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Asteroseismic analysis of the structure of HR1217

M.S. Cunha

Centro de Astrofísica da Universidade do Porto, Portugal and Instituto Superior da Maia, Portugal

J. Fernandes

Observatório Astronómico da Universidade de Coimbra, Portugal and Departamento de Matemática da Universidade de Coimbra

M.J.P.F.G. Monteiro

Centro de Astrofísica da Universidade do Porto, Portugal and Departamento de Matemática Aplicada da Faculdade de Ciências, Universidade do Porto, Portugal

Abstract. HR1217 is probably the best studied multi-periodic rapidly oscillating Ap star. In the present work we combine the observational data available for HR1217 and use it to constrain theoretical models of this star. In particular we try to establish which unknown model parameters are the most relevant to reproduce the seismic data.

1. HR1217

Pulsations were first found in HR1217 by Kurtz (1982), and have later been confirmed both in radial velocity data (Matthews et al. 1988), and in multi-site photometric campaigns (Kurtz et al. 1989, Kurtz et al. - in preparation).

Its parallax was measured by Hipparcos, from which different determinations were made of its luminosity. Some uncertainty is added in this process, as bolometric corrections of Ap stars are very hard to determine. In this work we consider the value L=7.8±0.7$L_\odot$ from Matthews et al. (1999).

Effective temperatures are particularly hard to determine in Ap stars. In the case of HR1217, photometric determinations based on Moon & Dworetsky (1985) give an effective temperature of $T_{\rm eff}$=7400±100 K (Martinez 1993, Matthews et al. 1999), while spectroscopic determinations give a smaller value of $T_{\rm eff}$=7250 K (Ryabchikova et al. 1997). The value derived by Martinez (1993) is used, but, taking into account the spectroscopic result, we assume an uncertainty in the effective temperature of +100/−200 K.

Finally, Ryabchikova et al. (1997) carried out spectroscopic observations of HR1217 from which they made a detailed surface abundance analysis. Using their determination for the iron [Fe/H]∼−0.34 (which we assume represents well the abundance of heavy elements) we compute Z=0.009 (assuming Y=0.26 for the star and Z/X=0.0245 for the Sun).

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2. Asteroseismology

The simplest quantity that can be identified in the oscillation spectrum is a regular spacing corresponding to the separation between modes of same degree and consecutive orders. This quantity - the *large frequency separation*, is defined as $\Delta\nu_{n,l} \equiv \nu_{n+1,l} - \nu_{n,l}$, where $\nu_{n,l}$ is the eigenfrequency of the mode of degree l and order n. This separation is a function of frequency (e.g. Monteiro et al. 2001). At higher frequencies the frequency dependence of the large separation is hardly noticeable, and therefore we can evaluate the latter at a fixed value of the frequency. Accordingly, and having in mind the observations available for HR1217, we consider as a reference value for the large separation in this star that given by $\Delta\bar{\nu} \equiv \Delta\nu(\nu{=}2653\mu\mathrm{Hz})$. The observed value is $\Delta\bar{\nu}_{\mathrm{obs}}{=}67.91{\pm}0.12\mu\mathrm{Hz}$.

From asymptotic analysis this quantity is expected to scale with the sound speed travel time of the star

$$\Delta\bar{\nu} \propto \left(2\int_0^R \frac{\mathrm{d}r}{c}\right)^{-1} \propto \left(\frac{M}{R^3}\right)^{1/2} . \tag{1}$$

This implies that a given star changes its large separation along the main sequence mainly due to changes of its radius.

The seismic data on the star must be consistent with all other observables for the star (see Monteiro et al. 2001). In particular it has to be consistent with the radius, which is a direct consequence of the measured luminosity and effective temperature. Unlike the radius, there are several aspects of the structure of ρAp stars that cannot be determined directly from the observations, and have to be described by parameters included in the models. At this point we consider as unknown parameters the helium abundance Y, the abundance of heavy elements Z, and those parameters related to the mixing length, α, and the amount of overshooting in the convective core α_{ov}. Moreover, as HR1217 does not belong to a binary system, its mass cannot be determined by direct observations either.

We note that, even though the abundance of heavy elements at the surface of HR1217 might be determined from the observations, that abundance is not necessarily a good representation of the abundance in the interior of the star. Introducing the correct treatment of diffusion in stellar models is particularly difficult when Ap stars are concerned, due to the presence of magnetic fields which strongly affect the diffusion process. Thus, even though surface chemical abundances are available for some Ap stars, one might not easily deduce the interior chemical abundances from the latter.

Clearly, there are different evolutionary tracks, corresponding to different combinations of the parameters, that satisfy the star luminosity and effective temperature. Our goal is to combine the extra constrain provided by the frequency separation in an attempt to discriminate between some of these equally valid solutions. Even though the modelling parameters introduce uncertainties in the output models, not all these uncertainties will propagate in the same way into the theoretical oscillation spectra of the stars.

3. Results

The effects of the different unknowns on the large separations of ρAp stars should be compared, before a more detailed investigation is carried on. To that

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aim we evolved a reference model and, keeping all but one of the unknown parameters constant at each time, we evolved new models which we compared with the reference one. All stellar models used here are computed using the *Code d'evolution stellaire adaptative et modulaire*, CESAM (Morel 1997).

