Eccentric binary black hole mergers in globular clusters hosting intermediate-mass black holes

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ABSTRACT

Globular clusters (GCs) may harbour intermediate-mass black holes (IMBHs) at their centres. In these dynamically active environments stellar-mass black holes (SBHs) sink to the center soon after formation, due to dynamical friction and start interacting among themselves and with the central IMBH. Likely, some of the SBHs will form bound systems with the IMBH. A fraction of those will be triple systems composed of binary SBHs and the IMBH acting as a third distant perturber. If the SBH binary orbit is sufficiently inclined it can develop Lidov-Kozai (LK) oscillations, which can drive the system to high eccentricities and eventually to a merger due to gravitational wave (GW) emission on short timescales. In this work, we focus on the dynamics of the IMBH-SBH-SBH triples and illustrate that these systems can be possible sources of GWs. A distinctive signature of this scenario is that a considerable fraction of these mergers are highly eccentric when entering the LIGO band (10 Hz). Assuming that \( \sim 20\% \) of GCs host IMBHs and a GC density in the range \( n_{GC} = 0.32-2.31 \text{ Mpc}^{-3} \), we have estimated a rate \( \Gamma = 0.06-0.46 \text{ Gpc}^{-3} \text{ yr}^{-1} \) of these events. This suggests that dynamically-driven binary BH mergers in this scenario could contribute a non negligible fraction to the merger events observed by LIGO/VIRGO. Full \textit{N}-body simulations of GCs harbouring IMBHs are highly desirable to give a more precise constrain on this scenario.

Key words: Galaxy: centre – Galaxy: kinematics and dynamics – stars: black holes – stars: kinematics and dynamics – galaxies: star clusters: general

1 INTRODUCTION

Black holes are divided into three categories according to their masses. (i) Stellar-mass black holes (SBHs) with typical masses of \( 10 M_\odot \lesssim M \lesssim 100 M_\odot \), are the remnants of massive stars. To present day, 20 SBHs in merging binaries have been observed by the LIGO-Virgo collaboration (The LIGO Scientific Collaboration & the Virgo Collaboration \textit{2018}). (ii) Supermassive black holes (SMBHs) having masses \( M \gtrsim 10^5 M_\odot \), reside in the centres of galaxies and shape the surrounding gas and the stellar distributions (Kormendy & Ho \textit{2013}; Alexander \textit{2017}). (iii) Intermediate-mass black holes (IMBHs) with masses \( 10^2 M_\odot \lesssim M \lesssim 10^5 M_\odot \), which have been postulated to form through several mechanisms (e.g. Portegies Zwart \& McMillan \textit{2002}; McKernan \textit{et al.} \textit{2012}; Giersz \textit{et al.} \textit{2015}). Though we still lack a concrete proof of their existence, a recent observation of a tidal disruption event in an off-centre stellar cluster, consistent with an IMBH of \( \sim 5 \times 10^4 M_\odot \), provides a strong supporting evidence of their existence (Lin \textit{et al.} \textit{2018}).

A natural place for IMBHs to reside is at the core of globular clusters (GCs), if the \( M-\sigma \) relation observed in SMBHs is valid also in the IMBHs mass range (Portegies Zwart \textit{et al.} \textit{2004}; Merritt \textit{2013}; Fragione \textit{et al.} \textit{2018}). Galactic nuclei may host IMBHs as well, possibly delivered by inspiraling stellar clusters (Mastrobuono-Battisti, Perets \& Loeb \textit{2014}; Arca-Sedda \& Gualandris \textit{2018}; Fragione, Leigh, Ginsburg \& Kocsis \textit{2018}) or formed \textit{in-situ} (McKernan \textit{et al.} \textit{2012}). They may merge with SBHs via gravitational waves (GWs) emission, as intermediate-mass ratio inspirals (IM-RI) (Fragione \& Leigh \textit{2018}).

