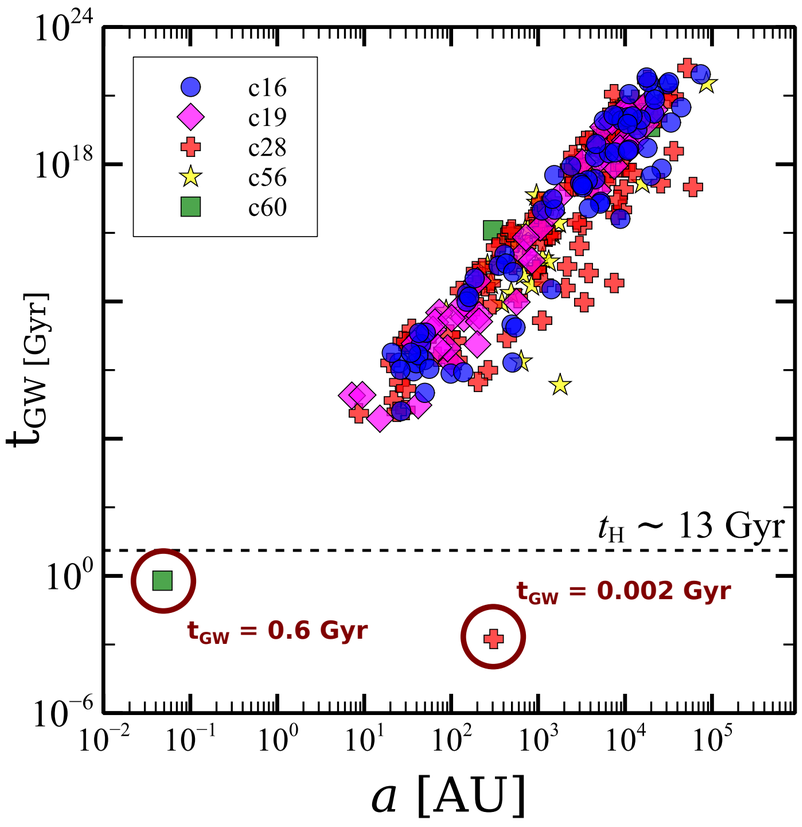
Outcomes

Orbital properties



- Distribution of the minimum semi-major axis of the BH-BH binaries per different initial conditions
- Note the single system, belonging to parameter set c60, with a much smaller semi-major axis
- Distribution of orbital parameters is critical for coalescence timescales and merger detection

Coalescence timescale



- Coalescence timescale (t_{GW}) is the time a system needs to reach semi-major axis a=0 due to orbital decay by GW emission (Peters 1964)
- Only two simulated BH-BH have $t_{GW} < t_H$ (where t_H is the Hubble time), and thus could be important for GW emission
- The system with a~5×10^{-2} AU in c60
- A very eccentric and unstable system in c28 that will break before the end of the simulation

Bibliography

- Ziosi et al., 2014, MNRAS, 441, 3703
- Mapelli et al. 2013, MNRAS, 429, 2298
- Portegies Zwart et al. 2001, MNRAS, 321, 199
- Peters P.C., 1964, Phys. Rev., 136, 1224