Decay of a photospheric transient filament at the boundary of a pore and the chromospheric response

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Abstract

Intermediate stages between pores and sunspots are a rare phenomenon and can manifest with the formation of transient photospheric penumbral-like filaments. Although the magnetic field changes rapidly during the evolution of such filaments, they have not been shown to be connected to magnetic reconnection events yet.
We analyzed observations of a pore in NOAA AR 12739 from the Swedish Solar Telescope including spectropolarimetric data of the Fe I 6173 Å and the Ca II 8542 Å line and spectroscopic data of the Ca II K 3934 Å line. The VFISV Milne-Eddington inversion code and the multi-line Non-LTE inversion code STiC were utilized to obtain atmospheric parameters in the photosphere and the chromosphere.
Multiple filamentary structures of inclined magnetic fields are found in photospheric inclination maps at the boundary of the pore, although the pore never developed a penumbra. One of the filaments shows a clear counterpart in continuum intensity maps in addition to photospheric blueshifts. During its decay, a brightening in the blue wing of the Ca II 8542 Å line is observed. The Ca II K 3934 Å and the Ca II 8542 Å lines show complex spectral profiles in this region. Depth-dependent STiC inversion results using data from all available lines yield a temperature increase (roughly 1000 Kelvin) and bidirectional flows (magnitudes up to 8 km/s) at log tau=-3.5.
The temporal and spatial correlation of the decaying filament (observed in the photosphere) to the temperature increase and the bidirectional flows in the high photosphere/low chromosphere suggests that they are connected. We propose scenarios in which magnetic reconnection happens at the edge of a rising magnetic flux tube in the photosphere. This leads to both the decay of the filament in the photosphere and the observed temperature increase and the bidirectional flows in the high photosphere/low chromosphere.

Observational data

Date: 2019-04-19
Target: Large, stable pore (NOAA 12739)
Heliocentric angle: 41° ($\mu = 0.75$)
Telescope: Swedish Solar Telescope (SST)

Instruments:
- CRISP: Fe I 6173 Å spectral line; Ca II 8542 Å sepctral line
- CHROMIS: Ca II K 3934 Å spectral line

