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Multi-channel observations of a solar flare

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Abstract. On August 13, 2006 we performed simultaneous observations in CaII*H*, G-band and FeI 6303 Å of a complex sunspot in NOAA 10904 with the Swedish Solar Telescope (SST) on La Palma, Canary Islands. From spectropolarimetric scans through the FeI line with the tunable SOUP filter we computed the full Stokes vectors at each pixel of the FOV. At 8:47 UT a weak flare eruption (GOES class B7.8) was registered in the line core of CaII*H*. We present the changing magnetic field and flow topologies in the underneath penumbral photosphere during the flaring phase. The unmatched spatial resolution of SST observations allows detailed simultaneous mapping of chromospheric and photospheric events.

1. Data

Multi-channel observations of the following sunspot in NOAA 10904 were carried out with the 1 m Swedish Solar Telescope (SST) in La Palma, Canary Islands. We obtained simultaneous data in the G-Band, the nearby blue continuum and at three positions in the CaII*H* 3968Å line. In addition, we obtained scans across the magnetic active FeI 6302 Å line using the SOUP tunable filter system. Full Stokes polarimetry at 6 spectral positions was carried out. Finally, the red continuum at $\lambda = 6302$ Å was observed.

Except from the line scans, all data were processed by using speckle interferometric techniques (Weigelt 1977; Pehlemann & von der Lühe 1989; de Boer 1996). Reconstruction of the narrow band data was carried out by applying the optical transfer functions obtained from reconstructing the strictly simultaneously recorded red continuum data (see Krieg et al. 1999). Instrumental polarization effects were demodulated by applying modulation matrices of the telescope and of the instrumental setup using a scheme developed by Selbing (2005).

The resulting filtergrams and maps of Stokes vectors are of unprecedented spatial resolution, close to the diffraction limits of 0.11 arcsec (blue channels) and 0.16 arcsec (red channels). The obtained cadence between subsequent reconstructed filtergrams is 19 s for the blue channels. One scan across the FeI 6302 Å line needed about 120 s.

2. Sunspot Structure

The evolution of the active region NOAA 10904 previous to the presented observations shows that the sunspot was formed by merging of two former spots. The resulting two umbral cores are divided by an area of disturbed granulation and several pores. Close to this disturbed region, at the center-side of the sunspot, also the penumbra shows a disturbed character with multiply crossing fibrils connected to several dark umbra-like structures.

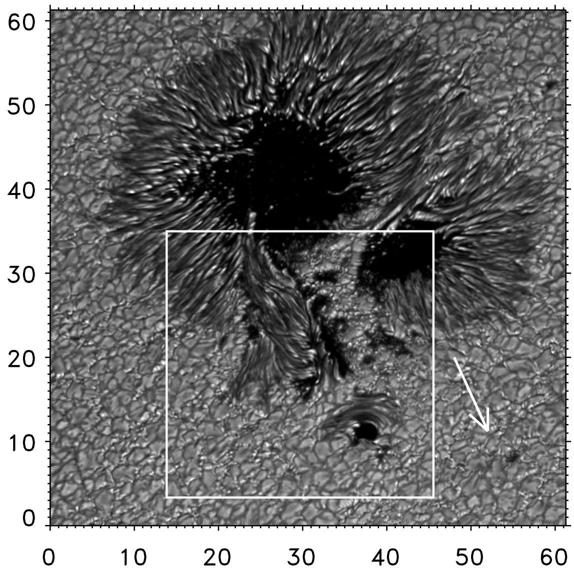

Figure 1. The following sunspot of NOAA 10904 on August 13, 2006, 8:44:31 UT as seen in the red continuum at $\lambda = 6302\,\text{Å}$. Its heliocentric position is approximately 40° ($\mu = 0.76$). The white square marks the subfields shown in Figs. 2 and 3. The arrow points towards disk center. Tickmarks are given in arcseconds.

3. Flare Evolution

Above the complex penumbral structure a weak flare eruption (GOES class B7.8) was released at 8:47 UT (see Fig. 2). The duration of the flare was only about 10 min. The chromospheric structure of the pre-flare region as seen in the CaII*H* line center shows a rather dark region of loop-like structures surrounded by distinct bright borders. As the flare brightening occurs these borders become co-spatial with the footpoints of a variety of a bright loops which are crossing above the disturbed penumbra region, i.e. although the flare was rather weak it shows a pronounced two-ribbon structure. After the flare eruption both the loops and the footpoints achieve their original brightness. Thus, the flare caused only marginal changes of the chromosphere above the disturbed penumbra.

4. Photospheric Dynamics

The photospheric dynamics below the flare can be studied by animating the time series of blue continuum or G-band images. Due to the high spatial and temporal resolution of these data a large variety of motions of the penumbral filaments can be detected. A horizontal flow map was obtained with Local Correlation Techniques (see November & Simon 1988) and gives an impression of these motions. The most significant feature is a fast converging flow towards the granular region between the outermost branch of the disturbed penumbra and an adjacent pore with a half-sided penumbral structure (i.e. at $x = 25$ arcsec, $y = 13$ arcsec in Fig. 1). Here the penumbral fibrils penetrate into the granular area with velocities up to $1.56\,\mathrm{km\,s^{-1}}$. Another convergent flow site, however

