Astronomy
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Astrophysics

New insight into the blinker phenomenon and the dynamics of the solar transition region

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Abstract. We present, for the first time, blinker phenomena being associated with brightenings in pre-existing coronal loops registered by the Extreme-ultraviolet Imaging Telescope (EIT) in Fe XII 195 Å. The brightenings occur during the emergence of new magnetic flux as registered by the Big Bear Solar Observatory (BBSO) magnetograph. The blinkers were identified using simultaneous observations obtained with the Coronal Diagnostic Spectrometer (CDS) and Solar Ultraviolet Measurements of Emitted Radiation (SUMER) spectrograph. In light of the new observational results, we present one possible theoretical interpretation of the blinker phenomenon. We suggest that the blinker activity we observe is triggered by interchange reconnection, serving to provide topological connectivity between newly emerging flux and pre-existing flux. The EIT images show the existence of loop structures prior to the onset of the blinker activity. Based on the available spatial resolution the blinker occurs within, or nearby, an existing coronal loop. The temperature interfaces created in the reconnection process between the cool plasma of the newly emerging loop and the hot plasma of the existing loop are what we suggest to causes the observed activity seen in both the SUMER and CDS data. As the temperature interfaces propagate with the characteristic speed of a conduction front, they heat up the cool chromospheric plasma to coronal temperatures, an increasing volume of which brightens at transition region temperatures. We believe this new interpretation gives further qualitative understanding about the evolution of newly emerging flux on the Sun. This also provides new insight into the dynamic nature of the solar transition region.

Key words. Sun: atmosphere – transition region – evolution – magnetic fields – UV radiation

1. Introduction

Based on data obtained by the Coronal Diagnostic Spectrometer (CDS) on board SoHO, Harrison (1997) discussed a class of transient phenomenon, which he termed blinkers. These brightenings were associated with enhanced emission in transition region (TR) lines, such as O III 599 Å, O IV 554 Å, and O V 629 Å (these lines have formation temperatures in the range $1.0–2.5 \times 10^5$ K), involving a typical size of $\approx 8'' \times 8''$, and having an average duration of approximately 17 min (Harrison et al. 1999; Bewsher et al. 2002). In a recent survey, Brković et al. (2001) reported lifetimes of blinker events in the range 3–110 min, based on observations that enabled better detection of short- and long-lived CDS brightenings. Spectral line ratio analysis suggested that the intensity enhancements associated with blinkers were consistent with an interpretation involving either an increase in mass density or *filling factor* rather than temperature (Harrison et al. 1999; Teriaca et al. 2001). Based on SUMER data, Madjarska & Doyle (2003) reported Doppler shifts that ranged

from –5 to 25 km s^{-1}, but were predominantly red-shifted. A transition from blue to red-shifted emission, in the course of the 200–300 s observations, was observed for one case. Bewsher et al. (2003), using CDS observations, derived Doppler shifts of 25–30 km s^{-1} in O V 629 Å. As reported by Harrison et al. (1999) and Bewsher et al. (2002), blinkers occur predominantly in the network lanes. This usually involves regions of large or strong magnetic fragments; in 75% of the cases one polarity is dominant (see Parnell et al. 2002).