Several attempts have been made in modeling the dynamics of GCs hosting IMBHs through direct \textit{N}-body simulations (Baumgardt \textit{et al.} \textit{2005}; Lützgendorf \textit{et al.} \textit{2013}; Leigh \textit{et al.} \textit{2014}; Baumgardt \textit{2017}). These simulations rarely include self-consistently the angular momentum and gravitational energy losses via GWs emission (Konstantinidis \textit{et al.} \textit{2013}; Haster \textit{et al.} \textit{2016}; MacLeod \textit{et al.} \textit{2016}). Moreover, a large initial population of binaries have been

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proven hard to simulate with $N$-body models, in particular when dealing with massive clusters and massive IMBHs (Trenti et al. 2007; Šubr et al. 2019).

Previous studies have focused on understanding the properties and the rates of IMRIs in GCs, as one of the most promising sources of GWs in the LISA band frequencies (e.g. Mandel & Gair 2009; Miller 2009; Amaro-Seoane 2018). Mandel et al. (2008) discussed the possibility that IMBH-SBH binaries may merge as a consequence of cumulative interactions with other stars in the cluster, or due to Lidov-Kozai (LK) oscillations whenever a third body is bounded to the IMBH-SBH binary. Recently, Fragione, Ginsburg & Kocsis (2018) and Fragione, Leigh, Ginsburg & Kocsis (2018) used a semi-analytic approach to calculate cosmological rates of IMRIs in an evolving population of GCs.

GCs are favorable locations for merger of binary SBHs, which should be quite abundant in such dense stellar environments. If a SBH binary (SBHB) forms a bound system with the IMBH, its eccentricity and inclination can oscillate due to the LK mechanism whenever the initial SBHB orbit is sufficiently inclined (Lidov 1962; Kozai 1962), similarly to what happens in galactic nuclei (Antonini & Perets 2012; Fragione et al. 2018; Grishin et al. 2018; Hoang et al. 2018). If the number of binary SBH interacting with the IMBH, is large enough, the IMBH-SBH scenario may contribute to the overall SBH merger rate predicted by other channels, which is estimated to be in the range $0.1–100$ Gpc$^{-3}$ yr$^{-1}$ (Belczynski et al. 2006; Antonini et al. 2017; Askar et al. 2017; Banerjee 2018; Giacobbo & Mapelli 2018; Rodriguez et al. 2018; Sanders et al. 2018; Fragione & Kocsis 2018).

In this paper, we discuss the dynamics of triple systems made up of the central IMBH and a SBHB (see Figure 1). We show that the SBHB can undergo repeated LK oscillations during which its eccentricity becomes as large as unity. The SBHB will merge soon after formation, due to efficient dissipation via GW emission at pericenter. We sample different distribution masses of the SBH population, calculate the merger fraction and deduce merger rates for different IMBH masses.

The paper is organized as follows. In Section 2, we discuss the properties and dynamics of SBHs in the core of GCs harbouring IMBHs. In Section 3, we present our numerical methods to determine the rate of IMBH-induced SBHB mergers and discuss the results. Finally, in Section 4, we discuss the implications of our findings, compare them to a similar scenario in galactic nuclei, and draw our conclusions.

## 2 DYNAMICS OF STELLAR BLACK HOLES NEAR AN INTERMEDIATE-MASS BLACK HOLE

Soon after the cluster is created, massive stars collapse and form SBHs with masses that depend on the progenitors masses and metallicities (Belczynski et al. 2016; Giacobbo & Mapelli 2018). Assuming a canonical Kroupa (2001) initial mass function, the number of SBHs is roughly proportional to the initial cluster mass with a coefficient

$$N_{\text{SBH}} \approx 3 \times 10^{-3} \frac{M_{\text{GC}}}{M_\odot} .$$

The SBHs segregate towards the GC center on a dynamical friction timescale of (Binney & Tremaine 1987)

$$t_{\text{seg}} \approx \frac{\bar{m}}{M_{\text{SBH}}} t_{\text{fr}} ,$$

where $\bar{m}$ and $M_{\text{SBH}}$ are the average stellar mass and SBH mass respectively and $t_{\text{fr}}$ is the half-mass relaxation time:

$$t_{\text{fr}} = 54 \left( \frac{N}{10^6} \right)^{1/2} \left( \frac{r_h}{1 \text{ pc}} \right)^{3/2} \left( \frac{1 M_\odot}{\bar{m}} \right) \text{ Myr} .$$

The SBHs segregate towards the GC center on a dynamical timescale of $t_{\text{seg}} \sim 10^8$ yr.

