SF2A 2016
C. Reylé, J. Richard, L. Cambrésy, M. Deleuil, E. Pécontal, L. Tresse and I. Vauglin (eds)

RED-GIANT STARS: CHEMICAL CLOCKS IN THE MILKY WAY

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Abstract. A broad effort is ongoing with large spectroscopic surveys such as APOGEE, ESO-Gaia, RAVE from which stellar parameters, radial velocities and detailed chemical abundances can be measured for CoRoT, Kepler, and K2 targets. In addition, asteroseismic data of red-giants stars observed by the space missions CoRoT and Kepler allow determination of stellar masses, radii, and can be used to determine the position and ages of stars. This association between spectroscopic and asteroseismic constraints provide a new way to understand galactic and stellar evolutions. To exploit all potential of this combination it would be crucial to develop our approach of synthetic populations. We compute stellar populations synthesis with the Besançon Galactic model including the asteroseismic and chemical properties from stellar evolution models. These synthetic populations can be compared with sinificant large surveys as APOKASC (APOGEE+Kepler) or CoRoGEE (CoRoT+APOGEE). We focus here on the carbon and nitrogen surface abundances of Kepler red-giant stars. We underline the importance of transport processes occurring in red-giant stars as rotation and thermohaline instability to understand chemical properties of stellar populations in the Galaxy. The future for this area also starts taking shape with the launch of Gaia, futur spectroscopic surveys such as 4MOST and WEAVE, and the future space mission PLATO that will provide seismic data for more than 100 000 red-giants. Such synthetic population model is a key tool to investigate future observations and better understand the evolution of the Milky Way.

Keywords: Stellar evolution, red giant stars, population synthesis, Galactic evolution

1 Introduction

Understanding stellar evolution is crucial to improve our knowledge of chemical and evolution properties of galaxies. As shown by the initial mass function (e.g. Salpeter 1955; Scalo 1986; Kroupa 2001; Luhman et al. 2000), low- and intermediate-mass stars are the most numerous stars in our Galaxy. They form the dominant stellar component of our Galaxy and represent a very important astrophysical interest. In their advanced phases, these stars undergo important changes of their structure and chemical composition. Due to strong winds during the superwind phase, which leads to the emergence of planetary nebula, they contribute significantly to the enrichment of the interstellar medium and to the chemical evolution of galaxies. They have a rich nucleosynthesis, with a large part of enrichment in ^{4}He, and they dominate the production of ^{13}C, ^{14}N, and main s-process elements. Red-giant stars cover a large domain in mass, age, chemical composition and evolutionary states. They are cool and high luminous stars making them easily observable. The oscillation spectrum of red-giant stars are very rich providing informations of deep stellar interior.

The observations of red-giant stars have been rised during the last decade. The very large surveys APOGEE (Majewski et al. 2015; SDSS Collaboration et al. 2016), and Gaia-ESO (Gilmore et al. 2012), provide global (gravity, effective temperature or radial velocity) and chemical properties for a large number of giants. The two satellites CoRoT (Baglin et al. 2006) and *Kepler* (Borucki et al. 2010) observed ∼20 000 giant stars, probing their stellar interior thanks to asteroseismology, and given their evolutionary states, stellar mass, radius, age and distance. In addition, the satellite Gaia (Perryman 2002) observe 1 billion stars in the Milky Way will provide accurate distances, proper motions or abundances. To exploit all potential of these different kind of observations, it is crucial to combine them together, and to develop the population synthesis approach. We show here the preliminarily results from the Besançon Galaxy model which take into account new stellar evolution models including rotation and thermohaline instability (Lagarde et al. 2012).

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2 Population synthesis with the Besançon Galaxy model

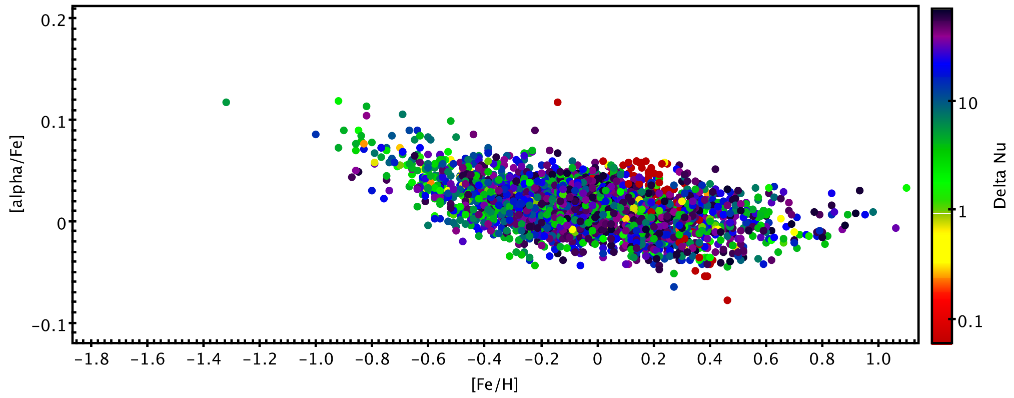

Fig. 1. Color-coded [α/Fe] abundance as a function of metallicity for the thin disc. The color code represents the values of the large separation $\Delta\nu$ provided by classical stellar evolution models.

