WHAT BLINKERS REALLY ARE?

D. Marik\textsuperscript{1} and R. Erdélyi\textsuperscript{2}

Space & Atmosphere Research Center, University of Sheffield, Department of Applied Mathematics, Hicks Building, Hounsfield Road, S3 7RH, Sheffield, UK
E-mail: \textsuperscript{1}D.Marik@sheffield.ac.uk, \textsuperscript{2}Robertus@sheffield.ac.uk

ABSTRACT

The transition region blinkers, according to the present model, may play a significant role not only in the solar transition region and the solar atmospheric plasma heating but may even contribute to the solar wind mass flux. They were mainly found, e.g., in He I, O III, O IV, O V and Mg IX, respectively (Harrison, 1997). Their typical lifetime is approximately 16s, the intensity enhancement ratios are around 1.8, and they appear at $1 - 20\text{s}^{-1}$ on the Sun. Blinker events seem to be increases in density and/or filling factor rather than to be increases in temperature. Most of the blinkers have repetitive nature and high percentage of these events occur above unipolar magnetic field. A simple physical model of blinkers based on the process of magnetic reconnection is developed. In the present paper results of solving the fully nonlinear, time-dependent, dissipative, radiative 2-D MHD equations are shown. By setting the initial parameters describing blinkers and taking into account the limit of the spatial resolution of SOHO CDS propagating reconnection jets are found to have properties described by CDS observations. Results may suggest SOHO CDS observes explosive events as blinkers in some cases.

Key words: explosive events – blinkers – magnetic reconnection.

1. INTRODUCTION

The transition region blinkers are controversial phenomena in the lower solar atmosphere observed in the past five years. According to the present suggested model these small-scale bright intensity enhancements may play a significant role not only in the solar transition region and in the solar atmospheric plasma heating but may even contribute to the solar wind mass flux. There are numerous observations about blinkers produced by the Coronal Diagnostic Spectrometer (CDS) of the Solar and Heliospheric Observatory (SOHO) (Harrison, 1997). CDS is a double spectrometer operating in the 150-800 Å region enabling to investigate the emission lines arising in the corona and the transition region at different (E)UV temperatures. The most frequently investigated lines are He I (584.33 Å), formed at $2 \times 10^4K$ (chromospheric line), O III (559.52 Å), O IV (554.52 Å) and O V (629.73 Å) formed in the transition region at $10^5K$, $1.6 \times 10^5K$ and $2.5 \times 10^5K$, respectively, and Mg IX (366.06 Å), Mg X (624.94 Å) formed at $10^6K$ and $1.2 \times 10^6K$. For illustration we show examples of a typical quiet Sun region in He I, O V and Mg IX in Figure 1.

In these images the typical cell sizes are of the order of 30–40 arc sec. In the He I image we can clearly see the supergranular network which is similar to the O V network. Although the network structure is identical, the brightest He I and O V locations do not necessarily correspond. The feature of the million degree coronal Mg IX emission is rather different from the He I and O V emission. Although some of the brightest area in He I and O V images overlap with the bright regions of the Mg IX image, the Mg IX structure has a much larger scale size.

Blinkers are best detected in the O V line and are found to occur in both the active and quiet regions of the Sun. The typical behaviour of the active-region blinkers is very similar to quiet-region blinkers. In order to understand the problem of blinker events we recall some characteristic blinker data obtained by Bewsher et al. (2002) in a quiet Sun region.

The mean lifetime of a blinker event is approximately 16 minutes, the mean rise and fall times are at around 8 minutes and the intensity enhancement ratios are around 1.8. The frequency of blinker events on the whole solar surface is at around $1 - 20\text{s}^{-1}$. The mean area of a blinker is $2.9 \times 10^7\text{km}^2$. Furthermore there is evidence that blinker events appear to be increases in density and/or filling factor rather than to be increases in temperature. Most of the blinkers have repetitive nature but according to Fourier and wavelet analysis of blinker data no evidence of any periodic behaviour in blinkers can be found.

O V blinker events are also identified as blinkers in O IV and He I with 80 - 90% and 23 - 28% of the O V blinkers detected in these lines, respectively. He I and O IV lines are one of the strongest chromospheric and transition region lines. Intensity enhancements also occur in O III but this line is much weaker and harder to detect. No significant enhancement is found in the lines Mg IX and Mg X simultaneously with the O V blinker events indicating there are no evidences that blinker events have a noticeable coronal signature. The lack of correlation between brightenings in the Mg IX and other lines could also mean that the corona is at least partly decoupled from the transition region and chromosphere (Briko
ci et al., 2001).

