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Small-scale brightenings observed in active regions with SST and Hinode

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Abstract. Ca ɪɪ H brightenings are good proxies of transient phenomena occurring in the solar chromosphere. We analyze temporal series of Ca ɪɪ H filtergrams taken with SST at extreme high resolution (0.″15) at different line positions, simultaneously with spectropolarimetric data in the Fe ɪ pair at 630.2 nm and Hinode/SOT data, to study the interactions between flux systems. Ca ɪɪ H core brightenings have been observed in areas surrounding the sunspot penumbra, following their evolution.

Key words. Sun: chromosphere – Magnetic reconnection – Techniques: high angular resolution

1. Introduction

High spatial and temporal resolution solar observations allowed us in the last two decades to investigate several disputed topics, amongst them the magnetic reconnection signatures.

The theoretical approach to explain the dynamics of reconnection processes is based on the idea that the approximation of frozen-in fields, used in ideal magnetohydrodynamics, is no longer valid. In most cases solar plasma, which has a high conductivity, satisfies the frozen-in fields condition. Nevertheless, under specific circumstances, when different plasma systems carrying oppositely directed magnetic field lines move one towards the other, a current sheet forms allowing plasma to diffuse and magnetic reconnection to occur.

First numerical simulations of magnetic reconnection were carried out in the early ’90s (Yokoyama & Shibata 1995). In the last years the interest on the evolution of EFRs (Emerging Flux Regions), appearing where an old flux system already exists, has increased both from the theoretical and observational point of view. In these circumstances we can often observe transient small-scale phenomena, with typical size of some Mm, like flux cancellations and brightenings (e.g., Guglielmino et al. 2008). Coronal and chromospheric plasma ejections may also occur (e.g.,

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Guglielmino et al. 2010; Singh et al. 2012). The release of energy during these processes may be interpreted as a consequence of magnetic reconnection events (Isobe et al. 2008). Moreover, they are thought to contribute, together with other phenomena such as shocks and wave leakages, to chromospheric heating in a manner that is still unclear.

During a joint Observational Campaign between the Swedish 1-m Solar Telescope (SST, Scharmer et al. 2003) and the Hinode satellite (Kosugi et al. 2007), we studied some events of magnetic interactions focusing on small-scale chromospheric brightenings observed in the Ca II H line core.

2. Observations and data reduction

From the 6th to the 19th of August 2011 an Observational Campaign was carried out in La Palma (Spain). During this campaign, ground-based telescopes (SST and the Dutch Open Telescope) and the Solar Optical Telescope (SOT, Tsuneta et al. 2008) aboard the Hinode satellite performed joint observations of the solar atmosphere.

The first active region analyzed is NOAA 11267, centered at solar coordinates (−219″, −370″) and observed on the 6th of August by the SST. The temporal coverage is about 37 minutes, from 09:00:05 UT until 09:37:37 UT. The CRisp Imaging SpectroPolarimeter (CRISP, Scharmer et al. 2008) installed at the SST acquired full Stokes data over the Fe I line at 630.25 nm, and spectroscopic data over the Fe I line at 557.6 nm. Filtergrams in the core of the Ca II H line at 396.8 nm were simultaneously acquired. The pixel scale of the CRISP cameras is 0.″0592 pixel^{-1}, while for Ca II H filtergrams is 0.″0338 pixel^{-1}.

CRISP acquired data every 4.4 pm along the Fe I line at 630.2 nm at 15 line positions from -30.7 pm to +30.7 pm with respect to the line center. Note that the last 5 spectral positions sampled the nearby O_2 telluric line. For each spectral point and for each polarization state of liquid crystals 10 frames were acquired. A complete scan took 28 s. Moreover, CRISP acquired spectral data along the Fe I line profile at 557.6 nm, with a step of 3 pm covering a spectral range of 20 spectral points, from -27 pm to +27 pm with respect to the line center, and taking also a spectral point in the continuum at +66 pm. Twenty frames for each spectral point were acquired. Each complete scan took 28 s.

