Non-adiabatic Pulsational Observables in δ Scuti and γ Doradus Stars: a Comparison of Different Numerical Codes

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Abstract. Phase lag ϕ^T and R, a parameter measuring the departure from adiabaticity, can be derived directly from multicolour observations. The same quantities can be also calculated from theoretical non-adiabatic pulsation models. We present here three different theoretical results which indicate that these quantities depend on the mixing length (ML) parameter used to treat the convection in the standard ML theory. The three models are: the one presented in this Conference by M.A. Dupret including interaction with the atmosphere, and two others based on the A. Claret evolutionary code and a new non-radial non-adiabatic pulsational code by R. Garrido and A. Moya with and without including the atmosphere in the pulsation equations as presented by M.A. Dupret.

Keywords: atmosphere-pulsation interaction

1. Introduction

The linear approximation to flux variations of a pulsating star was first derived by Dziembowski (1977) and then reformulated by Balona and Stobie (1979) and by Watson (1988). In Garrido et al. (1990) this formula was used to discriminate the different spherical orders l of some pulsating stars. Several attempts to fit real observations (Garrido, 2000) have shown that the method can be useful at least for low rotational velocities (Daszynska-Daszkiewicz et al., in *Astro-ph/0206109*).

Garrido et al. (1990) also showed that for low l values the wavelength dependence of the limb darkening integrals is very weak. Therefore combinations of several colours – at least three distributed in as wide a range of wavelengths as possible – allows us to give consistent values for the phase lag ϕ^T and R (Watson). This derived pair and other related quantities are generated in the stellar atmosphere. Therefore the treatment of the interaction between the stellar interior and the atmosphere within the pulsation code seems to be important in order to compare with these non-adiabatic observables.

The first goal of this study is to validate the two different sets of codes, the one by M.A Dupret (MA) and other by Garrido, Claret and Moya (GCA).

The second goal is to check how important is the treatment of the atmosphere (Dupret et al., 2002) by comparing the results with and without the interaction with the atmosphere.

2. Non-adiabatic Non-radial Theoretical Models.

The equilibrium models we are using have been extensively used and validated for other purposes (Claret, 1995; Claret and Willems, 2002; Deeg et al., 2001).

Adiabatic and non-adiabatic codes without atmosphere have been developed following closely the book by Unno et al. (1989). The inclusion of non-adiabatic calculations in the code allows us to derive $\delta T_{\rm eff}/T_{\rm eff}$, $\delta g_e/g_e$ (related with R) and ϕ^T . Rotation and convection-pulsation interaction are neglected in this study.

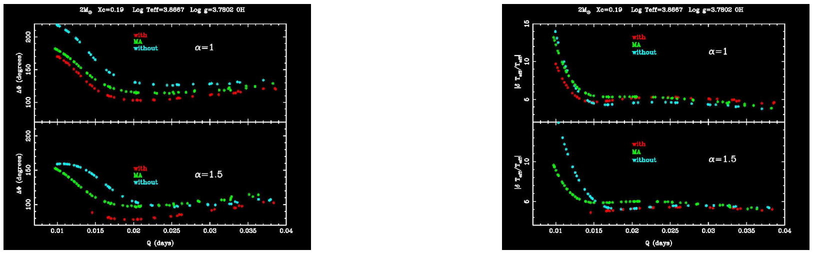
The interaction with the atmosphere is introduced by inserting the atmospheric pulsational equations (Dupret et al., 2002) in the non-adiabatic code, fixing the connecting layer at $\log\tau = 0$. The values of the observables are determined at $\log T = \log T_{\rm eff}$, where by convention the relative radial displacement is normalized to 1.

3. Comparison of Models (I) : δ Scuti Stars

A $2\,M_\odot$ Pop I star with $\log T = 3.8867$ and $\log g = 3.7802$ has been chosen as representing a typical δ Scuti star. In Fig. 1a we present the phase lag ϕ^T for the three codes with $\alpha = 1$ and $\alpha = 1.5$ for low order p- and g-modes with $l = 0,1,2$ and 3 for the MA and GCA models. We can see that the models with an atmosphere are very close together and that the effect of the atmosphere is small but significant, and a net difference between the two sets, mainly due, as we will see in the next figures, to the different size of the convection zone. In Fig. 1b we present the same comparison as in Fig. 1a but representing $|\delta T_{\rm eff}/T_{\rm eff}|$.

