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Uncertainties in the chemical composition of B-type stars: effects on the opacity and on the excitation of pulsation modes

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Abstract

Recent determinations of element abundances in early-B stars have shown a significant discrepancy with those derived for the Sun. β Cep pulsators are early-B stars whose pulsations are driven by the opacity mechanism operating at the Fe-group opacity bump (e.g. Dziembowski & Pamyatnykh 1993). Since each element contributes differently to the stellar opacity in the Z-bump region, differences in the metal mixture may affect the pulsation properties of these early-B stars. Here we study the role of different elements in the stellar opacity of B-type stars, and the consequences of the uncertainties in the composition of the metal mixture for the instability strip of β Cep stars.

Introduction

In the new solar mixture derived by Asplund et al. (2005, AGS05), the abundances of the elements that contribute the most to the metal mass fraction (Z), that is C, N, O, and Ne, decreased by 38% with respect to the Grevesse & Noels (1993) mixture (GN93), while that of Fe (generally used in deriving stellar metallicities) decreased by 15%. The solar metallicity (Z/X) has changed from 0.0245 down to 0.0167. For a fixed Z, the Fe mass fraction in the AGS05 mixture has increased by $\sim$25% with respect to the one in the standard GN93. While the lower O abundance in AGS05 ruins the good agreement between the solar model and the seismic one, a larger Fe mass fraction favourably affects the excitation of β Cep pulsation modes in early-type stars. But, is the solar mixture adequate to describe the chemical composition of B-type stars?

The examination of a sample of 150-200 early-B stars carefully selected in the literature (Morel 2009) has revealed that the element abundances in early-B stars in the solar environment are systematically and significantly lower even than those derived by AGS05 for the Sun. Is this discrepancy real or, on the contrary, are the B-star abundances underestimated due to theoretical uncertainties in atomic models or due to problems in the derivation of atmospheric parameters as claimed by Przybilla et al.(2008)? In addition to questions concerning the chemical evolution of the Galaxy, the pattern of element abundances derived by Morel (2009) (hereafter B-dwarfs Mix.) has important implications for the pulsation studies of β Cep stars.

Results

We have computed the contribution of each metal to the total opacity in a typical β Cep star. The results for the most relevant elements are shown in Fig. 1.

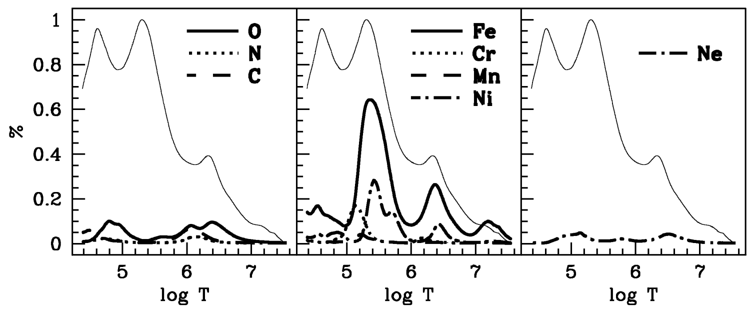

Figure 1: Opacity profile inside a 10 $M_\odot$ model (solid thin line) in the middle of the main sequence, and relative contribution to opacity of different elements: CNO (left panel), Fe-group elements (center) and Ne (right).

