Astron. Astrophys. 335, L97–L100 (1998)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Oscillations of sunspot magnetic fields

I. Rüedi[1], S.K. Solanki[1], J.O. Stenflo[1], T. Tarbell[2], and P.H. Scherrer[3]

[1] Institute of Astronomy, ETH-Zentrum, CH-8092 Zürich, Switzerland
[2] Lockheed Martin Research Laboratory, Department H1-12, Bldg. 252, Palo Alto, CA 94304, USA
[3] W.W. Hansen Experimental Physics Laboratory, Center for Space Science and Astrophysics, Stanford University, Stanford, CA 94305-4085, USA

Received 24 April 1998 / Accepted 27 May 1998

Abstract. We report on velocity and magnetic field oscillations observed in sunspots using the MDI instrument onboard SOHO. In addition to the well-known velocity oscillations, the data clearly show highly localised oscillations of the magnetogram signal in different parts of the sunspots. We show that only oscillations of the magnetic field vector can produce the observed magnetogram oscillations, and that the observed phase relations suggest an origin in terms of magnetoacoustic gravity waves.

Key words: Sun: activity – magnetic fields – oscillations – photosphere – sunspots

1. Introduction

Sunspot oscillations in the 3 and 5 mHz (i.e. 5 and 3 minute) bands 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 the underlying magnetoacoustic oscillations on the magnetic field are expected to be small (rms value of at the most a few G for a monolithic sunspot, Lites et al. 1998). Consequently, the results are controversial. In the recent literature only Horn et al. (1997) and Lites et al. (1998) report on sunspot magnetic field oscillations. The former authors present oscillations that are marginally significant, while the latter authors do not consider their own observations to be sufficiently reliable to represent a true detection. Ulrich (1996) also reported on magnetogram oscillations in active region, but at the very low spatial resolution of 20 $\times$ 20 arcsec^2.

Here we explore velocity and magnetic field oscillations observed in an active region with the Michelson Doppler Interferometer (MDI) onboard the Solar and Heliospheric Observatory (SOHO). In the present paper we concentrate on the oscillations of the two main spots of the region.

Send offprint requests to: I. Rüedi

2. Observations

We analyse high resolution MDI data (pixel size 0.605 arcsec) obtained in a big active region (NOAA 7999) located close to solar disc centre. The data analysed here consist of a time series recorded on 27 Nov., 1996 at a cadence of one minute and lasting 1.5 hours. They are composed of simultaneous observations of the continuum intensity, a proxy of the magnetic flux (magnetogram) and the line shift. Such data have the advantage that they show true solar variations in the absence of seeing fluctuations. This removes an important source of noise. In order to follow the same spatial points, we correct the data for solar rotation before constructing the time series.

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

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 disc 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 $y = 154.24$).

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 which show significant oscillations of the magnetogram signal.

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. Fig. 2 shows the temporal variation of such averaged signals for the leading spot with a threshold level of $B = 1800$ G. All these points lie within the umbra. Oscillations are clearly present in velocity and seem likely in the magnetogram signal, although the noise is larger. The two curves differ in phase by $63° \pm 5°$.