Until recently, it has being highly debated in the community why bi-directional jets (more often called explosive events), yet another transient phenomenon observed in transition region lines, do not have a counterpart in the CDS data. It was also questioned whether blinkers and bi-directional jets were the same transient phenomenon seen differently due to the different spectral and spatial capabilities of the CDS and SUMER instruments. This question remained open until simultaneous observations were made and reported by Chae et al. (2000) and Madjarska & Doyle (2003). Blinkers were identified in the relevant SUMER data as a series of short-lived, small-scale brightenings lasting about 2–3 min, and having a typical size of about 3''–5''. In a recent numerical study,
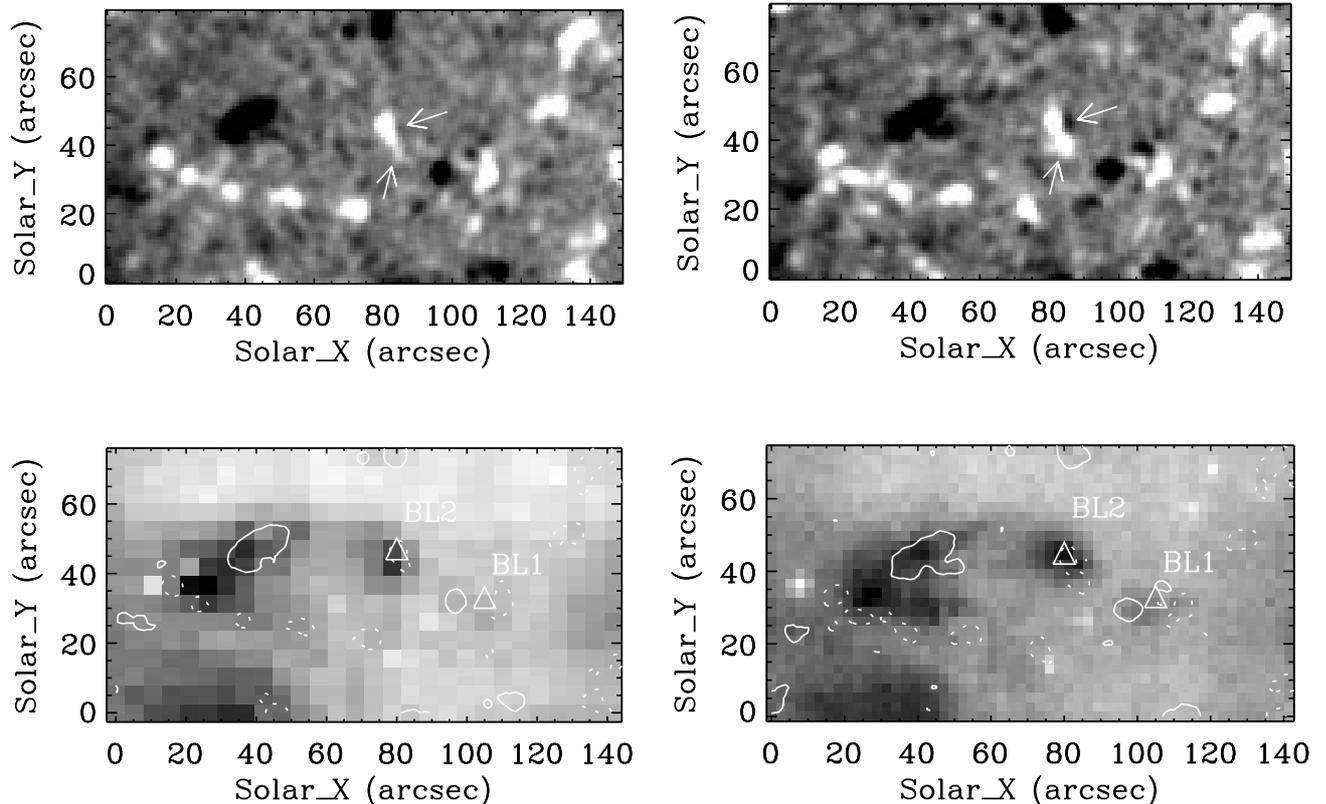
Letter to the Editor

Fig. 1. BBSO magnetograms (*top row*) with simultaneous reversed colour EIT Fe XII 195 Å images (*bottom row*), with the left two panels taken at 18:24 UT, and the right panels at 19:13 UT on October 23, 2001. BL1 and BL2 indicate the blinkers positions. The contours overplotted on the EIT images represent the ±25 G negative (solid line) and positive (dashed line) magnetic flux. The arrows point towards the newly emerging magnetic fluxes while the triangles show the locations of the blinkers identified in the CDS data. In Madjarska & Doyle (2003), these blinkers were labelled BL1 and BL2.

Marik & Erdèlyi (2002) argued that blinkers and bi-directional jets are the same phenomenon. They implied that the difference in integration time of the CDS and SUMER instruments is what distinguishes between the two events. This interpretation, how-ever, was not supported by the joint CDS/SUMER observations presented by Madjarska & Doyle (2003).

