Title: “The Secret Lives of Star Clusters: Formation and Dynamical Evolution”

Author: Elena Gavagnin

Abstract:

Stars are social animals, like humans. Indeed, they are mostly found in groups, called star clusters.
Since star formation is a collective process and a group of stars forms together from the same molecular cloud, star clusters are firstly nursery for stellar objects.
Moreover, once formed, stars interact gravitationally with each other, hence a star cluster is the smallest gravitational entity where we can study stellar dynamics.
On a bigger scale, star clusters are bricks of galaxies, therefore understanding how their formation and evolution work is of fundamental relevance for various field of research in astrophysics.
However, the detailed transition from dense gaseous cloud to star cluster is still an open question with a lot of partial answers and observations tell us that `star cluster' is a broad term which comprises completely different objects, such as globular clusters, open clusters, associations, young star cluster, nuclear star cluster, which differ in terms of number, masses, ages, sizes and therefore densities, stellar populations and distribution. Every subcategory presents unique features, which wait to be explained. Moreover, an eventual connection between all these forms of star clusters or the determination of the conditions under which one type or another forms, are still missing.

In this thesis, I focus on two big open questions. First I study the formation and emergence of a star cluster from its parent cloud. Using radiation hydrodynamical simulations, I analyse the collapse and dispersal of the cloud due to the photoionising radiation emitted by the newborn stars. We want to understand how feedback affects the structure and dynamical status of the young cluster. The results suggest that photoionisation is very effective in disrupting the cloud and producing a gas-free collection of stars.
Feedback has a huge impact on the star cluster characteristics, reducing the stellar density and hence allowing the formation of structures in virial equilibrium. Without feedback, the high values of density reached increases the frequency and strength of close encounters between stars, which cause a progressive disruption of the cluster.
Feedback is also responsible for stopping accretion onto massive stars. Survival of substructures and the extent of mass segregation are found to be higher in the model with the strongest feedback, which compares positively with observations. Multiple systems of stars and the number of high-velocity escapers also exhibit a dependence with feedback, which provides an interesting check for simulations on galactic scale.

The second topic of research looks at the interaction between already formed gas-free globular clusters as an explanation of their multiple populations and rotation. Using N-body simulations, I study whether merging of star clusters could explain these two characteristics in the specific case of iron-complex globular clusters. Iron-complex globular clusters exhibit both large star-to-star light elements abundance variations and, surprisingly, also Fe abundance variations. The globular clusters within this category show some unusual aspects in the metal-rich/metal-poor number ratio and relative concentration, not explained by the existing self-enrichment models for multiple populations. Moreover, rotation has been observed in several globular clusters, but there is not yet a general consensus for its origin. The key parameters explored are the initial mass and density ratio of the progenitors. The results indicate that the relative concentration of the two progenitors in the final merger output strongly depends on these two parameters. In particular, when the progenitors have similar initial densities, the more massive progenitor dominates the central part of the merger remnant and the less massive progenitor forms an extended population. To be more centrally concentrated, the low mass progenitor needs an initial density higher by roughly the mass ratio. The merger remnants show solid body rotation in the inner parts, becoming differential in the outer parts. Rotation velocity and ellipticity show agreement with models for oblate rotators with isotropic dispersion. The density ratio is found to have an impact on the rotation profile of the remnant in case of unequal mass mergers. This signature is a useful observational test for this model.