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Effects of diffusion of chemical elements on the period structure: an experiment with the pulsating DA white dwarf GD 165

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Abstract. An important result of our previous work on GD 358 (Fontaine & Brassard 2002) was that the diffusion of chemical species bears an imprint on the period structure of the DB white dwarfs. The purpose of this present work is to take another look at the effects of diffusion on the structure of a star, but this time on white dwarfs of the DA (ZZ Ceti) kind. We present here results from an analysis of the pulsation periods of the pulsating DA white dwarf GD 165.

Key words. Stars: interiors – Stars: diffusion – Stars: oscillations – Stars: white dwarfs

1. Introduction

The DA white dwarf GD 165 star has already been observed by us at the Canada-France-Hawaii Telescope in 1990 (Bergeron et al. 1993) and also in 1995. From the latter run, totalizing nearly 32 hours of observations, we have uncovered six distinct pulsation modes. A recent analysis of the optical spectrum of GD 165 gives the following atmospheric parameters: an effective temperature of $11,980 \pm 200$ K and a surface gravity (log g) of 8.06 ± 0.05 (Bergeron et al. 2004).

In the past, the effects of diffusion on the DA white dwarfs stars have been mostly overlooked. One of the reasons, besides the complexity of the computations, was because it was believed that the relative thickness of the H and He layers was ”thin” (like, for example, about 10^{-8} $M_\star$ or lower for H). In such case, the diffusive time-scale is short in comparison to the evolutionary time-scale and one could consider that the diffusive equilibrium was already reached. Thus the use of the much simpler equilibrium solution (no time dependency) was used to determine the run of chemical elements in the envelopes of our models. However, recent results [see, for example, papers from the group of Corsico et al., Pesh (2005, Ph.D. thesis), this work, and others in preparation] show that many pulsating DA white dwarfs have ”thick” layers. The canonical values for ”thick” layers are about 10^{-2} $M_\star$ for He and 10^{-4} $M_\star$ for H. These values do not come out straight from a hat, but represent the maximum values of H and He that can be left after the nuclear burning phases. This last case is more problematic because the diffusive time-scale is now comparable to the evolutionary time-scale. The reason is that the transition zones are now much more deeper in the star.

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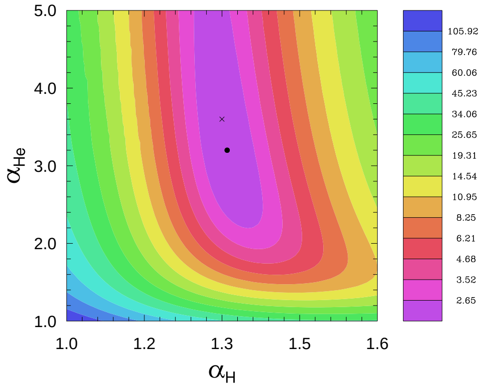

Fig. 1. Goodness-of-fit values [$\chi^2 = \sum(\mathrm{P(obs)} - \mathrm{P(model)})^2$] for the six observed periods of GD 165 assuming different steepness values of the composition gradient in the composition transition zones. The best fit value, given by $\chi^2 = 2.00$, is found at α_H=1.31 and α_{He}=3.20 and shown as the big dot on the figure. Value obtained from the evolutionary sequence with full diffusion computations is shown as the cross on the figure and is given by $\chi^2 = 2.03$ at α_H=1.3 and α_{He}=3.6. One can note that the usual diffusion equilibrium solution (α_H=α_{He}=1) gives a bad value of $\chi^2 = 140.71$.

Full evolutionary computations with diffusion of chemical species are now needed to know the exact shape of the transition zones.

We have computed an evolutionary sequence of a .6407 $M_\odot$ (the needed mass to get log g=8.06 at T_{eff}=11,980K) with the canonical values of 10^{-2} $M_\star$ for He and 10^{-4} $M_\star$ for H. Resulting composition runs have been used to fit the steepness of the transition zones of a static model.

2. Results

The technique, based on the forward method, that we have developed so far requires the computation of hundreds of thousands of models in order to find the model that best matches the observed periods. This, combined with the fact that computing an evolutionary sequence with diffusion calculations down to the ZZ Ceti stage can take about 6-8 hours on a fast PC, makes the complete treatment of the problem prohibitive in term of computational ressources. So, instead, we have devised a simple way to parameterize the steepness of the composition transition in static models.

In this experiment, we have chosen to change arbitrarily the equilibrium profiles by adding a multiplying factor α [α_H (α_{He}) for the H/He (He/C) transition zone] in the relation giving $d\ X_i/d\ \ln P$. The goal of the exercise is to consider α_H and α_{He} as free parameters measuring the steepness of the transition zones and to verify that the best match model found is consistent with an evolutionary model complete with diffusion computations. Result of our experiment are given in Figure 1. We have allowed α_H (α_{He}) to vary in the range 1.0 to 1.6 (1.0 to 5.0) with a resolution of 0.01 (0.05). Each of these 4941 points has been optimized for the values of the mass of H and He layers that best matches the observed periods. Over 800,000 models were needed to complete the computations. This task needed about 3 days of computations in our small cluster of 13 PCs. We found that our optimized values are near the canonical ones.

Our results show that the solution with diffusion is entirely consistent with our asteroseismological exercise: Can we conclude from this that asteroseismology now confirms the validity of the diffusion theory in ZZ Ceti stars? Maybe this is somewhat premature but, at least, we can say that the result is frankly taunting! Lastly, we have to make a precision here: we have fixed the effective temperature and the surface gravity to the spectroscopic values as well as the composition of the core to pure C in our models. So, allowing these parameters to be optimized too can provide a better match of the observed periods. Such an optimal model will be described elsewhere.

References

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