SENSITIVITY OF p AND g-MODES ON SPECIFIED PHYSICAL PROCESSES OF SOLAR MODELING

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1. Introduction

In this poster we would like to discuss the influence of the atmosphere laws, the equation of state, the opacities, the microscopic diffusion and some aspects of the nuclear reaction rates on the radial p-modes frequencies, the sound speed and the g-modes. We use the CESAM code developed by P. Morel (1996) and the pulsation code of J. Christensen Dalsgaard (1982) which are numerically accurate to discuss the new generation of experimental results (better than 10^{-4}), and compare the results to our previous calculations obtained with a Paszynski code (Turck-Chièze & Lopes 1993 (TCL93) and Dzitko, Turck-Chièze, Delbourgo-Salvador & Lagrange 1995).

2. Effects on radial p-modes

We have implemented in CESAM the most recent Livermore equation of state (EoS) and opacities (Iglesias & Rogers (1996), Swenson & Iglesias (1996)), microscopic diffusion of helium and heavy elements (Michaud & Proffit 1993) using Grevesse composition. Table 1 summarizes the different models we performed: 1, 1bis & 3 for the study of the atmospheric laws, 1, 2 & 5 for the role of the EoS along the structure and below $T = 5000K$ (e.g OPAL min value), 1 & 4 for the opacities, model 6 for the effect of the microscopic diffusion and models 7 & 8 for the influence of the nuclear reaction rates. In figure 1 we

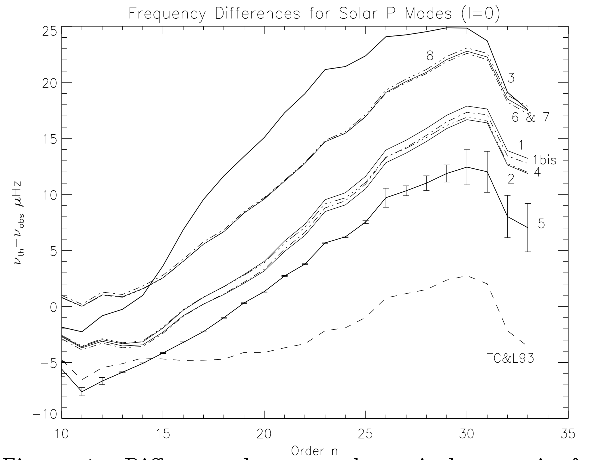

Figure 1: Difference between theoretical acoustic frequencies and preliminary GOLF data set taken between 11 April to 25 August 1996.

plot the discrepancy between theoretical predictions and the preliminary GOLF radial modes frequencies (M. Lazrek these proceedings). One sees a typical deviation towards the higher frequencies leading to variations up to $20\mu Hz$ .One notices:

- a slight improvement of the agreement (2-3μHz) at low order attributed to the EoS in the region of partial ionisation of elements for models 1 to 4 & 6 to 8 vs models (TCL93) & 5.
- an improvement of 4-5μHz at low order for models 6, 7 & 8 with microscopic diffusion, due to a higher helium and z elements composition in the radiative part of the sun, as well as a much better agreement of the predicted depth of the convection zone ($R_{bzc} = 0.71R_\odot$) with the observed one(e.g $0.713 \pm 0.003R_\odot$).
- a very small effect $< 0.5\mu$Hz for modification of the nuclear rates (models 7, 8 vs 6).

All the effects act like an offset and do not practically influence the slope of the discrepancy at high order. In fact the large dependence of the discrepancy comes from the choice of the atmospheric models.

- Effectively model 3 including an HSRA atmosphere (Gingerich & al 1971, Morel 1994) leads to a very poor reproduction of the high frequencies values. The most detailed atmosphere of Kurucz (1991) is even insufficient due to the hypothesis of the model.
- the best result is obtained when we solve the structure equation up to 10^{-4} above the effective radius (model TCL93).

We also see that modifying the position of match-

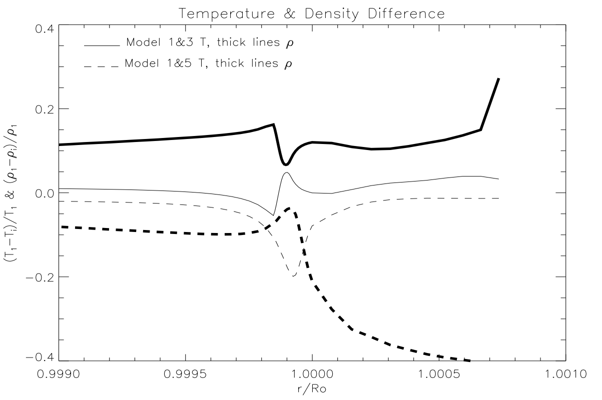

Figure 2: Zoom on the region located near the solar effective radius.Relative variation of the temperature and density to emphasize the transition with the atmosphere.

ing to the solar structure at different optical depth (τ = 10 or 0.7 in models 1, 1bis) or with different opacities (Kurucz or Livermore) between 9300 to

Table 1: Solar Models

τ_b is the optical depth of the bottom of the atmosphere, OPAL/K 5700k means matching between OPAL and Kurucz opacities at 5700K.
Models 7 & 8 are similar to Model 6 with respectively reaction rate modified by +5% for P-P and -30% for He3-He4, T_c en K & ρ_c en g/cm^3

