Jets and Eruptions in the Transition Region Observed with CDS, EIT and TRACE

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Abstract. Observations of active regions at the solar limb have revealed ejections of transition region material with unexpectedly high velocities. We present two types of ejections observed by CDS and EIT on SOHO and by TRACE, i.e. active region jets and active region eruptions. The jets are spike-like ejections of material and have been observed with CDS and EIT on SOHO. The plasma appears to follow large scale magnetic field lines to heights up to 170 Mm. The velocity perpendicular to the line of sight approaches 180 km s\(^{-1}\). Active region eruptions consist of much more spatially extended ejections of plasma. One of these was observed on the west solar limb on 19 May 1998 by CDS, EIT and TRACE, and was probably associated with a C4.4 flare recorded by GOES. Doppler shifts corresponding to velocities of 300 km s\(^{-1}\) away from the observer, i.e. parallel to the solar surface, were observed by CDS at the leading edge (top) of the eruption while high cadence observations with TRACE show that the plasma velocity perpendicular to the line of sight, i.e. along the solar vertical, reached at least 200 km s\(^{-1}\). Later the plasma apparently falls back down, partly along the same trajectories as it came up, but also along other paths. One may speculate that the earlier eruption, presented here, represents a “CME” that did not make it.

1. Introduction

Active regions have been observed with the EUV/UV instruments on the Solar and Heliospheric Observatory (SOHO) and recently also by the Transition Region and Coronal Explorer (TRACE). In particular observations of active regions on the solar limb have revealed that loops existing at transition region temperatures are highly dynamic in nature (e.g. Kjeldseth-Moe & Brekke 1998). Active region loops are difficult to distinguish on the disk because of their low contrast to the disk emission.
During some of the observations on the limb we see plasma ejected from the active regions. Spike-like jets of material have been observed with the Coronal Diagnostic Spectrometer (CDS) and the Extreme ultraviolet Imaging Telescope (EIT). Another type of eruption was observed by CDS, EIT and TRACE on 19 May 1998. In this latter case a spatially much more extended ejection of plasma on the west limb was observed, probably associated with a C4.4 flare registered with GOES. Below we will describe both types of eruptions.

2. Instruments and Observations

Spectral observations of the features presented here were obtained with CDS, while high cadence broadband images were taken with EIT and TRACE. Relevant instrument features are briefly described below.

CDS is a dual extreme ultraviolet (EUV) spectrometer covering the wavelength range 150–780 Å. The normal incidence spectrometer (NIS) gives stigmatic spectral images along a 240" long slit in two broad wavelength regions (308–381 Å and 513–633 Å). The astigmatic grazing incidence spectrometer (GIS) covers four wavelength bands in the range 150–780 Å. The wavelength ranges of both NIS and GIS contain emission lines covering temperatures from the chromosphere to the hot corona at T ≈ 3 MK. Spectral and angular resolution of CDS-NIS is λ/Δλ ≈ 3500 – 4500 and ≈ 4", respectively. For more details of the instrument and its performance we refer to Harrison et al. (1995).

The CDS data used in this investigation were obtained with NIS using the 4" slit. By rastering, i.e. moving the solar image perpendicular to the slit in steps of 4", the spectrometer builds up images of solar features in a series of selected spectral lines emitted at different temperatures. Using 40 slit positions, each with an exposure time of 10 s, a 160"×240" field of view was covered in 10 min. Each image retains detailed spectral information and can be used to give maps of total emission, velocities, line widths, plasma densities etc. Using this technique CDS can distinguish differences in the emitting plasma on a finer graded temperature scale than for example EIT.

EIT (see Delaboudinière et al. 1995) can produce images of the solar atmosphere with a resolution limited by the 2.59" pixel size. The multi-layer coating of different quadrants of the mirrors are tuned to four wavelengths centered around spectral lines formed at 80,000 K (He ii 304 Å), 1 MK (Fe ix/x 171 Å), 1.5 MK (Fe xii 195 Å), and 2.0-2.5 MK (Fe xv 284 Å).

