PHOTOSPHERIC AND CHROMOSPHERIC OSCILLATIONS IN SOLAR FACULAE

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Abstract. The differences between physical conditions in solar faculae and those in sunspots and quiet photosphere (increased temperature and different topology of magnetic field) suggest that oscillation characteristics in facula areas also have different properties. The analysis of 28 time sets of simultaneous spectropolarimetric observations in facula photosphere (Fe I 6569 Å, 8538 Å) and chromosphere (Hα, Ca II 8542 Å) yields the following results. The amplitude of five-minute oscillations of line-of-sight (LOS) velocity decreases by 20 – 40 percent in facula photosphere. There are only some cases revealing the inverse effect. The amplitude of four-five minute LOS velocity oscillations increases significantly in the chromosphere above faculae, and power spectra fairly often show pronounced peaks in a frequency range of 1.3 – 2.5 mHz. Evidence of propagating oscillations can be seen from space-time diagrams. We have found oscillations of the longitudinal magnetic field (1.5 – 2 mHz and 5.2 mHz) inside faculae.

1. Introduction

The character of oscillations in different solar phenomena has been the subject of investigation since the 1960s. Nevertheless, there is still incomplete information on the parameters of oscillations in faculae. It is clear that increased temperature and the presence of a magnetic field (200 – 400 Gauss) must in some way influence the characteristics of the oscillations. In one of his early papers Orrall (1965) found no difference between photosphere oscillations of line-of-sight (LOS) velocity in faculae and in undisturbed areas. In the majority of subsequent papers (Howard, 1967; Sheeley and Bhatnagar, 1971; Deubner, 1974; Teske, 1974) only a small decrease in the amplitude of five-minute photospheric oscillations in faculae, by comparison with the undisturbed photosphere, was noted. No difference was found in the frequency of the oscillations. However, Blondel (1971) noted an even longer period of about 700 seconds. Woods and Cram (1980) also observed some decrease in amplitude of five-minute oscillations in the photosphere of a facula and an increase in amplitude at a period of 500 seconds in the chromosphere (Ca II 8542 Å). Balthasar (1990), making observations in the non-magnetic line Fe I 5576 Å, found that the power of five-minute oscillations increases in some faculae, while in others they decrease. In some spectra he noted a period of about 500 seconds. As can be seen, there is not complete agreement among the earlier works. The present state of knowledge on this question is quite insufficient. Photosphere oscillations in the faculae of active regions are regarded as a direct reason for five-minute oscillations observed in the transition zone and corona (De Pontieu, Erdelyi, and de Wijn, 2003; De Pontieu, Erdelyi, and De Moortel, 2005; De Pontieu *et al.*, 2006). One can read in Aschwanden *et al.*(2002) about oscillations in sunspot coronal loops.

The aim of this work is to look into the nature of oscillations in photosphere faculae and the overlying chromosphere in more detail, based on an analysis of extensive observation data, and to ascertain the difference between oscillations in the faculae of active regions and faculae outside active regions.

2. Instrument and method

The observations were carried out on the Horizontal Solar Telescope at the Sayan Solar Observatory. The theoretical resolution of the mirror diameter of 800 mm is up to $0.2''$. However, atmospheric conditions (blurring and jitting) worsen the resolution to $1-2''$. The photoelectric guide has a margin of error of not more than $1''$ over ten hours and compensates for the image shift as a result of the Sun's rotation. A set of optical polarization devices permits modulation-free measurements of the longitudinal component of the magnetic field strength in a wide spectral range together with measurements of LOS velocity (Kobanov, 2001). A 256×1024 Princeton Instruments CCD-camera with thermoelectric cooling down to -40°C is used to record the spectrum. The pixel size of 24 μm corresponds to $0.25''$ along the slit. The details of our instrument and method are described in Kobanov and Makarchik (2004).

