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

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Stars more massive than about $3M_{\odot}$ sun 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 (Asplund et al. 2009) 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 to develop a loop in the HRD.

Introduction

When the central temperature reaches 10^8 K, intermediate and massive stars ignitiate helium in a non-degenerating 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 surrounding that core. Both these production of energy provide the total luminosity of the star. Actually 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 2 orders of magnitude brighter). Therefore the star has a large probability to be observed in that phase. The importance of one nuclear burning region to another plays an important role in the formation of a loop in the HRD [e.g. Salaris and Cassisi 2005].

In this work we wanted to compare the core He burning phase for $8M_{\odot}$ models computed with GN93 mixture (Grevesse and Noels 1993) and with models computed with the solar chemical composition, AGSS09 (Asplund, Grevesse, Sauval and Scott 2009), each with 'their' solar metallicity (Fig. 1). The models have been computed with the CLES evolutionary code (Scuflaire et al. 2008) 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 with GN93, Z=0.02, X=0.70, α_{ov} =0.0*
- ***AG1** for models with AGSS09, Z=0.014, X=0.72, α_{ov} =0.0*

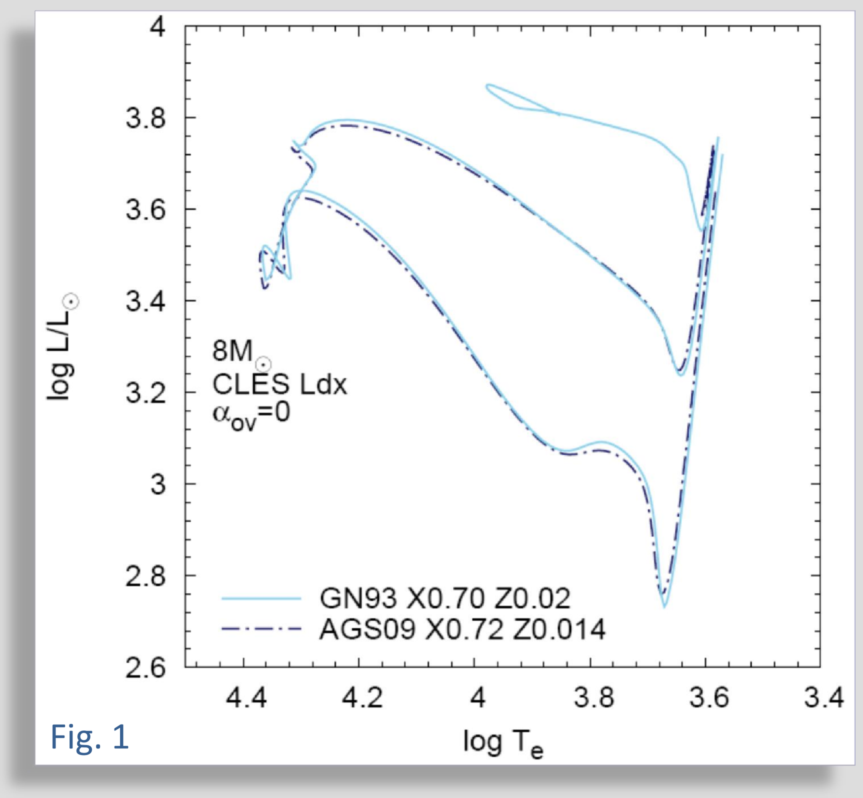

Fig. 1 HR diagram for $8M_{\odot}$ models computed with GN93 mixture (solid skyblue line) and with the colar composition AGSS09 (dashed midnight blue line).

