Temporal evolution of magnetic elements

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Abstract. We study the structure and evolution of the magnetic field of the quiet Sun by investigating weak spectro-polarimetric signals. To this end, we observed a quiet region close to the disk center with the German VTT in Tenerife, July 07, 2006. We recorded 38 scans of the same area. Each scan was eight arcsec wide and observed within about 100 seconds. We used POLIS to simultaneously observe Stokes profiles of the neutral iron lines at 630.15 and 630.25 nm, the Stokes-I profile of the Ca\textsuperscript{ii} H line at 396.8 nm, and a continuum speckle channel at 500 nm. We witness two examples of magnetic flux cancellation of small-scale opposite-polarity patches, followed by an enhanced chromospheric emission. In each case, the two opposite-polarity patches gradually became smaller and, within a few minutes, the smaller one completely disappeared. The larger patch also diminished significantly. We provide evidence for a cancellation scenario in the photosphere which leaves minor traces at the chromospheric level.

1. Introduction

Observations indicate that most of the magnetic flux passing through the photosphere is concentrated in magnetic elements, i.e., patches of high field strength that are embedded in relatively field-free plasma (Solanki 1993). The field lines of the magnetic elements are nearly vertical to the surface because of buoyancy forces. In the hierarchy of the magnetic structures, the magnetic elements take the position between dark and bright structures, i.e., between pores and network bright points (Zwaan 1987, Stenflo 1994). While the magnetic elements are not visible in continuum or line wing, they appear bright in the core of the chromospheric Ca\textsuperscript{ii} H and K lines. The convective motion associated with the photospheric granulation sweeps the magnetic flux toward the intergranular lanes. Due to the geometry of these lanes, the magnetic flux is arranged there either in chains of individual flux tubes or elongated sheets. This behavior is seen in high-resolution observations (Berger et al.2004; Rouppe van der Voort et al. 2005) as well as in numerical simulations (Steiner 2005, Vögler et al. 2005).

Magnetic flux cancellations are common events in the solar atmosphere. There are examples in which it leads to a clear enhancement in the chromospheric intensity (Bellot Rubio & Beck 2005; Beck, Bellot Rubio & Nagata 2005). Magnetic reconnection at the photospheric level was also studied by Litvinenko (1999) and Takeuchi & Shibata (2001). Rezaei et al. (2007b) presented Stokes-V profiles of the Fe 1630 nm line pair, where the two lines show opposite polarities in a single spectrum (OP profile). They suggested that it may be understood as
a magnetic reconnection event at the solar photosphere with a line of arguments similar to Steiner (2000).

In this contribution, we show the temporal evolution of physical quantities before and after this event. In addition to the polarimetric data, we investigate Ca ii H profiles which contain information about higher layers of the solar atmosphere.

2. Observations and data reduction

A time-series of a small quiet Sun region close to disk center \((\cos \theta = 0.99)\), was observed with the VTT in Tenerife, July 07, 2006. The seeing was good and stable during the observation. The Kiepenheuer Adaptive Optics System was used for maximum spatial resolution and image stability (von der Lühe et al. 2003). For 64 minutes, we scanned an area eight arcsec wide with a scanning cadence of about 97 s. The scanning step size and spatial sampling along the slit were 0.5 and 0.3 arcsec, respectively. The spectrograph slit was 0.48 arcsec wide. The slit height of the blue (396.8 nm) and red (630 nm) channels was 70 and 95 arcsec, respectively.

Full Stokes profiles of the Fe I 630 nm line pair and the Stokes-I profile of the Ca ii H line were observed strictly simultaneously with the red and blue channel of POLarimetric Littrow Spectrograph (POLIS, Schmidt et al. 2003, Beck et al. 2005b). The spectral sampling of 1.92 pm for the blue channel and 1.49 pm for the red channel leads to a velocity dispersion of 1.45 and 0.7 km s\(^{-1}\) per pixel, respectively. The spectrograph curvature was corrected using the routine described in Rezaei et al. (2006). The spectro-polarimetric data of the red channel were corrected for instrumental effects and telescope polarization with the procedures described by Beck et al. (2005a,b). The rms noise level of the Stokes parameters in the continuum was \(\sigma = 6.0 \times 10^{-4} I_c\). We normalized the Ca ii H intensity profiles at the line wing at 396.490 nm to the FTS profile (Stenflo et al. 1984). Following Cram & Damé (1983) and Lites et al. (1993), we define a set of parameters to quantify properties of the Ca ii H line profiles (Table 1).

