PhD Research project - Alice Mori

Exploiting Gaia data to understand galaxy formation

The standard cosmological model (i.e. ΛCDM) predicts a hierarchical formation for galaxies, from small subunits that subsequently merge to evolve into the galaxies that we observe nowadays. The study of a galaxy's merging history is thus crucial to understand how galaxies form and evolve. Moreover, the search for stars accreted from the building blocks of our Galaxy is a growing field of research, thanks to the unprecedented amount of data that the ESA astrometric mission Gaia and the complementary spectroscopic surveys are providing. In the last twenty years, many substructures have been found in the Galactic stellar halo (see Naidu et al. (2020) for a recent review), identified as stellar over-densities in particular regions of the kinematics-related spaces, like the energy-angular momentum space. It has indeed been demonstrated that these quantities should be conserved during the interaction. Secondly, if these kinematics-selected groups of stars also feature different chemical properties, they are associated to different original accreted satellites. The last significant merger experienced by the Milky Way was with the Gaia-Sausage-Enceladus (GSE) galaxy approximately 10 Gyr ago.

During my Master thesis, developed at the Observatoire de Paris, I exploited state-of-the-art simulations of merging galaxies, to characterise the GSE merger event. In particular, our aim was to probe thoroughly the kinematics-related spaces, in order to understand what over-densities in these spaces really mean and to what extent different regions of the $E - L_z$ space showing different metallicity distribution functions (MDFs) should be actually associated to different original satellites. In order to do so, we analysed the outcomes of high-resolution, self-consistent N-body simulations of a Milky Way-type galaxy accreting a satellite with mass ratio 1:10 (the one proposed for GSE), with different orbital parameters and different initial conditions for the metallicity gradients of the galaxies.

We found that energy and angular momentum are not generally conserved quantities for such a significantly massive satellite, due to the dynamical friction process, thus resulting in the satellite stars redistributing over a large fraction of the $E - L_z$ space. As a consequence of this broad redistribution in the $E - L_z$ space of the satellite stars and of the initial metallicity gradients, different regions of the $E - L_z$ can feature different MDFs even if caused by a single satellite merger event. Therefore, this work highlighted that one must be cautious when drawing conclusions from limited regions of the $E - L_z$ space, even when complementary chemical abundances information is provided. Nevertheless, we found some trends in the MDFs in the $E - L_z$ space. Hence, we suggested that it could be more useful to simultaneously study the global properties of the MDFs in the $E - L_z$ space.

Still many questions remain open: how to study past merger events? How to reconstruct a galaxy mass growth, and in particular the formation of the Galactic stellar halo? Which and how many ultra-faint dwarf galaxies contributed to its formation? Did they leave any signature in the data?

During the PhD, I would be interested in deepening the results of the simulations used during the Master, which did not take into account the chemical evolution of galaxies, with the outcomes of semi-analytical cosmological models developed at UniFi. These models could indeed provide the initial conditions for the dynamical simulations, but also the star formation and the chemical evolution history. Furthermore, they would supply the unique information about the first stars relics, which are usually not accounted for in the literature, but which would be necessary now that very metal-poor streams are being observed (Yuan et al. 2022).

The overall aim would be to be able to interpret the global MDF of the Galactic halo provided by the observational data, which at low metallicities features the contribution of the last significant merger (GSE), while at even lower metallicities could show the contribution of minor mergers with ultra-faint dwarf galaxies and of globular clusters. As far as different mass scales are concerned, I would like to study in more detail the following points:

1. **Massive mergers and global trends of the MDF**
   The global coherence in the trends of the MDF within the regions of the $E - L_z$ space, mentioned above, could be exploited to create models with which to interpret the observational data. To this end we need to perform a detail study of these trends for different initial metallicity gradients and to account for the chemical evolution history of the galaxies. Only in this way, indeed, we can build-up self-consistent and robust cosmological models.

2. **Minor mergers and Ultra-Faint Dwarf Galaxies (UFDs)**
   Concerning minor mergers, the aim is to understand which and how many dwarf galaxies merged in the Galactic stellar halo, at which time they were accreted and their contribution at different distances, metallicities and in different regions of the kinematic spaces. It would be then necessary to run new simulations considering more than one accreting satellite, with lower mass ratios and thus with higher resolution.

3. **Linking Ultra-Faint Dwarf Galaxies (UFDs) and Globular Clusters (GCs)**
   Finally, I would study the origin of the stellar streams observed in the Galactic halo usually associated to GCs. By exploiting the predictions of cosmological models that reproduce all the observed properties of UFDs, and the results obtained in (2), I will understand if the observed stellar streams can also be associated to UFDs. This will shed light on the link between UFDs and GCs, whose origin is still highly debated.

In conclusion, the proposed study will be crucial in the near future to model the unprecedented observational data flow, driven by the Gaia data, along with spectroscopic surveys. It could only be possible combining the cosmological simulations developed at UniFi (Salvadori, Koutsourudou) together with the merger N-body models developed at the Observatoire de Paris (Di Matteo, Haywood), thus being perfectly suitable for a PhD project in a co-supervision between UniFi and the Paris Observatory.