THE BIRTH OF Multiple stars and their mutation into sources of gravitational waves

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BACKGROUND

Stars form at all epochs in the post-recombination Universe and it remains a key challenge to modern astrophysics to determine whether the conditions that prevailed in the pristine, metal-depleted cosmos lead to the same demographics of the stars as those that form in the more recent epoch, in metal-rich pockets of dense, cold gas. To try and answer this fundamental question, and weigh its long-term consequences, a crucial ingredient born out by observations is that a high fraction of stars form as *multiple systems* (binaries, triples, etc) and in larger associations, clusters or groups, of thousands of stars. For example, in the Milky Way, high-resolution infra-red observations [e.g., APOGEE, Spitzer, Herschel] reveal complexes of stars and gas of filamentary- or otherwise irregular, clumpy geometry. The mutual interactions of clustered stars bear heavily on their long-term evolution and the production of *exotic remnants*, such as **neutron stars** and **black holes**. Gravitational waves detected since 2015 by the LIGO/Virgo consortium result from of the merging of two black holes of ~ 30 × the mass of the Sun. The **statistics of such events** is clearly rooted in the likelihood of forming exotic remnants, such as black holes and black hole binaries, through stellar evolution and gravitational dynamics.

Work plan, methodology

To address these issues requires to look at all the circumstances of the life-cycle of stars. Massive stars, for instance, 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 with computer models. The candidate will exploit a computational procedure developed recently in Strasbourg[1] to setup self-consistent systems of stars of a complex geometry, which match closely the photometric properties of real, observed systems (e.g., NGC1333, IC348). Synthetic images will be constructed from the computer models by using extinction maps at the position of observed star-forming regions. It will then be possible to derive their stellar *luminosity function* for comparison with observations, and so constrain the range of free parameters, including the fraction of binary stars. This part of the project should cover the **first year of the PhD** and lead to a refereed article.

A set of **N-body computer integrations** will perform the evolution in time of the models, including the internal evolution of the stars. The early evolution of the computer models will focus on the **morphology** of the system, and use the same synthetic image reconstruction procedure as in the above to monitor its evolution. For the longer-term evolution of the systems, and to pin down the statistics of black hole binaries especially, the candidate will make use of the fast **MOCCA** stellar dynamics package[3]. The combination of these two methods, each applied to different regimes of evolution, opens the door for further investigations into the dissolution of the stellar associations and groups, and the creation of streams of stars in the disc of the host galaxy, important topics in the era of GAIA and high-precision astrometry. Early **test runs** will be performed in the first year and become the **prime focus** of research from the beginning of the **second year**, so as to explore more efficiently the short-term evolution of the systems, requiring less computational time, before turning to the long-term runs and the statistics of black hole binaries. 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] As an 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.