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Research Note

Physical parameters of EUV explosive events

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Abstract. Previously published results of EUV explosive events and electron density enhancements in the solar transition region are revised. An attempt has been made to correlate both observational phenomena, and to associate the observed density enhancements to magnetic reconnection sites. The corresponding local magnetic field strength in these sites is estimated. These values are of the same order as previously measured in photospheric cancelling flux regions.

Key words: Sun: atmosphere – Sun: magnetic fields – Sun: particle emission – Sun: transition region – Sun: UV radiation

1. Introduction

The so called *EUV explosive events* represents one of the smallest scale flare-like phenomena directly observable on the Sun. These events have been observed to cover areas from one to a few arcsec squared, with lifetimes of between 20 and 200 seconds, and kinetic energies of the order of $\sim 10^{23} - 10^{25}$ erg. These explosive events are mostly seen at transition region temperatures (Brueckner & Bartoe 1983, Dere et al. 1989). Recent data suggest that their time variation and spatial structure are consistent with bi-directional plasma jets produced by magnetic reconnection (Dere 1991, 1994; Porter & Dere 1991; Innes et al. 1997; Pérez et al. 1999a; Benz & Krucker 1999).

Chae et al. (1998) and Dere (1991) observed explosive events occurring in bursts at intermittent locations along the boundary separating opposite polarity elements that were cancelling and reconnecting. Dere (1991) found that explosive event velocities were comparable to the Alfvén velocity, which supported the hypothesis that the acceleration of plasma is due to magnetic field annihilation between the emerging and the pre-existing magnetic field. In the area where the current sheet is formed, density and temperature enhancements are expected (Cheng 1980, Hayes & Shine 1987).

Pérez et al. (1999a), henceforth Paper I, studied EUV explosive events identified in two observational sequences made in July 1996. In a second paper (Paper II), Pérez et al. (1999b) discussed a density diagnostic carried out in a similar location on the Sun as the explosive events analysed in Paper I. These latter observational sequences were obtained very close in time to those presented in Paper I. Here, a suggestion is made about the possible connection between the variations observed in the electron density and the sites of the explosive events. Finally, an estimate of the magnetic field strength is given for the area where these events took place.

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Table 1. Description of observational data. The slit size and area rastered are given in arcsec squared.

Date (1996)	10 July	14 July
Paper I: Explosive Events		
Start (UT)	07:19:18	06:30:20
End (UT)	07:34:44	06:40:45
Pointing	(630,–200)	(2,910)
Slit	0.3×120	1.0×120
Raster	66×120	33×120
Location	AR: NOAA 7978	Northern CH
Exposure time	15 s	20 s
Spectral line	O VI 1032 Å	C IV 1548 Å
Log (T_e/K)	5.5	5.0
Paper II: Density Enhancements		
Start (UT)	07:36:15	00:46:42
End (UT)	08:42:56	02:14:04
Pointing	(630,-200)	(0,910)
Slit	0.3×120	1.0×120
Location	AR: NOAA 7978	Northern CH
Raster	$\sim 7 \times 82$	$\sim 1.5 \times 112$
Exposure time	20 s	20 s
Line Ratio	O IV 1399/1401	O IV 1399/1401
Log (T_e/K)	5.2	5.2

2. Observations

The observations discussed here were obtained on 10 and 14 July 1996 with the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) instrument on board the SOHO satellite (Wilhelm et al. 1997). In Table 1 details of the observations presented in Paper I & Paper II are outlined. The dataset centered at $(630, -200)$ arcsec, in active region NOAA 7978, was observed on 10 July in the O VI 1032 Å line and, less than two

Table 2. Observational characteristics of the EUV explosive events with the area given in arcsec squared.

