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The magnetic structure and dynamics of a decaying active region

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Abstract. We study the evolution of the decaying active region NOAA 12708, from the photosphere up to the corona using high resolution, multi-wavelength GREGOR observations taken on May 9, 2018. We utilize spectropolarimetric scans of the 10830 Å spectral range by the GREGOR Infrared Spectrograph (GRIS), spectral imaging time-series in the Na I D_2 spectral line by the GREGOR Fabry-Pérot Interferometer (GFPI) and context imaging in the Ca II H and blue continuum by the High-resolution Fast Imager (HiFI). Context imaging in the UV/EUV from the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) complements our dataset. The region under study contains one pore with a light-bridge, a few micro-pores and extended clusters of magnetic bright points. We study the magnetic structure from the photosphere up to the upper chromosphere through the spectropolarimetric observations in He II and Si I and through the magnetograms provided by the Helioseismic and Magnetic Imager (HMI). The high-resolution photospheric images reveal the complex interaction between granular-scale convective motions and a range of scales of magnetic field concentrations in unprecedented detail. The pore itself shows a strong interaction with the convective motions, which eventually leads to its decay, while, under the influence of the photospheric flow field, micro-pores appear and disappear. Compressible waves are generated, which are guided towards the upper atmosphere along the magnetic field lines of the various magnetic structures within the field-of-view. Modelling of the He I absorption profiles reveals high velocity components, mostly associated with magnetic bright points at the periphery of the active region, many of which correspond to asymmetric Si I Stokes-V profiles revealing a coupling between upper photospheric and upper chromospheric dynamics. Time-series of Na I D_2 spectral images reveal episodic high velocity components at the same locations. State-of-the-art multi-wavelength GREGOR observations allow us to track and understand the mechanisms at work during the decay phase of the active region.

Keywords. Sun: atmosphere, Sun: chromosphere, Sun: magnetic field, Sun: photosphere, Sun: oscillations

1. Overview

Active region NOAA 12708 was decaying during the observations on May 9, 2018 (Fig. 1). It contained several pores, a large one with a light-bridge at the negative polarity part, and a few smaller ones scattered in both polarities of the region. The magnetic field lines in Fig. 1 indicate the coexistence of several magnetic loops. The longer loops are

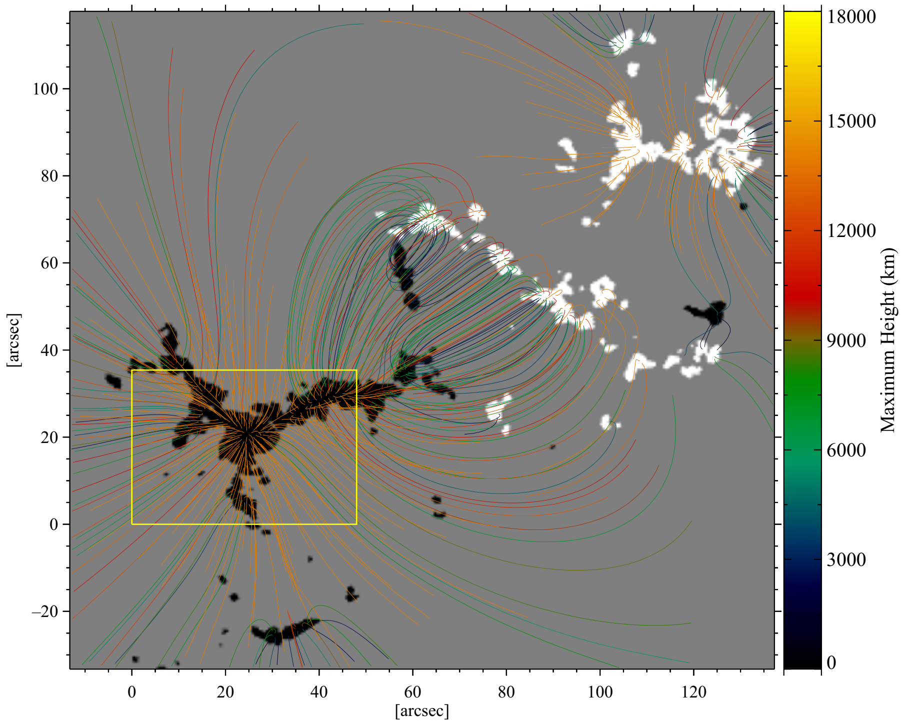

Figure 1. Active region NOAA 12708. Map of the photospheric radial component, Br, of the magnetic field provided by the HMI (Scherrer *et al.* 2012) onboard SDO (Pesnell *et al.* 2012). Overploted are the magnetic field lines which correspond to the extrapolated current-free (potential) magnetic field vector (Alissandrakis 1981). The yellow rectangle marks the region observed with GREGOR.

associated with higher emission in the hotter channels of AIA, e.g. in 171 Å (Fig. 2, bottom right). Upper chromospheric/transition region emission in He II 304 Å is more intense at regions with shorter loops, which connect the negative polarity magnetic elements with the nearby positive ones (see e.g. Kontogiannis *et al.* 2018).