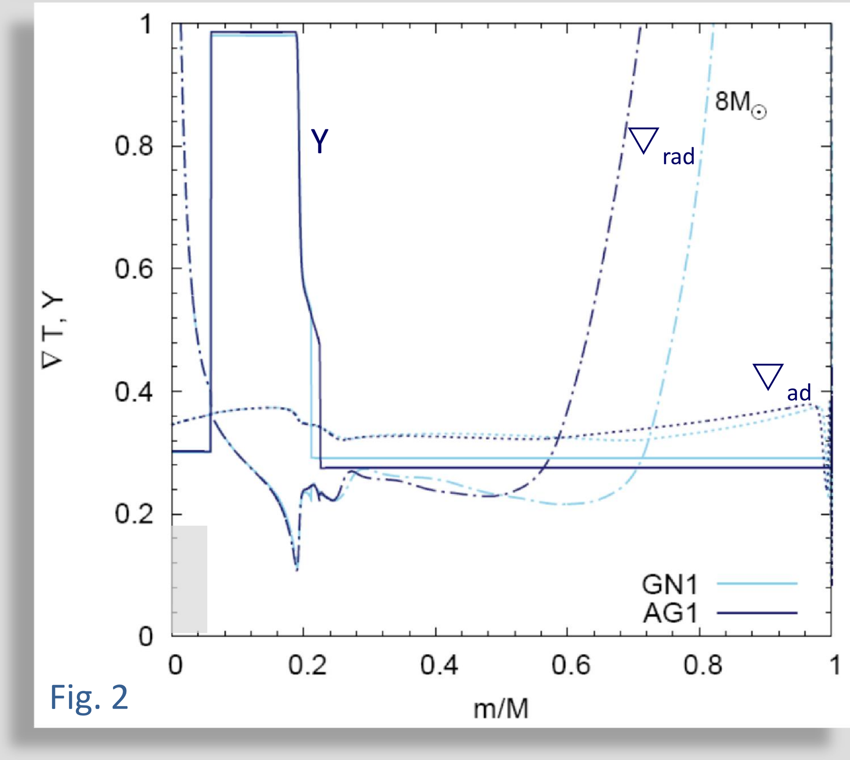

Fig. 2 Temperature gradients and Y profile as a function of the mass fraction in $8M_{\odot}$ stars for models GN1 and AGSS1. Solid lines stand for the He abundance, dotted and dashed lines correspond to the adiabatic and the radiative temperature gradient, respectively.

Fig. 1 shows that only the track computed with GN93 presents a loop during core He-burning.
The blue or red evolution of He-burning stars has been a lot inverstigated (e.g. Maeder and Meynet 2001). 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. Alongi et al. 1991, Stothers and Chin 1991, Renzini et al. 1992). 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.

Comparing the location of this H-discontinuity between GN1 and AG1 shows a much deeper location in GN model (Fig. 2) , which is in agreement with the argument described above:

H-discontinuity located at a mass fraction of - 0.212 for GN1
- 0.225 for AG1

Thus the envelope deepens into 78.8% of the mass of the star for GN1
77.5% of the mass of the star for AG1

In order to deepen the location of the H-discontinuity, 2 solutions are possible

Case 1 An undershoot below the convective envelope

Representative models AGSS09, Z=0.014, X=0.70 $\alpha_{ov\ env}$=0.3 **AG2**

An overshooting of 0.3 below the envelope is required to move the H-discontinuity location deep enough and hence to produce a loop for $8M_{\odot}$ models (see Fig. 3).

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. At the encounter, a sudden increase in this ratio is simultaneous to an increase in the effective temperature (Fig. 4).

H-discontinuity located at a mass fraction of 0.214 for AG2
Thus the envelope deepens into 78.6% of the mass of the star for AG2

