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Fast vector magnetic maps with imaging spectroscopy

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Abstract. We present a new observing mode of THEMIS / MSDP which can provide fast vector magnetic maps of the solar photosphere in the 610.27 Ca line.

Key words. Sun: atmosphere - Sun: magnetic fields

1. Fast scanning and increased spectral resolution

The MSDP (Multi-channel Subtractive Double Pass) is generally used to analyse broad lines of the solar spectrum by imaging spectro-polarimetry (Mein 2002). It can be characterised by two main advantages:
- high scanning speed due to its 2D-character
- high spatial resolution due to the absence of convolution by any entrance slit.

The peculiar case of vector magnetic-field observations implies to study narrow photospheric lines. In order to obtain the necessary increase of spectral resolution, we use a compromise between the spatial and spectral resolutions, without modifying the fast scanning capabilities. Figure 1 shows the corresponding interpolations in the plane $x\lambda$. The plane xy of 2D imagery is not represented. For a solar point at $x = 0$, line profile intensities are measured at points A and D from channels n and $n + 1$ (wavelengths λ_A and λ_D). Let us call B and C the points of channels n and $n + 1$, at solar locations $x = +/-0.35$ arcsec (wavelengths $\lambda_A + 2$ pm and $\lambda_D - 2$ pm). Let us call F and G the points $x = 0$ at the same wavelengths

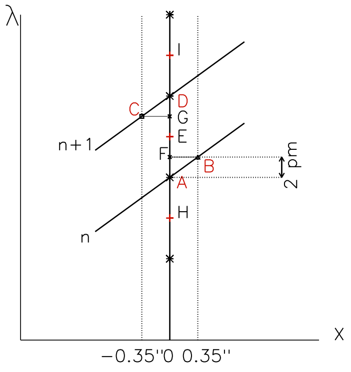

Fig. 1. Method of line-profile interpolation (see the text).

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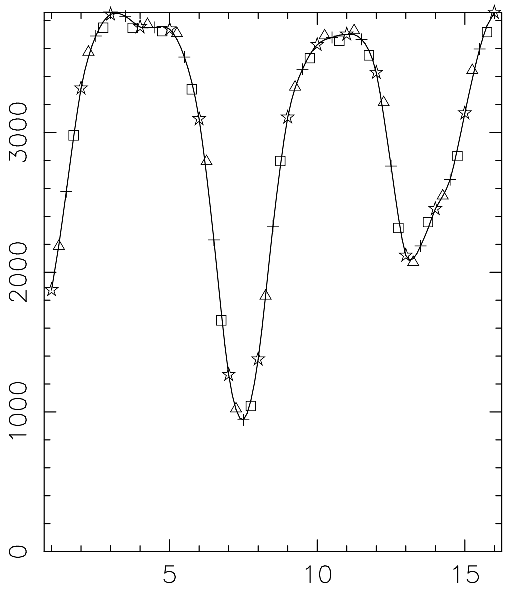

Fig. 2. Spectrum derived from the 16 MSDP channels around 610.27 nm CaI (deeper line). Stars correspond to points similar to A and D in Fig 1. Triangles correspond to points B, rectangles to points C and crosses to points E.

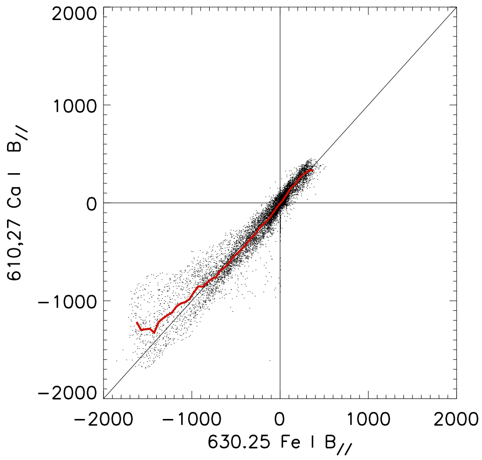

Fig. 3. Scatter plot of LOS magnetic field in MSDP data (Ca line), versus MTR data (Fe line),with UNNOFIT inversion.

