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ORIGIN OF CORONAL SHOCKS WITHOUT MASS EJECTIONS

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Abstract. We present an analysis of all the events (around 400) of coronal shocks for which the shock-associated metric type IIs were observed by many spectrographs during the period April 1997–December 2000. The main objective of this analysis is to give evidence for the type IIs related to only flare-blast waves, and thus to find out whether there are any type II-associated coronal shocks without mass ejections. By carefully analyzing the data from multi-wavelength observations (Radio, GOES X-ray, Hα, SOHO/LASCO and SOHO/EIT-EUV data), we have identified only 30 events for which there were actually no reports of CMEs. Then from the analysis of the LASCO and EIT running difference images, we found that there are some shocks (nearly 40%, 12/30) which might be associated with weak and narrow mass ejections. These weak and narrow ejections were not reported earlier. For the remaining 60% events (18/30), there are no mass ejections seen in SOHO/LASCO. But all of them are associated with flares and EIT brightenings. Pre-assuming that these type IIs are related to the flares, and from those flare locations of these 18 cases, 16 events are found to occur within the central region of the solar disk (longitude $\leq 45°$). In this case, the weak CMEs originating from this region are unlikely to be detected by SOHO/LASCO due to low scattering. The remaining two events occurred beyond this longitudinal limit for which any mass ejections would have been detected if they were present. For both these events, though there are weak eruption features (EIT dimming and loop displacement) in the EIT images, no mass ejection was seen in LASCO for one event, and a CME appeared very late for the other event. While these two cases may imply that the coronal shocks can be produced without any mass ejections, we cannot deny the strong relationship between type IIs and CMEs.

1. Introduction

The electromagnetic radiation in solar type II radio bursts is generally assumed to be generated by plasma emission mechanism. Shock waves are caused either by flares and/or by coronal mass ejections (CMEs). In the vicinity of fast mode MHD shocks, plasma oscillations (Langmuir waves) are generated by accelerated suprathermal electrons. These plasma oscillations are subsequently converted into radio waves due to scattering at ion density fluctuations. These radio waves are able to escape from the shock vicinity and are observed as slowly drifting features in the dynamic radio spectra from high to low frequencies. They are called type II radio bursts (Nelson and Melrose, 1985). They are usually observed in the frequency range $<$200 MHz for a duration of $\sim$5–15 min and a typical drift rate of $\mathrm{d}f/\mathrm{d}t < -0.1$ MHz s^{-1}. The emission frequency of type II bursts shows a negative drift with time in accordance with the shock propagating outward from the Sun and in accordance with the decreasing electron density with altitude in the corona. The frequency of the electromagnetic radio waves is given by the electron-plasma frequency $f_p \sim 9\sqrt{n_e}$, where f_p is in Hz and n_e is the electron density in m^{-3}. One can use an appropriate electron density model (Newkirk, 1961; Saito, 1970; Mann *et al.*, 1999) in order to calculate the plasma frequency or the height corresponding to the observed frequency. This electron-plasma frequency lies in the metric range in the corona and in the decametric-hectametric range in the near-Sun and interplanetary medium.

The origin of interplanetary shocks (or decametric – hectometric – kilometric type II radio bursts) is clear with the *in situ* observations of CMEs and interplanetary type IIs (for example, Cane *et al.*, 1982; Gopalswamy, 2004). Since the duration of these type IIs is longer and only CME-piston driven shocks are associated with them, all of the interplanetary type IIs are related to CMEs. However, the origin of coronal shocks (or metric type II radio bursts) is still under debate (Cliver, Webb, and Howard 1999; Cliver and Hudson, 2002; Gopalswamy, 2000) due to nearly simultaneous occurrence of both flares and CMEs. That is, it is not clear whether the coronal shocks are generated by impulsive flare blast wave shocks or CME piston-driven shocks (Gosling, 1993; Dryer, 1996; Cliver, Webb, and Howard, 1999; Classen and Aurass, 2002). A brief review on this problem can also be seen elsewhere (Cliver, Webb, and Howard, 1999; Gopalswamy *et al.*, 1998, 1999; Cliver *et al.*, 2004). Investigations in the past few decades showed more relationships between flares and metric type IIs than between CMEs and metric type IIs (Vrsnak *et al.*, 1995; Gopalswamy *et al.*, 1998, 1999; Gopalswamy, 2000; Vrsnak, 2001; Shanmugaraju *et al.*, 2003a,b). But Cliver, Webb, and Howard (1999) proposed that high-speed mass ejection is the preferable condition for producing the shocks. However, there have been many reports (e.g., Sheeley *et al.*, 1984; Robinson, 1985; Gopalswamy, 2000; Lara *et al.*, 2003) in the literature for lack of CMEs for nearly 30% type IIs. Regarding this problem, Cliver, Webb, and Howard (1999) suggested that mass ejections from the central region of the solar disk might have gone undetected. This may be because of low CME brightness caused by reduced Thomson scattering for ejecta propagating along the Sun-Earth line or equivalently for CMEs originating close to disk center and propagating radially outwards (Andrews, 2002).

