Title of your IAU Symposium: Universal Heliophysical Processes
Proceedings IAU Symposium No. 257, 2008
N. Gopalswamy, & D. Webb, eds.

DOI: 00.0000/X000000000000000X

Major Solar Flares without Coronal Mass Ejections

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Abstract.
We examine the source properties of X-class soft X-ray flares that were not associated with coronal mass ejections (CMEs). All the flares were associated with intense microwave bursts implying the production of high energy electrons. However, most (85%) of the flares were not associated with metric type III bursts, even though open field lines existed in all but two of the active regions. The X-class flares seem to be truly confined because there was no material ejection (thermal or nonthermal) away from the flaring region.

Keywords. coronal mass ejections (CMEs), flares, particle emission, radio radiation

1. Introduction

Magnetic energy release is a ubiquitous phenomenon on the Sun occurring at various spatial and temporal scales. Flares and coronal mass ejections (CMEs) are the two main manifestations of the energy release process. All CMEs are associated soft X-ray flares (if we include post-eruption arcades in X-ray images), but not all flares are associated with CMEs. The rate at which flares lack CMEs increases as one goes from stronger to weaker flares (Yashiro et al., 2005). It is known for a long time that flare with mass motion in H-alpha (also known as eruptive flares) have high rate of association with CMEs (Munro et al., 1979). Flare duration is another important parameter deciding the association with CMEs (Sheeley et al., 1983) because eruptive flares are of long duration, while confined flares are impulsive (Kahler et al., 1989). Recently, Akiyama et al. (2007) compared two active regions, one with flares poorly associated with CMEs and the other with high rate of association with CMEs. They found that the CME-poor flares were localized near the neutral line between the preceding and following polarity regions. On the other hand, the flares in the CME-rich region were scattered all over the active region. This was also confirmed by Wang and Zhang (2007) using a displacement parameter defined by the surface distance between the flare location and the centroid of magnetic flux distribution in the active region. Nindos and Andrews (2004) found that the coronal helicity is lower in active regions producing compact flares, compared to those with eruptive flares. In this paper, we investigate other aspects of CMEless X-class flares including the escape of nonthermal particles accelerated during the flares. For this purpose, we use the 13 CMEless X-class flares indentified during the interval 1996 to 2005 (inclusive), when the Solar Heliospheric Observatory (SOHO) mission has been imaging the corona over a field of view of 2–32 solar radii using the Large Angle and Spectrometric Coronagraph (LASCO).

2. Data Selection

We first collected all the X-class flares reported by the Solar Geophysical Data (SGD), with the start, peak and end times as well as the source locations from H-alpha flares or from GOES soft X-ray imager. We checked the flare list against the list of CMEs available online: http://cdaw.gsfc.nasa.gov keeping in mind that the CMEs are expected radially above the flare location (Yashiro et al., 2008). The vast majority of X-class flares were associated with CMEs. However, a set of 13 flares did not have corresponding CMEs. For each of these flares, we examined the association of microwave and metric radio bursts (type III and type II) from SGD. We also obtained the source active regions and the heliographic coordinates of the flare locations from SGD. We examined the potential field source surface extrapolation plots available from on line (http://www.lmsal.com/forecast/, courtesy of M. deRosa & K. Schrijver) to determine if open field lines exist in the active region. Ten of the 13 CMEless flares were listed in Wang and Zhang (2007), although they investigated only 4 flares (one of their flares – the 13:49 UT flare on 2004 July 16 – was associated with an uncataloged CME at position angle 130o and a metric type II burst).

