Stellar populations as sources of gravitational waves in galaxies

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A new window on high-energy astrophysics.

Gravitational waves detected since 2015 by the LIGO/Virgo consortium result from the merging of two **black holes** (BH) of ~ 30 × the mass of the Sun. The statistics of such events is rooted in the likelihood of forming compact remnants, such as black hole- and **neutron star** binaries, through stellar evolution and gravitational dynamics. A crucial ingredient born out by observations is that a high fraction of stars form as *multiple systems* (binaries, triples, etc) and in large associations, of thousands of stars or more. The mutual interactions of clustered stars bear heavily on their long-term evolution and possible merger leading to **gravitational waves**. The PhD project consists in exploring the evolution of realistic populations of stars with computer models to set constraints on the statistics of multiple stars becoming effective sources of gravitational waves over time and their likely spatial distribution at the core of large galaxies. Of special interest is the question of whether the distribution of gravitational wave sources can reach the range of so-called *intermediate-mass black holes*, with a merged mass in the range of 100 to 1000 Solar masses. This question has received much attention since the detection of the first IMBH candidate in September 2020 (source: Ligo/Virgo consortium).

Background work, methodology.

To address these issues requires to look at all the circumstances of the life-cycle of stars. Massive stars often sit in the densest part of the star formation volume, so they are subjected to strong interactions with their neighbours. These interactions can be studied in details with computer models. The PhD candidate will exploit a computational procedure developed recently in Strasbourg[1] to setup and evolve self-consistent star-forming regions. Synthetic images will be constructed from these computer models and classified using a **machine learning** algorithm (on-going DNIPRO project) to categorize their dynamical state. It will then be possible to set new bounds on the fraction of un-resolved binaries (or multiple stars), by direct comparison with observations of targeted regions[2]. This part of the project should cover the **first half of the PhD** and lead to a refereed article.

A set of **N-body computer integrations** will perform the orbital evolution of stellar associations embedded in the dense core of a host galaxy, on a star-by-star basis. The early stage of the computer models will focus on the **morphology** of the stellar associations, paying attention to the influence of the surrounding galactic potential. To account for galaxy mergers at low redshift, the N-body models will cover out-of-equilibrium (i.e., perturbed) galactic centers: synthetic images constructed from these models should help identify recent galaxy mergers. The impact of a binary of massive BH on the stars will also be mapped out. The long-term evolution of these systems will make use of the fast **MOCCA** stellar dynamics package[3]. The combination of N-body and MOCCA methods would allow the candidate to lead an investigation into the dissolution of stellar associations and groups, and the creation of **streams of stars** in the host galaxy, a key topic for Milky Way research in the era of ESO's GAIA high-precision astrometric space mission. The project has scope to explore the **mass influx** toward the galactic center and the evolution of BH-BH interactions, with the goal to understand the dynamics of multiple stars in the strong gravity regime. The research will benefit from external collaborations aimed at exploiting large simulation data cubes and their physical interpretation. Both N-body and MOCCA calculations should result in separate refereed articles.

[1] See Dorval, J., Boily, C., Moraux, E. et al. 2016, MNRAS 459, p. 1213 ; and 2017, MNRAS 465, p. 2198

[2] For example: https://en.wikipedia.org/wiki/NGC_1333 ; The Eagle Nebula : http://minsex.blogspot.fr/2012/01/messier-16-eagle-nebula.html

[3] MOCCA is an 'Monte Carlo' integrator developed by M.Giersz ; see https://moccacode.net for more details.