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High-resolution observations of interactions during the emergence of magnetic flux from the photosphere to the corona

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Abstract. Interactions occurring at sites where new flux emerges and an old flux system is already present can trigger various phenomena, such as flux cancellation, reconnection events, and even flaring. We analyze high-resolution observations of a small-scale flux emergence event in NOAA 10971, observed simultaneously by the Hinode satellite and the Swedish Solar Telescope in La Palma Island during a joint campaign. G-band, Hα, and Ca II H filtergrams were acquired together with Fe I and Na I magnetograms. The data show that the emerging region seen in the photosphere is associated with Ca II H brightenings and a Hα chromospheric surge. Moreover, EUV raster scans and XRT filtergrams show cospatial brightenings. Comparing our results with recent 3D simulations, we interpret our observations in the context of the low-altitude magnetic reconnection model, suggesting that interactions between the emerging flux and the pre-existing magnetic field can explain the observed coupling.

Key words. Magnetic reconnection – Sun: magnetic fields – Sun: photosphere – Sun: chromosphere – Sun: corona

1. Introduction

The magnetic flux emergence process occurs on the solar photosphere over a wide range of spatial scales, from the network to the large and complex active regions. These magnetic flux emergence episodes are often accompanied by highly energetic phenomena in the upper atmospheric layers (Zuccarello et al. 2008; Guglielmino et al. 2008). The current interpretation of these events is found in the interaction between the newly emerging flux and the pre-existing ambient field, already present in the emergence site, as demonstrated by numerical simulations. The results obtained

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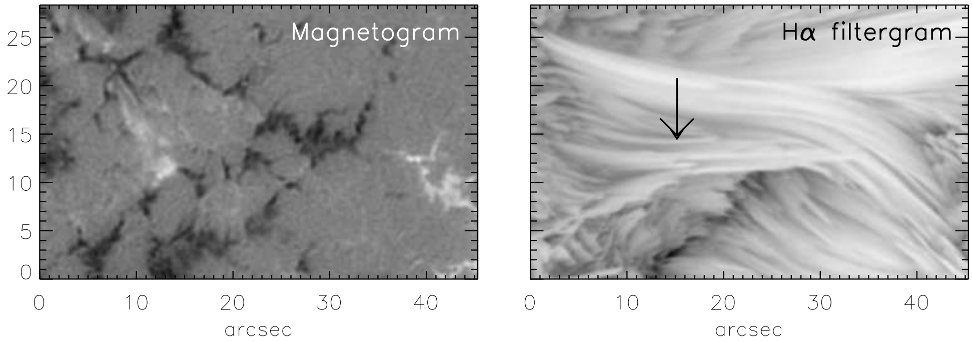

Fig. 1. High-resolution Fe I magnetogram of the emerging flux region, where white (black) areas indicate positive (negative) polarity, acquired by SST at 9:23 UT (*left panel*). Hα line core filtergram (negative), acquired by SST and restored with the MOMFBD technique, cospatial and cotemporal with the Fe I magnetogram. The arrow indicates the location of the chromospheric surge (*right panel*).

by the 2D models of Yokoyama & Shibata (1995) have been substantially confirmed by more recent 3D models (Archontis et al. 2004; Galsgaard et al. 2007), although in a more complicated manner.

Surges are straight or curved ejections of plasma with a filamentary structure and a speed of $\sim$ 50 km s^{-1}, usually seen in the chromosphere in the Hα and Hβ lines, cospatial to emerging flux regions (EFRs). They are also thought to share a common origin with Ellerman's bombs, small-scale brightenings observed in the wings of chromospheric lines (e.g., Matsumoto et al. 2008). In multiwavelength observations, Hα surges have been also correlated both in time and space with coronal events, such as UV/EUV brightenings and X-ray jets, even if this correlation is still disputed (Brooks et al. 2007).

