# BLACK HOLES BINARIES FROM GLOBULAR CLUSTERS - THE IMPACT OF A CENTRAL IMBH

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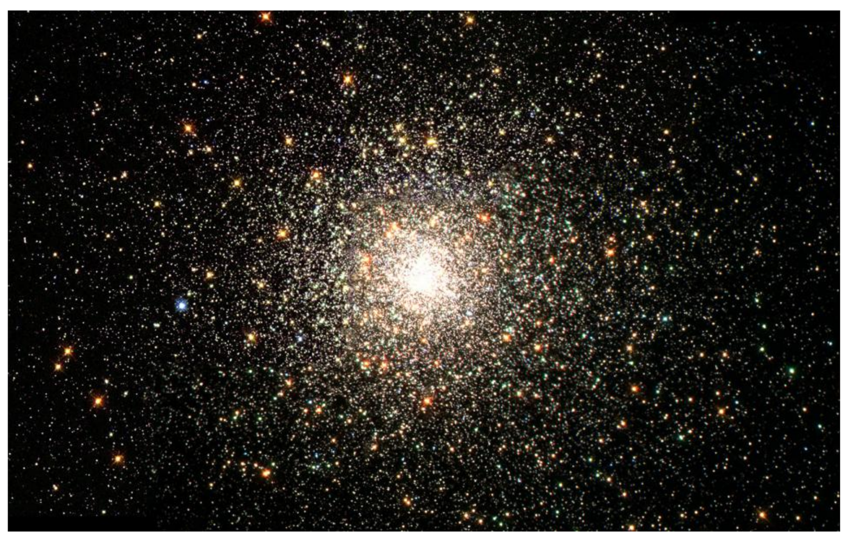
We analyze about a thousand globular cluster (GC) models simulated using the MOCCA Monte Carlo code for star cluster evolution to study black hole - black hole interactions in these dense stellar systems that can lead to gravitational wave emission. We extracted information for all coalescing binary black holes (BBHs) that merge via gravitational radiation from these GC models and for those BHs that collide due to 2-body, 3-body and 4-body dynamical interactions. By obtaining results from a substantial number of realistic star clusters evolution models, that cover different initial parameters (masses, metallicities, densities etc) we have an extremely large statistical sample of two black holes which merge or collide within a Hubble time. We found that creation of an Intermediate Mass Black Hole (IMBH, defined as a BH with mass above 100 $M_\odot$) in a GC's center has large influence on merger and collision rates.

## INTRODUCTION



**Globular Clusters**

- Spherical collection of stars that orbit a galactic core as a satellite.
- Comprise of 100,000 to millions of stars.
- Most of these stars are old Population II (metal-poor) stars.
- Globular clusters in the Milky Way are estimated to be at least 10 billion years old.
- Stars are clumped closely together, especially near the centre of the cluster.

**Importance of Globular Clusters**

- Witnesses of the early Galactic evolution
- Stellar Evolution Laboratories
- Stellar/Galactic Dynamics
- Populations of Peculiar Objects: eg. Stellar Mass Black Holes [15], Intermediate Mass Black Holes.

## METHOD

We use the well tested MOCCA (MOnte Carlo Cluster simulAtor) code ([8, 1]) which follows most of the important physical processes occurring during the dynamical evolution of star clusters. MOCCA includes:

1. synthetic binary stellar evolution using the prescriptions provided by [9] and [10] (BSE code),
2. direct integration procedures for small $N$ subsystems using the FEWBODY code [4],
3. a realistic treatment of escape processes in tidally limited clusters based on [3].

MOCCA has been extensively tested against the results of N-body simulations of star cluster models comprising of thirty thousand to one million stars [5, 7, 12, 13]. The MOCCA-SURVEY Database I cluster models are representative of the GC population [1].

## ACKNOWLEDGEMENTS

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## MERGING BBHS FROM GLOBULAR CLUSTERS

We restricted our analysis to star cluster models in which BH natal kicks were computed according to the mass fallback prescription given by [2]. In order to correctly determine the number of coalescing BBHs from 985 simulation models of MOCCA Survey Database I in which mass fallback was enabled, we specifically searched each simulated model for all BBHs that escape the cluster model and go on to merge within a Hubble time and also for BBHs that merge inside the cluster via GW emission.

