Astronomical and Astrophysical Transactions (*AApTr*), 2019, Vol. 31, Issue 2, pp. 125–132,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Peculiarities of the photospheric line-of-sight velocity field in the active region NOAA 12403 at the time of M2.9 solar flare

A.N. Koval, A.N. Babin*

Crimean Astrophysical Observatory, Russian Academy of Sciences, Nauchny, Bakhchisaray, 298409, Crimea, Russia

Received 1 October, 2018

On the basis of spectral observations we have studied the photospheric line-of-sight velocity field in the active region during the flare M2.9. In the small local region in the immediate vicinity of the flare ribbon we observed strong line-of-sight velocities in the opposite directions in contiguous fine-structure elements. The velocity amplitudes reached 3.2 km/s. These velocities increased noticeably during the period of rapid increase in the brightness of the flare and decreased with its fading. The pattern of the distribution of line-of-sight velocity along the slit suggests the spiral motions. The noticeable restructuring of the magnetic field in the investigated region occurred for several hours after the flare. The photospheric velocity phenomena precede the photospheric magnetic field modification.

Keywords: Sun: flares – Sun: photospheric velocity field – Sun: magnetic fields – Sun: line profiles

1 Introduction

Previous investigations of the structure of the velocity field in the active region and its connection with the magnetic field and flares had shown that the velocity field pattern as well as the structure of the magnetic field played an important role in the process of accumulation and realization of the flare energy. But the following studies were concentrated rather on the role of magnetic fields than of line-of-sight velocities. To date, the features of the distribution of such velocities in the active region and their connection with magnetic fields and flares remain poorly studied. In this paper, we investigate the peculiarities of the line-of-sight velocity field that were observed during a large M2.9 flare. Analysis had been limited to a small region with contiguous elements having mutually opposed velocities and located in the immediate vicinity of the flare ribbon.

*Email: babin@craocrimea.ru

2 Characteristics of the active region

From August 18 to August 31, 2015, the active region NOAA 12403 crossed the solar disk. This was rapidly developing spot group of $\beta\gamma/\beta\gamma\delta$ magnetic configuration. Figure 1 comprises images of the active region in the continuum and the magnetograms of the longitudinal magnetic field from the observations of SDO/HMI, showing the morphological changes in the spotgroup. This region undergoes considerable changes in the sunspot and magnetic field distribution. The active region emerged from behind the edge of the solar disk in the form of a large number of small spots scattered in latitude and longitude. During the passage through the disk, two large spots of a complex configuration with several nuclei in the same penumbra formed in it. The strength of the magnetic fields in the main nuclei reached 3000 Gs. The main feature of this group was instability of the morphology and magnetic field of the main spots, as can be seen from Fig. 1.

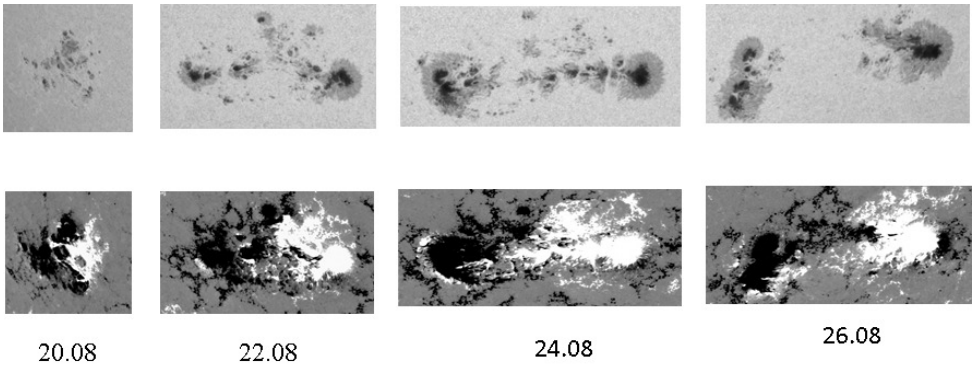


Figure 1 SDO/HMI pictures showing the development of NOAA 12403 active region (in the continuum and longitudinal magnetic field).

During the passage through the disk the active region produced 10 flares of the X-ray class M3.5-M1.2 and 66 flares of class C9.5-C1. An M2.9 flare on 27 August, 2015 started at 04:48 UT, reached a maximum at 05:44 UT and ended after 06:03 UT according the observation of GOES 15. Coordinates of the flare S16W58. Figure 2 shows an image of the flare in λ 1600 Å band from SDO/AIA observations, image of active region in the continuum (SDO/HMI) and soft X-ray flux in the 1–8 Å band, as observed by GOES 15.