In a recent study, Priest et al. (2002) discussed several phys-ical mechanisms that could explain the blinker phenomenon, namely: heating of cool spicular material; containment of plasma in low-lying loops in the network; thermal linking of cool and hot plasma in response to a coronal heating event; and cooling and draining of hot coronal plasma when the coro-nal heating is turned off. In each case, a blinker activity could occur during the granular compression of a network junction, since the micro-scale flux fibrils involved in this process spend more time at TR temperatures, increasing the filling factor ac-cordingly. Recent joint observations presented by Madjarska & Doyle (2003) favor yet another possibility, involving magnetic flux emergence, which we present here.

2. Summary of a joint observational effort

Details on blinkers identification and analysis in the SUMER, CDS, and BBSO data, as well as the data description and re-duction, can be found in Madjarska & Doyle (2003). Here we summarize only a few facts that we consider important for the present study.

The blinker identification in the relevant CDS data sets was done through a visual inspection, following the schemat-ics of Harrison et al. (1999). The main goal was to search for transient features with the characteristics of a classical blinker regarding size, duration, and intensity variations. All other transient brightenings were excluded from the analysis. As a result, three blinkers were identified in the CDS data. BL1 and BL2 here are the same as BL1 and BL2 in Madjarska & Doyle (2003). Despite the difference in spatial resolution be-tween SUMER and CDS, it was possible to find the exact coun-terparts of CDS blinkers in the relevant SUMER data. This was done by examining the N V 1238 Å intensity variations over the entire course of observations. A more detailed anal-ysis showed that the bright SUMER network was associated with a CDS blinker. The high-resolution SUMER data revealed the small-scale structure of the blinkers, consisting of 3″–5″ brightenings with a mean duration of ≈150 s. Similar findings were reported earlier by Chae et al. (2000). The Doppler shift associated with these events was derived for the first time, rang-ing from –5 to 25 km s^{-1}, but were predominantly red-shifted over the duration of the events. This was concluded to be the case for all three blinker events reported by Madjarska & Doyle (2003).

Longitudinal magnetograms, measuring the line-of-sight magnetic fields (Stokes-I' and V) of a selected region of 337″ × 332″, were also taken every 20 s at the BBSO. The analysis of

these data revealed that blinkers are associated with the emergence of new magnetic flux.

In order to find out whether blinkers are related to any already known phenomenon, we analysed a series of EIT Fe XII 195 Å images, most of which had a resolution of 5″.2. From the full Sun images, we selected sub-images with a field-of-view (FOV) larger than the CDS FOV in order to get an overview of the coronal structures in the close-by region, and their relation to the studied area. The same was done with the previously analysed BBSO data. Our next step was to align EIT and BBSO data. The analysis of the aligned images revealed the existence of small-scale quiet Sun coronal loops. These type of loops are usually called coronal Bright Points.

In Fig. 1, we show two examples of EIT and BBSO images, presenting the coronal features and the corresponding longitudinal magnetic field configuration at two instants of time. The first EIT image (Fig. 1; bottom left) has a spatial resolution of 5″.2, while the second one (Fig. 1; bottom right) has 2″.6. The first blinker (BL1) can be seen only on the latter due to its higher resolution. This blinker, in fact, represents a small coronal BP as seen on the EIT image (Madjarska et al. 2003). The BP formed around 8 UT (following the reformation of another BP close-by) and disappeared around 23 UT. The blinker was observed between 18 and 19:30 UT, i.e., in the middle of its lifetime. This does not exclude, however, that the blinker did not exist outside our observing time period. The BP is ∼70″, larger than the CDS field of view (24″ × 176″) and therefore its appearance and size can not be judged using only CDS images. Here we discuss only the second blinker (BL2), because of the bigger size of the loop associated with it and hence better appearance in the EIT images.