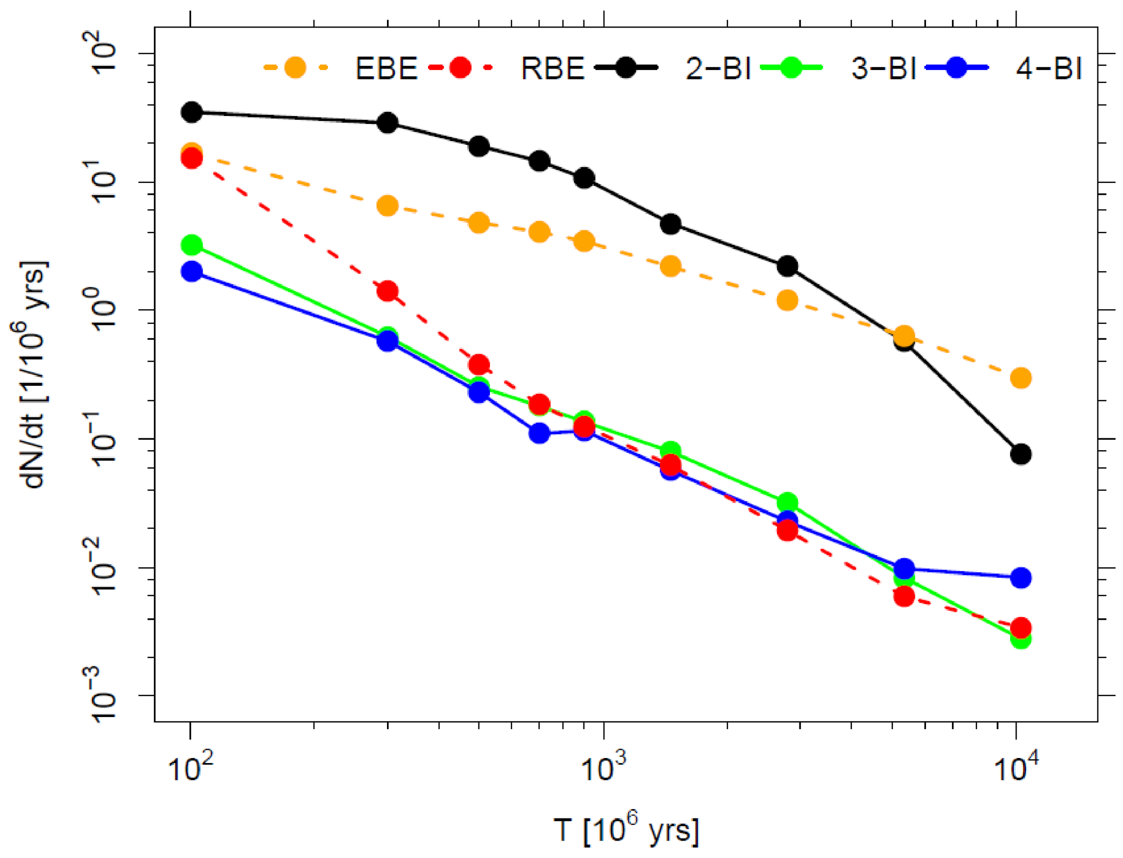


*Figure 1. Number of merging and colliding BBHs per unit time (1Myr), as a function of merger/collision time.*

In the MOCCA code we distinguish five different interactions, which can lead to the emission of *chirp* GW signal due to the coalescence of two black holes in a binary system or to the *burst* GW signal due to the collision of two BHs:

- EBE - Ejected Binary Evolution - a binary systems which, due to interactions in a cluster, gained sufficient velocity to escape the gravitational potential of GC. Such BBH systems evolve in isolation outside GC. This is the interaction that produces the largest number of GW *chirp* signal. Less than 1 % of these binaries contain IMBH, but in the absence of IMBH in the cluster, the number of escaping BBHs falls by about 60%.
- RBE - Retained Binary Evolution - BBH merger due to binary evolution or due to gravitational interaction inside the cluster. Most of these binaries, about 90% merge at early evolution time of the cluster model (up to $5 \times 10^8$ years), when the most massive stars evolve rapidly, there is ongoing mass segregation process and the dynamical interactions are very common. More than 80% of them are binaries, in which none of them is IMBH. As in the case of EBE interactions, the presence of IMBH results in a greater number of coalescence (over 2/3 of found binaries).
- 2-BI - 2-Body Interactions - a collision of two BHs, which is based on a physical collision (the minimum distance is less than the sum of the horizons of both BHs). Such collisions occur only in the clusters where an IMBH was formed, and the collision percentage in which it took part is 99.9%. Such objects have a significant influence on the evolution of the entire cluster.
- 3-BI - 3-Body Interactions - interactions involving three objects - a binary system and a star. In this interaction, as in the case of 2-BI, a dynamical physical collision occurs. These collisions are very rare. Over 97% of them are collisions in clusters with IMBH.
- 4-BI - 4-Body Interactions - interactions involving two binary systems, in which two BHs are colliding. These interactions have properties very similar to 3-BI, but with even less statistics, although more collisions were reported, both quantitatively and in percent, in clusters without IMBH.

