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Characteristics of Oscillations in Magnetic Knots of Solar Faculae

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Abstract—The characteristics of oscillations of the intensity, magnetic field, and Doppler velocity in facular magnetic knots are compared with those at the facula periphery, where the magnetic field has a moderate intensity. The analysis is based on images in the FeI 6173 Å, 1700 Å, and He II 304 Å lines obtained with the Solar Dynamics Observatory, which are formed in the lower photosphere, upper photosphere, and transition zone, respectively. The spectra of the oscillations of the longitudinal magnetic field in magnetic knots show peaks at a frequency of about 5 mHz, which are not observed at the faculae peripheries. The spectra of the photospheric oscillations of the intensity and Doppler velocity in magnetic knots and in areas of moderate magnetic field are similar, but the oscillation power is a factor of two to four lower in the knots. The maximum spectral peaks in the HeII 304 Å line are mainly distributed in the range 3–6 mHz above magnetic knots and in the range 1.5–3 mHz above periphery regions. It is proposed that this distribution of the oscillations is due to the magnetic-field topologies in faculae: the magnetic field lines are close to vertical above the magnetic knots and inclined above the facula periphery.

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1. INTRODUCTION

Waves propagating in the solar atmosphere can transport energy to and heat its upper layers. In addition, studying the parameters of waves observed in the solar atmosphere can aid in drawing conclusions about the physical conditions at various heights [1, 2]. Oscillations in faculae—regions of enhanced emission in photospheric and chromospheric lines covering a considerable fraction of the solar surface—have been a subject of research for already 50 years [3, 4].

The strength and configuration of the magnetic field directly influence the properties of the oscillations. For sunspots, it was established that high-frequency oscillations are concentrated in regions with vertical magnetic field, and low-frequency oscillations in regions where the field is closer to horizontal [5–7]. Short-period oscillations observed in the microwave range are also predominantly detected above regions with strong magnetic fields [8].

Similar properties in the distribution of the oscillations can also be supposed for solar faculae. Like sunspots, faculae are characterized by the presence of regions with various magnetic-field strengths and inclinations. As a rule, elements with the strongest magnetic fields are located in the central part of a facula. Oscillations with different frequencies are observed in different parts of faculae: three-minute and five-minute oscillations dominate inside cells, whereas oscillations with lower frequencies of 1.2–2 mHz are detected above the network [9]. De Wijn et al. [10] noted the vertical propagation of waves with a period of 3 min in the chromosphere of the central part of a facula, and waves with a period of 5 min at the facula periphery. Kostik and Khomenko [11] observed an increased oscillation period in regions of enhanced magnetic-field strength. Turova [12] analyzed oscillations in a facula at the base of a coronal hole using observations in the H and K lines of Ca II and the Ca II 8498 Å line. Powerful oscillations in the 5-min range were observed in the chromosphere of the facula, with the dominant frequency decreasing with increasing height in the solar atmosphere.

One of the probable factors influencing this distribution of oscillation frequencies in faculae is the configuration of the magnetic field. However, in contrast to sunspots, faculae have more chaotic magnetic-field configurations and random distributions of the azimuthal angle of the field lines [13]. This is likely the reason for the absence of a one-to-one correspondence between the phase and spectral characteristics of oscillations in the photosphere and chromosphere of faculae noted in [14]. Since the magnetic-field lines along which the waves propagate can considerably deviate from the normal to the surface at the facula periphery, the manifestations of the same wave at