Characteristic	Northern CH	AR (NOAA 7978)
Number of events	1	≥ 5
Life-time	160 s	60–90 s
Maximum Doppler velocity (v) in (km s^{-1})	150 (*blue*) 100 (*red*)	EVENT1: 150 (*blue & red*) EVENT2: 260 (*blue*), 215 (*red*) EVENT3&4: 200 (*blue*), 180 (*red*)
Extension (N-S)×(E-W)	6×8	EVENT1: 4×7–9 EVENT2: 4×4 EVENT3&4: 14×4
Temperature	Mid-Transition Region (10^5 K) Not seen at $\sim 2\,10^4$ K	High-Transition Region ($3.2\,10^5$ K)
Type of event	Bi-directional jet (reconnection jet)	Burst of events Bi-directional jets (reconnection jets)
Inclination	$\sim 13°$	$\sim 10° - 23°$
Length	$6\,10^3$ km	1.5–1.3 10^4 km
Line profiles	Asymmetric profiles Multi-Gaussians fitted (2–4)	Asymmetric profiles Multi-Gaussian fitting (2–3)
Other	Supersonic mass motions (sound speed ≈50 km s^{-1})	Supersonic mass motions (sound speed ≈95 km s^{-1}) Associated to photospheric magnetic flux cancellation & regions with weak & bipolar magnetic field

minutes later, in O IV 1399 Å & 1401 Å. On 14 July, observations were taken in the Northern coronal hole with a gap of 4h 16min between the C IV 1548 Å dataset and the dataset taken in the O IV lines.

3. Results and discussion

3.1. Paper I: Explosive events

Figs. 5 & 7 in Paper I, show the time series for the explosive events observed in the transition region lines of O VI 1032 Å and C IV 1548 Å. Table 2 summarizes the main results presented in Paper I, for the events observed in the Northern coronal hole and in the active region. Four events were studied for the active region dataset and in order to avoid confusion they have been labeled in Table 2 as EVENT *n*. This table gives the number of events observed in each region, their corresponding lifetime, the maximum Doppler velocity observed for each event analysed, their extension along the slit, and the corresponding temperatures of the lines in which these events were observed. Other relevant conclusions from this work are also summarized in Table 2, i.e. the bi-directional nature of the observed explosive events.

The locations of the explosive event sites found in the active region, as summarized in Table 3, are in very good agreement with the locations found in Paper II for the larger variations in the electron density. However, such a correlation is not present for the Northern coronal hole datasets. Therefore, at least in the case of the active region, given the spatial coincidence between the explosive event sites and the electron density enhancements, both phenomena might reasonably be considered to be physically related.

3.2. Paper II: Density enhancements

In Paper II we used the density-sensitive line ratio of O IV 1399.8/1401.2 to diagnose the electron density in the transition region of a coronal hole, an active region and a 'quiet' Sun region at disk center. All the data handling procedures applied to the original data and the atomic data used are described in this paper. Since the O IV lines used are not strong we used binning in time of four minutes and a running mean along the slit of five pixels, which constitutes our resolution element.

Figs. 5 & 9 of Paper II show the electron density values obtained for the coronal hole and active region dataset. These show variations along the slit as well as in the E-W direction, over time periods of a few minutes. Such variations can be as large as a factor of two in ∼5 minutes.

One possible explanation could be that explosive events occurring in the high-transition region (at $\sim\ 3\,10^5$ K) could be caused by the deposition of energy by, for example, magnetic reconnection at lower temperature region, (see Sarro et al. 1999). As a consequence, compression and, therefore, density enhancements would be observable at mid-transition region temperatures ($\sim 1.5\,10^5$ K). From this point of view, the higher frequency of occurrence of the density enhancements in the active region with respect to the observed explosive events could be indicative of a particular distribution/spectra of energy deposited over a period of time.

Dere et al. (1991) concluded that it is valid to use the O IV line ratios for the density diagnostic of explosive events, even if these are fast-varying phenomena. The time-scales needed to keep the hypothesis of ionization equilibrium, and of collisional and radiative equilibrium, are fast in comparison with the time-

Table 3. A lower limit to the magnetic field strength (B) for the explosive event sites analysed in Paper I and the corresponding electron density values found in Paper II.

Event no.	Location (N-S) x (E-W) (arcsec^2)	N_e (cm^{-3})	V_A (*red*) (km s^{-1})	B (*red*) (G)	V_A (*blue*) (km s^{-1})	B (*blue*) (G)
EVENT1	[−172, −176]	max: 3 10^{11}	150	33	150	33
	x [627, 626]	mean: 1 10^{11}		19		19
EVENT2	[−172, −176]	max: 3 10^{11}	215	47	260	57
	x [627, 626]	mean: 1 10^{11}		27		33
EVENT3&4	[−205, −210]	max: 1 10^{11}	180	23	200	25
	x [625, 623]	mean: 7 10^{10}		19		21
	[−214, −220]	max: 3 10^{11}	180	39	200	44
	x [625, 623]	mean: 1 10^{11}		23		25

scales observed for explosive events (20–60 s). Therefore, the electron density values given in Paper II can be regarded as being valid even if they correspond to explosive event sites.

