

Influence of the Magnetic Field on Oscillation Spectra in Solar Faculae

A.A. Chelpanov¹ · N.I. Kobanov¹ · D.Y. Kolobov¹

Received: 14 October 2015 / Accepted: 2 July 2016 / Published online: 27 July 2016
© Springer Science+Business Media Dordrecht 2016

Abstract We study oscillation parameters in faculae above magnetic knots and in the areas adjacent to them. Using *Solar Dynamics Observatory* (SDO) data, we analyse oscillations in magnetic field strength, Doppler velocity, and intensity signals for the lower photosphere, and in intensity for the higher levels. We find peaks in the oscillation spectra for the magnetic field strength in magnetic knots at a frequency of about 4.8 mHz, while there are no such frequencies in the adjacent facular patches, which have a moderate field strength. In contrast, the spectra for the Doppler velocity oscillations are similar for these types of regions: in both cases, the significant peaks are in the 2.5–4.5 mHz range, although the oscillations in magnetic knots are 2–3 times weaker than those at the facular periphery. In the upper photosphere, the dominant frequencies in magnetic knots are 0.5–1 mHz higher than in the medium-field regions. The transition region oscillations above magnetic knots are mainly concentrated in the 3–6 mHz range, and those above moderate-field patches are concentrated below 3 mHz.

Keywords Active regions, magnetic fields · Magnetic fields, photosphere · Oscillations, solar

1. Introduction

Studying waves in the solar atmosphere can help answer the question of energy transfer to the outer layers of the Sun. The observed characteristics of waves can also provide information on the physical conditions at different heights of the atmosphere (De Moortel and Nakariakov, 2012; Stepanov, Zaitsev, and Nakariakov, 2012). Oscillations in faculae have been of special interest for 50 years (Orrall, 1965; Howard, 1967) because faculae are the

Waves in the Solar Corona: From Microphysics to Macrophysics.
Guest Editors: Valery M. Nakariakov, David J. Pascoe, and Robert A. Sych.

✉ A.A. Chelpanov
chelpanov@iszf.irk.ru

¹ Institute of Solar–Terrestrial Physics of Siberian Branch of Russian Academy of Sciences, Irkutsk, Russia

most abundant solar magnetic activity manifestation and occupy a considerable fraction of the solar surface.

The characteristics of the magnetic field in active regions have been linked to the observed oscillation characteristics. For example, in sunspots, high-frequency oscillations tend to concentrate in the central part of a spot, where magnetic field lines are closest to vertical, and low-frequency oscillations are observed in the outer sunspot regions, where the magnetic field is inclined (Jefferies *et al.*, 2006; McIntosh and Jefferies, 2006; Kobanov *et al.*, 2011a; Reznikova *et al.*, 2012; Kobanov, Chelpanov, and Kolobov, 2013). Oscillations in microwave data are observed above regions with strong magnetic fields (Abramov-Maximov *et al.*, 2011).

Faculae are characterized by different magnetic field strengths and inclinations, although the spatial distributions of these parameters are more chaotic than in sunspots (Ishikawa *et al.*, 2008; Martínez Pillet, Lites, and Skumanich, 1997; Guo *et al.*, 2010). There are patterns in the observed oscillations, however: low-frequency oscillations increase at the facula boundaries, while three- and five-minute oscillations are observed within faculae (Kobanov and Pulyaev, 2011). De Wijn, McIntosh, and De Pontieu (2009) registered waves with three-minute periods propagating in the central facular chromosphere, and five-minute waves propagating at the peripheral regions. The influence of the magnetic field on oscillation characteristics in faculae was studied by Khomenko *et al.* (2008) and Kostik and Khomenko (2012, 2013). Kostik and Khomenko (2013) noted an increase in the observed period in regions with high magnetic field strengths. Turova (2011) reported a strong five-minute period in the chromosphere of a facula at the base of a coronal hole and a decrease in the oscillation period with increasing height.