3. Observations and reduction

The location of the facula area was determined according to the image in white light. For more exact definition of fine-structured faculae elements, bright regions of the continuous spectrum on working spectrograms were used. Most of the faculae observed were situated near the limb. The connection of faculae to active regions was determined in the following way. If a facula was observed on the eastern limb and over the following three days at this place within a radius of $150''$ the active region did not develop, the facula was considered not to be connected with the active region. For the western limb, the history of this region on the Sun over a period of three days before observations was considered. If there was a spot or part of the active region within a radius $150''$ from the center of the facula, then the facula was considered as belonging to this active region. Faculae are long-lived objects, so our classification is rather conditional. Nevertheless, as can be seen below, a difference between these two groups is noted. Observations were usually carried out in a few spectral lines corresponding to different levels in the Sun's atmosphere (photosphere-chromosphere or photosphere-zone of temperature minimum). The spectral pairs Hα and Fe I 6569 Å, Ba II 4554 Å and Fe I 4551.6 Å, Ca II 8542 Å and Fe I 8538 Å were used most frequently. Part of the observations were undertaken with polarization optics, that later permitted us to obtain information on the longitudinal component of the magnetic field in lines Fe I 6569 Å, Ba II 4554 Å, Ca II 8542 Å. Over the period $2002-2004$, 28 time series with an average duration of about an hour and $0.2-5$ seconds cadence were obtained. Of these, five were rejected on the grounds of bad atmospheric conditions. The atmospheric lines H_2O close to Hα and Ca II were used to remove spectrographic noise. LOS velocity was determined as the difference between intensities in the red and violet wings of the spectral line, normalized to their sum. To measure the magnetic field the centers of gravity $I+V$ and $I-V$ were calculated. FFT and wavelet-analysis were used for further analysis of the data. The horizontal lines in power spectra mark 95% significance level. Wavelet-analysis gives one the opportunity to examine the time distribution of separate modes and carry out their selective filtration. To check the statistical significance (95% level) a comparison was made with the theoretical spectrum of white noise according to Torrence and Compo (1998).

4. Results and discussion

At photospheric level for the majority of faculae a decrease of $20-40$ % in the amplitude of five-minute oscillations is noted by comparison with the undisturbed photosphere (see power spectra in Figure 1).

Only in a few faculae is this difference absent. Similar characteristics were noted by Balthasar (1990).

The chromosphere situation is more complex. The three-minute oscillations of some faculae so characteristic of the surrounding chromosphere decrease in amplitude more than a factor of two, while others increase (Figures 2 and 3). Peaks in the $1-2$ mHz range often dominate in the power spectra (Figure 3). The oscillation processes shift towards low frequencies in the chromosphere above a facula. These oscillation

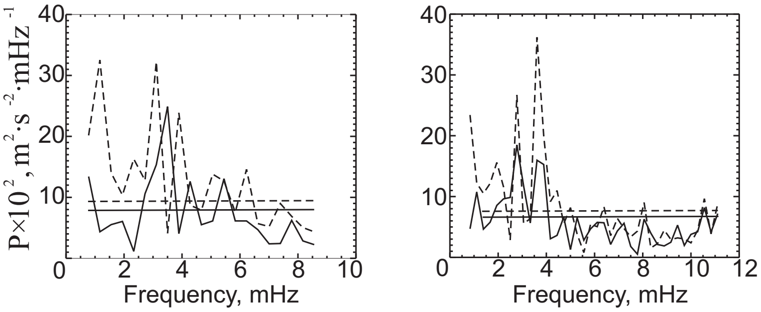

Figure 1. Power spectra of photospheric LOS velocity oscillations, solid line - inside facula, dashed line - outside facula. The left and right panels represent Fe I 6569 and Fe I 4551 accordingly

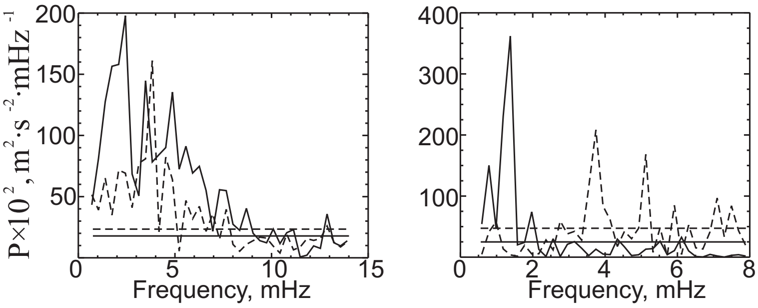

Figure 2. Power spectra of chromospheric LOS velocity oscillations (Hα ± 0.2 Å). Solid line - inside facula, dashed line - outside facula.

features can be seen in greater detail in the histogram in Figure 4. The histogram in Figure 4 with a discretness of 1 mHz represents the number of instances of decrease and increase in the power of oscillations normalized to the total number of time series (n/N). Faculae that have been identified as connected to the active region (Figure 5, left panel) show a decrease in oscillation amplitude more frequently than an increase. Whereas faculae outside the active region (Figure 5, right panel) more frequently show an increase in amplitude in the $1-5$ mHz range. A decrease in oscillation amplitude at frequencies of $6-8$ mHz is common to both groups of faculae.

