



# The granular magnetic field as observed with THEMIS

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**Abstract.** The search for correlation along the slit in THEMIS spectropolarimetric observations of a quiet region shows a positive autocorrelation of the magnetic field direction with a pixel size of 0.45 arcsec. Accordingly, the magnetic field appears as partially resolved with such a pixel size. Further spectropolarimetric observations have been performed by scanning a quiet region with THEMIS tip-tilt ON, in order to investigate a possible relationship between the granulation and the magnetic field vector which is known in each pixel of this observation (pixel size of 0.25 arcsec). As a result, we see a very clear correlation between the granulation observed in the continuum and the longitudinal velocity field observed via the Doppler effect, but the granulation and the magnetic field vector (strength and direction) appear us as uncorrelated, by looking at their respective maps. These quantities (velocity and magnetic field) have been derived from spectropolarimetric observations of the Fe I 6302.5 line, to which UNNOFIT inversion has been applied to derive the magnetic field vector.

**Key words.** Sun: granulation – Sun: magnetic fields

## 1. The solar magnetic field: network versus internetwork

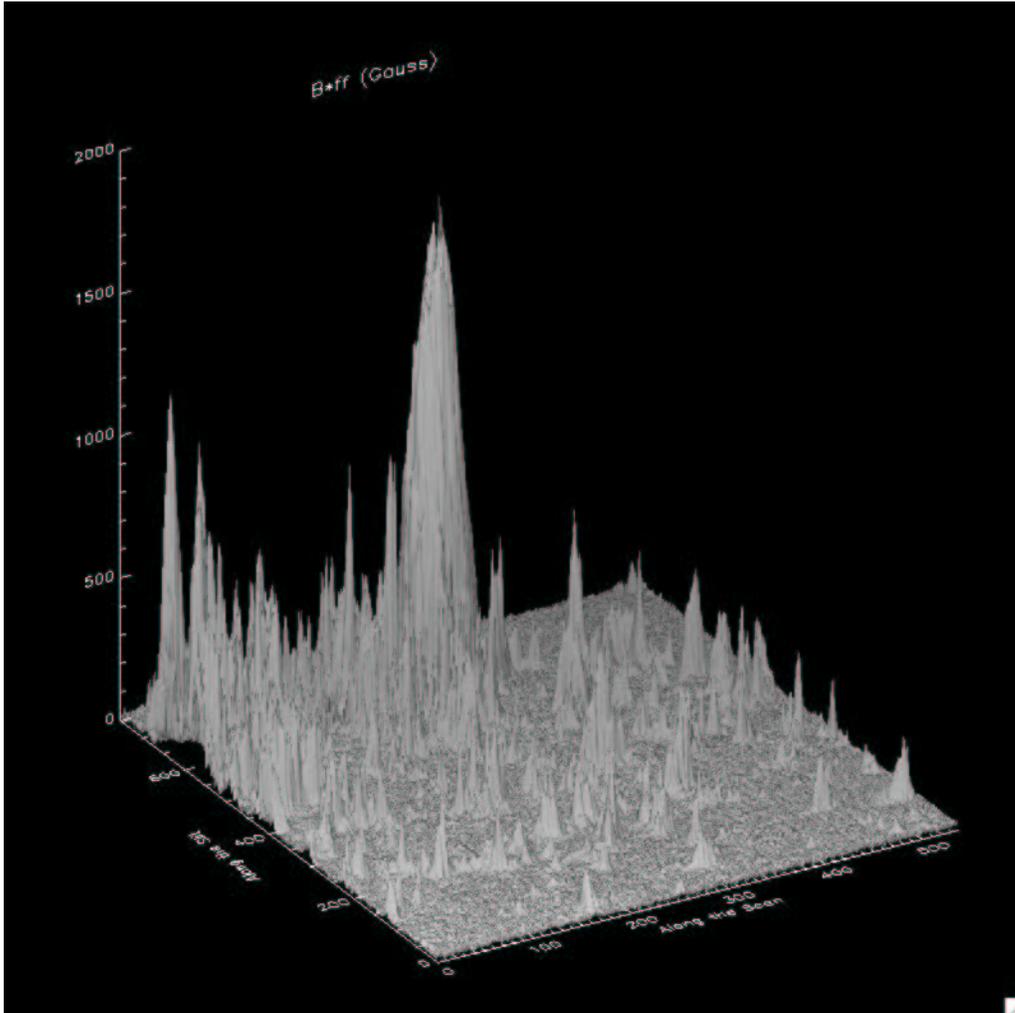
Recently, an inversion code entitled UNNOFIT has been tested and applied to spectropolarimetric data obtained with THEMIS in both lines Fe I 6302.5 and 6301.5 (Bommier et al. 2007). The UNNOFIT inversion code (Landolfi et al. 1984) is based on the Marquardt algorithm to reach the minimum theory/observation discrepancy with the theo-