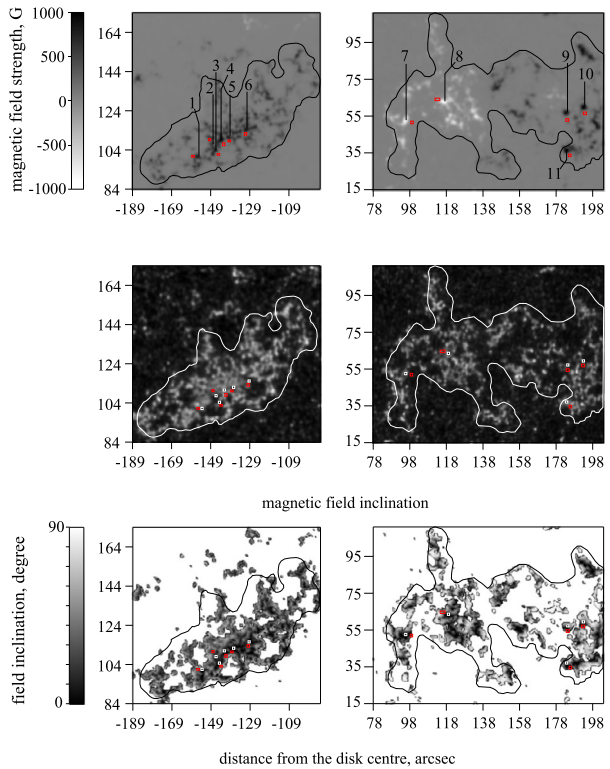
The magnetic field configuration is a probable cause for this distribution of oscillations in faculae. However, the magnetic field azimuthal angle in faculae seems somewhat random (Martínez Pillet, Lites, and Skumanich, 1997), and the connection between the oscillations at different height levels is difficult to trace (Kobanov *et al.*, 2011b).

In this work we analyse characteristics of intensity, Doppler velocity, and magnetic field oscillations in facular magnetic knots and compare them to those in facular patches with magnetic fields of a moderate strength.

2. Data and Methods

For this research we used data provided by the *Solar Dynamics Observatory* (SDO). The *Advanced Imaging Assembly* (AIA) provides full-disk images in 10 channels, of which we used three: the 1700 Å (continuum), He II 304 Å, and Fe IX 171 Å channels, corresponding to the upper photosphere, transition region, and lower corona, respectively. We also used the *Helioseismic and Magnetic Imager* (HMI) (Schou *et al.*, 2012) Dopplergrams, magnetograms, and intensity images in the Fe I 6173 Å line, which forms in the photosphere at a height of 200 km (Parnell and Beckers, 1969). The pixel size corresponds to 0.6'' for AIA and to 0.5'' for HMI. The time cadence of the AIA data is 12 and 24 s, and that of HMI data is 45 s. Level 1.5 data were prepared with the *aia_prep* routine. When needed, the co-alignment between the channels was corrected using sunspots on the solar disk as reference points. The full vector magnetic field parameters, specifically the field inclination, were retrieved from the Milne–Eddington inversion data available at the JSOC (Hoeksema *et al.*, 2014). The maps show an inclination towards the line of sight that differs from the inclination towards the solar radius by no more than 10° because the faculae are located close to disk center.

Figure 1 Upper row: distribution of the magnetic field in the studied faculae averaged over the series duration time. Middle row: boundaries of the faculae defined using the 1700 Å SDO/AIA channel based on the images averaged over the series time. Lower row: magnetic field inclination towards the line of sight in the Fe I 6173 Å line based on the first image of the series. Only the pixels whose magnetic field strength exceeds 70 G are displayed in the panel, since for weaker pixels the error is too large. The magnetic knots are labeled with numbers. The red rectangles indicate the patches within faculae that are taken as moderate-field comparison regions.



As objects for the research we picked two faculae located close to disk center, observed on 14 August, 2010 and 1 October, 2011 with observing intervals of 90 and 85 min, respectively. The faculae are shown in Figure 1.

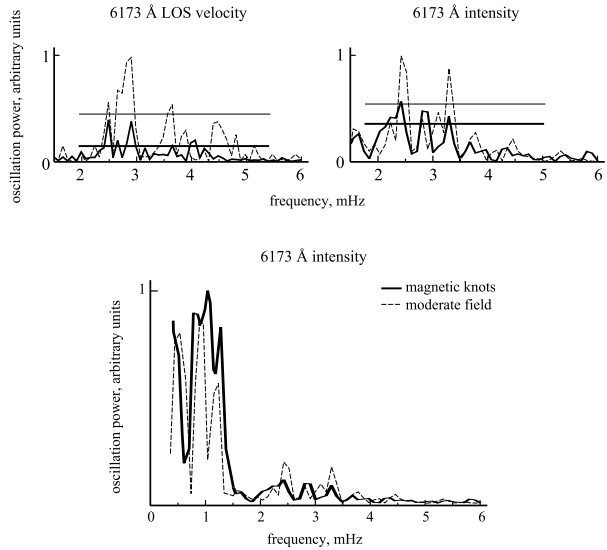
We defined the facula boundaries as 0.7 times the peak brightness level of the 1700 Å image averaged over the series time blurred by 20 pixels (see Figure 1, middle panel). A slow trend in the time series was removed by subtracting a smoothed signal from the original signal. For the analysis, we used the IDL Fast Fourier Transform (FFT) algorithm, and to estimate statistical significance, we used the algorithm described in Torrence and Compo (1998).

