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DOPPLER VELOCITY FIELDS IN MAGNETIC STRUCTURES AND THEIR SURROUNDINGS

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Conference paper

Abstract. We demonstrate the effect of a velocity shift of photospheric velocity fields in regions filled by magnetic field compared to the velocity fields of non-magnetic regions surrounding them. We analyze this effect on five different types of measurements in active region NOAA 8086 obtained by SOLMAG (Ondřejov magnetograph) in four spectral lines on September 18th, 1997. The mean value of the Doppler velocity field in regions filled by magnetic field shows a red-shift of 40–190 $\mathrm{m\,s^{-1}}$ with respect to the neighbouring non-magnetic regions.

Key words: Solar photosphere – velocity field – magnetic and non-magnetic regions

1. Introduction

Analyzing the velocity fields in the vicinity of active regions we noticed that the mean values of the Doppler velocity fields are influenced by the presence of the magnetic field (Bumba and Klvaňa, 1995). The regions filled by magnetic fields demonstrate a red-shift of these Doppler velocities compared to velocity fields in the neighbouring non-magnetic areas. This phenomenon was found by means of the analysis of magnetographic measurements of topological structures of active regions acquired by SOLMAG – the photoelectric magnetograph of Ondřejov Observatory (Klvaňa and Bumba, 1993).

In Figure 1 we can see Doppler velocity maps where the regions occupied by the magnetic field with the absolute magnitude of the intensity greater than 100 G are indicated by grey colour. We see that in these magnetic field regions the red-shift of the velocity field (away of the observer) dominates and the blue-shift (toward the observer) prevail in the adjacent regions without the magnetic field. We decided to analyze this topologically important phenomenon more in detail.

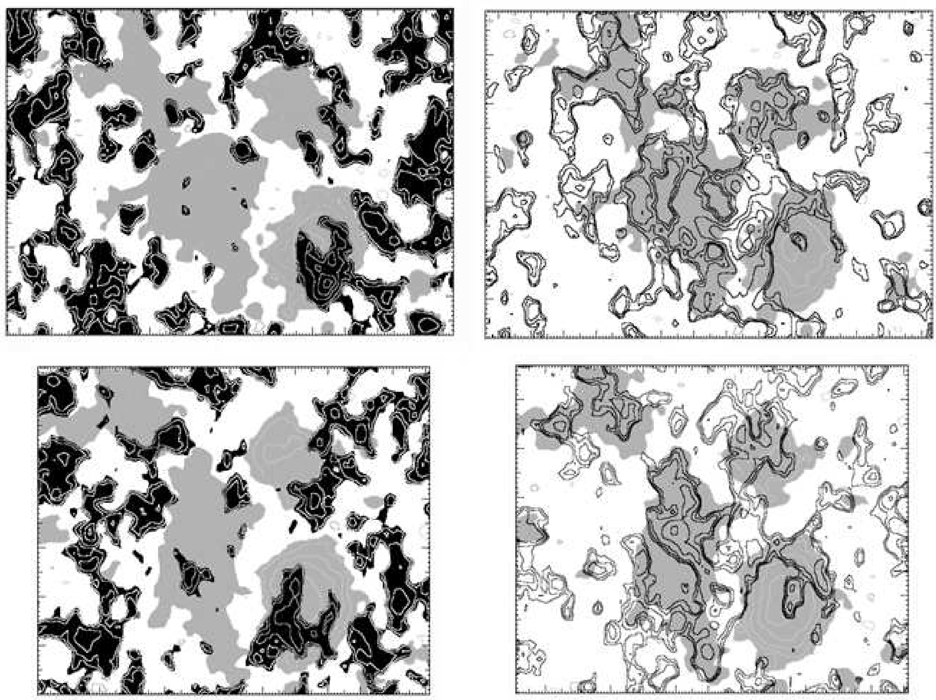

Figure 1: Doppler velocity field of the active region NOAA 7757 with separately drawn velocity polarities. The dark areas with bright velocity isolines (left) demonstrate motions toward the observer, on the contrary the bright areas with dark velocity isolines (right) show motions away from the observer. Intervals between the velocity levels are 200 $\mathrm{m\,s^{-1}}$. The grey areas indicate regions occupied by the magnetic fields (without distinguished polarities). Maps on the top were measured on July 21st, 1994, maps at the bottom were obtained on July 22nd, 1994. These maps demonstrate clearly that in regions covered by the magnetic fields, the velocities away of the observer dominate, while on the contrary, the velocities toward the observer dominate in non-magnetic areas surrounding them. Evershed effect of the big spot (right bottom quadrant of maps) disturb this separation with its own velocity field.

