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THEORETICAL DAMPING RATES AND PHASE-LAGS FOR SOLAR-LIKE OSCILLATIONS

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ABSTRACT

We present the theoretical damping rates obtained for a solar model, using a new non-local time-dependent convection treatment. Our structure models fit the description of the convective zone top given by 3D hydrodynamic simulations. We compare our results with the observed line-widths and phase lags between intensity and velocity curves. The sensitivity of our results to the free parameters of our model is discussed.

Key words: Convection; Asteroseismology.

1. INTRODUCTION

The energetic transfer mechanisms at the origin of the mode damping and the phase-lags between light and velocity curves take place essentially in the superficial layers of the stars, where the thermal relaxation time is of the same order or smaller than the oscillation periods. In solar-type stars, this region is located in the upper part of the convective envelope. There, the characteristic times associated with the most energetic convective motions are also of the same order as the oscillation periods, so that convection and oscillations are strongly coupled from an energetic point of view. Hence, the coherent interaction between convection and oscillations must be taken into account for the non-adiabatic modeling of the mode damping mechanisms in solar-type stars. Different perturbative theories have been proposed, following the Mixing-Length approach: Gough (1977), Gabriel (1996). Improvements of the Gabriel's theory were proposed by Grigahcène et al. (2005) and Dupret et al. (paper II, these proceedings). We have implemented these last treatments in our non-radial non-adiabatic pulsation code MAD.

The theoretical damping rates and phase-lags predicted with this treatment are very sensitive to the prescriptions of our time-dependent convection (TDC) treatment: parametrization of the non-locality, perturbation of the closure equations, description of convection (MLT versus 3D hydrodynamic simulations, ...). We compare here these different theoretical results with the observations given by the line-widths in the power spectrum (damping rates) and the phase-lags between intensity and velocity.

2. DAMPING RATES

We compare in this section the theoretical damping rates obtained with our non-adiabatic pulsation code, using different physical prescriptions in our TDC treatment. Comparison with the observations given by the half line-widths in the power spectrum is also considered, using the BiSON data (Chaplin et al. 2002) and the GOLF data (Baudin et al. 2005).

The main uncertainties associated with our treatment appear in the perturbation of the closure terms. Because of them, we have introduced a free complex parameter β in the thermal closure equation, as detailed in Grigahcène et al. (2005) and Dupret et al. (these proceedings, paper II, Eq. (12)). Another aspect is the non-locality of our treatment, as detailed in Dupret et al. (2006) and paper II. Following Balmforth (1992), we introduced three non-local parameters a, b and c associated to the convective flux, turbulent pressure and superadiabatic gradient respectively. Following Dupret et al. (2006), the default values we use for a and b are those deduced from the 3D simulations (Stein & Nordlund 1998): $a = 10$, $b = 3$, and we take $c = 3.5$. We have proposed in paper II a new TDC treatment based on structure models fitting the stratification given by 3D hydrodynamic models (Stein & Nordlund 1998), we use by default this new treatment. The integrations include the atmosphere, and we have also to be careful at this level. We use here the atmosphere models of Kurucz (1993) and the non-adiabatic treatment in the atmosphere of Dupret et al. (2002). Other atmosphere models have also been used with our non-adiabatic code, as for example the VAL models (Vernazza et al. 1981). This affects significantly the eigenfunctions in the atmosphere (Baudin et al., these proceedings), but the theoretical damping rates remain essentially the same for different atmosphere models.

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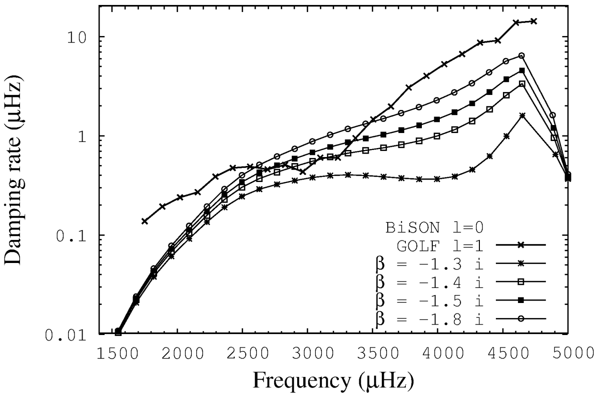

Figure 1. Comparison between the theoretical damping rates obtained with our new TDC treatment for different values of the closure parameter β. Observations with BiSON and GOLF are also given.