The Besançon Galaxy model is a stellar population synthesis model (Robin et al. 2003; Czekaj et al. 2014) intended to put together the formation and evolution scenarios of the Galaxy, stellar formation and evolution theory, models of stellar atmospheres as well as dynamical constraints in order to make a consistent picture of available observations (photometry, asteroseismology, astrometry, and spectroscopy) at different wavelengths. Each stellar population (thin and thick discs, halo, and bulge) was calculated given a particular initial mass function, star formation rate, age-metallicity relation, and evolutionary tracks.

To fully exploit the potential of recent asteroseismic and spectroscopic surveys, we use the stellar evolution models computed with the stellar evolution code STAREVOL (Lagarde et al. 2012) for low- and intermediate-mass stars ($1.0\mathrm{M}_{\odot} \leq \mathrm{M} \leq 6.0\mathrm{M}_{\odot}$). These models provide the relevant classical stellar parameters together with global asteroseismic properties and following 54 stable and unstable species from ^{1}H to ^{37}Cl at the surface of stars all along the stellar evolution. This is done from the pre-main sequence to the early-asymptotic giant branch. This stellar evolution grid contains models computed with rotation-induced mixing and thermohaline instability, along with standard models without mixing outside convective regions for comparison purposes (for more details see Lagarde et al. 2012).

Such population synthesis provides for the first time the seismic properties such as the large separation $\Delta\nu$, the frequency with the maximum amplitude ν_{max}, or the asymptotic period spacing of g-modes $\Delta\Pi$ for stars observed by CoRoT and *Kepler* in the thin disc. Figure 1 illustrates the alpha abundance ratio versus iron abundance for a sample of thin disc stars, colour-coded by the value of $\Delta\nu$ along the thin disc. Moreover, asteroseismology using the value of $\Delta\Pi$ help us to distinguish between clump and red-giant stars (Mosser et al. 2012). We can also compute the surface chemical properties of these stars to interpret large spectroscopic surveys (Figure 2).

Transport processes occuring in stellar interiors have a significant impact on global (e.g. luminosity, effective temperature, age), chemical, and seismic properties (e.g. Palacios et al. 2006; Lagarde et al. 2012; Bossini et al. 2015). Population synthesis simulations are powerful tools to study these processes using survey data. As discuss in litterature (e.g. Palacios et al. 2003; Charbonnel & Lagarde 2010), rotation-induced mixing and, more particularly for low-mass stars, thermohaline instability change the photospheric composition of giant stars. Thermohaline mixing induces the changes of surface abundances of ^{3}He, ^{7}Li, C and N for stars brighter than the RGB-bump luminosity (Charbonnel & Lagarde 2010). Rotation-induced mixing modifies the internal chemical structure of main sequence stars. A dispersion of initial stellar rotational velocity explains the observed dispersion of chemicals surface abundances in subgiant stars (Palacios et al. 2003, 2006). Figure 2 shows the effects of rotation-induced mixing and thermohaline instability on the surface ^{12}C/^{13}C of clump stars along the thin disc.

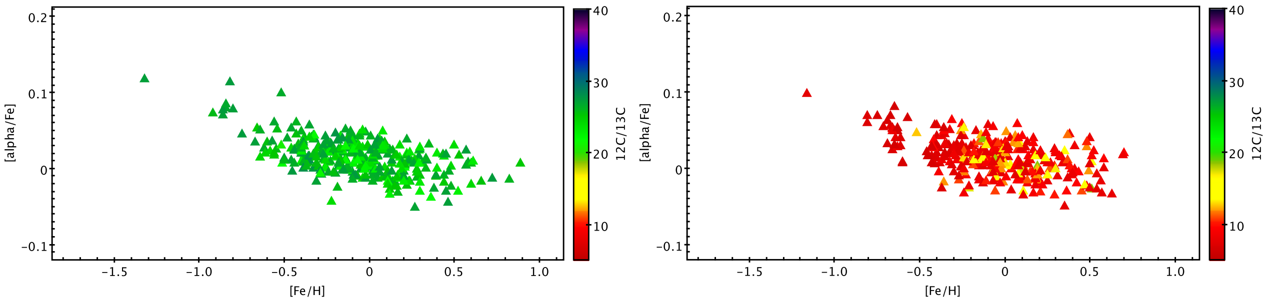

Fig. 2. Color-coded [α/Fe] abundance as a function of metallicity for the clump stars simulated in the thin disc. The color code represents the surface abundances of carbon isotopic ratio, using standard stellar evolution models (left panel), and using models including the effects of rotation-induced mixing and thermohaline instability all long the evolution (right panel).

3 Perspectives

Computations for a larger grid in stellar masses, metallicities, initial velocities, α-enrichments are now being performed in order to compare with large surveys (Lagarde et al 2016 in prep.). We plan to extend this study to all Galactic stellar populations, beginning with the thick disc. Thanks to WEAVE, 4MOST, and PLATO the future looks extremely bright in terms of collecting spectroscopic and seismic data for a large number of stars. The Besançon Galaxy model will be a key tool to exploit APOKASC and CoRoGEE catalogues and to prepare theses future instruments and missions as well as to give a better understanding of stellar and galactic evolution.

We acknowledge financial support from the french Programme National de Physique Stellaire (PNPS) of CNRS/INSU. N.L. acknowledges financial support from the CNES fellowship.

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