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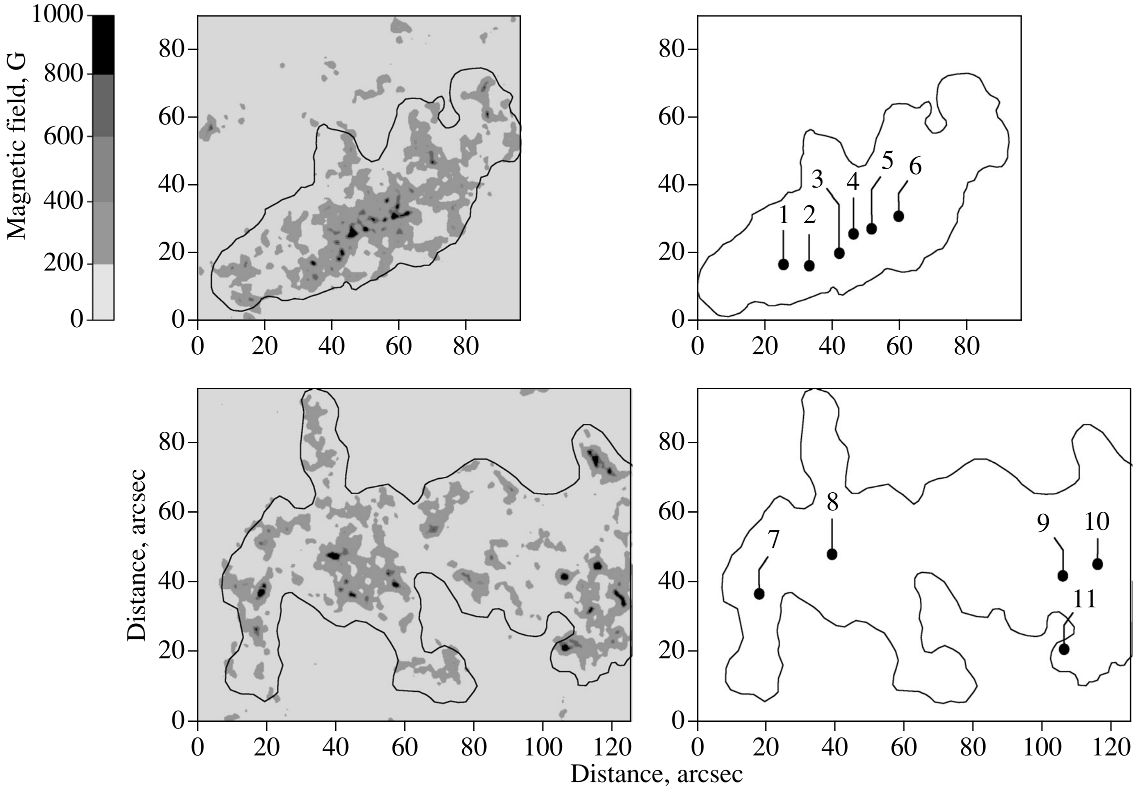

Fig. 1. Spatial distribution of the longitudinal magnetic fields in two faculae. Left: gray-scale maps; right: location of the studied magnetic knots—regions where the longitudinal magnetic field did not decrease below 600 G during the series. The faculae boundaries were determined using the 1700 Å images.

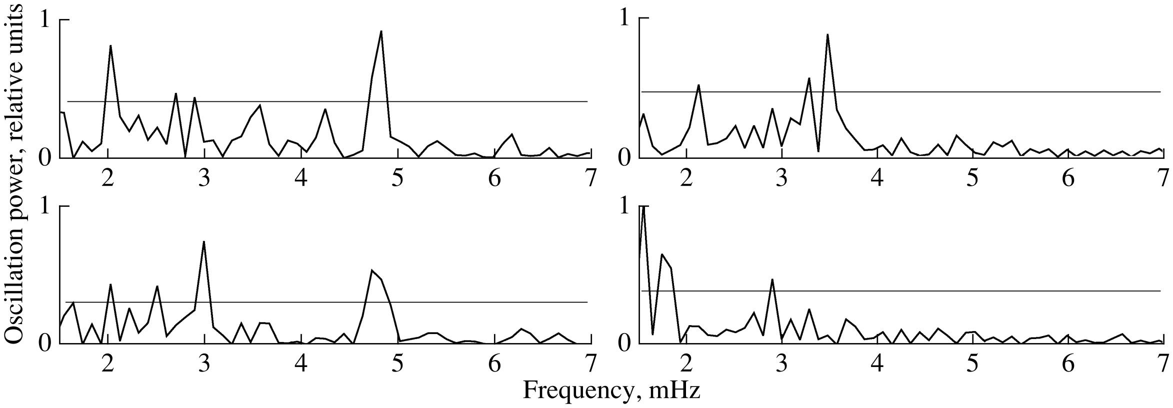

Fig. 2. Spectra of oscillations of the longitudinal magnetic field in magnetic knots (left) and at the facula peripheries (right). The horizontal lines show the 95% confidence level.

different heights in the atmosphere will be observed at different spatial points. In this case it is quite difficult to trace the actual trajectory of the wave propagation.

