TRANSITION REGION SMALL-SCALE DYNAMICS: UV EXPLOSIVE EVENTS

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ABSTRACT

High spectral, spatial and temporal resolution UV observations of the quiet Sun transition region show a highly structured and dynamical environment where transient events such as brightenings, blinkers and explosive events occur continuously. In particular explosive events are characterized by strongly non-Gaussian line profiles witnessing velocities up to 200 km s⁻¹. The high kinetic and enthalpy fluxes associated with these events could be important in the energy balance of the transition region and, perhaps, of the whole corona. In this paper we present a high spatial resolution (~ 1") spectroheliogram of a 270 x 290 arcsec² wide area of the quiet Sun acquired with SUMER/SoHO in the O vi 1032 spectral line. The extremely high quality of these observations allows us to identify tens of explosive events and to study their relationship with the underlying photospheric magnetic field. Moreover, the behaviour of lines emitted by plasma at chromospheric (2 x 10⁴ K) and coronal (10⁶ K) temperatures during transition region explosive events is investigated. We conclude that those events do not contribute significantly to the energy balance of the corona and seems typical of structure not obviously connected to the T ≥ 10⁶ K corona.

Key words: Solar transition region; Explosive events; Coronal heating.

1. INTRODUCTION

When observed with high spatial (~ 1 arcsec) and temporal (~ 10 - 100 seconds) resolution the "quiet" Sun transition region shows transient events such as brightening (e.g., Brković et al. 2000), blinkers (Harrison 1997; Harrison et al. 1999) and UV explosive events and jets (Brueckner & Bartoe 1983). In particular, UV explosive events are a class of dynamic events quite common in quiet Sun areas, with a birthrate over the whole Sun of between 600 s⁻¹ (Dere et al. 1989) and 3300 s⁻¹ (Ryutova & Tarbell 2000). Explosive events are characterized by spatial scales of ~ 2000 km, average lifetime of about 60 seconds and highly non-Gaussian line profiles showing Doppler shifts up to 250 km s⁻¹ (Dere et al. 1989). They are generally observed at the boundaries of the super-granulation cells (Porter & Dere 1991) in regions with weak and mixed polarity fluxes away from the brightest network regions (Chae et al. 1998). The often observed association with episodes of photospheric magnetic flux cancellation (Dere et al. 1991; Chae et al. 1998; Ryutova & Tarbell 2000) indicates magnetic reconnection to be their likely energy source.

In this paper we present high spatial resolution observations of a large quiet Sun area in the mid-transition region line O vi 1032 (3 x 10⁵ K). These observations allow us to identify tens of explosive events and to investigate their relationship with the magnetic network. The birthrate and the typical size of these events were also found. Moreover, their location in the wider frame-work of the outer solar atmosphere is also discussed through simultaneous observations of lines formed at chromospheric (S II 1250.6 2 x 10⁴ K), transition region (N v 1238 1.8 x 10⁴ K) and coronal (Mg x 1.1 x 10⁵ K) temperatures. From our results we make an estimation of the total energy (kinetic energy plus enthalpy) flux associated with these events and discuss the results with respect to the problem of coronal heating.

2. RELATION WITH THE MAGNETIC NETWORK

A raster of a 270 x 290 arcsec² quiet region around Sun centre (see Fig. 1) was obtained on 30 January 1996 in the O vi 1032 Å line through a series of spectra obtained exposing for 3 s the A detector of the SUMER spectrograph (Wilhelm et al. 1995). The observed area was covered by stepping of 0.75" the 1" x 300" slit 360 times. Around the same time 15 full disk magnetograms were acquired with MDI (Scherer et al. 1995), allowing us to build a good signal to noise average magnetogram to superpose to the
O vi observations. The structures visible in Fig. 1 and their relationship with the underlying longitudinal magnetic flux have been discussed in details by Warren & Winebarger (2000). Here, we want to focus on the analysis of the line profiles looking for the non-Gaussian profiles characterizing the explosive events.

To this purpose a single Gaussian has been fitted to all the $\sim 10^9$ spectra forming the raster. All line profiles, for which at least one of the fitted parameters (or the $\chi^2$) was diverging by more than 3-$\sigma$ from the average of its distribution, were first selected. All the profiles forming this sub-sample were, hence, visually inspected and all profiles for which at least 3–4 contiguous pixels were consistently diverging by a Gaussian profile (by more than their Poissonian errors) were flagged as explosive events. The positions of the flagged profiles are indicated by black + marks on the intensity image displayed in Fig. 1. The majority of the profiles show a stronger blue wing with average bulk velocities around 100 km s$^{-1}$.

It clearly visible that the selected points are not randomly distributed, but appear forming small patches. Considering all contiguous points as belonging to the same event, it is possible to count $N_E = 49$ explosive events in the observed area with an average size of $\sim 1800$ km (at the SoHO-Sun distance $1''\sim 715$ km). The observed events outline the
network but generally do not appear on the bright-est regions where the longitudinal magnetic flux is stronger. In fact, for 47 out of 49 of these events, the average absolute longitudinal flux in the underlying area is below 5 Gauss. Although a vector magnetogram with higher spatial resolution would be necessary to measure the true magnetic flux, these observations indicate explosive events to occur in regions different from the very bright network.

