SUNSPOT OSCILLATIONS OBSERVED WITH MDI

I. Rüedi[1], S.K. Solanki[1], J.O. Stenflo[1], P.H. Scherrer[2]
[1] Institute of Astronomy, ETH-Zentrum, CH-8092 Zürich, Switzerland
Tel: +41 1 632 3813, Fax: +41 1 632 1205, E-mail: ruedi@astro.phys.ethz.ch
[2] W.W. Hansen Experimental Physics Laboratory,
Center for Space Science and Astrophysics, Stanford University, Stanford CA 94305-4085

ABSTRACT

We report on velocity and magnetic field oscillations observed in sunspots using MDI. In addition to velocity oscillations, the data clearly show oscillations of the magnetogram signal in the parts of the sunspot with the strongest magnetic field. The frequencies of the velocity and magnetogram oscillations do not always coincide.

1. INTRODUCTION

Sunspot models predict velocity oscillations in the 3 and 5 mHz (i.e. 5 and 3 minute) bands. Such oscillations have been observed in both the intensity and the Doppler shift by a number of observers, and their properties have been investigated in detail (see the review by Lites 1992).

The effect of these oscillations on the magnetic field has, however, been investigated very little and the results are controversial. In the recent literature only Horn et al. (1997) and Lites et al. (1998) report on magnetic field oscillations. The former authors present oscillations that are just significant, while the latter authors do not consider their own observations to be sufficiently reliable to represent true detection.

Here we explore velocity and magnetic field oscillations observed in an active region with MDI. In the present paper we concentrate on the oscillations in the umbrae of the two main spots of the region.

2. OBSERVATIONS

We analyse high resolution MDI data obtained in a big active region (NOAA 7999) located close to solar disc centre. In this mode, the pixel size corresponds to 0.605″. The data consist of 3 time series recorded at a cadence of one minute and lasting between 1.5 and 4 hours. They were observed between Nov. 25 1996 and Nov. 27 1996, and contain simultaneous observations of the continuum intensity, the magnetic flux (magnetogram) and the line shift. Such data have the enormous advantage that they show true

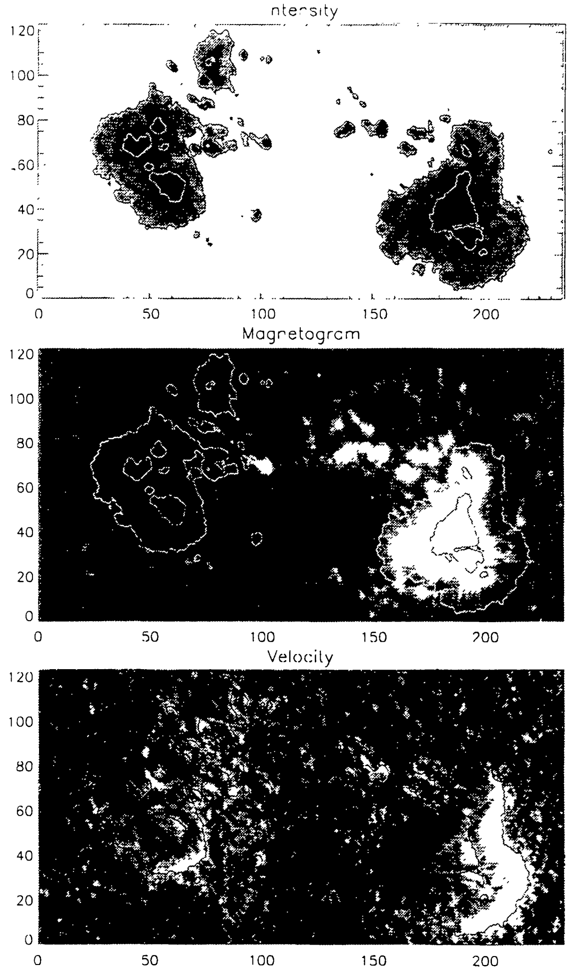

Figure 1. Typical intensity, magnetogram and velocity images of the active region under consideration. The scales on the axes are in arcseconds. The contours represent the umbral and penumbral boundaries derived from the brightness image.

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solar variations in the absence of seeing variations. This greatly removes an important source of noise to time series.

Figure 1 shows maps of each of these quantities. The contour levels drawn on each of them show the umbral and penumbral boundaries derived from the continuum intensity. The leading spot is to the right, the following to the left in the image.

The magnetogram in the central frame exhibits considerable fine structure, but this is not analysed here. It will be the subject of a separate paper. The lower frame depicts the Doppler velocity. The Evershed outflow can be clearly seen in spite of the fact that the region is located very close to disk centre (the central solar meridian is located at position $x = 8.1$ in this figure, i.e. slightly left of the leftmost sunspot, the equator lies at $y = 154.24$).

