Observations of a delta-spot during an M-class flare

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Abstract

We present a study of the physical parameters of a δ-spot within active region NOAA 11865 derived from spectro-polarimetric inversions before, during and after an M-class flare. The analysed near-infrared spectro-polarimetric measurements of high angular resolution were obtained in two spectral lines (Fe I 10783 Å and Si I 10786 Å) with the Tenerife Infrared Polarimeter (TIP II) at the Vacuum Tower Telescope in Tenerife on October 15, 2013. Acquired full Stokes spectra were inverted using the code 'Stokes Inversions based on Response functions' (SIR) which allowed us to study the morphology, the magnetic field strength and inclination, and the velocity field of the observed δ-spot. Properties of the related M-class flare were derived using EUV and UV filtergrams provided by Atmospheric Imaging Assembly (AIA) instrument on-board the Solar Dynamics Observatory satellite.

Introduction

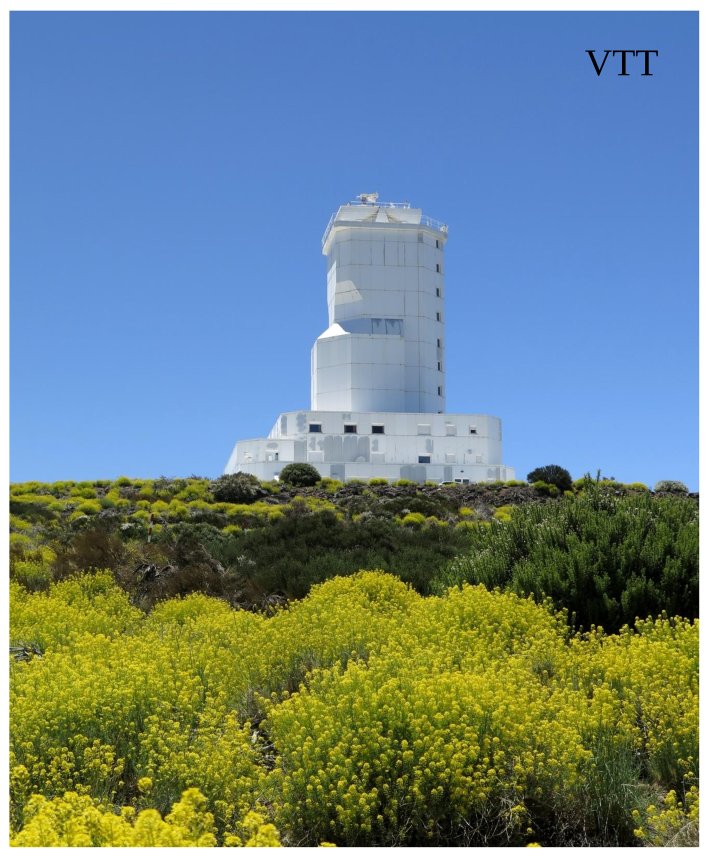
Sunspots of complex magnetic configuration harboring both magnetic polarities within one penumbra are called δ-spots. According to Zirin & Liggett (1987), they can form in three main ways: i) a single structure emerges with reverse polarity with respect to the Hale-Nicholson rules; ii) satellite dipoles emerge close to existing spots and the emerging flux region expands, converting a preceding (in the sense of solar rotation) spot into a following spot (or vice versa); and iii) a collision between two dipoles may occur so that opposite polarities are pushed together.

δ-Spots are often associated with flares. They are usually ignited when shear flows along the Polarity Inversion Line (PIL) build up magnetic shear or twist. However, there are only few observations which allow to analyze topological changes of the magnetic field within a δ-spot which are related to a flare. Moreover, existing studies show very different results. Hudson et al. (2008) showed evidences that magnetic vector changes into horizontal fields during the flare. This is supported by recent findings of Wang et al. (2012) who found significant increase of horizontal magnetic field along the PIL related to a flare activity. In contrast, Kuckein et al. (2015) reported strong decrease of the magnetic field strength (they found decrease of both, horizontal and vertical component) during the flare.