In some faculae the power spectra of variations of the longitudinal magnetic field show significant peaks. At the same time, outside a facula five-minute oscillations dominate, while three-minute and $8-11$-minute periods dominate inside the faculae. In the spectra in Figure 6a,b a maximum at 5.2 mHz is distinct. It could be supposed that corresponding variations of intensity or radial velocity crosstalk into the signal of the magnetic field. Still, power spectra of these parameters (Figure 7) do not have dominating peaks at 5 mHz which disproves the

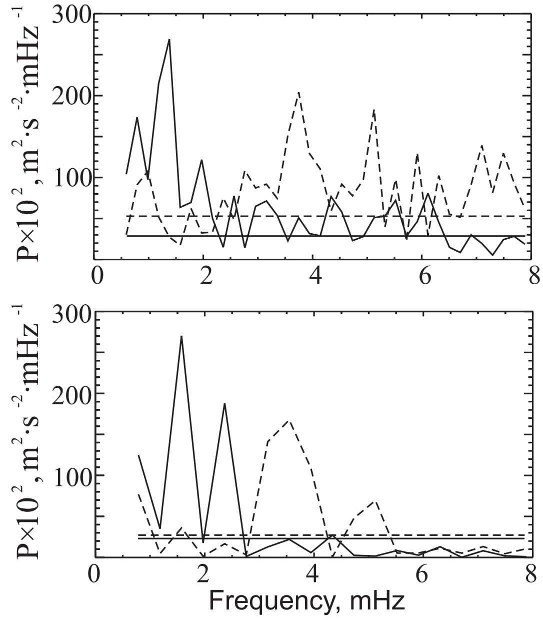

Figure 3. An example of frequency decrease. Power spectra of LOS velocity oscillations in chromosphere (solid line - inside facula, dashed line - outside facula). Top and bottom panels represent Hα ± 0.2 Å and Ca II 8542 accordingly.

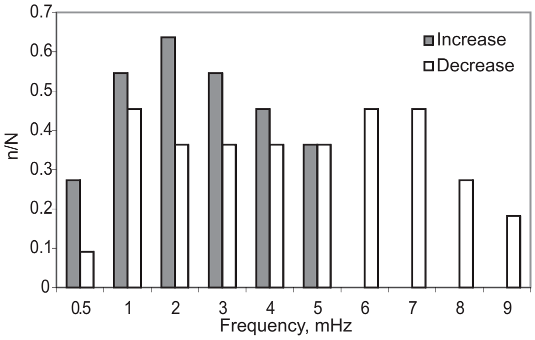

Figure 4. The histogram represents the number of instances of decrease and increase in the power of LOS velocity oscillations in facula chromosphere, normalized to the total number of time series (n/N), as a function of frequency.

signal crosstalk explanation. Outside a facula, oscillations of magnetic field strength with such a frequency are absent. The facts presented are evidence in favour of the reality of observable oscillations. On the other hand, the amplitude of oscillations (5% of the measurable strength of 380 Gauss) can appear too large, for example, by comparison with similar measurements in sun spots. All the same, similar estimates of the amplitude of oscillation of the magnetic field in faculae have

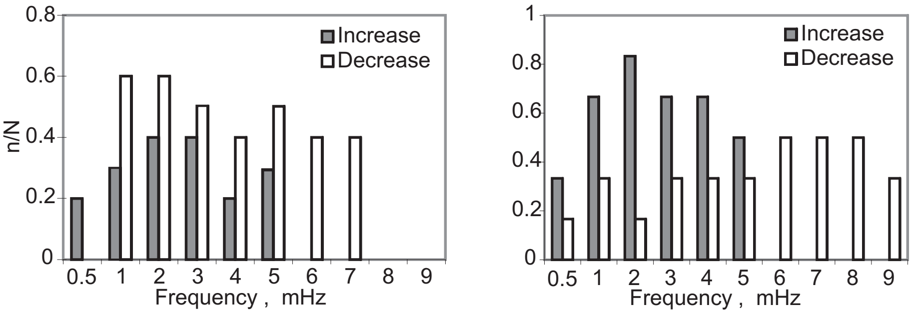

Figure 5. Same as Figure 4, but for faculae in active regions (left panel) and faculae outside active regions (right panel).