Figure 1 shows one of the CMEless flares – the X1.2 flare of 2005 January 15 at 00:22 UT originating from the northeast quadrant (active region 0720 at N14E08) as seen in EUV images obtained by SOHO's Extreme-ultraviolet Imaging Telescope (EIT). The flare peaked at 00:43 UT and ended at 01:02 UT (duration ∼40 min). The H-alpha flare had an optical importance 1F, but was not eruptive. Intense microwave burst was reported (peak flux ∼3000 SFU at 15.4 GHz) in SGD. The LASCO observations do not show any mass motion (in the direct or the difference image). The radio dynamic spectrum has no observable radio feature during the flare interval (neither type III nor type II bursts). Similar analysis was performed on all the 13 flares and the details are given in Table 1. Specifically, we list the flare start and end times, duration (Dur), X-ray importance (Imp), location, active region (AR) number, H-alpha flare importance (n – no flare reported), type III burst association (N – no, Y – yes), peak frequency of microwave burst (fpk in GHz) and flux in solar flux units (SFU).

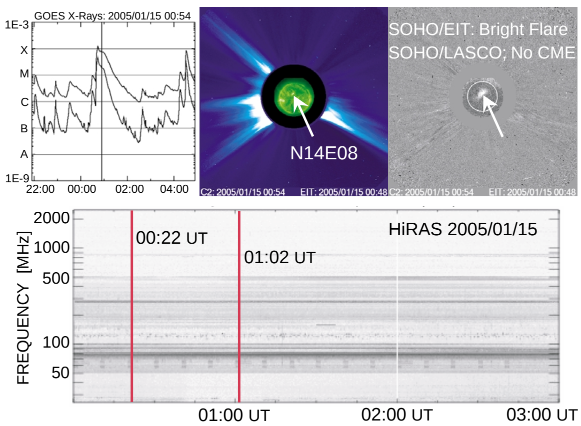

Figure 1. Figure 1. (top) GOES soft X-ray flare, SOHO/LASCO image with superposed EIT image showing the flare and SOHO/LASCO and EIT difference images. (bottom) Radio dynamic spectrum from the Hiraiso radio spectrograph (HiRAS) with the start (00:22) and end (01:02) times of the flare marked. The flare of interest is pointed by arrows. Note that there is no radio emission during the flare.

Table 1. X-class flares without CMEs during solar cycle 23 and their properties

#	Flare Start	Peak	Dur	Imp	Location	AR #	Hα	III	μfpk/flux
1	2000/06/06 13:30	13:39	16	X1.1	N18E12	9026[d]	N	N	2.7/560
2	2000/09/30 23:13	23:21	8	X1.2[c]	N07W90	9169	N	N	15.4/2800
3	2001/04/02 10:04	10:14	16	X1.4	N17W60	9393	1B[e]	Y	15.4/1200
4	2001/06/23 04:02	04:08	9	X1.2[c]	N10E23	9511	1B	N	5/100
5[a]	2001/11/25 09:45	09:51	9	X1.1[c]	S16W69	9704[d]	N	N	15.4/130
6	2002/10/31 16:47	16:52	8	X1.2[c]	N29W90	0162	N	N	8.8/3300
7[b]	2004/02/26 01:50	02:03	20	X1.1[c]	N14W15	0564	2N[e]	N	15.4/830
8	2004/07/15 18:15	18:24	13	X1.6	S11E45	0649	N	N	8.8/530
9	2004/07/16 01:43	02:06	29	X1.3	S11E41	0649	N	N	15.4/1900
10	2004/07/16 10:32	10:41	14	X1.1	S10E36	0649	1F[e]	Y	15.4/1200
11	2004/07/17 07:51	07:57	8	X1.0	S11E24	0649	3B[e]	N	5/820
12	2005/01/15 00:22	00:43	40	X1.2	N14E08	0720	1F	N	15.4/3000
13[a]	2005/09/15 08:30	08:38	16	X1.1	S12W14	0808	2N	N	15.4/4100

[a]There were frequent blobs of material along the streamer near the position angle of the flare throughout the day. [b]A small wisp of material was seen close to the north pole (PA ∼350) at flare peak. This is probably unrelated to the flare. [c]These flares were isolated; no other X-class flares from these regions. Rest of the regions had other X-class flares with CMEs. [d]These two regions had no open field lines. [e]Listed as eruptive H-alpha flare.

