

COMPARISON OF TRANSIENT NETWORK BRIGHTENINGS AND EXPLOSIVE EVENTS IN THE SOLAR TRANSITION REGION

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ABSTRACT

The relation between transient network brightenings, known as blinkers, and explosive events is examined based on coordinated quiet Sun observations in the transition region line O v $\lambda 630$ recorded by the Coronal Diagnostic Spectrometer (CDS), in the transition region line Si iv $\lambda 1402$ recorded by the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument, and in photospheric magnetograms taken by the Big Bear Solar Observatory videomagnetograph. From these observations, we find that (1) explosive events, which are traditionally defined as features with very broad UV line profiles, tend to keep away from the centers of network brightenings and are mostly located at the edges of such brightenings, (2) CDS blinkers consist of many small-scale, short-lived SUMER “unit brightening events” with a size of a few arcseconds and a lifetime of a few minutes, and most importantly (3) each SUMER unit brightening event is characterized by a UV line profile that is not as broad as those of explosive events, but still has significantly enhanced wings. Our results imply that, like explosive events, individual unit brightening events involve high velocities, and, hence, blinkers may have the same physical origin as explosive events. It is likely that transient network brightenings and explosive events are both due to magnetic reconnection—but with different magnetic geometries.

Subject headings: MHD — Sun: activity — Sun: transition region — Sun: UV radiation

1. INTRODUCTION

The variable nature of UV and EUV emission from the solar transition region has been well recognized from a series of space experiments: *Skylab* (Vernazza et al. 1975; Habbal & Grace 1991; Rabin & Dowdy 1992), the *Solar Maximum Mission* (SMM; Porter et al. 1987), and the Naval Research Laboratory (NRL) High-Resolution Telescope and Spectrograph (HRTS; Dere et al. 1981). Quite recently, the observations made by the Coronal Diagnostic Spectrometer on board *SOHO* (Harrison 1997; Tarbell et al. 1999; Harrison et al. 1999) revealed the existence of UV/EUV flashes, known as blinkers, which display their most significant brightenings in the transition region temperature lines, with modest to no detectable increase at higher or lower temperatures. The line emission characteristics strongly suggest that blinkers are distinct from the less frequent network flares that dominate high-temperature line emissions (Krucker et al. 1997; Krucker & Benz 1998; Benz & Krucker 1998; Berghmans, Clette, & Moses 1998; Aschwanden et al. 1999). Nevertheless, it appears that there is no reason, so far, to exclude the possibility that blinkers may be related to coronal heating, at least indirectly.

Another kind of small-scale activity at transition region temperatures, known as explosive events, was previously discovered by the NRL HRTS experiments (Brueckner & Bartoe 1983; Dere, Bartoe, & Brueckner 1989). Explosive events are characterized by very broad spectral profiles in transition region lines, indicating the presence of high-velocity plasmas. Dere et al. (1991) and Dere (1994) suggested that explosive events are small-scale reconnection events in the quiet Sun arising from the interaction of network magnetic fields and intranetwork fields which are swept to the network by supergranulation flow. Observations from the Solar Ultraviolet Measurements

of Emitted Radiation (SUMER) instrument on board *SOHO* produced results that support a magnetic reconnection origin of explosive events. Innes et al. (1997a) reported finding a spatial separation between blueshifted and redshifted streams in explosive events, supporting the prediction of Dere et al. (1991). Moreover, the majority of explosive events are found to be associated with flux cancellation (Chae et al. 1998b). Since explosive events have a much shorter timescale than flux cancellation, it has been anticipated that explosive events occur in a bursty way (Dere 1994), which was also confirmed from SUMER observations (Innes et al. 1997b; Chae et al. 1998b).

In the present work, we explore the spatial relationships, similarities, and differences between blinkers and explosive events by analyzing a set of coordinated observations jointed by the Coronal Diagnostic Spectrometer (CDS), SUMER, and the Big Bear Solar Observatory (BBSO) videomagnetograph (VMG). From this, we find that blinkers consist of many small-scale and short-lived brightening events, each of which is characterized by a transition region line profile that is not so broad as that from explosive events, but has significantly enhanced wings.