Using simultaneous high-resolution observations taken with the three telescopes onboard the *Hinode* satellite, in the visible, ultraviolet, and X-ray ranges, together with simultaneous ground-based filtergrams and magnetograms acquired by the Swedish 1-m Solar Telescope (SST), we analyze the emergence of a bipolar region within the active region NOAA 10971, which lead to the appearance of a Hα surge and of chromospheric and coronal brightness enhancements. We interpret these events in the framework of the low-altitude magnetic reconnection model.

2. Observations and data analysis

During the joint campaign between the Hinode satellite (Kosugi et al. 2007) and the solar telescopes in Canary Islands (Hinode Observing Plan 14), on 30 September 2007, the active region NOAA 10971,located at solar coordinates (174″, -79″), was simultaneously observed by the SOT (Tsuneta et al. 2008), EIS (Culhane et al. 2007), and XRT (Golub et al. 2007) telescopes and by the SST (Scharmer et al. 2003). At about 8:00 UT, a flux emergence event was observed at the internal edge of the main negative polarity of the active region.

SST observed the active region from 8:45 to 10:15 UT, acquiring simultaneous filtergrams in the Ca II H brightenings line core and in the G band, and covering a field-of-view (FoV) of 63″ × 64″ with a pixel scale of 0.0335″. At the same time, Hα line core images were taken, covering a FoV of 63″ × 60″ with a pixel scale of 0.0651″. High-resolution magnetograms were derived from the Stokes I and V signals measured by the Solar Optical Universal Polarimeter (SOUP) in the two wings of the Fe I line at 630.25 nm. The time series were post-processed using the Multi-Object Multi-Frame Blind Deconvolution technique (MOMFBD), obtaining filtergrams and magnetograms with a spatial resolution of about 0.2″and a cadence of one minute.

The method of analysis of SOT data was described in Guglielmino et al. (2008). As concerns EIS and XRT observations, we used the SolarSoft package to remove dark current and cosmic rays contamination, and to correct for the flat field. EIS performed a series of raster scans of the duration of 20 minutes, with FoV of 100″ × 240″ and a slit width of 2″. We developed a procedure to analyze these data that allows the user to select the ion of interest and the corresponding wavelength range and retrieves the integrated emission intensity, the background level, and the line centroid and line width from a Gaussian fit. The XRT images in the Carbon polyimide filter cover a FoV of 384″ × 384″ and were corrected for pointing jitter.

Using cross-correlation algorithms and transparency tools, all the channels were aligned, with a precision of ±0.1″ for SOT and SST filtergrams, and of about ±2″ for SOT/SST and EIS/XRT images.

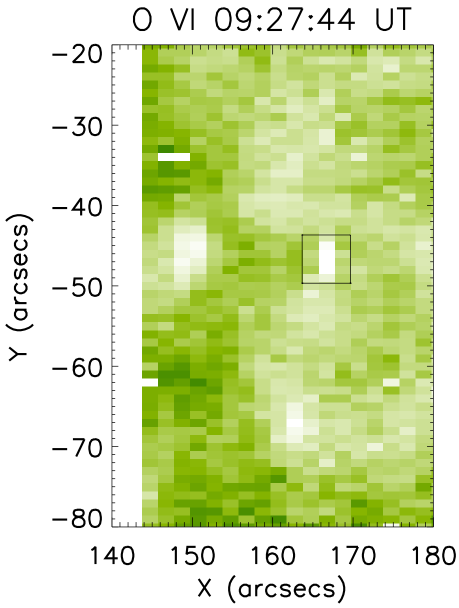

Fig. 2. Intensity of the O VI line in the EIS raster scan. The square indicate the site of the EUV brightening cospatial with the EFR.

3. Results

Figure 1 shows a magnetogram of the emerging flux region with a simultaneous Hα image of the same area, in which the chromospheric surge is displayed. Thanks to the extremely high spatial resolution, the filamentary structure of the surge is clearly visible. The sharp boundary of the surge allows us to estimate the apparent horizontal velocity, of the order of 50 km s^{-1}, in agreement with the estimates of previous works. Moreover, a Y-shaped feature at the base of the surge is recognized in the sequence, whose cross-point location later coincides with the site of the Hα and Ca II H brightenings.