In this paper, we analyze the spectral distribution of oscillations in the longitudinal magnetic field, Doppler velocity, and intensity by comparing these characteristics for facular magnetic knots and adjoining areas with moderate magnetic fields.

2. DATA AND ANALYSIS METHODS

This work is based on images of the total solar disk obtained with the Solar Dynamics Observatory (SDO). We used UV images in the 1700 Å and He II 304 Å lines from the Atmospheric Imaging Assembly (AIA) with a pixel size of 0.6″ and time resolutions of 24 and 12 s. Data of the Helioseismic and Magnetic Imager (HMI) in the Fe I 6173 Å line with

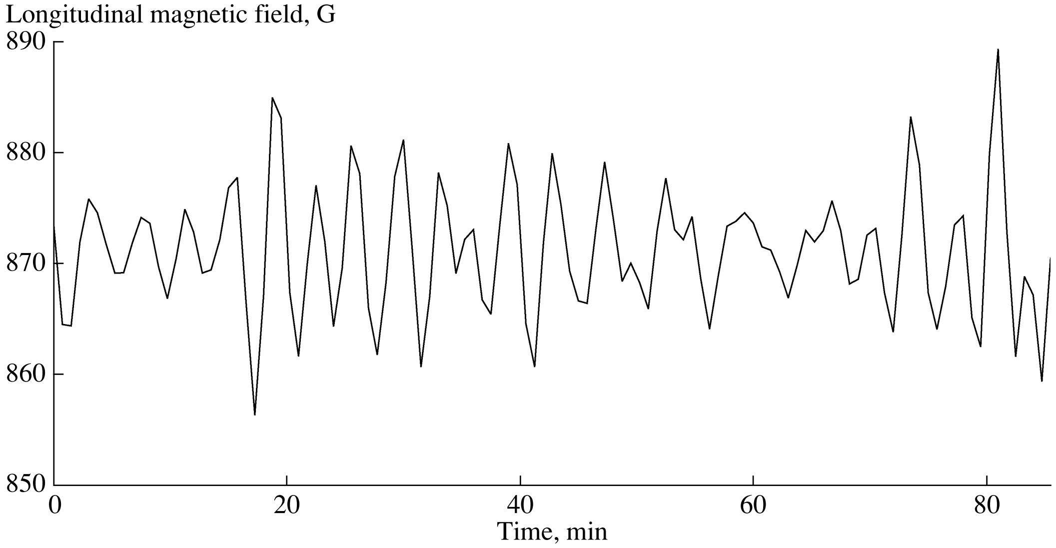

Fig. 3. Magnetic field strength in knot No. 3 filtered in the 2–7 mHz frequency band.