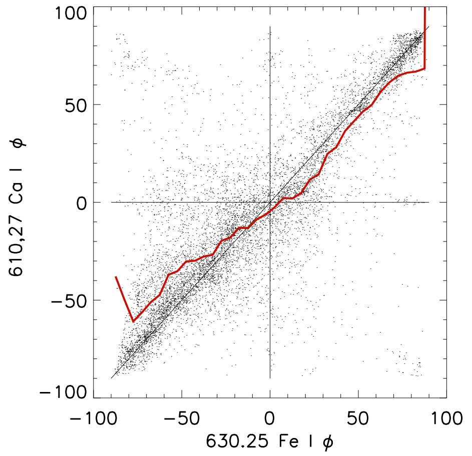

Fig. 4. Scatter plot of azimuth angles of transverse magnetic field in MSDP data (Ca line), versus MTR data (Fe line), with UNNOFIT inversion.

as B and C. The intensities at A,B,C,D,F,G satisfy generally $|I_F - I_B| << |I_F - I_A|$ and $|I_G - I_C| << |I_G - I_D|$ because the departure 0.35 arcsec is smaller than the spreading-width of seeing effects. So, by replacing intensities at F and G by intensities at B and C, we can derive the intensity at E from a cubic interpolation using points A,B,C,D.

Let us note also that, if some intensity gradient exists between solar locations at $+/-0.35$ arcsec, it is partially compensated in the interpolation by symmetrical positions of B and C. In this way, the spectral resolution of 8 pm (distance between A and D) is reduced to 4 pm.

Finally a sampling of 2 pm is again obtained by cubic interpolations (H,A,E,D for F, and A,E,D,I for G).

Figure 2 shows an example of spectrum deduced from MSDP data (intensities in arbitrary units). Points similar to A and D are represented by stars, B by triangles, C by rectangles and E by crosses.

2. Observations

On August 18, 2006, the active region NOAA 0904 was observed with the MSDP mode around 10:17 UT with the 610.27 nm CaI line (Lande factor 2.0). For comparison, MTR ob-

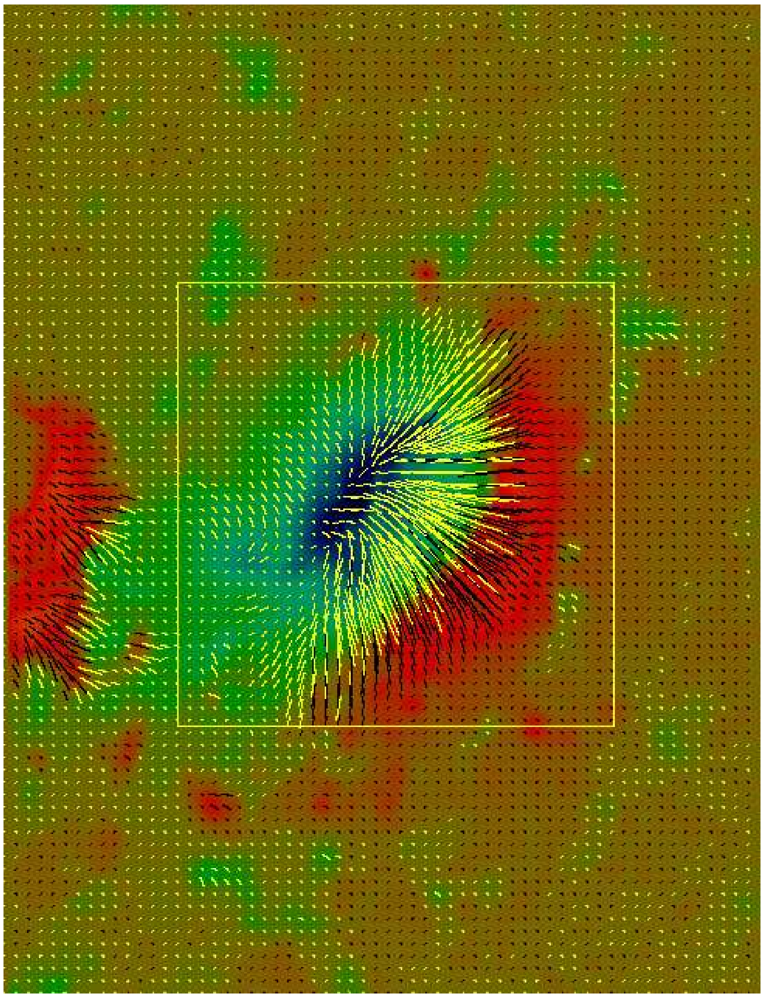

Fig. 5. Vector magnetic map derived from MSDP data (Ca line) and UNNOFIT inversion. The background color shows the LOS magnetic field. The transverse field is represented by dashes, the length of which are proportional to the amplitude of the field. The total field-of-view is 120 x 160 arcsec. The square of 70 x 70 arcsec specifies the field-of-view of MTR data.

servations were performed around 11:50 UT with the 630.25 FeI line (Lande factor 2.5).