In Fig. 1, the contours of the ±25 G magnetic flux are overplotted, showing that loops are connecting two opposite polarity magnetic flux regions. The negative polarity region is also connected to other positive polarity regions situated at lower Solar_Y. Figure 2a shows the CDS O V 629 Å radiance obtained after integrating over the blinker area, with Figs. 2b and 2c showing the unsigned magnetic flux at the foot-points of the loop associated with BL2 (Solar_Y = 40, Solar_X = 80 in Fig. 1) of the positive and negative polarities respectively. The positive polarity increases by a factor of 1.5–2.0, while the negative one shows some fluctuations that are not greater than 20%. The increase of the positive flux is due to the emergence of new magnetic flux in the lower part (smaller values of Solar_Y) of the positive polarity (shown with an arrow in Fig. 1). Figure 2d shows the unsigned magnetic flux of the smaller newly emerging negative magnetic flux in the region pointed with the arrow in Fig. 1. We believe these two newly emerging opposite polarity fluxes correspond to cool, small-scale loops, emerging into the physical environment of pre-existing hot loops.

3. Physical interpretation

The joint observations by Madjarska & Doyle (2003), and the most recent data presented above, provide new evidence about the emergence of magnetic flux on the Sun, associated with the blinker activity seen by CDS and SUMER. In favor of these
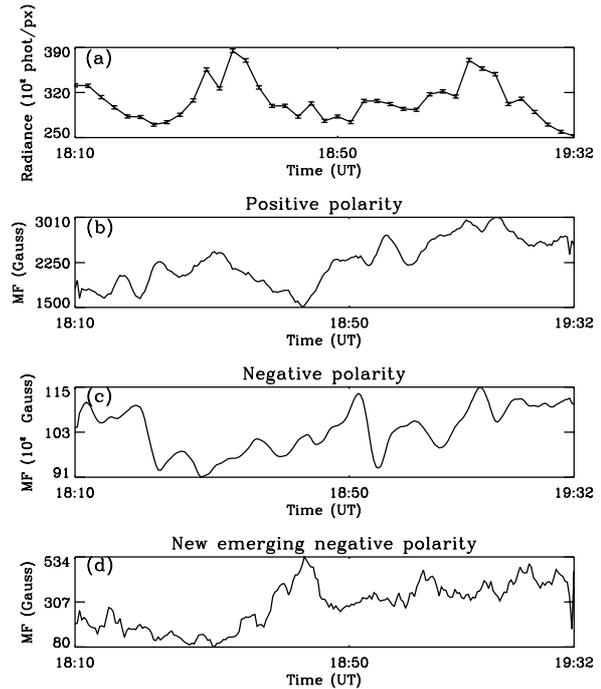

Fig. 2. a) CDS O V 629 Å radiance profile of blinker BL2 obtained by integrating over the blinker area; **b)** temporal evolution of the total magnetic flux (MF) from positive polarity fragments above 40 Gauss associated with BL2; **c)** total magnetic flux from negative polarity fragments above 40 Gauss underlying the loop associated with BL2; **d)** temporal variations of the new emerging magnetic flux of negative polarity above 15 Gauss appearing in the BL2 position.

findings, we provide a plausible physical scenario, which is rather similar to that proposed by Chae et al. (2000). The difference, however, is in the physical interpretation of the observable consequences of the reconnection process.

When analyzing the dynamical consequences of magnetic reconnection on the Sun, it is often neglected that the plasma embedded in the field lines of the two flux systems undergoing reconnection are not necessarily at the same temperature: one flux system may consist of cold plasma, while the other contains hot coronal plasma. Once reconnected, the newly created magnetic field lines will consist of plasma elements at different temperatures and a temperature interface (TI) between them. The field-aligned thermal conduction then becomes important in thermalizing the cold segment of a particular field line. We argue that this could explain the observational signatures of CDS blinkers, and perhaps some other transient phenomena contributing to TR dynamics.

In our scenario, as new magnetic flux emerges on the Sun, it undergoes flux cancellation (i.e. slow magnetic reconnection) with the pre-existing magnetic field. As a result of this process, numerous temperature interfaces (TIs) are created to buffer the cold and hot plasma elements of the reconnected field lines; the cool plasma at chromospheric temperatures is supplied by the emerging flux, whereas the hot plasma comes from the pre-existing magnetic field. The dynamics of the TIs are determined by the interplay between field-aligned thermal conduction, radiation, and volumetric heating. The characteristic speed, v_{TI}, at which a TI can travel along a field line can

be on the order of a few 10 km s^{-1}, which is the speed of a heat conduction front propagating through the cold plasma. By neglecting effects of radiative cooling and volumetric heating, the following approximate scaling law applies:

$$v_{\text{TI}} = 9.7 \left(T_e/10^6 \text{ K}\right)^{5/2} \left(n_e/10^{10} \text{ cm}^{-3}\right)^{-1}$$
$$\times \left(l/3 \times 10^8 \text{ cm}\right)^{-1} \text{ km s}^{-1}. \tag{1}$$