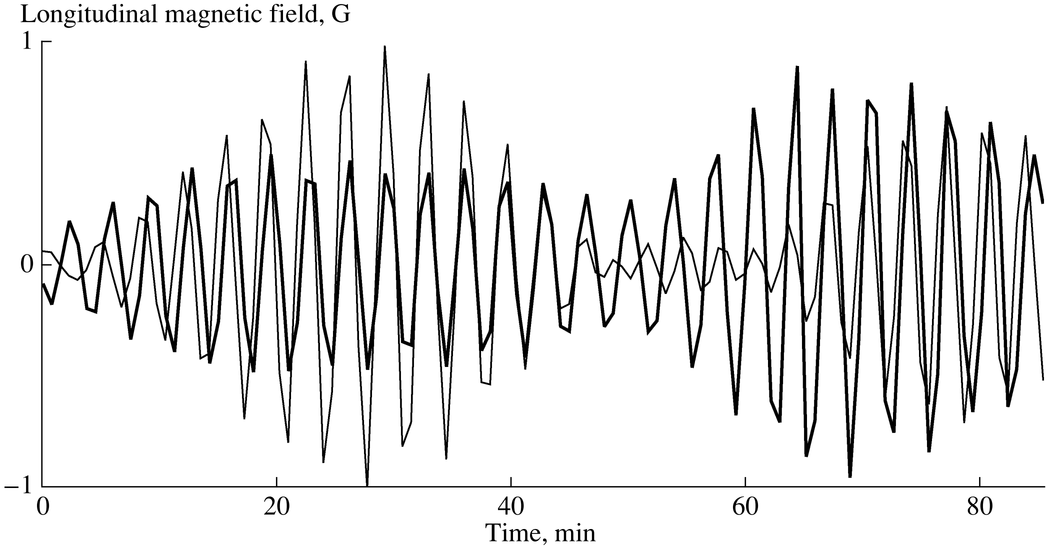

Fig. 4. Longitudinal magnetic-field strength filtered in the 4.4–5.2 mHz band at points on either side of the peak of magnetic knot No. 3.

a pixel size of 0.5″ and a time resolution of 45 s carry information on the magnetic field, Doppler velocity, and intensity. This line is formed in the photosphere at a height of 200 km [19]. The actual resolution of the SDO data is 1″–1.5″. We used data on two faculae, associated with the active regions NOAA 11098 and NOAA 11305, which were observed near the solar-disk center on August 14, 2010, and October 11, 2011. The central location of the faculae allowed us to use the same spatial points for different heights in the analysis. The durations of the time series were 90 and 85 min, respectively. We obtained the oscillation spectra using a Fast Fourier Transform (FFT) algorithm after removing a trend. The time resolution of the data enabled us to analyze frequencies of up to 11 mHz. The facula boundaries were derived from their 1700 Å images at the 0.7 level of the maximum facula brightness after smoothing over 20 pixels.

3. RESULTS AND DISCUSSION

We took magnetic-field knots (hills) to be facula regions in which the longitudinal magnetic field during a series did not fall below 600 G, while the maximum field intensity in both faculae was about 1 kG. Such knots are usually visible in the central part of faculae as small areas 1″–2.5″ in size (Fig. 1).

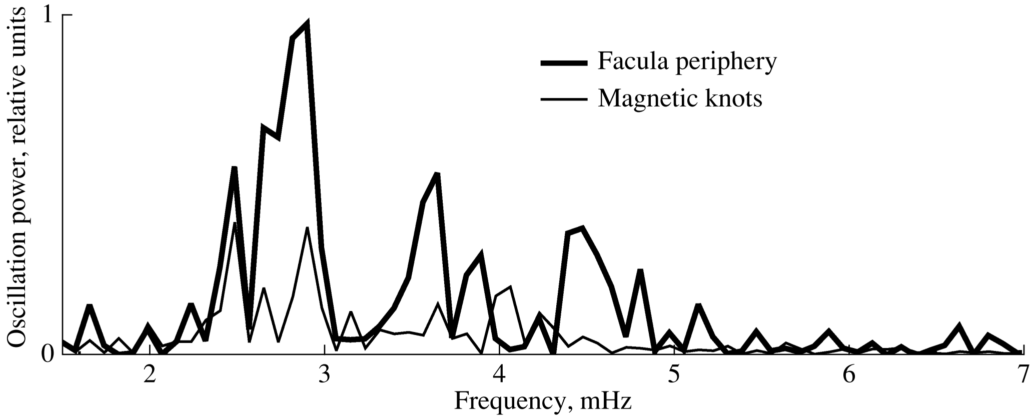

Fig. 5. Spectra of the line-of-sight velocity oscillations in the Fe I 6173 Å line in magnetic knots and at facula peripheries.