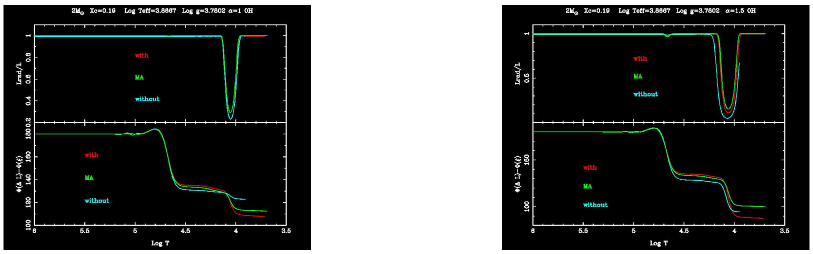
Comparison of different codes is sometimes not easy because we are comparing two slightly different stellar structures even if we choose the closest model of a given evolutionary track.

In Figs 2a,b we present the phase lag between the luminosity perturbation and the displacement and the radiative luminosity over the total luminosity for the three codes. We can see that there are two zones that introduces phase lags. The first one is situated at the driving zone (Helium II ionization) and is similar for all the models we present here, and the second is situated at the superficial convective zone, and the phase lag depends on the size of this zone.



a. ϕ^T b. $|\delta T_{\rm eff}/T_{\rm eff}|$

Figure 1. ϕ^T (left panel) and $|\delta T_{\rm eff}/T_{\rm eff}|$ (right panel) for two different sets of models with $\alpha = 1$ and $\alpha = 1.5$ and for the three codes.



a. $\alpha = 1$ b. $\alpha = 1.5$

Figure 2. Radiative luminosity divided by total luminosity for the three sets of models (upper panel) and the phase lag as a function of $\log T$ (lower panel).

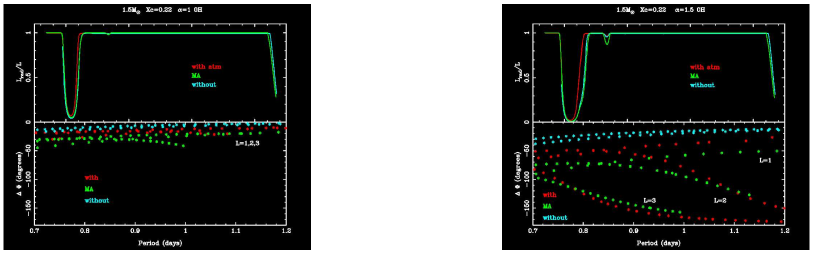
4. Comparison of Models (II) : γ Dor Stars

The non-adiabatic results for a $1.5\,M_\odot$ γ Dor model are given in Fig. 3. We see that the phase lag is very dependent on the size of the convective zone, but also on the treatment of the pulsation-atmosphere interaction. The models without atmospheric pulsation equations do not change very much for different ls and remain close to a 0° phase lag.

Models with interaction have very similar behaviour and are close to the model without atmospheric pulsation equations with $\alpha = 1$. For $\alpha = 1.5$ the phase lag changes drastically with the radial order n and the degree l going from -180° to 0°. This is a strong indication that the size of the convective zone is the more important physical reason for a change of the phase lag, and is very sensitive to the interaction with the atmosphere.

5. Conclusions

We have studied non-adiabatic theoretical properties of different numerical codes by comparing them for models of δ Scuti and γ Doradus stars. The



a. $\alpha = 1$ b. $\alpha = 1.5$

Figure 3. Radiative luminosity divided by total luminosity for the three sets of models as a function of $\log T$ (upper panel) and the phase lag for different l with the three codes with $\alpha = 1$ (lower panel) and $\alpha = 1.5$.

one developed by M.A. Dupret is presented as a talk in this Conference and the other two have been developed by the group in Granada, one with the atmospheric pulsation equations and the other without. Our final goal is to compare with real data as deduced from multicolor photometry and to provide a method for mode identification.

There is a general agreement between the two different codes with the atmosphere treatment, the size of the convective zone being the more relevant parameter changing the phase lag. The effect of the interaction with the atmosphere can be also of considerable importance depending on the stellar model. The other non-adiabatic quantities (R and related ones) are less sensitive to the size of the convection zone but can be very sensitive to the boundary conditions if no atmosphere-pulsation interaction is used or to the treatment of the interaction between atmosphere and pulsation otherwise.

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