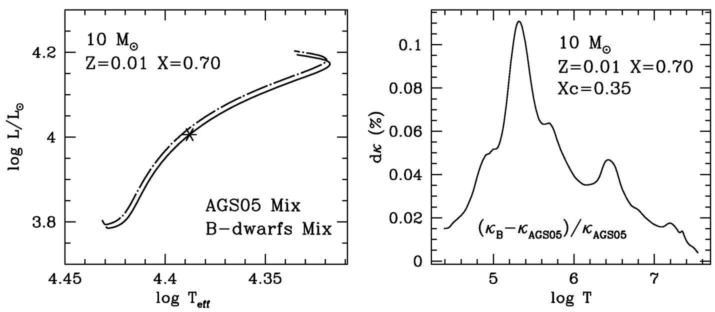

Figure 2: Left: main-sequence evolutionary tracks of 10 $M_\odot$ models computed with OPAL opacity tables for two different metal mixtures: AGS05 (dash-dotted line) and the one derived for B-dwarfs in the solar vicinity (within 1 kpc, in solid grey line). The asterisk marks the location of the model used in the right panel plot. Right: relative difference of opacity between AGS05 and B-dwarf mixtures for a fixed stellar structure of a 10 $M_\odot$, $X = 0.70$, $Z = 0.01$ model at the middle of the main sequence.

For a given metal fraction Z, the B-dwarfs Mix contains less C (17%), N (15%), O (2%), Al (41%), Si (55%) and Mg (2%) than the AGS05 mixture, and more Ne (26%), S (34%) and Fe (17%). For the other elements contributing to Z, the abundances of AGS05 are used, implying an increase of 30% for the remaining Fe-group elements (Cr, Mn, and Ni).

The effect of the difference of opacity on the evolutionary track is shown in the left panel of Fig. 2 where two main-sequence evolutionary tracks of a 10 $M_\odot$ star are plotted. The tracks were computed for fixed mass fractions of hydrogen (X) and metals (Z). The metal composition is different in the two cases and corresponds to AGS05 and to the B-dwarfs mixture. The higher opacity of the latter leads to a cooler track. Since the main contribution to κ comes from Fe-group elements, the difference shown in the right panel of Fig. 2 reflects the different relative contribution of the Fe-group elements to Z.

A higher and larger κ-peak at $\log T \sim 5.3$ implies a larger instability strip as well as a larger frequency domain of excited modes. In Fig. 3 we show the results of the nonadiabatic computation of oscillation frequencies for the models in the two evolutionary tracks of Fig. 2.

The abundance of Ne has recently been a matter of debate (see e.g. Morel & Butler 2008

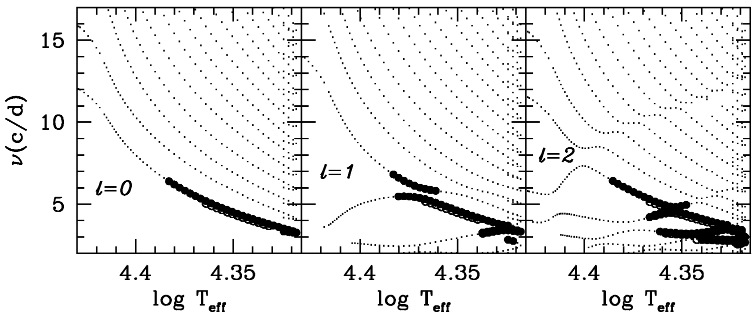

Figure 3: Frequencies of $\ell = 0$, 1 and 2 pulsation modes as a function of log $T_{\rm eff}$ for MS models of 10 $M_\odot$ in Fig. 2. Excited modes are symbolized by large-open circles (AGS05-mixture models) and large-solid circles (B-dwarfs).

and references therein). The contribution of Ne to κ at the bottom of the solar convective region is of the order of 20%, therefore, an increase of Ne could help to recover the agreement with helioseismic constraints as suggested by Bahcall et al. (2005). For early-B stars, however, the density at log $T_{\rm eff} \sim 6.3$ is almost two orders of magnitude smaller than in the Sun and the role of Ne in the opacity is almost negligible (Fig. 1). The effect of Ne on pulsation properties of β Cep stars is only a collateral one. In fact, varying Ne for a given Z will change the Fe-group relative abundance. The difference in Ne abundance between Cunha et al. (2006) and AGS05 has only a slight effect on the instability strip of B-type stars.

Conclusions

Since each element contributes differently to the stellar opacity in the Z-bump region, differences in the metal mixture for a given Z may significantly affect the excitation of β Cep pulsation modes. The determination of the detailed element abundances is essential for the stability analysis of β Cep stars.

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Session 6
What about real stars ?