See see Lindner et al. 2023. for more details of the data

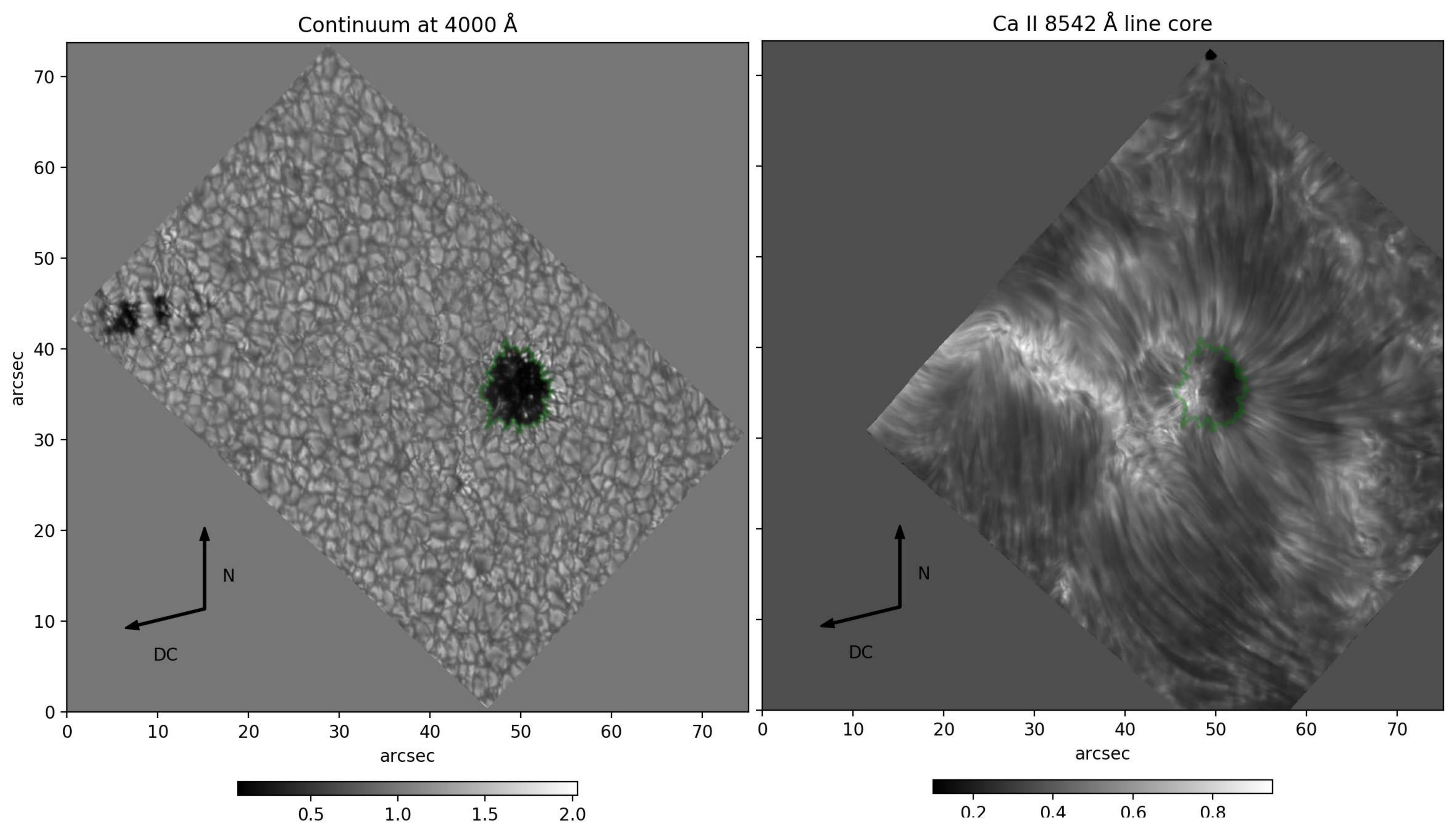

Fig. 1: Full FOV maps showing an image at the continuum wavelength point for CHROMIS at 4000 Å (left) and one image at a wavelength in the core of the Ca II 8542 Å line for CRISP (right). The time step shown here is the first one at 10:33 UT.

Analysis: Transient filaments

- Atmospheric parameters in the photosphere of all timesteps and the full field-of-view (FOV) were obtained from inversions of the Fe I 6173 Å spectral line. The computationally efficient Milne-Eddington inversion code VFISV (Borrero et al. 2011) was used.
- Transient filaments were identified as elongated features in the map showing the local-reference-frame (LRF) inclination angle of the magnetic field (see Fig. 2).
- The decaying filament F4 was accompanied by an elongated brightening in the blue wing of the Ca II 8542 Å line.
- For a temporal evolution showing the decay of filament F4, see Lindner et al. 2023.