## LOCAL RATE DENSITY OF BBH MERGERS

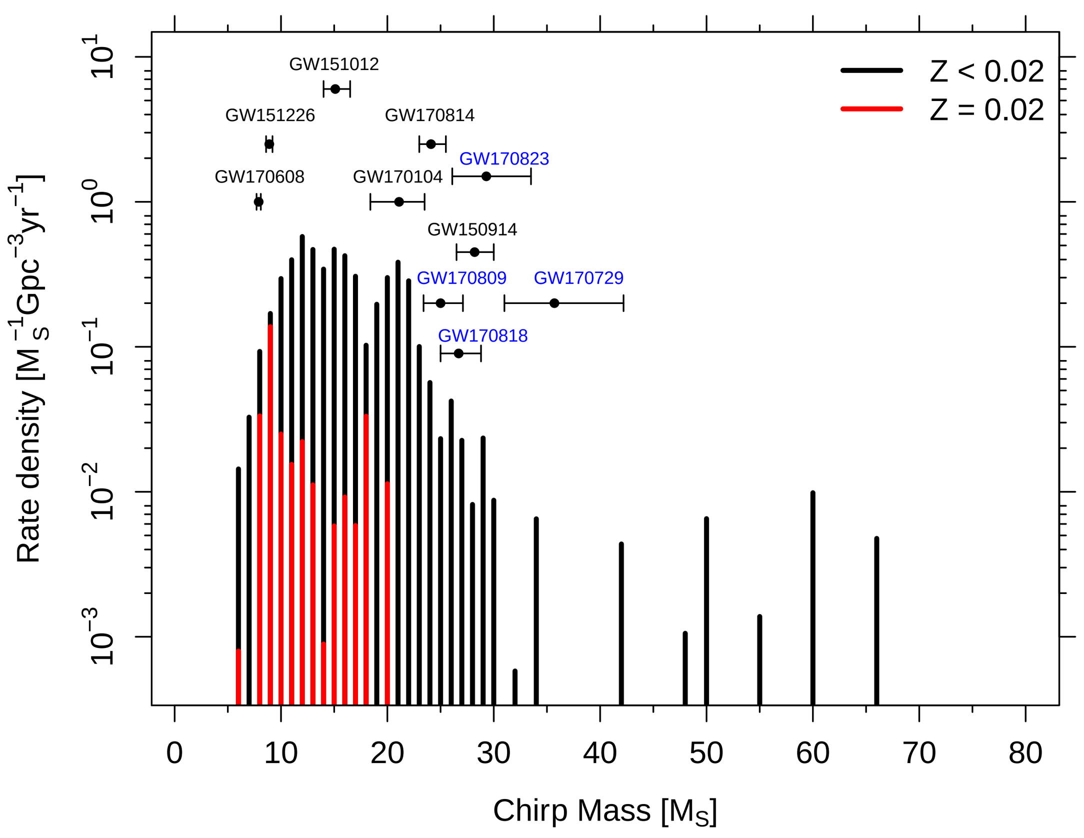


*Figure 2. The differential rate density per unit chirp mass of coalescing BBHs.*

- We find a local merger rate density of at most $30 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- BH masses strongly depend on the initial mass and the stellar evolution (approximate prescriptions provided by SSE/BSE code) of BH progenitors.
- Number of merging BBHs depends on cluster metallicity and initial cluster mass.

## SUMMARY

- Escapers dominate the local merger rate density. Rate of BBHs merging inside the cluster drops significantly within 1Gyr.
- BBH production efficiency depends on initial GC mass and metallicity.
- Merger rate density of BBHs with stellar mass and massive stellar BH components originating from GCs would not be more than $\sim 30~\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
  - Compatible with the lower bound value of the estimated LIGO BBH merger rate density of $9 - 240 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ [11]
- GCs are more efficient at producing BBHs compared to the field - however GC could contain less than 1% mass of a galaxy.
- The creation of an Intermediate Mass Black Hole in a GC's center has large influence on merger and collision rates
- Observed events likely to have different formation histories.

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