Traditionally the segregated SBHs were thought to be decoupled from the rest of the cluster. They were postulated to undergo strong gravitational interactions with each other which lead to their ejection out of the cluster (Spitzer 1969). In practice the SBH sub-system is only partially decoupled from the cluster. Recent Monte-Carlo simulations by Morscher et al. (2013) have found no evidence for the classical Spitzer instability, with only the innermost few tens of SBHs segregating significantly, while the majority remaining well mixed with the rest of the cluster. As a consequence, fewer than $\sim 50\%$ of the SBHs ($\sim 20-25\%$ of which are in binaries) will be ejected due to dynamical interactions at the cluster core.

In stellar clusters hosting IMBHs, typically one of the segregated SBHs forms a bound pair with the central IMBH. Using $N$-body simulations, Leigh et al. (2014) showed that the formation time for such a pair $\lesssim 100$ Myr, for clusters of masses $2.0 \times 10^4 M_\odot$–$8.0 \times 10^4 M_\odot$. Generally, the IMBH captures SBHs via the two-body capture process by gravitational radiation on a timescale (Miller 2002)

$$t_{2,\text{cap}} = 50 \left( \frac{10^6 \text{ pc}^{-3}}{n} \right) \left( \frac{10 M_\odot}{M_{\text{SBH}}} \right)^{11/7} \times \left( \frac{100 M_\odot}{M_{\text{IMBH}}} \right)^{12/7} \left( \frac{\sigma_1}{10 \text{ km s}^{-1}} \right)^{11/7} \text{ Myr} ,$$

![Figure 1. The three-body system studied in the present work.](image-url)
and from three-body encounters on a timescale (Miller 2002)
\[
\tau_{3,\text{enc}} = 5 \left( \frac{100 \, M_\odot}{M_{\text{IMBH}}} \right) \left( \frac{10^6 \, \text{pc}^{-3}}{n} \right) \text{Myr}.
\] (5)

In the above equations, \( n \) is the stellar number density, \( \sigma_d \) their velocity dispersion, and \( M_{\text{IMBH}} \) and \( M_{\text{SBH}} \) are the masses of the IMBH and SBH, respectively. Shortly after formation, the IMBH-SBH binary usually has a very high eccentricity, which leads to a decrease of the semi-major axis due to dynamical friction. Later, the binary interacts with ambient stars and compact objects via scattering slingshots at the typical hardening radius (Merritt 2013)
\[
a_h = \frac{M_{\text{SBH}}}{M_{\text{IMBH}} + M_{\text{SBH}}} \frac{r_{\text{inf}}}{4},
\] (6)
where \( r_{\text{inf}} = GM_{\text{IMBH}}/\sigma_d^2 \) is the influence radius of the IMBH. Typically, \( a_h \) ranges from a few AU in the most massive clusters to a few hundreds AU in the lightest ones, which have smaller velocity dispersions and less massive IMBHs.

As the IMBH-SBH binary hardens and the semi-major axis decreases, it becomes comparable to the typical radius over which gravitational radiation becomes important: (Haster et al. 2016)
\[
a_{\text{GW}} \approx \frac{0.1 \text{AU}}{(1 - e^2)^{7/10}} \left( \frac{M_{\text{IMBH}}}{10^4 \, M_\odot} \right)^{1/5} \left( \frac{M_{\text{SBH}}}{10 \, M_\odot} \right)^{1/5} \times \frac{\sigma_d}{10 \, \text{kms}^{-1}} \left( \frac{10^5 \, \text{pc}^{-3}}{n_c} \right)^{1/5}.
\] (7)