In the present paper we concentrate on the data observed on Nov. 27 1996, since the active region seemed to evolve more slowly at that time. Unfortunately, this is also the shortest time series, lasting 90 minutes. In order to follow the same spatial points, we correct the data for solar rotation before computing the time series.

3. ANALYSIS

We analyse the temporal and spatial variations of the velocity and magnetogram signals throughout the active region, but concentrate here on selected positions, such as the sunspot umbrae. Just before computing the power spectrum of any pixel or region, we remove the long-term evolution by subtracting a 3rd order polynomial fit laid through the considered time series.

In the temporally averaged magnetogram, we define regions that have a magnetogram signal above a certain threshold. Then, the magnetic (or velocity) signal is averaged at each time step over the chosen region. The averaging is done in order to increase the signal-to-noise ratio. Figure 2 shows the temporal variation of such averaged signals for the leading spot (to the right in Fig. 1) with a threshold level of $B = 1800$ G. All these points lie whithin the umbra. Oscillations are clearly present in velocity and seem likely in the magnetogram signal, although the noise is larger.

Next, power spectra of these spatially averaged regions are computed. Figure 3 shows examples. The plots to the left display the power spectra obtained in the biggest umbra of the following spot. There the signal was averaged over all pixels for which the time-averaged magnetogram signal was smaller than -1600 G. The plots to the right correspond to the umbra of the leading spot using a contour level of 1800 G. (Note that the contour levels drawn in Fig. 1 do not correspond to these averaging areas but are brightness contours.) The horizontal lines correspond to the 99% confidence levels determined according to Groth (1975).

The 5 minute (3.2 mHz) velocity oscillations appear clearly in the velocity power spectra of both spots.

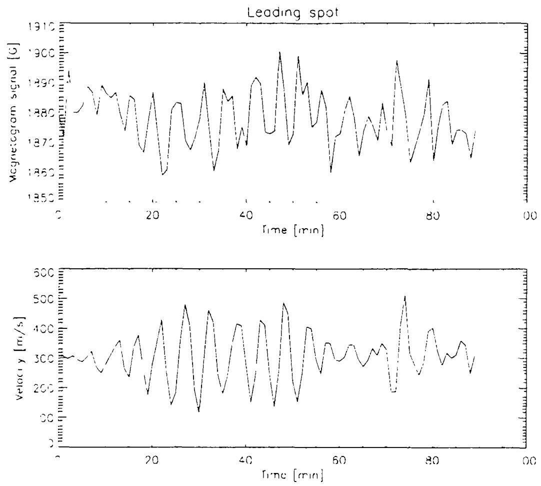

Figure 2. Averaged magnetogram and velocity signal as a function of time. The signal shown here corresponds to the average of the points having a magnetogram signal larger than 1800 G in the spot to the right in Fig. 1 (leading spot).

However a different behaviour is seen in the power spectra of the magnetogram signal. For the leading spot, the magnetic peak is located at the same frequency as the velocity peak, approximately 3.2 mHz for both, while for the following spot the peaks have different frequencies: the velocity signal still peaks at 3.2-3.3 mHz, whereas the magnetic peak now appears at 5.9 mHz.

It appears that the oscillations seen in the magnetogram strongly favor those positions which show the strongest magnetogram signal, but which need not correspond to the darkest region of the sunspot (although there is a certain, incomplete overlap between the two). The magnetic power in the rest of the sunspot is much lower though not completely absent (see below).

We have also averaged over other regions. For example, we find that no oscillations of the magnetogram signal are detected when the averaging is carried out over the darkest parts of the umbra. This does not necessarily mean that no magnetogram oscillations are present, but rather that they cannot be coherent over that region.

Figure 4 shows the power of the magnetogram signal oscillations at two different frequencies: 3.2 mHz and 5.9 mHz. Here the signal has been spatially smoothed over 3 × 3 pixels before computing the power spectra. The purpose of this figure is to show that these oscillations are not cospatial and that although most power is located in the umbrae only a (small) part of a given umbra exhibits significant power.