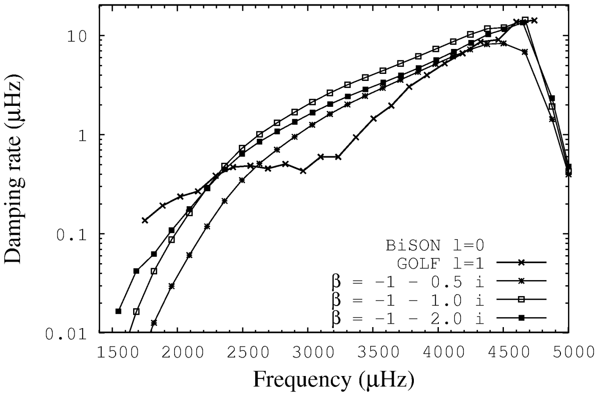

Figure 2. Same caption as in Fig. 1 but for other values of β.

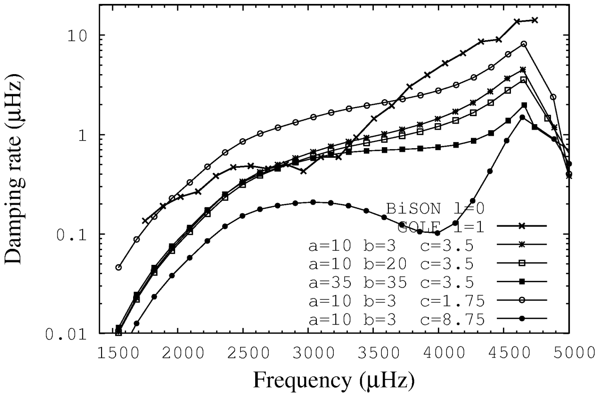

Figure 3. Comparison between the theoretical damping rates obtained with our new TDC treatment for different values of the non-local parameters a, b and c.

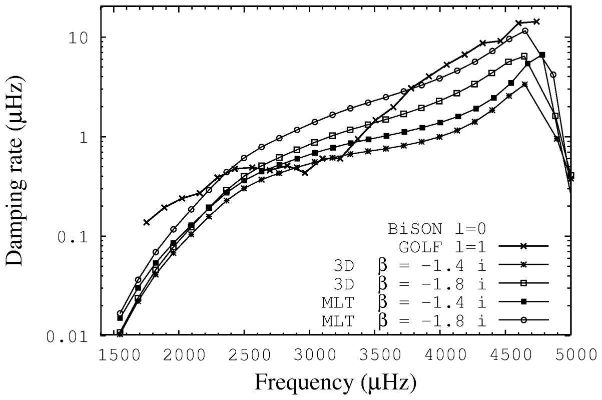

Figure 4. Comparison between the theoretical damping rates obtained with our new TDC treatment fitting the stratification of 3D hydrodynamic models (paper II) and with the MLT treatment of Grigahcène et al. (2005) and Dupret et al. (2006).

We begin by comparing in Figs. 1 and 2, the theoretical damping rates obtained for models with different values of the complex parameter β associated to the closure of the problem. As can be seen, the theoretical results are extremely sensitive to this parameter. For some other values not given here, it is even possible to predict unstable modes, which is of course not acceptable. For some values of β, it is possible to reproduce more or less the observed plateau around 3000 μHz.

In Fig. 3, we compare the results obtained for different values of the non-local parameters a, b and c. We see that the theoretical damping rates are very sensitive to the non-local treatment. The value of the complex parameter β used in this figure is $\beta = -1.5i$. For this value, the local treatment predicts unstable p-modes, which is of course not acceptable. We see that it is possible to obtain a reasonably good agreement with observations for the values $a = 10$ and $b = 3$ deduced from the 3D simulations. For this reason, we use them as default values in our treatment.

Finally, we compare in Fig. 4 the results obtained using our new perturbative treatment fitting the mean stratification of 3D hydrodynamic models (paper II) with those obtained with the treatment of Grigahcène et al. (2005) and Dupret et al. (2006). We see that the shapes of the curves are not much affected by this treatment. More precisely, the new results are very close to the old ones with slightly different β. Hence, the agreement with observations cannot be improved with the new treatment.

