DESCRIPTION FOR THE GENERAL PUBLIC

In the Universe, matter is concentrated in isolated islands, called galaxies, each of them containing millions to billions of stars, often accompanied by huge clouds of gas and dust and, importantly, very likely also by large amounts of material which is completely invisible to astronomical instruments and manifests its presence only through its gravitational interaction with the rest of the galaxy - the famous “dark matter”. The galaxies are in constant development as stars are being born from clumps in the gas and die in sometimes very powerful explosions, but also as the galaxies interact or even merge with each other due to their constant mutual movement.

Even in this short description, two key challenges of contemporary galactic astronomy can be already seen. Firstly, as for many galaxies the dark matter may form the bulk of their mass, the understanding of their properties crucially depends on the distribution of this dark matter, which is however a priori unknown due to its practical invisibility. Secondly, the processes that shape the galaxies, such as their mutual interactions and mergers, occur on such long timescales, that for every individual galaxy we can obtain merely a snapshot frozen in time. Interestingly, many galaxies that might at first appear to be currently at peace, show under a deeper investigation some peculiar features that are likely to result from past mergers, revealing important information about their violent history. Moreover, the development of those features is heavily influenced by the distribution of dark matter in the galaxies -- thus their study allows us to investigate both of the key questions at once.

Among merger-induced features, two are especially useful for this purpose, namely the galactic cores with unusual velocity distributions and stellar shells. The unusual cores arise in a situation where the inner part of the galaxy exhibits a different type of movement than the rest of it and can be discovered by looking at the spectrum of light coming from different parts of the galaxy, as the movement of visible matter is imprinted in the spectrum through the Doppler effect. The shells can be imagined as thin surfaces of denser material at various distances around the center of the galaxy and are usually visible as thin arcs in carefully processed images.

A key idea of this project is not to just study those effects in isolation, but as a feature of a large number of galaxies. This has been recently made possible by advances in observational surveys, where a large number of galaxies is observed in an uniform way and thus information about frequency of appearance of certain features and the distribution of their properties is available, as well as by the recent dramatic improvements in large cosmological simulations. These simulations generate a “toy Universe” aimed to be as similar to the real one as possible, with the immense added benefit of the fact that we know all its properties, including those that are not directly observable (such as the dark matter distribution) and the complete history of each galaxy in it.

Three major opportunities arise from the simulations. Firstly, the methods developed to extract information from observed phenomena can be tuned, because the desired results are known, and then applied to observational data to obtain previously unknown information. Secondly, observed features can be related to the history of the galaxy and explanation for their appearance can be found. Finally, the distributions of features in the simulations can be compared to those of the surveys to establish how faithfully the simulation reproduces the observable universe as far as the merger-induced phenomena are concerned.

We plan to explore all three of these paths using the data of the Illustris simulation, one of the largest cosmological simulations ever done. The amount of data produced by such a large simulation is immense, but we have already obtained considerable expertise in working with these data during our previous research. This also puts us in an advantageous position in anticipation of the release of a new generation IllustrisTNG results in 2018, as our complex tools and computer codes will be directly applicable to this exciting new data as well.