Flare induced changes of the photospheric magnetic field in a δ-spot deduced from ground-based observations

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Abstract

We present a study of the physical parameters of a δ-spot within the 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 the Atmospheric Imaging Assembly (AIA) instrument on-board the Solar Dynamics Observatory satellite.

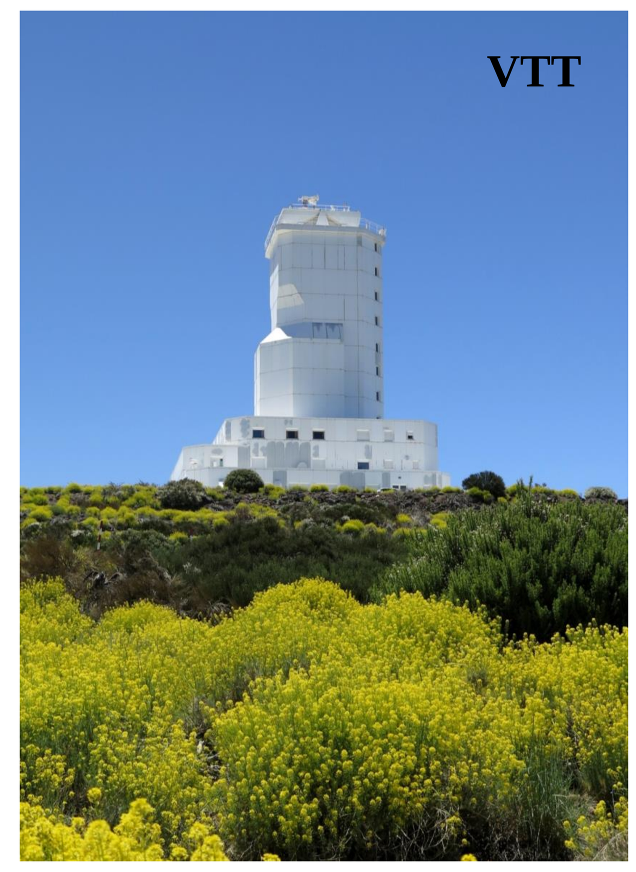
Introduction

Sunspots of complex magnetic configuration harboring both magnetic polarities within one penumbra are called δ-spots. δ-spots are often associated with flares. Flares are usually ignited when shear flows along the Polarity Inversion Line (PIL) build up magnetic shear or twist. However, there are only a few observations analyzing topological changes of the magnetic field within a δ-spot related to a flare. Moreover, existing studies show very different results. Hudson et al. (2008) showed evidences that the orientation of the magnetic vector became more horizontal during a flare. This is supported by recent findings by 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 an M-class 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.

Data and data reduction

- target: δ-spot in the NOAA 11865 (cos θ = 0.86, θ ~ 30°)
- date of observations: October 15, 2013
- instrument: TIP II/VTT (Collados et al. 2007)
- type of observations: scanning
  - spectral lines: Fe I 10783 Å and Si I 10786 Å
  - timing: 7:45 – 8:09 UT → SCAN 1
    8:10 – 8:33 UT → SCAN 2
    8:37 – 9:00 UT → SCAN 3
  - 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 the residual cross-talk