2. OBSERVATIONS

We have analyzed two sets of CDS/SUMER joint observations of different areas in the quiet Sun performed on different days, 1997 April 18 and August 26. The observing sequence was nearly the same on both days. Moreover, we have obtained essentially the same results from observations taken on different days. Therefore, we will focus on observations and results mostly based on the data from 1997 August 26.

The joint observations on 1997 August 26 were performed from 16:00 to 20:30 UT. The target was a quiet region with

SOHO solar coordinates $X = 264''$ (west) and $Y = 340''$ (north). The characteristics and performance of the SUMER instrument were described by Wilhelm et al. (1995, 1997) and Lemaire et al. (1997). In our observations, SUMER repeatedly recorded the Si iv $\lambda 1402$ line with 30 s integrations using detector B. The nominal slit ($1'' \times 300''$) was initially used but was later replaced by a shorter slit ($1'' \times 120''$). The telescope was fixed in one position allowing features on the surface to drift across the slit as the Sun rotates. The 4.5 hr observation resulted in a drift raster scan of width of $43''$, which is large enough to reveal quiet Sun network structures. The observing sequence also shows a temporal evolution of solar features during a period shorter than 430 s, which is the time required for $1''$ drift across the SUMER slit. Meanwhile, the BBSO VMG produced a series of deep magnetograms with a flux density sensitivity of 2 G and a time resolution of about 3 minutes. The detailed characteristics, data analyses, and some results of the present SUMER and VMG observations have been described by Chae et al. (1998b, 1998c).

CDS is a double spectrometer operating in the EUV range 151–785 Å. It has been described in detail by Harrison et al. (1995). We used the normal incidence component with a slit of $2'' \times 240''$. The nominal observing sequence, named BASIC, was used to record the three strong lines He i $\lambda 584$, O v $\lambda 630$, and Mg ix $\lambda 368$. A total of 120 successive exposures of 15 s duration were taken to obtain one set of raster data, which covers a field of view $244'' \times 240''$ during a period of 40 minutes. The raster scan was repeated three times. The data were debiased and then corrected for spiky noise using standard reduction programs.

3. RESULTS

Figure 1 shows the CDS O v $\lambda 630$ and SUMER Si iv $\lambda 1402$ line intensity images of the observed area taken at different times. Note that the peak abundance temperatures of Si iv and O v ions are 0.7×10^5 and 1.8×10^5 K, respectively (Arnaud & Rothenflug 1985). The field of view is $45'' \times 100''$. A careful comparison of the O v images reveals that the line emission is continually changing at virtually every point in the network. Harrison et al. (1999) have selected for blinkers O v brightening events that display more than 10% intensity increase. The criterion appears rather arbitrary in that it depends on the observing parameters like spatial and temporal resolutions. Since our observing sequence is different from theirs, it is not possible to apply the same criterion to our data to select blinkers, especially small blinkers. Therefore, we do not attempt to make a complete list of blinkers from our data set, but we rather focus on the two circled areas, denoted A and B in the SUMER image, which display the most noticeable changes in the O v line intensity. The plots of the mean intensities of these areas as functions of time indicate that the respective intensity variations of 70% and 40% took place in about 40 minutes. The He i $\lambda 584$ and Mg ix $\lambda 368$ line data taken simultaneously with the O v line data, however, do not display such significant intensity changes as the O v data. These characteristics of A and B are compatible with those of a typical blinker, as reported by Harrison et al. (1999). By comparing the H α data and the computed potential field lines, Woodard & Chae (1999) showed that the magnetic field in the area A is highly nonpotential. In accordance with Harrison (1997), we could not find any sign of high-velocity motion in blinker A from the CDS O v line profiles.

