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(S02) Simulating galaxies: from stellar to cosmological scales

Dynamical formation of binary black holes in massive star clusters: a cosmological approach

With nearly 200 hundred gravitational-wave detection candidates reported by the LIGO-Virgo-KAGRA Collaboration over the past decade, we are now entering an era where the statistical analysis of the properties of double compact objects provides us with a better understanding of the physical processes behind these extreme objects. However, the question of the astrophysical origin of merging binary black holes (BBHs) remains unsolved. The two main formation channels generally considered are the isolated evolution of binary stars and the dynamical assembly in dense star clusters. Behind these two scenarios lie astrophysical principles that act on a wide range of scales, such as the evolution of massive stars, cosmological star formation and metallicity evolution, star cluster formation, and even galaxy interactions.
Here we focus on the dynamical formation channel and on understanding the role played by the galactic environment in shaping the population of merging binary black holes.

To this end, we developed a new framework to model the formation of massive star clusters in individual galaxies identified in `FIREbox`, a cosmological volume simulation. Each galaxy provides a realistic environment, with its unique star formation history, which is used to trace the formation of star clusters across cosmic time. Combined with a grid model of star cluster evolution, we are able to produce populations of dynamically formed merging BBHs across cosmic time in a large sample of galaxies.
The low metallicity environments found in low-mass galaxies are expected to be highly favourable to the formation of double compact objects via the isolated channel. We show here that this result is no longer valid for the dynamical channel, as massive star clusters preferentially form in the densest massive gas clouds, which are rarely found in these low-mass galaxies. Therefore we expect low-mass galaxies to make a limited contribution to the global production of dynamically formed merging BBHs. Furthermore, we find that massive clusters can host hierarchical BBH mergers: a massive second-generation BH, formed from an earlier BBH merger, pairing with a first-generation BH. These particular events are expected to have clear, identifiable physical properties. Identifying the formation channel of some of the observed BBH mergers could be the first step towards identifying their host galaxies, providing valuable information about physical processes that act at widely different scales. Looking at the evolution of the BBH merger rate in different galaxies, we find strong correlations between BBH mergers and the most extreme episodes of star formation, indicating a potential relation between galaxy interactions and the formation of these extreme objects.