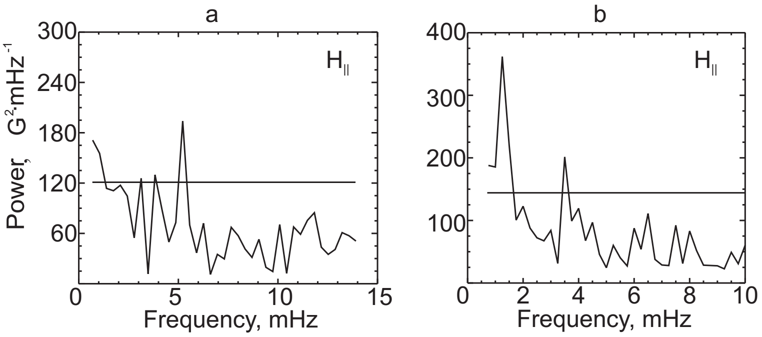

Figure 6. Examples of power spectra of longitudinal magnetic field oscillations in different facula pozitions (Fe I 6569).

been found (Muglach *et al.*, 1995). Nevertheless, questions exist. For example, De Pontieu *et al.* (2006) found that the intrinsic structure of faculae can change on timescales of the order of a few minutes. Khomenko, Collados, and Bellot Rubio (2003) point out a possibility

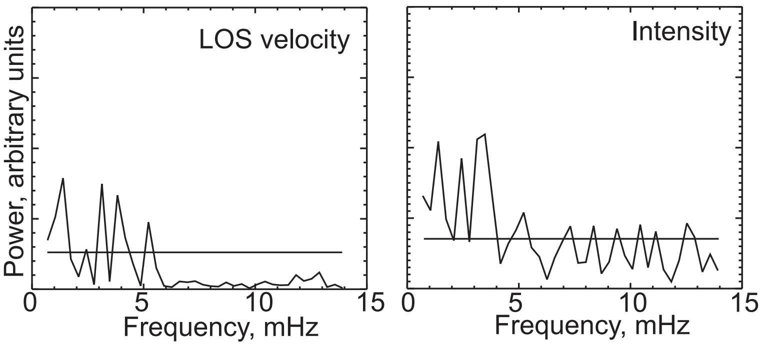

Figure 7. Power spectra of LOS velocity and intensity oscillations (Fe I 6569) in the same facula location as that in Figure 6a.

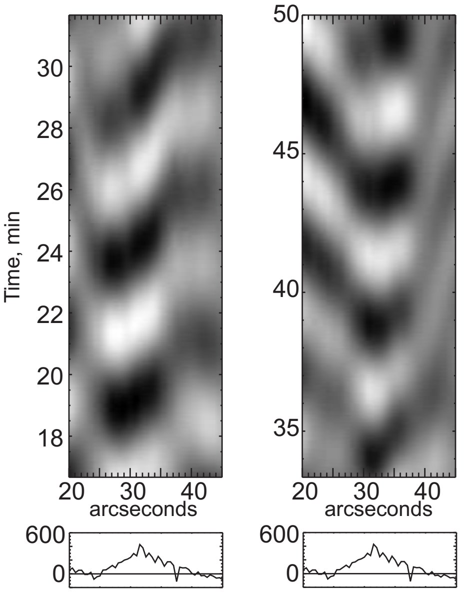

Figure 8. Traveling waves in facula chromosphere. Left and right panels represent the fragments of space-time diagram of LOS velocity in Hα (dark areas - velocity away from observer, light areas - velocity toward observer). Bottom panel - longitudinal magnetic field strength along slit, averaged over time series.

of false magnetic field oscillations due to opacity effects. One cannot neglect completely the influence of stray light and seeing variations (Landgraf, 1997).

