SUNSPOT SEISMOLOGY

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The 5 minute oscillations in a sunspot umbra are the response of the sunspot to forcing by the 5 minute p-modes in the surrounding convection zone (Thomas 1981). This interaction of solar p-modes with a sunspot can be used to probe the structure of a sunspot beneath the visible surface of the Sun (Thomas, Cram, and Nye 1982). Here we report briefly the results of both an observational study and a simple theoretical analysis of this interaction. A full account of these results will be published elsewhere (Abdelatif, Lites, and Thomas 1986; Abdelatif and Thomas 1987).

The observations were made with the vacuum tower telescope, echelle spectrograph, and 100 × 100 pixel CCD array at the National Solar Observatory (Sunspot, NM). Time series of velocity maps of two isolated sunspots and their surroundings were recorded in Fe I λ6302.5 and the umbral line Ti I λ6303.8. The 5 minute oscillations are found to have reduced amplitude in the umbra, with an rms velocity about half that in the surrounding photosphere. The sunspot umbra appears to act as a selective filter in transmitting certain frequencies in the power spectrum of p-modes in the surroundings. A comparison of the k-ω power spectra of oscillations in the umbra and in the surrounding photosphere shows this selective transmission and also shows a general shift of power to longer horizontal wavelengths in the umbra. There is a sharp drop in power in the k-ω power spectrum of the umbra for waves with horizontal phase speeds less than about 25 km s^{-1}.

These two observed effects - the selective transmission of p-modes into the umbra and the shift of power to longer horizontal wavelengths in the umbra - are both reproduced by a simple theoretical model of a sunspot magnetic flux tube and its surroundings. The sunspot is modeled as a uniform vertical magnetic slab or magnetic cylinder, and vertically trapped acoustic waves (p-modes) outside the sunspot are set up by rigid, reflecting

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horizontal boundaries. Horizontally propagating p-modes incident upon the sunspot are partially transmitted into the sunspot as fast magneto-acoustic waves and partially reflected. The transmitted magneto-acoustic waves have increased horizontal wavelength compared to the incident acoustic waves. This explains, at least qualitatively, the observed horizontal wavelength shift of power in the umbra. In the model, all of the transmitted power is in the form of waves with horizontal phase speeds greater than the fast magneto-acoustic speed in the umbra; at photospheric heights, this speed is close to the 25 km s^{-1} derived from the observations. Selective filtering of p-modes by the model sunspot occurs because of the variation of transmission coefficient with horizontal wavelength for a magnetic slab of finite width, i.e., because of the "resonant transmission" of waves with an integral number of horizontal wavelengths across the width of the sunspot.

Our theoretical model assumes that a sunspot consists of a single, monolithic magnetic flux tube, which is the traditional picture. Alternatively, Parker (1979) has proposed that a sunspot consists of a collection of distinct flux tubes separated by field-free gas (see also Spruit 1981). Bogdan and Zweibel (1986) have investigated the transmission and reflection of acoustic waves by a fibril magnetic field of the sort envisioned in Parker's model. Further development of theoretical models of the interaction of solar p-modes with both monolithic and fibril sunspot magnetic fields, along with improved observations, offer the hope that "sunspot seismology" can provide a definitive test of these two competing theoretical models of the subsurface structure of a sunspot.

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