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Research Note

On the convective envelope of AGB stars

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Abstract. We discuss evolutionary computations investigating the efficiency of the convective "drift" which should affect the location of the inner boundary of the convective envelope in cool giant stars. We find that the drift is at the work in structures undergoing the second dredge up, accelerating the sinking of the envelope into the inner He rich layers and producing smaller C-O cores at the onset of thermal pulses or at the C-ignition. However, such differences appear rather small, with mild consequences on the overall evolutionary scenario.

Key words: convection – stars: evolution – stars: interiors – stars: AGB and post-AGB

1. Introduction

More than twenty years ago it was convincingly demonstrated (Castellani et al. 1971) that the discontinuity in chemical composition at the edge of the convective cores in He burning stars induces the instability and, thus, the growing with time of these cores. The underlying mechanism appears rather straightforward: since the opacity of C enriched matter in the core is larger than the opacity of the surrounding He rich layers, even a microscopic amount of overshooting from the core causes a propagation of the convective instability until the radiative gradient at the inner boundary of the core matches the local value of the adiabatic gradient. In the following we will refer to such a mechanism as the convection "drift".

Much more recently, Boothroyd & Sackmann (1988) and Castellani et al. (1990) have drawn the attention to the evidence that quite a similar mechanism should be at work in red giant structures, when H rich convective envelopes sink into a He enriched stellar interior, since H opacity appears larger than opacity of He at the given local conditions. Such an occurrence has been further discussed in connection with Asymptotic Giant Branch structures undergoing the third dredge up (see e.g. Frost & Lattanzio 1996). However, to our knowledge no evolutionary sequence in the literature has properly taken into account the efficiency of such a mechanism during previous evolutionary phases and, in particular, during the first and the second dredge up. Because of numerical difficulties Boothroyd & Sackmann (1988) artificially limited the sinking of convection, whereas Castellani et al. (1990) simply neglected the mechanism. This is also the case for several evolutionary computations appeared in the literature, as Castellani & Tornambe' (1991) or Cassisi et al. (1996). Nor mention of the mechanism during the second dredge up can be found in relevant papers concerning AGB evolution such as, for instance, Herwig et al. (1997).

To investigate such an evolutionary feature, we performed a set of numerical experiments, computing stellar evolutionary models according to Wood's (1981) prescriptions for the newly mixed regions and by requiring that the bottom of the convective envelope extends till reaching the convective neutrality. In this way it becomes quite clear that all along the first red giant branch phase and the early AGB phase, preceding the second dredge up, the mechanism is quite inefficient, the extra-extension of the envelope being negligible. This can be easily understood since in those evolutionary phases the convective envelope is sinking into H rich layers and the chemical discontinuity at the bottom of the convective envelope is quite small.

However, for structures approaching the second dredge up the chemical discontinuity is not marginal and the mechanism should reach a seizable efficiency. Unfortunately, one finds that the simple computational procedure outlined above does not work any more, and the models experience random sudden growing of the envelope till failing to reach the convergence. In the next section we will discuss this point, shortly describing the computational procedure which allowed us to follow the development of the second dredge up under the quoted condition of convective neutrality. Evolutionary results for two selected models of 5.0 and 7.0 $M_\odot$ will be reported and shortly discussed.

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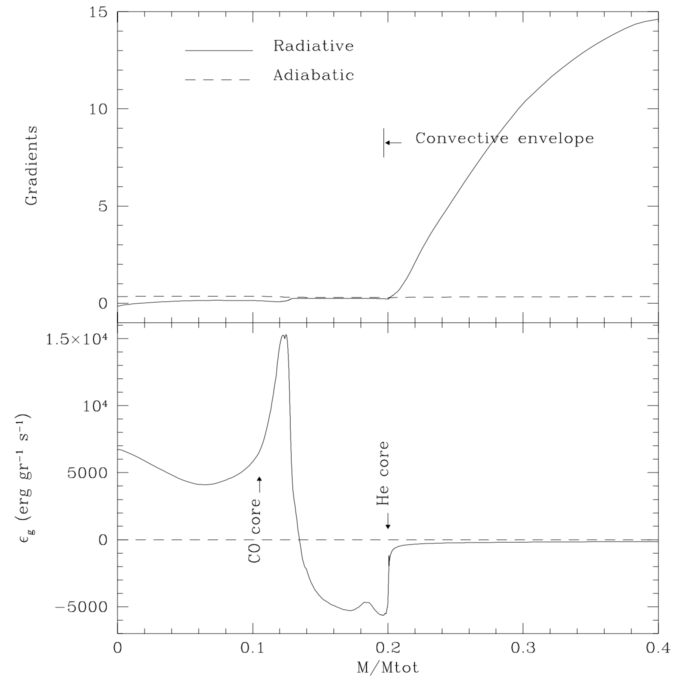

Fig. 1. The behavior of gradients (upper panel) and the run of the gravitational energy generation (lower panel) in the central region of a 7$M_\odot$ model, during the second dredge up.

