Globular Cluster Archeology in Light of State-of-the-Art Stellar Physics

Open PhD project

Department of Astronomy, University of Geneva (Switzerland)
Supervisor Prof. Corinne Charbonnel
Project 169125 (Globular Cluster Archeology) founded by the Swiss National Science Foundation
Starting date: September 1, 2017 (or earlier according to mutual agreement)

Qualifications

The candidate should have an excellent Master in Science (M.Sc) in Astrophysics or Theoretical Physics or Fluid Dynamics of Plasma Physics. Strong competence and interest in mathematical modeling will be appreciated.

Application

Closing date for applications is June 30, 2017.
Applications and informal inquiries can be directed to Corinne.Charbonnel@unige.ch.
Applications should include a full CV, a covering letter describing the interest and background of the applicant relevant to the area of research, a copy of diploma, marks and ranking since the first university years, and contact details of at least one referee. Personal circumstances that may be of positive relevance in merit evaluation should be mentioned in the list of qualifications (CV).
The University of Geneva aims for diversity and gender balance. We therefore welcome applicants of all nationalities and of any gender.

Astrophysical context

Globular clusters (GCs) are fundamental benchmarks for stellar physics, and of prime interest for a broad variety of topics ranging from Galactic evolution to cosmic reionization and cosmology. The discovery of the ubiquitous presence of multiple stellar populations (MSP) in GCs has recently revolutionized the field. Unprecedented spectroscopic and photometric analysis with VLT and HST revealed that these MSPs display complex abundance patterns and leave specific imprints in the observed color-magnitude diagrams (CMD) that have not been observed in any other environment. These peculiar features are recognized to result (at least partly) from GC self-enrichment with hydrogen-burning ashes that were released by a first population of stellar polluters out of which MSPs could form. Complementary clues are now searched for in young massive star clusters in nearby and interacting galaxies, in particular with ALMA and HST.

This new paradigm challenges all the current concepts regarding the formation, evolution, and the role GCs play in the assembly of galaxies and of their substructures in a cosmological context. A considerable surge of theoretical and numerical developments has thus been deployed over the past decade to explain the unique properties of GC MSPs. Up to know, most of the theoretical efforts focused on the nature of the massive, short-lived, long-disappeared stellar polluters at the origin of GC self-enrichment. See Charbonnel (2016, arXiv:1611.08855) for a review.

Project goals

In this thesis, we propose to focus on the physics and evolution of the low-mass stars we are observing in GCs, and to study and model all the physical processes that may have modified their chemical and structural properties since they were born 9 to 13 Gyrs ago. The central questions to be answered can be summarized as follows: What is the influence of multi-dimensional hydrodynamical mechanisms and of atomic diffusion on the properties and evolution of GC low-mass stars born with very peculiar initial compositions, and how can these processes modify the current interpretation of the observed abundance patterns and of the clusters' CMDs on which all self-enrichment GC models are based?

To reach this goal, the PhD student will compute tailored stellar evolution models for the low-mass stars that populate GCs today. These models will include the relevant initial chemical composition (spreads in helium and light elements, for the whole metallicity range of Galactic GCs) and, for the first time, atomic diffusion as well as the sophisticated hydrodynamical mechanisms that are being at act in stars of different masses. The student will first study the impact of rotation-induced processes and of thermohaline mixing coupled to atomic diffusion on the stellar properties at different phases of the evolution from the pre-main sequence to the white dwarf cooling sequence. The possible impact of internal gravity waves and magnetic fields will be studied in a second step.
This work aims at firmly establishing which of their present-day chemical and photometric properties the GC low-mass stars inherited at birth, and which are the actual results of in-situ secular evolution, using also comparisons with the properties of field stars and stars belonging to open clusters.

These state-of-the art stellar models will then be used by the PhD student to build isochrones and advanced population synthesis models adapted to the case of GCs with MSPs. The presence of non-coeval, non-chemically homogeneous stellar populations born with an initial distribution in rotation velocities will be taken into account.
The PhD student will use these tools to determine the ages of Galactic GCs taking into account for the first time the presence and the characteristics of their MSPs. These predictions will be fundamental to constrain the formation of massive star clusters at all redshifts.