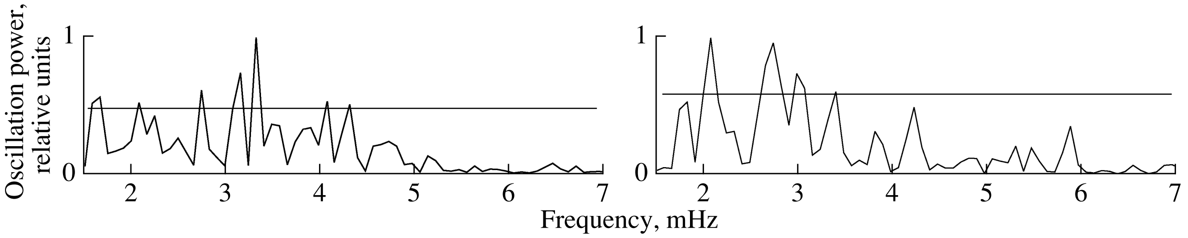

Fig. 6. Spectra of the intensity oscillations in the 1700 Å line in magnetic knots (left) and in regions with moderate magnetic-field strengths (right). The horizontal lines show the 95% confidence level.

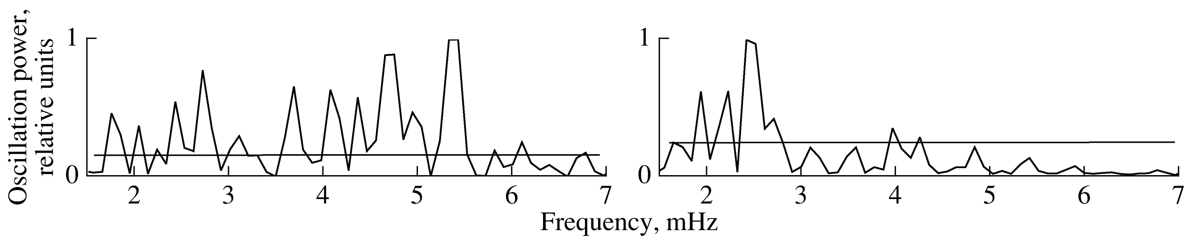

Fig. 7. Same as Fig. 6 for the He I 304 Å line.

Appreciable differences are observed in the spectra of oscillations of the longitudinal magnetic field: a peak at a frequency of 4.8 ± 0.1 mHz is clearly visible in each of the magnetic knots, which is absent in the spectra for regions at the facula periphery, where the magnetic field strength is 100–200 G (the spectra in knots Nos. 3 and 8 are presented in Fig. 2). Three-minute oscillations are clearly visible in the field strength in magnetic knots filtered in the 2–7 mHz range (Fig. 3). This peak in the spectra is a manifestation of changes in the magnetic flux, not the result of motion of the magnetic field hills, since the positions of the magnetic-field hills remained unchanged during the analyzed time series. Even if we suppose that periodic shifts of a magnetic hill in the plane of the sky exist but cannot be resolved because they have an amplitude smaller than the spatial resolution, such shifts would lead to changes in the magnetic-field strengths at points on the side of the hill. To test whether this is the case, we compared the magnetic-field oscillations filtered in the 3-min range for points on opposite sides of a hill at various distances from the point with the maximum field. The resulting oscillations turned out to be synchronous (Fig. 4). This behaviour corresponds to the case of magnetic-flux oscillations in the knot: if the oscillations were due to oscillatory motions of the image, the signals on opposite sides of the magnetic hill would be in antiphase. The existence of real oscillations of the magnetic fields in faculae was also stated earlier in [15, 16].

Table 1. Comparative distribution of the power of the intensity oscillations in the 1700 Å line in and outside magnetic knots (values in parantheses; see text) in three frequency ranges

Knot number	$\lvert B\rvert_{\max}$, G	$V_{\max}$, m/s	Power in percent of the 2–7 mHz range		
			2–3 mHz	3–5 mHz	5–7 mHz
1	915.1	630.2	57 (38)	31 (56)	11 (6)
2	808.2	684.0	40 (32)	56 (47)	4 (22)
3	1069.7	557.1	33 (67)	58 (26)	9 (7)
4	900.0	668.5	35 (44)	51 (51)	14 (5)
5	767.4	661.8	32 (45)	56 (46)	12 (9)
6	953.8	694.3	26 (46)	67 (42)	7 (12)
7	957.9	558.8	48 (52)	48 (38)	4 (10)
8	1001.0	643.2	32 (28)	64 (61)	7 (10)
9	947.9	643.8	25 (43)	70 (44)	6 (13)
10	870.1	1059.2	25 (41)	67 (48)	8 (11)
11	968.7	758.2	43 (37)	49 (55)	8 (8)

