631. Wilhelm und Else Heraeus-Seminar: Stellar aggregates over mass and spatial scales
December 5 - 9 2016, Physikzentrum Bad Honnef, Germany

SAPIENZA
UNIVERSITÀ DI ROMA

# Stellar Black Hole Binary Merging in Open Clusters

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**Abstract**

We present the very preliminary results of our ongoing work about the possible merging of stellar black hole binaries (BHB) in Open Clusters. By means of n-body simulations, carried out with NBODY7, we studied the dynamical interactions of a massive BHB placed in the very centre of a low density stellar system (OC). We observed that after few Gyr as the BHB shrinks, the pericenter decreases by a factor up to 90%.

## Introduction

The recent detection of the gravitational waves signal GW150914 by the LIGO/VIRGO collaboration (Abbott B. P., et al., 2016) produced by the merging of two massive (M~29 and M~36 $M_\odot$ ) black holes, provides the first confirmation that such massive systems exist and may coalesce in an Hubble time. Our project, on the basis of this discovery, aims to study the dynamical evolution of a massive (M >25 $M_\odot$ ) stellar black hole binary (BHB) placed in the very center of a stellar cluster . The main goal of this work is to constrain the probability that a BHB merger may occur in a low density environments on reasonable time-scales. We choose an Open Cluster (OC) as the environment in which develop our investigation. Open clusters are young, collisional and dynamically active stellar systems. Most of them dissolve in the disc of the host galaxy in $t < 10^8$ yr. OCs are generally low massive ($M_{Cl} < 10^5 M_\odot$ ) and small (half-mass radius $r_{hm} \leq 1$pc) (Portegies Zwart et al. 2010). In such low density environments the stochastic gravitational collisions between stars are thought to be more efficient with respect to globular clusters (McMillan et al., 2004). In fact the collision rates in massive clusters (like GCs) are considerably smaller than for clusters with smaller relaxation times as in the case of OC (Portegies Zwart & McMillan, 2002). Indeed we expect that all the gravitational collisions between a massive BHB and a sea of less massive particles (the OC environment), will cause the BHB shrinking. This mechanism may lead to the merging of the BHB with releasing of gravitational waves.

## Method

In order to develop our work we made use of direct N-body simulations by means of two codes: **NBODY6** (Aarseth 1999) and **NBODY7** which have been successfully tested for modeling stellar systems on various astrophysical scales. NBODY6 uses the KS (*Kustaanheimo–Stiefel*, Kustaanheimo P., & Stiefel E. 1965) method while NBODY7 made additional use of the Algorithmic Chain Regularization (ARC). In particular the latter allows a complete and reliable treatment of multiple systems that continue to form dynamically in any dense environment, especially of those involving one or more massive objects like BHs (Banerjee, S. 2016). Moreover, a full post-Newtonian treatment is also included (Aarseth, 2012), together with tidal disruption in the ARC procedure (Mikkola & Merritt 2008). A further advantage of these numerical codes is the possibility of exploiting a high computational efficiency running on Graphic Processing Units (GPUs) (Nitadori K., & Aarseth S. J., 2012; Wang et al., 2015). The parallelization on GPU is a great advanced method that reduces the computing time with a ~100 factor. In the case of the N-body simulations, the force between each particles is calculated by all the cores of each GPU and therefore there is a higher parallelization efficiency in a lower computing time.

## Preliminary Results

We ran a set of 200 simulations by using NBODY7 for an evolution time of ≃3 Gyr. The suite of initial conditions selected for the stellar environment is based on observations, while the BHB system is modeled on the basis of the recent LIGO/VIRGO detection. All the initial conditions adopted are summarized in Table **T1**. The stellar environment is a low density isolated open clusters, populated with approximately one thousand stars. In particular the OC is modeled with an uniform sphere and a Kroupa IMF ($M_{max}$=100 $M_\odot$ and $M_{min}$=0.1 $M_\odot$). The OC has an initial mass of about $M_{Cl} \simeq 500\ M_\odot$ and a total radius of ≃1 pc with solar metallicity. The BHB has a total mass of 60 $M_\odot$ with a unitary mass ratio, and an initial separation of ≃ 0.01 pc. In order to improve our investigation we ran 100 simulation considering a BHB with initial circular orbit and 100 with eccentric orbit ($e_i$=0.0 and $e_i$=0.5).