3. Results

We determined facular magnetic knots as regions within facula boundaries whose magnetic field strength does not drop below 600 G during the time series. As a rule, such regions are located in the central part of a facula, and their size is 1'' to 2.5''. As comparison regions we use moderate-field regions within the faculae, whose magnetic field strength is 100–300 G. The magnetic knots and comparison regions are shown in Figure 1.

We restrict our main analysis to the 1.5–6 mHz range. The oscillation power of the line-of-sight (LOS) velocity and magnetic field strength signals is noticeably lower than the significance level beyond this range. In addition, this excludes low-frequency oscillations, which dominate in intensity signals and impede a higher-frequency component analysis. This can be seen in the lower panel of Figure 2, which shows an expanded spectrum of the

Figure 2 HMI velocity and intensity spectra in magnetic knot 4 (see Figure 1) and those in a moderate-field patch. The horizontal lines indicate 95 % significance levels. The lower panel shows the same spectra with the frequency scale extended down to zero.



intensity oscillations in the Fe I 6173 Å line. In this range, the spectra of the oscillations at the lowest level of the solar atmosphere available, which are the photospheric signals of the HMI Fe I 6173 Å line, show no significant difference between magnetic knots and peripheral facular regions. This similarity in the spectral composition is characteristic of both intensity and Doppler-velocity oscillations. The oscillation power, however, is different: the oscillations in magnetic knots are on average 2–3 times weaker than those in the medium-field regions, again, in both the intensity and Doppler-velocity signals (Figure 2). The moderate-field regions that we used to compare with the magnetic knots have the same sizes as the magnetic knots. To calculate the spectrum of a single magnetic knot or moderate-field region, we averaged the signals over the knot area and then Fourier transformed the resulting signal.

The magnetic field strength spectra demonstrate a more noticeable difference: there are significant peaks in the magnetic knot spectra at a frequency of 4.8 ± 0.1 mHz. Figure 3 shows individual and averaged magnetic field oscillation spectra for the magnetic knots compared with those for the moderate-field regions. The question about these oscillations is now whether they are real oscillations of the magnetic flux or a product of magnetic hill horizontal movements that may be caused by, *e.g.*, horizontal waves. To test this hypothesis, we compared oscillations of the points placed at opposite sides of the magnetic hills. This analysis is based on the assumption that in the case of a horizontally moving hill the resulting signals will have opposite phases, even if the horizontal movements are on a sub-resolution scale. If the oscillations are caused by the real magnetic field strength variations, the signals will be in-phase (Figure 4a). The overwhelming majority of the observed signal pairs show similar phases (Figure 4b), which led us to conclude that the oscillations are indeed real oscillations of the magnetic flux.

To examine the possible reasons for these oscillations, we compared them with the velocity oscillations. Figure 5 demonstrates that neither the oscillation phase nor the wave-train structure of the velocity oscillations show a correlation with those of magnetic field oscillations. Although Figure 5 shows only one knot, this result is typical of all of the studied magnetic knots. Muglach, Solanki, and Livingston (1995) and Kobanov and Pulyaev (2007) have previously reported real oscillations of the magnetic flux in facular regions.

Figure 3 Upper: examples of the magnetic field spectra in magnetic knots and in moderate-field regions. Bottom: spectra of the magnetic field signals averaged over 11 knots and 11 moderate-field regions within the faculae. The horizontal lines indicate 95 % significance levels.