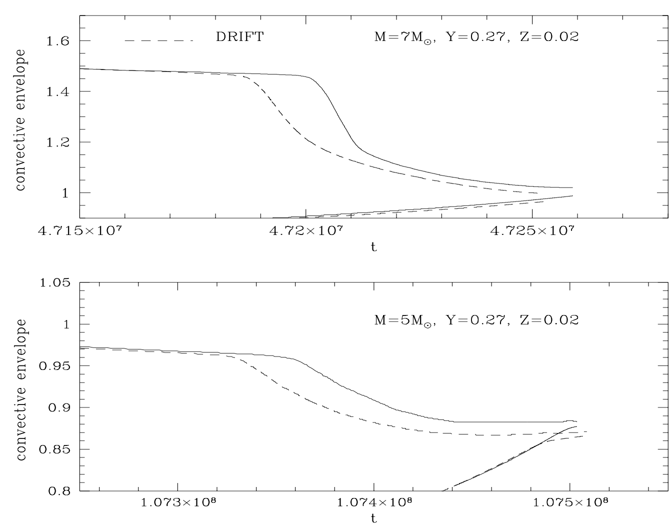

Fig. 2. The locations of the bottom of external convection and of the edge of the C-O core as a function of time for the model of 5.0 $M_\odot$ (lower panel) or 7.0 $M_\odot$ (upper panel). Full lines show the results when the drift is not taken into account.

2. Modeling the second dredge up

As quoted in the introduction, if one simply forces the bottom of the envelope to reach the convective neutrality, during the second dredge up the model starts to include abruptly several meshes, thus stopping the sinking for several time steps, until a new block of meshes is included. Such an occurrence can be easily understood as an evidence of a not negligible coupling between the chemical and physical structures of the models. As a matter of fact, the evaluation of the amount of mixing after the model convergence is correct only if the new distribution of matter has a negligible influence on the behavior of physical quantities (like pressure and temperature) throughout the structure. The quoted behavior of the models shows that this is not the case, and that the adopted numerical procedure tends to overestimate the amount of mixing.

A close inspection into the structure of models undergoing the second dredge up casts new lights on the origin of such a behavior. As an example, Fig. 1 (upper panel) shows the behavior of gradients in the internal region of a 7 $M_\odot$ together with the run of the gravitational energy generation through this region (lower panel). It appears that the inner portion of the structure is undergoing a rather complex mechanism of simultaneous contraction-expansion, with the bottom of external convection playing the role of a sort of external boundary for this mechanism. Numerical experiments show that even small variations in the location of the bottom edge of convection have deep consequences on the physical structure of the more internal layers unaffected by convection, accounting for the quoted evidence of a strong coupling between the extension of convection and the model structure.

To overcome such a spurious behavior, at each time step we allowed only a limited amount of mixing, followed by a series of models with much smaller time steps, so that the structure can readjust according to the mixing. By adopting such a procedure we were able to obtain satisfactory evolutionary models, following the second dredge up phase in two models with Z=0.02, Y= 0.27 and with masses 5.0 and 7.0 $M_\odot$, respectively. The 5.0 $M_\odot$ model was followed till the onset of thermal pulses, whereas the 7.0 $M_\odot$ model was stopped at the carbon ignition. Fig. 2 shows the run with time of the bottom of the convective envelopes for both models, as compared with similar results but for "normal" models where the drift of convection was not taken into account.

Tables 1 and 2 compare selected physical quantities for the final models with the same quantities but from a "normal" evolutionary code. The tables give the luminosity (in solar units) and effective temperature of the model, the mass of the CO core (M-CO) and the abundance by mass of He in the envelope (Y-env). As expected, one finds that both stars end the phase of quiet

Table 1. Selected physical quantities for the 5.0 Mo model at the onset of thermal pulses with or without drift of the convective envelope.

	No Drift	Drift
logL	4.388	4.254
M-CO	0.874	0.866
Yenv	0.299	0.301

Table 2. Selected physical quantities for the 7.0 Mo model at the ignition of C burning with or without drift of the convective envelope.

	No Drift	Drift
logL	4.434	4.432
M-CO	0.988	0.965
Yenv	0.339	0.341

He shell burning earlier and with smaller CO-core (and, thus, at lower luminosities). However, the differences between the two different assumptions about the drift appear rather small, with reduced consequences on the overall evolutionary scenario. As a conclusion, we find that the drift of the convective envelope does not cause relevant variations to the current evolutionary computations, solving in this way an - in principle - relevant open question of the current evolutionary scenario.

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