We estimated the variation of the BHB pericenter ($r_p$) for each run according to: $r_p$= a·(1 - e). **Fig. 1** and **Fig. 2** show the distribution of $r_p$ at two evolutionary time t≃1.5 Gyr (**Fig.1a, 2a**) and t≃3 Gyr (**Fig.1b, 2b**), distinguishing between the cases of a circular (**Fig. 1**) and eccentric orbit (**Fig. 2**). In the case of a circular orbit the initial pericenter value is $r_{pi}$=0.01 pc. After 1.5 Gyr a considerable number of simulations show an **average pericenter decrease of 93%**. This result is maintained also after 3 Gyr. This means that the BHB continuously shrinks its semi major axis during the evolution of the stellar cluster. A quite similar result is obtained for an initial eccentric orbit. In this case the initial pericenter value is $r_{pi}$=0.003 pc. After 1.5 Gyr the average **pericenter decreases by a factor up to 85%** which is also more or less the behavior shown at t=3 Gyr. Generally we notice that after an evolution time of few Gyr the tail of the distribution at high pericenter moves to smaller values. These preliminary results support the idea that the gravitational collisions within a stellar cluster may led to the shrinking of the BHB semi major axis. In addition our results suggest that the BHB shrinking may occur soon after few Gyr and that it may be quantitatively significant. In order to improve the quality and the quantity of our results we are going to run additionally set of simulations, varying the initial conditions in order to span a wide range of physical situations.

**Initial Conditions**

| Stellar Cluster | | BHB | |
|---|---|---|---|
| N particles | $10^3$ | Mass | 60 $M_\odot$ |
| Mass | $5\cdot10^2\ M_\odot$ | Mass ratio | $q = M_{BH1}/M_{BH2}=1$ |
| Total radius | 1 pc | Separation | 0.01 pc |
| Density profile | Uniform Sphere | Eccentricity | e=0.0<br>e=0.5 |
| IMF | Kroupa | | |
| Field | isolated Cluster | | |
| Metallicity | $Z/Z_\odot=1$ | | |

**T.1:** Initial conditions chosen for a set of 200 simulations in which we vary the eccentricity of the BHB (circular and eccentric orbit).

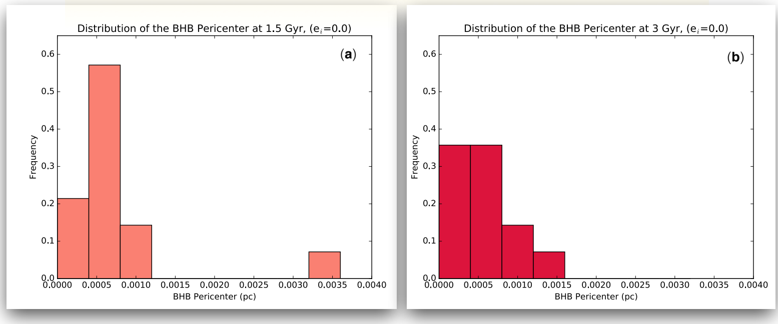


**Fig.1**: Distribution of the BHB pericenter in the case of an initial circular orbit. Panel *(a)* refers to an evolutionary time of t=1.5 Gyr and panel *(b)* refers to t=3 Gyr.

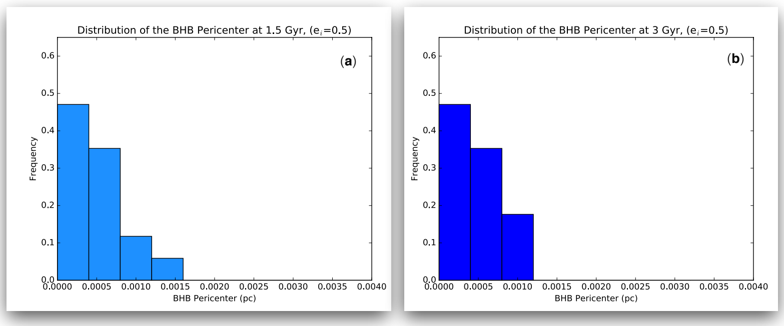


**Fig.2**: Distribution of the BHB pericenter in the case of an initial eccentric orbit. Panel *(a)* refers to an evolutionary time of t=1.5 Gyr and panel *(b)* refers to t=3 Gyr.

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