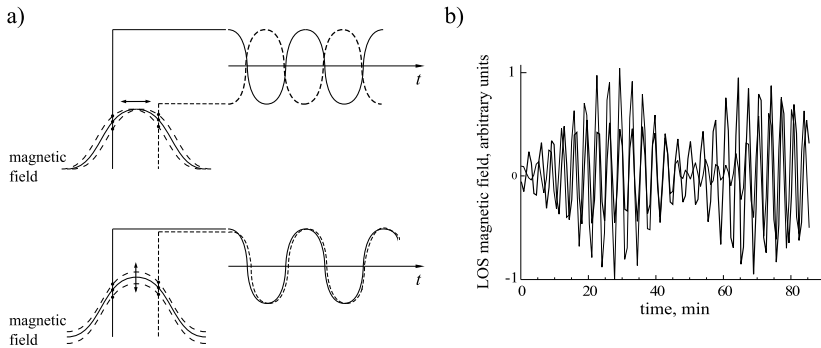
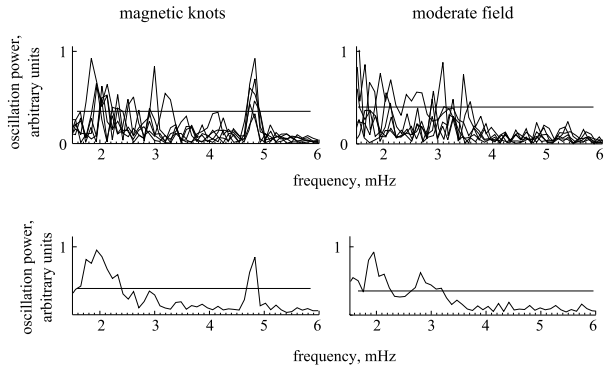


Figure 4 a: Notion of the phase relation between the magnetic field signals around a magnetic knot in two scenarios of the variation origin; b: an example of magnetic field signals of the points located at opposite sides of magnetic knot 4. The signals are filtered in the three-minute range.

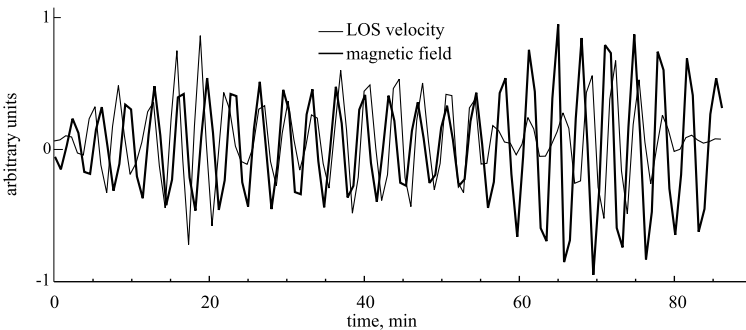


Figure 5 Oscillations of the magnetic field strength and line-of-sight velocity in magnetic knot 4 filtered in the three-minute range.

Here, the term “real oscillations” implies that the observed oscillations are of solar origin and not a result of instrumental artifacts. In the solar origin signals we also include the possible cross-talk of the quasi-periodic plasma movements into the magnetic field signal. There are several scenarios for such cross-talk: 1) small-scale spatial unresolved movements can

Figure 6 The 1700 and 304 Å line intensity oscillation spectra in magnetic knot 2 (see Figure 1) and in the adjacent area. The horizontal lines indicate 95 % significance levels.

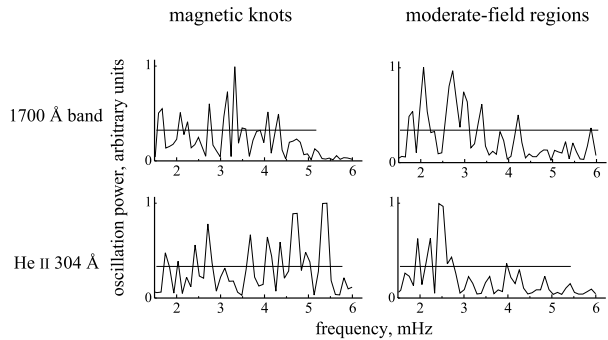
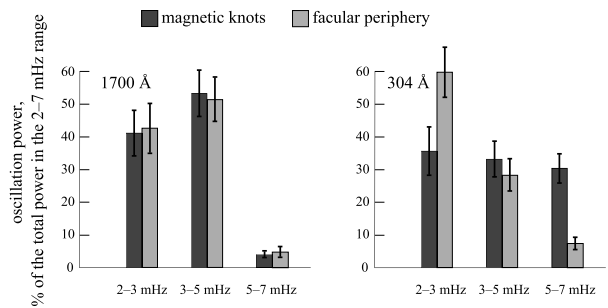