There are no appreciable differences in the oscillation spectra for the intensity and Doppler velocity of the Fe I 6173 Å line in magnetic knots and in regions with weaker magnetic field. The power of the velocity oscillations in magnetic knots is a factor of two to four lower than at the facula peripheries (Fig. 5). The reduction of the power of photospheric oscillations in facular regions compared to the unperturbed photosphere was also noted earlier [16–18].

Table 2. Comparative distribution of the power of intensity oscillations in the He 304 Å line in and outside magnetic knots (values in parentheses; see text) in three frequency ranges

Knot number	Power in percent of the 2–7 mHz range		
	2–3 mHz	3–5 mHz	5–7 mHz
1	61 (52)	33 (31)	6 (17)
2	22 (59)	48 (32)	30 (9)
3	38 (41)	51 (45)	11 (14)
4	19 (44)	62 (40)	19 (16)
5	29 (56)	55 (34)	16 (10)
6	39 (59)	49 (29)	12 (12)
7	51 (46)	42 (43)	8 (11)
8	42 (68)	43 (21)	15 (11)
9	37 (54)	52 (39)	11 (7)
10	43 (45)	43 (38)	14 (17)
11	43 (57)	47 (30)	10 (13)

The spectral compositions of the 1700 Å intensity oscillations in magnetic knots and at facula boundaries differ only insignificantly: a small increase in the oscillation power in the 4–6 mHz range is observed in magnetic knots (Fig. 6).

More substantial differences are observed in the spectra of the He II 304 Å intensity, formed at a height of 2200 km in the transition zone [6]. While peaks with frequencies 3 mHz and lower are prominent in the region with moderate magnetic field, a considerable fraction of the oscillation power above magnetic knots is distributed in the 3–5 mHz range (Fig. 7). We analyzed 11 magnetic knots in the two regions; the results are listed in Tables 1 and 2. The magnetic knots are numbered in accordance with Fig. 1. The last three columns of the tables contain the oscillation power calculated using the Fourier spectra. The oscillation powers at the same frequencies for areas with moderate magnetic fields at distances of $5''$–$7''$ from the corresponding magnetic knots are given in parentheses. Table 1 also lists the maximum longitudinal magnetic fields $|B|_{\max}$ and maximum Doppler velocities $V_{\max}$ during the series for each of the magnetic knots. The velocities are given relative to the velocity averaged over the field of view.

These characteristics of the spectral compositions of the oscillations in the lower photosphere and transition region can be understood as a consequence of the fact that the magnetic-field lines at the formation height of the Fe I 6173 Å line (200 km) [19] are close to vertical over the entire area of the facula, in spite of differences in the field strength. At higher levels the magnetic lines begin to deviate from being vertical, and the field inclination is higher at the facula edges than at its center. This enables waves with longer periods to propagate upward, since the cutoff frequency is proportional to the cosine of the angle between the magnetic-field lines and the normal to the surface [20].

Note that our results contradict the conclusions of Kostik and Khomenko [11], who observed an increase in the period of the dominant oscillations in the photosphere and chromosphere with increasing magnetic-field strength. Kostik and Khomenko [11] observed in the Ba II 4554 Å and H Ca II lines. The magnetic-field strength in the facula they observed reached 2 kG, twice the maximum field strengths in the faculae we used in our analysis. To some extent, this could be a consequence of better resolution: their data were obtained on a ground-based telescope with a spatial resolution reaching 0.2$''$. Analyzing changes in the oscillation spectra in the photosphere and chromosphere with the magnetic-field strength increasing from 500 to 1500 G, they observed a growth in the oscillation period by 15–20%.

4. CONCLUSIONS

The observed oscillations of the longitudinal magnetic field at a frequency of about 5 mHz are enhanced in the magnetic knots of solar faculae; this is not observed in facular areas with moderate and low magnetic fields.