The typical time to the next interaction falls below the GW timescale. Thus the IMBH-SBH merge within a Peters (1964) timescale
\[
T_{\text{GW}} = \frac{3}{85} \frac{G^3 a_{\text{GW}}^4 e^5}{M_{\text{IMBH}} M_{\text{SBH}} M} (1 - e^2)^{7/2},
\] (8)
where \( a \) and \( e \) are the binary semi-major axis and eccentricity, respectively, and \( M = M_{\text{IMBH}} + M_{\text{SBH}} \). Using N-body simulations, Leigh et al. (2014) showed that \( T_{\text{GW}} \) is typically at the range \( \sim 10^5 - 10^6 \) yr. If this happens and the merger product is not ejected due to GW recoil kick (Holley-Bockelmann, Gültekin, Shoemaker & Yunes 2008; Konstantinidis, Amaro-Seoane & Kokkotas 2013; Fragione, Ginsburg & Kocsis 2018; Fragione, Leigh, Ginsburg & Kocsis 2018), it will capture another SBH, commonly less massive than the previous one, and the new-born binary will undergo the dynamical phases previously described.

SBHBs are frequently formed in the core of the cluster due to the high stellar density there. Since they are more massive than single SBHs, they sink more rapidly (see Eq. 2) and eventually form bound triple systems with the central IMBH. This process takes place on a typical timescale \( \tau_{z_2,\text{cap}}/\eta \), where \( \eta \) is the fraction of SBHBs in binaries. If the SBHB orbits the IMBH in a plane with inclination \( i_0 \sim 40^\circ - 140^\circ \) with respect to the SBHB inner orbital plane, Lidov-Kozai (LK) cycles can influence the SBHB dynamics (Lidov 1962; Kozai 1962). In this scenario, the SBHB eccentricity oscillates on a typical timescale (Antognini 2015; Naoz 2016)
\[
T_{\text{LK}} = \frac{8}{15\pi} \frac{m_{\text{tot}}}{M_{\text{IMBH}}} \frac{P_{\text{IMBH}}^2}{P_{\text{SBH}}} (1 - e_{\text{out}}^2)^{3/2},
\] (9)
where \( m_{\text{tot}} = m_1 + m_2 + M_{\text{IMBH}} \), and \( P_{\text{IMBH}} \) and \( P_{\text{SBH}} \) are the orbital periods of the inner and outer orbits, respectively. Assuming \( m_1 = m_2 = 10 \, M_\odot \), \( M_{\text{IMBH}} = 10^3 \, M_\odot \), \( a_{\text{in}} = 1 \) AU and \( a_{\text{out}} = 100 \, \text{AU} \), \( T_{\text{LK}} \approx 10^2 \) yr. At the quadruple order of approximation, the maximal eccentricity is simply a function of the initial mutual inclination
\[
e_{\text{in}} = \sqrt{\frac{1}{3} \frac{5}{3} \cos i_0}.
\] (10)

which approaches unity as \( i_0 \) approaches \( \sim 90^\circ \). In some configurations, LK cycles can be suppressed by relativistic precession (Naoz 2016), which operates on a timescale
\[
T_{\text{GR}} = \frac{a_{\text{in}}^{5/2} e_{\text{in}}^2 (1 - e_{\text{in}}^2)}{3G^{5/2} (m_1 + m_2)^{3/2}}.
\] (11)

Assuming \( m_1 = m_2 = 10 \, M_\odot \), \( M_{\text{IMBH}} = 10^3 \, M_\odot \), \( a_{\text{in}} = 1 \) AU and \( a_{\text{out}} = 100 \, \text{AU} \), \( T_{\text{GR}} \approx 6 \times 10^4 \) yr. In the region of the parameter space where \( T_{\text{LK}} > T_{\text{GR}} \), the LK oscillations of the SBHB orbital elements are damped by relativistic effects.

Compared to the case the IMBH forms a binary system with a single SBH, the evolution of an IMBH-SBHB is dynamically rich (Chen & Han 2018). The large eccentricity values reached by the SBHB make its nominal Peters’ merger time (Eq. 8) shorter, since it efficiently dissipates energy when \( e \sim e_{\text{in}} \) (e.g., see Antonini & Perets 2012). Eventually, the SBHB binary is lead to a merger as a consequence of the GW radiation emitted at the pericenter. Even if the binary does not merge, it may appear in the the LISA frequency band and can be observed with a large enough signal-to-noise ratio (Randall & Xianyu 2019), thus possibly revealing the presence of the IMBH.