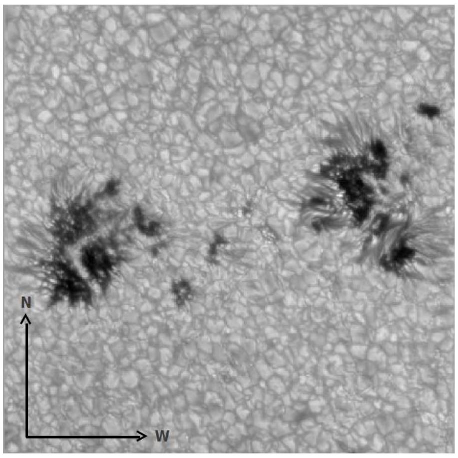

Fig. 1. NOAA 11267 observed by the SST in the continuum of the Fe I line at 557.6 nm. The image shows the details of the main sunspots. The FoV is about 57.″5 × 57.″3. The north is on the top of the image and the west is on the right.

Data acquired at the SST on the 6th of August were calibrated using the standard reduction for dark current and flat field. These data were also processed with the Multi-Object Multi-Frame Blind Deconvolution (MOMFBD, van Noort et al. 2005) technique, which can restore ground-based data affected by blurring and wave-front distorsions. This algorithm permits to obtain near diffraction-limited observations (0.″15), simultaneously correcting images acquired at different spectral ranges that refer to the same region of the solar disk. This allows us to obtain a correspondence between phenomena which occur in different layers of the solar atmosphere. We restored CRISP data acquired in the spectral range of the two Fe I lines and images acquired in the core of the Ca II H line.

Furthermore, we analyzed active region NOAA 11271, observed by the SST on the 18th of August. A subset of SST data for this day, with the same spectral coverage and temporal

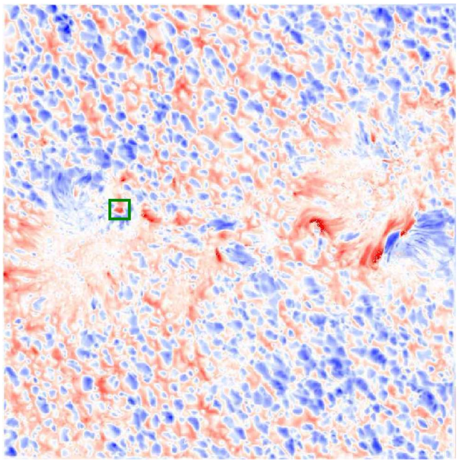

Fig. 2. Velocity map of the active region NOAA 11267, obtained using filtergrams in the Fe I line at 557.6 nm. It is possible to distinguish downward and upward plasma motions along the line of sight. Velocities are displayed in a color scale from -3 km s^{-1} (blue) to 3 km s^{-1} (red). The green square indicates the same area highlighted in Fig. 4.

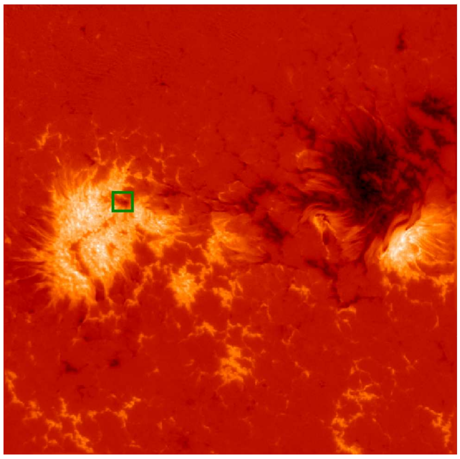

Fig. 3. Circular polarization map of the active region NOAA 11267 observed at the Fe I line at 630.2 nm. The polarization degree is scaled between -15% (black) and 15% (white). The green square indicates the same area highlighted in Fig. 4.

cadence, was processed using the same algorithms mentioned above.

