COMBINED SPACE AND GROUND BASED OBSERVATIONS OF A C-1 FLARE

L. Teriaca\textsuperscript{1}, A. Falchi\textsuperscript{1}, G. Cauzzi\textsuperscript{1}, R. Falciani\textsuperscript{2}, L.A. Smaldone\textsuperscript{3}, and V. Andretta\textsuperscript{4}

\textsuperscript{1}Osservatorio Astrofisico di Arcetri, Largo Fermi 5, 50125 Firenze, Italy
\textsuperscript{2}Dipartimento di Astronomia e Scienza dello Spazio, Università di Firenze, Largo Fermi 5, 50125 Firenze, Italy
\textsuperscript{3}Dipartimento di Scienze Fisiche, Università di Napoli “Federico II”, 80126 Napoli, Italy
\textsuperscript{4}Osservatorio Astronomico di Capodimonte, Via Moiariello 16, 80131 Napoli, Italy

ABSTRACT

We present temporally and spatially resolved space and ground based observations of a C1 flare. Ground based spectroheliograms were acquired at the Dunn Solar Tower of NSO/Sacramento Peak in several chromospheric lines. Simultaneously, the Coronal Diagnostic Spectrograph (CDS) aboard SoHO was used to obtain rasters of the same active region in transition region (TR) and coronal lines. This unique dataset provides us, for the first time, with spatially resolved observations of velocity fields during the impulsive phase of the flare, from the chromosphere up to the TR and the corona. At the time of the emission peak, a large area of the flaring kernel observed in TR lines is characterized by upward velocities. A \( \sim 6'' \times 6'' \) kernel displays upflows velocity above 80 km s\(^{-1}\). In this area we found, in data obtained about 3 minutes later, chromospheric downflows of 10 - 20 km s\(^{-1}\). This is the first time that opposite directed flows at different atmospheric levels are observed in the same spatial location during a flare.

Key words: Sun; XUV; flares.

1. INTRODUCTION

Hydrodynamical models of flares, developed from the years 1980s onward, have stressed the relevance of the so-called “chromospheric evaporation”, a sudden increase of the chromospheric temperature to coronal values, occurring when the chromospheric plasma is heated beyond its ability to radiate. This evaporation results in strong upflows of coronal plasma and downflows of chromospheric material, simultaneous with hard X-ray bursts (Nagai & Emslie, 1984; Fisher, 1986; Gan et al., 1991). Up to now, upflows in hot coronal ions (Ca xix, Fe xxv, S xv) during the impulsive phase of a flare have always been measured without spatial resolution (cf. review by Culhane, 1995).

The only indirect observational proof that both coronal upflows and chromospheric downflows originate in the same spatial location has been provided by Wüser et al. (1994). They show that the kernels of chromospheric downflows spatially coincide with the soft X-ray loop footpoints, presumably the loci of energy deposition and coronal upflows.

New instruments such as the Coronal Diagnostic Spectrometer (CDS) on board SoHO, that provide both spectral and spatial information, offer new insights into this problem. Spatially resolved observations of the late gradual phase of a large two-ribbon flare have been obtained by Czaykowska et al. (1999) using CDS data. They observe blueshifts in spectral lines of O v, Fe xvi and Fe xix, located in the outermost region of the ribbons, and interpret such signatures as evidence of chromospheric evaporation for ongoing magnetic reconnection. However, spatially resolved, simultaneous, observations of flows in chromospheric and upper atmospheric layers during the development of a flare are still lacking.

We present in this paper temporally and spatially resolved space and ground based observations of a small two-ribbon flare (GOES class C1), developing in region NOAA 9468 (cos$\phi=0.99$) on May 26, 2001 around 16 UT. We compare intensity and velocity

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{X-ray full disk fluxes at 1 AU.}
\end{figure}
maps obtained at different layers from the chromosphere to the corona (up to ~ 6 MK).

2. OBSERVATIONS

Observations here discussed are part of an observational campaign carried out from May 20 to May 26 2001. Each day space and ground simultaneous observations of an active region were performed from 13:00 to 18:00 UT.

Spectroheliograms were acquired with CDS/SoHO on the active region in five windows around the He I 584, He II 304, O V 630, Fe XVI 360, and Fe XIX 592 \AA\ spectral lines. The useful field of view is 148'' × 138'' wide, with an effective spatial resolution of 6'' × 3.4'' per pixel. The temporal cadence for each raster scan was ~5.5 minutes.

Solar EUV Monitor (SEM) data were used to monitor the EUV flux during the flare (Figure 1). The instrument measures the full disk solar flux in the He II 304 \AA\ line (304 ± 40 \AA\ waveband), as well as the absolute integral flux between 1 and 500 \AA. It should be noted that the detector is much more efficient at shorter wavelengths, effectively measuring the soft X-ray output in the 1-500 \AA\ channel.

One full disk magnetogram was acquired by MDI at 16:00 UT, and was used to define the magnetic neutral line shown in Figures 2, 3 and 4.

Spectroheliograms were acquired in several chromospheric lines such as Ca II K, HIX, He I 5876 \AA\ (D3) and He I 10830 \AA. The useful FOV (160'' × 140'') is slightly shifted westward with respect to the one observed with CDS. The temporal cadence of the raster scans was about 5 minutes, and the final spatial resolution corresponds to 2'' × 2''.

