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THEORETICAL INSTABILITY STRIPS AND NON-ADIABATIC PHOTOMETRIC OBSERVABLES FOR δ SCUT AND γ DOR STARS

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ABSTRACT

Theoretical instability strips (IS) for radial and non-radial modes of δ Sct and γ Dor stars are presented, using the time-dependent convection (TDC) treatment derived by Gabriel (1996) and presented in Dupret et al. (these proceedings). Preliminary results were given by Grigahcène et al. (2004) and Dupret et al. (2004). For models with mixing-length parameter $\alpha \simeq 1.8$ (solar calibrated value), we obtain a very good agreement with observations. We study also the influence of our TDC models on the theoretical amplitude ratios and phase differences. Confrontation to observations allows the identification of the degree ℓ of the modes and to test the envelope convection models. We show that our TDC models better agree with observations than frozen convection (FC) models.

Key words: Stars: oscillations; Convection; Stars: interiors; Stars: variables: δ Sct; Stars: variables: general.

1. THEORETICAL INSTABILITY STRIPS FOR δ SCT STARS

It is well known that the location of the δ Sct instability strip (IS) blue edge is explained by classical κ-mechanism in the HeII partial ionization zone, but the determination of the theoretical red edge is a more difficult matter, because it requires a non-adiabatic treatment of the interaction between convection and pulsation. Xiong et al. (2001) succeeded to obtain a theoretical red edge for radial modes, using the non-local time-dependent convection theory of Xiong et al. (1997), and Houdek (2000) studied the convective effects on radial p-mode stability in δ Sct stars, using the time-dependent convection treatment of Gough (1977). We present here theoretical blue and red edges of the δ Sct IS obtained for non-radial modes as well, following the time-dependent convection (TDC) treatment presented in Dupret et al. (these proceedings). In Fig. 1, we present the theoretical IS obtained for radial modes (top panel) and $\ell = 2$

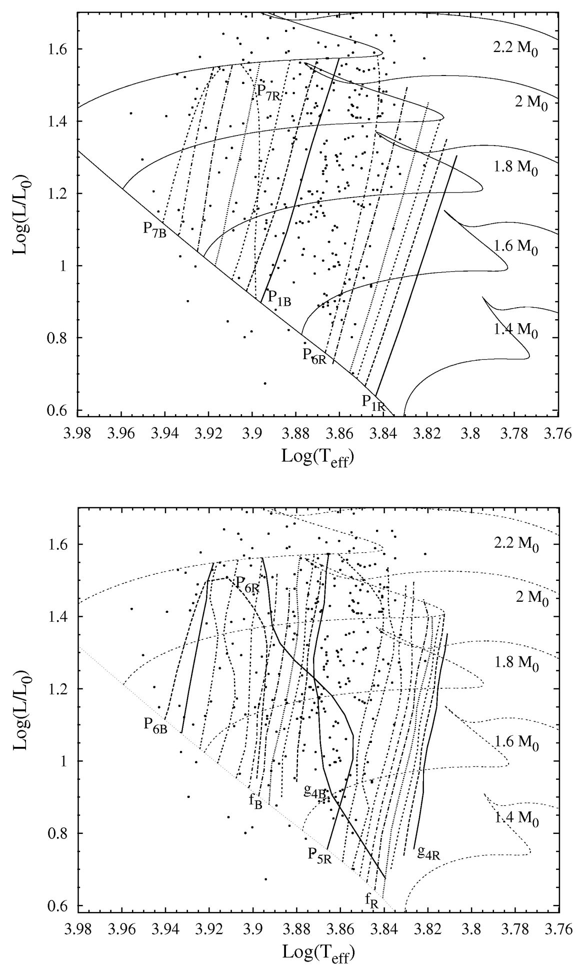

Figure 1. Blue and red edges of the δ Sct theoretical IS obtained with our TDC models ($\alpha = 1.8$). Top panel is for radial modes and bottom panel is for $\ell = 2$ modes.

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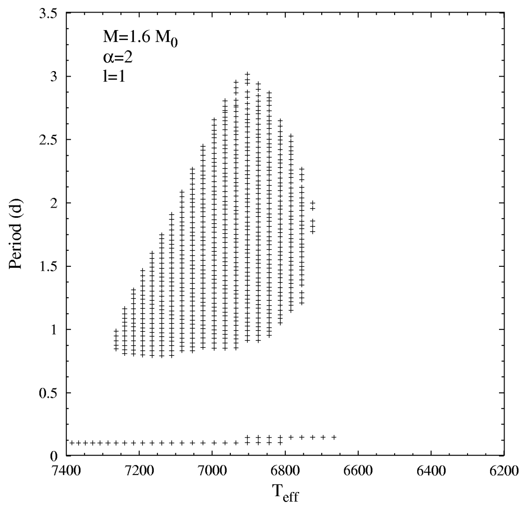

Figure 2. Periods (in days) of the unstable gravity modes of typical γ Dor models.

