Dynamical Evolution of Dense Stellar Systems
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Tracing Intermediate-Mass Black Holes in the Galactic Centre

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Abstract. We have developed a new method for post-Newtonian, high-precision integration of stellar systems containing a super-massive black hole (SMBH), splitting the forces on a particle between a dominant central force and perturbations. We used this method to perform fully collisional N-body simulations of inspiralling intermediate-mass black holes (IMBHs) in the centre of the Milky Way.

Keywords. Galaxy: centre, methods: n-body simulations, black hole physics, stellar dynamics

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Most massive galaxies are now believed to host SMBHs. While such SMBHs have been directly observed as radio sources and compact massive objects, the existence of IMBHs with masses $10^2\,M_\odot < M_{\rm IMBH} < 10^4\,M_\odot$ is still a matter of debate.

In this work, we present new results on the inspiral of IMBHs, using a novel method for studying the dynamics of Galactic-centre-like systems where stars orbit a central SMBH on weakly perturbed Keplerian orbits.

1. Integration Method

The basic idea for our new method is to split the force calculation between the dominating central force (exerted by the SMBH) and the perturbing forces (due to the cluster stars). It is comparable to the so-called *mixed variable symplectic* methods (*MVS*, Wisdom & Holman 1991), as it makes use of Kepler's equation to integrate along the orbit. However, our method is not symplectic, as it is based on the Hermite scheme to allow for large N, close encounters, and use of the *GRAPE* special-purpose hardware.

For a given average number of steps per orbit, our method is almost a factor of 100 more accurate than the standard Hermite method, as it does not accumulate an error in the orbital motion around the SMBH. To account for relativistic effects, we extend our integration method by post-Newtonian correction terms.

2. IMBH inspiral

Theoretical arguments and N-body simulations have shown that a stellar system around a SMBH evolves into a cusp with an $\alpha = 1.75$ power-law density distribution (Bahcall & Wolf 1976; Baumgardt et al. 2004a,b).

Following the results of Baumgardt et al. (2006), we started our calculations with a $10^3\,M_\odot$ IMBH on a circular orbit around a $3 \cdot 10^6\,M_\odot$ SMBH with semi-major axis $a_{\rm IMBH} = 0.1\,{\rm pc}$ (run *A*). Fig. 1 shows that the inspiral process follows the theoretical description very well until the IMBH has depleted the inner cusp and the density profile is flattened (like it has recently been observed for the Galactic centre).

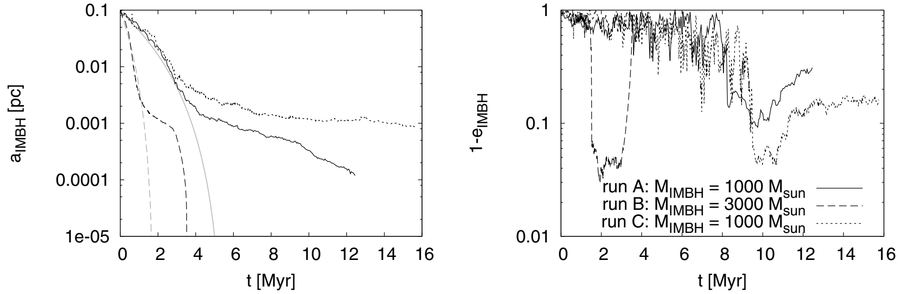

Figure 1. Evolution of the semi-major axes $a_{\rm IMBH}$ and eccentricities $e_{\rm IMBH}$ of three subsequent inspiralling IMBHs. The theoretical curve predicting the inspiral is left once the IMBH has depleted the inner cusp. As an IMBH acquires a highly eccentric orbit due to interactions with passing stars, emission of gravitational waves becomes important, eventually leading to coalescence with the SMBH.

If an additional IMBH spirals into such a flat cusp, the inspiral process due to two-body encounters may terminate at a central distance of 10^{-3} pc (see run C in Fig. 1). At this point, the estimated time until coalescence due to gravitational wave emission may be of the order of 1 Gyr, thus allowing for direct observation in the near future.

3. Ejection of hyper-velocity stars

During the inspiral process, a number of hyper-velocity stars (HVSs) are ejected from the system by close encounters with the IMBH.

Our simulations show that there should be a population of HVSs with very high velocities ($v > 1000$ km/s) which has not been observed so far. However, from the small amount of observational data currently available, the IMBH HVS ejection model can neither be excluded nor concluded for our Galaxy.

If a star's encounter with a massive black hole that leads to HVS ejection is close enough, tidal effects become important. One effect would be that, as a result of the encounter, rotation is induced in the star. We find that fast rotation of a HVS would be evidence for an IMBH in the Galactic centre, but can only be expected among the very fast moving HVSs ($v > 1000$ km/s) (see Löckmann & Baumgardt 2007, for details).

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