The statistical analysis of blinkers also shows that the distribution of blinkers is not uniform, they are located in regions of strongest emission in the chromospheric and transition region lines. In addition, almost the total number of blinkers occur above well defined strong magnetic fragments and approximately 75% of this events can be found above the regions where only one polarity dominates.

Despite factors of about 2 in intensity increase, the O-line ratios remain stable. The lack of a change suggests that increase in emission measure which characterises the blinker is due predominantly to an increase in density and/or filling factor, and this is most evident in transition region temperature plasma. Typical cooling times for such plasma at typical transition region densities and O V temperatures are in the region of just a few seconds to a few tens of seconds. Plasma with higher temperatures (around 1 million K) and typical coronal densities have much more longer cooling time (~ 1000 s). Taking into account these conditions it is probable that the blinker events are driven by activity which most likely continues to dump energy into the plasma throughout the blinker duration. There is a continuous energy input during the event (Harrison et al., 1999). On the other hand temperature balancing in transition region blinker plasma is not a realistic assumption because of small cooling times (Sarro et al., 1999). Temperature change takes place on time scales smaller than the ionization and recombination time scales of the plasma. In this case time-dependent ion populations are needed to be calculated.

The present idea to model blinker events is the phenomena of magnetic reconnection. Here our aim is to investigate the reconnection jets caused by the process of magnetic reconnection in a 2D physical environment representing the solar transition region. Magnetic flux cancellation is initiated by a localized increase of the magnetic diffusivity in the current concentration separating two semi-infinite magnetised plasma. Reconnection results in jet ejections along the current sheet.

CDS has a spatial resolution of 1.7" × 4.0" which more than overlaps the area of an average blinker size on the solar surface. Hence, CDS provides unresolved integrated images from the whole blinker surface (and of course also from the whole depth of the domain). Taking into account these facts MHD reconnection simulations of (which are suggested to describe explosive events by many authors) will result in blue jet velocity profiles similar to observations describing blinker events. This may suggest blinkers could be in reality identical to explosive events, but CDS cannot resolve these events.

2. PHYSICAL DESCRIPTION OF THE PROBLEM

In the present paper we consider the solar atmospheric plasma as an ideal gas embedded in an intermittent inhomogeneous magnetic field. For the sake of simplicity, the effect of gravity is neglected. The governing equations of a 2D dissipative, radiative MHD can be seen in, e. g., Roussev et al. (2001a).

We consider the initial magnetic field configuration
as follows

$$\mathbf{B} = (0, B_y); \quad B_y = B_0 \tanh \left( \frac{C x}{L_0} \right),$$

where $L_0$ and $B_0$ are the typical values of a length scale and magnetic field strength, respectively, and $C$ is a constant. (In the model the $y$ axes is perpendicular to the solar surface.) The initial equilibrium velocity is assumed to be zero throughout the computational domain. The total pressure balance can be considered as

$$\frac{B^2}{2} + P = \frac{B^2}{2} + P_0 = \text{const.}$$

where $P$ is the kinetic gas pressure. A uniform kinetic gas pressure distribution in the $y$-direction is assumed and, as a result, the thermal energy $e = P/(\gamma - 1)$ is also uniform in the $y$-direction. Taking into account the condition for total pressure balance in the entire domain, one can write for $e$:

$$e(x, y) = e(x) = e_0 \left[ 1 + \beta - \frac{B_y B_0}{\beta} \right]^{\frac{2}{\gamma - 1}},$$

where $\beta = P/P_m$ ($P_m$ is the magnetic pressure). To represent the transient region containing a current sheet the density stratification in the $y$-direction is given by:

$$\varrho(y) = \varrho_0 \left( 1 + \Delta \varrho \left( 1 - \tanh \left( \frac{\varrho}{\varrho_0} (y + y_s) \right) \right) \right),$$

where $\varrho_0$ represents a typical value of the mass density in the low density region and $2\Delta \varrho$ means the jump in density across the transition region. $\varrho$ is a steepness parameter and $y_s$ is a shifting parameter.

In the $x$ direction we use the following form of the mass density distribution:

$$\varrho(x) = \varrho_0 \left( \frac{P}{P_m} \right)^{\theta} = \varrho \left( \frac{e}{e_0} \right)^{\theta},$$

where $\theta$ is a free parameter (one over the polytropic index). Finally we also assume energy balance in the entire physical domain for the initial state: $S(x,y) - \nabla \varrho(x,y) - L_r(x,y) = 0$ at $t = 0$, where $S$, $\varrho$ and $L_r$ are the volumetric heating rate, the heat flux and the radiative loss, respectively.