EIS observed a brightening in the transition region and in the lower corona when the slit scan coincided the surge at 09:45 UT. Although weak brightenings were detected in the $10^{5.4} - 10^{6.1}$K range, the most pronounced brightening was found in the coolest lines, i.e., He II, Mg VII, and O VI, as displayed in Fig. 2. The EUV brightenings were also cospatial with the site of the Ca II H brightenss enhancements.

In Fig. 3 we plot the temporal evolution of the mean intensity in the core of the Hα and Ca II H lines and in X-rays. It is evident that the X-ray peak, that occurred at about 9:45 UT, is simultaneous with the peaks of the Hα and Ca II H brightenings. We have also calculated the temporal evolution of the mean intensity in the XRT filtergrams in three control regions, selected outside the active region, in order to demonstrate that the X-ray enhancements are solar in origin and not due to variations in the XRT filter transmission.

Temporal sequences of simultaneous G band filtegrams, Fe I magnetograms, Ca II H and Hα filtergrams, and XRT C/poly images show that the Ca II H and Hα brightenings, seen at the basis of the chromospheric surge, overlap also with an X-ray loop with enhanced emission, originating at the site of the Ca II H brightenings.

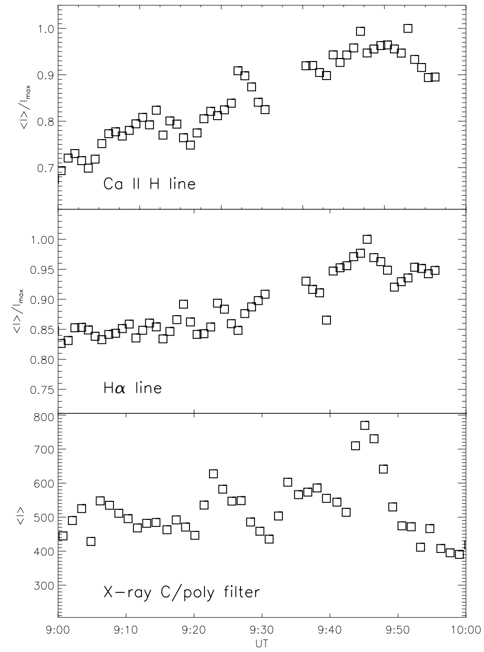

Fig. 3. Light curves of the mean intensity for Ca II H and Hα lines, normalized to the maximum value, and for X-ray. The X-ray peak is simultaneous with the peaks of the chromospheric lines.

Preliminary extrapolations of the magnetic field in the upper atmospheric layers indicate that the site of brightenings and the chromopsheric surge coincide with a magnetic null point at low altitude and a spine, respectively.

4. Conclusions

Taking into account the timing between the chromospheric brightenings in Ca II H and Hα lines, the emission enhancements in EUV cool lines, and the X-ray brigthening in C/poly filter, as well as the spatial coincidence between the location of the emerging bipolar region and the sites of the brightenings and of the chromospheric surge, we conclude that this event confirms that the chromospheric and coronal high energetic phenomena can be a consequence of the emergence and subsequent interaction of the new bipole with the ambient magnetic field, as shown also by the magnetic topology of the overlying field.

Our analyses indicate that Joule dissipation may be a significant source of chromospheric and coronal heating during the reconnection process between the two flux systems, supporting the predictions of the low-reconnection model and recent numerical simulations also at small scales (Archontis et al. 2004).

These findings are important also in the context of the processes that might be responsible of the heating of the solar corona. The continuous emergence of magnetic flux at small scales, the subsequent rearrangement of the local magnetic topology, and its interaction with the ambient magnetic field, may lead to several, perhaps undetectable, magnetic reconnection events that may contribute to the heating of the outer layers of the solar atmosphere.

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