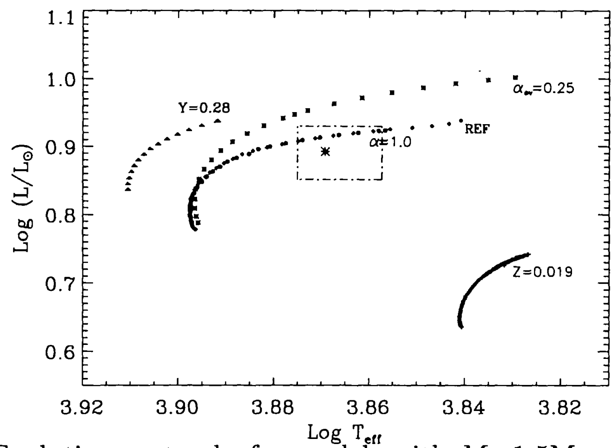

Figure 1. Evolutionary tracks for models with M=1.5$M_\odot$. The reference model (diamonds) has α=1.6, α_{ov}=0.0, Y=0.26 and Z=0.009. To evolve the other models, all but one (whose new value is shown in the figure) of the parameters characterising the reference model were kept constant. Also shown is the observed effective temperature and luminosity (big star) and the box of the corresponding uncertainties.

Figure 1 shows the evolutionary tracks for models with a mass M=1.5$M_\odot$. The reference model has α=1.6, α_{ov}=0.0, Y=0.26 and Z=0.009. This figure illustrates how, at constant mass, the effect produced in the evolutionary tracks by a change in the abundance of heavy elements Z, is much greater than the effect produced by a change in any of the other parameters. This implies that models with different Z might only be reconciled with the same observed effective temperature and luminosity if their masses are significantly different. Thus, we expect that models with different sets of parameters (M, Z), all reproducing the observed effective temperature and luminosity of HR1217, will produce oscillation spectra that are more easily differentiated than those produced by models in which a different pair of parameters is changed. Consequently, we now turn our attention to the dependence of the oscillations of models appropriate to HR1217 on the abundance of heavy elements Z.

Figure 2 shows the evolutionary tracks of four models, each characterised by a different pair of parameters (M, Z). From each of the evolutionary tracks shown, we have chosen a model lying within the box of uncertainties for the observed effective temperature and luminosity of HR1217. Oscillation spectra appropriate to these models were calculated, by means of a linear, adiabatic oscillation code with a surface boundary condition which is fully reflective.

In order to compare with the observations we correct the large separations using Eq. (1). We note that the change in the mass needed to bring all four models to exactly the same radius is very small, and thus can be neglected. We find that the large separations of models with a lower abundance of heavy elements have values that are closer to that observed. However, the error bars due to the uncertainty in the radius of the star are very large, making it hard

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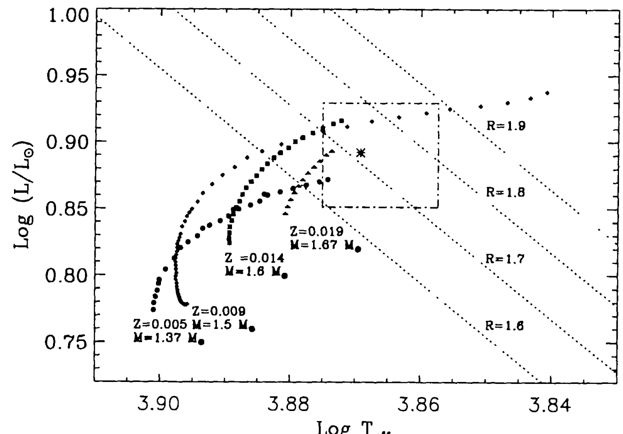

Figure 2. Evolutionary tracks for models with M=1.37M$_\odot$ and Z=0.005 (circles), M=1.5M$_\odot$ and Z=0.009 (diamonds), M=1.6M$_\odot$ and Z=0.014 (squares) and M=1.67M$_\odot$ and Z=0.019 (triangles). Also shown are lines of constant radius (dotted lines) and the observed effective temperature and luminosity (big star) together with the corresponding box of uncertainties.

to discriminate between our models, based on the observed oscillation spectrum - see also Cunha et al. (2002) for further details.

It is also of interest to consider the mass and abundance of heavy elements that a stellar model would have, if its radius and large separation were equal to the corresponding observed values. From Eq. (1) we estimate that mass to be M=1.37M$_\odot$, and with the evolutionary code we find that a model with that mass would only cross the luminosity and effective temperature of HR1217 (see Figure 2) if its abundance of heavy elements were Z=0.005. Moreover, the age at which the star would reach that point in the HR diagram would be 1.8 Gy. Clearly this is not a plausible model for HR1217.

To summarise, if we were to assume for a moment that the abundance of heavy elements is the only unknown in the modelling of HR1217, we would conclude that the interior abundance of heavy elements of this star is not most probably solar. However, the large uncertainties associated with the values of its effective temperature and luminosity do not allow us to rule out any of the models considered based solely on its oscillation spectrum.

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