INFLUENCE OF THE Z-VALUE ON THE SOLAR FIVE-MINUTE OSCILLATION

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Summary

Two solar models with different heavy element abundances ($Z = 0.018$ and $Z = 0.02$) have been computed. Their theoretical oscillation frequencies for low ℓ, with periods around five minutes have been computed and compared to the observed ones. The discrepancy between the observed and computed spectra cannot be resolved by the choice of an appropriate value of Z.

Introduction

Up to now, more than 150 frequencies of solar oscillation modes corresponding to small ℓ values have been observed, with periods around five minutes. These observations put constraints on solar models which are difficult to satisfy. Several recent attempts have been made to reduce the discrepancy between observed and computed spectra. Ulrich and Rhodes (1983) have computed solar models with the equation of state introduced by Ulrich (1982), taking into account the influence of the scattering states, the theory of which has been developed by Larkin. The chemical profile of their standard model is deduced from the standard model of Bahcall et al. (1982). They have also considered variants, with different chemical profiles. Gabriel et al. (1983) have also considered models with an abundance profile modified by hydrogen and helium diffusion. These attempts fail to reduce the discrepancy between observed and computed spectra below the level of observational or computational errors. Neither successive improvements in the computation code of the models (Shibahashi et al. 1983, Gabriel et al. 1983, Noels et al. 1984) improve the agreement between observation and theory. We report here on our latest results obtained with two solar models with different chemical compositions.

Models

Two evolution sequences with different primordial chemical compositions ($Z = 0.018$ and $Z = 0.020$) have been computed with our Henyey code (Henyey et al. 1964, 1965). A number of improvements have been brought to this code in order to obtain enough accuracy for the computation of oscillation frequencies. The finite difference method has been replaced by a fourth order progressive method in the computation of the external layers of the model ($T < 10^6$K). The computation of the boundaries of the convective zone has been improved as described in the paper of Noels et al. (1984). The models include a chromosphere (model of Vernazza et al., 1973) extending up to 2300 km above the photosphere. Several improvements have been introduced in the equation of state. It includes the electrostatic corrections according to the Debye-Hückel theory (Shibahashi et al. 1983) and a special care was given to the computation of the partition functions (Noels et al. 1984). The opacities are those of Huebner et al. (1977). We have used the same interpolation formula as Bahcall et al. (1982) for model 1. For model 2, we have used the same type of formula with coefficients modified to fit the table for the given composition. The opacity tables of Alexander (1975) have been used for temperatures lower than 10^4K. The nuclear reaction rates are given by Fowler et al. (1975). Table 1 gives a few characteristics of the models. Grevesse (1983) gives the following observational constraint on the Z value : $0.0191 < Z < 0.0213$. Our first model does not satisfy this constraint. However the difference of Z between both models is of the order of magnitude of the observational uncertainty.

Table 1

The symbols have their usual meanings. The subscript c denotes the center of the model and e the base of the convective zone. ℓ/H is the ratio of the mixing-length to the pressure scaleheight.

	Model 1	Model 2		Model 1	Model 2
X	0.7275	0.7109	T_c (K)	1.540 (7)	1.562 (7)
Y	0.2545	0.2691	r_e/R	0.734	0.730
Z	0.0180	0.0200	m_e/M	0.9814	0.9804
age (yr)	4.67 (9)	4.61 (9)	ρ_e (g cm^{-3})	0.1463	0.1538
X_c	0.3656	0.3495	T_e (K)	2.007 (6)	2.072 (6)
ρ_c (g cm^{-3})	154.6	153.6	ℓ/H	1.846	1.979
$\rho_c/\bar{\rho}$	109.9	109.1			

Computed frequencies

The theoretical adiabatic frequencies have been computed as described by Boury et al. (1975). The accuracy of the computation code has been tested (Noels et al. 1984) and we are convinced that the errors on the computed frequencies, due to the code, do not exceed 1 μHz. Ulrich and Rhodes (1983) have shown that the choice of the outer boundary condition has no significant influence on the frequencies provided the boundary condition is applied at a point high enough above the photosphere. Our own computations confirm entirely this conclusion (Noels et al. 1984). Modes of both models have been computed for a few ℓ values (0,1,2,3,4,5,10 and 20) and with periods around five minutes.

Observed frequencies

The observed frequencies, used for comparison in the present work, have been obtained essentially by two methods. In the first one, the fluctuations of the sun brightness are observed (Deubner 1981, Woodard and Hudson 1983). The second method consists in measuring the velocity field on the solar disk through a Doppler shift (Claverie et al. 1981, Grec et al. 1983, Scherrer et al. 1983, Duvall and Harvey 1983).

