SUMER OBSERVATIONS OF BI-DIRECTIONAL FLOWS IN CORONAL PLASMAS

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ABSTRACT

Jet-like signatures are repeatedly found in SUMER spectra taken above active regions. Two selected off-disk observations in EUV emission lines of N vii and Fe xix are presented, corresponding to line formation temperatures of $8 \times 10^6$ K and $8 \times 10^6$ K, respectively. Both spectra show bright knots with high Doppler velocities which are interpreted as bi-directional plasma flows. We compare the morphology and the time evolution of the high-velocity events. Although the temperature of line formation for both observations is totally different, the observed features are strikingly similar. The observations support models of magnetic reconnection above active regions.

Key words: EUV spectroscopy; transient events; flows; coronal brightenings

Harrison (1997) suggested the name Blinkers for a similar group of events observed in transition region lines by the CDS spectrometer, although they did not seem to see the Doppler shifts reported by others.

Flare observers (e.g. Schmieder et al. 1996) classify their observed events Microflares or Nanoflares with regard to the estimated energy release during the event lifetime.

XR Bursts and Active Region Transient Brightenings have been reported from the Yohkoh SXT instrument e.g. by Shimizu (1994) and Shibata (1992). This states that transient events are often seen in hot plasma. Radio observers (e.g. Krucker et al. 1997) have suggested that Radio Bursts may be linked to optical brightenings.

2. INSTRUMENTATION

SUMER – Solar Ultraviolet Measurements of Emitted Radiation – is a stigmatic, high resolution normal incidence spectrograph operating in the range from 465 to 1610 Å onboard the SOHO spacecraft. The instrument is characterized by a spatial resolution close to 1 arcsec (715 km on the Sun), a spectral pixel size of $\approx 44$ mÅ with subpixel resolution, and by a time resolution down to 250 milliseconds. The photon-counting detectors operate almost free of noise, a prerequisite for off-limb observations. SUMER capabilities are described by Wilhelm et al. (1995), and the inflight performance is presented in Wilhelm et al. (1997) and Lemaire et al. (1997).

Here, we present two SUMER observations of high Doppler shifts associated with small sites of bright EUV emission in the corona. The small knots stem from strong emission in small volumes of highly dynamic gas. Primarily, they have been seen in transition region lines (cf. Korendyke et al. 1995, Curdt et al. 1997), but they also occur in hot spectral lines. The knots can best be seen in off-limb observations, where the line-of-sight confusion with the disk is avoided.


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3. COLD PLASMA TRANSIENT EVENT

This data set was taken above the Active Region NOAA 7974 which was positioned right on the East equatorial limb at that time. The slit was stepped in increments of 4 arcsec starting at 40 arcsec off the limb and 36 spectra were taken altogether with an exposure time increasing exponentially from 250 s to 867 s. The observation started on June 20, 1996 at 20:11 UT (cf. EIT image in Figure 1).

At each raster position two spectral bands have been recorded extending from 980 to 1020 Å and from 1173 to 1213 Å, respectively. These include the forbidden lines of Ne VI and some cold lines, mainly N III and Si III with their respective temperatures of formation at 400 000 K, 80 000 K and 50 000 K. The raw data have been reduced using standard procedures for decompression, flat-field-correction and geometrical distortion correction. Finally, scattered light from the disk has been subtracted.

The total line intensity of three lines in band 1, namely Ne VI 999 Å, Ne VI 1005 Å, and N III 992 Å across the area rastered is displayed in Figure 2.

Figure 1. The SUMER raster superimposed on the EIT He II 304 Å image showing the active region NOAA 7974 on the limb and its neighbor NOAA 7973 (photo-negative representation, courtesy of the EIT consortium).

Figure 2. Images of the total line intensity in N III 992 Å, Ne VI 999 Å, and Ne VI 1005 Å from the 300 × 140 arcsec² section observed with SUMER.

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As expected, there are loop structures extending from the active region out into the corona. The feature of interest here is the small region of bright N\textsc{iii} that can be seen at 80 Mm above the limb and seems to be disconnected from the loop structure below. A closer look into the spectra reveals that this feature is seen in three consecutive exposures (Figure 3). The N\textsc{iii} profiles show a blue-shift of up to 170 km/s in spectrum 16, a strong brightening at zero-velocity at spectrum 17 and a red-shift of up to -100 km/s in spectrum 18. This event was seen for 39 minutes, which is two orders of magnitude longer than the cooling time expected for a plasma at temperature $T = 10^8$ K and an electron density of $n = 3 \times 10^8$ cm$^{-3}$ from

$$t_{cool} = \frac{3kT}{A(T)n}.$$

Here, $A(T)$ is the radiative loss function (Innes et al. 1987).