3 Observations and analysis

3.1 Spectral observations

Spectral observations of the active region using 53 cm Nikolsky-type coronagraph KG-2 of the Crimean Astrophysical observatory were started at 05:05 UT. At the

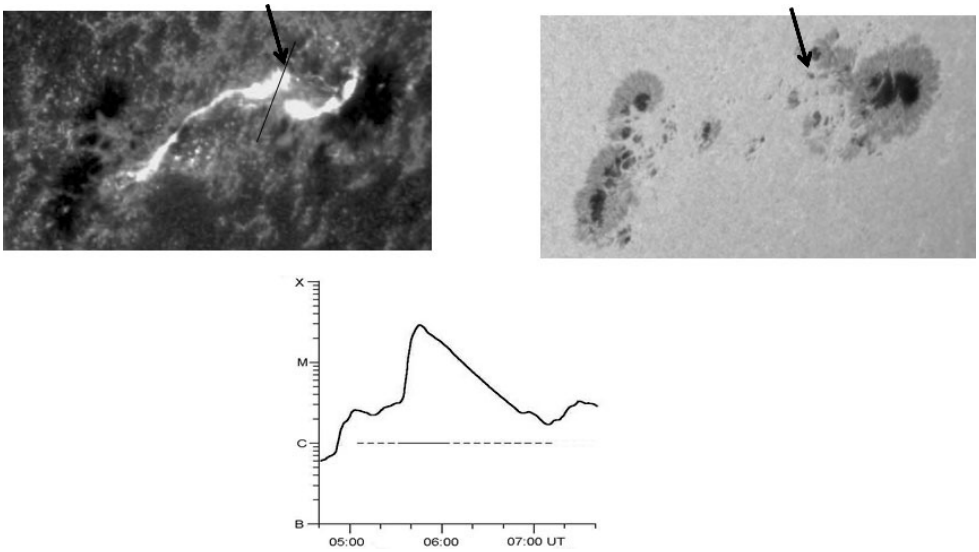


Figure 2 Image of the flare at the time of maximum development in the 1600 Å band (SDO/AIA) and in the continuum (SDO/HMI), arrows point out the investigated region, inclined line marks the position of spectrograph slit. Below soft X-ray flux in the 1–8 Å band (GOES 15). The horizontal line shows the time of observations on KG-2 (dashed – visual, solid – photographing of the spectra).

beginning of our observations the slowly developing flare was already in the process: small point-like emission structures were observed, some of them were located above the spot nuclei. The emission in the Hα line was, basically, without wings. There were a lot of the moustaches in the eastern part of the leading region. Around 05:30 UT the brightness of the flare increased noticeably, and we began to take pictures of the spectra, choosing the most interesting places.

The first spectrogram of the flare on KG-2 was obtained at 05:36 UT. Observations were made in the third order of the grating spectrograph at the wavelength region $\lambda\lambda$ 6526-6577 Å which includes the hydrogen Hα line and a number of photospheric lines of different Rowland's intensity. The linear dispersion of the spectrograph is 0.575 Å/mm. The diameter of the solar image on the spectrograph slit was 180 mm.

During the observations (05:36 UT- 06:01 UT) we obtained a series of spectrograms in which, in the small region adjacent to the flare ribbon, the photospheric lines were shifted by Doppler movements to the blue and red regions of the spectrum. The position of this region is noted in Fig. 2. A part of the spectrogram taken at 05:40 UT reproduced in Fig. 3. The arrows indicate the position of fine-structured contiguous elements with oppositely directed Doppler shifts of photospheric lines. A fairly strong flare emission is visible in the Hα line. The analysis of the line-of-sight velocity field at the photospheric level during the flare is limited only to this region.

To study the peculiarity of line-of-sight photospheric motions the lines of different Rowland's intensity were chosen. Data on these spectral lines are given in Table 1 (Moore 1933).

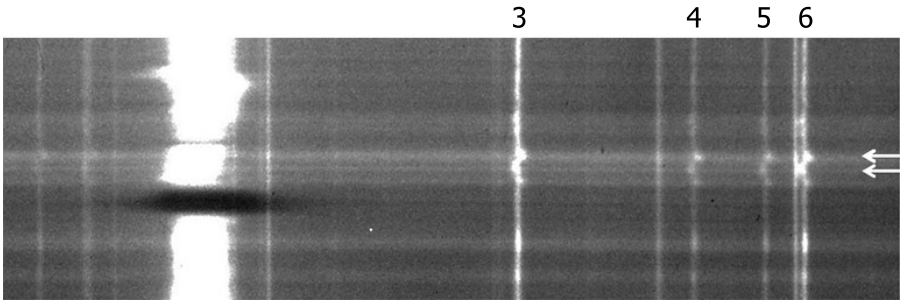


Figure 3 A part of the spectrogram (negative) obtained at 05:45 UT showing the behaviour of solar photospheric lines in the immediate vicinity of the flare ribbon, numbers indicate the lines under study in accordance with Table 1.

Table 1 List of studied spectral lines.

