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Nonadiabatic observables in main sequence δ Scuti stars

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Abstract. Using a theoretical nonadiabatic pulsation model, phase differences and amplitude ratios between the relative effective temperature variation and the relative radial displacement have been calculated. These quantities, when compared with photometric observations in different colours, provide an efficient instrument for mode identification, the first step to understand the internal structure of the stars. The theoretical results presented in this paper show a dependence for δ Scuti stars on the mixing length parameter α used to treat the convection using the standard Mixing Length Theory. The nonadiabatic pulsational code developed here includes the pulsation-atmosphere interaction as described by Dupret et al. (2002). The equilibrium models are provided by the CESAM evolutionary code, where a complete reconstruction of non-grey atmospheres (Kurucz models) is included.

1. Introduction

Asteroseismology is presently being developed as an efficient instrument for the study of stellar interiors and evolution. Pulsational periods are the most important asteroseismological observational inputs. However, for δ Scuti stars the information contained in these periods is not sufficient for adequate constraints on theoretical predictions. Without additional observational data, mode identification is, therefore, not easily feasible.

One way to obtain more information on the basis of photometric observations is to study the multicolour flux variations, where theoretical and observed amplitude ratios and phase differences between different colour photometric bands can be compared. In this paper the physical dependences of the theoretical nonadiabatic observables (phase lags and relative variations of the effective temperature) are investigated. These nonadiabatic observables are calculated by a code developed by R. Garrido and A. Moya (Moya, Garrido, & Dupret 2003) where the stellar pulsation is solved following Unno et al. (1989), but including the pulsation-atmosphere interaction described by Dupret et al. (2002).

The equilibrium models are provided by the CESAM evolutionary code. The convective zones present in δ Scuti stars are described using Mixing Length Theory (MLT) and the equation of state used was CEFF.

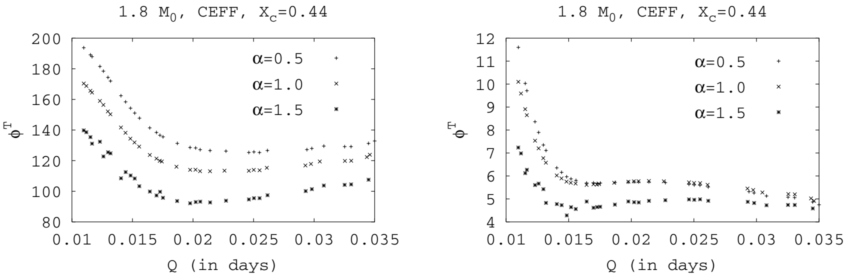

Figure 1. Phase lag (left panel) and relative variations of the effective temperature (right panel) as a function of the pulsation constant Q of a δ Scuti star of 1.8 $M_\odot$ for $\alpha = 0.5$, 1 and 1.5.

2. Dependence on α

A dependence on the MLT parameter α becomes apparent by calculating the phase lag and the relative variations of the effective temperature for different models with different values of α. In Fig. 1 these quantities are displayed for the pulsational modes of a δ Scuti star of 1.8 $M_\odot$. The results for three values of α are shown in that figure. The relative variations of the effective temperature are different for larger values of α, while the phase lag presents different results for each α value, growing further from the adiabatic value (180°) as α increases.

3. The physical sources of the phase lag in the stellar interior

In Fig. 2 ϕ_L is defined as the phase lag between the eigenfunctions $\frac{\delta L}{L}$ and $\frac{\xi_r}{r}$ and it is directly related with the nonadiabatic observable phase lag. This quantity is displayed as a function of the logarithm of the temperature for 1.8-$M_\odot$ models in the left panel and 2.0-$M_\odot$ models in the right one. Here it is shown that the most of the star has an adiabatic behaviour (its phase lag is 180°), and then two sources of phase lag appear. A first one is in the He^+ ionization zone and is independent of α; a second one is in the H and He ionization zone, where the α dependence becomes apparent, but is different for each stellar model.

Fig. 3 shows a separate study of both sources of phase lag for the fundamental radial mode of a complete set of models with 1.8 and 2.0 $M_\odot$ and $\alpha = 0.5$, 1 and 1.5. The left panel shows the phase lag introduced in the first ionization zone, here referred to as "κ phase lag" (ϕ_κ), and the right panel shows the one introduced in the H and He ionization zone, here referred to as "convective phase lag" (ϕ_{conv}), both as a function of the effective temperature of the model.