Here, we present an analysis of changes of the magnetic field topology of a δ-spot caused by a M1.8 flare. We found local areas with increased as well as places with a decreased line-of-sight component of the magnetic field. However, we discovered a significant increase in the transversal magnetic field in places connecting umbrae of opposite polarities. The detected changes in the line-of-sight and transversal components of the magnetic field led to almost constant total magnetic field strength of the δ-spot during whole observation.

Data and data reduction

- target: δ-spot in the NOAA 11865 centered at x = 220"; y = -440"
- date of observations: October 15, 2013
- instrument: TIP II (Collados et al. 2007) attached to the VTT
- type of observations: scanning
  - wavelength region: ~10780 Å (including Fe I and Si I lines)
  - timing: 8:10 – 8:33 UT → SCAN 1
    8:37 – 9:00 UT → SCAN 2
  - step size: 0.35 arcsec; number of steps: 140
  - exposure time: 250 ms for each Stokes component
    (8 exposures added up to increase S/N)
- data reduction:
  - photometric calibration (dark current, flat-field)
  - compensation for the instrumental polarization
  - removing residual cross-talk
  - compensation of the geometrical foreshortening
- context data: SDO satellite
  - HMI: line-of-sight magnetograms, continuum intensity
  - AIA: filtergrams in the 1600 Å and 171 Å channels