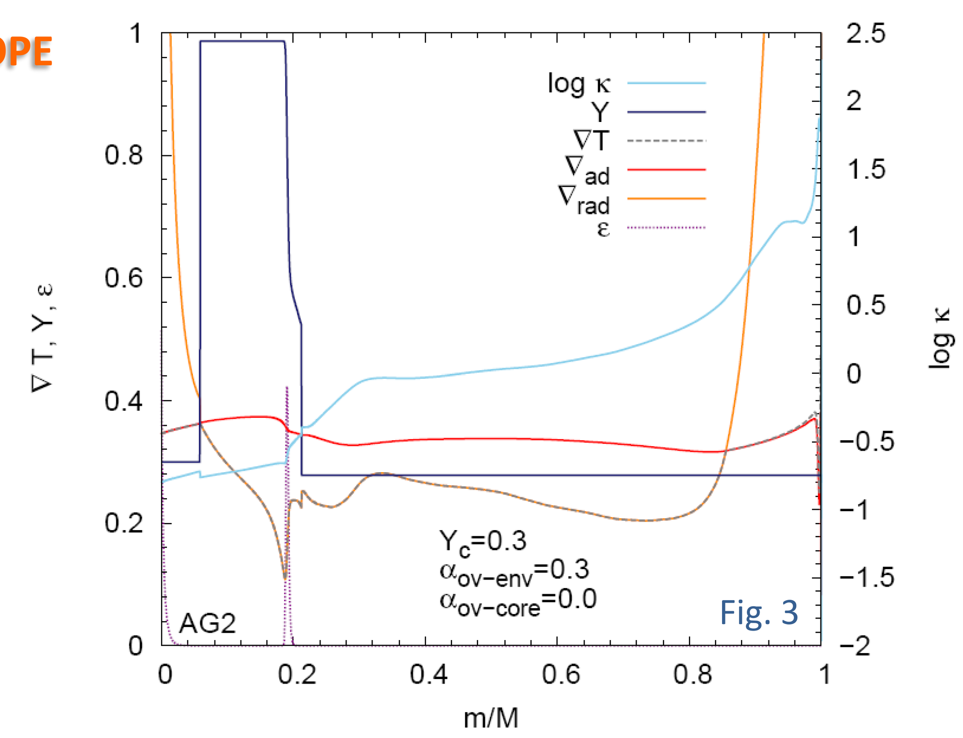

Fig. 3 Temperature gradients and Y profile as a function of the mass fraction in $8M_{\odot}$ star for AG2 models, at Y_c=0.3.

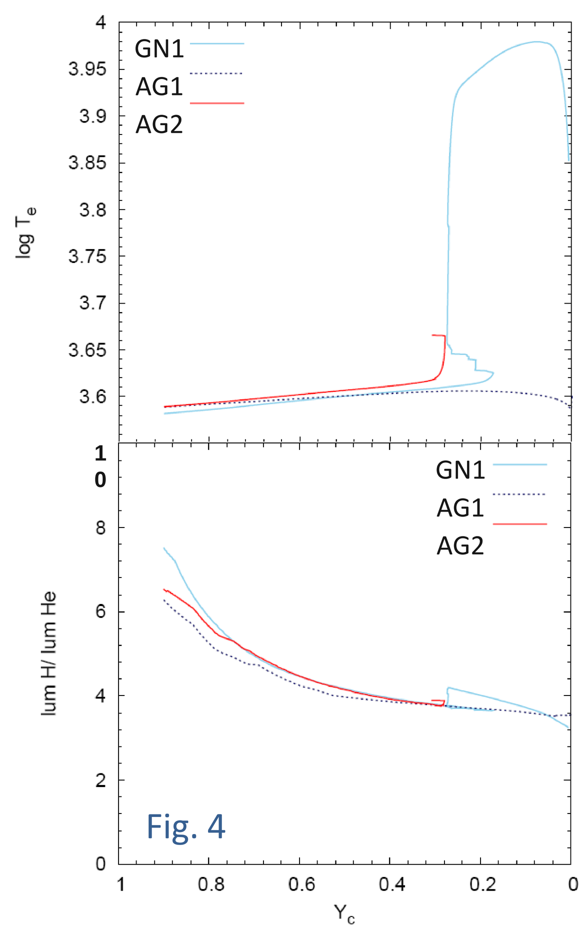

Fig. 4 Evolution of the effective temperature **(top panel)** and of the ratio between the energy produced by the H-burning shell and that produced by the He burning core **(bottom panel)** as a function of the central He abundance for $8M_{\odot}$ models computed with GN1, AG1, AG2 during core He burning.