Though there have been several reports about the relationship among flares, type IIs and CMEs (Classen and Aurass, 2002; Lara *et al.*, 2003; Shanmugaraju *et al.*, 2003a,b), there is still a lack of clear evidence for coronal shocks without mass ejections (Cliver and Hudson, 2002). Hence the generation of coronal shocks by flare blast waves alone is still under debate (Cliver *et al.*, 2004). In this paper, we present an analysis of several events of coronal shocks observed during the period April 1997–December 2000 especially looking for the events for which there were no reports of SOHO/LASCO CMEs. From a large number of type II bursts (nearly 400) reported during this entire period, we have finally obtained a sample of 30 events for which there were no reports of SOHO/LASCO CMEs. But among these 30 events, 12 cases (nearly 40%) seem to be associated with weak and narrow mass ejections. The remaining set of 18 events were analyzed in detail. From the investigations of this set of 18 events, we have found that only two events occurred beyond a longitudinal range of 45 degree from the central meridian.

In the next section, we describe the data analysis. Results are given in Section 3 and the discussions about them in Section 4. Finally, a brief summary and conclusion are delivered in Section 5.

2. Data Selection

We have considered all the type IIs (around 400) reported in the NGDC/NOAA website[1] by all the spectrographs during the period April 1997–December 2000 and the NGDC/NOAA X-ray flare and H_α flare catalogs available online.[2] Regarding the CME and EIT data, we have utilized the CME online catalog.[3] The SOHO/EIT and SOHO/LASCO running difference images were analyzed in conjunction with X-ray and H_α data to identify the activities corresponding to these type IIs.

We have used several criteria to select a set of type II events. That is, we excluded the following events: (i) corresponding to data gaps in SOHO/LASCO; (ii) CCD blackouts in SOHO/LASCO and SOHO/EIT; (iii) those for which there are reports of both the flares and CMEs within approximately ± one hour; (iv) those for which there are no reports of X-ray flares; and, finally, (v) those for which the flares are reported without locations. A sample of 30 events was obtained from the analysis for which there were no reports of CMEs.

[1] *ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_RADIO/SPECTRAL.*

[2] *ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA.*

[3] *http://cdaw.gsfc.nasa.gov/CME_list.*

3. Results

When these events were analyzed further using the LASCO and EIT running difference images, we identified weak and narrow ejections (which were not reported earlier) for some cases. These ejections are found to nearly agree with the flare locations. A list of 12 such events (for which there are weak and narrow mass ejections) is given in Table I: type II data – date and period are given in columns 2 and 3; X-ray flare data – class/time and location are given in columns 4 and 5; remarks about the mass ejections seen in LASCO are given in the last column. For example, Figure 1 shows the SOHO/LASCO running difference images of four events in which narrow mass ejections can be seen. Another list of the other remaining 18 events for which there are no mass ejections in LASCO is given in Table II.

Because of the absence of mass ejections, these type IIs can be assumed to be related to the flares reported around the duration of type II. The locations of these flares are as follows: 16 events are located within the 45° from the central meridian (i.e., longitude $\leq 45°$). The remaining two events have locations beyond this range. A histogram of longitude is shown in Figure 2.

If there were mass ejections for two cases, they would have been detected in these cases. Among these two events, for the event on 27 July 2000, the flare location (N10W72) was near the limb. There are no signs of mass ejections in LASCO C2 running difference images corresponding to this type II event (04:11–04:15 UT). While there is an indication of weak EIT dimming in the north-west quadrant, no mass ejections are seen except a very weak circular wave front in the north-west quadrant. As shown in Figure 3, there are clear evidences of EIT brightening in the

TABLE I

List of Type IIs for which weak/narrow mass ejections are seen in LASCO.

No.	Date (yy/mm/dd)	Type II period (UT)	X-ray flare class/time (UT)	Flare location	Mass ejection time/quadrant
1	97/04/02	0527–0541	C1.3/0527–0537	S25E05	0601(SE)
2	97/04/02	0927–0934	B6.8/0924–0942	S24E07	0935(SE)
3	97/09/12	1605–1608	B6.0/1604–1610	N24W20	1741(NW)
4	97/09/24	0248–0258	M5.9/0243–0252	S31E19	0255(SE)
5	97/09/24	1103–1120	M3.0/1057–1110	S28E18	1110(SE)
6	97/09/24	1834–1841	C8.3/1824–1845	S29E15	1853(SE)
7	98/04/29	0827–0831	C1.7/0754–0827	S17E23	0927(NE)
8	98/11/06	2211–2216	C9.4/2205–2211	N15W37	2256(NW)
9	99/06/09	0025–0034	C1.2/0007–0031	N21E05	0120(NE)
10	99/07/13	0602–0608	C2.9/0522–0609	N17E06	0606(NE)
11	99/12/06	0718-	C8.4/0700–0734	N10E43	0830(NE)
12	00/09/16	1652–1713	C1.8/1641–1650	S12E56	1706(NE)

