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Mass Motions in a Young Active Region

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Abstract. We present an observational program devoted to the study of dynamic phenomena at small spatial and temporal scales throughout the solar atmosphere, with special attention to chromospheric events that have an impact on the coronal structure. On the one hand, we show the existence of flare signatures in the chromosphere at the smallest scales, supporting the idea that (micro)flares represent a viable mechanism for supply of heat and mass to the corona. On the other, such events are quite scarce in our dataset, while much more common are surge-like events, occurring repeatedly in the same locations and visible both in the chromosphere and the corona, and that do not display obvious flare signatures.

Key words. Solar activity – flares – surges

1. Introduction

The study of chromospheric dynamics and heating processes can provide further insights into the fundamental problem of the coronal structure. As pointed out in Aschwanden (2001), recent observational results obtained by soft X-rays and EUV instruments clearly indicate that the chromosphere does play an active role in the existence and sustenance of the corona. Such results include for example the overdensity of (hot) coronal loops, not easily produced by compression mechanisms alone in the corona, or the direct observation of upward motions of chromospheric heated plasma. Moreover, beside acting as a reservoir for the coronal mass supply (see e.g. Brown et al. 2000), the chromosphere bears clear signatures of physical processes relevant to the coronal heating itself, such as flaring or other activity phenomena. In early 1999 we activated an observational program devised for a comprehensive view of dynamic phenomena throughout the whole solar atmosphere. The program involved the facilities of the National Solar Observatory (Sac Peak) on the ground and the TRACE satellite in space, and provided high-cadence and high-resolution observations at several wavelengths of a target ac-

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Table 1. Summary of main features of the observing program.

Instrument	Observing λ (Å)	FOV	Spat. resol.	Δ t (s)
DST Images	6562.8 (Hα center)	$2' \times 2'$	$(0.5'')^2$	12
	6561.3 (H$\alpha - 1.5$ Å)	$2' \times 2'$	$(0.5'')^2$	12
	5500 (white light)	$2' \times 2'$	$(0.5'')^2$	3
	6564.3 (H$\alpha + 1.5$ Å)	$2' \times 2'$	$(0.5'')^2$	1
DST Spectra	3900−3950 (CaII K)	$0.5'' \times 2'$	$(0.5'')^2$	3
	4334−4352 (Hγ)	$0.5'' \times 2'$	$(0.5'')^2$	3
TRACE	171 (Fe IX/X)	$6.5' \times 6.5'$	$(0.5'')^2$	40
	1600 (UV Continuum)	$6.5' \times 6.5'$	$(0.5'')^2$	40
	5000 (white light)	$6.5' \times 6.5'$	$(0.5'')^2$	40

tive region, followed for several hours each day. Such a dataset is particularly suitable for the study of the topics just described. We present in this paper some early results about the dynamics of "minor" activity phenomena and how they manifest themselves at different atmospheric layers.

2. Observations

Table 1 summarizes the observational program's main features. In the following, we will limit our analysis to the observing period 15:30 – 17:30 UT on Feb. 9, 1999, centered on young active region NOAA 8456. NSO white light images allowed us to follow the evolution of the target region, and provided a reference for overlapping the space-based data, while images in both Hα center and Hα wings (± 1.5 Å) were necessary to identify the various phases of activity and dynamic phenomena (e.g Falchi 2002). Spectra in various chromospheric lines, from which to derive velocities, were acquired with a very high temporal cadence, suited for highly dynamical phenomena. The spectrograph slit was set on two different positions during the interval analyzed, for roughly an hour each. Three bands were sampled by TRACE: 171 Å, 1600 Å, and white light, with a cadence of about 40 s. The 171 Å band contains emission lines of Fe IX/X, and is representative of plasma at temperatures around 1 MK (Handy et al. 1999). The broad band 1600 Å images provide diagnostics of the UV continuum, and sample temperatures ranging from 4,000 to 10,000 K. A precise overlapping of these images with the ground-based ones was obtained, within about $1''$.

3. Motions in AR 8456

3.1. Micro-flares

The first type of dynamical events connecting chromosphere and corona that we investigated is that of flares.

Although of ultimate coronal origin, the flare phenomenon drives, either through precipitation of nonthermal particles or a conduction front, an upflow along the loops of chromospheric plasma heated at coronal temperatures, the so-called chromospheric evaporation. The cool temperatures counterpart of the evaporation is observed as large chromospheric downflows quite localized in time and space around the impact site (see Falchi 2002). Such a supply of mass from the chromosphere to the corona seems to be present also in much smaller events, dubbed "micro-" and "nano-"flares, that could hence represent a viable mechanism for sustaining the corona (see e.g. Aschwanden et al. 2000; Krucker & Benz 2000). However, the upflows of hot plasma are rarely observed in small events (but see Teriaca et al. 2003 for CDS observations in a C1.1 flare), while the chromospheric signature could be much more readily identified, given the higher sensitivity afforded by ground-based instruments.

We searched our high resolution dataset for the presence of impulsive chromospheric downward motions of small duration and

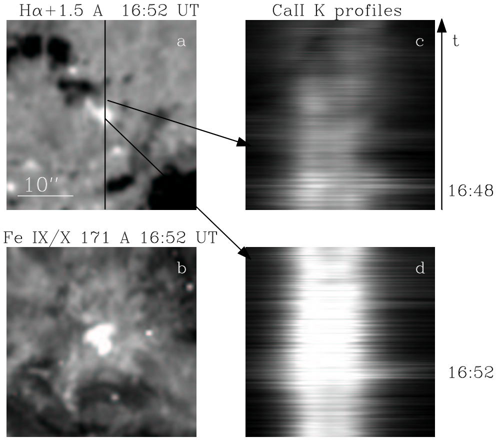

Fig. 1. a) part of the Hα red wing image acquired at the time of a flaring episode; b) corresponding TRACE image at 171 Å . The black line corresponds to the position of the spectrograph slit. c) temporal stack of chromospheric CaII K profiles, acquired in the position indicated by the upper arrow. d) Same as c), for the lower flaring kernel. Intensity scale is the same for both panels. Longer wavelengths are on the right-hand side of the profile.