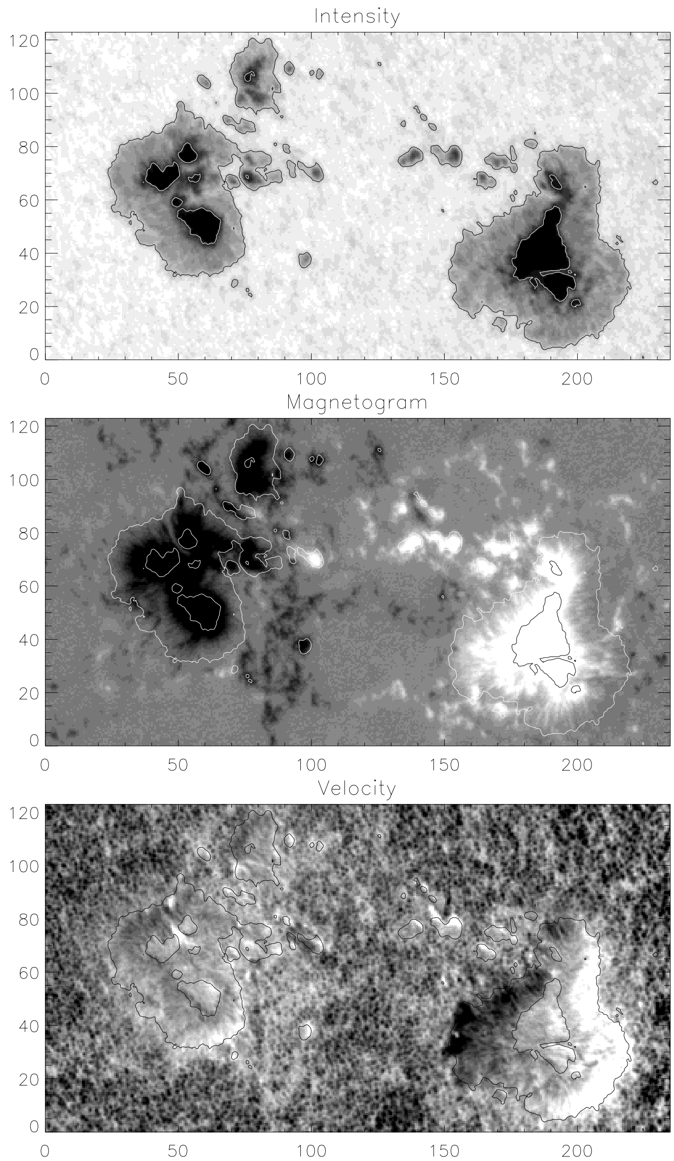

Fig. 1. Typical intensity, magnetogram and velocity images of the active region under consideration. The scales on the axes are in arcseconds. The contours represent the umbral and penumbral boundaries derived from the brightness image.

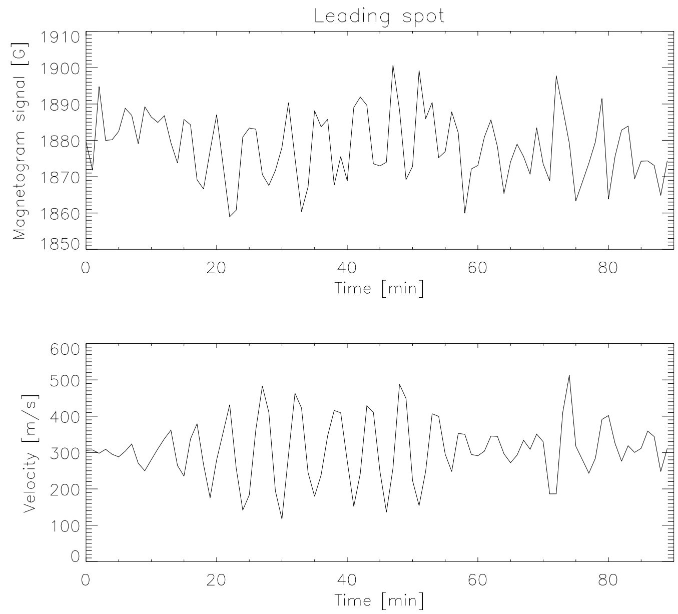

Fig. 2. Magnetogram and velocity signals as a function of time. The signal shown here corresponds to the average of the points having a magnetogram signal larger than 1800 G in the spot to the right in Fig. 1 (leading spot).

Next, power spectra of these spatially averaged regions are computed. Before computing the power spectrum of any pixel or region, we remove the long-term evolution by subtracting a 3rd order polynomial fit to the considered time series. Fig. 3 shows examples of power spectra. 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 these contour levels do *not* correspond to the brightness contours drawn in Fig. 1. The extremal values of the magnetogram signal amount to -1730 G in the following sunspot and 1960 G in the leading sunspot.) The horizontal lines correspond to the 99% confidence levels determined according to Groth (1975).

The 5 minute (3.2 mHz) oscillations appear clearly in the velocity power spectra of both spots, but only in the power spectrum of the magnetogram signal of the leading spot. For the following spot the magnetic peak lies at 5.9 mHz.

It appears that the oscillations seen in the magnetogram strongly favor those positions that 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 significant 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.

Fig. 4 shows the power of the magnetogram signal oscillations at 3.2 mHz (upper frame) and 5.9 mHz (lower frame). Here the signal has been spatially smoothed over 3×3 pixels before computing the power spectra in order to reduce the noise. The purpose of this figure is to show that these oscillations are not cospatial and that the sites of strong power are very localised. If a slit is placed randomly through an umbra, then it can easily miss the magnetic oscillations sites. This may explain why Lites et al. (1998) saw no such oscillations. The phase shifts observed between the magnetogram and velocity signals in the regions of strong power in Fig. 4a typically range between 60° and 80°.