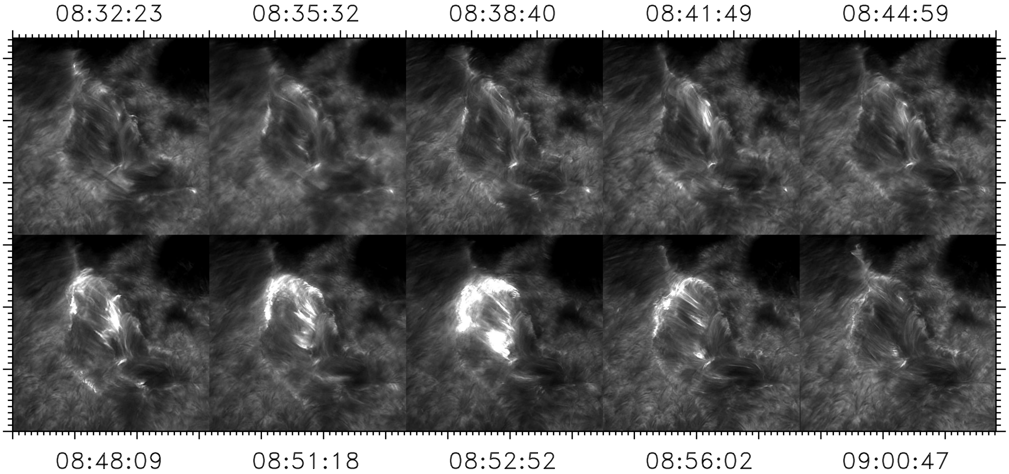

Figure 2. Time evolution of the B7.8 class flare as observed in the center of the CaIIH 3968 Å line. The width of the filter was approximately 1 Å. Times are given in UT; tickmarks are separated by 1 arcsec.

with much lower velocities of 0.18 km s^{-1}, is the elongated dark structure at ($x = 31$ arcsec, $y = 22$ arcsec) arcsec. In addition, an animation of the data shows at many positions oppositely directed motions of adjacent penumbral fibrils. These shear flows are smeared out by the LCT code and result in rather slow average flow velocities within the largest fraction of the disturbed penumbral region.

5. Stokes Profiles

Maps of the components of the Stokes vector $\boldsymbol{S}^{\mathrm{T}} = [I, Q, U, V]$ show an enormously complex structure in the flare region. In Fig. 3 the Stokes vector as seen in the blue wing of the FeI 6302 Å line is displayed. At this spectral position ($\lambda - \lambda_0 = -75$ mÅ) strong signals for average penumbral field strengths of 1 to 1.5 kG are expected. The obtained V signals vary in a range between $-0.2I$ and $0.3I$ and the corresponding Q and U signals are in a range between $-0.15I$ and $0.25I$ which is consistent with the expected field strengths.

Close to the convergence centers of the horizontal flow fields the signs of the obtained Stokes parameters are changing, indicating polarity reversals of the magnetic fields. This simple interpretation is, however, misleading since the observed line profiles are highly asymmetric and, moreover, strong Doppler shifts have to be taken into account (for empiric penumbral models see Müller et al. 2006). Strong line asymmetries can be detected in the V profiles which show uncommon high signals even at ($\lambda - \lambda_0 = -250$ mÅ). For example the V profile at ($x = 17$ arcsec, $y = 53$ arcsec, white cross in Fig. 3) shows a signal strength of $V/I = 0.1$ at this wavelength although the zero crossing appears at approximately ($\lambda - \lambda_0 = -35$ mÅ) which corresponds to a line-of-sight velocity of 1.7 km s^{-1}. At this position, therefore, a second atmospheric component which

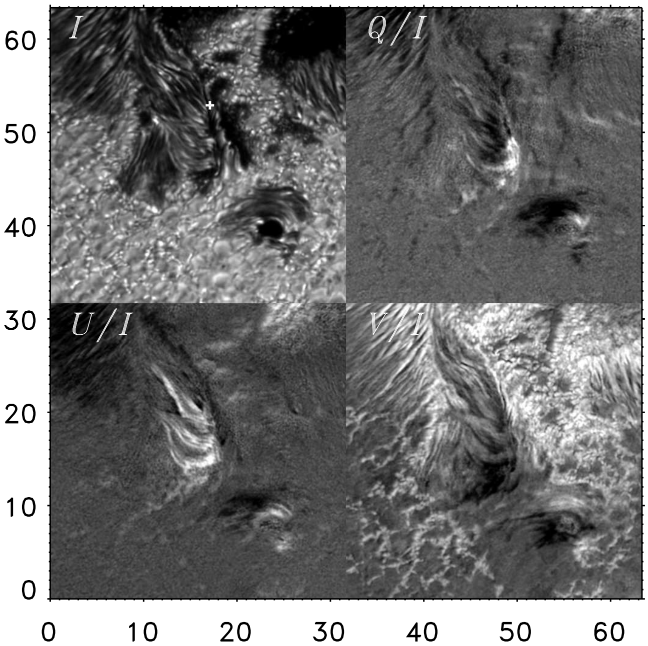

Figure 3. Maps of the four components of the Stokes vector as obtained from the blue wing ($\lambda - \lambda_0 = -75\,\mathrm{m\AA}$) of the FeI 6302 Å line on the verge of the flare eruption (8:44:31 UT). The width of the narrow band filter (SOUP) was 75 mÅ. Tickmarks are given in arcseconds.

is blue-shifted by more than $6\,\mathrm{km\,s^{-1}}$ have to be assumed. Thus, the flare seems to cause photospheric flows with velocities higher than the sound speed.

From the above considerations it might be concluded that the complex flow and field topology in the disturbed penumbral region cannot be reliably retrieved with simple Stokes vector analysis methods. In order to obtain the small scale structure of the magnetic atmosphere below the flare, which becomes visible in our high resolution data, careful inversion calculations of the (polarized) radiative transfer equation are required. Preliminary results from one- and two component inversions indeed show crossing penumbral branches with oppositely directed magnetic fields and Evershed motions. At considerable large fractions of the analyzed area supersonic flow velocities are detectable. Next steps are to fine-tune the inversion procedure and to process the entire time series in order to make possible an association of chromospheric and photospheric features.

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