The overall process that leads to the formation of a triple IMBH-SBHB depends mainly on the IMBH mass and on the core density of the host cluster, thus ultimately on the cluster mass if the IMBH mass correlates with it (Portegies Zwart & McMillan 2002). As discussed, the formation of an IMBH-SBHB triple occurs on a timescale \( \tau_{z_2,\text{cap}}/\eta \), which is of the order of a few Myrs for typical GC parameters. Thus, the SBHB can be driven to merge by tidal interactions in the LK regime with the IMBH, before the binary orbit is perturbed by other SBHs and stars (Leigh & Sills 2011) and before the IMBH interacts with different single or binary SBHs.

In the next Section, we consider IMBH-SBHB triples formed through the processes described above. We integrate their equation of motions to quantify the fraction of mergers, and give an estimate of the possible SBH merger rate from this channel.

3 NUMERICAL SIMULATIONS OF STELLAR BLACK HOLE MERGERS

To illustrate the efficiency of the IMBH-SBHB mechanism and to examine its dependence on the cluster properties, we perform high-precision N-body simulations of the dynamics of the triplet in GCs with various central IMBHs and background stellar cusp objects. The properties of the stellar cusp will determine the typical time for the triplet to have strong interactions with a cusp object. We therefore set the total integration time to be the minimum between \( \tau_{z_2,\text{cap}} \) and \( \tau_{3,\text{enc}} \), an order of a few Myr. The simulations are performed with the ARCHAIN code (Mikkola & Merritt 2006, 2008). ARCHAIN is a fully regularized code able to model the
The evolution of systems of arbitrary masses, radii and eccentricities with extreme accuracy and includes Post-Newtonian corrections up to order PN2.5.

We consider three different masses for the IMBH: $M_{\text{IMBH}} = 10^3 M_{\odot}, 10^4 M_{\odot}, 10^5 M_{\odot}$. Stars and compact objects tend to form a power-law density cusp ($n(r) \propto r^{-\alpha}$) around an IMBH similar to galactic nuclei, where lighter (heavier) objects develop shallower (steeper) cusps (Bahcall & Wolf 1976). Typically, stars tend to have $\alpha \sim 1.5-1.75$, while SBHs $\alpha \sim 2-3$ as a result of mass segregation (Alexander 2017; Baumgardt et al. 2018). Therefore, we assume that the background SBH number density follows a power-law distribution ($n \propto M^{-\beta}$). We take the maximum outer semimajor axis to be $0.1 \times (M_{\text{IMBH}}/4 \times 10^6 M_{\odot})^{5/9}$ pc (Hoang et al. 2018).

We choose a negative power-law distribution for the SBH mass

$$\frac{dN}{dM} \propto M^{-\beta}$$

in the mass range $5 M_{\odot} - 100 M_{\odot}$ (Hoang et al. 2018) and study how the results depend on the slope $\beta$ by running models with $\beta = 1, 2, 3, 4$ (O’Leary et al. 2016).

We assume that the distribution of the semi-major axes of the SBH binaries is flat in log-space (Öpik’s law), while the inner and outer eccentricities are drawn from a thermal distribution (Jeans 1919). The initial inclination $i_0$ between the plane of the SBHB and the pair’s orbital plane around the IMBH is sampled from an isotropic distribution (i.e. uniform in cos i). The other relevant angles are drawn randomly.

After we sample from the relevant distributions, we check that the Mardling & Aarseth (2001) criterion

$$\frac{R_{\text{in}}}{a_{\text{in}}} \geq 2.8 \left( \frac{1 + \frac{M_{\text{IMBH}}}{m_1 + m_2}}{1 + \frac{1 + e_{\text{out}}}{1 - e_{\text{out}}} - \frac{1}{2}} \right)^{2/7} \left( 1.0 - 0.3 \frac{i_0}{90} \right),$$

is satisfied, where $R_{\text{in}}$ is the pericenter of the outer orbit. If the system is stable, we start the integration, otherwise we sample again the relevant parameters of the triple.