3. PHASE-LAGS

The theoretical phase-lags between intensity and velocity curves can also be obtained with our non-adiabatic code. An observational determination of these phase-lags was

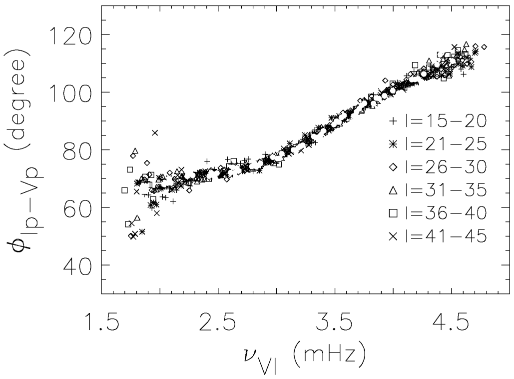

Figure 5. Observed p-modes phase differences between the intensity and the velocity, as observed with GONG. Figure from Barban et al. (2004).

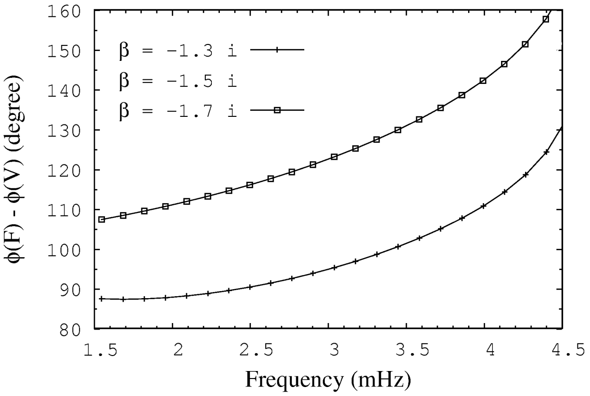

Figure 6. Comparison between the theoretical phase differences between flux variations and velocity obtained for radial modes, with our new TDC treatment, and for different values of the parameter β.

done by Barban et al. (2004), using the GONG data for 600 modes from $\ell = 15$ to $\ell = 50$, and using the model of Severino et al. (2001). The coherent component of the signal that includes the p-modes is considered here (I_{P}). As can be seen in Fig. 5, these observed phase-lags go from about 60° at low frequencies to about 120° at high frequencies.

The theoretical phase differences between flux variations and the velocity obtained with our new TDC treatment for radial modes are given in Figs. 6 and 7. The results are very similar for non-radial modes of small ℓ. We considered different values of the complex parameter β. The results obtained in Fig. 6 give phase-lags a little too high compared with observations, and for these values of β the theoretical damping rates are in reasonably good agreement with observations. But the results of Fig. 7 where $\Re\{\beta\} = -1$ are unrealistic.

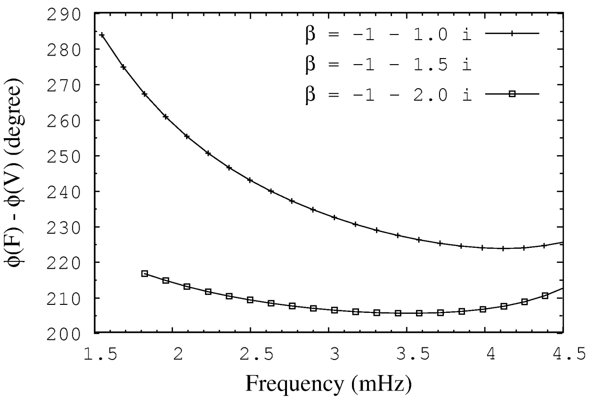

Figure 7. Same caption as in Fig. 6 but for other β.

4. CONCLUSIONS

The theoretical predictions for the damping rates and the phase-lags obtained with our non-adiabatic code are very sensitive to the prescriptions of our TDC treatment. Comparison with observations allows to constrain these prescriptions. Reasonably good agreement with observations can be obtained for some sets of parameters and models. But work remains to be done to understand the details of the non-adiabatic coherent interaction between convection and oscillations in solar-type stars. Present models are not complete enough to allow using them confidently in a predictive way.

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