Results, discussion and conclusions

SDO / HMI, AIA

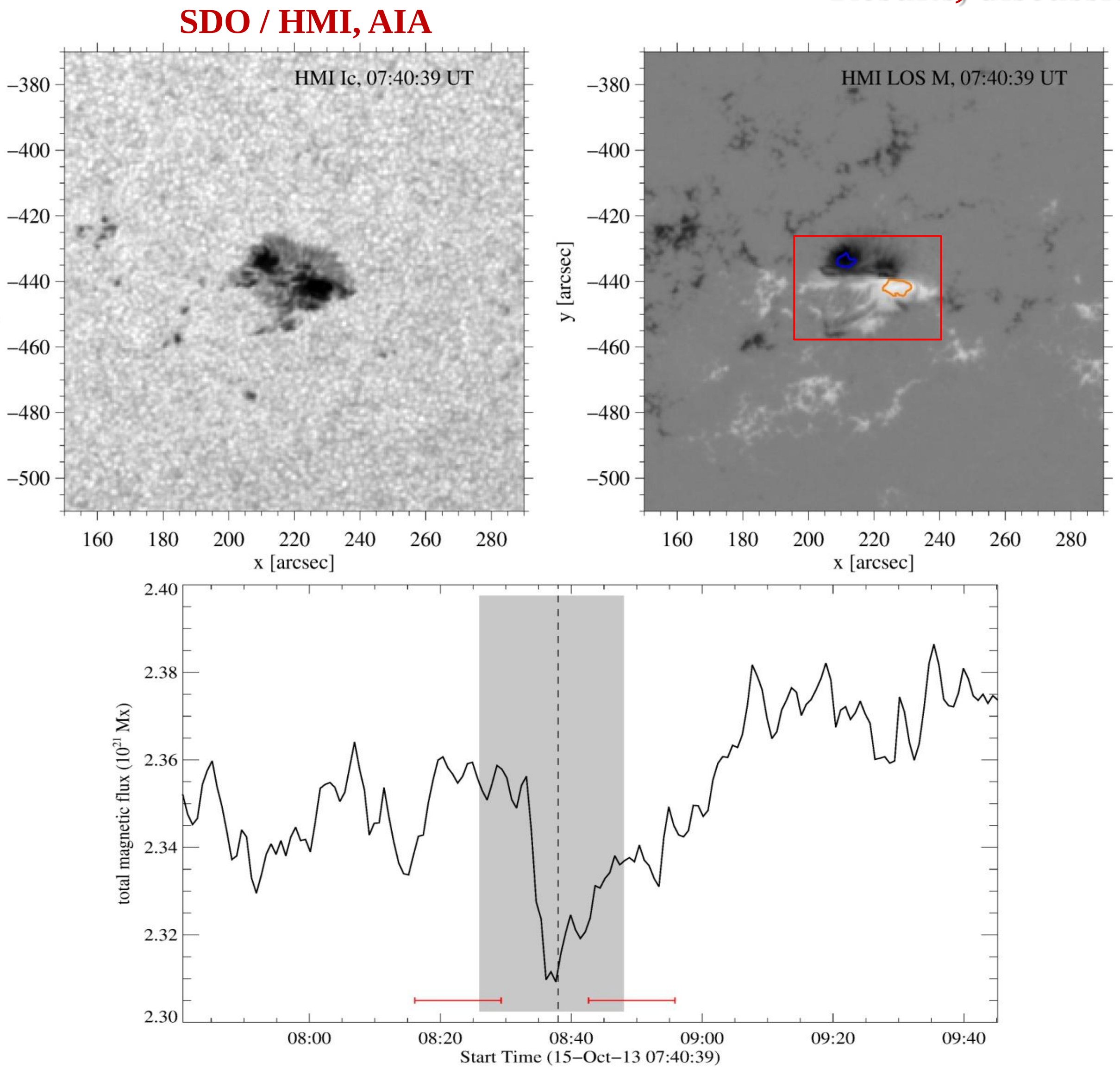


Figure 1. *Top*: Continuum intensity and line-of-sight magnetogram taken by the SDO/HMI showing part of the NOAA 11865 with the δ-spot. The blue and orange contours in the magnetogram represent the umbrae. The red rectangle marks the region used to calculate total magnetic flux. *Bottom:* Evolution of the total magnetic flux estimated using HMI magnetograms for the area covering the δ-spot. The gray region represents the temporal interval of the flare. The dashed line marks the time of the flare peak. The horizontal red lines denote time ranges when the TIP II was scanning internal parts of the δ-spot (see Figure 3).