An SBHB is expected to be significantly perturbed by the tidal field of the IMBH whenever their mutual orbit is sufficiently inclined with respect to the orbital plane around the IMBH, $i_0 \sim 40^\circ-140^\circ$ (Lidov 1962; Kozai 1962). According to Eq. 10, the SBHB eccentricity reaches almost unity when $i_0 \sim 90^\circ$. Figure 2 shows the probability distribution function (PDF) of the initial binary plane inclination angle in those systems, which ended up in a merger. The distributions are shown for SBHs orbiting a $1 \times 10^3 M_{\odot}$ IMBH, having different values of $\beta$ and $\alpha = 2$. Independently of the slope of the SBH mass function, the majority of the mergers take place when the initial inclination is $\sim 90^\circ$. In this case the LK effect is maximal, leading to eccentricity oscillates up to unity. The SBHB experiences rapid gravitational energy loss due efficient energy dissipation near the pericentre, which ends in a merger.

The slope of the SBH mass function, $\beta$, is largely unknown. To understand the effect it has on the masses of the SBHBSs that undergo mergers we study four different slopes. Fig. 3 illustrates the mass distribution function of merging SBHs orbiting an $1 \times 10^3 M_{\odot}$ IMBH, for different values of $\beta$.

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1 Recent theoretical results on pulsational pair instability limit the maximum mass to $\sim 50 M_{\odot}$ (Belczynski et al. 2016).
and $\alpha = 2$. Initial mass function with steeper slopes (larger $\beta$’s) lead to smaller masses of the merging SBHs, while shallower SBH mass functions (smaller $\beta$’s) favours more massive SBHs. We find that 90% of the mergers have total masses smaller $\sim 100 M_\odot$, $\sim 40 M_\odot$, $\sim 30 M_\odot$, $\sim 15 M_\odot$ for $\beta = 1$, $\beta = 2$, $\beta = 3$, $\beta = 4$, respectively.

In Figure 4 (top panel), we report the cumulative distribution function (CDF) of merging SBHs outer orbits as a function of the mass of the IMBH for $M_{\text{IMBH}} = 10^3 M_\odot$ and different values of $\beta$ and $\alpha$. We find that if the slope of the SBH cusp is shallower (smaller $\alpha$’s), SBHB merge at larger semi-major axes with respect to the orbit around the IMBH, on average. Additionally, the mass of the IMBH also affects the typical $a_{\text{out}}$ at which the SBHBs merge. Figure 4 (bottom panel) shows the CDF of merging SBHBs outer orbits as a function of the IMBH mass for $\beta = 1$ and $\alpha = 2$. SBHB merge typically closer to lighter IMBHs than heavier IMBHs. Lighter IMBHs have smaller influence spheres and SBHB have to be closer in order to avoid evaporation due to the interaction of surrounding stars and compact objects before merging due GW emission induced by LK oscillations.

SBHB in hierarchical configurations like IMBH-SBHB

Figure 4. Cumulative distribution functions of merging SBHBs outer orbits as a function of the slope of the SBHB cusp for $M_{\text{IMBH}} = 10^3 M_\odot$ and $\beta = 1$ (top panel) and as a function of the IMBH mass for $\beta = 1$ and $\alpha = 2$ (bottom panel).

are expected to have large eccentricities in the LIGO frequency band (10 Hz), as a consequence of the perturbation by the third body and the LK cycles (see e.g. Fragione et al. 2018). For the SBHBs that merge in our simulations, we compute a proxy to the GWs frequency, which we take to be the frequency corresponding to the harmonic that gives the maximal emission of GWs (Wen 2003)

$$f_{GW} = \frac{\sqrt{G(m_1 + m_2)}}{\pi} \left[ \frac{1 + e_{\text{in}}}{a_{\text{in}}(1 - e_{\text{in}}^2)^{1.5}} \right].$$  \hspace{1cm} (14)