TRACE (see Handy et al. 1998) is a Small Explorer Mission (SMEX) devoted to the study of the evolution and propagation of fine-scale magnetic fields and plasma structures throughout the solar atmosphere. The instrument consists of a telescope with a 30 cm primary mirror, normal incidence coatings for three EUV bands at 171, 195 and 284 Å, and interference filters for UV bands with maximum transmission at 1216, 1550, 1600, and 1700 Å, as well as a “white light” channel with actual contributions from 1700 Å to 10 000 Å. The 1550 and 1600 Å bands contain the C iv resonance lines at 1550 Å. This allows for a selection of temperature ranges from 6 000 K to 2.5 MK. The 1024×1024 pixel CCD camera has a field of view of 8.5′×8.5′ with a spatial resolution of 1 arcsec and exposure times ranging from 0.002 s to 260 s with a cadence as short as two seconds are available.
3. Active Region Jets

Observations of spike-like jets of plasma were made with CDS and EIT on 9 December 1997. The plasma emerged from NOAA AR8113 located on the NW limb. Fig.1 shows raster images of the active region and the jet above the solar limb in 6 lines observed with CDS ordered from left to right with increasing temperature of formation. The lines include He i 584.3 Å (1.6×10⁴ K), O iii 599.6 Å (9.1×10⁴), O v 629.7 Å (2.3×10⁵), Ne vi 562.7 Å (4.3×10⁵), Mg ix 368.1 Å (0.96 MK), Fe xvi 360.8 Å (2.7 MK).

The raster images demonstrate the clear difference between the transition region emission and the hotter coronal lines, both in the active region loops and in the jet. In the transition region up to 0.5 MK, including the He i line, loops are clearly outlined and the jet is prominent and changing rapidly with time. In the corona the emission is more fuzzy and the jet is not visible. The same general temperature dependence in the dynamical behavior, with a distinguishing difference at 0.5 MK, is also common for Doppler shifts registered in active region loops without ejections or jets.

The plasma at transition region temperatures seems to be ejected along a curved large scale magnetic structure. The 10 minute time cadence is not fast enough to follow the phenomenon, and this makes it difficult to estimate the perpendicular velocity, i.e. normal to the solar surface. However, the CDS raster images retain their spectral information and the line of sight velocities can be determined at each image element. In the O v raster image in Fig.2 (left panel) the jet appears to be moving with velocities of 45 km s⁻¹ and 75 km s⁻¹ towards the observer at the positions marked A and B, respectively, (see right panel). The highest velocity occurs in the upper region, B. This is consistent with a motion of the gas along a loop curving towards the observer. It seems likely that the actual flow velocities are much larger than the values measured from the Doppler shifts, since the curved trajectory probably has a considerable
Figure 2. The left panel shows a monochromatic image of an active-region loop system above the west limb observed in O IV 629 Å. The image field of view is 160′′ × 240′′. Line profiles in three spatial positions, A, B and C, have been marked and are displayed in the panel to the right. The area marked C represents the average disk with zero velocity.

Figure 3. Four EIT images in the Fe XII 195 Å band showing the active region jet of 9 December 1997. The images are selected from a larger series with 30 s cadence.

component perpendicular to the line of sight. Region C represents the area on the disk defining the zero velocity value.

The jet was also co-observed with EIT running in a sub-field mode with a time cadence of 90 s and tuned to the Fe XII 195 Å band (T=1.5 MK). Selected exposures from the EIT observing sequence are displayed in Fig.3. The images show a running difference to better enhance the changes. From the EIT time sequence we have estimated that the ejected plasma is moving with a velocity of 180 km s$^{-1}$ perpendicular to the line of sight. This is not inconsistent with the line of sight velocities derived from CDS spectral images described above. The plasma appears to follow large scale magnetic field lines to altitudes of 170 Mm.

4. Active Region Eruptions

The second type of ejection, the active region eruption, was observed during a Joint Observing Program (JOP) with CDS, EIT and TRACE, starting at 07:00
UT on 19 May 1998. Active region NOAA AR8218 had just rotated around the west limb when a large eruption of plasma was observed, most probably related to a spiked, brief flare of type C4.4 registered by GOES. The flare started at 07:56 UT and ended at 08:04 UT. The TRACE instrument recorded images in the 1216 Å and 1600 Å channels as well as in the white light channel. The cadence between images in each channel was 30 s. Figure 4 shows the eruption observed in the 1600 Å band at 08:05:07 UT, 5 min after it started. Outside the solar limb it seems reasonable to assume that the C iv lines at 1550 Å (T = 10⁵ K) are the only significant contributors to the image intensity, with only weak contributions from the continuum, and from neutral and singly ionized lines within the band. We note the abundant and inhomogeneous detail in the structure. The extent in height of the eruption at this time is 62 Mm, and later it reached a maximum of 120 Mm 12 min after start.