Figure 7 Integral oscillation power in three frequency ranges in percent of the total 2–7 mHz range oscillation power averaged over all of the 11 magnetic knots (see Figure 1) compared with 11 peripheral regions in the two faculae with the error bars showing the standard deviation over all of the studied regions. The diagrams show only peaks whose power exceeds the 95 % significance level threshold.



cause quasi-periodic variations of the Stokes-V; 2) large-scale sub-photospheric and photospheric movements can cause the magnetic tube direction to periodically divert near the line of sight, which, in turn, results in measured magnetic field signal variations, even given the fixed spatial location of the observed object; 3) density variations caused by the p -mode lead to periodic changes in the line formation height, which ends up in the magnetic field signal variations given the vertical gradient in the magnetic field. We note that the cross-talk problem is relevant for all instruments, both ground- and satellite-based. Analysing magnetograms from the *Michelson Doppler Imager* onboard the *Solar and Heliospheric Observatory* (SOHO/MDI), Norton *et al.* (1999) found magnetic field oscillations in a sunspot in three frequency ranges: 0.5–1.0, 3.0–3.5, and 5.5–6.0 mHz. Later, Settele *et al.* (2002) showed that the observed oscillations result from the velocity signal cross-talk. Liu *et al.* (2012) claimed that such cross-talk is absent from the HMI magnetograms. However, as shown here, the situation does not seem this straightforward. A more detailed investigation of the magnetic field variation sources constitutes a separate problem, which is beyond the scope of this work.

At the next height level that we studied, the 1700 Å spectral band forming in the upper photosphere, the magnetic knot spectra peaks show a slight shift to the high-frequency range compared to the moderate-field spectra (Figure 6, upper row). The He II 304 Å line intensity spectra representing the transition region of the solar atmosphere differ more noticeably: the significant peaks in the magnetic knot oscillation spectra are concentrated in the 3–6 mHz range, and those of the peripheral-region oscillation spectra are distributed below 3 mHz (Figure 6, lower row).

The diagram in Figure 7 is based on the data on all the magnetic knots in the two faculae. It summarizes the oscillation power distribution in the upper photosphere and transition region. The power is given in percentage of the total 2–7 mHz oscillation power. When

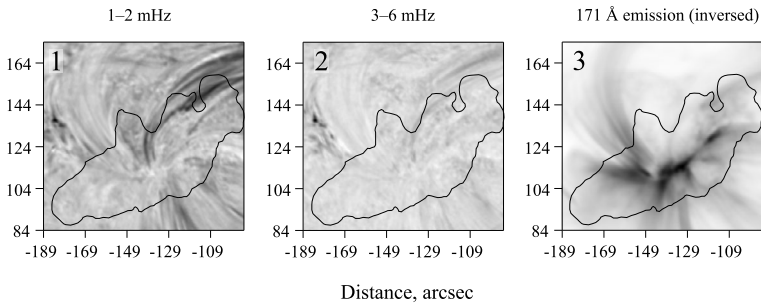


Figure 8 Panels 1 and 2: spatial distributions of the 1–2 and 3–6 mHz range oscillation power in the Fe IX 171 Å line. Each element of the spatial distributions is the total power of the Fourier transformed signals within the given frequency range. To minimize the influence of the brightness difference between the loops and the background, we subtract the mean values from each pixel signal and normalize the resulting oscillations to the original signal brightness. Dark indicates high oscillation power. Panel 3: the facula in the time-averaged Fe IX 171 Å line emission with the marked magnetic knot locations. The black and white colors are shown in inverse to highlight the loops.

constructing this diagram, only peaks exceeding the $2\sigma^2$ level were used. Again, we note that only frequencies above 2 mHz were used in the analysis because lower frequencies would take a large portion of the integral oscillation power if they were included in the diagrams (Figure 2, lower panel).

Previously we noted that low-frequency oscillations dominate above faculae in the lower corona observed in the Fe IX 171 Å line (Kobanov, Kolobov, and Chelpanov, 2015; Kobanov and Chelpanov, 2014). The spatial distributions of the low-frequency oscillation power outline loop and fan structures seen in the coronal emission lines (Figure 8). Most of the loops seem to have footpoints anchored approximately in the magnetic knots, although the co-alignment is the least precise for the Fe IX 171 Å line.