This is derived from the assumption that the enhanced heat flux is balanced by the oppositely directed enthalpy flux. (The hydrodynamic flux is neglected in this estimate.) At the characteristic speed given by this formula, a TI travels a distance of 195 km over 20 s, which is the integration time of the SUMER dataset of Madjarska & Doyle (2003). In CDS the integration time is longer, and so the distance traveled by TIs is even greater here. Therefore, over the integration time of these spectrographs, the *filling factor* of plasma emitting at TR temperatures is increased, resulting in enhanced emission, accordingly. Furthermore, since the background emission of both cool chromospheric and hot coronal plasma is strong, the relative changes in the emitted flux at these temperatures will be smaller compared to those detected in TR lines.

In light of this mechanism, the duration of blinkers may depend on many factors, such as: characteristic time of flux emergence ($\approx 1/2$ h); actual field geometry and specifics of the reconnection process; and thermodynamic state of the plasma elements in the two magnetic flux systems. There are perhaps other physical effects not taken into consideration here, which may be important. Note that the complexity of field geometries and physical circumstances on the Sun results in unique observational consequences, even in the scope of a particular transient phenomenon, such as blinkers.

4. Other consequences and conclusions

In the classical picture of the solar atmosphere, the interface between the cool chromosphere and the much hotter corona is termed as the transition region (TR). A purely naive interpretation of the latter would be a static layer, in which the temperature increases by two orders of magnitude, while the mass density decreases accordingly. The wealth of solar observations taken over the past decade have revealed the complex dynamic nature of the solar TR. One important question still remains: What are the physical causes of the observed variability in TR lines, as seen by SUMER and CDS on board SoHO?

Based on the new observational evidence presented here, we propose that the emerging magnetic flux, as it interacts via slow magnetic reconnection with a pre-existing flux system, makes it possible to create numerous microscopic TIs. These are, in essence, TRs served to buffer the cool and hot plasma elements (originally belonging to the two separate magnetic flux parents) of newly reconnected field lines. The enhanced emission at TR temperatures, resulting from the increased *filling factor* of TR plasma as the TIs propagate, is what we suggest causes some of the observed blinker activity. The enhanced heat conduction flux over a length l determines the speed at which TIs move along the reconnected field lines and thermalize the plasma elements. As a result, oppositely directed enthalpy and hydrodynamic fluxes are generated to balance the heat flux. The enthalpy flux causes evaporation of cold material at the base. The characteristic time of this process is $\sim l/v_{\text{TI}}$. The observed Doppler shift during blinkers should be the result of hydrodynamic flows, since bulk motions of plasma are caused by density gradients along the reconnected field lines, and also due to relaxation of the field lines.

If the reconnected field lines turn open, the upward moving material may result in spicules, otherwise the evaporated material travels along closed magnetic loops, manifesting siphon flows. In this context, some spicules may be associated with blinkers, and most probably observed at the boundaries of unipolar magnetic regions (coronal holes). Blinkers and spicules are then expected to be seen where newly emerging flux interacts with the pre-existing open field region.

One important dynamic consequence, on a global scale, is that the reconnection process allows part of the open magnetic flux to become disconnected from the parent region, and so serves to redistribute open flux on the Sun. Future joint observations, combined with a realistic follow-up numerical investigation coupled with line synthesis, is required to examine the observable consequences of this model in the context of blinkers. At least, we provide one more interpretation of the blinker phenomenon, which adds to the range of possibilities presented by Priest et al. (2002). It has also become evident that some of the blinkers represent brightenings in coronal BPs which is not surprising taking into account their location, intensity variations, Doppler shift etc. A forthcoming study will explore this relation.

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