ABSORPTION OF WAVES IN SUNSPOTS

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ABSTRACT

Sunspots absorb and scatter the sun’s global modes, the $f$- and $p$-modes. Initial hopes were that this would allow us to probe the subsurface structure of spots, as helioseismology has been probing the sun on a global scale. However, it has turned out to be more difficult than first imagined. At the INTAS Workshop on MHD Waves in Mallorca in 2001, I explained the supposed mechanism, coupling to slow magnetoacoustic waves, but gave a rather gloomy picture of its ability to quantitatively match observations. However, recent advances in modelling in CSPA at Monash have for the first time produced results which seem to explain much of the data. In this talk, a simple model is presented, and its predictions compared with the best available observational Hankel data. Discrepancies concerning near-surface wave speeds between Hankel and holographic analyses on the one hand and time-distance inversions on the other are discussed. It is suggested that helioseismic inversions of active regions should address magneto-acoustic mode coupling if they are to fully account for absorption and wave speed variations.

1. INTRODUCTION

It has long been known that sunspots absorb $p$-modes [1, 2]. Decomposition of observed solar surface oscillations in annuli around active regions into ingoing and outgoing Hankel functions indicates that, depending on frequency and $p$-mode ridge, absorption coefficients $\alpha$ as high as 50% are common. However, several complicating factors (e.g. acoustic glories [3]) may disguise the true extent of absorption.

A ‘purer’ measure of the influence of the spot on traversing waves is the phase shift $\delta$ [4]. Fig. 1 presents a typical scenario: each $p$-mode ridge rises superlinearly with frequency from zero, and each successive ridge is shifted to the right. The interpretation is clear. On a particular ridge, increasing frequency corresponds to increasing spherical harmonic order $\ell$ and decreasing turning depth. For higher radial orders $n$ (at fixed frequency), the turning depth is deeper, and so higher frequencies are required to reduce the depth of their cavities to corresponding levels.

Figure 1. The phase shift (degrees), averaged over a small range of cylindrical degree $m$, for the successive $p$-mode ridges $n = 1, \ldots, 8$ (left to right, with changing symbols) as a function of frequency for the sunspot group NOAA5254 [4].

This suggests that there is a shallow layer in a sunspot where the wave speed is increased relative to the quiet sun.

Any description of sunspot interaction with acoustic waves must explain the phase shifts, as well as provide sufficient absorption to match or exceed the observed values. A recent model based on slow mode conversion in inclined magnetic field permeating a simple polytropic atmosphere [5] appears to do both, and therefore suggests that magnetic effects alone can produce both the observed absorption and phase shifts. However, thermal differences are obviously implicated too. Work currently underway (Cally and Crouch) based on a more realistic atmosphere will address the question of the relative importance of the magnetic and thermal contrasts between sunspot and quiet sun.

Whereas Hankel analysis relies on a modal description of solar oscillations, another recent method, time-distance helioseismology (TD), adopts a ray theoretic description. The foundations of TD are set out in [6, 7]. Surprisingly, TD inversions of sunspot subsurface layers indicate a wave speed decrease of several hundred $\text{m s}^{-1}$ up to 1 $\text{km s}^{-1}$ in the top $\sim 4 \text{ Mm}$, in direct contradiction to the Hankel analysis results, and also those of acoustic holography [8]. The reasons for the discrepancy are