The polarimetry was the same in both modes. A grid was used in front of the polarization analyser, and Stokes parameters I+S and I-S were observed simultaneously (S = +Q,-Q,+U,-U,+V,-V successively). The grid period is 33 arcsec, and image restorations were obtained by 4 steps of 8.2 arcsec in *y*. The scanning steps in *x* were 5 arcsec for MSDP and 0.5 arcsec for MTR. MSDP uses 5 grid-periods and MTR 2 grid-periods. The total fields-of-view are 120x160 and 70x70 arcsec, respectively. The scanning time for MSDP was close to 11 minutes.

In both cases, line profile inversions were performed thanks to the UNNOFIT code (Landolfi, Landi Degl'Innocenti and Arena,

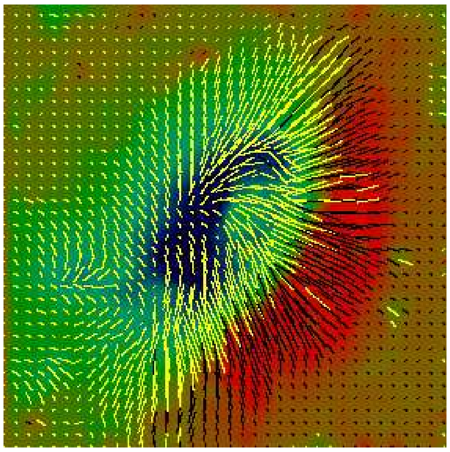

Fig. 6. Vector magnetic map derived from MTR data (Fe line) and UNNOFIT inversion. The background color shows the LOS magnetic field. The transverse field is represented by dashes, the length of which are proportional to the amplitude of the field. The total field-of-view is 70 x 70 arcsec.

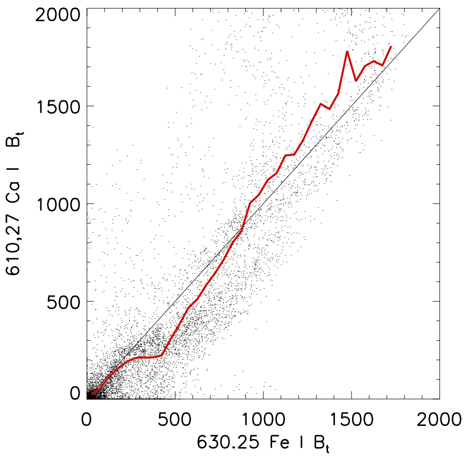

Fig. 7. Scatter plot of transverse magnetic field in MSDP data (Ca line), versus MTR data (Fe line), with UNNOFIT inversion.

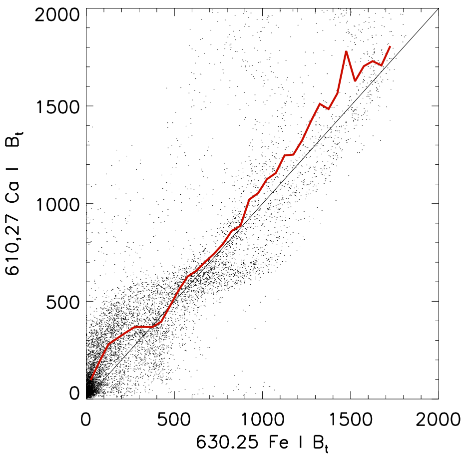

Fig. 8. Scatter plot of transverse magnetic field in MSDP data (Ca line), versus MTR data (Fe line), with modified UNNOFIT inversion.

1984) with the parallel computer of the Paris-Meudon Observatory.

3. Results with UNNOFIT inversion

Figures 5 and 6 show the maps of local average vector magnetic field derived from MSDP and MTR data, respectively. In spite of the time interval (rougly 1 hour 30 mn), and the

