A SEARCH OF THE EFFECTS OF MAGNETIC FIELD IN THE SOLAR FIVE-MINUTE OSCILLATIONS

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ABSTRACT. An overshoot region near the base of the solar convection zone may be the region where intense magnetic fields are stored during the solar cycle (Spiegel and Weiss, 1980; Schmitt and Rosner, 1983; Pidatella and Stix, 1986). In this report we study the possible influence of such a field on the frequencies of the solar five-minute oscillations.

Direct computations for the solar model were done using the convenient form of the perturbation technique developed on the basis of Rayleigh principle (Vorontsov, 1985). We use the symmetric form of the Lagrangian

$$\begin{aligned}\mathcal{L} = {} & \Gamma_1 p_0 (\nabla\cdot\vec{u}^*)(\nabla\cdot\vec{u}) + \frac{1}{2}\Big[\rho_0(\vec{u}\cdot\nabla)(\vec{u}^*\cdot\nabla\psi_0) + \rho_0(\vec{u}^*\cdot\nabla)(\vec{u}\cdot\nabla\psi_0) + \\ & + (\nabla\cdot\vec{u}^*)(\vec{u}\cdot\nabla p_0) + (\nabla\cdot\vec{u})(\vec{u}^*\cdot\nabla p_0) + \rho_0(\vec{u}\cdot\nabla\psi_1^* + \vec{u}^*\cdot\nabla\psi_1) + \\ & + (1/4\pi G)\nabla\psi_1^*\cdot\nabla\psi_1 - \rho_0\omega^2\vec{u}^*\cdot\vec{u} + \\ & + (1/4\pi)\vec{H}_1^*\cdot\vec{H}_1 - (1/8\pi)\big[(\nabla\times\vec{H}_0)\times\vec{H}_1^*\cdot\vec{u} + (\nabla\times\vec{H}_0)\times\vec{H}_1\cdot\vec{u}^*\big],\end{aligned} \qquad (1)$$

were the Eulerian perturbation of the magnetic field $\vec{H}_1 = \nabla\times(\vec{u}\times\vec{H}_0)$. The perturbations of the eigenfrequencies are given by

$$\delta(\omega^2)\int_V \frac{\partial\mathcal{L}}{\partial(\omega^2)}dV = -\int_V \frac{\partial\mathcal{L}}{\partial p_k}\delta p_k\, dV. \qquad (2)$$

The 'parameters' p_k denote the components of $\vec{H}_0$,equilibrium values of ρ_0 , p_0 , ψ_0 , Γ_1 , which are perturbed in the model, and their space derivatives.

The computations were done for the solar model of Abraham and Iben (1971) with the convection zone model of Spruit (1974). The thickness of the disturbing layer was assumed to be small compared with the radial wavelength of the oscillations. The magnetic field in the layer was taken to be toroidal, with a strength proportional to $\sin\theta$. The choise of the solar model and the field geometry are not very important

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because we limit the present study by the general character of the frequency perturbations and the magnitude of the effect.

The results for l = 2 are shown in Fig.1, were P_H denotes the magnetic pressure in the equatorial plane and h is the thickness of the disturbing layer. It was found that about 80 - 90 per cent of the total effect is governed by the inertial term in the Lagrangian (the second term in the third line of eq.(1)). The effect is larger for the modes described by tesseral harmonics ($m = \pm 1$) because their amplitudes concentrate towards the equatorial plane, were the magnetic field is larger (the results for $m = \pm 1$ are intermediate between those shown for $m = 0$ and $m = \pm 2$).

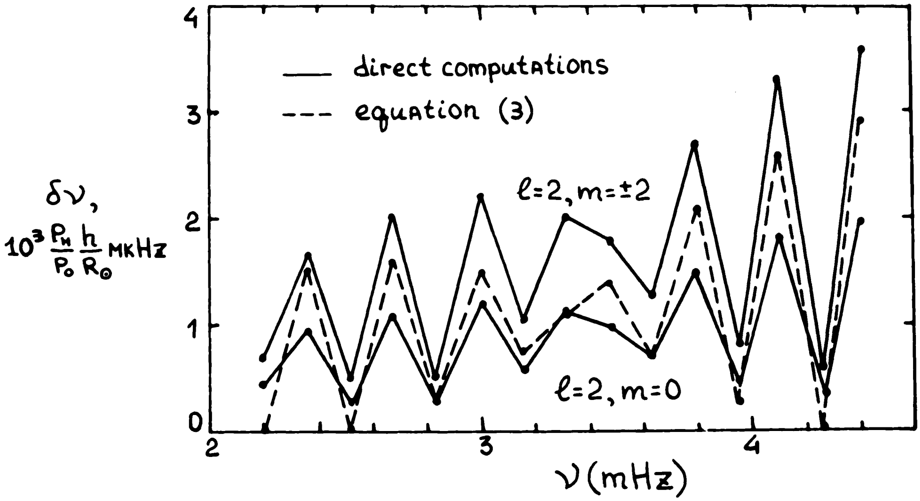

Figure 1. Perturbations of the eigenfrequencies of the solar model.