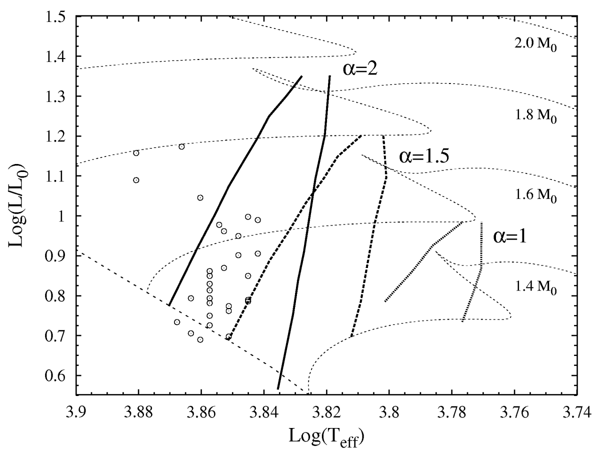

Figure 3. γ Dor theoretical IS for $\ell = 1$ modes and models with α = 1, 1.5 and 2 obtained with our TDC treatment.

modes (bottom panel), for models with $\alpha = 1.8$. Each curve corresponds to the blue or red edge of a mode of given radial order n. The small points correspond to the position of observed δ Sct stars, as taken from the catalogue of Rodriguez et al. (2000), using the calibrations of Moon & Dworetsky (1985).

2. THEORETICAL INSTABILITY STRIPS FOR γ DOR STARS

γ Dor stars are a recently discovered class of F-type near main sequence g-mode pulsators. Using frozen convection (FC) models, Guzik et al. (2000) showed that the driving of the γ Dor g-modes can be explained by a flux blocking mechanism at the base of their convective envelope (CE). A first theoretical IS has been obtained by Warner et al. (2003), following this approach. However, in a significant part of the CE, the FC approximation is not valid, because the lifetime of the convective elements becomes shorter than the pulsation period. Therefore, it is very important to test the validity of this mechanism with TDC models. We have shown in Dupret et al. (these proceedings) that the contribution of the convective flux variations to the driving and damping near the CE base is small so that the Guzik et al. (2000) conclusion is essentially correct, even if FC models lead to larger growth rates than TDC models. In Fig. 2, we show the periods range of the unstable modes predicted by our TDC models as function of the effective temperatures, for $\ell = 1$ modes and main sequence models of 1.6 $M_{\odot}$ with $\alpha = 2$. Each cross corresponds to an unstable mode. Results are given for all the modes with pulsation constant $Q = P\, t_{\mathrm{dyn},\odot}/t_{\mathrm{dyn}} \geq 0.04$ days. The periods and T_{eff} ranges of the unstable g-modes of our models are in agreement with the typical observations for γ Dor stars. In Fig. 3, we show the theoretical IS of γ Dor $\ell = 1$ modes obtained with our TDC treatment, for three families of models with different values of the mixing-length parameter α: 1, 1.5 and 2. In this case, we give global IS and not individual ones for each mode. The small circles correspond to the observed positions of *bona fide* γ Dor stars from the catalogue of Handler (2002). We see that the theoretical IS are very sensitive to α and that the best agreement with observations is for $\alpha = 2$ models.

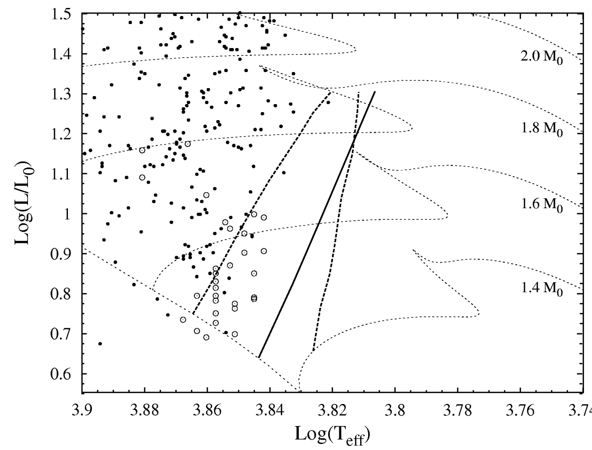

Figure 4. γ Dor IS for $\ell = 1$ modes (dashed lines) and δ Sct IS red edge for the p_1 radial mode (solid line), for $\alpha = 1.8$ models. The small full points and empty circles correspond to observations of δ Sct and γ Dor stars respectively.

