MW-Gaia STSM

Simulation Stellar Clusters

Dr Tristan Cantat-Gaudin from the Institut of Cosmos Science of the University of Barcelona spent a week (19-25/01/2020) at the Leiden University thanks to a GP1 STSM grant to collaborate with Prof. Simon Portegies Zwart and Dr. Anthony Brown.

Tristan Cantat-Gaudin research focuses on stellar clusters in the disc of the Milky Way. Thanks to the data provided by the ESA Gaia mission, many nearby clusters have resolved internal kinematics, which means that we can follow the individual motions of stars within clusters, and characterise their dynamical state. In particular, a complex spatial distribution of young stars was recently identified in the nearby Vela region. The purpose of this visit was to begin an investigation of the dynamical state and establish a possible formation scenario for this region, combining observations and numerical simulations.

Visiting the Leiden Observatory allowed the direct collaboration with A. Brown, who has expertise in the characterisation of young stellar aggregates and is the world expert on the advanced use of Gaia astrometric data, and with S. Portegies Zwart, professor of computational astrophysics and developer of the software environment AMUSE. The aim was to be able to perform simple simulations, taking into account the following physical processes: gravitational interactions of stars within a cluster, influence of the Galactic tidal field, and stellar evolution.

The main activity during the exchange was the technical implementation of the tools needed in order to simulate the structure and evolution of the Vela region. The software suite AMUSE is a modular environment that allows to simulate various astrophysical processes. A simulation reproducing the gravitational interaction between stars within a cluster was initially set up. Then the influence of a simple Galactic potential on the dynamical evolution of the cluster was added. Later a more complex Galactic potential was added by interfacing AMUSE with Galpy, a powerful and widely-used Galactic dynamics Python package. The third physical process relevant to this simulation is stellar evolution, which AMUSE allows taking into account. By assigning masses to the stars in the simulations and running a stellar evolution code, the fact that over several millions of years the most massive stars explode as supernovae and their mass no longer contributes to gravitational interactions within the cluster could be reproduced. Finally, simulations were run where several stellar clusters of different ages interact with each other, which is necessary in order to reproduce the overlap of populations of different ages in the Vela region.

Main achievements

The main objective of this visit, which was to set up a numerical simulation including at the same time the effect of 1) gravitational interactions between stars, 2) the influence of the Galactic tidal field, and 3) the effect of stellar evolution including subgroups ofdifferent ages, was achieved.

Using the stellar evolution codes included in AMUSE, it was possible to estimate that, given the number of young stars currently observed in Vela, a large number of supernova explosions (possibly up to 100) took place in the past 50 Myr. It is therefore possible that the formation of several of the observed clusters was triggered by supernovae.

This visit was a part of an ongoing collaboration. Two possible angles for further studies of this complex region were identified:

The first goal was to look for evidence of the processes that drove star formation and left their imprint in the observed spatial and kinematic structure of the stellar population. The plausibility of the supernova scenario can be further explored by looking for high-velocity stars in and around Vela (ejected by the supernova explosion of their companion, if they were part of a binary system). Evidence for such an intense supernova activity might also be found in the expansion of the large gas shell surrounding the entire region.

The second aim was to rely on numerical simulations to understand on which time scale the Vela stars will disperse into the Milky Way field population, and whether some of the denser stellar aggregates can remain gravitationally bound clusters. This requires not only that the simulation reproduces the observed characteristics of Vela, but also that it includes the low-mass stars for which observations are missing. Further work to investigate how different prescriptions on how to include these unobserved stars in the simulation affect the predictions of the modelled Vela will be developed.

The collaboration is still ongoing to build on what was done during the visit to set up a numerical simulation of the entire Vela-Puppis complex and determine if some of the dense clumps are going to remain gravitationally bound and form star clusters. The first challenge for this is methodological: it is necessary to account for the stars that Gaia does not see, and for those that can be seen but whose motions cannot be measured. The second challenge is technical: the volume of space represented by this simulation is large, and in order to explore several possible outcomes for the dynamical evolution of the stellar structures, the project may require significant computing resources.