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Models of red giants in the CoRoT asteroseismology fields combining asteroseismic and spectroscopic constraints

Lagarde Nadège

School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
email: `lagarde@bison.ph.bham.ac.uk`

Abstract. The availability of asteroseismic constraints for a large sample of red-giant stars from the CoRoT and Kepler missions paves the way for various statistical studies of the seismic properties of stellar populations. We use a detailed spectroscopic study of 19 CoRoT red-giant stars (Morel *et al.* 2014) to compare theoretical stellar evolution models to observations of the open cluster NGC 6633 and field stars. This study is already published in Lagarde *et al.* (2015)

Keywords. asteroseismology, stars: abundances, stars: evolution, stars: rotation, stars: interiors

1. Introduction

Spectroscopy provides the surface chemical properties of stars, while the informations of the stellar structure is given by asteroseismology. These two different observations paves the way to better understand the physics of transport processes occuring in giant stars. We propose in this study to combine these two kind of observation with stellar evolution models and use them to improve our knowledge of stellar interiors. We propose two complamentary approaches to test model predictions of chemical transport with spectroscopic observations, and couple these predictions with seismic constraints on stellar properties. We use the spectroscopic determinations of chemical abundances published by Morel *et al.* (2014). This sample is composed of 19 red-giant targets of which 15 were observed by CoRoT including three members of the young open cluster NGC 6633. Morel *et al.* (2014) (M14) derived the lithium abundances for all the stars in the sample and $^{12}C/^{13}C$ for four of them. The asteroseismic parameters large separation, $\Delta\nu$, and frequency of maximum oscillation power, max, are also taken from M14. Three different methods were used to obtain these global asteroseismic properties (Mosser & Appourchaux (2009), Hekker *et al.* (2010), Kallinger *et al.* (2010a)). More detailed of this comparison is published in Lagarde *et al.* (2015).

2. Stellar parameters

Figure 1 presents the stellar radii, masses and distances determined using asteroseismic constraints (ν_{max},$\Delta\nu$) and $T_{\rm eff}$ as well as the Hipparcos distance (red triangles). The weighted average of the relative difference between seismic and Hipparcos distances is -0.12 with a statistical uncertainty of 0.03. These differences suggest that the seismic distances are overestimated compared to the Hipparcos distances, with consequences for the seismic radii and masses. The weighted average of the relative difference between Hipparcos and seismic distances for the stars in the cluster is -0.23 ± 0.10. The accuracy of Hipparcos parallaxes has recently been questioned by Melis *et al.* (2014) in the case of the Pleiades, suggesting that the Hipparcos distance is overestimated by ∼12%.

