RECURSIVE NARROW CMEs WITHIN A CORONAL STREAMER

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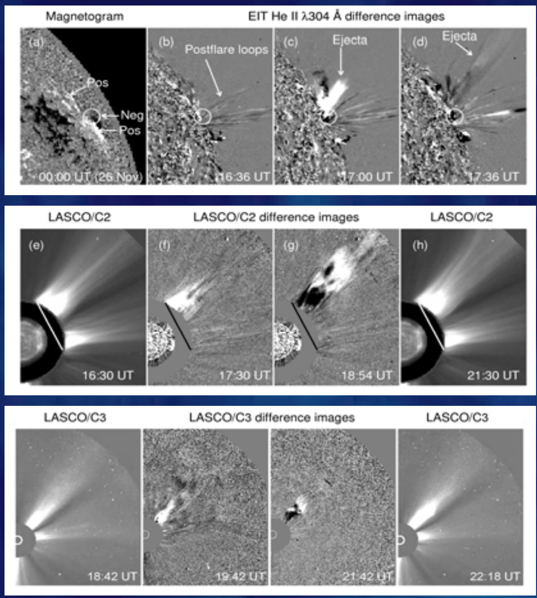
ABSTRACT

SOHO EIT, UVCS and LASCO observed recurrent (about 6 – 8 per day) ejections occurring over November 26 – 29, 2002 from the NW solar limb, several of which resulting in narrow CMEs that moved out along a coronal streamer. EIT He II 304 images show the source of the ejections to be compact and homologous eruptions. UVCS detected these ejections at 0.7 R_{sun} over the limb in cool lines (e.g., C III), but not in hot lines (e.g., Fe X).

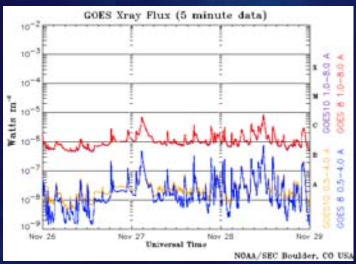
There is a one-to-one correspondence between the He II and C III events when the data sets overlap. Some of these ejections continue out into the interplanetary medium, appearing as the narrow CMEs in LASCO C2 and C3 data. The stronger of these narrow CMEs show plasmoid–type structure, while the weaker ones appear more like a gust of solar wind along the streamer. Several of the other He II ejections do not perturb the streamer in the LASCO images. MDI magnetograms show that the ejections originate from near an included polarity in an active region located in the outskirts of the base of the streamer. While the streamer is disturbed by each narrow CME, its general structure persists throughout the entire series of events; this is a basic difference from "streamer blowout" CMEs, in which the magnetic arcade base of the streamer erupts and greatly disrupts the streamer. We therefore take our streamer disturbances to be a new variety of narrow CME, which we call "streamer puffs". Our observations led us to infer the magnetic configuration and mechanism that likely produced these events.



1. MDI, LASCO & EIT OBSERVATIONS

We use the right Figure to illustrate our observations. Panel 1a is a MDI magnetogram near the West limb showing the active region that is the source of the recurring eruptions, with the white circle showing the compact mixed-polarity region from which the eruptions originate. This compact region is at the north edge of a positive-polarity sunspot. In Figure 1a the black outside the circle on the limbward side of this sunspot is actually an area of positive polarity; it appears negative due to line-of-sight projection of the nearly horizontal penumbral field, as shown by earlier magnetograms (e.g., that for 2002 November 21). The location of the circle is a true negative-polarity feature embedded in a sea of positive polarity.

Panels (b, c, d) are a sequence of EIT He II λ304Å difference images showing the lower atmosphere before (b) and during (c, d) one of the eruptions occurring on November 27 next to a set of pre-existing evolving postflare loops (from a large-scale event on the previous day). Images are of the same scale as (a), and registered with (a) in the north-south direction. The circle is from (a), and shows the location of embedded polarity at the limb.



This ejected He II feature corresponds to a narrow ejection visible in LASCO, as shown by LASCO/C2 (panels f and g) and C3 (panels j and k) difference images (the bars in these panels show the location of the UVCS slit). The outward-moving bright structure is similar to larger CMEs, and suggests a plasmoid-type magnetic structure. The non-differenced LASCO/C2 (panel e) and C3 (panel i) images before the event show the presence of a streamer centered north of the location of the He II ejections. A comparison with the same images after the event (panels h and l) reveals that the coronal streamer in which the eruption occurs is largely unaffected by the event: the overall streamer structure was largely undisturbed by the passage of the narrow CME. This is one of our stronger streamer puffs.

Some of these ejections were observed during EIT's high-cadence (12 min) observations made with its He II λ304Å filter (lasting until 00:48 UT on November, 28), which detects upper chromosphere and transition region plasma at around $6 \cdot 10^4$K. Later, EIT's 12-minute-cadence observations were made with its Fe XII λ195Å filter, which observes the low corona at around $1.5 \cdot 10^6$K. However, our compact eruptions at the base of the streamer are much less visible in the Fe XII movies than in the He II movies, implying that we are observing the ejection of low temperature chromospheric plasma.