Results, discussion and conclusions

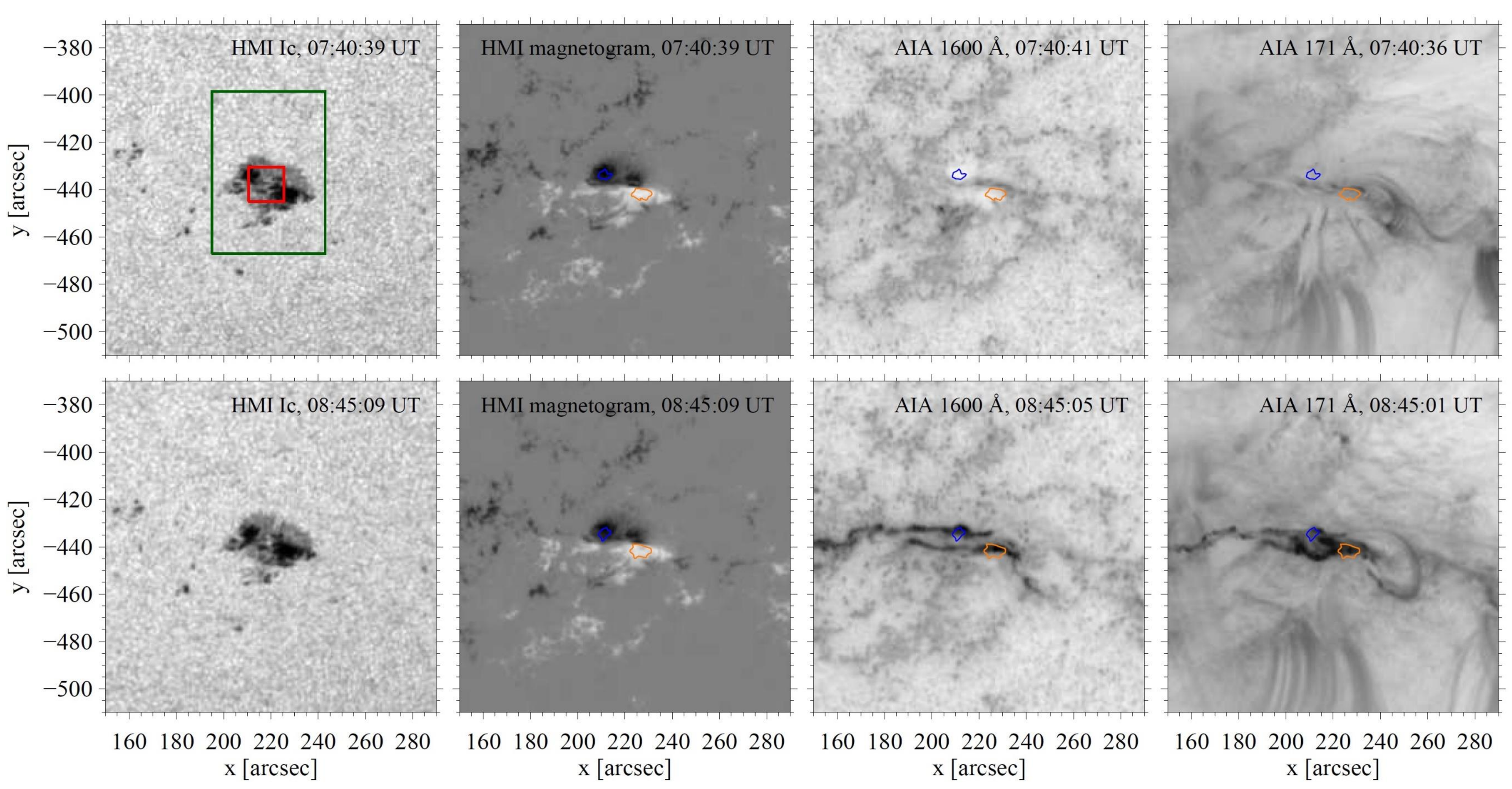


Figure 1. Overview images showing AR 11865 slightly before (top panels) and during (bottom panels) ground-based observations. The first two panels of each row show the HMI continuum intensity and line-of-sight magnetic field, respectively. The last two panels are AIA filtergrams taken in the 1600 Å and 171Å channels. They are displayed on logarithmic scale and a reversed intensity scaling is used. The times listed in the upper right corner of each panel correspond to the midpoint of the particular HMI or AIA exposure time. The overplotted blue and orange contours represent the umbrae of opposite polarity within the δ-spot. The dark green rectangle outlines the full field-of-view (FoV) of the TIP II instrument. The red square shows the area displayed in Fig. 3.

