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A PECULIAR EFFECT OF CORE OVERSHOOTING ON THE INTERNAL STRUCTURE OF LOW-MASS STARS

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ABSTRACT With the aid of detailed stellar model computations, we analyse the consequences of applying a mild overshooting to 1.0 $M_\odot$ to 1.2 $M_\odot$ stars with solar metallicity. It is shown that solar models with a small convective core can be constructed, resulting in a decrease in the ^{8}B neutrino flux that can amount to 30% relative to the value obtained in models without convective core.

INTRODUCTION

It is by now accepted that convective penetration must be present at the border of convective cores (Zahn 1991). Evolutionary models taking this effect into account (Maeder and Meynet 1989) show a better agreement with observations. Such a treatment is, however, limited to intermediate-mass and massive stars, low-mass stars being supposed to have a radiative core. In fact, solar models with an "ad hoc" mixed core have been computed to try to explain the low value of the observed neutrino flux (see for example Provost *et al.* 1990, and Sienkiewicz *et al.* 1990). The origin of this assumed convective core is, however, unidentified.

The aim of this study is to show that a mixed core in a low-mass star can be the natural consequence of a mild overshooting applied at the end of the Pre-Main Sequence phase when a small convective core appears, which would otherwise disappear. Section 2 gives a brief description of the evolutionary code and the initial models, and Section 3 gives some results for the low-mass stars in the range 1.0 $M_\odot$ to 1.2 $M_\odot$. Consequences for the internal structure of the Sun are also presented. More complete results will be published elsewhere (Mowlavi and Forestini 1992).

THE MODELS

All models are computed with the hydrodynamical stellar evolution code developed by Forestini (1992). It is extended in order to include overshooting. The distance of overshooting is given by $d_{over} = \alpha_{over} \times H_p$. We limit the maximum growth of the convective core to twice its mass, so that

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$$d_{over} = \min(\alpha_{over} \times H_p, d_{2M_{cc}}),$$

where H_p is the pressure scale height evaluated at the border defined by the Schwarszchild criterium ($\nabla_{RAD} = \nabla_{AD}$), and $d_{2M_{cc}}$ is the distance over which the mass of the convective core doubles. Initial models are taken from PMS models calculated until the development of a small convective core. The initial abundances are taken from Anders and Grevesse (1989), and the rates of the pp and CNO reactions are taken from Caughlan and Fowler (1988).

For each overshooting parameter, we calibrate the initial He content (Y) of the 1 M$_\odot$ star to reproduce the solar luminosity within less than 1% at the age of the Sun. These values of Y (see Table 2) are not very different for the different overshooting parameters: they vary from $Y = 0.2752$ in absence of overshooting [which is the He abundance suggested by and Grevesse (1989)] to $Y = 0.2798$ for $\alpha_{over} = 0.30$. These adopted initial values are kept for the 1.2 M$_\odot$ star.

RESULTS

We find that an overshooting of $0.05 \times H_p$ maintains a convective core in the Sun during its first 2.5 billion years, and that an as mild overshooting as $\alpha_{over} = 0.10$ is enough to keep it throughout the entire hydrogen burning phase. The Sun's lifetime is affected very little by the core mixing: with $\alpha_{over} = 0.20$, it is only 7.6% longer than the standard case without convective core.

The 1.2 M$_\odot$ star has, without overshooting, a very small convective core containing a minimum of 0.22% of the total mass of the star (at the age of 2 billion years), which grows to 5.11% toward the end of hydrogen burning (at 4.3 billion years). This growth is due to the enhancement of the energy contribution from the CNO cycle. When an overshooting of $\alpha_{over} = 0.20$ is applied, this enhancement is not present and the convective core receeds gradually from 14% in mass at the beginning of the MS phase to 5% at the age of 5.9 billion years. The time spent to burn its central hydrogen is then increased by 21.3% (see Table 1).

TABLE I Lifetimes (in 10^9 yr) of the convective core (t_{cc}) and the Main Sequence phase (t_{MS}) for 1.0 M$_\odot$ and 1.2 M$_\odot$ stars

α_{over}		0.00	0.05	0.10	0.20
1.0 M$_\odot$	t_{cc}	0.16	2.56	9.59	10.98
	t_{MS}	10.20	10.22	10.32	10.98
1.2 M$_\odot$	t_{cc}	4.83	4.89	5.25	5.97
	t_{MS}	4.92	5.05	5.30	5.97

We want to make a comment on the – arbitrary – constraint that the extended convective core has a maximum possible mass of twice the mass of the classical convective core. In the case of the solar models, this constraint limits the growth of the convective core due to overshooting. It seems reasonable to impose a maximum extension, but its amplitude is arbitrary as long as a reliable theory of overshooting has not been developed. Maeder and Meynet (1989) adopt a maximum extension in terms of the radius of the convective border, $d_{over} = \min(\alpha_{over} \times H_p, 0.25 \times R_{conv})$, which gives a slightly less extended core than ours, but it has no effect in their results as they do not predict convective cores for stars less massive than 1.1 $M_\odot$.

Finally, we present in Table 2 the mass of the convective core that is expected in the Sun when overshooting is taken into account, the hydrogen abundance at its center and the neutrino flux from ^{8}B decay relative to the case without overshooting. The flux reduction amounts up to 30% for $\alpha_{over} = 0.30$, with a convective core containing 14% of the solar mass.

TABLE II Initial He content Y, mass contained in the convective core of the Sun (M_{cc}), central hydrogen abundance in mass fraction [X_c(H)], and expected ^{8}B neutrino flux for different overshooting parameters. The flux is normalized to the value obtained in absence of overshooting ($\alpha_{over} = 0$)

α_{over}	0.00	0.05	0.10	0.15	0.20	0.25	0.30
Y	0.2752	0.2752	0.2762	0.2772	0.2784	0.2789	0.2798
M_{cc}	0.000	0.000	0.035	0.074	0.106	0.132	0.143
X_c(H)	0.369	0.387	0.461	0.493	0.512	0.530	0.530
^{8}B ν flux	1.00	1.00	1.04	0.92	0.84	0.71	0.71

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