3. δ SCT AND γ DOR SIMULTANEOUS PULSATIONS

An important result is that our TDC models predict the existence of hybrid δ Sct – γ Dor stars. More precisely, we see in Fig. 2 that our models with unstable long periods gravity modes have also unstable short periods pres-

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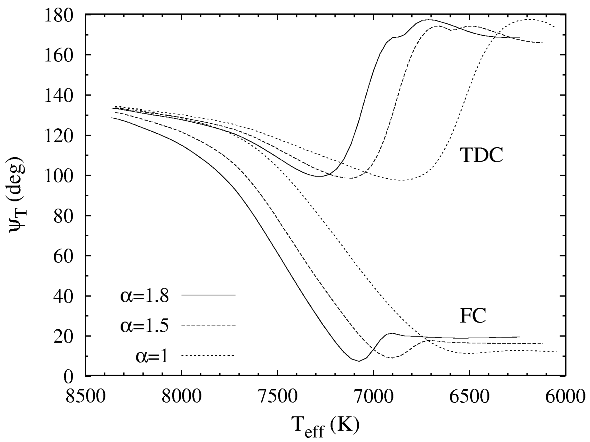

Figure 5. ψ_T as function of $T_{\rm eff}$ for the p_1 radial mode of TDC and FC models with different α.

sure modes. In Fig. 4, we give in the same figure the theoretical γ Dor instability strip and the δ Sct instability strip red edge, for $\alpha = 1.8$ models. We see that a significant part of the γ Dor instability strip is inside the δ Sct one. All the theoretical models in this intersection have both types of unstable modes. One star with both types of modes has been found: HD 209295. However, this star is very peculiar: it is a close binary and the long period modes could be tidally excited (Handler et al. 2002). We think that it is very important to continue the search of such stars with both g-modes probing the deep interior and p-modes probing the more superficial layers, which would be of considerable interest for asteroseismology.

4. AMPLITUDES AND PHASES OF δ SCT STARS

The mode identification is a very difficult matter in δ Sct and γ Dor stars, contrary to solar-like oscillations. The normalized amplitude ratio $f_{\rm T} = |\delta T_{\rm eff}/T_{\rm eff}|$ and phase difference ψ_T between the local effective temperature perturbation and the radial displacement can be computed by our non-adiabatic pulsation code. These two quantities are basic ingredients for the determination of the amplitude ratios and phase differences between different photometric passbands (Dupret et al. 2003a) and their accurate determination is thus crucial for the photometric identification of ℓ. Moya et al. (2004) determined these quantitities for typical δ Sct models, using FC models and the perturbed atmosphere modeling of Dupret et al. (2002a). An important problem to address is the effect of our TDC treatment on the amplitudes and phases.

In Fig. 6, we compare the evolution of the phase-lag ψ_T as function of $T_{\rm eff}$ for the fundamental radial mode and for TDC and FC $1.8\,M_\odot$ models with different α. Typical observations of δ Sct stars indicate values of ψ_T between $90°$ and $135°$. This is in perfect agreement with our TDC models. On the contrary, cold FC models give much too small values for ψ_T. The larger is α (directly linked to

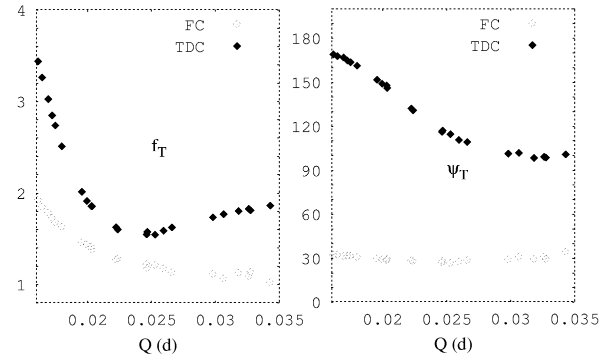

Figure 6. f_T (left) and ψ_T (right) as function of Q for $\ell = 0-3$ modes, δ Sct model with $T_{\rm eff} = 7150$ K.