2. Measurements

SOLMAG measures the longitudinal magnetic field, Doppler velocity and intensity fields simultaneously. The mutual comparison of the magnetic, velocity and intensity topological structures of the same measurement is therefore exact. We analyzed characteristic properties of the velocity field in five successive measurements of the active region NOAA 8086 acquired on September 18th, 1997. We selected these observations due to the fact that they were made in different spectral lines. Therefore, such a selection was from the studied effect point of view just accidental. The selection of individual measurements in Figure 1 was made in a different way – according to strong visual similarity of both magnetic and velocity fields. Figures 2–6 demonstrate maps of the individual velocity field measurements overlapped by the contours of the magnetic field without polarities resolved. Areas of velocities toward the observer are dark grey, away from the observer light grey.

These repeated measurements of the same active region were made in four different spectral lines. The first up to the fifth measurements (Figures 2–6) were made in the following way: the first one in the standard magnetically sensitive spectral line FeI with the wavelength (λ) 525.35 nm and Landé factor $g = 1.5$. For the second one in Figure 3 the spectral line with $\lambda = 517.27$ nm and $g = 1.75$ was used. This spectral line belongs to MgI and originates in the bottom part of the chromosphere, just above the photosphere. In our measurements this line describes the highest tested layers. In Figure 4 we see the third measurement obtained in the magnetically non-sensitive line FeI, $\lambda = 512.37$ nm, $g = 0$. We used this line to find whether the studied effect does not originate from the light polarization in the magnetograph, due to the Zeeman's splitting. The last used spectral line FeI, $\lambda = 525.02$ nm, $g = 3$ is strongly sensitive to the magnetic field (Figure 5).

3. Data Processing

On the basis of the appearance of topological structures we assume that the mean velocity value of the Doppler velocity field in the area occupied by the magnetic field is shifted with respect to the mean Doppler velocity value of the non-magnetic structures. Our program package enables to segment

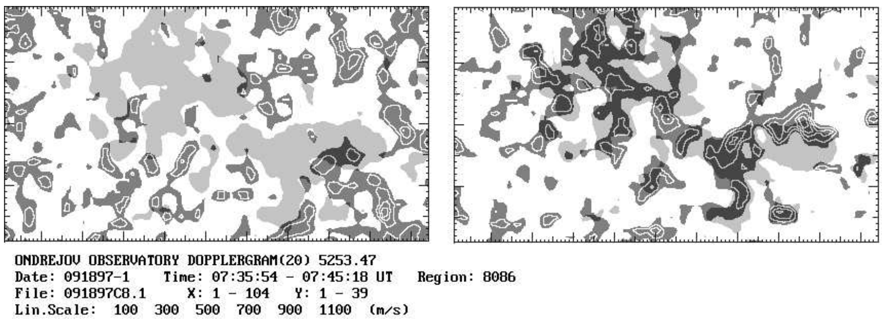

Figure 2: The separated polarities of the Doppler velocity field (left picture – blue shift, right picture – red shift) with the gray areas of the non-distinguished polarities of the magnetic field. The data were measured simultaneously in the spectral line FeI 525.347 nm with $g = 1.5$, usually used during the standard routine photospheric measurements.

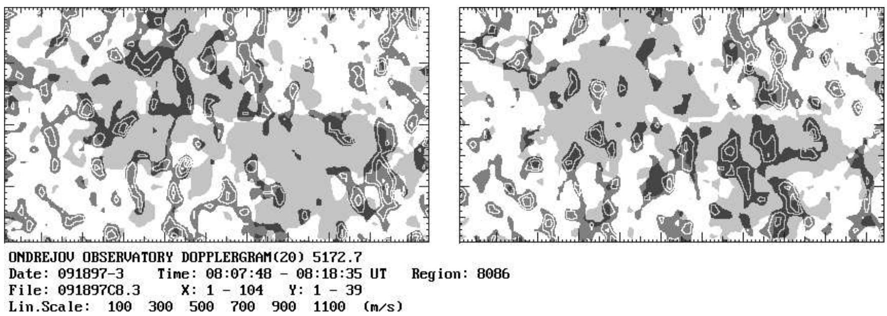

Figure 3: The separated polarities of the Doppler velocity field (left picture – blue shift, right picture – red shift) with the grey areas of the non-distinguished polarities of the magnetic field. The data were measured simultaneously in the spectral line MgI 517.27 nm with $g = 1.75$, which is generated in the bottom part of the chromosphere.