This active region was also observed by the Hinode satellite on the 19th of August, from 08:05 UT until 11:48 UT, located at solar coordinates (-454", -166"). The SOT Broadband Filter Imager (BFI) acquired filtergrams in the core of the Ca II H line and in the G-band at 430.5 nm, while the Narrowband Filter Imager (NFI) acquired Stokes I and V filtergrams in the wings of the Mg I line at 517.2 nm. The SOT spectro-polarimeter (SP) perfomed five scans of the active region from 08:05 UT to 10:21 UT acquiring the Stokes I, Q, U, and V profiles along the Fe I pair at 630.2 nm, with a pixel size of $0\overset{''}{.}32$ pixel^{-1} (Normal Mode).

We corrected the SOT/SP images and the SOT/FG filtergrams for dark current, flat field and cosmic rays using the standard SolarSoft routines and we aligned them through cross-correlation algorithms.

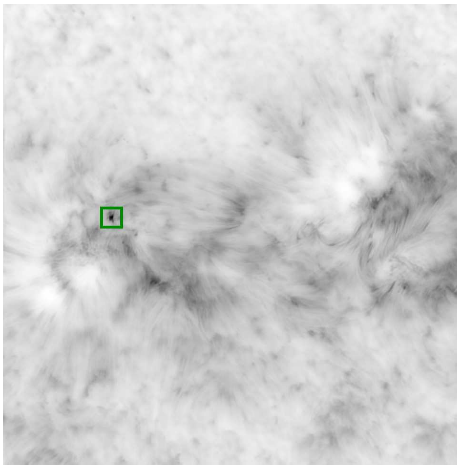

Fig. 4. NOAA 11267 observed in Ca II H line core (reversed gray scale). The green square indicates the area where the brightening occurred.

3. Results

3.1. NOAA 11267

Active region NOAA 11267 was observed when it was still a recently formed region. It is characterized by two main sunspots of opposite polarity, as shown in Fig. 1. We studied the small-scale evolution of this active region,

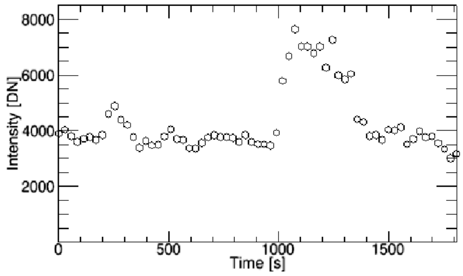

Fig. 5. Evolution of the Ca II H intensity in a box containing the region centered around the brightening site. The peak occurred at 09:24 UT.

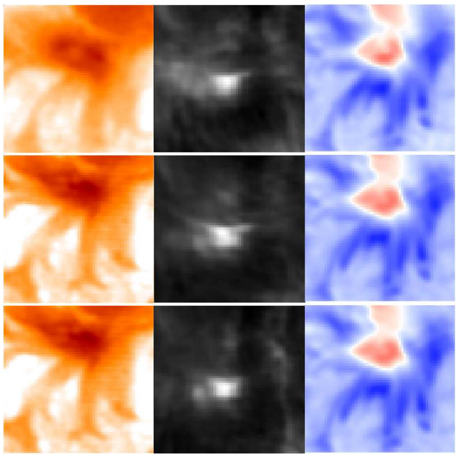

Fig. 6. Evolution of the brightening observed in the Ca II H line. The central row refers to the peak of intensity. Vertical panels, from the left to the right, show respectively: circular polarization, the Ca II H intensity, and the velocities along the line of sight. The polarization degree value is between -1% (dark red) and 1 % (white). Downward and upward motions are scaled respectively between -3 kms^{-1} (blue) and 3 kms^{-1} (red).

analyzing line-of-sight velocities and polarization signals. We first obtained the Doppler velocity using a Gaussian fit to the Fe I line at 557.6 nm. The velocity was calibrated by imposing the average velocity of the entire field of view (FoV) to be equal to zero. In Fig. 2 downward and upward plasma motions in the entire FoV are clearly visible, while the umbrae of the sunspots are on average at rest. It is possible to notice peculiar downward and upward motions at large scale, next to the western sunspot.

