CHAPTER 3

LONGTERM VARIATIONS IN THE SUN

TIME VARIATIONS OF THE FREQUENCIES OF LOW-DEGREE SOLAR P-MODES

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ABSTRACT. A comparison of three separate years (1980, 1984, 1985) of SMM/ACRIM solar total irradiance data reveals small but significant changes in the frequencies of low-degree solar p-modes. Specifically, a decrease in the mean frequency of the nine strongest $\ell = 0$ and 1 oscillation peaks was observed between 1980 and 1984 such that

$$\langle \Delta\nu \rangle_{1984 - 1980} = -0.41 \pm 0.13 \ \mu\text{Hz}.$$

A further comparison, between 1980 and 1985, gives

$$\langle \Delta\nu \rangle_{1985 - 1980} = -0.45 \pm 0.23 \ \mu\text{Hz}.$$

Thus, the mean frequency of these modes is approximately 1.5 parts in 10^4 higher at the time of solar maximum than near solar minimum, a result which may shed light on the mechanism of the solar activity cycle.

J. Christensen-Dalsgaard and S. Frandsen (eds.), Advances in Helio- and Asteroseismology, 197–200.

We describe an analysis of low-degree solar p-mode frequency variations using the ACRIM solar total irradiance data(1). The reduced data consist of flux estimates obtained at the rate of 1/131.072s imposed by the periodic chopping of the solar input to the ACRIM sensor. A Fourier spectral analysis was performed on three epochs of data: in 1980 from 18 February to 1 December, in 1984 from 1 May through 31 December, and in 1985 from 1 January through 31 December. Subsequent ACRIM data, continuing to the time of this writing, have yet to be analyzed. A frequency determination of individual low-ℓ p-modes was performed for each of the three above-mentioned epochs. Figure 1 shows the 1985 frequencies of the nine best $\ell = 0$ and 1 oscillation peaks relative to their 1980 values, plotted as a function of mode frequency. A decrease since the time of solar maximum (~ 1980) is clearly evident. For both 1984 and 1985 we give the average of the nine frequency differences:

$$(1) \quad \langle \Delta\nu \rangle_{1984 - 1980} = -0.41 \pm 0.13 \ \mu\,\mathrm{Hz}$$

$$\langle \Delta\nu \rangle_{1985 - 1980} = -0.45 \pm 0.23 \ \mu\,\mathrm{Hz}$$

The (1σ) errors are calculated from the scatter of the individual frequency differences, by making the convenient, but only approximately correct, assumption that each point has the same error. The mean and error of the 1980-85 comparison are indicated in the right-hand part of Figure 1. The decline of the p-mode eigenfrequencies by ~ 1.5 parts in 10^4 between 1980 and 1985, given by (1) has a roughly 2σ formal significance in contrast to the 5σ significance quoted at the meeting. It is now known that the original 1985 ACRIM reduction program contained an error which has been since corrected.

An alternative look at the frequency variations was obtained by a method analogous to the 'superposed frequency' analysis of Grec et al(2). Peaks in the spectrum of a particular subinterval of data were superposed using a set of reference frequencies (rather than by folding the spectrum on a fixed frequency interval) to obtain a 'superposed spectrum' consisting of a single, composite oscillation peak. The reference frequency of a given oscillation mode is simply the mode frequency estimated from a power spectrum of <u>all</u> the data from the three years analyzed so far. Thus, for a given subinterval of data, the position of the composite peak is a measure of the shift (relative to that obtained from the data as a whole) of the mean frequency of the modes used in the superposition. Figure 2 shows the frequency shift gotten from the 'composite peak' analysis for the set of $\ell = 0$ & 1 modes given in Figure 1. Each point represents a subinterval of ~ 100 days, with a separation of ~ 100 days between consecutive points. (The ~ 3.5 year break is a period of diminished

SMM pointing ability.) The three curves visually confirm the decrease quoted in eq. (1).