In order to characterize the diffusion of the magnetic field we can initiate a localized magnetic diffusion as follows

$$\eta_{loc} = \eta_0 F(t) \exp \left\{ -\frac{\alpha}{L_0^2}[x^2 + (y + y_0)^2] \right\},$$

where $F(t)$ is a function of time, $\alpha$ is a steepness parameter, $y_0$ is a shifting coefficient and $\eta_0$ defined as $\eta_0 = V_{A0} L_0/R_m$ ($R_m$ is the magnetic Reynolds number, $V_{A0}$ is the Alfvén speed given by $V_{A0} = B_0/\sqrt{\varrho_0}$.

This model may represent the physical situation and geometry when two magnetic flux tubes of opposite polarity are pushed together and come into contact due to their foot-point motions.

3. NUMERICAL METHOD

We have used a 2D compressible MHD code based on staggered meshes (Nordlund et al., 1995). The MHD equations are solved in a 2D domain using non-uniform staggered grids. The MHD code conserves mass, momentum, energy and magnetic field divergence.

4. SIMULATION

When the localized magnetic diffusion parameter is switched on the magnetic field on either side of the current concentration starts to reconnect. This process changes the topology of the magnetic field and the magnetic flux starts to advect into a so-called X-point along the $x$-axis, and is expelled from the diffusion region through two reconnection jets along the $y$-axis of the domain. Fig. 2. shows there is a blue shifted jet propagating towards the high temperature region reaching a higher velocity and there is a red shifted jet moving towards the high density region. Similar simulations were carried out by Roussev al. (2001abc) where they modelled explosive events. We suggest they have used unrealistic high Reynolds number for their jet of explosive events simulations. Explosive events seen by SUMER may give the impression to have different properties from blinker events seen by CDS. For example they are smaller and their lifetime is much shorter. The characteristics of the maximum jet velocity profile is rather different, because explosive events have maximum jet velocity around the Alfvén speed. We do not have reliable data about blinker jet speeds. According to previous spectral studies it is predicted to be only around 20 km/s (7) (Harrison et al., 1999).
In order to obtain solutions similar to blinker events we need to find the appropriate initial parameters. The most important parameters are \( \eta_0, t_{\text{rl}}, t_{\text{rr}}, \Delta \theta, \) \( y_0, \) and \( y_d. \) One also has to take into account several requirements, for example: the evolving jets must show density enhancement effect rather than temperature enhancement. The maximum velocity of the jets must be less than 20 km/s. One also needs to consider the reported duration and the rising time of blinkers.

5. VELOCITY PROFILE

Let us focus on the velocity profile of the outward propagating jets fund in the simulations. Before we determine the maximum velocity characteristics for the jets we wish to recall: (i) a CDS pixel overlaps a \( 1.7' \times 4' \) domain which actually corresponds to a whole blinker area on the surface of the Sun. Hence, one observes with CDS an averaged integrated entire blinker surface; (ii) the CDS exposure time is around 10 sec.; (iii) images are averaged over the whole depth of the domain. Taking into account all these facts we have to make mean values of the numerically found velocity along the \( z \)-axis at every points of the \( y \)-axis. In the model the domain along the \( x \)-axis was \( [0.25L_0, 0.25L_0] \) symmetric about the \( y \)-axis. This domain on the solar surface corresponds approximately to \( 1.7' \). The next step is to take a mean value along the \( y \)-axis and finally we have to integrate the velocity profile in time for every 10 sec interval. The difference between the actual simulation and what CDS would 'see' as an integrated velocity profile is given in Figure 3.

6. DISCUSSION

Figure 3 shows, that the integrated velocity profile riches a much lower velocity than the one found by the simulations. Unfortunately we cannot simulate blinker effects longer than 6-8 minutes this time, because a simulation of 8 minutes event takes approximately two days of CPU time. We also report there is no saturation of the integrated velocity profile around the observed 20 km/s blinker velocity. However, the location of the blue jet after 300 sec is anyway already in the solar corona and would be not visible in transition region lines. Since the averaged mean velocity remains small the reconnection model could describe blinkers.

On the other hand one has to recall that 80 - 90 % of the blinker events are in unipolar magnetic field dominated areas which may contradict blinkers are the results of magnetic reconnection unless there is a tilt in the unipolar magnetic field. This latter requires more observations to be carried out.

![Jet Velocity vs. Time](image)

**Figure 3.** The 'actual' numerical simulations (long dashed) and the integrated (dotted) velocity profiles obtained from Fig. 2. \( V_{\text{jet}} \) is in Alfvén speed units \( \left( V_{\text{A0}} = 1.293 \cdot 10^7 \text{ cm s}^{-1} \right) \).

7. ACKNOWLEDGEMENTS

R. Erdélyi acknowledges M. Kéray for patient encouragement and the support from Nuffield Foundation. The authors also acknowledge the financial support obtained from the NSF Hungary (OTKA, ref nr. TO32462).

REFERENCES