Comparing SUMER data and CDS data is not straightfor-

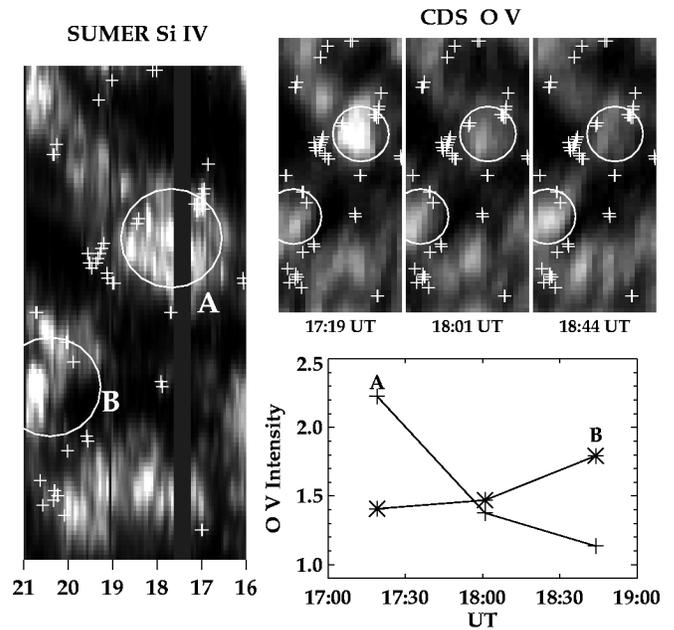


FIG. 1.—SUMER Si iv integrated line intensity images of a quiet area showing transient network brightenings. The symbols mark the locations of the explosive events. The intensities in the plot have been normalized by the spatial average value of the quiet Sun.

ward because of the different ways in which the data were taken. Nevertheless, it is clear from the figure that the two blinkers identified from the CDS data are prominent in the SUMER data, too. The SUMER data have been used to identify explosive events, whose locations are marked with symbols on the SUMER image and CDS images in the figure. Specifically, we used the criterion of $\xi > 45 \text{ km s}^{-1}$ to identify explosive events, where ξ is the most probable speed of nonthermal motion. The cutoff value is 5σ above the spatial average. Comparing the relative location of blinkers and explosive events shows that explosive events tend to keep away from the centers of blinkers and are preferentially located at the edges of blinkers. This finding is not surprising because blinkers are a kind of network brightening, and it has been known from previous studies (Porter & Dere 1991; Chae et al. 1998b) that explosive events occur away from the larger concentration of magnetic flux in the network which gives rise to bright network emission.

The observed spatial relationship may naturally lead to the conclusion that explosive events and blinkers represent two different kinds of activities: high-velocity events and transient brightening events. Porter & Dere (1991) drew a similar conclusion that *SMM* Ultraviolet Spectrometer and Polarimeter microflares do not imply particularly high velocities, unlike HRTS explosive events. Despite the mismatch, however, we emphasize that high-velocity events as represented by explosive events and brightening events as represented by CDS blinkers may not be physically independent of each other, for many explosive events occur at the edges of the blinkers—and at the same time as the blinkers. Thus, we examine carefully the SUMER Si iv line data at the blinking areas to search for further similarities and differences between blinkers and explosive events.

Figure 2 presents the time series of SUMER slit images of the Si iv line taken during the period from 17:38 to 18:54 UT. It shows line intensity variations of two network areas: one with the blinking activity (the upper one designated by A) and

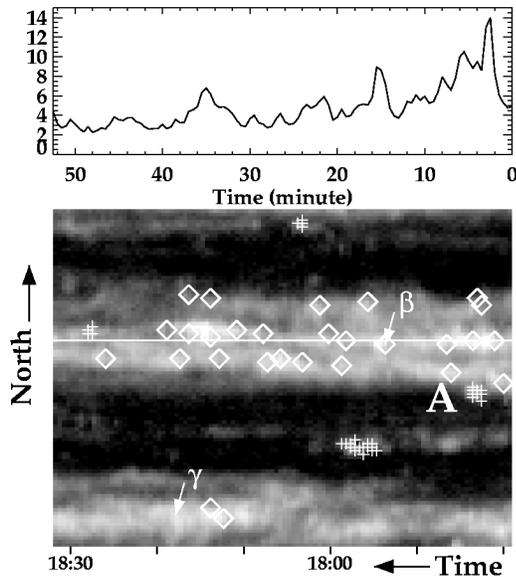


FIG. 2.—Time series of slit images taken during the period from 17:38 to 18:54 UT (without rotation correction). The upper panel is the intensity profile of the horizontal cut. The plus signs represent the locations of explosive events, and the diamonds represent brightening events showing enhanced wings in the spectral profiles.

the other without such activity. The figure shows that the blinking activity consists of many small-scale, short-lived brightening events, which we call “unit brightening events.” A typical unit brightening event lasts about 2–3 minutes and has a size of about $3''$ – $5''$. Most of unit brightening events that make up blinkers display spectral line profiles with enhanced wings, which we will describe later in this section. The diamonds mark the positions and times of brightening events that produce line emissions with enhanced wings. Table 1 presents the numbers of such unit brightening events identified at two blinking areas on different days. The result indicates that the two blinkers on April 18 and August 26 may comprise 625 and 529 SUMER unit brightening events, respectively, when it is assumed that the blinkers have square shape, unit brightening events take place uniformly at the blinker areas, and blinkers last about 40 minutes.

