Analysis of coronal O VI emission during flares and comparison with soft X-ray observations

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Abstract

In this work, we present the analysis of a set of flares investigated by comparing the O VI 1032 Å luminosities collected with off-limb measurements by the UVCS/SOHO instrument with the corresponding X-ray luminosities obtained by GOES. The analysis of the OVI 1032 Å spectral line as a function of time during a flare event is able to provide information on the transition region luminosities during and just after the impulsive phase of a flare (i.e, before the CME plasma reaches the the UVCS field of view). Comparison of spectroscopic UV observations with simultaneous soft X-ray measurements is important in that it can provide a means to pinpoint the likely source (chromospheric evaporation, footpoint emission or heated prominence ejecta) for the observed transition region emission. In a previous work, Johnson et al. (2011) found meaningful correlations between the X-ray emission and the UV luminosities but with substantial scatter due to the relatively scarce set of data (29 events). Our study is aimed to extend the above statistics by adding a further set of flare events that were found by a careful analysis of the UVCS database.

1. Introduction

Raymond et al. (2007) presented a technique to measure flare UV photons that are scattered in the corona. The Ultraviolet Coronagraph Spectrometer (UVCS) on board *SOHO* performs UV spectroscopy in the extended solar corona between 1.5 and 10 $R_\odot$. During its activity, UVCS has recorded several observations of flare-related O VI 1032 Å photons. These events present the characteristics of flare radiation resonantly scattered by coronal O VI ions: the emission brightens simultaneously along the entire UVCS slit, it precedes any other CME emission, and it shows no Doppler shift or increased line width compared to the pre-event line profile. Since collisional excitation in the corona produces a 2:1 intensity ratio $I_{O\,VI\,1032}/I_{O\,VI\,1037}$ ratio, a further key requirement is that the O VI intensity ratio be consistent with 4:1, indicating scattering of disk radiation.

It should be taken into account, however, that there is a strong bias towards events quite close to the solar limb, since the intensity of the flare emission in the corona drops rapidly with distance from the flare. Moreover, most of these flares were associated with CMEs: when the CME reaches the position of the UVCS slit, it blows the pre-event corona away, so that the intensity of scattered photons rapidly declines. Thus, this technique provides intensities only for about 15 min in the impulsive phase of the flare. Raymond et al. (2007) determined the O VI and transition region luminosities and compared them with X-ray temperatures and luminosities from *GOES* and *RHESSI* data for 5 events. In a subsequent work, Johnson et al. (2011) analyzed other 24 events.

In this work, we are extending the above analyses. Tens of candidate events have been in fact pinpointed, and nine of them have been selected here for a preliminary analysis. These events were found during a thorough search of the CDAW LASCO CME catalog for events where the UVCS slit was positioned roughly over the flare. Further information about the UVCS observations is available in the pages of the UVCS/CME catalog, which are linked to the events listed in the CDAW LASCO CME catalog (http://cdaw.gsfc.nasa.gov/CME_list/).

The observation parameters for each event are shown in Table 1.

Table 1. New UVCS solar flare observations

	Event	Flare Class	Flare Position	Flare x[b] "	Flare y[b] "	PA ccw	height ($R_\odot$)	Exptime (s)	Slit (μm)
1	19990802	X1.4	18S 46W	663	-299	225	1.55	75	50
2	20010915	M1.4	21S 49W	683	-347	225	1.74	120	96
3	20011229	M9.3	07S 85W	958	-118	282	1.90	200	98
4	20020718	X1.8	19N 30W	458	315	0	2.07	120	150
5	20030320	M1.5?	...[a]			253	1.63	120	102
6	20031103	X3.9	08N 77W	935	135	245	1.67	120	96
7	20040716	X3.6	10S 35E	-547	-168	90	3.00	120	99
8	20040727	X3.6	04N 54W	782	68	270	1.77	120	200
9	20050710	C9.9	00N 90W	969	0	284	2.42	120	76

[a] *Flare position not available, likely behind limb*
[B] *Computed from (lat, long) coordinates (4th column)*

2. Data analysis

2.1 March 20 2003 M1.5 flare

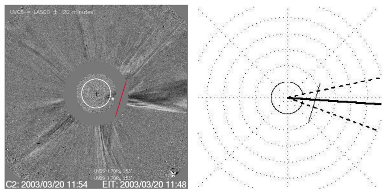

Figure 1. Left: LASCO and EIT difference image at the time of the X flare with superimposed the UVCS slit positions. Right: X flare position is unknown.

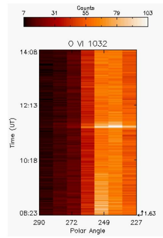

Figure 2. O VI 1032 counts image.

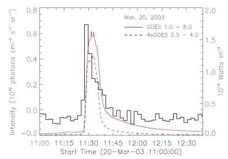

Figure 3. O VI 1032 intensity after subtraction of the pre-event intensity (histogram) plotted against time for the event of 2003 March 20. The GOES soft X-ray flux is plotted as red solid line. The GOES hard X-ray flux is shown with the blue dashed line.

2.2 August 2 1999 X1.4 flare

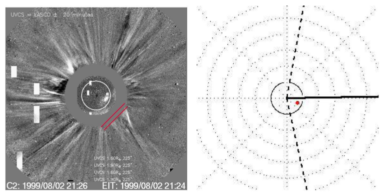

Figure 4.— Left: LASCO and EIT difference image at the time of the X Flare with superimposed the UVCS slit positions. Right: X flare position is shown on the solar disk (red circle).

