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Tests of parametric models for convection

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Abstract. In this study, we compare the effect of a modified convection parametrization in solar models on oscillation frequencies with different empirical correction schemes.

1 Introduction

It is well-known that current solar models cannot reproduce the observed oscillation frequencies. A common approach to remedy this situation consists in correcting the theoretical frequencies using empirical models. Another approach, which we explore here, consists in modifying the physics of the upper stellar layers to reinforce the agreement. We compare here both approaches.

2 Frequency-shift model comparison

2.1 Parametric convection model

We test here a convection model alternative to the mixing-length theory [1]. They significantly modify the superadiabatic layers and affect the oscillation frequencies accordingly to inverse of the observed shifts. In particular, the temperature gradient becomes more superadiabatic (see Fig 1, left panel), and the modes crossing this region become evanescent, whereas the lower degree modes, whose energy bulk is concentrated in lower regions are much less affected by this effect. The expression for the convective flux is

$$F = \Delta \nabla T \Phi, \tag{1}$$

with Φ the convection efficiency, which has been parametrized the following way (see [1] for details)

$$\Phi(\Sigma) \propto a_1(m,\beta_c)[\nabla - \nabla_{\mathrm{ad}}]^m[(\sqrt{1 + a_2(m,\beta_c)\Sigma})^{(7.5-2m)/(2-m)} - 1]^{(2-m)}, \tag{2}$$

Here m and β_c are new free parameters controlling, respectively, the relative strength of the superadiabatic gradient between the efficient (high Φ) and inefficient (low Φ) convection regimes and the transition between these regimes. In our database, we selected a solar model with (β_c, m) such that the atmospheric characteristic of the Sun are well-reproduced and that gives the best fit to the individual frequencies.

2.2 Empirical frequency shifts

Another approach to oscillation-frequency shift modelling, far more widespread, consist in correcting them by imposing a parametric model that reproduces the offsets observed for the Sun [2]. Basing

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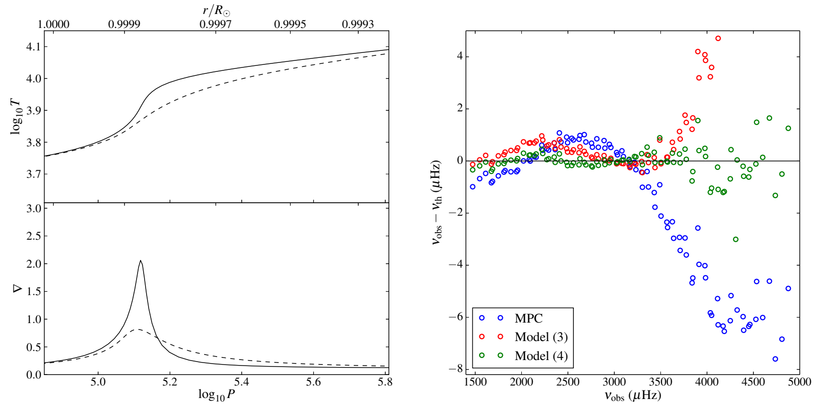

Fig. 1. Left: Comparison of the temperature stratification (upper panel) and the temperature gradient (lower panel) in the superadiabatic layers of the upper convective zone; for the standard solar model (dashed lines) and the one including modified convection treatment (full lines). Right: Difference between the observed and theoretical frequencies for the direct output of ASTEC using the modified parametric convection model (MPC, blue dots) or the empirically corrected frequencies of our reference solar model using model (red and green dots).

ourselves on the frequencies obtained from the GOLF experiment [3] and on a reference solar model computed with ASTEC [4], we considered two such parametric models. The first is similar to the one used by Kjeldsen et al.

$$a\left(\frac{\nu}{\nu_0}\right)^b. \tag{3}$$

The second one introduces additional parameters that allow to reproduce the behaviour of the shift at high frequencies

$$\frac{a}{1+(\nu/\nu_0)^b}+c. \tag{4}$$

The value of the parameter for model (3) are taken from Kjeldsen et al. (2008). For model (4) they have been estimated using a COBYLA minimization algorithm.

3 Results and perspectives

It appears that our parametric convection models can allow us to reach a level of agreement with the observed frequencies comparable with the one obtained from empirically corrected frequencies using (3). However, both approaches are outperformed by model (4), but with an additional parameter, which means that improvement is still sorely needed (note that even the latter empirical correction remains far from ideal!).

Of course, the model presented here does not pretend to solve the problem of surface frequency shift. In particular, it neglects potentially very important effects, such as the departure of pulsation modes themselves from adiabaticity and time dependent effects in convective layers. However, this encourages us to look for better parametrizations in stellar modeling, in order to improve the agreement between observations and theory.

References

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