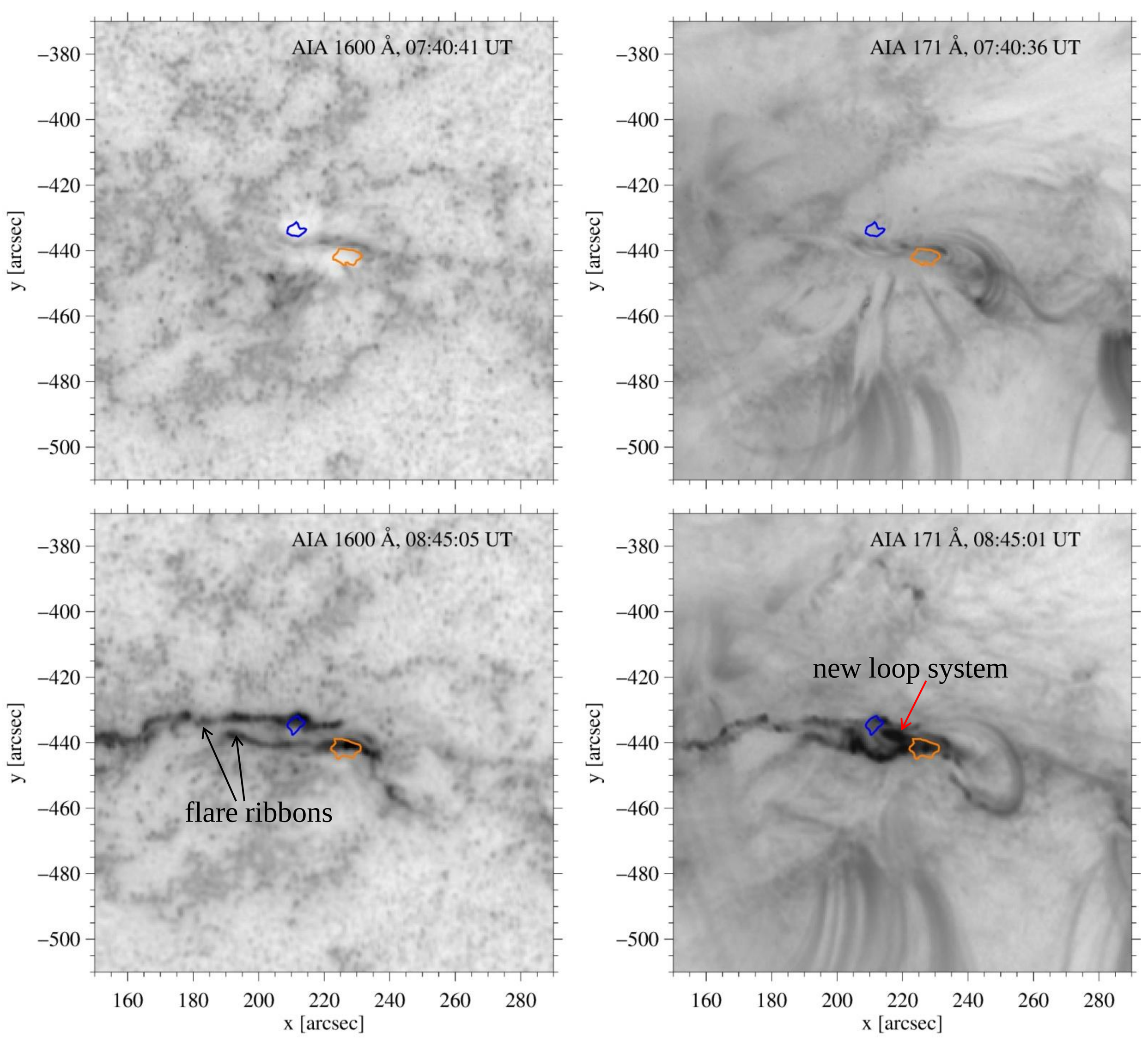


Figure 2. Filtergrams obtained by the SDO/AIA instrument in the 1600 Å *(left)* and 171 Å *(right)* channels showing the NOAA 11865 before *(top)* and during *(bottom)* the flare. The flare ribbons (highlighted by black arrows) are clearly visible during the flare. The red arrow marks the appearance of a newly formed structure of hot loops. Umbrae of the δ-spot are marked by blue and orange contours for negative and positive polarity, respectively. The filtergrams are displayed on logarithmic scale and a reversed intensity scaling is used.

- an M 1.8 flare occurred during the observations; start: 8:26 UT, peak: 8:38 UT, end: 8:48
- no obvious changes related to the flare activity found in the HMI continuum intensity and line-of-sight (LOS) magnetograms
- closer inspection of LOS magnetograms → calculation of the total magnetic flux for selected region
  - clear decrease of the total magnetic flux before the flare peak (see Figure 1) → evidence of the weakening of horizontal magnetic field
  - total magnetic flux recovers after the flare peak and reach the pre-flare (and higher) values in ~ 30 min
- the AIA 171 Å observations show a new system of hot loops which evolves during the flare and connects the umbrae within the δ-spot (see Figure 2)
  - the occurring loop system is not visible in the AIA 1600 Å observations