3.3. Estimation of the local magnetic field strength

Imagine an xy-plane which represents a neutral current sheet with say, thickness of $2l$. Thus an inflow of magnetic field at velocity v from the x-direction is balanced by an outflow along the y-direction. Integrating over the current sheet gives

$$j_z = \frac{cB_y}{4\pi l}. \tag{1}$$

Suppose the plasma is incompressible and in steady-state, the equilibrium pressure balance can be written as

$$\delta p = p_i - p_o = \frac{\rho v_y^2}{2}, \tag{2}$$

where p_i, p_o are the gas pressure inside and outside the current sheet, respectively. In an equilibrium state

$$\delta p \approx \frac{B_y^2}{8\pi}, \tag{3}$$

i.e., the pressure balance is set equal to the magnetic pressure outside the reconnection region. Combining these equations, one arrives at

$$v_y = \frac{B_y}{(4\pi\rho)^{1/2}} = v_A = 2.5\ 10^6\ B\ {N_e}^{-1/2}\ \ (\mathrm{km\,s^{-1}}) \tag{4}$$

where ρ is the mass density. In the above we have assumed $N_p \sim 0.8N_e$ where N_e is in cgs units of cm^{-3} and v_A is the Alfvén speed. This is the classical Sweet-Parker steady-state solution which assumes that the outflow pressure is the same as that at the neutral point. However, if the outflow pressure was less than the input pressure then $v > v_A$, i.e. the reconnection rate is enhanced. On-the-other-hand, if the outflow pressure is large, then $v < v_A$ (see Priest & Forbes 2000 for further details). These latter situations are not applicable to explosive events, due to the time duration of the jets and the lack of an observed acceleration/de-acceleration in the jet velocity. Thus in the discussion which follows, we assume $v = v_A$ where the maximum observed Doppler velocity for each explosive event is given in Table 2. It should also be noted that these Doppler velocities are only approximate, since we are unable to correct for line-of-sight effects. Table 3 shows the local magnetic field strengths (B), calculated using Eq. 4. These values have been estimated for both the red-shift and blue-shift velocities given in Table 2. The maximum and averaged electron density values for each selected region are shown in Table 3.

The electron density values presented in Table 3, for each observed explosive event in the active region dataset, are generally very similar except for the event located between $[-205, -210]$ (N-S) and [625, 623] (E-W) which is, nevertheless, similar in magnitude. Therefore, we may assign a maximum electron density value of $3\,10^{11}$ cm^{-3} and an averaged value of 10^{11} cm^{-3}, for the explosive events observed in the active region dataset. The corresponding variation of magnetic field strengths is mainly due to the changes observed in the Doppler velocities, which could be affected in part by line-of-sight effects since the observed values are only the projected velocity values in the radial direction. The estimated magnetic field strength ranges between 19–57 G for the active region. These field strengths are of the same order as those measured in the photospheric cancelling flux regions by the Big Bear magnetograph (Martin 1984).

Dere et al. (1991), using the same method described here, inferred field strengths of 15 G for the red wing plasma and 24 G for the blue wing plasma of an explosive event seen in the S IV 1406 Å line in a 'quiet' Sun region. The density values used by Dere et al. were $7\,10^{10}$ cm^{-3} for the red wing and $6\,10^{10}$ cm^{-3} for the blue wing. The averaged density value found here is similar, within errors, to those calculated by Dere et al. (1991) for an explosive event occurring in O IV lines. Moreover, their inferred field strengths are of the same order as those estimated here. Therefore, it seems reasonable to assume that the observed electron density enhancements coincide with explosive event sites.

In conclusion, the observed electron density enhancements, in particular in the active region dataset, are consistent with increases in the electron density due to transient events

(Cheng 1980, Hayes & Shine 1987, Dere 1991). On the other hand, the proximity in time and co-spatial location of the explosive events described in Paper I, together with their observed burst-like occurrence, indicates that there is a good probability that these events are occurring at the same time as the electron density enhancements. Finally, the values of the local magnetic field strength confirm this hypothesis, correlating the observed density enhancements to regions of magnetic field cancellation and, therefore, with reconnection sites.

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