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On the evidence of extra mixing in models of 8 $M_\odot$ computed with the new solar abundances

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Abstract. Stars more massive than about $3M_\odot$ are known to experience loops in the HR diagram during their core helium burning phase. Except for very massive stars the extent of their loops increases with the stellar mass. We show that a stellar evolution track for a $8M_\odot$ star computed with the new solar abundances [2] shows only a very tiny loop located near the red giant branch. An overshooting below the convective envelope is required to obtain a H-discontinuity located deep enough in the μ-gradient region and thus to allow the development of a loop in the HR diagram.

1. INTRODUCTION

When the central temperature reaches about 10^8 K, intermediate and massive stars ignite helium in a non-degenerate core at the tip of the RGB, reversing the upward climbing along the RGB. The star is composed of a He burning core and a H burning shell, both these regions producing the total luminosity of the star. The presence of a H shell allows the core to grow, and this phase is thus characterized by a long lifetime (about 20% of the core H burning phase while the star is almost two orders of magnitude brighter). Therefore the star has a large probability to be observed in that phase. The relative importance of one nuclear burning region to another plays an important role in the formation of a loop in the HRD (e.g. [5]).

2. WHAT ABOUT THE NEW SOLAR ABUNDANCES?

We have compared the core He burning phase for $8M_\odot$ models computed either with GN93 mixture [3] or with the new solar chemical composition, AGSS09 [2], each with "their" solar metallicity. The models have been computed with the CLES evolutionary code [7] with the OPAL opacities and with the Ledoux's criterion for the appearance of a convective zone. For the sake of clarity we will refer to the models in the following as GN1 for models computed with GN93, $Z = 0.02$, $X = 0.70$, and as AG1 for models computed with AGSS09, $Z = 0.014$, $X = 0.72$ (both models computed without overshooting).

The blue or red evolution of He-burning stars has been widely investigated (e.g. [4] and references therein). As expected, the track computed with GN1 presents a loop during core He-burning, however, this loop is absent for AG1 track. It is well known that the location of the H discontinuity at the maximum extent of the convective envelope plays an important role in the formation of a loop during the late phases of core helium burning (e.g. [1, 6, 8]). This is indeed the encounter of the H-shell with this discontinuity that suddenly increases the contribution of the H-shell to the total luminosity with a consecutive heating of the envelope and the formation of a loop. If the discontinuity is too superficial, the whole core He-burning takes place before such an encounter and no loop can be formed.

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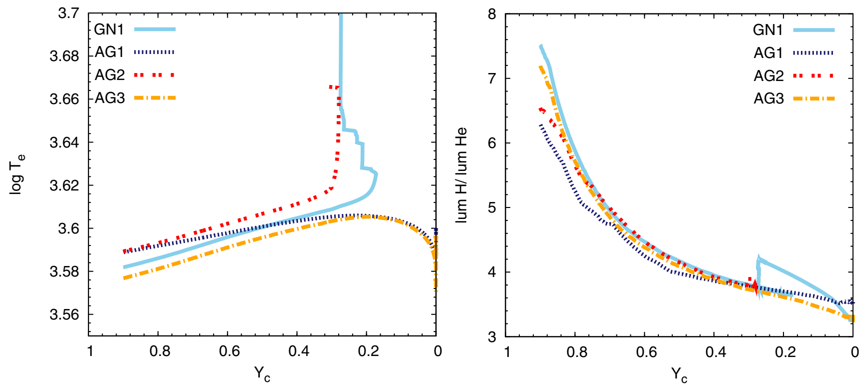

Figure 1. Evolution of the effective temperature (left panel) and of the ratio between the energy produced by the H-burning shell and that produced by the He burning core (right panel) as a function of the central He abundance for $8M_{\odot}$ models computed with GN1, AG1, AG2 and AG3 during core He burning.

Comparing the location of this H-discontinuity between GN1 and AG1 shows a deeper location in GN1 model, which is in agreement with the argument described above: the envelope includes 78.8% of the stellar mass for GN1 and 77.5% only for AG1. In order to deepen the location of the H-discontinuity, two solutions are possible:

- **An undershoot below the convective envelope (AG2)** With an overshooting extent of $0.3\,H_p$ below the envelope the H-discontinuity location moves deep enough to produce a loop for $8M_{\odot}$ models computed with AGSS09, $Z = 0.014$, $X = 0.70$. To illustrate the encounter of the H-shell and the H discontinuity, we have plotted the ratio of the energy produced by the the H-shell to the energy produced in the He core (Fig. 1). At the encounter, a sudden increase in this ratio is simultaneous to an increase in the effective temperature. The H-discontinuity is located at a mass fraction of 0.214 for AG2: thus the envelope includes 78.6% of the stellar mass for AG2.
- **An increase in the metallicity (AG3)** With a metallicity of 0.02 and with the AGSS09 mixture, the H discontinuity is very close to the one obtained with GN1 and AG2. However, the envelope opacity is larger in the iron peak layers with AGSS09 which prevents the shrinking of the convective envelope and the formation of the loop.

Finally, we have tested the effect of a core overshoot only during the He-burning phase. Our results show that for an overshoot of $0.2\,H_p$ and even $0.1\,H_p$, a loop can be formed with models computed with AGSS09, $Z = 0.014$ and $X = 0.70$. This suggests that the formation of a loop is closely related to the mass extent between two discontinuities: (1) the C/He discontinuity at the top of the helium burning core and (2) the H discontinuity left at the maximum penetration of the convective envelope.

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