retical profiles given by the Unno-Rachkowsky solution, which provides the Stokes profiles emerging from a Milne-Eddington atmosphere embedded in a homogeneous magnetic field. It has been complemented by Bommier et al. (2007) to add the magnetic filling factor  $\alpha$  determination, but finally the local average magnetic field  $\alpha B$  can only be determined with one line.

The observations treated in that paper concern the active region NOAA 517 and a quiet neighboring region. The methods applied for

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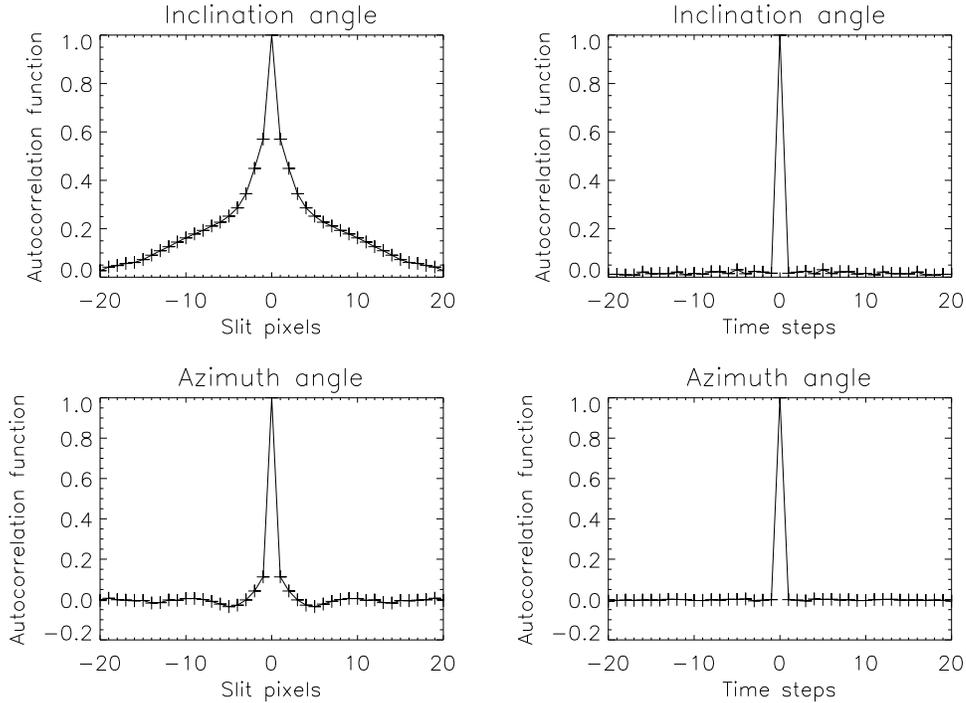


**Fig. 1.** Variation of the local average magnetic field strength along the scan and along the slit. The scan contains a sunspot (NOAA 517 observed on 7 december 2003). This figure makes appear the internetwork as a sort of 20 Gauss ground on which the network emerges. The magnetic field was obtained by UNNOFIT inversion of Fe I 6302.5 spectropolarimetric observations (from Bommier et al. (2007)).

line straightening and flat field correction are the ones described in Bommier & Rayrole (2002). In particular, the method of line position measurement, which is at the basis of this treatment, is described in this reference. The polarimetric analysis was done as described in Bommier & Molodij (2002), except for the ‘generalized beam exchange’, which had become unnecessary with the new polarization analyzer now free to take any position needed.