The following sunspot is composed of different umbrae. Three of these have regions with magnetic field strength lower than -1600 G. It appears that the magnetogram signals of these 3 umbral regions are not oscillating in phase. Furthermore, the oscillation frequency of the different umbrae are not the same:

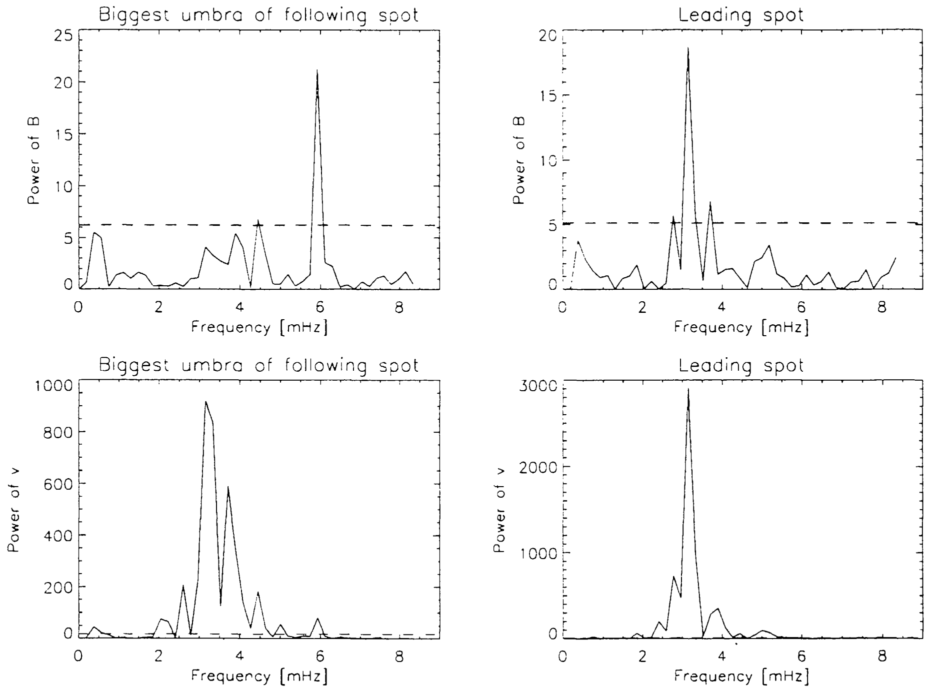

Figure 3. Power spectra of the magnetogram signal (upper panels) and Doppler shift (lower panels) for the two largest umbrae of the region. The dashed lines represent the 99 % confidence levels. In the lower right panel this level is so low that it cannot be distinguished from the zero line.

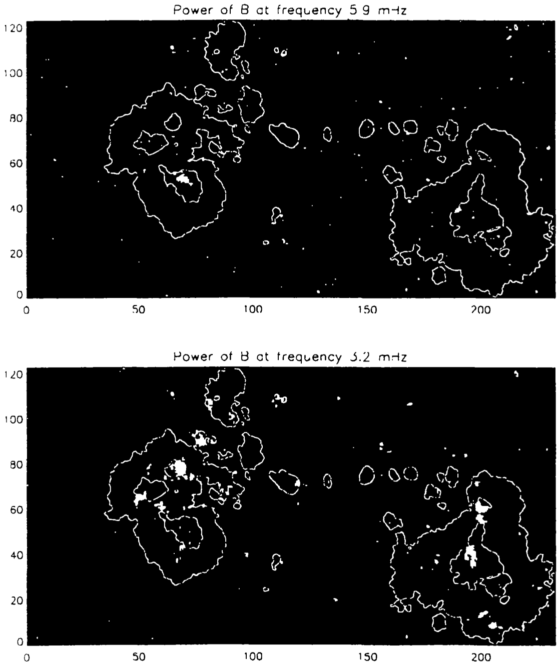

Figure 4. Map of the power in the oscillations of the magnetogram signal at two different frequencies: 5.9 mHz (top) and 3.2 mHz (bottom).

the 5.9 mHz oscillation is seen only in the lowest (largest) umbra.

The question arises whether the oscillations seen in the magnetogram signal are due to oscillations of the magnetic vector (field strength or inclination to the vertical) or has an instrumental source (cross-talk from the velocity oscillations). If they are produced by cross-talk, we would expect to observe a similar behaviour of the different umbrae when using averaging areas with the same magnetic threshold value. This is not the case. In addition, we would expect them to show the same frequency as the velocity oscillations. At least in the main umbra of the following spot the magnetic oscillation frequency is distinctly different from that of the velocity (or from its second harmonic). However, this question will only be fully settled once the influence of the velocity oscillations on the magnetogram signal has been carefully modelled with spectral line calculations.

4. SUMMARY

- Oscillations are detected in the Doppler shift and the magnetogram signal in sunspot umbrae.
- While the velocity signal is observed throughout the umbra, the oscillations are concentrated at the positions with the largest magnetic field strength.
- Different umbrae can have different magnetic oscillation frequencies, including different umbrae of the same sunspot.
- It cannot yet be completely ruled out that the oscillations are due to cross-talk from the veloc-

ity oscillations (since the magnetogram signal is also sensitive to velocity).

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