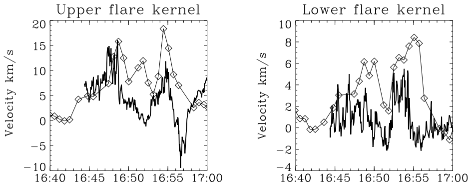

Fig. 2. Left panel: Chromospheric velocities in the upper flaring kernel (thick line), vs. light curve of Fe IX/X 171 Å . Right panel: Same as left, for lower (main) flaring kernel. Curves for Fe IX/X are displayed on arbitrary scales.

size, and checked their possible relationship with coronal brightenings signalling a flaring event. Fig. 1 shows two of these "chromospheric velocity episodes". While panels a) and b) evidence the spatial correspondence of chromospheric and coronal brightenings, panels c) and d) show that impulsive episodes of strong chromospheric downflows (bright streaks in the red wing of the CaII K profiles) do occur at different times on the locations of the brightenings. In Fig. 2 we plot the chromospheric velocity overlayed on the light curves of Fe IX/X 171 Å obtained averaging over an area of about 3×3 arcsec (3 arcsec along the slit for the velocity) around the positions outlined by the arrows of Fig. 1. Left and right panels refer to the upper and lower (main) flare kernels. The curves of chromospheric velocities for both kernels display an impulsive behavior that clearly indicate the time of impact of the primary coronal disturbance. The Fe IX/X curves show related brightenings, that generally reach their maximum few minutes after the appearance of the chromospheric downflows. This might be explained if the chromosphere undergoes an explosive evaporation filling the flaring loop with plasma heated at coronal temperatures, that later cools off to the ≈1 MK giving rise to EUV emission (Aschwanden et al. 2000), consistently with the general idea of the flare mechanism.

3.2. Surges, jets, or more

The two velocity episodes described above are the only unambiguous flaring events within the whole 2 hr dataset, while other types of motions were observed much more frequently. Fig. 3 (upper panels) shows the development of an "ejection" of chromospheric plasma, visible as a dark strike in the upper central part of the Hα−1.5 Å images. Structures of this kind repeatedly formed and disappeared several times over the course of our observations, and all seemed to originate at or nearby the bright point outlined by the slit in Fig. 3 a. Although for some aspects they resemble chromospheric surges, the ejecta do not display other signatures such as evidence of plasma returning towards the solar surface. Moreover, the spectra acquired at the base of the ejecta during many of the episodes do not show typical flare signatures such

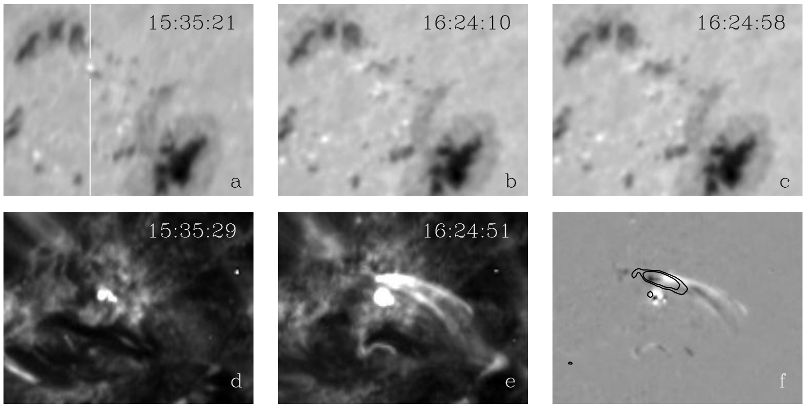

Fig. 3. Panels a, b, c: Hα -1.5 Å images, 60" × 45". The white line in panel a marks the spectrograph slit, and outlines a bright point where chromospheric motions originate. Panels d and e: overlaying TRACE 171 Å images. Panel f (gray scale): intensity variation in TRACE 171 Å between 16:24:12 and 16:24:51 UT. Black contours represent chromospheric upflows.

as correlated chromospheric downflows and brightenings.

The corresponding TRACE images display both bright and dark elongated structures temporally and spatially correlated with the chromospheric ejecta. The Fe IX/X 171 dark structures are in general cospatial with the chromospheric ones, and their projected velocity on the Sun, measured as a proper motion of the dark front, is very close to the chromospheric one. They can hence be interpreted as due to the same cool plasma of the ejection, absorbing the background EUV radiation and appearing as dark in Fe IX/X 171 (e.g Mein et al. 2001). Bright coronal structures are instead often on the side of the chromospheric ones, sometimes overlapping but not completely as shown in the bottom panels of Fig. 3: the development of a bright loop-like structure in the 1 MK Fe IX/X images, related to the "surge", is visible comparing panels d and f. Their exact spatial relationship is instead given in panel f, where the gray scale shows the TRACE 171 intensity variation between 16:24:12 and 16:24:51 UT, while the black contours represent the chromospheric upflow. The bright coronal structures could be identified as hot jets, present side by side with cool surges in some theoretical flare models (Yokoyama & Shibata 1995), but we stress again that in our observations the base of these "surges and jets" lacks any typical flare signatures. Either the flaring episodes are so small to fall below the instrumental threshold, or some other heating mechanism must be at work.

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