The normalization procedure of the calcium line profiles is very similar to that described by Rezaei et al. (2007a).

| quantity          | definition                      |
|-------------------|---------------------------------|
| H-index           | 396.849 ± 0.050                 |
| H\(_{2v}\)        | 396.833 ± 0.008                 |
| H\(_{2r}\)        | 396.865 ± 0.008                 |
| V/R               | \(H_{2v}/H_{2r}\)              |
| W1 (outer wing)   | 396.632 ± 0.005                 |
| W2 (middle wing)  | 396.713 ± 0.010                 |
| W3 (inner wing)   | 396.774 ± 0.010                 |

Simultaneously to observations of spectral lines, a continuum speckle channel in POLIS recorded a larger field of view at 500 nm. The speckle reconstruc-
Temporal evolution of magnetic elements

The temporal evolution of magnetic elements was performed using the Kiepenheuer-Institut Speckle Imaging Package (Mikurda & von der Lühe 2006, Wöger 2006). The spatial resolution of the reconstructed image is about 0.3 arcsec (Figs. 1 and 2, column b). We used the POLIS intensity map (Figs. 1 and 2, column c) and the reconstructed image (column b) to align the data.

We used the procedure explained in the Appendix of Beck et al. (2007a) to remove effect of the differential refraction between the red and blue beams of POLIS. There is a time lag between co-spatial data in the two channels; the polarimetric data was actually recorded 10 seconds later than the calcium data for the case shown in Fig. 1. Figures 1 and 2 show two examples of flux cancellation event: one with and one without significant chromospheric brightening. This can be seen by comparing the maps (4 − i) in Fig. 1 and (3 − i) in Fig. 2.

We use the signed integral of the Stokes-V profile, $V_{tot}$, which traces the magnetic flux (Lites et al. 1999; Rezaei et al. 2007b). It enables us to follow weak polarimetric signals where the Stokes-V amplitude is below the 3σ noise level. The column a of Figs. 1 and 2 shows the variation of $V_{tot}$ for seven time steps around the reconnection frame (row 4). The cancellation starts as the smaller (white in Fig. 1) patch concentrates and lasts until it has almost disappeared.
The V/R is a measure of the asymmetry between the violet and red emission peaks in the calcium profile. Signatures of bright and dark structures in V/R maps (column j) can be directly compared with H$_{2v}$ and H$_{2r}$ maps (columns g and h, respectively). The wing intensities show the gradual variation of the intensity, in-between the Stokes-I and the calcium core parameters. The photospheric velocity, column k, shows the patterns of up- and downflow structures corresponding to granules and intergranular lanes (e.g., compare the upper left corner of (3 - b) and (3 - k)).

Figure 2. Same as Fig. 1 but for another example of flux cancellation in our data. In this case, there is a significant enhancement in the chromospheric emission (H-index, H$_{2v}$, and H$_{2r}$), far stronger than the case in Fig. 1.

3. Discussion

Similarities: The negative polarity patch in Fig. 1 (column a) was a network patch, which was present during the whole observing run. In contrast, the positive patch gathered from diffuse flux, enhanced, and almost disappeared (the positive patch corresponds to the white color in Fig. 1, Rezaei et al. 2007b). Since the magnetic flux is continuously replaced in the network, events like this may be common in the solar photosphere (Schrijver et al. 1997). The strong positive patch in Fig. 2 (column a) was not a network component. However, it was much stronger than the negative one and persisted for the whole observing run. Although, the larger patches in both cases survived the cancellation event, they weakened clearly. In both cases, the cancellation event happened in an intergranular vertex (see panel (4 - b) in Figs. 1 and 2). Therefore, these two events have comparable configurations at the photospheric level.
Differences: Comparison of the two flux cancellation events presented in the previous sections demonstrates essential differences in the chromospheric reaction. In the first case, we have mild chromospheric brightening in the cancellation site, e.g., row (4) in Fig. 1. In contrast, rows (3-5) of Fig. 2 show a brightening in the H-index on the cancellation site. Note that the colorbar has similar scales for the H-index. In the latter case, we observe stronger violet emission than red one, either by investigating columns $g$ and $h$ or by inspecting the asymmetry parameter, V/R in column $j$. In contrast, we have a stronger red emission peak in the first case (map (4 $-$ $j$) in Fig. 1). Figure 3 shows the evolution of calcium profiles on and near the cancellation site. During the cancellation, the profiles display a H$_{2v}$ peak that is much stronger than H$_{2r}$. It is in contrast to the average quiet Sun profile where it was interpreted as the signature of upwards propagating acoustic waves (e.g., Beck et al. 2007b). Hence, both the integrated intensity and the asymmetry parameter indicate important differences in the reaction of the chromospheric layers to the flux cancellation.

Figure 3. Variation of emission peaks at three locations ([1,3] top, [0.5, 2.6] middle, [0.5, 2.2] bottom) in time-steps 3 (left), 4 (middle), and 5(right) for the Fig. 1 example. The gray profile is the average of a few thousand profiles. The dashed lines show a distance of $\pm 0.05$ nm from the average calcium core, indicated by a vertical dotted line.

4. Conclusions

Time-series of co-spatial and co-temporal polarimetric data of a quiet Sun region revealed a variety of connections between photospheric flux cancellations
and chromospheric enhanced emissions. We present two examples of magnetic flux cancellations with different levels of the enhanced chromospheric emission. We attribute the difference to the geometrical height at which the cancellation happened. This is in accordance with the interpretation of the opposite polarity profile as a signature of photospheric reconnection by Rezaei et al. (2007b).

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