VTT / TIP II

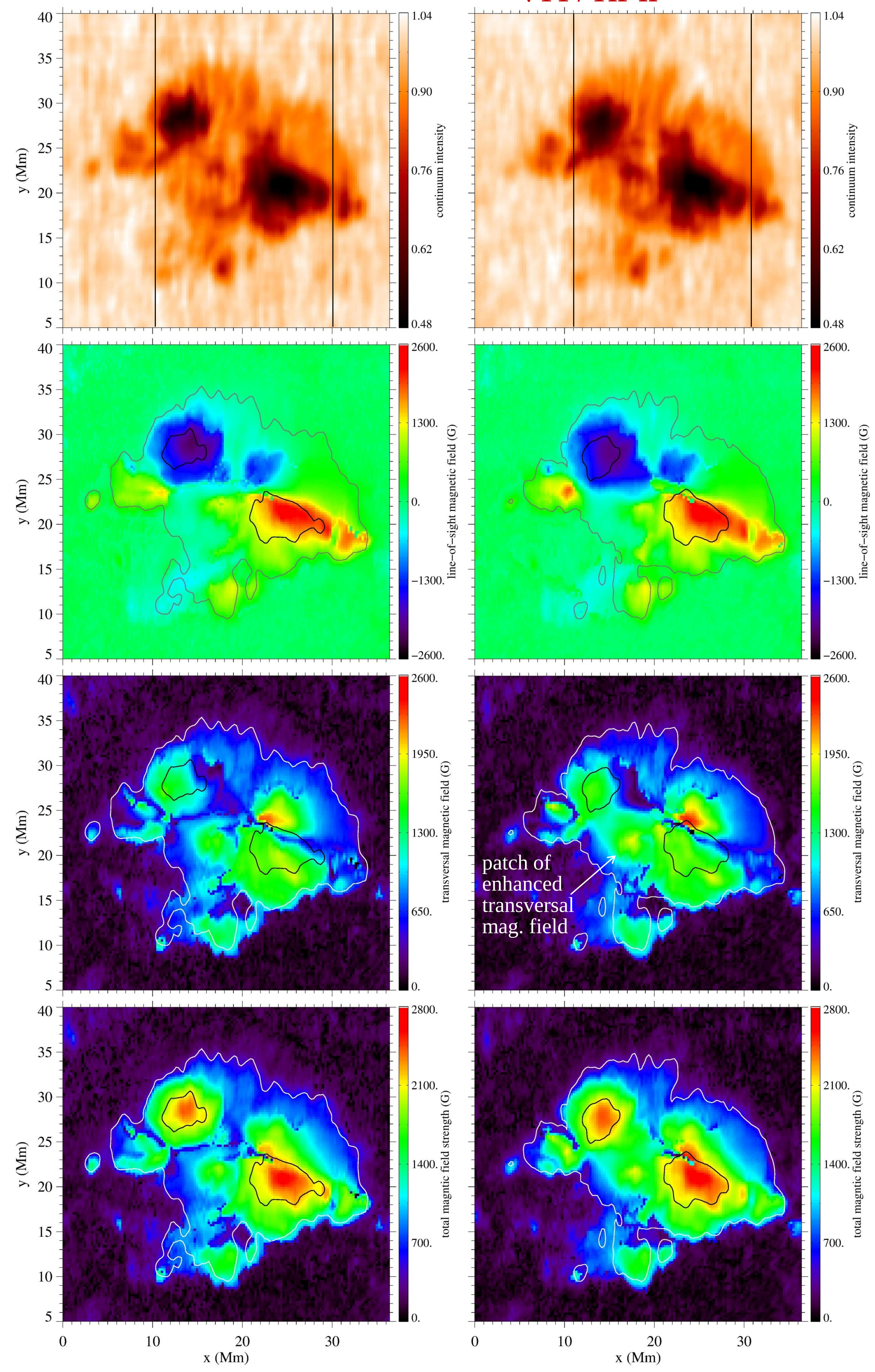


Figure 3. The TIP II observations of the δ-spot performed before *(left)* and after *(right)* the main phase of the flare. Panels in the *first* row show the continuum intensity. The line-of-sight and transversal components of the magnetic field are displayed in the *second* and *third* row, respectively. The *last* row shows panels of the total magnetic field strength. The parameters of the magnetic field were derived from the Fe I 10783 Å spectral line using the SIR code (Ruiz Cobo & del Toro Iniesta, 1992). The arrow marks a patch of enhanced transversal magnetic field. The vertical lines mark an area within the δ-spot which was scanned during the time intervals marked by the horizontal, red lines in the *bottom* plot of Figure 1.

- LOS component of magnetic field before and after the flare peak: local increases as well as decreases found
  - total magnetic flux: SCAN 1 = 3.56×10^{21} Mx; SCAN 2 = 3.54×10^{21} Mx → slight weakening of the LOS magnetic field during flare
- transversal component of the magnetic field before and after the flare peak: local decreases but patch of increased transversal field bridging the neutral line and connecting the umbrae within the δ-spot is detected → enhancement of horizontal magnetic field
- total magnetic field strength remained almost constant during the flare evolution

- both observations confirm **a weakening** of the vertical magnetic field during the flare
- polarimetric measurements taken by TIP II revealed a patch of increased transversal magnetic field which is co-spatial with the newly formed system of the hot loops visible in the AIA 171 Å → **enhanced horizontal magnetic field related to the new system of loops**
- **disputable question**
  - Fe 10783 Å spectral line → sampled atmospheric heights: 150 – 200 km (Balthasar & Gömöry, 2008)
  - AIA 171 Å filtergrams → sampling coronal temperatures ⟹ **Can it be the same structure?**

References

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Acknowledgements

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