No substantial differences were detected in the oscillation spectra for the intensity and Doppler velocity in the lower photosphere (the Fe I 6173 Å line) in different parts of the faculae. However, the oscillation power in both the intensity and velocity in magnetic knots is lower than in other parts of the faculae.

The low frequencies in the oscillations of the He II 304 Å line intensity in the transition zone are more pronounced at the facula periphery. At this height, the magnetic-field lines are not vertical over most of the facula area: the field lines have become inclined, with this inclination being more pronounced at the periphery. This enables lower-frequency oscillations to propagate in this region, while the prevalence of high-frequency oscillations (4–6 mHz) is maintained in the magnetic knots. This confirms earlier conclusions that high-frequency oscillations predominantly propagate in regions with vertical magnetic field, and the frequency of the observed oscillations decreases with increasing inclination of magnetic-field lines [6, 7].

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REFERENCES

1. I. de Moortel and V. M. Nakariakov, Phil. Trans. R. Soc. London, Ser. A **370**, 3193 (2012); arXiv: 1202.1944 [astro-ph.SR] (2012).
2. A. V. Stepanov, V. V. Zaitsev, and V. M. Nakariakov, Phys. Usp. **55**, 929 (2012).
3. F. Q. Orrall, Astrophys. J. **141**, 1131 (1965).
4. R. Howard, Solar Phys. **2**, 3 (1967).
5. N. I. Kobanov, D. Y. Kolobov, S. A. Chupin, and V. M. Nakariakov, Astron. Astrophys. **525**, A41 (2011); arXiv: 1111.6676 [astro-ph.SR] (2011).
6. V. E. Reznikova, K. Shibasaki, R. A. Sych, and V. M. Nakariakov, Astrophys. J. **746**, 119 (2012); arXiv: 1109.5434 [astro-ph.SR] (2011).
7. N. I. Kobanov, A. A. Chelpanov, and D. Y. Kolobov, Astron. Astrophys. **554**, A146 (2013); arXiv: 1305.4718 [astro-ph.SR] (2013).
8. V. E. Abramov-Maximov, G. B. Gelfreikh, N. I. Kobanov, K. Shibasaki, and S. A. Chupin, Solar Phys. **270**, 175 (2011); arXiv: 1102.1074 [astro-ph.SR] (2011).
9. N. I. Kobanov and V. A. Pulyaev, Solar Phys. **268**, 329 (2011); arXiv: 1110.1444 [astroph. SR] (2011).
10. A. G. de Wijn, S. W. McIntosh, and B. De Pontieu, Astrophys. J. Lett. **702**, L168 (2009); arXiv: 0908.1383 [astro-ph.SR] (2009).
11. R. Kostik and E. Khomenko, Astron. Astrophys. **559**, A107 (2013); arXiv:1310.0184 [astro-ph.SR] (2009).
12. I. P. Turova, Astron. Lett. **37**, 799 (2011).
13. V. Martínez Pillet, B. W. Lites, and A. Skumanich, Astrophys. J. **474**, 810 (1997).
14. N. I. Kobanov, A. S. Kustov, V. A. Pulyaev, and S. A. Chupin, Astron. Rep. **55**, 532 (2011).
15. K. Muglach, S. K. Solanki, and W. C. Livingston, in *Infrared Tools for Solar Astrophysics: What's Next?,* Ed. by J. R. Kuhn and M. J. Penn (World Scientific, Singapore, 1995), p. 387.
16. N. I. Kobanov and V. A. Pulyaev, Solar Phys. **246**, 273 (2007).
17. H. Balthasar, Solar Phys. **127**, 289 (1990).
18. N. I. Kobanov, D. Yu. Kolobov, A. A. Sklyar, S. A. Chupin, and V. A. Pylyaev, Astron. Rep. **53**, 957 (2009).
19. R. L. Parnell and J. M. Beckers, Solar Phys. **9**, 35 (1969).
20. N. Bel and B. Leroy, Astron. Astrophys. **55**, 239 (1977).

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