Bull. Astr. Soc. India (2000) **28**, 97-99

Effect of asymmetry in peak profile on f-mode frequencies

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The fundamental mode or f-mode of solar oscillation is believed to be a surface gravity mode whose frequency is essentially independent of the stratification in the solar interior. Hence the difference between the observed frequencies (cf., Duvall et al. 1998 and references therein) and those of solar models have been interpreted to be due to velocity field or other effects. These frequencies were obtained by fitting symmetric peak profiles to the observed power spectra. However, the peaks, in general, are not symmetric (Duvall et al. 1993; Nigam & Kosovichev 1998) and the use of symmetric profiles may cause the fitted frequency to be shifted away from the true value. In this work we attempt to fit the frequencies using asymmetric peak profiles and attempt to determine the frequencies to very high degree ($\ell = 4000$) using the data obtained by Michelson Doppler Imager (MDI) on board the Solar and Heliospheric Observatory (SOHO).

We adopt the ring diagram technique (Hill 1988) to determine the mean frequency of solar oscillations at high degree ($\ell > 200$) (cf., Fernandes et al. 1992). From spectra obtained using high-resolution Dopplergrams we have taken sum over 24 spectra covering the available data for March, June and July 1997.

These summed 3d spectra are averaged in the azimuthal direction to obtain 2d spectra in the horizontal wavenumber k and ν. We fit the sections at constant k (or l) in the averaged spectra to an asymmetric profile of the form (cf., Nigam & Kosoviche 1998),

$$P(\ell, \nu) = \frac{e^{A_0}\left[\left(1 + B\,\frac{\nu - \nu_0}{w_0}\right)^2 + B^2\right]}{1 + \left(\frac{\nu - \nu_0}{w_0}\right)^2} + e^{b_1}[1 + b_2(1 - \nu/\nu_c)], \qquad (1)$$

where the 6 parameters A_0, B, ν_0, w_0, b_1 and b_2 are determined by fitting the spectra using a maximum likelihood approach (Anderson, Duvall & Jefferies 1990). Here ν_c is the central value of ν in the fitting interval, ν_0 is the fitted frequency and w_0 is the half-width, while the parameter B controls the asymmetry.

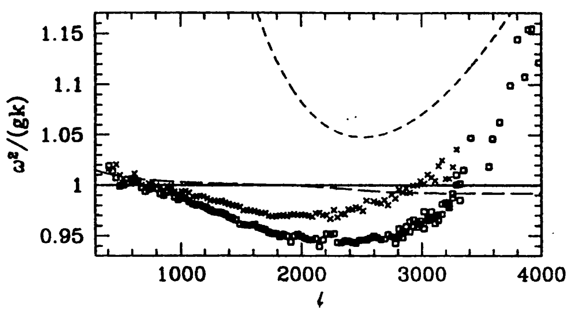

Figure 1. The ratio w^2/gk for fitted frequencies of f-modes using symmetric (squares) and aymmetric (crosses) profiles. The long-dashed and short dashed lines respectively, show the result for f-mode and the lowest chromospheric mode in a solar model.

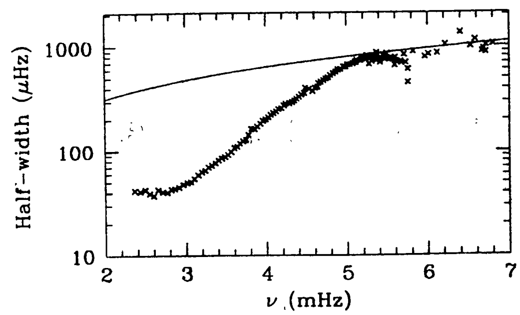

Figure 2. The half-width of the fitted f-modes. The continuous line marks the width for which the damping time is equal to the time-period of oscillation.

We are able to detect the f-mode ridge up to $\ell \approx 4000$ and the results obtained by fitting symmetric and asymmetric peak profiles are shown in Fig. 1. This figure shows w^2/gk evaluated at the surface ($r = R_\odot$) for various observed frequencies. This figure also shows w^2/gk for a solar model. The dip in the observed w^2/gk at $l = 1000 - 2000$ has been interpreted as being due to turbulent velocity fields in the solar convection zone (Duvall et al. 1998). We see that although the use of asymmetric profiles reduce the difference between model and observed frequencies, the difference is still significant. Thus asymmetry in peak profile cannot explain the entire difference between observed and model frequencies

Fig. 2 shows the width of these modes. The width increases rapidly and becomes very large by $\ell \approx 3000$ ($\nu \approx 5.35$ mHz) and the corresponding damping time ($1/2\pi w_0$) is comparable to the time-period of the oscillation. Hence beyond this point the mode cannot be considered to exist as a normal standing wave. This is expected since beyond this value of ℓ, the kinetic energy density for f-mode will not decrease with height. At even higher degrees, it appears that the width becomes roughly constant with increasing frequency and we believe that the mode is no longer an f-mode.

From Fig. 1 it appears that at very high ℓ the frequencies of the f-modes tend towards those of the chromospheric modes in a solar model. It may be noted that because of very large half-width ($\approx$ 1mHz) and low power it is not possible to separate the f-mode ridge from the lowest chromospheric mode ridge in this region. It is quite possible that for $\ell \gtrsim 3000$ the f-mode power reduces sharply and hence the corresponding ridge in the observed spectra is dominated by that of the chromospheric mode. This probably explains the sharp increase in w^2/gk seen in Fig. 1 and also the fact that the width appears to become roughly constant for $\ell \gtrsim 3000$.

This work utilizes data from the SOI/MDI on the Solar and Heliospheric Observatory (SOHO). SOHO is a project of international cooperation between ESA and NASA.

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