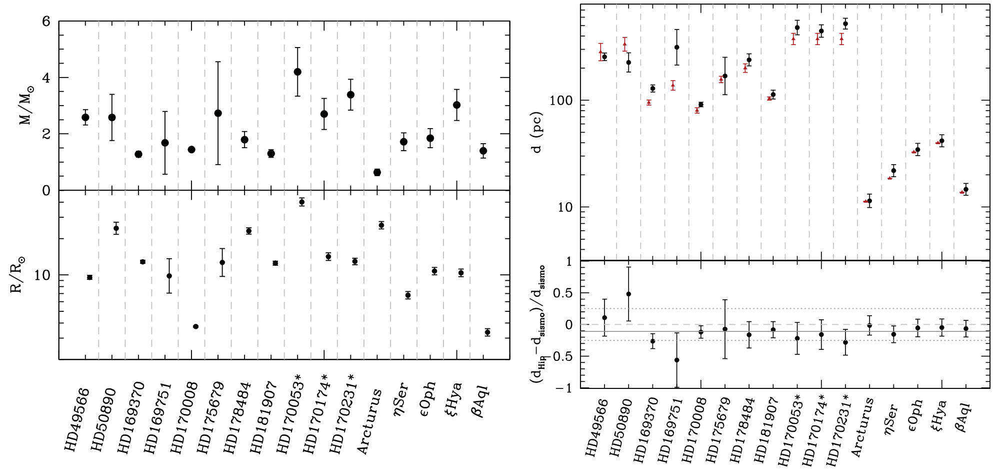

Figure 1. *Left panel:* Stellar masses and radii determined using asteroseismic constraints (ν_{max},$\Delta\nu$) and $T_{\rm eff}$. Asterisk identify the cluster members. *Right panel:* Comparison between the distances determined from asteroseismic constraints (ν_{max} ,$\Delta\nu$) and $T_{\rm eff}$ (black open circle), and the Hipparcos distance (red triangle). In the lower panel, the grey solid line represent the weighted average difference, while the grey dashed lines represent a difference of 25%. Figure from Lagarde *et al.* (2015)

However, our current poor knowledge of systematic uncertainties on the seismically determined distances prevents us from contributing to this debate.

3. Comparison with spectroscopic observations of CoRoT red giant targets

Using the stellar properties determined from asteroseismology, we compare in Figs. 2 the theoretical predictions of our models with respect to observations of lithium and carbon isotopic ratio in red giant target. Theoretical models used are described in Lagarde *et al.* (2012a) and Lagarde *et al.* (2015) and were computed with the code STAREVOL (e.g. Lagarde *et al.* (2012a)). They take into account (1) rotation-induced processes following the formalism by Zahn (1992) and Maeder & Zahn (1998), known to change chemical properties of main sequence and sub-giant stars (e.g. Palacios *et al.* (2006)) and (2) thermohaline mixing as described by Charbonnel & Zahn (2007), which governs the surface chemical properties of low-mass RGB stars (e.g. Charbonnel & Lagarde (2010)). For low-mass stars like Arcturus and HD181907, we show that the low carbon isotopic ratio is nicely explained by thermohaline instability. On the other hand, for more massive stars it is rotation that is the most efficient transport process for chemical species. Our models at different initial velocities can explain the surface abundances of lithium and $^{12}C/^{13}C$.

4. NGC6633

NGC 6633 is a first example of a cluster observed by CoRoT including RGB stars (Fig.3), for which spectroscopy is also available. It is found that the distances for the cluster members deduced from asteroseismic properties are self consistent, but slightly large compared to Hipparcos distances (see Fig.1). In addition, the age of the cluster

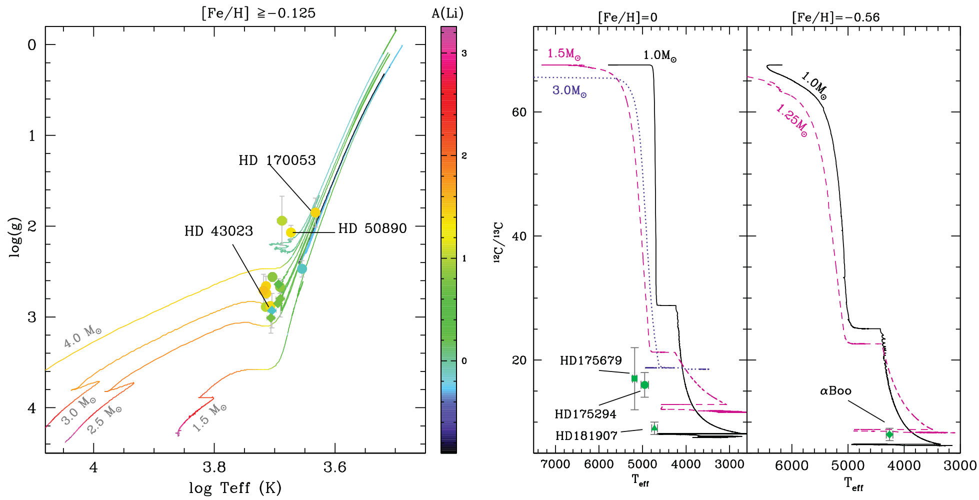

Figure 2. *Left panel:* Color-coded HR diagram for different stellar masses. The color code represents the values of A(Li) at the stellar surface. *Right panel:* $^{12}C/^{13}C$ data in our red-giant stars that are segregated according to their metallicity (left and right panels include respectively sample stars with metallicity close to solar and [Fe/H] = -0.56). Theoretical $^{12}C/^{13}C$ surface abundance is shown from the ZAMS up to the TP-AGB. Various lines correspond to predictions of stellar models of different masses including effects of rotation-induced mixing (with an initial V/Vcrit=0.30) and thermohaline instability. Figures from Lagarde *et al.* (2015)