Discussion

Figures 1 and 2 show echelle diagrams for $\ell = 0$ and 2. To each frequency ν is associated a point with coordinates (r,q) defined by $\nu = aq + r$ where $a = 136$ μHz, q integer, $0 \leqslant r < a$. Our first conclusion is that a change in chemical composition of the order of what is allowed by the observational uncertainty on the solar composition produces only a small change in the theoretical spectrum. The second conclusion is that the theoretical spectrum has not the good curvature to fit the observational spectrum. For modes of low order, the slope of the theoretical spectrum seems to be satisfactory but for modes with order beyond 20 the separation of the theoretical frequencies are larger than the observed ones. The same situation prevails for other ℓ values (diagrams not shown here). Thus we must recognize that a serious discrepancy exists between the observed and computed spectra. Despite several attempts, this discrepancy cannot be reduced either by imporvements in the computations or by minor changes in the solar models. It is likely that more computations will prove useless if they do not rest upon a really new idea.

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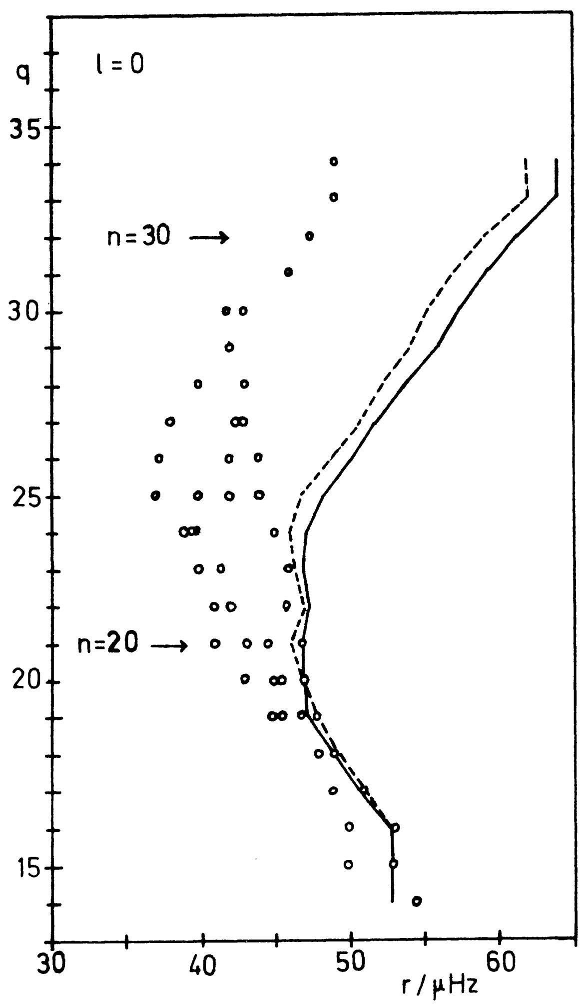

Fig.1

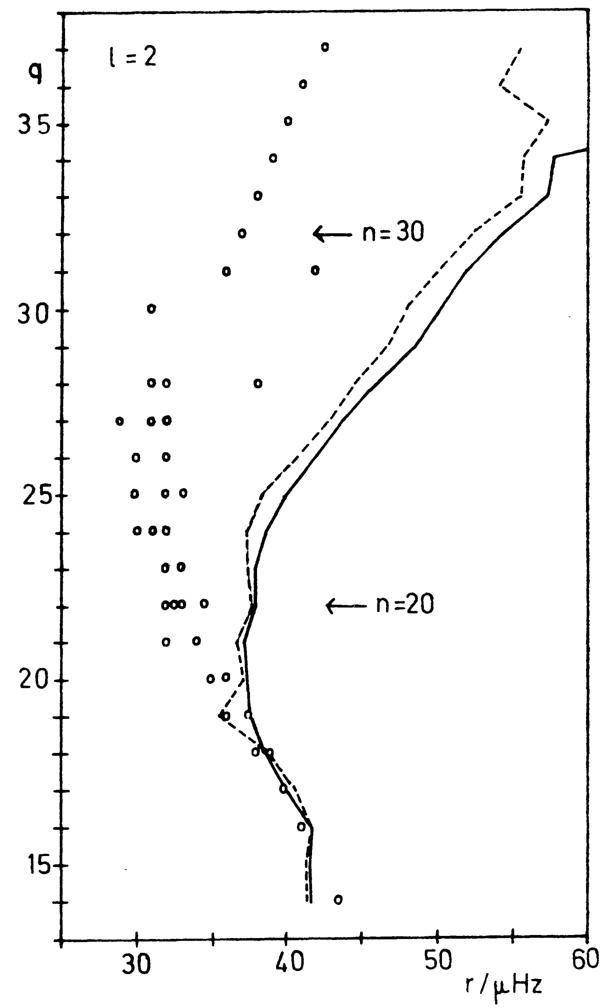

Fig.2

The circles represent observed frequencies (from the authors cited in the text); the solid line joins computed frequencies of model 1; the dashed line joins computed frequencies of model 2; n is the order of the mode.