The usual beam exchange was then done sequentially in each Stokes parameter,  $Q$ ,  $U$ , and  $V$ .

As a result, two kinds of magnetic field were obtained: a) the network field, which is stronger (hundreds of Gauss) and nearly vertical, located on the frontiers of supergranules and in the active region; b) the internetwork field, which is of the order of 20 Gauss and is turbulent in direction with a horizontal trend.



**Fig. 2.** Fixed slit observation of a quiet region at disk center (300 images with time step 4.6 s). Autocorrelation of the field inclination (first row) and field azimuth (second row), along the slit (left column) and along the time (right column). The magnetic field was obtained by UNNOFIT inversion of Fe I 6302.5 spectropolarimetric observations.

The solar nature of this turbulence was inferred from the coherence observed between the field directions derived from the two lines Fe I 6302.5 and 6301.5 that were recorded on different camera pixels. Fig. 1 makes appear the network field as emerging from the ‘carpet’ of weak turbulent internetwork field.

The fact that the turbulence of the field direction was observed is in itself a sign that the field direction was partially resolved. The pixel size was 0.45 arcsec. If the coherence length of the field direction was much smaller than the resolution element, the average transverse field would be zero, and the observed one was not zero. This trend of a partial resolution of the transverse field with a pixel size of 0.45 arcsec was confirmed by a further observation of a quiet region that is presented below (Sect. 2). This observation was performed by accumul-

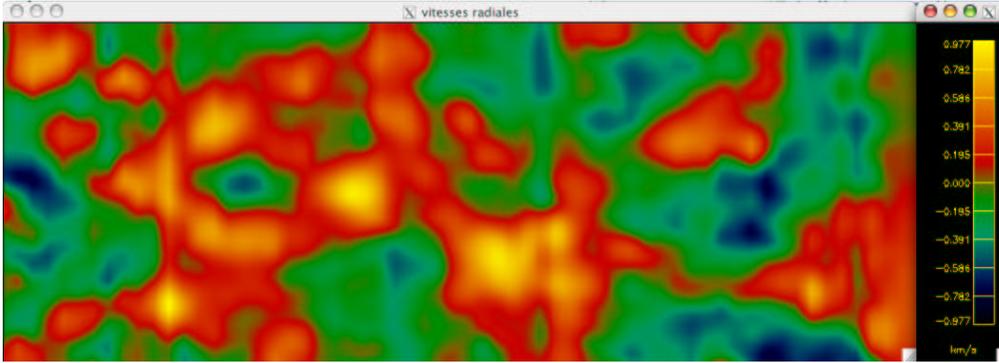
ing 300 images keeping the slit fixed on the solar surface, to investigate also the temporal autocorrelation. The result of the partial resolution of the field direction with a pixel size of 0.45 arcsec has thus been confirmed. This has led us to investigate the correlation between the granulation and the magnetic field vector. This research leads to a negative result and is presented in Sect. 3.

## 2. The internetwork magnetic field: a resolved turbulent field ?

The observations were performed on 12 June 2005. The slit was kept fixed on the solar surface at the quiet disk center, and 300 images were successively recorded (with the full Stokes parameter sequence), with a 4.6 s time step. The pixel size was 0.45 arcsec. The spec-



**Fig. 3.** Scan of a quiet region at disk center performed with tip-tilt ON on 21 August 2006. Size of the scan:  $30 \times 11.5$  arcsec. Granulation observation in the continuum near Fe I 6302.5.



**Fig. 4.** Line-of-sight velocity observed in Fe I 6302.5. Positive velocities (warm colors: yellow and red) are velocities coming out of the sun. Same region as in Fig. 3.

tropolarimetric data obtained with Fe I 6302.5 were inverted with the UNNOFIT code. Fig. 2 presents the average autocorrelation along the slit (averaged on the 300 time steps) and along the time (averaged along the slit), for the field inclination and azimuth angles. The plotted autocorrelation function is

