SEISMOLOGY OF SUNSPOT ATMOSPHERES*

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Abstract. The present work deals with the theory of oscillations with periods of about 3 min observed in
the chromosphere above sunspot umbrae. The model of these oscillations (slow mode magneto-acoustic
waves trapped in a chromospheric resonant cavity) provides an independent method of checking empirical
models of the chromosphere above sunspots.

Making use of this method, we investigate sunspot models which have been derived from spectroscopic
data; the calculated periods of the oscillations fit well the observed periods.

1. Introduction

Empirical models of the thermodynamic structure of sunspot umbrae seem to be well
established at photospheric levels. For lack of reliable observations and difficulties in
their interpretation uncertainties arise, however, at larger heights starting from the
temperature minimum ($T_{\text{min}}$). Recently, the situation improved because EUV sunspot
observations with high spatial and spectroscopic resolutions became available, including
hydrogen Lx line contours from HRTS (Basri et al., 1979) and OSO-8 (Kneer et al.,
1981); and a unified working model of sunspot structure from the subphotosphere (that
is, the upper part of the convective zone) up to the base of the transition layer between
chromosphere and corona has been derived using these data (Staude, 1981). Such
models cannot be defined unambiguously, however, as long as the EUV data are
available only for a small number of sunspots and spectral lines.

Oscillations in velocity and brightness observed at photospheric and chromospheric
layers of sunspots could provide an independent method of investigating the atmospheric
structure. In a recent paper, Żugżda and Locāns (1981) proposed such a type of sunspot
seismology assuming a model for a chromospheric resonant cavity which is forced from
below by acoustic noise produced in the convective zone.

In the following section we shall summarize observations and different efforts
towards its interpretation. The subsequent sections will give a description of our models

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of sunspot structure and chromospheric oscillations, followed by a discussion of the results and conclusions for further work.

2. Observations and Suggestions for the Interpretation

Intensity and velocity oscillations in chromospheric lines of sunspot umbrae are observed with periods $P$ between about 2 and 3 min. Beckers and Tallant (1969) first discovered oscillatory-type phenomena in the Ca II H and K lines and the infrared triplet, which were called 'umbral flashes'. Havnes (1970) suggested that such flashes could be produced by compression waves. Later umbral velocity oscillations were also observed in Hα and other chromospheric lines, e.g. by Giovanelli (1972) and Giovanelli et al. (1978).

At photospheric levels of umbrae, oscillations occur in a much broader range of $P$ between 2 and 8 min. Most of these observations concern velocity oscillations, but there are also reports on oscillations of the magnetic field vector (Mogilevsky et al., 1973). A clear correlation with the chromospheric oscillations does not exist (Beckers and Schultz, 1972; Bhatnagar et al., 1972). In the present paper we shall mainly deal with the chromospheric oscillations.

Recently umbral oscillations in velocity and partly also in brightness have been discovered, even in the transition region at a temperature of $T \approx 10^5$ K. These oscillations observed on the SMM spacecraft (Gurman et al., 1982; Tandberg-Hanssen et al., 1981) show periods of $129 \leq P \leq 173$ s similar to those in the chromosphere; they seem to represent upward propagating compression waves. Clear correlations between the parameters $P$, oscillation amplitude, umbral area, and the magnetic field $B$ do not exist.

In theoretical efforts to explain the umbral oscillations, most authors looked for the resonant response of the umbral atmosphere to forcing from below. Different wave modes have already been considered:

Uchida and Sakurai (1975) assumed Alfvén waves already being downward reflected at the layers around $T_{\text{min}}$ by the strong increase of the Alfvén speed $v_A$ with increasing height and decreasing mass density $\rho$ (see Figures 3 and 4). However, there is no effective upward reflection of downward propagating waves from the subphotosphere (Thomas, 1978; Žugžda and Locâns, 1980, 1982), hence, a resonant cavity cannot form.

'Fast' mode magneto-atmospheric waves were considered by Antia and Chitre (1979) as well as by Scheuer and Thomas (1981), and Thomas and Scheuer (1982). Downward reflection of these waves can occur due to the increase of $v_A$, as in the case of the Alfvén mode, but now also an upward reflection from the subphotosphere is possible due to the increase of the sound speed $c_s$, and a photospheric resonant cavity will form. This mode could explain the umbral oscillations observed in the photosphere. At higher levels, a pure acoustic wave will propagate along the magnetic field; its energy is much smaller than that of the mainly horizontal oscillations in the photosphere, but the amplitude is large enough to explain observed chromospheric oscillations. However, in this model the oscillations in the chromosphere should show a clear correlation to those