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Asteroseismology of the β Cephei star HD 129929 Effects of a change in the metal mixture.

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Abstract

We show that the constraints on the mass and on the rotation law in the envelope of the β-Cephei star HD129929 are robust against a change in the metal mixture. The constraints on the metallicity and on the overshooting parameter, however, are dependent on the assumed metal mixture.

Introduction

β Cephei stars are excellent targets for asteroseismology. Indeed, these stars have a relatively simple structure, made of a convective core surrounded by a radiative envelope. Their pulsation modes are low-order pressure and gravity modes, and some of the excited modes in those stars have a mixed pressure-gravity character. These mixed modes probe the interior of the star, while having a large amplitude at the stellar surface. The frequency spectrum of β Cephei stars is sparse, allowing a relatively easier mode identification than for lower-mass pulsators.

Several very precise frequencies were recently obtained by Aerts et al. (2004) for the β Cephei star HD129929. The modes of pulsation associated with these frequencies have been identified, giving one radial mode ($f_5 = 6.590940$ cd^{-1}), the three components of a $l = 1$ triplet ($f_2 = 6.978305$ cd^{-1}, $f_4 = 6.990431$ cd^{-1}, $f_6 = 6.966172$ cd^{-1}) , and two consecutive components of an $l = 2$ quintuplet ($f_1 = 6.461699$ cd^{-1}, $f_3 = 6.449590$ cd^{-1}).

Stellar models were computed for this star, using the *Code Liégeois d'Evolution Stellaire* (CLES) and the Warsaw-New Jersey evolution code (Aerts et al. 2003, Dupret et al. 2004). The evolutionary tracks were computed for different values of the mass M, the hydrogen and metal fractions X and Z, and the overshooting parameter α_{ov}. We then performed a frequency fitting, trying to find the stellar models for which the theoretical frequencies match the observed ones. Along each evolutionary track we selected the model which fits one of the two well identified axi-symmetric modes, here, f_2. Searching amongst these selected models those which also fit the other axi-symmetric mode, here f_5, then gives a relation between two of the four free parameters, for given values of the other two. For example, if the overshooting parameter and the hydrogen fraction are fixed, we get a relation between the mass and the metallicity for the models fitting exactly f_2 and f_5. Finally, for all the models fitting exactly f_2 and f_5, we compare the value of the theoretical frequency for the axi-symmetric mode of degree l=2 to the four possible observational values for this mode. Indeed, given that we have two consecutive frequencies for this quintuplet, there are four possible values for the frequency of the axi-symmetric mode. The results are shown as plain lines in figure 1, for a fixed value of $X = 0.70$. We show the frequency of this mode as a function of metallicity in the left panel, and as a function of the mass in the right panel, for different values of the overshooting parameter.

Effects of a change in the metal mixture on the mass, metallicity, and overshooting parameter.

All the calculations described in the previous paragraph were performed assuming a standard solar metal mixture. In order to study the influence of the assumed metal mixture, we performed those calculations again, using a different metal mixture. We present here the results obtained with a metal mixture containing five times more iron than the standard solar mixture. Even though this is obviously an ad-hoc assumption, the results will tell us which of the conclusions we reached for the star parameters and rotation law are robust against such a change in composition, and which ones are not. Moreover, Pamyatnykh et al. (2004) have shown that some of the modes in the β cephei star ν Eri are not excited unless the iron fraction in the excitation layer is higher than solar.

We followed exactly the same procedure as the one described in the previous section to find the models which fit the observed axisymmetric frequencies f_2 and f_5, and the values for the theoretically calculated frequency of the axisymmetric $l = 2$ mode are shown in figure 1 as dashed lines.