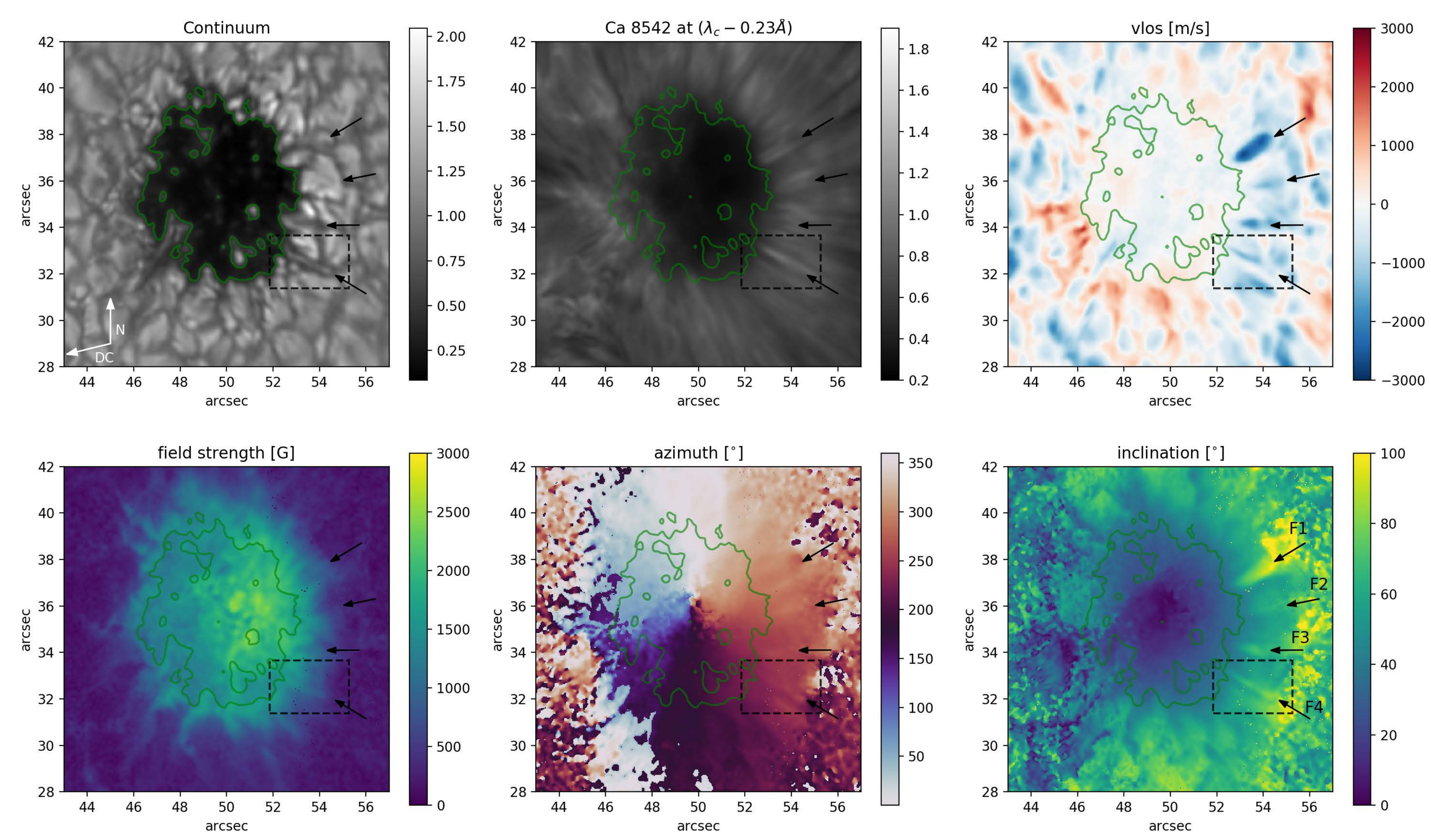

Fig. 2: Maps showing continuum (from the CHROMIS instrument at 4000 Å) on the top left, the blue-wing intensity from the Ca II 8542 Å line (from the CRISP instrument) at the center-top, and the VFISV inversion results LOS velocity (top right), magnetic field strength (bottom-left), LRF azimuth angle (bottom-center), and LRF inclination angle of the magnetic field (bottom right). The value range of the inclination map has been clipped for better visibility. Time step: $t_{obs} = 0$s.

Spectral analysis and STiC Inversions

Blue wing peak (BWP)
- The brightening in the blue wing maps of the Ca II 8542 Å line in the location of filament F4 is caused by an emission peak in the blue shoulder. (see Fig. 3, orange profile P2)
- Pixels with a BWP can be identified by the intensity difference:
$$\Delta I = I(\lambda_c - 0.23\ \text{Å}) - I(\lambda_c - 0.5\ \text{Å})$$
- Pixels with a large and positive value of ΔI are mostly present in the vicinity of the transient filaments F1, F2, F3, and F4.