Figure 2. Isocontours of the He I radiance are reported using black dotted lines. The left panels (a,c) show also the O V radiance isocontours (black solid lines) while those of the Fe XVI (white solid lines) and Fe XIX (black solid lines) are shown on the right panels (b,d). A white dashed line marks the position of the magnetic neutral line on panels (a) and (c) and also in Figures 3 and 4.
Due to the acquisition process, CDS and ground based spectra are not strictly simultaneous with time lags depending on the considered X position on the FOV. Times given throughout this paper refer to the moments in which slit crossed position $X = -30''$.

3. RESULTS

3.1. Intensity evolution

Figure 2 shows images in Hα center obtained from the spectroheliograms, at two different times during the flare evolution, corresponding at the two peaks in the soft X-ray emission, shown in Figure 1. The two flare ribbons are clearly visible on either side of the magnetic neutral line (depicted as white dashed line in the left panels). It must be noted that at the first time (16:00:26 UT), the two ribbons are not yet fully developed, and the main Hα emission comes from a small area embracing both polarities.

Two comments are in order on this figure. First, it is evident that the transition region (TR) emission (especially the He i) maps well the spatial distribution of the Hα intensity, and the brightest contours outline the footpoints of the flaring loops. On the other hand, the coronal emission is mostly located between the ribbons, i.e. it is more representative of the loop tops. Second, one notices that while the total emission of the TR lines decreases with time, the opposite is true for the coronal lines.

To compare the temporal evolution of the footpoints emission with that of the loop tops we determine different areas from where the emission originates as indicated in the top panel of Figure 3. In Figure 3A and Figure 3C we show the light curves computed for the emission of O V, He i and Hα lines separately for regions A and C. The light curves for the emission of Fe XVI and Fe XIX in region B are given in Figure 3B. Each light curve is normalized to its pre-flare value. A comparison with the solar fluxes measured by SEM in the two wavebands (1-500 and 260-340 Å) and by GOES in the range 0.5 - 4 Å (see Figure 1) clearly shows that the first peak (~ 16:02 UT) is more relevant at longer wavelengths while the second one (~ 16:20 UT) is more relevant at shorter ones.

The first flaring episode is clearly seen in the light curves of the TR and chromospheric lines in both A and C regions, although the emission in region C is lower. At this time the coronal lines begin to slowly increase in region B, but reach their maximum emission only later, at the time of the second flaring episode seen by GOES and SEM at shorter wavelengths. This second episode is present in Hα emission in both regions A and C and corresponds to an enhancement of the southern ribbon. However, it is much less evident in the light curves obtained with TR lines, although the He i isocontours (Figure 2c) still outline the flaring footpoints quite well.

Figure 3. Black boxes in top panel outline the regions A and C including the loop footpoints while the white box outlines the region B of the coronal emission. Panels marked A & C show the light curves computed for the emission of the O V 630 (solid), He i 584 (dashed) and Hα (dotted) spectral lines for regions A and C, respectively. Panel B shows the Fe XVI 360 (solid) and Fe XIX 592 (dashed) light curves in region B. Light curve are normalized to their pre-flare values. Hα light curves were scaled for displaying purposes, having only a ~ 30% variation between the pre-event and the maximum values.

3.2. Velocity development

As remarked in the Introduction, the development of flows in the flaring atmosphere is an important diagnostic tool to test theoretical models of flares. Our dataset, combining spatially resolved, simultaneous observations from the chromosphere and the upper
atmospheric layers, seems particularly suitable for this task.

Figure 4a displays the contours of the velocities measured around 16:02 UT with the O V and He I 584 overlaid over the Hα image at 16:00:26 UT. The most conspicuous feature is given by a large area of upward directed motions seen in O V, embedding smaller areas of He I 584 upflows. A small patch of downward motions is also visible in both lines within the northern ribbon. Figure 4b shows the same O V velocity contours, together with contours of velocities derived from He I 5875 from the ground at 16:00:26 UT. This latter line shows patches of both upflows and downflows positioned on the two ribbons. The He I 10830 shows a similar distribution of velocity.

4. CONCLUSIONS

The velocity maps obtained at chromospheric levels with the He I 5875 and He I 10830 stress the existence of low-lying loops connecting the two ribbons that display material flowing from one ribbon to the other (siphon flows), probably triggered by the flare itself. The He I 584 velocity maps also hint at a similar phenomenon.

The maximum upward velocities in both O V 630 and He I 584 are not coincident with their maximum intensities (compare Figure 2a with Figure 4a). Rather, they are spatially located on a portion of the flare ribbon that will reach its maximum Hα intensity only in the next raster scan from ground.

At that later time (~ 16:05:22 UT), the chromospheric velocity measured in that area (marked with a black asterisk in Figure 4b) using the Ca II K, He I 5875 and He I 10830 lines is directed downward and reaches values of ~10-20 km s⁻¹. Considering that the CDS and ground-based spectra in this particular area have been obtained at times differing by about 3 minutes, this seems consistent with the model of chromospheric evaporation. This is the first time that opposite directed flows at different atmospheric levels are observed in the same spatial location during a flare.

A measure of flows in the coronal layers would be of utmost importance to support this hypothesis. However, since this flare is not very powerful, and the CDS instrumental profile has degraded after the SoHO recovery, the Fe XVI and Fe XXI data have to be analyzed with great care before one can give a reliable value of the velocity.

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