The explosive events birthrate \( R \) is given by:

\[
R = \frac{N_{EE}}{t_{exp} A_{obs}},
\]

where \( t_{exp} \) is the exposure time and \( A_{obs} \) the observed area. Given an observed area of \( 3.2 \times 10^{16} \) cm\(^2\), from Eq. 1 we obtain a birthrate \( R = 4 \times 10^{-20} \) events cm\(^{-2}\) s\(^{-1}\) (or \( \approx 2500 \) events s\(^{-1}\) over the whole Sun).

3. CHROMOSPHERIC AND CORONAL SIGNATURES

Despite the fact that UV explosive events have been observed for almost 20 years (see Teriaca et al. 2002 and references therein) their location in the wider frame-work of the outer solar atmosphere is still uncertain since the large majority of the observational work was restricted to lines formed below 10\(^{6}\) K. Teriaca et al. (2002) obtained observations of the quiet Sun transition region and corona in the N \( \mathbf{v} \) 1238.8 Å and Mg X 625 Å lines recorded simultaneously with the SUMER spectrograph. These observations, avoiding the difficulties of comparing observations obtained with instruments characterized by different resolutions, sensitivity and spectral responses, clearly show that explosive events detected in N \( \mathbf{v} \) have no observable counterpart in the 1.1 \times 10^{6} K coronal plasma in which the Mg X line is formed. In general, instead, a signature of the events is found in chromospheric lines (Teriaca et al. 2002; Majjarska & Doyle 2001). Figure 2 shows light curves of the large explosive event observed on October 2001 by Teriaca et al. (2002) in S \( \mathbf{v} \) 1250.6 (top panel), N \( \mathbf{v} \) 1238 (mid panel) and Mg X 625 (bottom panel). The absence of any observable signature in the coronal Mg X line is evident.

4. ENERGETICS OF EXPLOSIVE EVENTS

The absence of signatures in plasma at coronal temperatures shows that, at sites of strong velocities, the plasma is not heated to coronal temperatures indicating that energy is mostly used to accelerate it. The presence of velocities up to 250 km s\(^{-1}\) would, within this framework, suggest a possible role for kinetic and enthalpy energy fluxes associated with explosive events in heating the quiet Sun corona.

\[
KE = 0.4m_H N_e u^2 v A \tau
\]

where \( m_H \) is the mass of the hydrogen atom, \( N_e \) the electron density and \( u, A \) and \( \tau \) the typical speed, area and lifetime of explosive events. \( f \) is the volumetric filling factor accounting for the filamentary structure of the transition region. Values of \( f \) in the literature are around 0.01 (Feldman et al. 1979). However, in a large explosive event, Dere (1991) found a value of \( 10^{-4} \) by comparing the electron density derived from the ratio of density sensitive lines with that obtained by calculating the volumetric emission measure. Applying the same technique to the event reported in their Table 2 by Teriaca et al. (2001) a value \( 7 \times 10^{-3} \) is found. Taking \( A = 3.2 \times 10^{14} \) cm\(^2\) and \( u = 100 \) km s\(^{-1}\) from our O \( \mathbf{v} \) data, \( N_e = 2 \times 10^{10} \) cm\(^{-3}\) (Teriaca et al. 2001), \( f = 7 \times 10^{-3} \) and \( \tau = 60 \) s (Dere et al. 1989), we obtain from Eq. 2 a kinetic energy \( KE = 2 \times 10^{33} \) erg for a typical event.

Similarly, the enthalpy energy flux is:

\[
H = 5N_e KTfuA \tau
\]

where \( K \) is the Boltzmann constant and \( T \) the line formation temperature. Taking \( T = 3 \times 10^{5} \) K (O \( \mathbf{v} \)),

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Light curves of a large explosive event observed on October 2001 in S \( \mathbf{v} \) 1250.6 (top panel), N \( \mathbf{v} \) 1238 (mid panel) and Mg X 625 (bottom panel).
}
\end{figure}
we obtain \( H = 5 \times 10^{23} \) erg. Finally, the total energy flux associated with explosive events is obtained by multiplying the typical energy for one event and the birthrate: \( E_{\text{tot}} = (KE + H) \times R = 3 \times 10^4 \) erg cm\(^{-2}\) s\(^{-1}\). This value is at least one order of magnitude smaller than the integrated radiative loss around \( 3 \times 10^5 \) K \((\approx 4 \times 10^6 \) erg cm\(^{-2}\) s\(^{-1}\)\) calculated by Dere & Mason (1993).

5. CONCLUSIONS

Around 2500 event s\(^{-1}\) are present over the whole Sun. They are located along the network but seem to avoid regions with strong magnetic flux concentrations. They are not observed in plasma at temperatures higher than \( 10^6 \) K and the associated kinetic energy plus enthalpy fluxes are not relevant in terms of the energy budget of the outer solar atmosphere. It is interesting also to note that explosive events have spatial scales \((\approx 1800 \) km\) much larger than the thickness of the transition region in classical loop models \((\approx 100 \) km\). The absence of any observable variation in the plasma at \( 10^6 \) K temperatures would be consistent with the idea that part of the transition region may be dominated by structures not connected with the corona as suggested by Feldman (1983) and Feldman et al. (1999).

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