OBSERVATIONS OF LOW-DEGREE MODES FROM THE SOLAR MAXIMUM MISSION
(Extended Abstract)

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Mean frequencies, amplitudes, and linewidths for the solar 5-min p-mode oscillations of degree 0, 1, and 2 have been obtained from ~280 days of SMM-ACRIM total irradiance data (Woodard and Hudson, 1983). The frequencies are in good agreement with measurements obtained from velocity data, and are given in the Table. The amplitudes of the modes lie along a well defined envelope of power vs. frequency, which peaks at 3.1 mHz and has a width of 0.7 mHz (FWHM). The r.m.s. amplitude of the highest peak in the spectrum ($n=21$, $\ell=1$) is ~3 ppm of the total flux. The linewidths of the narrowest $\ell=0$ modes are ~1 μHz (FWHM). A broad "continuum" of power caused both by solar surface granulation and by instrumental noise interferes with the analysis of 5-min modes. The continuum spectral power in a 1 μHz band near 3 mHz corresponds to an apparent r.m.s. variation of ~0.5 parts per million of the mean solar flux.

These results have been interpreted in terms of a model in which the amplitudes of the separate ($n\ell m$) modes obey a damped harmonic oscillator equation and are excited stochastically by broad-band noise. The full width at half maximum of the implied Lorentzian line profiles, $\Delta\omega$ (angular frequency), is related to the e-folding decay time, τ, of the squared mode amplitude:

$$\tau=1/\Delta\omega$$

giving $\tau=$ ~2 days for the longest-lived $\ell=0$ modes. Consistent with this estimate is an upper limit τ = 6 days inferred from the dispersion in the power of the dominant $\ell=0$ modes. To obtain this limit, I assume that the spread in power within the ensemble of peaks in the overall spectrum indicates the time variations in the power of a typical individual mode. The chaotic oscillator model predicts the relation

$$\sigma^2 = 2\tau/T$$

for the fractional variation in power, σ, in an interval of duration T. Allowance was made for dependence of the mode power upon frequency by taking the deviation in mode power about a best-fit parabolic envelope.

No fine structure of the type claimed by the Birmingham group ("rotational" splitting) is seen in the $\ell=1$ or 2 modes. The $\ell=1$ modes appear to be broader than the $\ell=0$ modes, an indirect indication of splitting. If, as seems reasonable, the m-substates of $\ell=1$ multiplets have the same width as the $\ell=0$ modes, then the observed $\ell=1$ widths can be used to measure solar internal rotation. Experiments with simulated data show that the signal-to-noise ratio of the ACRIM data is capable of distinguishing the splitting (~0.43 μHz per m-state) expected from uniform solar rotation at the surface rate from the splitting corresponding to a mean interior rotation rate exceeding twice the surface rate. Precise limits will be the subject of a future paper.

Several additional analyses have been performed. Time variations in the power of individual $\ell=0$ modes (n=19,..,23) among non-overlapping ~50-day sub-intervals of data have been measured directly and imply a lifetime between 1 and 5 days, in agreement with the 2-day lifetime inferred from linewidth. An attempt was made to measure secular changes in the frequencies of normal modes by dividing the data into ~100-day data sub-strings. The amount of variation is consistent with the random fluctuation expected from the oscillator model of excitation and with the amount of background noise in the data. If the frequencies of the main $\ell=0$ and 1 modes vary in unison then the amount of variation which occurred over the ~10 month observation span must be significantly less than 1 μHz. Uncorrelated frequency drifts of this magnitude cannot be discounted, however.

The statistical uncertainty, $\delta\nu$, in the frequency estimate from a data string of length T, computed with the aid of the chaotic oscillator model, is ideally given by

$$(2\pi\delta\nu)^2 = 1/2\tau T$$

so that for $\tau = 2$ days and $T = 300$ days $\delta\nu = 0.05$ μHz. More realistic error estimates which take into account the background noise level of the data imply errors of ~0.2 μHz for the dominant modes. These error bars are significantly less than the frequency splittings expected from uniform solar rotation and indicate the accuracy to which the solar internal rotation rate can eventually be inferred from p-mode data. Detailed results concerning frequency and amplitude variations and the method of error analysis will be presented in a future paper.

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Reference

Woodard, M. and Hudson, H.S., 1983, Nature 305, p. 589.

Table of frequency centroids (μHz)

(Note that the errors quoted here are larger than those in the reference article, as a result of further tests with simulated data.)

Order n	Degree, ℓ 0	1	2
17		2559.2±0.3	2619.7±0.5
18	2629.5±0.5	2693.7±0.2	2755.0±0.5
19	2765.0±0.4	2828.7±0.2	2890.0±0.4
20	2899.1±0.3	2963.5±0.2	3024.5±0.3
21	3034.0±0.2	3098.7±0.2	3160.0±0.3
22	3169.4±0.2	3233.4±0.2	3295.2±0.5
23	3303.8±0.3	3369.5±0.2	3433.2±0.5
24	3439.8±0.3	3505.1±0.3	
25		3642.5±0.5	