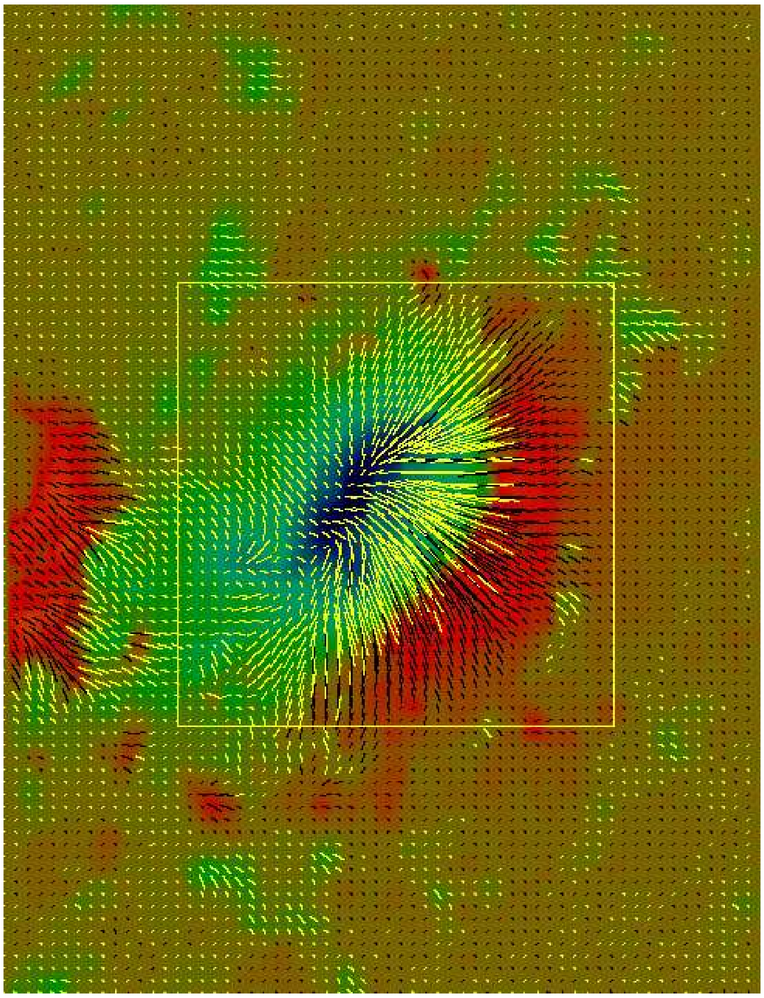

Fig. 9. Vector magnetic map derived from MSDP data (Ca line) and modified UNNOFIT inversion (see the text). Same caption as Fig.5.

fact that the observed lines are different, both maps are similar in the common field of view. Scatter plots are presented in Figs. 3, 4 and 7 in this field. The full line shows the average values of ordinates (MSDP data) versus abscissae (MTR data). Line-of-sight (LOS) magnetic fields (Fig. 3) are well correlated, except for high magnetic field values in spot centre. Average values of azimuth angles (Fig. 4) are also in rather good agreement even if ambiguities between +/- 90 degrees disturb the plot at both edges.

The main difficulty seems to arise from the transverse field (Fig. 7) below 1000 G. The average curve of the Ca line (MSDP data) exhibits too low values compared to the Fe line (MTR data). In some points, the transverse field is even put to zero in the Ca line. This is also visible in the maps. In particular, some magnetic structures surrounding the spot in Fig. 6 are missing in Fig. 5.

4. Sensitivity of MSDP data

To be sure that low field values are yet present in MSDP data, we use a very crude modification of the UNNOFIT code. Assuming that Stokes parameters Q and U are roughly proportional to the square of the transverse field in the case of weak fields, we multply by 4 the Q- and U-profiles entering the UNNOFIT code at all points where the transverse magnetic field is smaller than 500 G. Then, we divide the resulting transverse-field values by 2.

Figure 8 shows the new scatter plot. The average curve is quite good between 500 and 100 G. Below 500 G, a reverse situation can be seen between both lines.

The new MSDP map of the Ca line (Fig. 9) is also much more similar to the MTR map of the Fe line (Fig. 6), as far as the solar structures around the spot are concerned.

Let us repeat that this crude modification of the UNNOFIT inversion was only used to check the sensitivity of data. Further developments will be needed in the future to get reliable results.

5. Conclusion

In addition to the usual standard mode of THEMIS/MSDP which provides fast maps of the LOS magnetic field across the photosphere and the chromosphere, with a rate of 1 arcmin square per 1 minute of time (Na D_1 line + H_α line), a new standard mode is now available. Fast vector magnetic maps can be observed in the 610.3 Ca line with the rate of 1 arcmin square per 2 minutes of time. However, further developments will be needed in the future to get a correct inversion in all the pixels of the Ca I 610.27 map.

References

Landolfi, M., Landi Degl'Innocenti, E., and Arena, P. 1984, Solar Physics, 93,269.

Mein P. 2002, A&A 381,271.