No	λ, Å	Element	Int. (disc)	Int. (spot)
1	6546.26	Fe I	6	7
2	6556.086	Ti I	1	5
3	6569.22	Fe I	4	3
4	6572.79	Ca I	1	6
5	6574.23	Fe I	1	3
6	6575.02	Fe I	4	5

The shift of the absorption lines were measured from microphotometer records of the spectral line profiles. Figure 4 shows examples of spectral line profiles in elements with blue and red shifts.

To study the velocity distribution along the slit, microphotometric cuts of the spectrograms were made through 1 arc sec. The wavelength of the center of the absorption line was determined with respect to the telluric lines, then it was compared with the wavelength of the line center in the region of photosphere without movement. By the difference in wavelengths, the radial velocities of the moving elements were determined. The typical examples of the line-of-sight velocity distribution along the spectrograph slit for the lines Fe I 6569.22 Å and Ca I 6572.79 Å are shown in Fig. 5.

From observational results we can note the main characteristics of photospheric motions in the investigated region.

1. Positive and negative velocities are simultaneously present in fine-structured contiguous elements.

2. Diameters of fine-structure elements are about 3 arc seconds (about 2000 km).

3. In the range of Rowland's intensities 0–4, the profiles of photospheric lines in moving elements are symmetrical, somewhat broadened and displaced as a whole. The marked asymmetry is present only in the wing of FeI 6546.26 Å line (Rowland's intensity 6).

4. The maximum line-of sight velocity of the descending elements is about 3.2 km/s, ascending 1.7 km/s. The spatial gradient of line-of-sight velocities is about 800 m/s/arc sec.

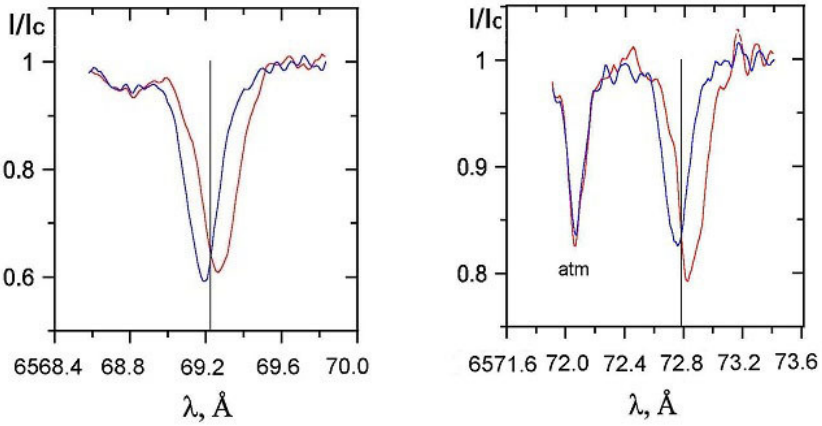


Figure 4 The profiles of the lines 6569.22 Å FeI and 6572.79 Å CaI in the red and blue shifted elements. Vertical lines denotes the line locations in the undisturbed photosphere

.

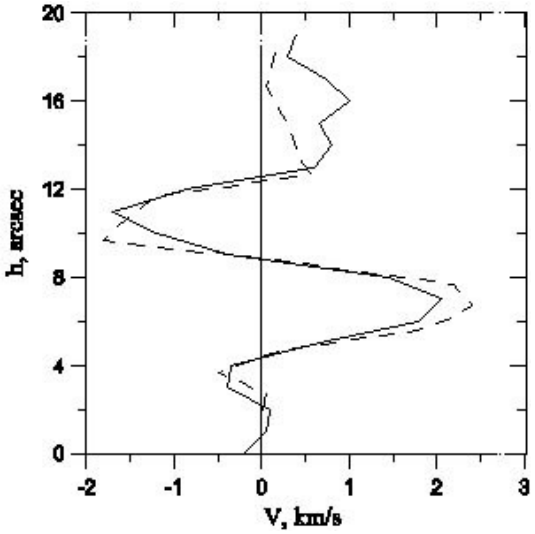


Figure 5 The distribution of the line-of-sight velocity along the spectrograph slit for profiles of the lines 6569.22 Å FeI (solid lines) and 6572.79 Å CaI (dashed lines).

5. From observations of Fraunhofer lines with different Rowland's intensities we studied the magnitude of line-of-sight velocity as a function of depth. A quantitative analysis of the results of measurements shows that the mean velocity for descending elements is 3.1 km/s as determined by weak lines (Rowland's intensities 0–1) and 2.2 km/s for moderate lines (4–6). For ascending elements the mean velocity value increases from 1.5 km/s for weak lines to 1.7 km/s for moderate lines. Thus the character of line-of-sight velocity variations with depth of the photosphere was opposite in the red and blue shifted elements.