N^o	α	X init/surf	Z elts initial/table	Eq of State	Opacity	Atmosphere	T_c	ρ_c	X_c
1	1.6613	0.7117	1.74E-2 / 1.73E-2	OPAL/VDC 5010k	OPAL/K 5700k	K5750 τ_b = 10	1.554E7	148.5	0.361
1bis	1.6413	0.7117	1.74E-2 / 1.73E-2	OPAL/VDC 5010k	OPAL/K 5700k	K5750 τ_b = 0.7	1.554E7	148.5	0.361
2	1.6606	0.7117	1.74E-2 / 1.73E-2	OPAL/EFF 5010k	OPAL/K 5700k	K5750 τ_b = 10	1.554E7	148.5	0.361
3	2.0126	0.7117	1.74E-2 / 1.73E-2	OPAL/VDC 5010k	OPAL/K 5700k	HSRA τ_b = 10	1.554E7	148.5	0.361
4	1.7251	0.7117	1.74E-2 / 1.73E-2	OPAL/VDC 5010k	OPAL/K 9300k	K5750 τ_b = 10	1.554E7	148.5	0.361
5	1.6739	0.7105	1.74E-2 / None	VDC	OPAL/K 5700k	K5750 τ_b = 2	1.544E7	148.7	0.3605
6	1.8956	0.7093/0.7392	1.91E-2 /1.90E-2	OPAL/VDC 5010k	OPAL/K 6200k	K5750 τ_b = 2	1.557E7	151.5	0.347
7	1.9161	0.7084/0.7377	1.91E-2 / 1.90E-2	OPAL/VDC 5010k	OPAL/K 6200k	K5750 τ_b = 2	1.547E7	148.8	0.349
8	1.8882	0.7099/0.7399	1.91E-2 / 1.90E-2	OPAL/VDC 5010k	OPAL/K 6200k	K5750 τ_b = 2	1.555E7	151.6	0.356

5700 K (models 1, 4) or different EoS in the external part ($T < 5000K$ models 1, 2) (EFF, or Vardya EoS + electronic degeneracy and coulomb pressure (VDC)) as well as along the solar structure (models 1, 5) (VDC, or OPAL) have practically no effect on the discrepancy.

The solar structure uncertainty is located at 1 solar radius with a range of 10^{-4} $R\odot$ where the cut-off frequency varies from 1 mHz to 5 mHz. This region is mostly sensitive to the T(τ) law used. In figure 2 we show the relative variation of the different models for temperature and density. When the disagreement with observation is observed, a clear discontinuity is noticed. In this part of the Sun, the opacities are dominated by atomic and H^- contributions and consequently the Kurucz & OPAL results are very close. For the EoS, the improvements done by the Livermore group are crucial but, nowadays, the problem is pushed toward the treatment of the production of H_2 and of the surface coulomb effect. New improvements pass through a better atmospheric T(τ) law including a smoother reconnexion to the main structure, turbulent pressure and non adiabatic effects in the outer layers (Guzik,1996).

3. Effects on the sound speed and g-modes

Figure 3 compares theoretical sound speed with the one deduced by Basu and Christensen-Dalsgaard for the preliminary GOLF results. One notices the progress done by the introduction of the microscopic diffusion (model 6, 1) and that the error of the available data (BiSON, LOWL, GOLF) (superimposed in this plot on model 1) begins to be sufficient to examine the solar core (models 7, 8 vs 6), see poster Turck-Chièze & al these proceedings.

The g-modes are a better probe for the nuclear core and we note as expected that they are unaffected by the effects of the outer layers, so we discuss only the models 6, 7 & 8. The modification of the nuclear reaction rates introduced in models 7 & 8 does not change significantly their fundamental period (T_0), they induce a variation of frequency of 2 μHz in the range between 150-350 μHz. This is largely above the experimental resolution and could be measured if the g-modes could be identified. We also notice that the microscopic diffusion changes the g-modes frequencies in the opposite direction by ($\sim 2\mu Hz$) (see for example central density of models 1, 6 & 7).This emphasizes the fact that a coupled analysis of p and g-modes could be useful to differentiate different physical processes.

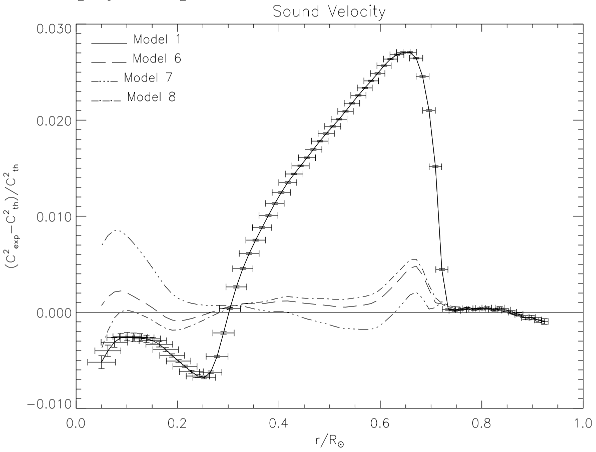

Figure 3: Sound speed difference between the Sun (see Lazrek & al these proceedings) and different solar models

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