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Extreme mass ratio inspirals in nuclear star clusters: a post-Newtonian orbit-resolved approach

Extreme mass ratio inspirals (EMRIs) are highly eccentric and tight binary systems consisting of a massive black hole (MBH) and a compact object. These systems emit gravitational waves in the mHz frequency range during each pericentre passage, thus representing primary sources for the upcoming Laser Interferometer Space Antenna (LISA). Due to the emission of gravitational waves, the compact object slowly inspirals towards the MBH over thousands of orbits, until they eventually merge. On the other hand, if the merger occurs after few orbits or in a head-on collision it is referred to as a direct plunge (DP).

In nuclear star clusters, MBHs are surrounded by a large number of stars and compact objects. Here, the formation of EMRIs is facilitated by frequent two-body interactions that can easily scatter a compact object onto a very eccentric orbit around the MBH.

In this work we present a novel few-body/Monte Carlo approach to simulate the formation of EMRIs as a consequence of two-body relaxation in nuclear star clusters. For the first time, we depart from the commonly used approximation of averaging the effects of two-body relaxation over an entire orbit, performing our simulations in what we call "orbit-resolved" regime. Moreover, we use post-Newtonian corrections and a two-population model for the nuclear star cluster, which accounts both for the presence of Sun-like stars and of stellar-mass black holes.

We apply this model to the study of the ratio of EMRIs to DPs forming as a function of the initial semi-major axis of the orbit. It is currently believed that this ratio should always approach zero for large initial semi-major axes, where only DPs are expected to form. However, the recent emergence of "cliffhanger EMRIs" (which are EMRIs that form following a failed DP) is challenging this notion, particularly for low-mass MBHs.

Our simulations confirm the existence of cliffhanger EMRIs. Moreover, we find that both the post-Newtonian treatment and the introduction of a population of stellar-mass black holes significantly enhances the number of cliffhanger EMRIs that form from initially wide orbits. Instead, the EMRI-to-DP ratio is only slightly influenced by the choice of averaging or not the effects of two-body relaxation.

These findings call for a reassessment of predicted LISA detection rates to account for this new EMRI population in the low-mass MBH regime.

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