STiC inversions
- The timestep with the maximum value of Ca II 8542 Å blue wing brightening close to the transient filament F4 was inverted with the STiC Code (de la Cruz Rodríguez et al. 2019, 2016)

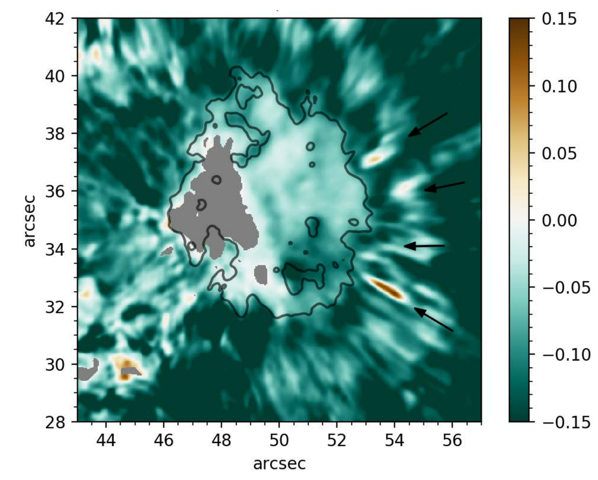

Fig. 3: Maps showing the blue-wing slope, as calculated from the intensity difference ΔI for the Ca II 8542 Å line. Pixels showing a strong line core emission are masked out in gray.