The observed spectral characteristics in the photosphere and transition region can be explained by the magnetic field configuration in the faculae. At the height of 200 km, where the Fe I 6173 Å line forms (Parnell and Beckers, 1969), the magnetic flux is closer to vertical in regions with strong and medium field strengths. At the higher level, the field lines begin to divert from the vertical more significantly, and the inclination is greater at the periphery of a facula than at its center. This allows longer-period waves to propagate upward at the periphery, since the cut-off frequency depends on the angle between the magnetic field and the wave vector, which influences the transformation between the MHD modes and may form magneto-acoustic portals for low-frequency wave propagation (Bel and Leroy, 1977; Schunker and Cally, 2006; Jefferies *et al.*, 2006; McIntosh and Jefferies, 2006).

It might be suggested that similar to sunspots, each magnetic knot is surrounded by a magnetic field canopy. It would be natural to expect that in this case the spatial distribution of the dominant frequencies has the characteristics mentioned in the articles by Moretti *et al.* (2007), Krijger *et al.* (2001), and Muglach, Hofmann, and Staude (2005). In faculae, however, canopies of the randomly-located magnetic knots intersect, forming a more complicated magnetic field topology. This impedes the unambiguous interpretation of the 2D distributions of the dominant frequencies in faculae. The task becomes even more complex when the analysis is carried out for several levels of the solar atmosphere. Hence in this work we restrict attention to a comparison of the oscillation spectral characteristics in magnetic knots and in the adjacent moderate field regions.

We note that our results disagree with those of Kostik and Khomenko (2013), who also studied the dependence of the oscillation characteristics on the magnetic field strength in faculae in the Ba II 4554 Å and Ca II H lines. The authors of this study observed an increase of 15–20 % in the photospheric and chromospheric dominant oscillation period with increase in the field strength. They used regions with a vector field strength ranging from 500 to 1600 G, however, while in our analysis the longitude field strength only reaches 1 kG values, which might in part be due to the lower spatial resolution of the data we used. In addition, the data series in our analysis are 2–3 times longer than the series used by Kostik and Khomenko (2013). This provides a higher frequency resolution and allows us to extend our analysis to lower frequencies. We cannot exclude the possibility that the differences are due to the different properties of the spectral lines used in the two studies. This suggests that the stated problem exists, and solving it requires further research in a wide spectral range with greater sets of observational data.

4. Conclusions

The main conclusions are as follows.

i) Magnetic field strength oscillation power spectra in facular magnetic knots have prominent peaks at a frequency of about 4.8 mHz, while spectra of moderate-strength patches lack such peaks. ii) The intensity and Doppler velocity spectral composition of the photospheric Fe I 6173 Å line is constant over the area of faculae. In magnetic knots, however, the oscillation power is reduced 2–3-fold in both intensity and velocity signals. iii) At the upper photospheric level of the 1700 Å line, the dominant frequency of the oscillations in knots is increased by 0.5–1 mHz compared to the moderate-field patches. iv) In the transition region, that is, in the He II 304 Å line, the significant peaks of the magnetic knot oscillation spectra are located between 3 and 6 mHz, and those of the peripheral region spectra are located below 3 mHz.

These parameters of the oscillation distributions are probably caused by the magnetic field configuration in faculae. At low atmospheric heights, the magnetic field lines are close to vertical across the whole area of a faculae, and the spectral composition at these heights does not change significantly in different parts of a facula. The field lines are inclined at the facular periphery in the upper photosphere, and more so in the transition region. This causes a decrease in the cut-off frequency and enables low-frequency waves to propagate upwards.

Acknowledgements This study was supported by Project No. 16.3.2 of ISTP SB RAS, by the Russian Foundation for Basic Research under grants 16-32-00268 mol_a and No. 15-32-20504 mol_a_ved. We acknowledge the NASA/SDO Science Team for providing the data. We are grateful to the highly skilled anonymous referee, whose valuable remarks and suggestions helped us to greatly improve the article.

