OBSERVATIONS OF SUNSPOT UMBRAL VELOCITY OSCILLATIONS

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Abstract. Sunspot umbral molecular lines have been used to look for the oscillatory velocities in the umbra. Power spectrum analysis showed conspicuous power for periods in the range between 448 and 310 s. The maximum peak-to-peak amplitude of the umbral oscillatory velocity component is observed to be in the order of 0.5 km s^{-1}.

1. Introduction

It has been a long standing problem in solar physics to explain the missing energy due to the presence of sunspots on the Sun. Several theories have tried to explain the energy transport in sunspots, assuming unstable convective, radiative transport or oscillatory (overstable) modes in the presence of strong magnetic fields. This last mode of the energy transport, proposed by Danielson and Savage (1968), seems to be a very promising one and it is possible to observationally test the theory. It has been established by Howard (1967), Sheeley (1971), and Sheeley and Bhatnagar (1971) that in the presence of a magnetic field, such as in plages and in active regions, the amplitude of the oscillatory velocity field is considerably reduced compared to the non-magnetic regions on the Sun. In the stronger sunspot fields the amplitude may be further reduced if it is a monotonic function of the magnetic field strength. The first indication of such a reduction was seen in the observations of Howard *et al.* (1968). In an earlier work one of us (Bhatnagar, 1971) tried to look for the oscillatory velocity field in sunspot umbrae, using the Mount Wilson magnetograph and the λ 5250 and λ 5123 ($g=0$) lines. The amplitude of the oscillatory velocity observed with these lines is considerably reduced in umbrae and, also, some evidence for a fluctuating velocity field was noticed. However, as it was not possible to completely remove the influence of the photospheric stray light from the velocity data, the results of the observed oscillatory velocity were considered very tentative.

In the present study we have used lines which are formed only in the sunspot

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umbrae and show no Zeeman splitting. Thus our present velocity measurements are free from any cross talk introduced by photospheric and penumbral scattered light. In addition, since the lines show no Zeeman splitting, there can be no modulation introduced by varying field strength as might occur with a slight change of position within the umbra.

2. Observations

The magnetograph in conjunction with the 82-cm image of the Kitt Peak National Observatory was used for the velocity field observations in sunspot umbrae (Livingston, 1968). In the Doppler mode the velocity signal is obtained as the encoder readout of the Doppler servo. The error signal for this servo is derived from the difference of the wing intensities. Simultaneously the sum of the wing intensities is also obtained. The Doppler (difference) and the intensity (sum) signals are displayed on a CRT and recorded on magnetic tape for later data analysis. These observations were made using a fixed, i.e. non-scanning, aperture of $2.5 \times 2.5''$. The sunspot umbra was centered on the aperture and the solar image was photoelectrically guided. To compensate for solar rotation, the image was periodically moved eastward. Visual monitoring of the wing intensity channel greatly helped in following the same region of the umbra. Most of the observations were made for a period of 4096 s, with a sampling interval of 1 s in time. The same spot was observed both on November 22 and 23, 1971. The spot was isolated and round, located at E4, S6 with a maximum magnetic field strength of +2500 G on November 23, according to Mount Wilson measurements. The umbral diameter was about 14″. As the spot was near the central meridian on November 23, the measured umbral velocity component is essentially vertical, normal to the solar surface.

Three sunspot umbral lines, λ 6021.037, λ 6525 and λ 6910 were selected from a photographic sunspot atlas made by one of us (JWH). Because the lines were not detectable in the photosphere and showed no Zeeman effect, we believe that they are molecular in origin, but no definite identification is available (Sotirovski, 1972). For comparison purposes and to determine the spectrograph drift and noise characteristics due to atmospheric pressure, temperature changes and seeing, we have interlaced the umbral velocity observations with similar runs on telluric lines. Figure 1 shows a typical run of the velocity and the wing variations in sunspot umbra in the λ 6021.037 line observed on November 23. Figures 2 and 3 show the velocity and intensity runs on the telluric line λ 6290.2 and photospheric line λ 6518.6 (Fe I), both taken at the center of the disk and outside of an active region. The velocity run in the sunspot umbra (Figure 1) shows conspicuous velocity oscillations, although considerably reduced in amplitude (maximum peak-to-peak amplitude of 0.5 km s^{-1}) compared to the photospheric 5-min oscillations (Figure 3). The velocity data also contain a slow drift which is due to spectrograph drift in wavelength. A careful examination of the wing intensity runs show a periodic brightness variations of small amplitude in both phtospheric and telluric lines. We believe that this is a manifestation of the known continuum brightness oscillations (cf. Tanenbaum *et al.*, 1969).