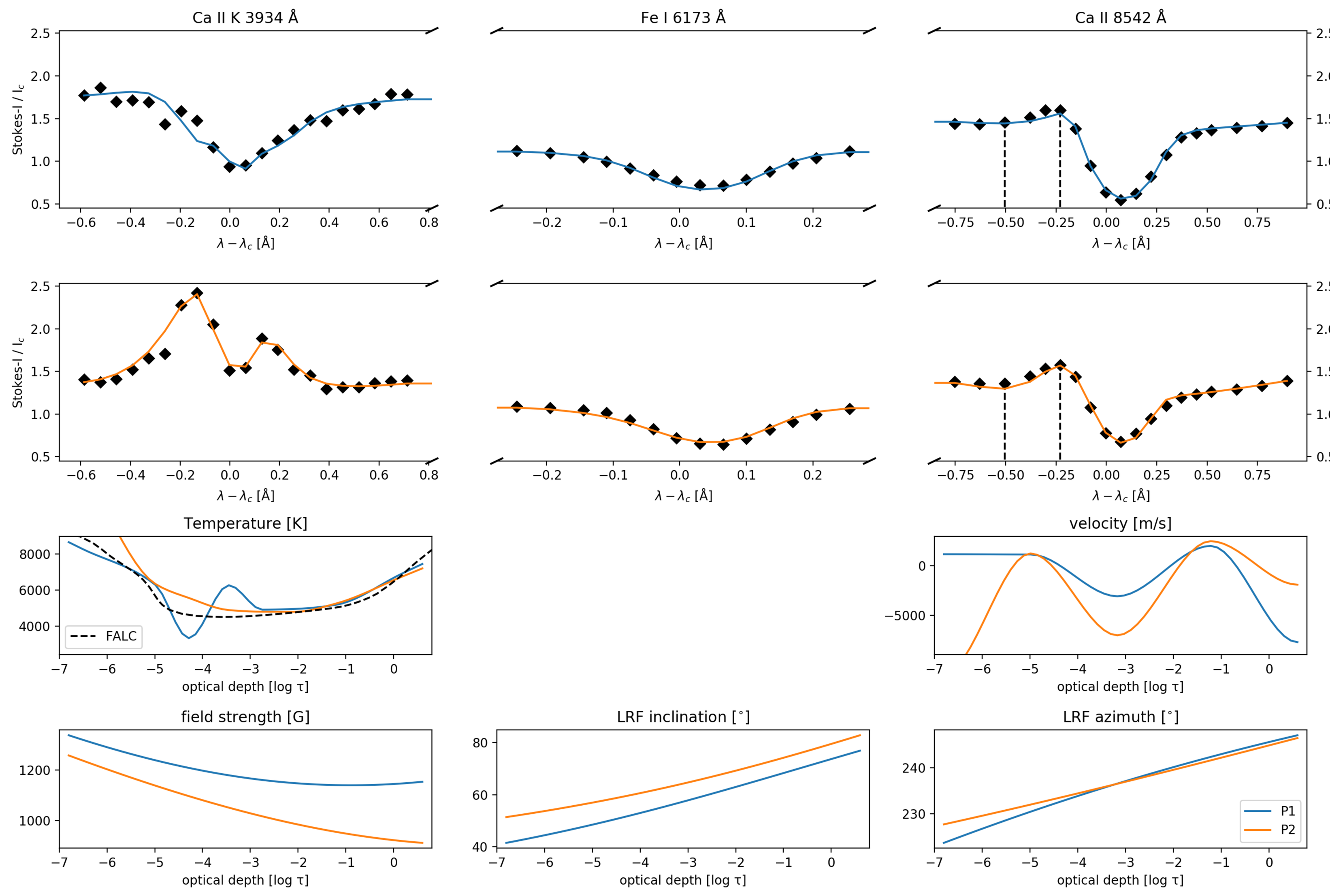

Fig. 4: Fit and corresponding depth-dependent atmospheric models from the STiC inversion for two example pixels P1 (blue solid lines) and P2 (orange solid lines). The observed wavelength points are shown as diamonds. The locations of P1 and P2 are shown in Fig. 5. Vertical black-dashed lines in the Ca ii 8542 Å line spectra depict the wavelength positions, from which the difference maps shown in Fig. 3 are calculated.