and, using various masks, to select different parts of magnetic structures (for example sunspots, individual segments of positive, as well as negative polarity). We can then in the selected segments and simultaneously in the remaining points of the map estimate the mean velocity of the Doppler velocity field. We used four types of masks: generated from the magnetogram covering both polarities (with the field intensities greater than 100 G), separate masks for the positive and negative polarities, and based on the photospheric picture of the sunspot also a mask for this spot.

We analyzed the properties of the velocity fields in magnetic as well as

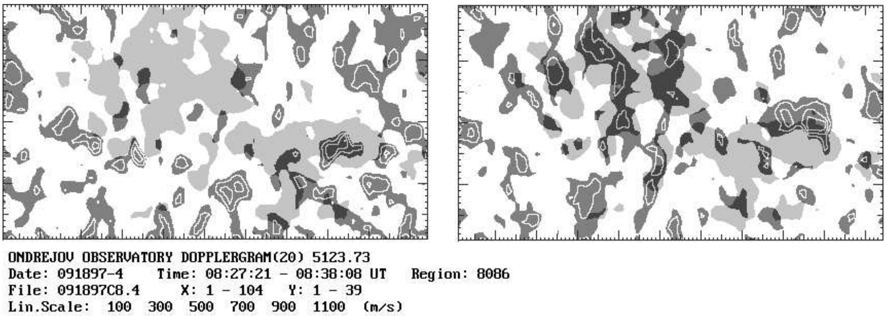

Figure 4: The separated polarities of the Doppler velocity field (left picture – blue shift, right picture – red shift). The Doppler velocity field was measured in the magnetically non-sensitive spectral line FeI 512.37 nm with $g = 0$. The gray areas of both non-distinguished magnetic polarities were taken from the measurement shown in Figure 2.

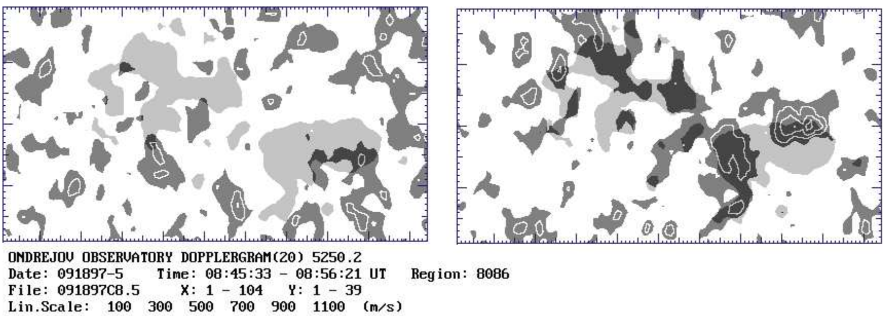

Figure 5: The separated polarities of the Doppler velocity field (left picture – blue shift, right picture – red shift) with the gray areas of the non-distinguished polarities of the magnetic field. The data were measured simultaneously in the spectral line FeI 525.02 nm with $g = 3$. This line is strongly sensitive to the magnetic field.

in non-magnetic areas. The sunspot velocity field with the strong Evershed effect can have a different character of the shift. Therefore, we analyzed the segment of a sunspot separately from the remaining magnetic fields. Using the method of the mutual correlation of the spot positions on maps from their individual measurements we selected their common part. The mean velocity value of the Doppler velocity field we calculated for both the whole adjusted segments and the mask's points. The area of the magnetic field of the given measurement was delimitated using a mask of the simultaneously