Figure 3 compares three types of network emissions showing different line profile shapes: an explosive event (α), a brightening event showing enhanced wings in its spectral profile (β), and a normal network emission without enhanced wings (γ). As seen from the figure, the spectral profile of the line emission produced by the explosive event (α) is very broad and strongly deviates from the shape of a single Gaussian. Quite often, the spectral profiles of explosive events are neatly decomposed into three Gaussian components: two high-velocity (red- and blue-shifted) components and one stationary component (e.g., Chae et al. 1998c). On the other hand, the spectral profile of the line emission produced from the normal network area (γ) is fairly close to a single Gaussian and does not show any signature of high-velocity components. The spectral profile of the brightening event (β) displays an intermediate characteristic: it has enhanced wings that indicate the existence of high-velocity plasmas within the spatial resolution element, even though the intensity of high-velocity components is much lower than the stationary component—typically by 10%–20%. The existence of transition region line profiles with enhanced wing emissions was first reported by Kjeldseth-Moe & Nicolas (1977) and

TABLE 1
NUMBERS OF SUMER UNIT BRIGHTENING EVENTS
IN THE TWO CDS BLINKER REGIONS

Date (1997)	Spatial/Temporal Coverage (arcsec/minute)	Number
Apr 18	$1 \times 15/40$	25
Aug 26	$1 \times 10/45$	23

further studied by Dere & Mason (1993) and more recently by Chae, Schühle, & Lemaire (1998a). Chae et al. (1998a) compared the line profiles with enhanced wings and those of explosive events and suggested that both may have the same physical origin. The present study is the first to report that it is unit brightening events that produce transition region line emissions with enhanced wings.

Figure 3 further compares the magnetic configurations of the three kinds of network emission features. The explosive event (α) occurs at the edge of a network with weak and mixed polarity magnetic fields, as already reported by Chae et al. (1998b). The size of the magnetic system that may be directly responsible for the event can be estimated from the separation of magnetic concentrations with opposite polarities, which is about $3''$ or 2000 km. The brightening event (β) occurs at the center of a network with strong and mixed polarity magnetic fields. The size of the associated magnetic system is estimated to be $6''$ – $8''$ or 4500–6000 km. The normal network emission (γ) without enhanced wings occurs at the center of a network with strong and predominantly unipolar fields. The size of the associated magnetic system seems to be much larger than 10^4 km.

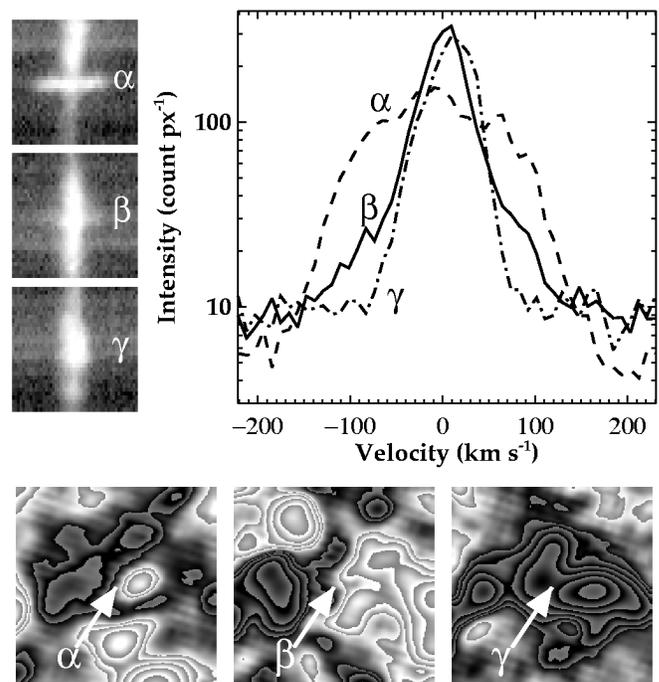


FIG. 3.—Upper row: Spectrograms and spectral profiles of an explosive event with very strong high-velocity components (α) and at a bright network area with a weak high-velocity component (β), and at another network area without any significant high-velocity component (γ). Lower row: Magnetic flux distributions at the regions of the three features. Gray-scale discontinuities have been introduced to represent the apparent flux density levels of ± 5 , 10, 20 G, and so on. The field of view of the magnetograms is $10'' \times 10''$.