References

- Abramov-Maximov, V.E., Gelfreikh, G.B., Kobanov, N.I., Shibasaki, K., Chupin, S.A.: 2011, Multilevel analysis of oscillation motions in active regions of the Sun. *Solar Phys.* **270**, 175. DOI. ADS.
- Bel, N., Leroy, B.: 1977, Analytical study of magnetoacoustic gravity waves. *Astron. Astrophys.* **55**, 239. ADS.
- De Moortel, I., Nakariakov, V.M.: 2012, Magneto-hydrodynamic waves and coronal seismology: An overview of recent results. *Phil. Trans. Roy. Soc. London Ser. A, Math. Phys. Sci.* **370**, 3193. DOI. ADS.
- De Wijn, A.G., McIntosh, S.W., De Pontieu, B.: 2009, On the propagation of p-modes into the solar chromosphere. *Astrophys. J. Lett.* **702**, L168. DOI. ADS.

- Guo, Y., Schmieder, B., Bommier, V., Gosain, S.: 2010, Magnetic field structures in a facular region observed by THEMIS and Hinode. *Solar Phys.* **262**, 35. DOI. ADS.
- Hoeksema, J.T., Liu, Y., Hayashi, K., Sun, X., Schou, J., Couvidat, S., Norton, A., Bobra, M., Centeno, R., Leka, K.D., Barnes, G., Turmon, M.: 2014, The Helioseismic and Magnetic Imager (HMI) vector magnetic field pipeline: Overview and performance. *Solar Phys.* **289**, 3483. DOI. ADS.
- Howard, R.: 1967, Velocity fields in the solar atmosphere. *Solar Phys.* **2**, 3. DOI. ADS.
- Ishikawa, R., Tsuneta, S., Ichimoto, K., Isobe, H., Katsukawa, Y., Lites, B.W., Nagata, S., Shimizu, T., Shine, R.A., Suematsu, Y., Tarbell, T.D., Title, A.M.: 2008, Transient horizontal magnetic fields in solar plage regions. *Astron. Astrophys.* **481**, L25. DOI. ADS.
- Jefferies, S.M., McIntosh, S.W., Armstrong, J.D., Bogdan, T.J., Cacciani, A., Fleck, B.: 2006, Magnetoacoustic portals and the basal heating of the solar chromosphere. *Astrophys. J. Lett.* **648**, L151. DOI. ADS.
- Khomenko, E., Centeno, R., Collados, M., Trujillo Bueno, J.: 2008, Channeling 5 minute photospheric oscillations into the solar outer atmosphere through small-scale vertical magnetic flux tubes. *Astrophys. J. Lett.* **676**, L85. DOI. ADS.
- Kobanov, N.I., Chelpanov, A.A.: 2014, The relationship between coronal fan structures and oscillations above faculae regions. *Astron. Rep.* **58**, 272. DOI. ADS.
- Kobanov, N.I., Chelpanov, A.A., Kolobov, D.Y.: 2013, Oscillations above sunspots from the temperature minimum to the corona. *Astron. Astrophys.* **554**, A146. DOI. ADS.
- Kobanov, N., Kolobov, D., Chelpanov, A.: 2015, Oscillations above sunspots and faculae: Height stratification and relation to coronal fan structure. *Solar Phys.* **290**, 363. DOI. ADS.
- Kobanov, N.I., Pulyaev, V.A.: 2007, Photospheric and chromospheric oscillations in solar faculae. *Solar Phys.* **246**, 273. DOI. ADS.
- Kobanov, N.I., Pulyaev, V.A.: 2011, Spatial distribution of oscillations in faculae. *Solar Phys.* **268**, 329. DOI. ADS.
- Kobanov, N.I., Kolobov, D.Y., Chupin, S.A., Nakariakov, V.M.: 2011a, Height distribution of the power of 3-min oscillations over sunspots. *Astron. Astrophys.* **525**, A41. DOI. ADS.
- Kobanov, N.I., Kustov, A.S., Pulyaev, V.A., Chupin, S.A.: 2011b, The role of faculae in wave-energy transfer to upper layers of the solar atmosphere: Observations. *Astron. Rep.* **55**, 532. DOI. ADS.
- Kostik, R., Khomenko, E.V.: 2012, Properties of convective motions in facular regions. *Astron. Astrophys.* **545**, A22. DOI. ADS.
- Kostik, R., Khomenko, E.: 2013, Properties of oscillatory motions in a facular region. *Astron. Astrophys.* **559**, A107. DOI. ADS.
- Krijger, J.M., Rutten, R.J., Lites, B.W., Straus, T., Shine, R.A., Tarbell, T.D.: 2001, Dynamics of the solar chromosphere, III: Ultraviolet brightness oscillations from TRACE. *Astron. Astrophys.* **379**, 1052. DOI. ADS.
- Liu, Y., Hoeksema, J.T., Scherrer, P.H., Schou, J., Couvidat, S., Bush, R.I., Duvall, T.L., Hayashi, K., Sun, X., Zhao, X.: 2012, Comparison of line-of-sight magnetograms taken by the Solar Dynamics Observatory/Helioseismic and Magnetic Imager and Solar and Heliospheric Observatory/Michelson Doppler Imager. *Solar Phys.* **279**, 295. DOI. ADS.
- Martínez Pillet, V., Lites, B.W., Skumanich, A.: 1997, Active region magnetic fields, I: Plage fields. *Astrophys. J.* **474**, 810. ADS.
- McIntosh, S.W., Jefferies, S.M.: 2006, Observing the modification of the acoustic cutoff frequency by field inclination angle. *Astrophys. J. Lett.* **647**, L77. DOI. ADS.
- Moretti, P.F., Jefferies, S.M., Armstrong, J.D., McIntosh, S.W.: 2007, Observational signatures of the interaction between acoustic waves and the solar magnetic canopy. *Astron. Astrophys.* **471**, 961. DOI. ADS.
- Muglach, K., Hofmann, A., Staude, J.: 2005, Dynamics of solar active regions, II: Oscillations observed with MDI and their relation to the magnetic field topology. *Astron. Astrophys.* **437**, 1055. DOI. ADS.
- 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.
- Norton, A.A., Ulrich, R.K., Bush, R.I., Tarbell, T.D.: 1999, Characteristics of MHD oscillations observed with MDI. In: Schmieder, B., Hofmann, A., Staude, J. (eds.) *Third Advances in Solar Physics Euroconference: Magnetic Fields and Oscillations*, *Astronomical Society of the Pacific Conference Series* **184**, 136. ADS.
- Orrall, F.Q.: 1965, Observational study of macroscopic inhomogeneities in the solar atmosphere, VI: Photospheric oscillations and chromospheric structure. *Astrophys. J.* **141**, 1131. DOI. ADS.
- Parnell, R.L., Beckers, J.M.: 1969, The interpretation of velocity filtergrams. I: The effective depth of line formation. *Solar Phys.* **9**, 35. DOI. ADS.
- Reznikova, V.E., Shibasaki, K., Sych, R.A., Nakariakov, V.M.: 2012, Three-minute oscillations above sunspot umbra observed with the Solar Dynamics Observatory/Atmospheric Imaging Assembly and Nobeyama radioheliograph. *Astrophys. J.* **746**, 119. DOI. ADS.