6. The pattern of the distribution of line-of-sight velocity along the slit suggests the spiral motions.

3.2 Spatial and temporal relationship between the velocity field, flares and magnetic fields

1. As can be seen from the spectrograms, a region with special line-of-sight velocities is located near, but not in the place of flares emission in Hα.

2. Since our observations were started, when the current flare in active region was already in progress, we cannot establish a temporary connection between beginning of photospheric movements and flare. We can only note that the line-of-sight velocities increased noticeably during the period of rapid increase in the brightness of the flare and decreased with its fading.

3. A comparison has been made between velocity data and morphology of magnetic field. We used observation of longitudinal magnetic fields obtained on SDO/HMI. It showed that noticeable changes in the structure of the magnetic field occurred just in the region of particular line-of-sight velocities. Magnetograms reveal in this region the birth and disappearance of small spotless structures of the opposite (parasitic) polarity in the postmaximum period of the flare and after its termination. A number of the longitudinal magnetic field magnetograms of the leading spot group region are presented in Fig. 6. The arrows indicate the area under investigation.

4. Since the velocities to the maximum of the flare have already reached the highest values, and the rapid changes of the magnetic fields in this region were detected in the postmaximum period, we come to the conclusion that the photospheric motions of

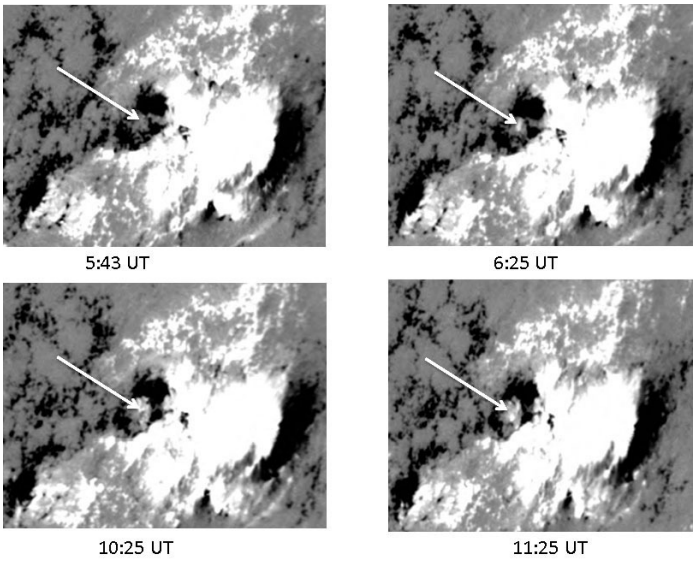


Figure 6 Time sequence of magnetograms of the leading spot region on August 27. Arrows point out the area under investigation.

special configuration preceded changes in the structure of the magnetic field. Similar results were obtained in a number of studies on the development of active regions (Martres et al. 1973; Kawaguchi and Kitai 1976; Grigoriev et al. 2009).

Conclusions

Our observations showed that the appearance of the line-of-sight velocity field of especial configuration at photospheric level precedes changes in the magnetic field distribution. Further observations are required to establish the connection of movement at the level of photosphere and flares. In the number of earlier works (Bumba 1960; Yoshimura et al. 1971; Zirin and Tanaka 1973; Rust 1973; Harvey K. and Harvey J. 1976; Babin and Koval 1992) it was obtained that a special picture of the line-of-sight velocities precedes the appearance of flares. The time interval between the appearance of movements and beginning of a flare is quite different: from several hours to tens of minutes.

Further research is needed on the role of movements in the storage and realization of flare energy in order to use the pattern of movements to predict the location and timing of flare appearance.

Acknowledgements

The authors thank the SDO/HMI and AIA science teams for the data, and the use of JHelioviewer (http://jhelioviewer.org/) for browsing data. This research was partially supported by the RFBR grant N 16-02-00221 A and the Presidium of the Russian Academy of Sciences Program 28.

References

Babin A.N., Koval A.N. (1992) Publ. Crim. Astrophys. Obs. 86, 152.
Bumba V. (1960) Publ. Crim. Astrophys. Obs. 23, 253.
Grigoriev V.M., Ermakova L.V., Khlystova A.I. (2009) AZh. 86 (N9), 935.
Harvey K.L. and Harvey J.W. (1976) Solar Phys. 47, 253.
Kawaguchi I. and Kitai R. (1976) Solar Phys. 46, 125.
Martres M-J., Soru-Escaut T., Rayrole J. (1973) Solar Phys. 32, 365.
Moore C.E. (1933) Atomic lines in the sun-spot spectrum, Princeton, N.J.
Rust D.M. (1973) Solar Phys. 33, 205.
Yoshimura H., Tanaka K., Shimizu M., Hiei E. (1971) Publ. Astron. Soc. Japan, 23, 443.
Zirin H. and Tanaka K. (1973) Solar Phys. 32, 173.