We analyzed the maps of the FoV of circular polarization signal, defined as the integral of Stokes V over 10 spectral positions of the Fe I 630.2 nm line. An example of these maps is shown in Fig. 3. The measure of the circular polarization, which is a proxy for the longitudinal magnetic field, provides information about magnetic flux and allows us to study flux emergence events.

We notice the western part of the active region is characterized by the presence of a small positive polarity sunspot, located right next to the main sunspot with negative polarity. The peculiar plasma motions mentioned above were observed along the region of strong polarity gradient between the two sunspots.

Inspection of the Ca II H line core data revealed short living sudden brightenings occurring at small spatial scales. Figure 4 shows one of these brightenings, occurring near the penumbra of the eastern sunspot. Focusing on this event, we computed a time-intensity plot of the region, shown in Fig. 5: a sharp increase of intensity occurred almost 20 minutes after the beginning of the observations.

We found that this brightening region has a size of about 0.1 Mm^2 and it seems to be associated with a negative-polarity flux patch emerging in the photosphere. This could give a hint that the brightness increase visible in the Ca II H line core is associated with the emergence of a negative magnetic flux patch in a region where positive magnetic flux was already present. The observed transient heating phenomenon could therefore be related to the interaction of the magnetic patch with the ambient field, likely leading to magnetic reconnection.

In order to further study the brightness enhancement in the studied region, we analyzed the integrated Stokes V, the Ca II H intensity, and the Doppler velocity in the region centered around the brightening site. Figure 6 displays the time evolution of these parameters with a cadence of one minute. Each square refers to the same region for which we have obtained the time-intensity plot.

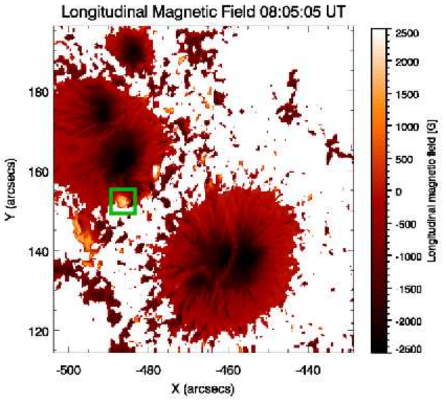

Fig. 7. Longitudinal magnetic field configuration map of the active region NOAA 11271 on the 19th of August, from Hinde/SOT measurements. Pixels with a polarization degree smaller than 1% are not considered. The green square indicates the site where the brightening occurred.

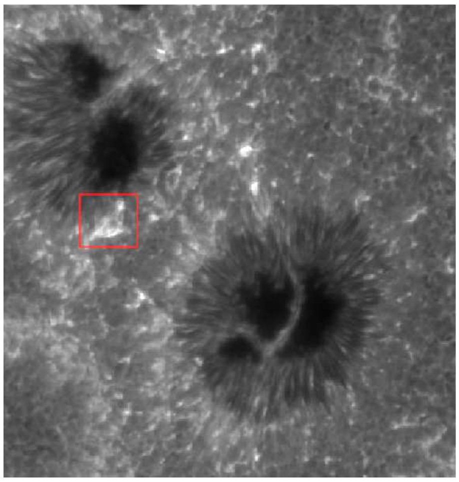

Fig. 8. NOAA 11271 observed in the Ca II H line core. The plasma jet, occurred near one of the two sunspots present in the FoV, is indicated with the red rectangle.

It is possible to notice that the magnetic flux increases while the brightening, as well as both upward and downward plasma motions enhancements take place. Both the plasma motions and the magnetic flux enhancements are cospatial with the brightening.

These results suggest that the spatial coincidence and the temporal delay between the emerging flux and the brightening may be due to magnetic interaction processes responsible for localized release of energy.