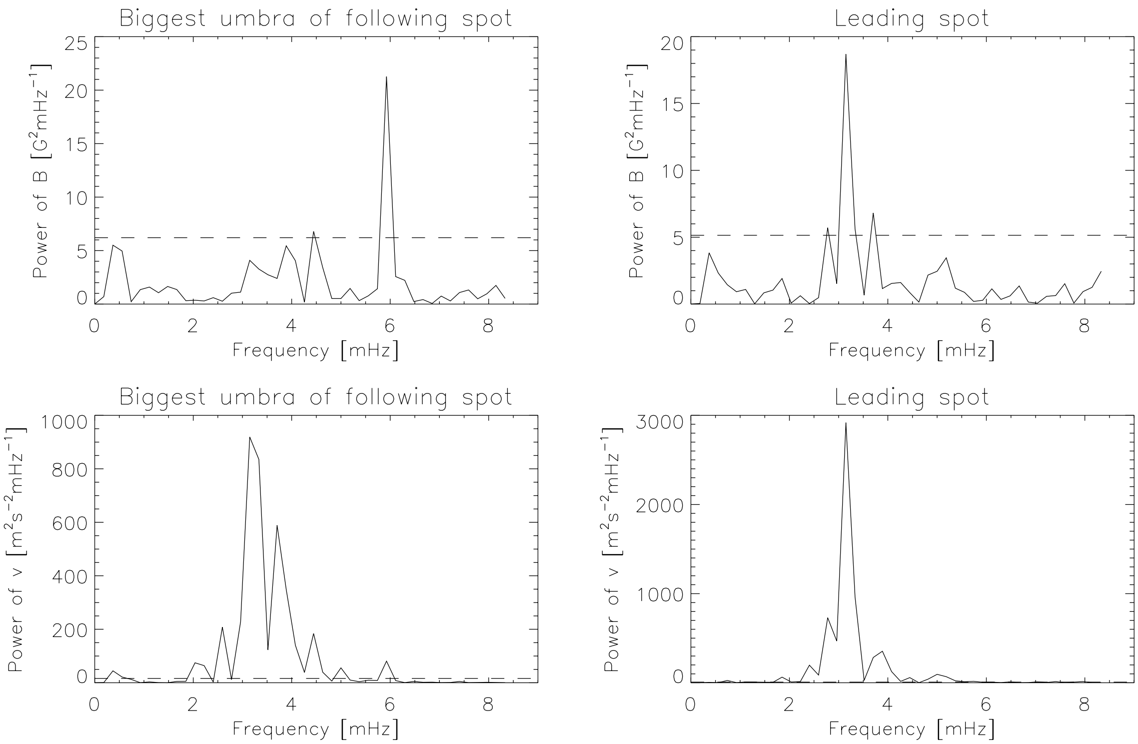

Fig. 3. Power spectra of the magnetogram signal (upper panels) and Doppler shift (lower panels) for the two largest umbrae of the region. The dashed lines represent the 99% confidence levels. In the lower right panel this level is so low that it cannot be distinguished from the zero line.

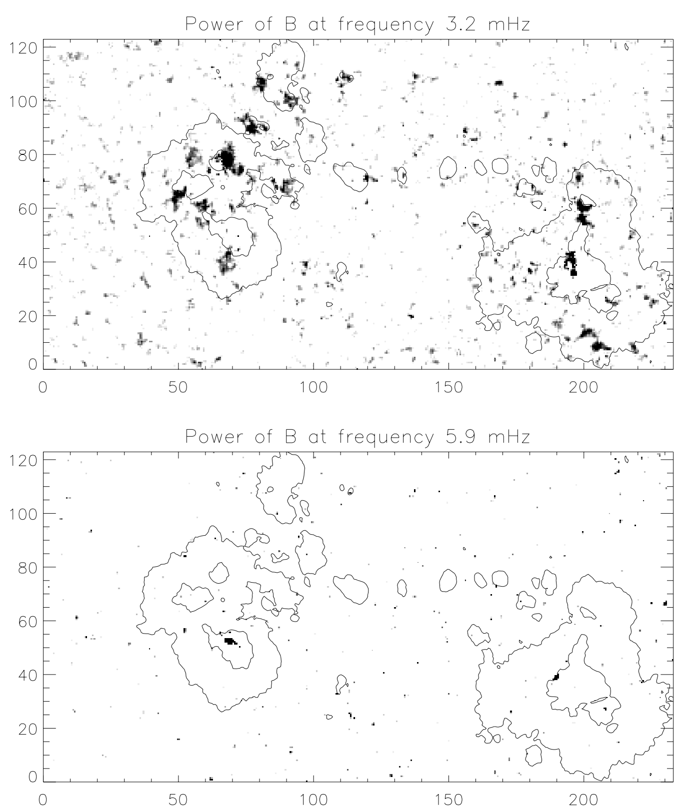

Fig. 4. Map of the power in the oscillations of the magnetogram signal at two different frequencies: 3.2 mHz (top) and 5.9 mHz (bottom).

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 velocity and magnetogram signals of these 3 umbral regions are not oscillating in phase. Furthermore, the magnetogram signal oscillation frequencies of the different umbrae are not the same: the 5.9 mHz oscillation is seen only in the largest umbra.

4. Simulation

We now test whether the oscillations seen in the magnetogram signal are due to oscillations of the magnetic field 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 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).