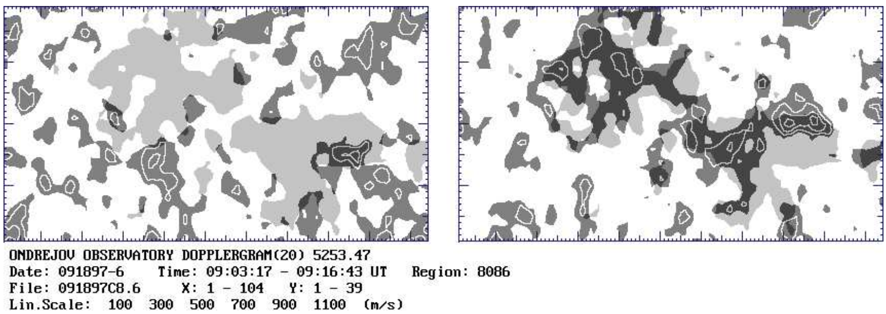

Figure 6: The repeated measurement in the same spectral line like in Figure 2. The simplification of the velocity structure in the pictures is due to the deterioration of the seeing during the day.

measured longitudinal magnetic field, only for the measurements made by the magnetically non-sensitive line in Figure 4, we used the mask from the first measurement. The separated polarities of the Doppler velocity field (left picture – motion to the observer, right picture – motion from the observer) with the gray areas of the non-distinguished polarities of the longitudinal magnetic field are shown in Figures 2–6.

We did not suppress the five-minute oscillations in all the velocity field of Figures 2–6 and therefore they can display themselves in a form of changes of some local features. Due to the fact that we investigate the mean velocities in relatively large areas, the five-minute oscillations can be averaged and their influence is weakened.

4. Results

1. The Doppler velocity field in the area of the active region's magnetic field:

    (a) In all five cases we observe the red-shift in the Doppler velocity field compared to the velocity field of the surrounding areas without the magnetic field.

    (b) For individual measurements, the amplitudes of this red-shift differ. Depending on the conditions and parameters of the measurement, the value of the red-shift changes in the interval of 40–190 $m\,s^{-1}$.

(c) It seems that the amplitude of the observed red-shift is influenced by the quality of the observational conditions. The first and the last measurements in the spectral line FeI 525.35 nm differ in the image quality, which descends continously during the day.

(d) The minimum value of the red-shift we found in the spectral line MgI 517.27 nm, generated at the highest level. The magnetic field topology obtained in this line differs substantially by its larger area compared to those measured in the FeI lines. This fact brings a clear evidence about the difference in the physical conditions existing in the layers where the spectral lines are generated.

(e) The red-shift was measured also in the magnetically non-sensitive spectral line FeI 512.37 nm. Therefore we conclude that the found red-shift does not represent an artefact connected with the polarization and Zeeman's splitting of spectral lines in the magnetic field.

2. The Doppler velocity field in the area of the separated magnetic field polarities:

   The global character of the Doppler velocity red-shift remains in all magnetic field areas. There are only two exclusions in our measurements: The minus polarity area in the second and the plus polarity area of the third measurements, where a blue-shift instead of the red-shift was measured in the magnetic field areas. We cannot exclude the influence of the local velocity fields (for example, of five-minute oscillations) there, due to the small area for which the velocities were averaged. This effect must be studied more in detail.

3. The Doppler velocity field in the area of a sunspot:

   Although the Evershed effect deforms strongly the figure of the velocity field in the magnetic field areas by its own velocity field, our conclusions concerning the velocity field in the area of a sunspot essentially coincide with our conclusions made for the areas generally occupied by the magnetic fields. Also in this case (cf. Tab. I) the shift in the velocity field in sunspots has negative values.

We bring up the summary of obtained results in Tab. I. In the column "*Param.*" the mean Doppler velocity value "$\langle v \rangle$", total number of points

Table I: Influence of presence of the magnetic field on the shift of the mean values of the Doppler velocities. The positive velocities in the Tab. I correspond with the blue-shift (motion toward the observer).