3. Results

Several results can be directly extracted from Table 1: (i) The CMEless flares occurred only during the maximum (5 flares) and declining phases (8 flares) of solar cycle 23. (ii) The flares were generally impulsive, with durations ranging from 8 min to 40 min (average value ∼16 min). (iii) The X-ray flare classes were in the narrow range of X1.0 to X1.6 (average ∼X1.2). (iv) The source locations were at all longitudes, some of them being limb events, for which it is easy to detect CMEs. (v) The 13 flares occurred in 10 different active regions, with one region (AR 0649) producing 4 flares. Interestingly, half of the active regions produced other X-class flares (two or more) associated with CMEs. (vi) Only four of the 13 flares were reported to be "eruptive" in H-alpha (SGD). However, the mass motion is likely to be in the horizontal direction. (vii) It is remarkable that only two of the 13 flares were associated with metric type III bursts (very brief). Since there is no spatial information for the type III bursts, we cannot be sure whether the temporal association in the two cases means spatial association with the flares. (viii) All the flares were associated with intense microwave bursts with peak fluxes varying from 100 SFU to 4100 SFU. The peak emission frequency was around 15.4 GHz for 8 events implying that ∼MeV were electrons accelerated during the flare that emit gyrosynchrotron radiation. (ix) All but two active regions had open filed lines from one of the polarity patches.

4. Discussion

Microwave emission from flares is caused by high energy (several hundred KeV to MeV) electrons trapped in flare loops. The association of intense microwave bursts during all the 13 flares suggests that nonthermal electrons were produced. However, during 11 out of the 13 (or 85%) flares, no metric type III burst was reported (type III bursts reported in 2 cases, but we cannot say if they were spatially associated with the CMEless flares without spatial information). Only ∼25 KeV electrons propagating along open field lines are required to produce type III bursts. Lack of type III bursts may be due to : (i) lack of low energy electrons that produce Langmuir waves, (ii) lack of open field lines in the active region, and (iii) the low energy electrons without access to the open field lines in the active region. It is unlikely that high-energy electrons are produced (for microwave emission) without lower energy electrons (for type III bursts). Potential field extrapolation indicates presence of open filed lines in most of the active regions. Therefore, we can eliminate the possibilities (i) and (ii) and conclude that the accelerated electrons did not have access to the open filed lines. If the accelerated electrons are confined to the active region core fields, type III bursts are not expected even if there are open field lines at the edges of active regions. Thus, confined flares lack not only thermal material (CMEs) but also nonthermal material (accelerated electrons). Complete lack of type II bursts during the confined flares has also implications for the source of coronal shocks. The impulsive flares are well-suited to produce blast waves, yet none of the flares was associated with metric type II bursts. This suggests that the presence of CMEs is a must for type II bursts, supporting the view that coronal shocks are likely to be driven by CMEs.

It is significant that half of the active regions producing CMEless flares also produced two or more X-class flares with CMEs. Some of these are super active regions (AR 9393, 0720, & 0808) that produced a large number of energetic flares and CMEs of great heliospheric consequence (Gopalswamy et al., 2006). It will be worthwhile to investigate the relative positions of the confined and eruptive flares from the same active region to further understand the two types of flares.

5. Conclusions

We identified thirteen X-class flares during cycle 23 that were not associated with CMEs. The flares were generally impulsive (duration ∼16 min) and the X-ray peak flux never exceeded X1.6. The flares showed heating and particle acceleration, but lacked material motion in the vertical direction. While the presence of intense microwave bursts imply copious production of high energy electrons, the lack of type III bursts suggest that the accelerated electrons did not escape from the flare site even though the active regions had open filed lines. Many active regions produced both eruptive and confined flares, which needs further investigation to see if confined flares contribute to the eventual occurrence of eruptive flares.

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