Since the frequency perturbations are due predominatingly to the density perturbation, they may be estimated in a much more simple way. For a thin spherically-symmetric density perturbation located at $r = b$, it may be shown, using the asymptotic eigenfunctions, that for the oscillations of low degree

$$\frac{\delta\nu}{\nu} \simeq -\frac{1}{2}\,\frac{\delta\rho_0}{\rho_0}\,\frac{h}{c(b)}\left(\int_0^{R_\odot}\frac{dr}{c}\right)^{-1}\left[1+\cos\left(2\pi\nu\cdot 2\int_b^{R_\odot}\frac{dr}{c}+\varphi\right)\right], \qquad (3)$$

were c is the sound speed and φ is determined by the structure of the outermost solar layers.

The eq.(3) predicts that the relative frequency perturbation $\delta\nu/\nu$ should have a periodic component when regarded as a function of frequency, which provides the effective way to reveal these effects in the experimental data even without multiplet splitting measurements.

The expected magnitude of frequency perturbations is very small. If the field occupies the layer with the thickness h equal to few tenths of the pressure scale height, with the current accuracy of frequency measurements the field of at least 10^6 G is needed to provide an observable effect. Although such a strong field seems to be rather unrealistic, the search of these effects in the experimental data is reasonable because with a large number of experimental frequencies available the periodic signal could be detected well under the noise level.

The experimental frequencies of the solar five-minute oscillations obtained by Libbrecht and Zirin (1985) for $5 \leqslant l \leqslant 20$ have been used for this analysis. It may be shown that if the disturbing layer is located near the base of the convective envelope, these l values are small enough in order that the periodic signal (which we are looking for) not to be destroyed (in terms of the ray theory, the curvature of the acoustic ray paths in the convective envelope is not significant). This signal should appear as the periodic component in the 'effective phase shift' $\alpha(\omega)$ determined from the experimental frequencies (Brodsky and Vorontsov, 1986). Instead of the direct application of eq.(9) of Brodsky and Vorontsov (1986), $\alpha(\omega)$ was calculated as

$$\alpha(\omega) = \frac{\omega}{\pi} F(w) - n \,, \qquad (4)$$

in order to avoid the smoothing of possible periodic component when the derivatives in the right-hand side of eq.(9) are estimated. After the substraction of the best-fit second-order polynomial the Fourier analysis of $\alpha(\omega)$ were done.

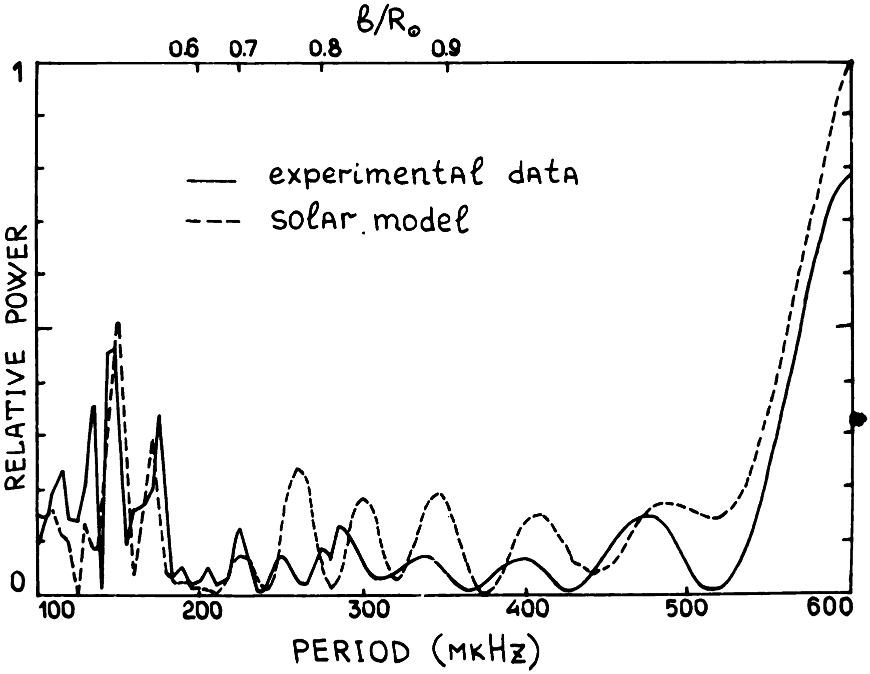

Figure 2. Harmonic analysis of the 'effective phase shift' $\alpha(\omega)$.

The results are shown in Fig.2, together with those obtained for the theoretical frequencies computed with the accuracy of about 0.1 per cent for the solar model 1 of Cristensen-Dalsgaard (1982). The upper scale indicates the radius of the possible disturbing layer. The absence of significant peaks in the power spectrum leads to the conclusion that the accuracy of the experimental data currently available is insufficient to reveal the possible concentration of the magnetic field near the base of the solar convective envelope.

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REFERENCES

Abraham Z. and Iben I.,Jr. *Astrophys.J.*,1971,170,157.
Brodsky M.A. and Vorontsov S.V. , *these proceedings.*
Christensen-Dalsgaard J. *Mon.Not.Roy.Astron.Soc.*,1982,199,735.
Libbrecht K.G. and Zirin H. Submitted to *Astrophys.J.*,1985.
Pidatella R.M. and Stix M. *Astron.Astrophys.*,1986,157,338.
Schmitt J.H.M.M. and Rosner R. *Astrophys.J.*,1983,265,901.
Spiegel E.A. and Weiss N.O. *Nature*,1980,287,616.
Spruit H.G. *Solar Phys.*,1974,34,277.
Vorontsov S.V. Submitted to Proc.IAU Colloq.90 *'Upper Main Sequence Stars with Anomalous Abundances'*,Crimea,May 1985.