The two vertical lines in the left panel of figure 1 are the constraints obtained on the metallicity Z with a non-adiabatic analysis, in the case of a standard solar mixture. The modes observed have to be excited, which imposes a lower limit on Z, and the theoretical amplitude ratios must be in agreement with

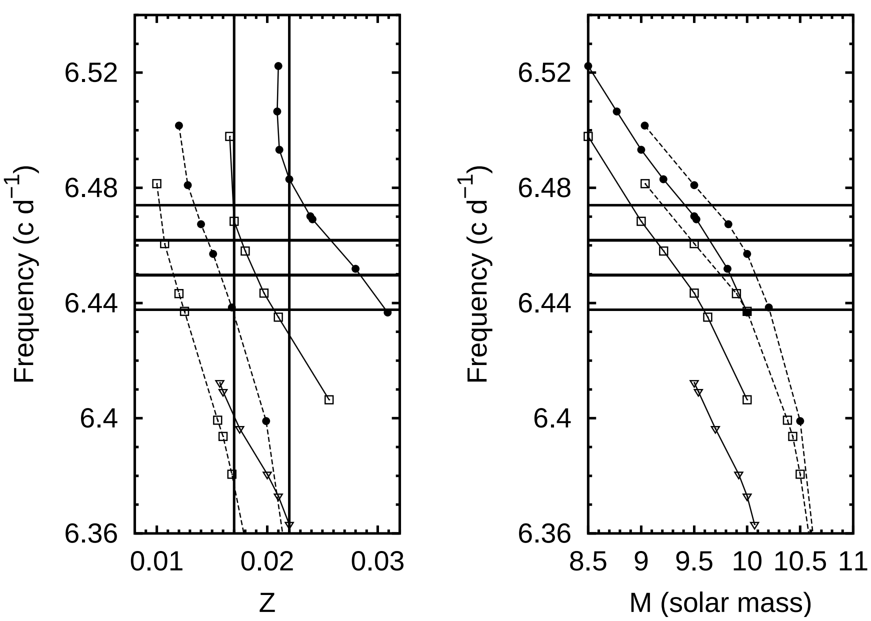

Figure 1: Frequency of the $l = 2$ g_1 axisymmetric mode, as a function of the metallicity in the left panel, and as a function of the mass in the right panel. The full lines are the results obtained with a normal solar mixture of chemical elements, while the dashed lines are obtained with an increased iron content. The theoretical results obtained for models fitting exactly f_2 and f_5 are represented by squares, circles and triangles for models with $\alpha_{ov} = 0$, 0.1 and 0.2 respectively. The four possible values for the observed frequency of this mode are given by the horizontal lines.

the observations, which gives an upper limit on Z. A similar analysis should be performed using the non-standard mixture.

In figure 2 we show two evolutionary tracks, and along those tracks, we show as dots stellar models which have the same values for three frequencies: f_2, f_5, and the axisymmetric $l = 2$ g_1 mode. The plain line represents the evolution of a star with the standard solar metal mixture, $X = 0.70$, $M = 10$, $Z = 0.0309$, $\alpha_{ov} = 0$; the dotted line is obtained with an iron-enriched (5 times) metal mixture, $X = 0.70$, $M = 10.204$, $Z = 0.0168$, $\alpha_{ov} = 0$. The models which fit the three same frequencies have an age of 12.839 and 14.830 million years respectively; a central hydrogen fraction of $X_c = 0.406$ and $X_c = 0.373$, and a convective core mass of $M_c/M = 0.224$ and $M_c = 0.243$.