All along the PhD thesis, the stellar and synthesis model predictions will be compared to the large set of spectroscopic and photometric observations that are already or will soon be available like the FLAMES@VLT survey of GCs, the Hubble Space Telescope UV Legacy Survey of Galactic GCs, the space mission GAIA and the GAIA ESO-survey. We will also benefit from data coming from original observational programs that we have designed and that we are currently conducting with FLAMES@VLT. The global asteroseismic properties of the stellar models will also be compared to those of the various Galactic stellar populations revealed by CoRoT, Kepler, and K2. This will prepare the ground for the exploitation of the future major space mission for the discipline PLATO (PLAnetary Transits and Oscillations of stars; ESA). The ultimate goal is to reconcile the spectroscopic, photometric, and asteroseismic signatures of GC MSPs, which is mandatory to understand their formation in a global galactic and cosmological picture.

This work will prepare the ground for future observations with ALMA and later SKA and JWST that will open the possibility to resolve extragalactic super star clusters and to study their relation to globular clusters, as well as with the next ESO multi-object facilities on VLT and ELT, which will represent the ideal machine to follow-up on the results of this project, being able to target hundreds of objects simultaneously in any given field, thus mapping chemically, kinematically, and dynamically globular clusters.

Method

For the stellar models, the PhD student will use our stellar evolution code STAREVOL, which is designed to model low- and intermediate mass rotating stars (e.g. Forestini & Charbonnel 1997; Charbonnel & Lagarde 2010; Amard et al. 2015). STAREVOL is the only stellar evolution code that includes state-of-the-art 1.5D treatment of the hydrodynamical mechanisms that transport angular momentum and chemicals in stellar interiors and that are known to strongly impact the stellar properties, i.e., rotation-induced meridional circulation and turbulence (Lagarde et al. 2012b; Amard et al. 2015), thermohaline mixing (Charbonnel & Zahn 2007a), and internal gravity waves (Charbonnel & Talon 2005; Charbonnel et al. 2013). The student will apply in particular the most up-to-date theoretical description of anisotropic turbulent transport of angular momentum in stably stratified rotating stellar radiation zones for which we have recently obtained stringent constraints from asteroseismology and from multi-dimensional numerical simulations and laboratory experiments (Mathis et al. a, b, 2017, Amard et al. 2017, submitted to A&A). These state-of-the art prescriptions will be used here for the first time for the specific modeling of stars born with peculiar initial composition like GC stars. STAREVOL includes today a simplified treatment for atomic diffusion (Richard et al. 1996) that needs to be updated. The PhD student will revise the numerical implementation of atomic diffusion to model it from first principles (Richard et al. 2002). She/he will also incorporate a robust treatment of radiative accelerations (LeBlanc & Alecian 2004), which is necessary to investigate the impact of these processes from the main sequence up to the horizontal branch. This will be done in collaboration with Dr A.Palacios and Dr O.Richard (Montpellier, France; cotutelle agreement possible).

For the synthesis models the PhD student will use and update the Geneva population synthesis code SYCLIST (SyntheticCLusters, Isochrones, and stellar Tracks; Georgy et al. 2014, Chantereau et al. 2016). SYCLIST produces isochrones, time evolution star counts, and synthetic coeval populations taking into account various initial rotation velocities, gravity darkening, as well as binary fraction and photometric noise. The PhD student will first adapt SYCLIST to the case of MSPs.

International collaborations

The PhD student will benefit from the broad and well-established international network of collaborations of Prof. C.Charbonnel with some of the best world specialists working on theoretical stellar and interstellar matter hydrodynamics, numerical multi-dimensional simulations, galactic chemical evolution, N-body simulations, and multi-wavelength high-precision photometry, spectroscopy, and astrometry. She/he will be strongly encouraged to collaborate with the different parties. This collaborative approach aims at reaching in the near future a reliable, correct, and consensual explanation to the origin of multiple stellar populations in globular clusters and to their contributions to galactic stellar populations.

Bibliography (some publications of our group on GC-related topics)

https://obswww.unige.ch/~charbonnel/research/globular-clusters/

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