Measurement NOAA 8086 1997 09 18	Param.	All points	Method of the selection of the mask points							
			both polarities		plus polarity		minus polarity		sunspot only	
			mask	rest	mask	rest	mask	rest	mask	rest
1st measurement										
FeI: $\lambda = 525.347$ nm	$\langle v \rangle$ [m s^{-1}]	−11	−158	34	−164	5	−152	13	−172	−5
$g = 1.5$	N [points]	91 207	21 189	70 018	8 298	82 909	12 823	78 384	3 079	88 128
7.35–7.44 UT	*shift*		−192 m s^{-1}		−169 m s^{-1}		−164 m s^{-1}		−167 m s^{-1}	
2nd measurement										
MgI: $\lambda = 517.27$ nm	$\langle v \rangle$ [m s^{-1}]	4	−19	19	−65	19	18	0	−13	5
$g = 1.75$	N [points]	91 207	35 671	55 536	15 735	75 472	19 522	71 685	3 147	88 060
8.07–8.10 UT	*shift*		−37 m s^{-1}		−84 m s^{-1}		+18 m s^{-1}		−18 m s^{-1}	
3rd measurement										
FeI: $\lambda = 512.37$ nm	$\langle v \rangle$ [m s^{-1}]	−7	−72	13	0	−7	−116	11	−101	−4
$g = 0$	N [points]	91 207	21 189	70 018	8 298	82 909	12 823	78 384	2 855	88 352
8.27–8.38 UT	*shift*		−85 m s^{-1}		+8 m s^{-1}		−127 m s^{-1}		−98 m s^{-1}	
4th measurement										
FeI: $\lambda = 525.02$ nm	$\langle v \rangle$ [m s^{-1}]	−12	−126	9	−146	−1	−109	−3	−188	−5
$g = 3$	N [points]	91 207	13 858	77 349	6 622	84 585	7 236	83 971	3 098	88 109
8.45–8.55 UT	*shift*		−135 m s^{-1}		−144 m s^{-1}		−106 m s^{-1}		−183 m s^{-1}	
5th measurement										
FeI: $\lambda = 525.347$ nm	$\langle v \rangle$ [m s^{-1}]	−56	−169	−21	−163	−42	−175	−39	−191	−50
$g = 1.5$	N [points]	91 207	21 468	69 739	10 238	80 969	11 217	79 990	3 695	87 512
9.03–9.17 UT	*shift*		−148 m s^{-1}		−121 m s^{-1}		−136 m s^{-1}		−141 m s^{-1}	

"N" and the mutual "*shift*" of the mean values of the Doppler velocities in the masked and non-masked parts of the map. In the column "*mask*", these parameters are given for all points selected by the relevant mask, and in the column "*rest*", these values are given for points outside the mask. The number of the points in the map and the average of the Doppler velocities in the whole map are shown in the column "*all points*".

5. Conclusions

Comparing the mean values of the Doppler velocity fields in areas occupied by the magnetic fields and in areas without the magnetic fields surrounding them, we found that there exists a red-shift of the averaged values of the Doppler velocities in the magnetic areas. For the segmentation of the magnetic and non-magnetic areas we used the magnetic intensity value of 100 G.

We found the red-shift in five measurements of the same active region in magnetically sensitive spectral lines FeI: $\lambda = 525.35$ nm (190 and 150 $\mathrm{m\,s^{-1}}$), FeI: $\lambda = 525.02$ nm (140 $\mathrm{m\,s^{-1}}$), MgI $\lambda = 517.27$ nm (40 $\mathrm{m\,s^{-1}}$), as well as in the magnetically non-sensitive line FeI: $\lambda = 512.37$ nm (90 $\mathrm{m\,s^{-1}}$).

The effect of the red-shift of the averaged values of the Doppler velocity fields could be connected with the blocking of the granular motions in the magnetic areas, and consequently by the reducing of the convective blue-shift, caused by them.

Our results have a character of a preliminary information only. We have to evaluate a much greater number of measurements to confirm them.

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POLJA DOPPLEROVIH BRZINA U MAGNETSKIM USTROJSTVIMA I NJIHOVU OKOLIŠU

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Izlaganje sa znanstvenog skupa

Sažetak. Ustanovljen je efekt pomaka brzina fotosferkih polja brzina u područjima prožetim magnetskim poljima u usporedbi s poljima brzina okolnih ne-magnetskih područja. Taj efekt se analizira pomoću pet različitih vrsta mjerenja aktivnog područja NOAA 8086 obavljenih instrumentom SOLMAG (Ondřejovski magnetograf) u četiri spektralne linije 18. rujna 1997. Srednja vrijednost Dopplerovog polja brzina u područjima prožetim magnetskim poljima pokazuje crveni pomak od 40–190 m s^{-1} s obzirom na ne-magnetska okolna područja.

Ključne riječi: Sunčeva fotosfera – brzina polja – magnetska i ne-magnetska područja