In order to strengthen the case against a cross-talk origin of the magnetogram signal oscillations, we have modelled the influence of the velocity oscillations on the magnetogram signal with spectral line calculations. Here we discuss the results for the leading spot's umbra. Tests for the other umbrae give similar results.

We have computed a spectral line profile to simulate the magnetogram signal at the locations showing magnetogram oscillations. We use the non-grey radiative equilibrium model of Kurucz with effective temperature 4000 K (representative of the

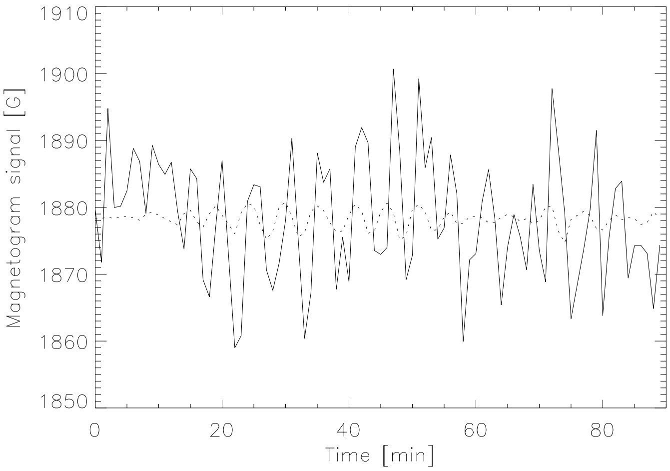

Fig. 5. The solid line is the same as in Fig. 2a. The dotted line represents the magnetogram signal that would be expected from cross-talk from the velocity oscillations.

continuum contrast of the biggest spot). We then create a time series by shifting the synthetic line profile by the Doppler shift time series (lower panel of Fig. 2). Finally, using the filter functions of MDI, we compute the fluctuations in the magnetogram signal that are due to cross-talk. The results of these computations are presented in Fig. 5. The solid line corresponds to the observed magnetogram signal (same as upper panel of Fig. 2), while the dotted line is the result of the computations. The computed signal does show oscillations, but with a very small amplitude. The rms fluctuations of the magnetogram signal in the 5 min band corresponds to 6.4 G for the observed data, but only to 1.2 G for the simulated data. In addition, the observed and computed magnetogram signals differ in phase by $63°$. We have also considered other possibilities, such as errors in the spot effective temperature or oscillations of the temperature. None of these could reproduce the observed magnetogram oscillations. Hence these oscillations cannot be of instrumental origin, but must be solar. It is not possible to tell if they are due to oscillations of the magnetic field strength (magnetoacoustic gravity waves) or of the inclination angle of the magnetic field vector (Alfvén waves) directly from the data.

An oscillation amplitude of less than $0.5°$ for the inclination angle would produce oscillations of the observed amplitude. Such an oscillation of the field direction is small and entirely possible. However, in the case of Alfvén waves, which cause fluctuations of the magnetic field orientation, the magnetic and velocity signals are expected to oscillate in phase, which doesn't correspond to our measurements. In the absence of radiative damping, the magnetic and velocity signal of a magnetoacoustic gravity wave are expected to be $90°$ out of phase. Radiative damping could lower this value to the observed range ($60° - 80°$). Our observations are therefore better explainable in terms of magnetoacoustic gravity waves.

5. Summary

- Oscillations have been detected in the Doppler shift and the magnetogram signal in sunspot umbrae.
- While the velocity signal is observed throughout the umbra, the magnetogram oscillations are highly localised.
- Different umbrae (even in the same sunspot) can have different magnetic oscillation frequencies.
- The oscillations of the magnetogram signal cannot be due to cross-talk from the velocity oscillations, but must be intrinsically solar.
- The observed phase relations between the magnetic and velocity oscillations indicate that the magnetogram oscillations are due to magnetoacoustic gravity waves.
- The patchy distribution of magnetogram power may be suggestive of an inhomogeneous field in the subphotospheric layers.

Acknowledgements. We thank Horst Balthasar for providing clarifications regarding the computation of the confidence levels and Tom Bogdan and Jürgen Staude for helpful comments. SOHO is a cooperative mission between ESA and NASA. This work has been partly supported by the Swiss National Science Fundation, grant No. 21-45083.95, and by a grant from ETH Zürich.

References

Groth E.J., 1975, ApJS 29, 285
Horn T., Staude J., Landgraf V., 1997, Sol. Phys. 172, 69
Lites B.W., 1992, in *Sunspots: Theory and Observations*, J.H. Thomas and N.O. Weiss (Eds.), Kluwer, Dordrecht, p. 261
Lites B.W., Thomas J.H., Bogdan T.J., Cally P.S., 1998, ApJ 497, 464
Ulrich R.K., 1996, ApJ 465, 436