LOW DEGREE OSCILLATIONS MODES AND VIRGO RESULTS

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ABSTRACT

Preliminary VIRGO data are compared with theoretical p modes frequencies for different standard and non standard solar models. The sensitivity of the predicted low frequency spectrum to the internal structure of these models is analysed.

1. COMPARISON OF VIRGO RESULTS WITH THEORETICAL PRESSURE MODE FREQUENCIES

We have studied the sensitivity of the p mode frequencies of a set of solar models to updated physics and to some physical processes like microscopic diffusion and mass loss (Morel et al 1997a, 1997b). Here we focus on the properties related to the structure of the solar core and on the comparison with VIRGO results (Fröhlich et al. 1997).

The differences of frequencies of low degree p modes $\Delta\nu_{n,\ell} = \nu_{n+1,\ell} - \nu_{n,\ell+2}$ for $\ell=0$ and 1 is strongly related to the variation of the sound speed in the solar core. It is an almost linear function of the radial order n:

$$\Delta\nu_{n,\ell} \sim \delta\nu_{02} + \mathrm{S}_0(n - n_0) \qquad (1)$$

The values of the intercept $\delta\nu_{02}$ and slope S_0 of this approximation for $\ell=0$ are given in Figure 1 for VIRGO/LOI observations with 1σ error bars and for different solar models (Morel et al. 1997a). The points corresponding to models with (left D) and without (right S) microscopic diffusion are well separated. There is a better agreement with the observations for D models. The D models, either which include a mild mass loss rate or which are older, are farthest left from the observations. It can be noted that the models which include up-to-date physics (OPAL equation of state and opacities, microscopic diffusion of helium and heavy elements) have a slightly larger value of $\delta\nu_{02}$ compared to the LOI observations. The slope S_0 is almost independent of the model and compatible with these observations.

2. SENSITIVITY OF LOW FREQUENCY MODES TO SOLAR STRUCTURE

In order to help the detection of modes in the low frequency spectrum observed by the helioseismology experiments on board SoHO, we have studied the sensitivity of low frequency modes to solar structure.

The frequency differences between two models have been computed for gravity modes and pressure modes with degrees ℓ=0 to 3 and frequencies from 50 to 900 μHz (Figs. 2, 3 and 4). The points corresponding to different degrees are well mixed. The differences vary almost linearly in g modes range up to 200 μHz and become smaller in the p mode frequency range.

The linear behavior at low frequencies can be explained in asymptotic approximation. For a frequency small enough, the first order asymptotic period is given by:

$$P \sim \frac{P_0}{\sqrt{\ell(\ell+1)}}\,(n + l/2 + \vartheta) \qquad (2).$$

$$\text{with} \qquad P_0 = 2\pi^2 / \int_0^{r_{zc}} (N/x)dx \qquad (3)$$

N is the Brunt-Väisälä frequency and r_{zc} is the lower boundary of the solar convection zone. See Provost & Berthomieu 1986 for more details. Hence comparing the modes of same n and ℓ of models 1 and 2 one obtains:

$$\frac{(\nu^1_{n,\ell} - \nu^2_{n,\ell})}{\nu^1_{n,\ell}} \sim -\frac{(P^1_0 - P^2_0)}{P^1_0} \; .$$

The slopes measured on Figures 2, 3 and 4 in the low frequency range correspond well to the relative differences of the characteristic periods P_0 of the gravity modes for the considered models.

The frequencies in the low frequency range are higher for a model with microscopic diffusion than for a standard one, with differences up to 10 μHz around 300 μHz and of order 2 μHz in p mode range (Fig. 2).

The g mode frequencies are lower for models with convective core overshoot during the beginning of solar evolution. For a model with an overshoot parameter of 0.2 H_p, the low frequencies are decreased by an amount up to 4 μHz, as seen in Figure 3a, while the p mode ones are almost not modified. We have studied the effect of a mass loss of 0.1 $\mathrm{M}_\odot$ occuring during the first stage of evolution. The low frequencies are increased by an amount which depens on the mass loss rate. A strong mass loss rate (Fig. 3 b) results in a smaller change of the solar structure, hence of the solar oscillations frequencies, than a mild mass loss rate which increases the frequencies up to 4 μHz (Fig. 3 c).