determined by isochrone fitting in Smiljanic *et al.* (2009) (t = $4.5.10^8$ yrs) implies that stars in the He-core-burning stage have $2.8<M/M_\odot<3.0$, which is compatible with the stellar mass determined with asteroseismology. Although the stellar masses deduced from seismic properties present significant uncertainties, it is clear that the cluster members are in the mass range where rotation is the most efficient transport processes for chemical elements. Additional information of the rotation profile of these stars is needed to improve our understanding of red giant stars in this cluster.

5. Conclusions

In this study, we demonstrate the power of the combination of seismic and spectroscopic constraints to improve our understanding of the physical processes and specifically extra-mixing taking place in the interior of red giant stars. Indeed, asteroseismology provides us new informations on stellar interiors and accurate estimates of stellar mass, radius, and evolutionary state. Spectroscopy gives complementary information about surface chemical properties of stars. This study (Lagarde *et al.* (2015)) significantly advances the study of CoRoT red giants as presented by M14 with a comparison using modern stellar models that include rotation and thermohaline mixing.

The space mission Kepler and K2 (and PLATO in the future) have observed many more open clusters with different turnoff masses, which give us a unique opportunity to follow the evolution of stellar properties through the evolution, and to probe the role of transport processes at different evolutionary phases and different masses. For many of these stars we will be able to develop a more detailed comparison using period spacing and rotational splitting to determine evolutionary state and core rotation rate. To obtain the most information possible from the data set, the asteroseismic properties must be matched by the knowledge of the surface chemical abundances. We have shown in this paper how this complementary data set allows us to provide constraints on the physical

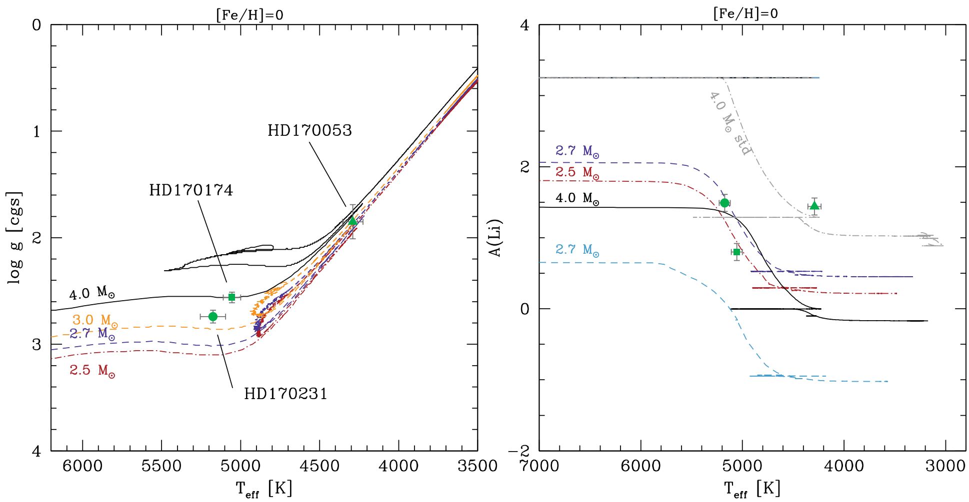

Figure 3. $^{12}C/^{13}C$ data in our red-giant stars that are segregated according to their metallicity (left and right panels include respectively sample stars with metallicity close to solar and [Fe/H]=-0.56). Theoretical $^{12}C/^{13}C$ surface abundance is shown from the ZAMS up to the TP-AGB. Various lines correspond to predictions of stellar models of different masses including effects of rotation-induced mixing (with an initial V/Vcrit=0.30) and thermohaline instability. Figure from Lagarde *et al.* (2015)

processes in stellar interiors. In the future, the Gaia-ESO survey and APOGEE would be extremely helpful

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