Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
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A critical test to disentangle the role of overshooting and rotation in stars

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Abstract. We study the mixing in low-intermediate massive stars using eclipsing binaries. We compute stellar evolutionary models with a varying convective core overshooting parameter and different rotation rates. Using a Bayesian estimation method, we found that the coexistence of the two phenomena may be a reasonable explanation of the observed extra-mixing.

Keywords. stars: evolution, (stars:) binaries: eclipsing

1. Introduction and methodology

Detached double-lined eclipsing binaries (DLEBs) are an ideal laboratory to investigate the mixing processes that are at work in deep stellar interiors. For example, their position in the HR diagram at a given age strongly depends on the amount of internal mixing during the previous evolution. Claret & Torres (2018, 2017) analyzed 37 such binaries to calibrate the strength of core overshooting, one of the sources of extra mixing. They found a growing efficiency from $\sim$1 to $\sim$2 $M_\odot$ and a constant value thereafter. An important feature of their results is the presence of a significant star to star variation in the adopted Mixing Length parameter. Here we use the same sample to check the possible role of the additional mixing induced by rotation. To this purpose, we analyze the above DLEB sample with the code PARAM (Rodrigues *et al.* 2014, 2017). For each observed star, we have accurate determinations of mass M, radius R, effective temperature $T_{\rm eff}$ and metallicity Z. We explore two different hypotheses. In the first one, we assume that the extra mixing is only due to overshooting from the convective core while, in the second one, we ascribe the extra mixing to the interplay of overshooting and rotation. We computed evolutionary tracks with an updated version of the PARSEC code that account for rotation (V2.0, Costa et al. 2018, in prep.). For the first hypothesis, the model dataset consists of non rotating stellar models with an overshooting efficiency $\lambda_{\rm ov}$ from 0 to 0.8 $H_{\rm p}$ in steps of 0.1 (in our scheme the mean free path of the elements is across the border, i.e. $\sim$ twice the value commonly adopted). In the second case, we computed sets of models with a fixed overshooting $\lambda_{\rm ov}$= 0.4 and different initial rotational velocities, with angular rotation rate over the critical one, ω, from 0.0 to 0.6 in steps of 0.1. In all cases, the metallicity varies from Z = 0.002 to 0.02, and the MLT parameter is fixed (1.74). With PARAM, we apply a Bayesian estimation method to compute the posterior probability density function (PDF) for the age and $\lambda_{\rm ov}$ parameters (age and ω in the second case). To derive the best age and $\lambda_{\rm ov}$ parameters (or age and ω in the second case), we finally constrain the binary components to be coeval. More details can be found in Costa et al. (2018 in prep).

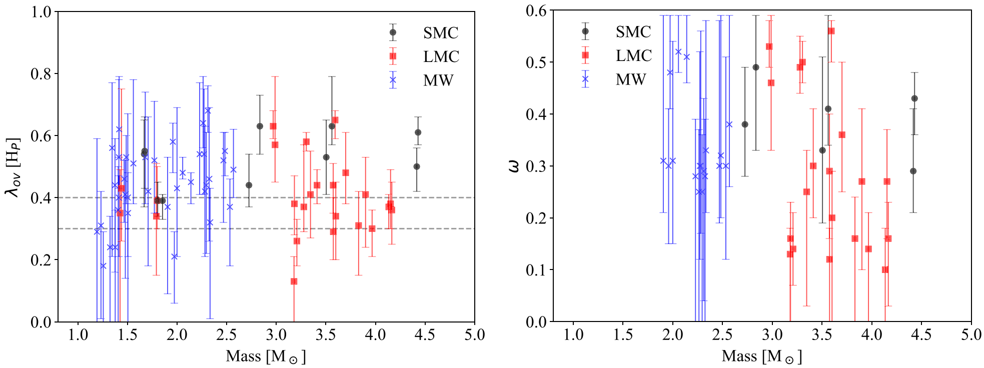

Figure 1. Left panel. λ_{ov} as a function of M_i for the 37 DLEBs. The best values and the error bars are coloured to divide stars of different galaxies. The gray dashed lines are drawn for an easier reading. Right panel. Angular velocity rate ω as a function of the M_i for $M_i \geq 2.0\ M_\odot$.

2. Results and conclusions

From the PDF maps, we extract the best values of the parameters using the median value of the marginalized distribution. These values are shown in Fig. 1 as a function of the initial mass. If we interpret the extra mixing only in terms of overshooting (left panel), we may draw the following conclusions:

1. There is a trend of λ_{ov} as a function of the mass, that grows from ~ 1 to $2\,M_\odot$, and remains flat ($\lambda_{ov} \sim 0.45$) at greater masses (see (Claret & Torres 2017, 2018)).
2. In the flat region, λ_{ov} shows a large scatter, even for similar initial masses.
3. In the flat region, there is an evident lack of points below λ_{ov}= 0.3–0.4.

A large scatter in λ_{ov} at the same initial mass is difficult to explain within the current convection theories that assume fixed values for the mixing parameters (including the MLT value). At the same time, point 3 suggests the existence of a minimum extra-mixing. We argue that the minimum extra-mixing is the result of convective overshooting and that the scatter above this value is caused by the additional mixing eventually induced by rotation. In this second scenario, we considered only DLEBs with $M_i > 2$ $M_\odot$ which populate the region of the unexpected large scatter in λ_{ov} and the results are shown in the right panel of Fig. 1. To conclude, our analysis provides insights into the relative role played by the overshooting and rotation in stellar interiors, and in particular, indicates that both may significantly contribute to internal mixing already from the H-burning stage. The overshooting seems responsible for only a fraction of the extra mixing, $\lambda_{ov} = 0.3$–0.4. Meanwhile, rotation provides a likely explanation of the additional mixing which shows a stochastic behaviour above the minimum threshold. These effects will propagate until the most advanced stellar phases and the impact on the evolved phases, in particular on the calibration of the AGB phase, will be soon investigated. Evolutionary tracks and isochrones will be soon available at: http://stev.oapd.inaf.it/cmd or http://starkey.astro.unipd.it/cgi-bin/cmd.

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