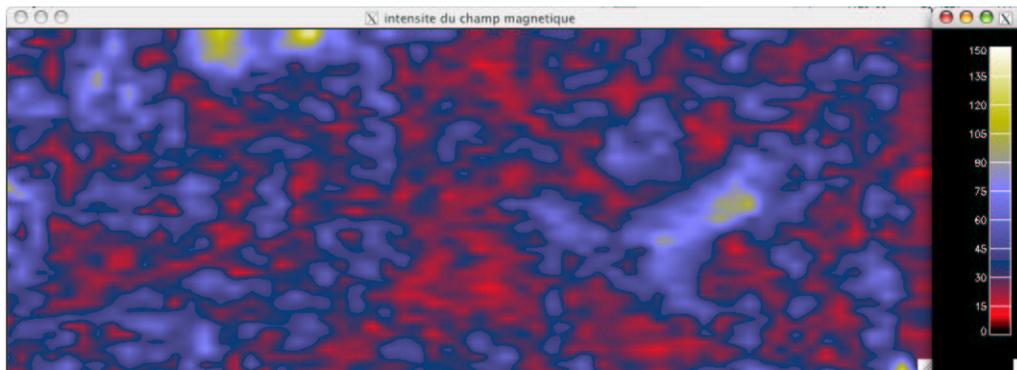
$$P_X(\pm L) = \frac{\sum_{k=0}^{N-L-1} (x_k - \bar{x})(x_{k+L} - \bar{x})}{\sum_{k=0}^{N-1} (x_k - \bar{x})^2}, \quad (1)$$

where  $L$  is the distance in pixels or time steps where the correlation is searched for. For  $L = 0$  the obtained value is obviously 1.

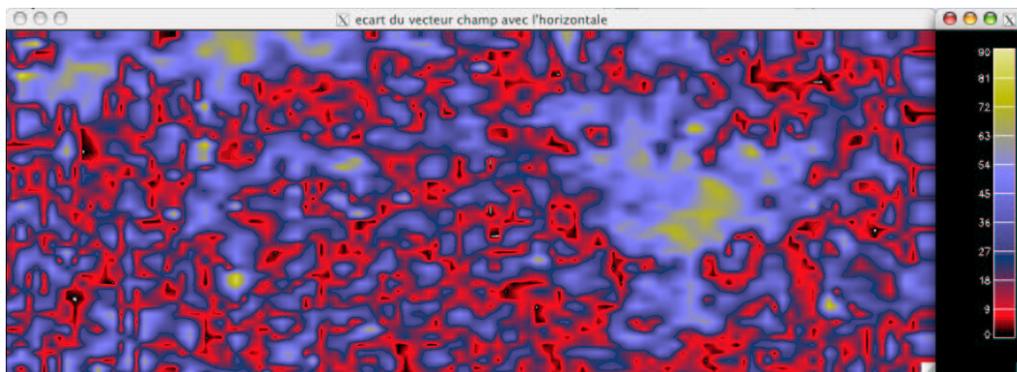
As a result, a non-zero autocorrelation is observed along the slit. The shape of the wings

of the autocorrelation function of the inclination angle may be due to the fact that a more or less horizontal field has been observed in the internetwork. Such wings could be the result of this general trend. Owing to this, the results may be considered as more convincing in the azimuth where a non-zero autocorrelation function is also obtained. The halfwidth of the peak (in both field inclination and azimuth) being about half a pixel, the autocorrelation length can be evaluated to be half a pixel long. As the pixel size is 0.45 arcsec, the obtained correlation length is about 160 km.

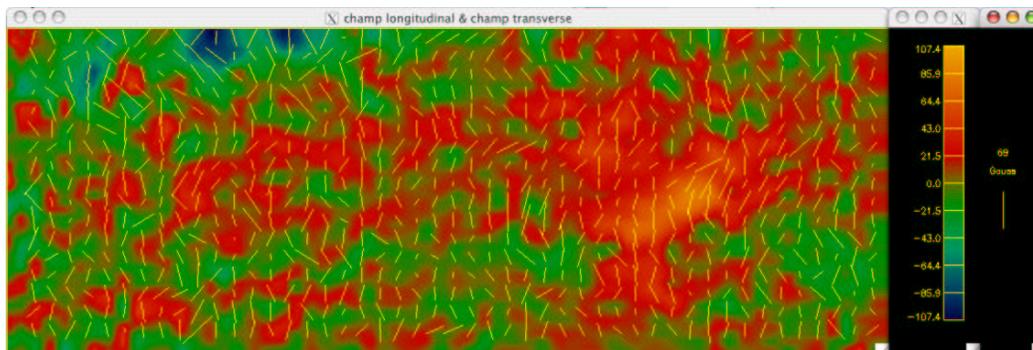
Surprisingly, no autocorrelation is obtained along the time, as if the correlation time was much smaller than the time step of 4.6 s. This