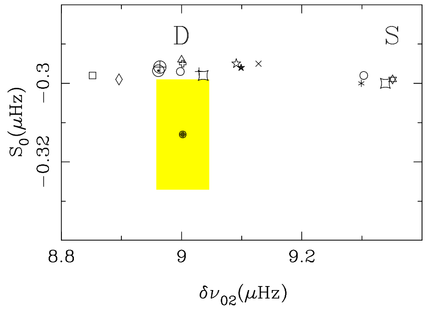

Figure 1: Intercept $\delta\nu_{02}$ and slope S_0 defined by relation (1) for $\ell = 0$ and n_0=20, for preliminary VIRGO/LOI data with their error bars and for different solar models.

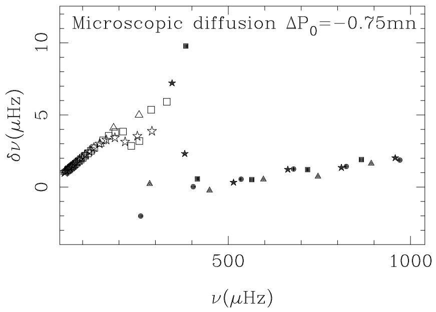

Figure 2: Difference of the frequencies of gravity modes (open symbols) and low frequency p modes (full symbols) between models with and without microscopic diffusion, for modes of degree ℓ=0 (circle), 1 (triangle), 2 (star) and 3 (square). For the D model, P_0= 35.75 mn.

We have studied the sensitivity of low frequency spectrum to some solar parameters, like the age and metallicity measured by the ratio of heavy elements to hydrogen contents Z/X. The frequencies decrease with increasing Z/X (Fig. 4a) and with decreasing age (Fig. 4b).

In conclusion all these differences, specially around 300-400μHz, may have implications on modes identification in that frequency range. A more detailed analysis is in progress (Provost et al. 1997). We acknowledge P. Morel for computing the solar models.

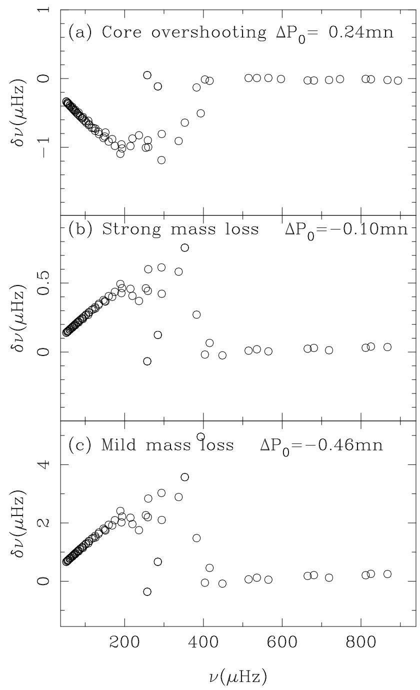

Figure 3: Effect of convective core overshoot and mass loss, during first stage of evolution, on the differences of low frequency modes between two solar models, respectively: **(a)** models with and without a convective core overshoot (parameter of $0.2H_p$); **(b)** models with and without a strong mass loss rate; **(c)** models with and without a mild mass loss rate.

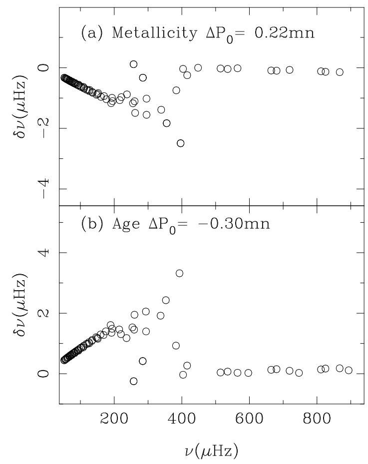

Figure 4: Effect of the metallicity and age on the differences of low frequency modes between two solar models: **(a)** : model Z/X=0.0260 - model Z/X=0.0245; **(b)** : model t$\odot$=4.65Gy - model t$\odot$=4.55Gy.

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