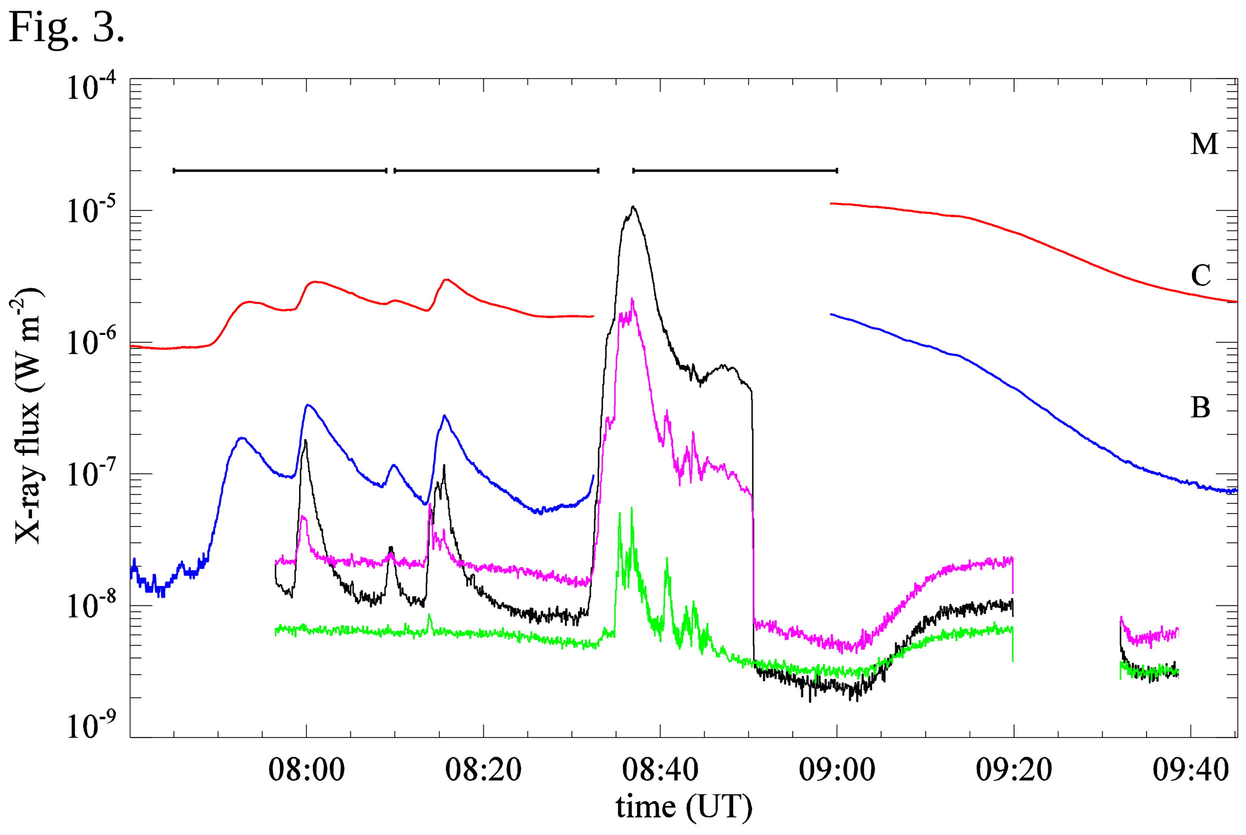


Figure 2. GOES (red, blue) and FERMI (green, black, magenta) X-ray light curves showing flaring activity in the observed region during TIP II observations. The sharp decrease visible in the FERMI data (8:50 UT) is an artifact caused by satellite entering the night. The three horizontal black lines correspond to the time of scans 1, 2, and 3 of the VTT.

