Star clusters are densely packed groups of stars attracting each other by mutual gravitational forces. A particular place between star clusters hold globular clusters (GC) which can consist of hundreds of thousands of very old stars (even 10 billion years old) and fly around galaxies including the Milky Way. Stars in GCs experience much different conditions than our Sun. In the latter case, the nearest star, Proxima Centauri, is located 4.37 light years away, whereas, in a typical GC there are thousands to millions stars inside such a distance. In consequence, stars living in GCs can frequently get close to each other. During these so-called close encounters, stars interact strongly with each other, including even an extreme case of a direct collision, which strongly influences the stellar evolution.

The situation complicates even further when we account for the fact that a lot of stars, in contrast to the Sun, exist in binary systems, i.e. are strongly gravitationally bound to another star and revolve around each other. These “binary stars” are currently extremely interesting astrophysical objects due to the plethora of phenomena connected to them including X-ray binaries and double black hole mergers.

Binary stars existing in disks of galaxies evolve nearly unaffected, however, those in GCs undergo many interactions which significantly alter their properties and even form exotic objects not present elsewhere like blue stragglers. Especially interesting is the “hardening” of a binary when many weak interactions (“fly-bys”) result in shortening the orbital period effectively bringing the stars in the binary closer to each other. Subsequently, when the separation is short enough, the stars can merge bringing into existence new varieties of objects or producing observable gravitational radiation.

All these interesting processes happening in GCs make them very good laboratories for theoretical studies of the gravitational N-body dynamics including close interactions. On the other hand, the theoretical studies of the GC evolution from the first principles are very difficult. In addition, all these physical processes need to be simultaneously considered when we want to understand the life of GCs. Therefore, numerical simulations are required to achieve this goal. The most accurate is the method called direct N-body, in which a force acting on a star is calculated by adding the Newtonian attraction forces of all other stars. However, this kind of simulation is very time consuming and may take over a year for a realistic GC. What is more, typically a large number of initial parameters determining the subsequent cluster evolution needs to be tested, which makes the N-body method even more impractical. The alternative is the MOCCA code. Developed in the Nicolaus Copernicus Astronomical Center Polish Academy of Sciences by Mirek Giersz's group, this code is based on the Monte Carlo method that makes it extremely fast, while taking into account all the relevant physical processes discussed above. The comparison between results of the MOCCA and the direct N-body simulations shows a very good agreement, which makes the MOCCA code a perfect choice to conduct surveys of GC models.

The primary objective of the project will be to carry out a thorough analysis of the few thousand star clusters models that will be evolved using the updated version of the MOCCA code in order to investigate populations of compact objects in the dense stellar environments. The most massive and dense star clusters, like GCs, are expected to contain thousands of compact objects that form as end points of stellar evolution. Gravitational interactions in dense star clusters can lead to the formation of exotic binary or hierarchical systems. When they contain black holes, such systems can be important sources of gravitational waves, high energy electromagnetic radiation and other transient events. The observational instruments that can detect such exotic objects are becoming more sophisticated and there is a need to make predictions and compare new observational results with theoretical predictions. We will find numbers, masses and properties of compact objects in single, binary and hierarchical systems that form in the GC models and elucidate their exact formation and merger channels. We seek to systematically examine how the number and properties of compact objects evolve with time and how they depend on the initial structural properties of star clusters and different stellar and binary evolution prescriptions.

We hope that the buildup of a new GC model database of thousands of real star cluster models will allow us to identify undiscovered channels for mergers between compact objects and formation processes for very luminous transient sources. The results from the planned simulations will give a full picture of all the unique channels and properties with which gravitational wave sources can form in such dense environments. We will be also able to make comparisons and provide predictions for present and planned gravitational wave and X-ray/gamma-ray observations of such compact objects that can help better understand a myriad of uncertain physical processes and key questions in the field of compact objects.