From the observation in band 2 there is evidence that the emission is not continuous, but coming in bursts which could explain the dilemma. A fainter high velocity event is observed some minutes later in the northern slit section. The N\textsc{iii} intensity outside the events stems entirely from scattered light. This has been subtracted and for the main event the red- and blue-shifted spectra have been superimposed to illustrate the evolution (cf. Figure 4). The event extends 15 Mm along the slit, the northern part being red-shifted and the southern part being blue-shifted. We also see a brightening in Ne\textsc{vi} sunward of the event. This is very likely related to the event.

We interpret the observation as a bi-directional high-velocity flow of cold, high emissivity plasma. The Ne\textsc{vi} brightening may be interpreted as the termination shock and stagnation point. The observational geometry is illustrated in Figure 5. A more detailed analysis of this dynamic event is given by Innes et al. (1998).
4. HOT PLASMA CORONAL EVENT

This data set was taken between 19:31 UT on September 5, 1997 and 01:02 UT on September 6, 1997 above the active region NOAA 8076 when it had almost reached the North-West solar limb.

The instrument performed multiple routine 'REFSPEC' spectral surveys, stepping through the full spectral range in 13 Å increments. The pointing of the slit is depicted in Figure 8. An optical, radio and X-ray flare is reported to have occurred about 7 hours earlier from this region. The spectral band from 1098 to 1138 Å shown in Figure 7 was covered at 20:31 UT and at 22:22 UT. For the latter the averaged profile and the identification for the most prominent lines are also given (cf. Feldman et al. 1997).

Figure 4. The NIII 998 Å lines of raster positions 16 and 18 have been superimposed and the scattered light contribution has been removed. The bi-directional jet shows up.

Figure 5. The observational geometry

Figure 6. The SUMER slit position superimposed on the HeII 304 Å EIT image showing the active region NOAA 8076. (EIT image by courtesy of the EIT consortium)
At 20:31 UT the spectrum is structureless and dominated by hot coronal lines like Al\textsc{i} 549.975 Å, Ca\textsc{x} 557.755 Å (both observed in second order), and Ca\textsc{xiii} 1133.700 Å. No Doppler shifts can be seen.

Two hours later these lines remain unchanged, but now Fe\textsc{xix} 1118.07 Å dominates the spectrum as a new line. We see a volume with a linear extent of 20 Mm with bright emission and bi-directional Doppler flows of ± 100 km/s. Another fainter region, 40 Mm apart, provides evidence of a double structure of the feature. The event is exclusively seen in Fe\textsc{xix} 1118.07 Å and Fe\textsc{xix} 592.20 (observed in second order), lines which are formed at $8 \cdot 10^6$ K.

In the spectra preceding and following the spectral window displayed in Fig. 7, the event is altogether seen for approximately 30 min and there are indications that it is very variable with time. This may indicate that the event is not continuous, but coming in bursts which could not be resolved by our limited time resolution of 120 s.

5. Summary

In one case we see small regions of cold plasma high up in the corona. This kind of plasma cannot possibly be explained by any standard temperature gradient model. The EUV emission sites are small-scaled which indicate that the plasma is filamented, and possibly of sub-pixel size.

Dynamical events are evidently more readily seen in cold rather than in hot plasmas. This may suggest that the magnetic field confines and preserves the cold plasma.

But in the other case we see an event exclusively in emission lines formed at much higher temperatures.

Except for their temperatures, the events are strikingly similar. In both cases the features have a double structure and a linear extent of 15 – 20 Mm along the slit.

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We observe bi-directional flows of 100 – 200 km/s. Despite of their high Doppler-velocities, the features are stationary, there is no evidence for proper mass motion. But the events do not seem to be continuous. The temporal variability within the total duration of ≈ 30 minutes suggests a bursty nature.

In both cases, the origin of the events is unknown. It may be that at the event site anti-parallel magnetic fields reconnect ejecting a bi-directional plasma jet.

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