4. DISCUSSION

We have examined the spatial relationships, similarities, and differences between blinkers and explosive events. Apparently blinkers and explosive events look different because of the differences in size and duration. We confirm that their spatial locations are a little different, too. Nevertheless, blinkers and explosive events appear to be closely related to each other, for explosive events occur at the edges of blinkers at the same time as the blinkers. Moreover, we find that CDS blinkers consist of many small-scale and short-lived SUMER unit brightening events having sizes and durations that are very comparable to those of explosive events. Most of the unit brightening events produce line emissions with enhanced wings. These latter findings indicate that unit brightening events are similar to explosive events and, hence, may have a common physical origin. Since observations seem to support a magnetic reconnection origin of explosive events as described in § 1, unit brightening events that make up blinkers may also result from reconnection events in quiet Sun networks, as suggested by Harrison et al. (1999).

The difference in spectral characteristics between unit brightening events and explosive events might be attributed to different magnetic reconnection geometries. The evidence for this proposition comes from our result that explosive events and unit brightening events occur at different locations with different magnetic configurations. Figure 4 illustrates possible magnetic geometries of explosive events and unit brightening events, as implied by our observations. Explosive events are considered to occur as a result of the collision of a network flux thread (which is a part of a very large loop) and an intranetwork flux thread (which is a part of very small loop; Figs. 4a and 4b). At the intersection point, the two flux threads are more or less antiparallel, forming a relative angle that is greater than 90° . So, the reconnection at the intersection point could produce strong bidirectional outflows. On the other hand, unit brightening events are considered to occur as a result of two network flux threads, both of which are parts of moderately large loops (Figs. 4c and 4d). The two threads are more or less parallel at the intersection point but make a relative angle that is significantly greater than 0° and smaller than 90° . The reconnection due to the collision of such threads also produces bidirectional outflows, but the outflows are not well-collimated. Therefore, combined with the projection effect, the emission

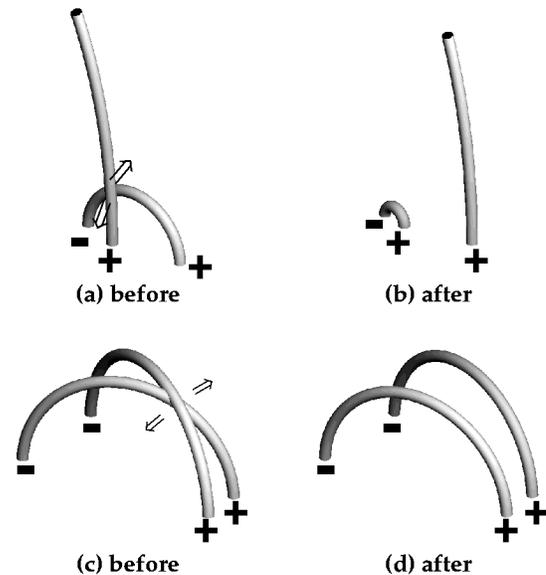


FIG. 4.—Magnetic geometry models of (a, b) explosive events and (c, d) brightening events. The arrows indicate reconnection outflows.

from plasmas that move quickly along the line-of-sight direction may be weak compared with the emission from stationary plasmas. This may explain the spectral characteristics of unit brightening events as illustrated in Figure 3. Further comparisons of the two kinds of reconnection, small and large angle reconnection, are given by Chae (1999). Since the relative angle between two threads may range continuously from 0° to 180° , it is expected that there would be also a continuous transition of line profile shapes from explosive events showing high-velocity motions to brightening events without showing any noticeable high-velocity motion. Note that different network locations may have different magnetic geometries.

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