3.2. NOAA 11271

We studied active region NOAA 11271, characterized by a complex group of sunspots, one of which had a light bridge. The FoV of Hinode/SOT covers the western part of this active region. In this case, the temporal coverage guaranteed from the Hinode satellite allowed us to complement SST information with magnetic field configuration maps and chromospheric images.

We obtained maps of the Doppler velocity and of the vector magnetic field of this region using the Milne-Eddington standard inversion realized by the CSAC Hinode Data Center. We noticed a small-scale emerging positive magnetic patch near the penumbra of one of the two sunspots, as shown in Fig. 7. In the same region a brightness enhancement was observed in the Ca II H line core.

A plasma jet, cospatial with the brightening, was observed: note it in the red square in Fig. 8. Figure 9 shows the time evolution of this jet with a cadence of 2 minutes. The mean values of longitudinal magnetic field of the close opposite polarity features at the base of the jet are equal to +850 G and −470 G, where the positive one refers to an emerging magnetic patch. The magnetic configuration suggests that the jet was caused by magnetic interactions between the positive emerging flux and the negative ambient field already present in the region.

Moreover, on the 18th of August a brightening in the Ca II H line core was observed by the SST at large scale in this active region. It seemed to connect the western sunspots of the active region during its evolution: it might represent the chromospheric counterpart of a compact flare occurred at 14:59 UT.

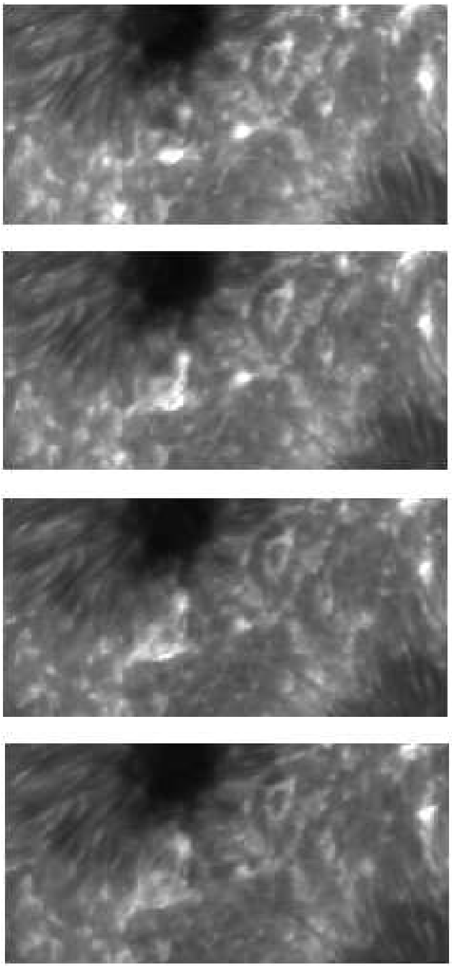

Fig. 9. Time evolution of the plasma jet with a temporal cadence of 2 minutes. The second panel from the top refers to the Ca II H peak of intensity at 08:35 UT, shown in Fig. 8.

4. Conclusions

We have studied small-scale flux emergence events analyzing spectropolarimetric data and filtergrams acquired by the SST and Hinode. We found that small-scale transient events of chromospheric brightness enhancement are associated with magnetic flux emergence and peculiar plasma motions. The timing of such phenomena suggests that the emergence process takes place in the photosphere and then evolves in the chromosphere.

Ca II H brightenings, observed at small scale, could be explained through magnetic reconnection. They may occur because of flux cancellation events between the flux system already present in the active region and the emerging magnetic flux (Isobe et al. 2008).

During magnetic interaction events occurring at small scale a certain amount of magnetic energy is dissipated, providing a source of chromospheric heating. As shown in this work, brightenings in the Ca II H line could be used as diagnostic instrument to study EFRs, as suggested by Balasubramaniam (2001).

These results are very preliminary and data acquired during this Observational Campaign need further investigations to improve our knowledge about emerging flux events and their propagation through the various layers of the solar atmosphere.

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