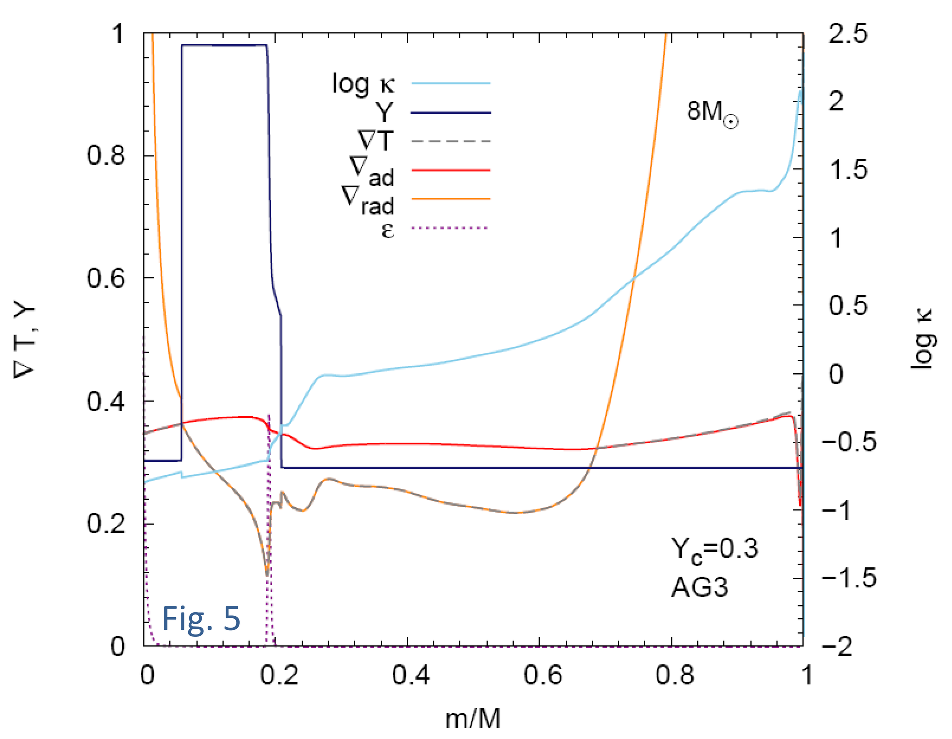

Fig. 5 Temperature gradients, Y and opacity profile as a function of the mass fraction in $8M_{\odot}$ star for AG3 models, at Y_c=0.3. The nuclear energy rate ε is also shown to illustrate the location of the H-shell.

Case 2 An increase in the metallicity

Representative models: AGSS09 mixture Z=0.02, X=0.70 **AG3**

With a metallicity of 0.02 and with the AGSS09 mixture, the H discontinuity is very close to the one obtained with GN93 (Fig. 5). 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.

H-discontinuity located at a mass fraction of 0.214 for AG3
Thus the envelope deepens into 78.6% of the mass of the star for AG3

Overshoot on top of the convective He core

Representative models AGSS09, Z=0.014, X=0.70 $\alpha_{ov\ core}$=0.2 **AG4**

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 and even 0.1, a loop can be formed. Our results suggest that the formation of a loop is closely related to the mass extent between 2 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 (Fig.6)

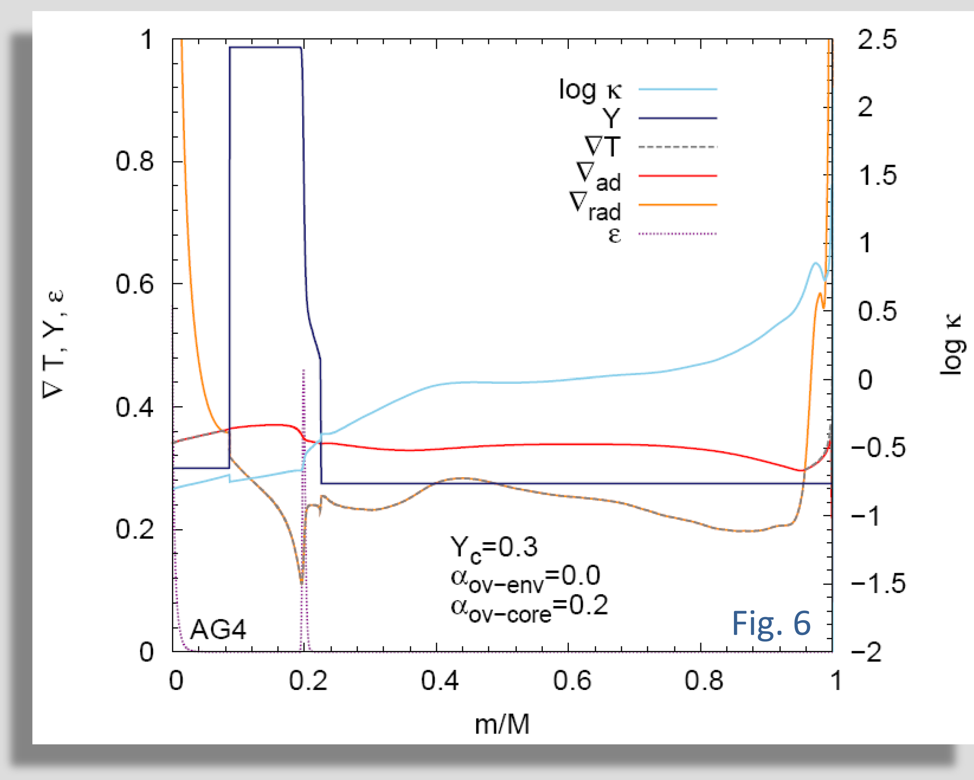

Fig. 6 Temperature gradients, Y and opacity profile as a function of the mass fraction in $8M_{\odot}$ star for AG4 models, at Y_c=0.3. The nuclear energy rate ε is also shown to illustrate the location of the H-shell.

References

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