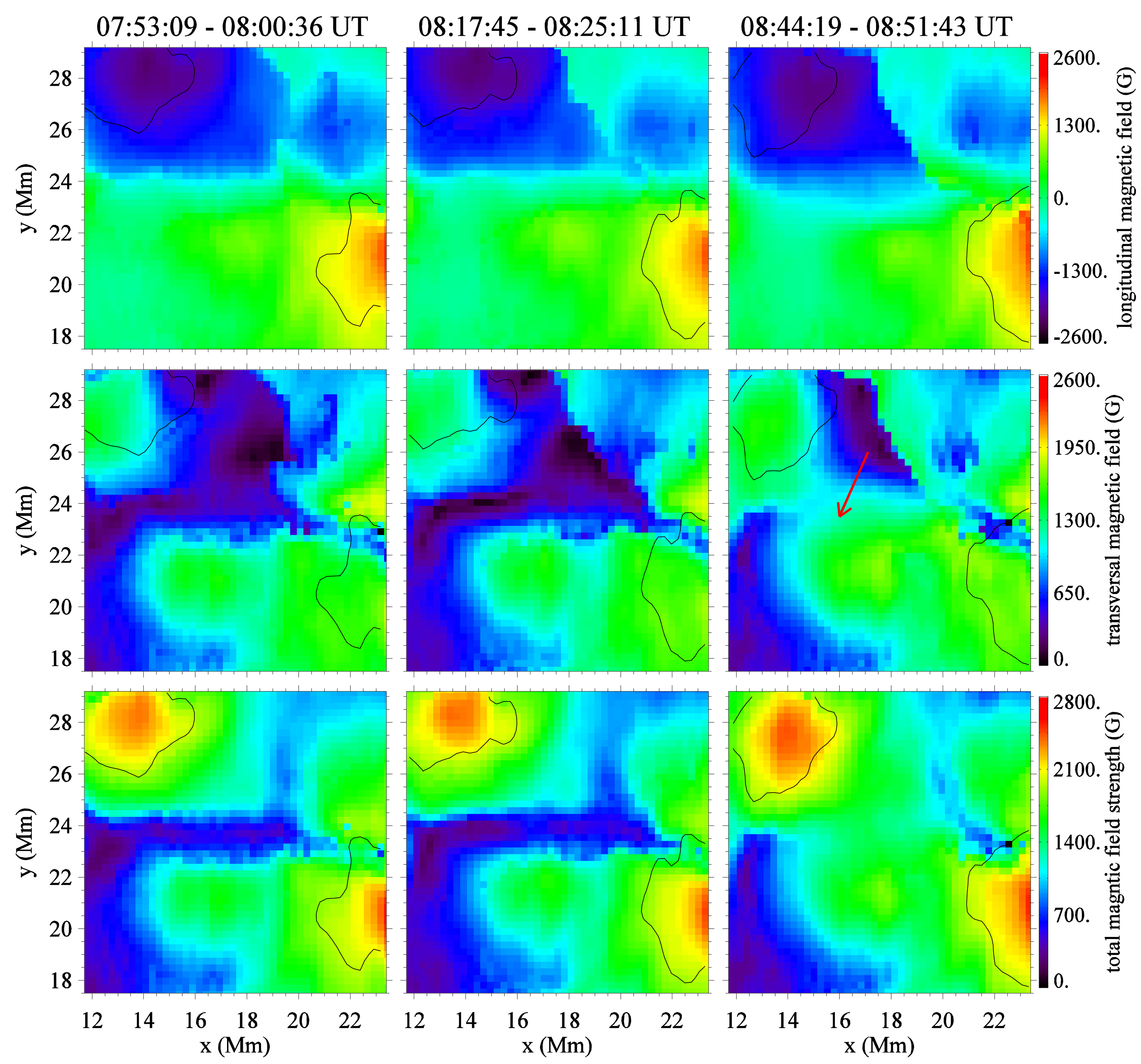


Figure 3. *From top to bottom:* cut-out corresponding to the red box in Fig. 1 of the longitudinal, transverse, and total magnetic field strength inferred from the Si I 10786 Å inversions. Scans 1 until 3 are shown from *left to right*. The red arrow marks a new enhanced patch of transversal magnetic field (detected in scan 3) which appeared as a consequence of the M-class flare. The black contours represent umbrae of the spot.

- four C- and one M-class flare (see Fig. 2) appeared in the observed area (see Fig. 1)
- C-class flares: no obvious changes in the magnetic field of the δ-spot (Fig. 3, *left and middle rows*)
- after M-class flare: **newly formed significant patch of the transverse field** (see the red arrow in Fig. 3) bridging the polarity inversion line and connecting the umbrae within the δ-spot, but only small changes visible in the longitudinal filed (Fig. 3, *right column*)
  - an increase of ~550 G detected for transverse field (δB_{TR})
  - changes of the longitudinal magnetic field do not reach more than 200 G (δB_{LOS})
- Fisher et al. (2012): changes of the radial Lorentz force given by the following formula

$$\delta F_r = \frac{1}{8\pi}\int_{A_{ph}} \left(\delta B_{LOS}^2 - \delta B_{TR}^2\right) dA \approx \frac{1}{8\pi}\left\{\langle \delta B_{LOS}\rangle^2 - \langle \delta B_{TR}\rangle^2\right\} A_{ph}$$

  where surface integral involves the photospheric domain experiencing the magnetic field changes → i.e., from its estimated area $A_{ph} \approx 5$ Mm² and the values given above (see also Fig. 3, *right column*) follows: **$\delta F_r \approx 5.3 \times 10^{20}$ dyn**
- patch of increased transversal magnetic field is co-spatial with the newly formed system of the hot coronal loops visible in the AIA 171 Å (see Fig. 1) → **can it be the same structure?**

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