In space-time diagrams of the LOS velocity (Figure 8) it is possible to see chevron structures that are evidence of propagating wave processes (Kobanov, Kolobov, and Makarchik, 2006). The center of the chevron in Figure 8 coincides with the point of maximum strength of the magnetic field in a facula. At present we are unable to say whether or not this coincidence is accidental. Notice, upward-and downward propagating waves were observed by Finsterle *et al.* (2004) in plages near sunspots. Muglach, Hofmann, and Staude (2005) found that the power of three-minute chromospheric oscillations increases in regions with a vertical magnetic field.

5. Conclusions

In the photosphere of faculae the oscillation power of the LOS velocity decreases 20 − 40% by comparison with the undisturbed photosphere. At same time there is no noticeable difference between faculae in the active regions and outside.

Spectra of variations of the longitudinal magnetic field in facular areas show significant peaks at 1.5 − 2 mHz and 5.2 mHz.

In the chromosphere above faculae connected with an active region, more often than not a decrease in oscillation amplitude of the LOS velocity is observed in the 3 − 5 mHz range, whereas faculae outside the active region show a significant increase in amplitude of these oscillations. A weakening in high-frequency oscillations and the appearance of low-frequency oscillations (1 − 2 mHz) is characteristic for both facular groups.

In some instances signs of propagating waves in the chromosphere have been noted which coincide with the local maximum of the photospheric magnetic field.

Acknowledgements

The work is supported in part by the State Support of Leading Scientific Schools of the Russia Federation, grant NSh-4741.2006.2, Basic Research Program P-16 of the Presidium of the Russian Academy of Sciences and RFBR Grant 05-02-16325. We are very grateful to the anonymous referee, whose comments and suggestions have improved the paper. We gratefully acknowledge discussions on this topic with Prof. Grigoryev and thank J. Sutton for her help in preparing the English version of the manuscript.

References

Aschwanden, V.J., De Pontieu, B., Schrijver, C.J., Title, A.M.: 2002, *Solar Phys.* **206**, 99.

Balthasar, H.: 1990, *Solar Phys.* **127**, 289.

Blondel, M.: 1971, *Astron. Astrophys.* **10**, 342.

Deubner, F.-L.: 1974, *Solar Phys.* **39**, 31.

Finsterle, W., Jefferies, S.M., Cacciani, A., Rapex, P., Giebink, C., Knox, A., Dimartino, V.: 2004, *Solar Phys.* **220**, 317.

Howard, R.: 1967, *Solar Phys.* **2**, 3.

Khomenko, E.V., Collados, M., Bellot Rubio, L.R.: 2003, *Astrophys. J.* **588**, 606.

Kobanov, N.I.: 2001, *Instr. and Exp. Tech.*, **44**, 524.

Kobanov, N.I., Makarchik, D.V.: 2004, *Astr. Rep.* **48**, 954.

Kobanov, N.I., Kolobov, D.Y., Makarchik, D.V.: 2006, *Solar Phys.* **238**, 231.

Landgraf, V.: 1997, *Astron. Nachr.* **318**, 129.

Muglach, K., Hofmann, A., Staude, J.: 2005, *Astron. Astrophys.* **437**, 1055.

Muglach, K., Solanki, S.K., Livingston, W.C.: 1995, In Kuhn, J. R., Penn, M. J. (eds.), Infrared Tools for Solar Astrophysics: What's next?, World Scientific, Singapore, 387.

De Pontieu, B., Erdelyi, R., de Wijn, A.G.: 2003, *Astrophys. J.* **595**, L63.

De Pontieu, B., Erdelyi, R., de Moortel, I.: 2005, *Astrophys. J.* **624**, L61.

De Pontieu, B., Carlsson, M., Stein, R., Rouppe van der Voort, L., Löfdahl, M., van Noort, M., Nordlung, Å., Scharmer, G.: 2006, *Astrophys. J.* **646**, 1405.

Orrall, F.Q.: 1965, *Astrophys. J.* **141**, 1131.

Sheeley, N.R., Bhatnagar, A.: 1971, *Solar Phys.* **18**, 379.

Teske, R.G.: 1974, *Solar Phys.* **39**, 79.

Torrence, C., Compo, G.P..: 1998, *Bull. Am. Meteo. Soc.* **79**, 61.

Woods D.T., Cram L.E.: 1981, *Solar Phys.* **69**, 233.