The upper photosphere and lower chromosphere are observed in great detail by the GREGOR (Schmidt *et al.* (2012)) instruments (Fig. 2, top row). The broad-band filters of HiFI (Kuckein *et al.* 2017; Denker *et al.* 2018) show the granulation pattern while at the Na I D_2 flanks, sampled by GFPI (Puschmann *et al.* 2012), reversed granulation is more prominent, due to the upper photospheric/lower chromospheric origin of the line. The blue wing of this line can also be used to track bright points (BPs; Kuckein 2019). These observations reveal the impact of convective motions on the magnetic bright points, the micro-pores and the pore, the latter being slowly eroded and the light-bridge becoming wider.

In the upper chromosphere, in the region observed in He I thin absorption features are jutting out from the magnetic bright points and the pores (Fig. 3). These are more dense at the upper right part of the region, where the concentration of BPs and micro-pores is more prominent. They exhibit wider and deeper He I profiles and intense downflows and upflows near the footpoints.

2. Light-Bridge

The convective motions intrude into the magnetized region of the pore forming a light-bridge (Fig. 4, left panel) signifying the decay of the structure. The granule inside the

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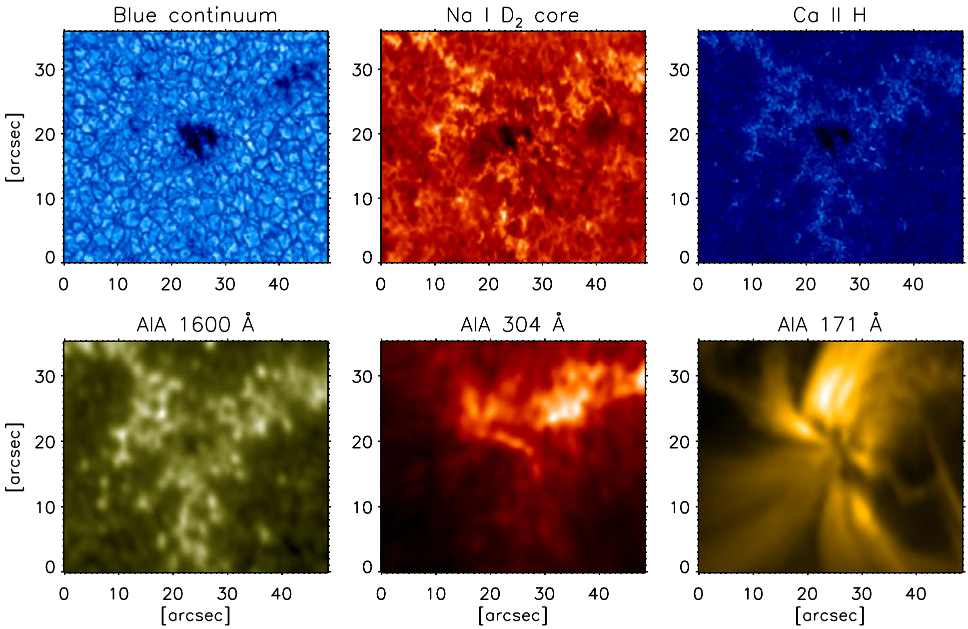

Figure 2. The region enclosed by the yellow rectangle in Fig. 1 seen with the HiFI blue continuum (top left) and the Ca II H broad band filter (top right), at the Na I D_2 spectral line flanks scanned by the GFPI (top middle), and at the three AIA channels (bottom row).