Fig.5 shows a series of TRACE images consisting of every fifth frame in the 1600 Å band sequence. The eruption throws plasma to a great altitude with plasma velocities along the solar vertical reaching 200 km s⁻¹ as measured from the expansion of the leading edge of the eruption. The upward motion then seems to slow down and the plasma apparently falls back down, partly along the same trajectories as it came up, but also along other paths. A possible picture is of plasma being transported up one loop leg, with part of it going beyond the summit point before falling back to the solar surface. Similar structures and time development are observed in the 1216 Å band. Perhaps more surprisingly, the ejection is also observed in the white light channel, albeit at low altitudes during first 5-10 min of the eruption.

Figure 6 shows a selected frame of the eruption from EIT in the 195 Å band together with a simultaneous TRACE image. The EIT frame is a difference image from the previous exposure to enhance the erupting material. It is
Figure 5. Series of every fifth TRACE frame in the 1600 Å band from the active region ejection on 19 May 1998, showing its development with time.

Figure 6. Simultaneous EIT and TRACE images, showing the eruption from the active region ejection on 19 May 1998.

It is interesting that the eruption also can be seen in the EIT images, emitted from a plasma at much higher temperatures than the 1600 Å band TRACE images.

Figure 7 shows two selected sets of CDS raster images made during the eruption. Again the size of the rasters is 160"×240" and the cadence is 10 min. The lines are the same as in Figure 1 for the jet, i.e. at the same temperatures. The rasters in the two sets start at 08:00:54 UT and 08:22:21 UT respectively, i.e. a time difference between the sets of 22 min. The first set is taken at the time when the TRACE images showed the initial rise in the eruption, i.e. between 08:00 UT and 08:11 UT. The second set is taken at a time when material is falling back to the solar surface. In the eruption phase the material appears to fill a large volume, revealed by the TRACE observations as a densely packed trunk of many finer structures. The material falls back through an increasingly simplified set of loops that are only partly the same as those emitting during the rise phase. The emitting loops at temperatures below 0.5 MK are similar in structure and time development, and may appear co-located to within the accuracy of the observation. This does not rule out different temperatures occurring in different
locations, but means that the loops may have fine structures, thin strands that are far smaller than the instrument resolution. In the hot plasma of 1 MK or more, we do not note the eruption. Again this agrees with the dynamic behavior of non-erupting loops described by Kjeldseth-Moe and Brekke (1998).

In contrast the eruption is clearly visible in the EIT 195 Å band (see Figure 6). The difference between CDS (1 MK and 2.7 MK) and EIT (1.5 MK) images might be a "true" effect i.e. co-located solar plasmas emitting below 0.5 MK and at 1.5 MK, but not at a temperature of 1 MK. Alternatively the EIT bandpass may contain lines that are cool and sufficiently strong to cause structures very similar to the TRACE C IV eruption at 100 000 K. Both explanations would require a very special mix of hot and cool gas in the particular case of the eruption.

In contrast the eruption is clearly visible in the EIT 195 Å band (see Figure 6) which is emitted from a 1.5 MK plasma. The difference between CDS (1 MK and 2.7 MK) and EIT (1.5 MK) could either be a solar effect (eller kanske bare REAL) or the EIT bandpass may be contaminated by some cooler emission. The latter should be possible to confirm by co-observing with EIT and CDS/GIS which includes the Fe XII 195 Å line.

Figure 8 shows in the left panel the CDS image in O V 620 Å together with the observed line profiles (in the right panel) from tree locations marked A, B and C. Location C represents the disk region defining the reference wavelength. We notice how the observed Doppler shifts correspond to material moving away from the observer with velocities of 120 km s\(^{-1}\) and 290 km s\(^{-1}\) in A and B, respectively. Location B is at the top of the expansion and may represent a purely horizontal velocity at the summit of a magnetic loop. In this case the 290 km s\(^{-1}\) velocity would represent the true flow speed in the loop. This, however, is not certain since the eruption continue to expand another 40 Mm before reaching its maximum altitude, i.e 120 Mm.
Figure 8. Monochromatic image of the eruption above the east limb observed in O v 629 Å. Line profiles in three spatial positions, A, B and C, have been marked and are displayed in the panel to the right. The area marked C represents the average disk with zero velocity.

5. Concluding Remarks

The two types of ejections, jets and active region eruptions, are remarkably similar in velocities and in temperature dependence of the dynamical behavior. Perhaps they are the same phenomenon on different geometrical scales. Secondly, we note that the centripetal force from the magnetic field applied to the gas flowing in the loops during the eruption is considerable, i.e tree times the solar gravity at the loop summit in Fig.8. Thus, the eruption may perhaps represent a “CME” that did not make it.

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References