- Schou, J., Scherrer, P.H., Bush, R.I., Wachter, R., Couvidat, S., Rabello-Soares, M.C., Bogart, R.S., Hoeksema, J.T., Liu, Y., Duvall, T.L., Akin, D.J., Allard, B.A., Miles, J.W., Rairden, R., Shine, R.A., Tarbell, T.D., Title, A.M., Wolfson, C.J., Elmore, D.F., Norton, A.A., Tomczyk, S.: 2012, Design and ground calibration of the Helioseismic and Magnetic Imager (HMI) instrument on the Solar Dynamics Observatory (SDO). *Solar Phys.* **275**, 229. [DOI](#). [ADS](#).
- Schunker, H., Cally, P.S.: 2006, Magnetic field inclination and atmospheric oscillations above solar active regions. *Mon. Not. Roy. Astron. Soc.* **372**, 551. [DOI](#). [ADS](#).
- Settele, A., Carroll, T.A., Nickelt, I., Norton, A.A.: 2002, Systematic errors in measuring solar magnetic fields with a FPI spectrometer and MDI. *Astron. Astrophys.* **386**, 1123. [DOI](#). [ADS](#).
- Stepanov, A.V., Zaitsev, V.V., Nakariakov, V.M.: 2012, Coronal seismology. *Phys. Usp.* **55**(27), A04. [DOI](#). [ADS](#).
- Torrence, C., Compo, G.P.: 1998, A Practical guide to wavelet analysis. *Bull. Am. Meteorol. Soc.* **79**, 61. [DOI](#). [ADS](#).
- Turova, I.P.: 2011, Peculiarities of the mode of oscillations in a floccule and its neighborhoods at different chromospheric levels. *Astron. Lett.* **37**, 799. [DOI](#). [ADS](#).