Analysis of a magnetic reconnection event

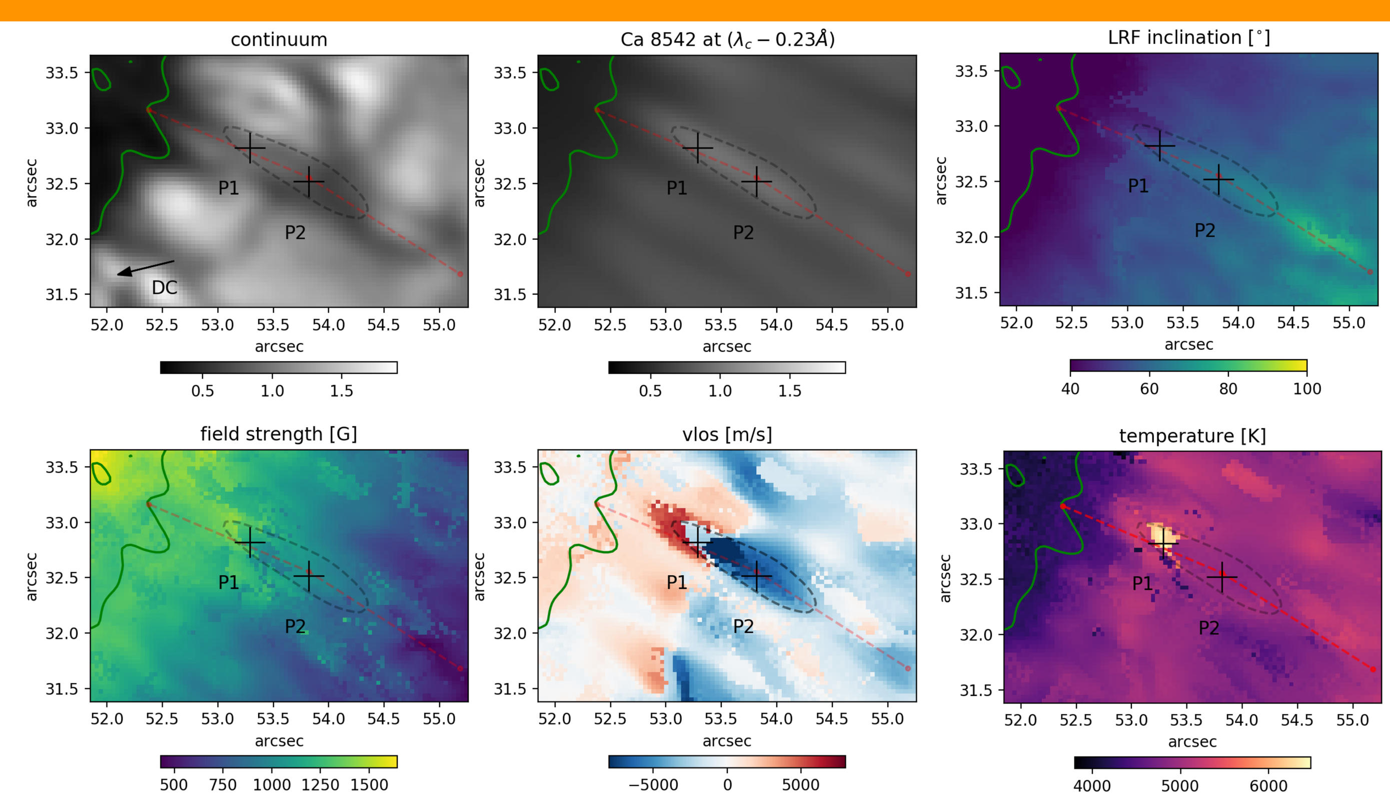

Fig. 5: Cropped Intensity images and STiC atmospheric parameters at log τ = −3.5 from the time step at 02min 55sec. Gray-dashed line represents a contour in the blue-wing slope maps (see Fig. 3) at the level of zero. The value range of the inclination map was set to [40,100]. The black arrow in the bottom-left corner of the continuum maps points toward disk center. The green contour outlining the pore was produced from the CHROMIS image at the continuum wavelength point at 4000 Å and is overplotted on the other panels.

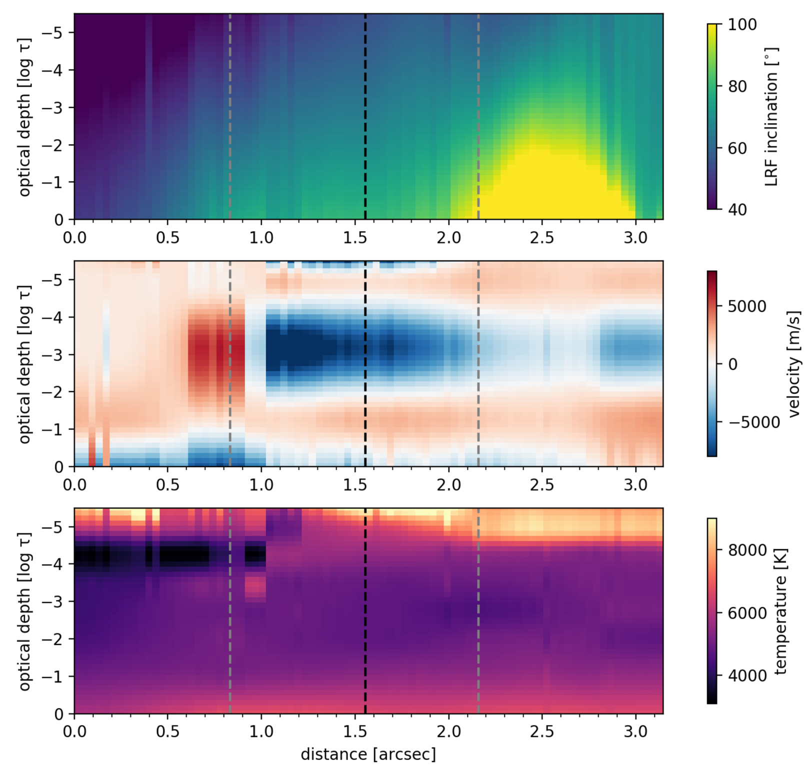

Fig. 6: Vertical cut through the STiC model atmosphere along the red-dashed line. The distance of 0 arcsec corresponds to the left end of the line (close to the pore) and the distance of 3.1 arcsec corresponds to its right end. The location of the kink in the red line (close to pixel P2) is depicted as vertical black-dashed lines. The intersections of the gray contour from Fig. 5 with the red-dashed line are depicted with gray-dashed lines. The value range of the inclination map was set to [40,100].

Summary and discussion

Signatures of magnetic reconnection
- BWP in Ca II 8542 Å line
- Bidirectional flows in the location of filament F4 (see Fig. 5)
- Confined region with temperature enhancement of ~1000 K in STiC maps at log τ = −3.5 (see Fig. 5) in beween the bidirectional up- and downflows

Proposed reconnection scenario
1) A magnetic flux tube is moving from the deep photosphere toward the high photosphere.
2) The flux tube becomes instabil because of a decrease in gas pressure.
3) Magnetic reconnection happens at the boundary surface between the flux tube and the background magnetic field of the pore.
4) Temperature increases and bidirectional flows develop similar to Yokoyama & Shibata (1995) and Díaz Baso et al. (2021).
5) See Lindner et al. 2023 for detailed mechanisms leading to the observed flow fields.

References

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