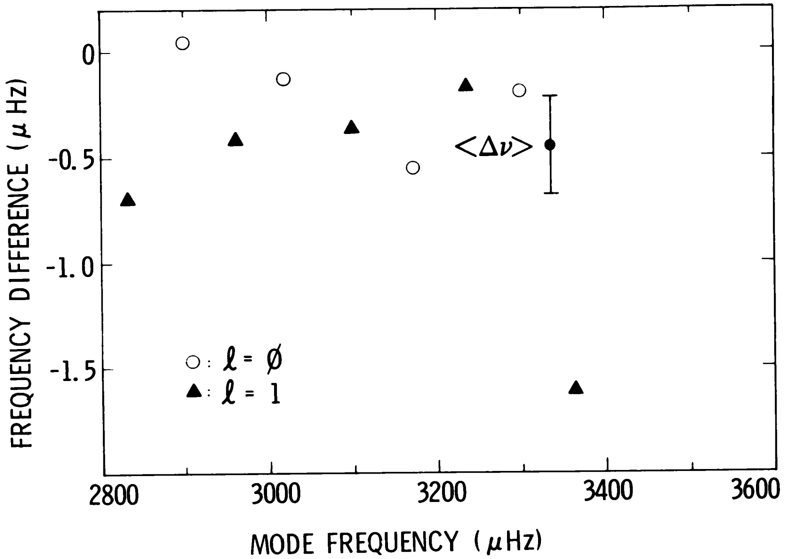

Figure 1

We note that, asympotically, the frequencies of the low- ℓ p-modes are proportional to the inverse wave-travel time across the cavity in which the pmodes are trapped, which in turn depends on the wave propagation speed within the solar interior and on the radius of the wave-reflection surface near the photosphere. Thus, the observed frequency change could be identified with a relative radius variation of similar magnitude ($\sim 1.5 \times 10^{-4}$), such that the solar radius is largest at sunspot minimum. Pending analysis of recently obtained solar radius measurements, we speculate no further as to the reality of a radius variation. As an alternative explanation we consider the possibility that either magnetic fields or turbulent velocities in the upper portion of the convective zone are responsible for all or part of the observed frequency changes, since the amplitude of both internal magnetic fields and turbulence probably varies with the solar activity (see ref. 1 below for further references). If a modification of the upper part of the convection zone is the main cause of the observed frequency change then one might expect a larger effect in p-modes of higher ℓ . We also suggest that if the fields were to be distributed anisotropically, concentrated, for example, near the solar equator, the m-state splitting of the p-modes, especially at high ℓ , might vary with the solar cycle. We hope that further study of oscillation frequency changes will lead to a better understanding of the distribution and strength and solar magnetic fields and of solar activity cycle in general.

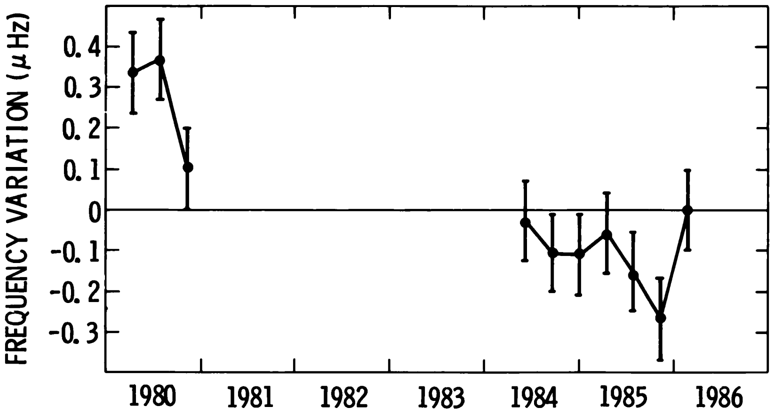

Figure 2

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REFERENCES

1. Woodard, M. F., and Noyes, R. W., Nature 318, 449-450 (1985).
2. Grec, G., Fossat, E. and Pomerantz, M., Sol. Phys. 82, 55-66 (1983).