The left Figure gives informations on concurrent GOES soft X-ray bursts: we do not know with certainty the source of the GOES events, but the close time correspondence (see later, Table 1) suggests our events are likely candidates. These data, together with LASCO and EIT observations, imply that our streamer puffs were consequences of ejective flares from a compact mixed-polarity region at the base of a coronal streamer.

2. UVCS OBSERVATIONS

UVCS observations started on November 26, 18:39 UT and lasted until November 29, 02:56 UT, with occasional gaps. The UVCS slit was 27" wide, and was centered on and oriented normal to the solar radius 27° north in the west quadrant, at 1.7 R_{sun} from disk center. The selected spectral ranges cover both cool (e.g. C III and O VI, with a temperature of maximum formation of, respectively, $10^{4.8}$ and $10^{5.5}$ K), and hot ions (e.g. Fe X, Si XII and Fe XVIII, with a temperature of maximum formation of, respectively, $10^{6.0}$, $10^{6.3}$, and $10^{6.7}$ K).

The right Figure (top) shows UVCS C III λ977Å line intensity evolution during the observation period. There are several sudden, strong bright events apparent. The first five C III events are during the EIT He II interval and correspond closely to the He II ejections. All these features appear in UVCS at position and times consistent with the observed EIT He II ejections making the association between the UVCS events and the He II eruptions unambiguous.

The bottom panel shows the time-distance evolution of the LASCO/C2 (from 2 to 4 R_{sun}, red) and C3 (from 4 to 16 R_{sun}, blue) white light intensity integrated between latitudes N35° and N70°. The average intensity at a time preceding the first event has been subtracted from all images. The thin horizontal band at 1.7 R_{sun} (green) shows the C III λ977Å line intensity integrated along the UVCS slit and the UVCS data gaps (black intervals). In both panels, events are labeled by their UVCS number (see Table 1).

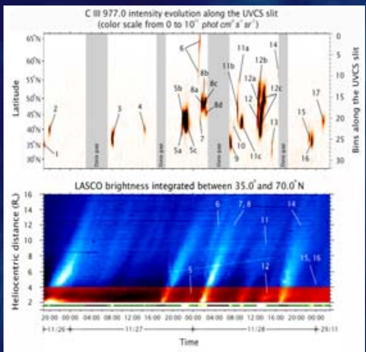
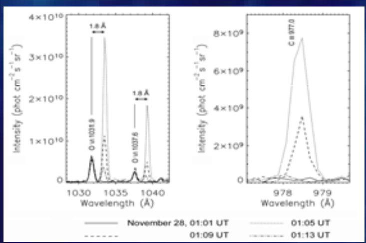


Table 1: Ejecta Observed by EIT He II and UVCS C III: Kinematic Parameters and Correspondence with GOES X-Ray Bursts and LASCO Streamer Puffs

He II[1] Event #	C III[2] Event #	Date (2002 Nov)	$t_{st}(EIT)$[3] (UT)	$v_{la}(EIT)$[4] ($km\,s^{-1}$)	θ[5] (deg)	GOES Burst? (Y/N, Class[6])
1	1	26	17:42 ±6'	–	25 ± 5	N
2a		26	18:30 ±6'	–	–	Y, C3
2b	2	26	18:42 ±6'	> 130	15 ± 5	Y, C3
3	–[7]	27	04:30 ±6'	140 ± 40	30 ± 5	?[8]
4	3	27	07:12 ±24'	160 ± 60	?[9]	Y, B1
5	4	27	13:12 ±24'	> 90	20 ± 10	Y, B1
6	–[7]	27	16:42 ±6'	180 ± 60	25 ± 5	Y, C4
7a	5a	27	21:01 ±12'	180 ± 60	20 ± 5	Y, C3
	5b	27	–[10]	–	–	Y, C3
7b	5c	27	21:30 ±6'	> 130	30 ± 5	Y, C3
He II Event #	**C III Event #**	**Date (2002 Nov)**	**$t_{st}(UVCS)$[11] (UT)**	**$v_{la}(EIT/UV)$[12] ($km\,s^{-1}$)**	**α[13] (deg)**	**Streamer Puff?[14] (Y/N)**
1	1	26	18:46 ±4'	130 ± 20	75 ± 5	–[15]
2b	2	26	19:32 ±4'	170 ± 35	4 ± 2	–[15]
3	–[7]	27	–	–	–	N
4	3	27	07:51 ±4'	> 120	< 50	N
5	4	27	14:18 ±4'	150 ± 65	0.	N
6	–[7]	27	–	–	–	Y
7a	5a	27	21:44 ±4'	220 ± 80	50 ± 15	Y[16]
–	5b	27	21:46 ±4'	–	–	Y[16]
7b	5c	27	22:14 ±4'	195 ± 45	4 ± 2	Y[16]