In Figure 5, we illustrate the distribution of eccentricities at the moment the BH binaries enter the LIGO frequency band. We show results for mergers produced by SBHB with $M_{\text{IMBH}} = 10^3 M_\odot$ and different values of $\beta$ and $\alpha$. SBHBs that merge through this channel have larger eccentricities than those formed through other channels, like mergers of isolated binaries or of SBHBs ejected from stellar clusters (Belczynski et al. 2008; Fragione & Kocsis 2018; Rodriguez et al. 2018). Note that, mergers that follow from the GW capture scenario in clusters (Zevin et al. 2018) and from hierarchical triples and quadruples (Antonini et al. 2017; Fragione & Kocsis 2019) also present a similar shape and a similar peak at high eccentricities. We also show a vertical line at the level $e_{\text{LIGO}} = 0.081$ where LIGO/VIRGO can start to detect sources (Gondán & Kocsis 2019). Thus, highly-eccentric mergers might be an imprint of SBHBs that merge through this channel and can thus reveal the presence of an IMBH.

### 4 DISCUSSION AND CONCLUSIONS

GCs may harbour IMBHs in their centres. In such a dynamical active environment, SBHs sink to the center soon after formation, due to dynamical friction and start interacting among themselves and with the central IMBH. Likely, some of these SBHs will form bound systems with the IMBH. If some of these SBHs are in binaries, the system they form with the IMBH is actually a triple, where the IMBH act as...
a third distant perturber. If the SBHB orbit is sufficiently inclined, it can develop LK oscillations which can drive the system to high eccentricities and merge due to GW emission on short timescales.

In this paper, we focus on the dynamics of IMBH-SBHB systems, that can form in cores of GCs. We illustrate how the LK mechanism operates in such a system. We consider different IMBH masses, adopting a mass spectrum for the BHs, and study different spatial distributions for the SBHB binaries. We show that the majority of systems merge when the SBHB orbital plane is initially inclined at \( \sim 90^\circ \) with respect to the orbit of the SBHB around the IMBH, independent of the SBHB mass function slope, \( \beta \). However, \( \beta \) controls the mass distribution of the merging SBHs, while the IMBH mass and the slope of the SBH cusp distribution (\( \alpha \)) control the distribution of the semi-major axis of merging SBHBs. A distinctive signature of this scenario is that a considerable fraction of mergers is highly eccentric when entering the LIGO band.

Although we still lacking confirmed evidence, GCs hosting IMBH should not be rare. Giersz et al. (2015) found that the fraction of clusters that may host an IMBH can be as high as \( \sim 20\% \). To accurately determine the global BH merger rate from this channel, we would need to quantify the population of SBHBs that orbit an IMBH in GCs. A precise answer to this question would require running numerous N-body models of GCs harbouring IMBHs, which is beyond the scope of the present paper. We can use the simulations we have run in this work as a proxy for inferring an order of magnitude estimation to the merger rate of SBHBs interacting with IMBHs. In the last column of Table 1, we report the fraction of SBHB that merge in our simulations. Typically, it lies in the range \( \sim 1-4\% \), with higher fractions for more massive IMBHs and steeper cusp densities. Assuming that 20\% of GCs host IMBHs, a GC density of \( 10\% \), we find a rate \( \Gamma = 0 \). McMillan 2000; Rodriguez et al. 2015), and a SBHB fraction in the range \( 1–4\% \), with higher fractions for more massive IMBHs and steeper cusp densities.

A similar mechanism to the one studied here, has shown to occur at galaxies centers, where the SBHB interact with the SMBH (Antonini & Perets 2012; Fragione et al. 2018; Hamers et al. 2018; Hoang et al. 2018). The estimated rates are of the same order of magnitude, however their location in the host galaxy will be different. While the SBHB mergers driven by SMBHs will appear at the center of the galaxies, IMBH driven mergers will occur predominantly at the galactic bulges and halos. Thus, if given a good enough localization these events can be disentangled. Finally, we note that while neutron star-neutron star (NS) mergers can happen through the same process near SMBHs, this should be uncommon in GCs harbouring IMBHs, where NSs are likely ejected due to birth kicks and interactions with SBHs (Fragione et al. 2018), thus preventing the formation of IMBH-NS-NS triplets.

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