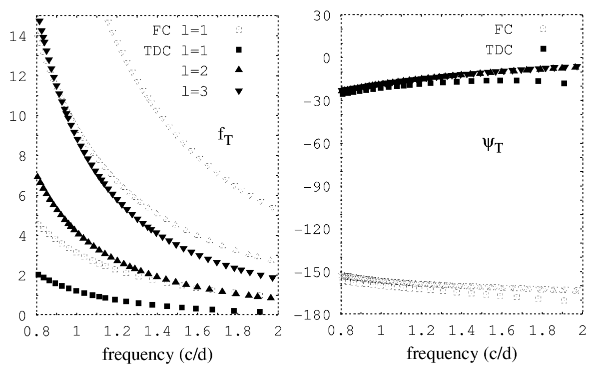

Figure 7. f_T (left) and ψ_T (right) as function of frequency for $\ell =$ 1-3 modes, γ Dor model with $T_{\rm eff} = 6980$ K.

the CE size), the larger is the difference between TDC and FC models. In Fig. 6, we give the values of f_T and ψ_T for modes with $0 \leq \ell \leq 3$ as function of the pulsation constant Q (days), for a model with $M = 1.8\,M_\odot$, $\alpha = 1.5$ and $T_{\rm eff} = 7150$ K. Again the TDC phases-lags better agree with typical observations than the FC ones.

5. AMPLITUDES AND PHASES OF γ DOR STARS

In γ Dor stars, the mode identification is also a difficult matter. Dupret et al. (2002b, 2003b) showed that the values of f_T and ψ_T are extremely sensitive to α for FC models. We show here that there is also a huge difference between TDC and FC results. In Fig. 7, we give the values of f_T and ψ_T for modes with $1 \leq \ell \leq 3$ as function of the frequency (cycles/day), for a model with $M = 1.5\,M_\odot$, $\alpha = 1.8$ and $T_{\rm eff} = 6980$ K. Full and empty symbols correspond to TDC anf FC results respectively. TDC models give much smaller f_T than FC models. The phase-lags are completely different: in TDC models $\psi_T \simeq 0°$ while in FC models $\psi_T \simeq -180°$. Simultaneous photometric and spectroscopic observations of the γ Dor star HR 8330 = HD 207223 (Kaye et al. 1999) show that our TDC phase-lags better agree with

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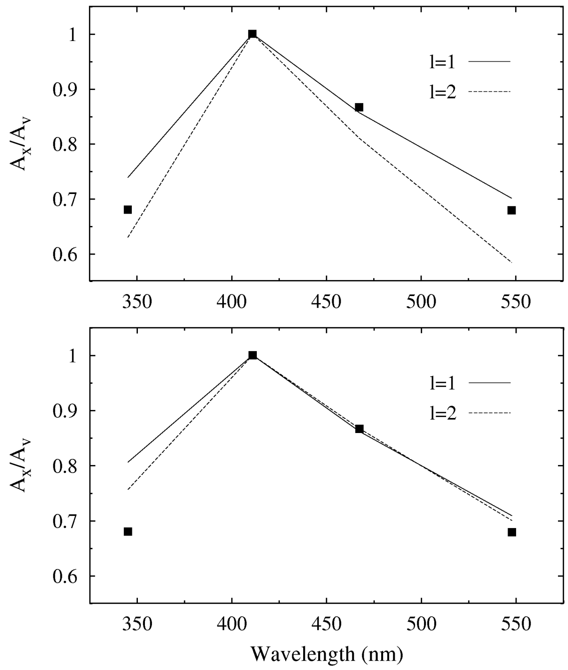

Figure 8. Amplitude ratios for Stroemgren photometry. The lines are the theoretical predictions for TDC (top) and FC (bottom) models. The squares are the observation for the γ Dor star HD 164615.

observations than FC ones. In Fig. 8, we confront the theoretical and observed amplitude ratios between the different Stroemgren photometric passbands, for the γ Dor star HD 164615 and the mode with frequency: 1.2328 c/d. The lines are the theoretical predictions for TDC (top panel) and FC (bottom panel) models. We used the atmosphere models by Heiter et al. (2002) and the limb-darkening by Barban et al. (2003). The squares are the observed amplitude ratios (Zerbi et al. 1997). First, we see that we identify this mode as an $\ell = 1$ mode. Secondly, we see that a much better agreement between the theoretical and observed u/v amplitude ratios is obtained with our TDC model (top panel).

6. CONCLUSIONS

Using the TDC treatment presented in Dupret et al. (these proceedings), we computed theoretical instability strips for δ Sct and γ Dor stars radial and non-radial modes. Good agreement with observations is obtained for solar calibrated values of the mixing-length parameter α. We also showed that the theoretical amplitude ratios and phases differences predicted by our TDC models better agree with observations than FC models. Therefore, using our TDC models improves the reliability of photometric mode identification for these stars.

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