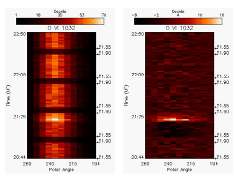

Figure 5. Left: O VI 1032 counts image. Right: difference image.

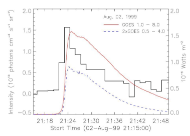

Figure 6. O VI 1032 intensity after subtraction of the pre-event intensity (histogram) plotted against time for the event of 1999 August 2. The GOES soft X-ray flux is plotted as red solid line. The GOES hard X-ray flux is shown with the blue dashed line. The left–hand scale applies to O VI, and the right–hand scale to GOES.

3. Preliminary results

There are three likely sources for the O VI emission:
a) *chromospheric evaporation* (evaporating gas that is being heated toward the ~10^7 K temperatures of the post-flare loops),
b) *footpoint emission* (chromospheric plasma heated by energetic particles or shocks in the footpoints, in which case either upflows or downflows might be seen);
c) *heated prominence ejecta* (plasma in the ejected prominence that is heated as it is being accelerated).
All three sources may contribute in different events or even in a single event, and the relative timing of UV and X-ray brightness peaks, the flow speeds, and the total O VI luminosity favor each source in one or more events. The correlations between X-ray and UV intensities expected in these three cases can be considered and thus compared to the observations.

In the evaporation scenario, one expects that the thermal X-ray emission peaks after the emission from the evaporation flow as the loops fill with hot plasma. In Fig. 7, we show a plot of the GOES peak flux against the time lag from the O VI peak to the GOES soft X-ray peak. In 5 cases, within the quoted uncertainties, the GOES peaks at roughly the same time (0 to 2 min) as the O VI intensity, while in 4 other cases the GOES peak occurs somewhat later (3 to 5 min) than the O VI peak. We remark that Johnson et al. (2011) found that only about 66% of their events (19 out of 29) had positive (or zero) lags (please note that Fig. 8 only includes those events analyzed by Johnson et al. (2011) in which the lag was found to be positive), while all our observations only show positive (< 5 min or zero) lags. The large number of events analyzed by Johnson et al. (2011) with a negative time lag (34%, or 10 out of 29) is unlikely in the evaporation picture, and unexpected in the footpoint picture, so it tends to favor O VI emission from the erupting prominence. By adding our set of data, we thus find that the almost 1/4 of events (71%, or 27 out of 38) show positive (< 12 min or zero) lags. Another result that comes out from this preliminary analysis is that our data *do not support* the supposed correlation found by Johnson et al. (2011) that larger flares tend to have the GOES peak later than the O VI peak, while in smaller flares it can either lag or be simultaneous.

In Table 2, we finally show a list of candidate O VI flares that might be further included in this work.

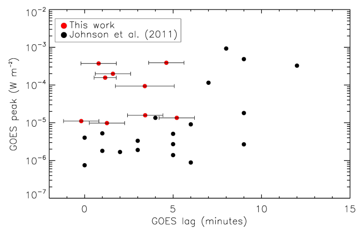

Figure 7. Peak flux in GOES soft X-rays plotted against the time lag between the peak of the Ovi luminosity and the peak of the X-ray luminosity.

***Table 2**: List of the UVCS CMEs from catalog with possible O VI flare detection*

	CME ID	PA Deg	Speed km/s	XFl	OFl	MxB km/s	MxR km/s
1	19990601.132514.p313s	307	300	Yes	?	0	0
2	20000304.095405.p329s	351	955	No	?	0	0
3	20000307.185405.p215s	219	555	Yes	?	30	0
4	20000427.143005.p301s	298	1110	Yes	?	120	40
5	20000621.193155.p244s	239	432	Yes	?	0	0
6	20000623.145405.p293s	282	847	Yes	?	300	20
7	20001026.165005.p098g	114	359	Yes	?	0	30
8	20010326.230605.p077s	72	635	No	?	0	50
9	20010402.220607.p293g	261	2505	Yes	?	120	60
10	20010501.013145.p220g	219	177	No	?	30	0
11	20010510.013140.p289g	246	1056	Yes	?	0	0
12	20011227.033005.p254s	260	148	No	?	30	10
13	20020123.043005.p277n	281	407	Yes	?	0	0
14	20020130.040606.p231n	238	183	Yes	?	0	0
15	20020322.110605.p259n	Halo	1750	Yes	?	120	0
16	20020417.082605.p292g	Halo	1240	Yes	?	0	0
17	20020421.012720.p282g	Halo	2393	Yes	?	500	850
18	20020521.215005.p054g	56	853	Yes	?	460	0
19	20020630.075406.p251n	255	333	No	?	0	0
20	20020823.085005.p064s	106	999	Yes	?	0	360
21	20021025.005005.p035g	60	535	Yes	?	0	0
22	20021025.180605.p352g	336	1030	Yes	?	0	0
23	20030103.150605.p029g	9	238	Yes	?	0	0
24	20030215.103539.p109g	111	808	No	?	0	0
25	20030216.230807.p311g	279	603	Yes	?	0	0
26	20030502.082606.p228g	221	685	No	?	0	0
27	20030526.165005.p084g	95	762	Yes	?	0	0
28	20031118.095005.p087s	95	1824	Yes	?	0	115
29	20050201.110607.p042s	Halo	1380	No	?	0	0
30	20050205.133148.p129g	126	711	No	?	0	290
31	20050506.233005.p267g	256	525	Yes	?	0	145
32	20050822.173005.p227s	Halo	2378	Yes	?	50	0
33	20050904.144805.p058s	57	394	Yes	?	0	0

References

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