**Fig. 5.** Magnetic field local average magnetic field strength observed in Fe I 6302.5. Same region as in Fig. 3. The magnetic field was obtained by UNNOFIT inversion of Fe I 6302.5 spectropolarimetric observations.



**Fig. 6.** Magnetic field inclination (departure from the horizontal plane) observed in Fe I 6302.5. Same region as in Fig. 3. The magnetic field was obtained by UNNOFIT inversion of Fe I 6302.5 spectropolarimetric observations.



**Fig. 7.** Magnetic field vector observed in Fe I 6302.5. The longitudinal field is in color: warm colors (yellow, red) for field going out of the Sun, cold colors (blue, green) for field entering the Sun. The transverse field is drawn with dashes without arrow, because the  $180^\circ$  ambiguity is not solved. Same region as in Fig. 3. The magnetic field was obtained by UNNOFIT inversion of Fe I 6302.5 spectropolarimetric observations.

surprising result has to be further investigated to be understood.

### 3. Search for a correlation between the granulation and the magnetic field vector

The observations were obtained on 21 August 2006, by scanning the quiet disk center, the THEMIS tip-tilt being ON. The observations were performed in the MTR-grid mode, where the two polarization states to be subtracted for the polarization analysis are interleaved along the bars of a grid. The map presented here corresponds to one bar of the grid and is  $30 \times 11.5$  arcsec wide. The pixel size along the slit was 0.25 arcsec, and the scan step was 0.5 arcsec. The anamorphosis was corrected by a linear interpolation in the scan direction. The magnetic field map presented here is the result of the UNNOFIT inversion of spectropolarimetric data obtained in the Fe I 6302.5 line. For plotting the maps of Figs. 3-7, the IDL REBIN function has been moreover applied with a magnifying factor of 8, which means that each original pixel of the map (after anamorphosis correction) has become  $8 \times 8 = 64$  pixels of the plotted map.

Fig. 3 presents the granulation as observed in the continuum near the Fe I 6302.5 line. This is a continuum intensity map.

Fig. 4 is the map of the longitudinal velocity field as derived from the Doppler effect measured in the Fe I 6302.5 line. The correlation between the granulation and the longitudinal velocity field is expectable and appears clearly by comparison by eye of the figures.

Figs. 5-7 display the magnetic field vector. The comparison by eye of these maps with the granulation map of Fig. 3 does not reveal any correlation. No visible correlation between the magnetic field vector and the granulation can be derived from these figures. Our search for a correlation between the magnetic field vector and the granulation leads to a negative result.

Moreover, the spatial structuration of the turbulent magnetic field seems to have a characteristic length much smaller than the characteristic length of the granules (it has to be recalled here that we previously found an autocorrelation length of about 160 km). At this stage, it has not to be forgotten that a magnifying factor of 8 in each spatial dimension has been applied to plot the maps, after the anamorphosis correction. The spatial structuration of the magnetic field that appears in the maps may be the result of the REBIN magnifying function, so that the real structure may even be smaller.

In the magnetic field map, two network points appear, having a vertical stronger field. One is twofold and is located on the upper left edge. It is of negative polarity (see Fig. 7). The other is located in the middle right of the map, and is of positive polarity. The fact that at these points the field is stronger appears clearly in Fig. 5. The fact that at these points the field is nearly vertical appears clearly in Fig. 6. Elsewhere, one has the turbulent and weaker internetwork field. It is generally expected that the field would be stronger in the intergranule. One can also expect a field diverging from the center of the granule towards the intergranule, leading to a more vertical field in the granule center and a more horizontal field in the intergranule. A close inspection by eye of our figures does not confirm at all these expectations.

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