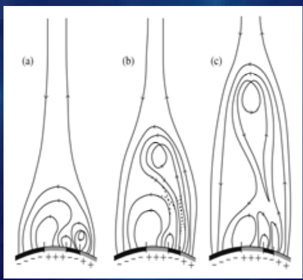
(1) Sequential identification of events seen in He II.
(2) Sequential identification of events seen in C III; differs from column 1 numbers since not all events are seen in both instruments.
(3) Estimate of ejection start in He II. Uncertainties determined by EIT time cadence.
(4) Velocity estimate from EIT images. Uncertainties due to EIT cadence and to visual estimates of ejection front in images.
(5) Approximate inclination from vertical at solar surface of ejection early in its evolution.
(6) Background-subtracted GOES level.
(7) Occurs during UVCS data gap.
(8) Obscured by elevated GOES flux.
(9) Eruption start not seen well enough to estimate this quantity.
(10) Seen in UVCS only; possibly unresolved in EIT due to insufficient cadence.
(11) Time of first sighting in UVCS.
(12) Velocity estimate based on $t_{st}(EIT)$ and $t_{st}(UVCS)$.
(13) Ejection inclination along line of sight; see text. Positive is away from the observer.
(14) 'Y' indicates discernible in the LASCO C2 running difference movie.
(15) Can not be determined, due to overlap with CME event of 26 November, 17 UT.
(16) These three Y's refer to a single puff.

Table 1 gives kinematical parameters we derived for the ejections from EIT He II (top) and UVCS (bottom) observations. The ejection angle α from the plane of the sky has been derived from Doppler shifted line profiles by estimating the velocity component v_{los} along the line of sight. To this end, since there was no reference C III background coronal emission, and ejections are also visible in the UVCS O VI λ1032-1037Å doublet (see right figure), we resort to these lines to determine v_{los}. We first determined v_{los} by fitting a Gaussian to the O VI line profile derived by subtracting the average coronal profile before the ejection arrival (right figure, solid line) from the following exposures. This allowed us to derive, from the v_{le}(EIT/UV) values (see Table 1), an estimate for the α angle. All of the ejections were observed to be red shifted in the UVCS spectra, indicating the ejecta moved westward as well as northward from the source region. Comparing the top and bottom of Table 1 shows that, for the events not in UVCS data gap, there is a *one-to-one correspondence* between the EIT He II and C III UVCS events.



3. THE MECHANISM

We found a near one-to-one correspondence be-tween He II ejections and the C III events (when the He II and UVCS obser-vations overlap), but (left figure) only some of the C III events go on to become strong plasmoid-type nar-row CMEs in LASCO data. We conclude that virtually all the ejections reach a distance of at least 0.7 R_{sun} but only some of these escape as strong CMEs, while others are apparently trapped at heights below 2 R_{sun} and result in weak gust-type CMEs (weak streamer puffs) or no detectable puff at all. We now present a possible scenario to explain these properties.



The top Figure **(a)** gives the pre-eruption magnetic configuration that we draw based on MDI and LASCO data. Wedged inside of the southern end of the streamer is the compact bipole at the northern edge of the sunspot; the positive polarity of this bipole is against or inside of the main positive spot. An eruption **(b)** occurs along the magnetic neutral line of the bipole, resulting in an expulsion of the bipole field up a loop of the streamer arcade. The exploding core field reconnects in its interior ("internal reconnection") producing flare-like emissions low in the atmosphere observed in GOES X-rays for most events (Table 1). In addition to the internal reconnection, "external reconnection" will occur between the exploding bipole field and the arcade field of opposite polarity on the north side of the exploding bipole. The external and internal reconnections result in the configuration of panel **(c)**, where the central part of the exploding field has become largely disconnected from the photosphere and moves out along the streamer, creating the streamer puff. Since the exploding region is compact, only a small portion (a loop) of the streamer arcade will be blown out with the ejection, leaving the large bulk of the streamer arcade and streamer intact.

Ejections not resulting in any streamer-puff CME could be due to the ejected plasmoid not having enough energy to break through the closed arcade portion of the streamer or to inflate strongly the loop top. The non-plasmoid puffs appear as gusts in the LASCO images (e.g., UVCS events 5, 12, and 15 and 16).

4. DISCUSSION & CONCLUSIONS

All of our streamer puff events originate from a compact source located away from the main neutral line of the streamer, and they leave the streamer largely intact. As sketched in the above cartoon, we expect that these CMEs result from the compact flare eruption inflating or blowing out a relatively small part of the closed portion of the streamer field. This is different from commonly-reported streamer-associated CMEs, which originate from the main neutral line and blow out the entire streamer.

Gilbert *et al.* (2001) studied 15 narrow CMEs, and Dobrzycka *et al.* (2003) examined UVCS data of five of those. Different from our events, only one of the Gilbert *et al.* events was streamer related, and their events were not homologous. Several of the Gilbert *et al.* events were related to filaments, and so it could be that some of their narrow CMEs are small-scale versions of the "standard model" for solar eruptions. Dobrzycka *et al.* (2003) observed their UVCS events primarily in H Lyα and O VI lines, and we also saw our events in the O VI lines. However, only one of Dobrzycka *et al.* events was visible in C III emission and the line intensity was weak. This implies that the emitting plasma was either hotter than plasma in our events or that underwent a larger Doppler dimming.

From the above considerations, we believe that the **streamer puffs** reported here are **produced in a different way** than has been recognized in previous studies of narrow CMEs.

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