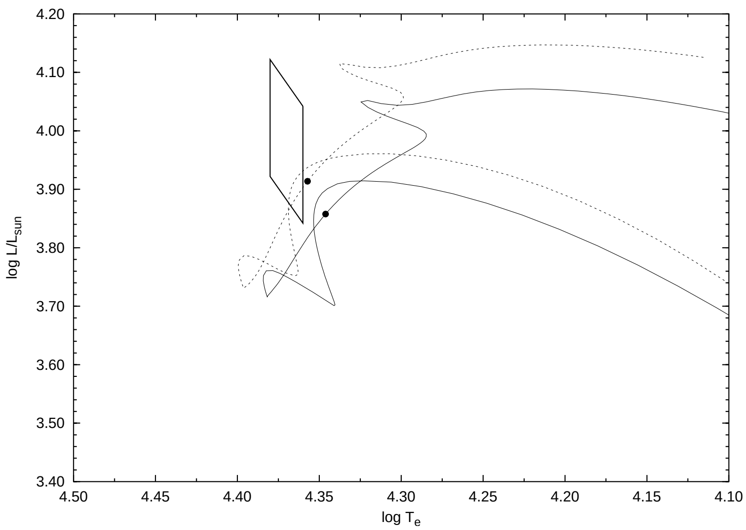

Figure 2: Evolutionary tracks of a star with the standard solar mixture (plain line) and a star with an iron-enhanced metal mixture (dotted line). The dots represent models which fit the same three frequencies, corresponding to the observations. The box is the observational error box on the effective temperature and the luminosity

Conclusions

Using the standard solar mixture, we concluded that the overshooting parameter had to be smaller than 0.15 and larger than 0.05; the mass of the star was between 9 and 9.5 $M_{\odot}$, the age was between 16 and 18 million years, and $0.016 \leq Z \leq 0.02$ (Aerts et al. 2003, Dupret et al. 2004).

With the iron-rich mixture, we see that the models which fit the three observed frequencies have a much lower metallicity and that the constraints on the overshooting parameter are very much dependent on the chosen metal mixture (see left panel of fig. 1). On the other hand, the range of acceptable masses for the star is not changed by a large fraction, with a mass slightly higher with the new metal mixture.

Constraints on the internal rotation

Using the two observed rotational splittings for this star, Aerts et al. (2003) and Dupret et al. (2004) have shown that rigid-body rotation can be ruled out in the envelope of this β cephei star.

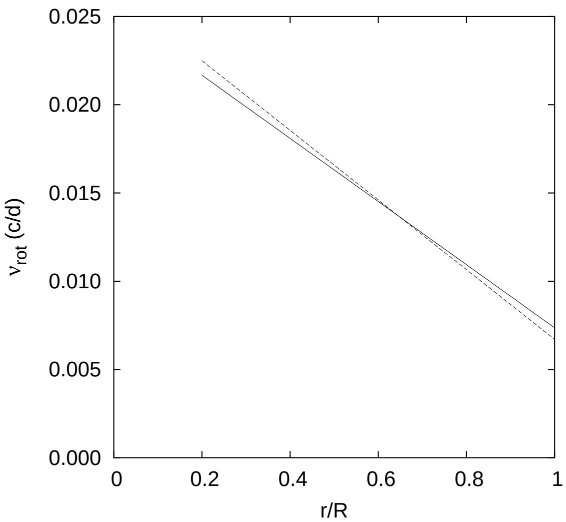

Figure 3: The rotation law deduced with the standard metal mixture (solid curve) and with enhanced Fe (dashed curve).

We use the same method as described in Dupret at al. (2004) to describe the rotation in the star in the case of the iron-enhanced metal mixture. If the star rotates rigidly, we can write

$$\Omega = \Delta\sigma/\beta$$

where Ω is the (constant) angular rotation frequency, $\Delta\sigma$ is the frequency splitting, and β is the usual Ledoux splitting constant. We find, again, that the two splittings are inconsistent with a rigid rotation. Since we have two constraints (from the two multiplets) we consider a linear law of the form (Ω_0 is the surface angular velocity)

$$\Omega(x) = \Omega_0 + (x-1)\Omega_1\,.$$

We get a system of two equations with two unknowns

$$\Delta\sigma_i = \beta_{0,i}\Omega_0 + \beta_{1,i}\Omega_1\,, \quad i = 1, 2$$

where the values of $\beta_{0,i}$ and $\beta_{1,i}$ for our best model are given by

	β_0	β_1
$\ell = 1,\ p_1$	0.960637	-0.288077
$\ell = 2,\ g_1$	0.803517	-0.340458

These values are very close to those obtained with the standard mixture. Figure 3 shows that the resulting change in the rotation law is insignificant. The corresponding equatorial velocities are 2.143 and 1.981 km s^{-1} for the standard and the Fe enhanced metal mixture models respectively.

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