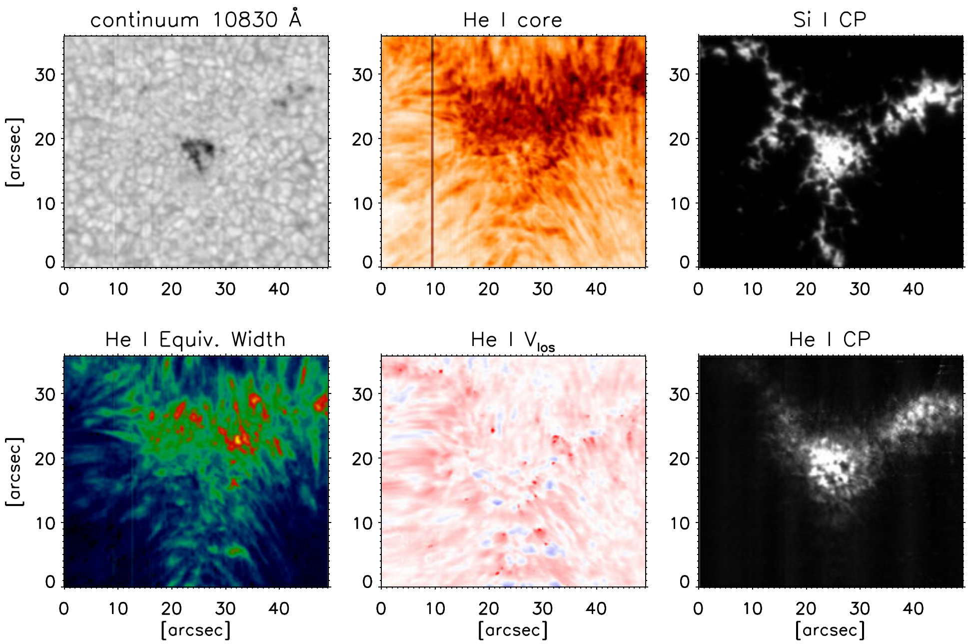

Figure 3. Top row: The pore as seen in the 10830 Å continuum (left) and the He I core (middle). Bottom row: Map of the He I equivalent width (left) and the line-of-sight velocity (middle; see e.g. González Manrique *et al.* 2018 for the spectral line fitting technique). The last column contains the maps of the circular polarization (CP) in Si I and He I (top and bottom row respectively).

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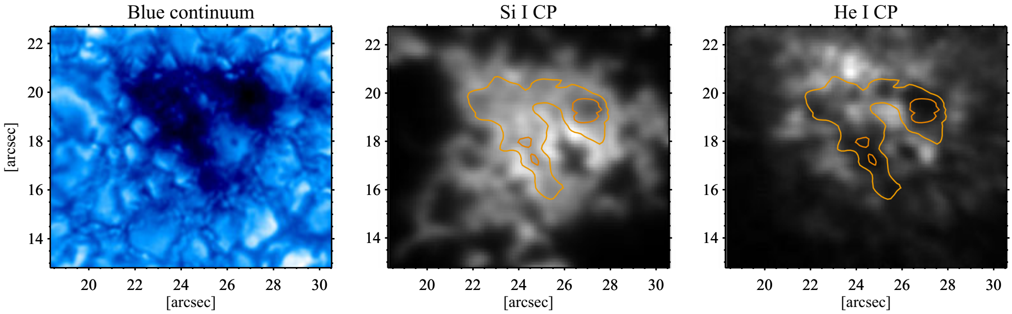

Figure 4. Close-ups of the pore and the light-bridge in the blue continuum (left) along with the corresponding maps of the circular polarization in the Si I and He I spectral lines (middle and right).

light-bridge is distorted and exhibits small-scale, fast evolving structures. The atmosphere within a light-bridge is complicated due to the interaction between the strongly magnetized plasma and the convection (e.g. Lagg *et al.* 2014). The magnetic field of a light-bridge usually forms a canopy-like structure, with field lines from the adjacent magnetic footpoints converging above the light-bridge. The polarization signal in the Si I (upper photosphere) and He I lines agree with such an interpretation. These maps also reveal that the pore is not a monolithic structure but consists of regions with different strengths and geometries of magnetic field.

3. Velocity Oscillations in Na I D_2

The power spectra of the Na I D_2 Doppler velocity oscillations exhibit considerable differences in the different regions of the pore. Power spectra from the light-bridge and the left part of the pore show a clear peak at 3.5 mHz, which is typical of the photospheric 5-minute oscillations. This peak is lower at the power spectra of other parts of the pore, which exhibit, also, a second peak at 3 min ($\sim$5 mHz), of chromospheric origin. The differences will be further investigated, taking into account the formation of the Na I D_2 line in the presence of strong magnetic field (Rutten *et al.* 2011), the detailed magnetic field and atmospheric stratification of the pore and their impact on the propagation of magnetoacoustic waves in the pore (e.g. Felipe *et al.* 2019). The latter will be determined by the spectropolarimetric inversions of the Si I and He I lines.

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