The behaviour of ϕ_κ is completely independent of α along the HR diagram, presenting dependences only with the temperature and the density of the star. This suggests that the main physical source for the phase lag in this zone comes from the κ mechanism, very efficient in this ionization zone.

The contribution to the convection zone phase lag, in this case ϕ_{conv}, is in turn a sum of two phase sources. For hot models the κ driving mechanism is not yet efficient enough to introduce a phase lag, and the behaviour of ϕ_{conv}

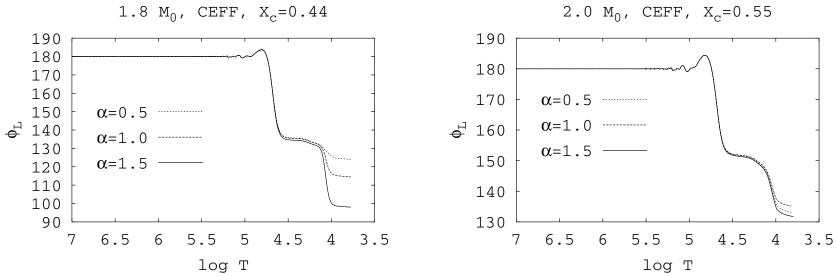

Figure 2. ϕ_L as a function of the temperature logarithm along 1.8-M$_\odot$ (left panel) and 2.0-M$_\odot$ (right panel) models, for $\alpha = 0.5$, 1 and 1.5.

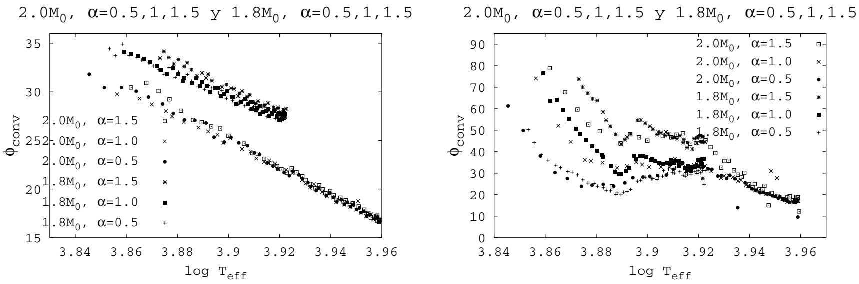

Figure 3. ϕ_κ (left panel) and ϕ_{conv} (right panel) as a function of the effective temperature along the evolutionary tracks of 1.8-M$_\odot$ and 2.0-M$_\odot$ stellar models, for $\alpha = 0.5$, 1 and 1.5.

depends mainly on the convection treatment. When the convective layers are not efficient, models with different values of α produce the same values of ϕ_{conv}. At $\log T_{eff} \approx 3.91$ the convective layers become sufficiently efficient to distinguish between models using different values of α, independently of the mass. From $\log T_{eff} = 3.88$ to cooler models, an increase is observed in the value of this phase lag, again displaying different behaviours for different masses and values of α. This is accounted for by the fact that, within this range of temperature, the κ driving mechanism in the H I and He I ionization zone becomes efficient enough to make a significant contribution to ϕ_{conv}.

4. Conclusions

This paper uses the CESAM code to generate equilibrium models. A new non-adiabatic pulsation code has been developed and applied to the study of δ Scuti stars, where particular consideration is given to pulsation treatment in the atmosphere. Photospheric observables become determinable as a solution of a set of differential equations taking into account nonadiabatic terms.

The non-adiabatic results presented here are highly sensitive to the characteristics of the superficial convective zone, parametrized by using the mixing length parameter α. In particular, we have shown that there are two regions in which the phase lag originates. A first phase lag takes place in the partial ionization zone of He II, where the κ mechanism drives the oscillations. This phase lag is very sensitive to the evolution phase. A second one occurs in the convective envelope (partial ionization zone of H I and He I) and is sensitive mainly to α. Though to a lesser extent, this phase lag is also sensitive to the evolutionary phase because of the κ driving mechanism and the size of the convection zone change.

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