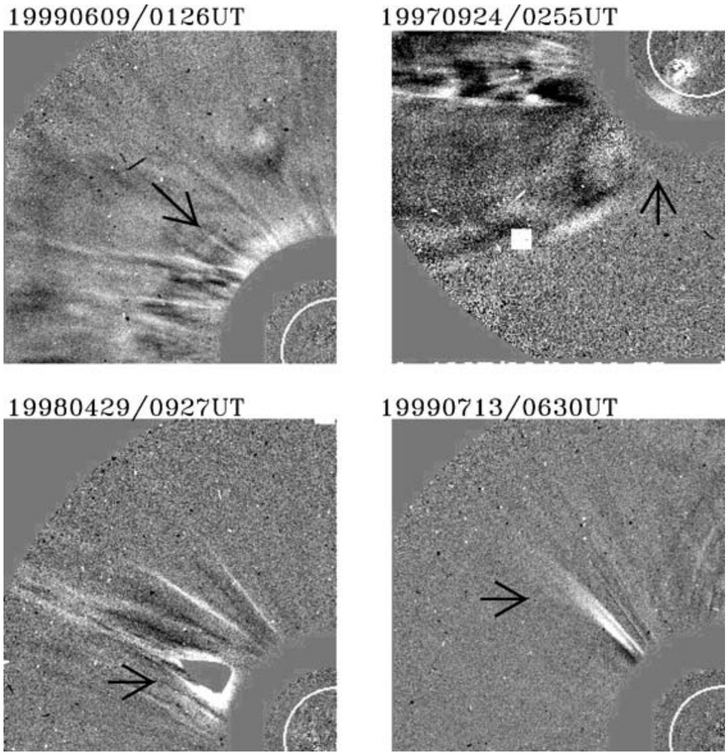

Figure 1. SOHO/LASCO C2 running difference images of four selected events in which weak narrow mass ejections were identified, as indicated by *arrows*. EIT running difference images are superimposed at the *center*. The *white circle* represents the photosphere.

image taken at 04:12 UT. Also there are dimming regions in the subsequent images that are clearly seen in the running difference images (especially, 04:24-04:12) in the bottom row of Figure 3.

Similarly, the SOHO/EIT running difference images (Figure 4) corresponding to the type II event on 2000 August 01 show clear evidence of EIT brightening and displacement of loop like structures. There is no mass ejection seen in LASCO C2 before 06:30 UT (for example, a LASCO C2 running difference image at 04:54 UT is shown in Figure 5). However, a CME was observed very late at 06:30 UT in LASCO C2 which might correspond to this limb event. The reason for the late appearance of this backsided CME is most likely due to the projection effect.

4. Discussion

As described in the last section, from a large sample of type II bursts (around 400) observed during the period April 1997– December 2000, only a small number

TABLE II

List of Type IIs without mass ejections.

No.	Date (yy/mm/dd)	Type II period (UT)	X-ray flare class/time (UT)	Flare location
1	97/04/01	0801–0806	C2.2/0752–0804	S25E20
2	97/04/01	1032–1038	C2.1/1023–1038	S25E27
3	97/04/15	1415–1426	C1.0/1409–1426	S23E14
4	97/09/25	1147–1148	C7.2/1140–1155	S27E02
5	99/05/26	0235–0249	C2.3/0225–0235	N22E41
6	99/07/01	0148–0150	C5.4/0141–0152	S15W16
7	99/07/12	1948–2006	C1.5/1942–1956	N19E12
8	99/08/02	0540–0550	C5.8/0528–0536	S28W28
9	00/04/12	0632–0641	C2.1/0622–0633	S19W28
10	00/04/29	1151–1156	C3.0/1123–1234	S11W06
11	00/06/01	0733–0738	C8.2/0728–0739	S14E24
12	00/06/21	0812–0818	C3.9/0756–0802	N19W37
13	00/07/21	1439–1457	M5.5/1430–1443	N12E05
14	00/07/27	0411–0415	M2.4/0406–0413	N10W72
15	00/08/01	0347–0353	C2.8/0337–0354	N15E90
16	00/08/17	0847–0852	C4.9/0831–0845	N17E28
17	00/08/28	1713–1718	C3.3/1656–1728	S17E24
18	00/09/15	1652–1713	C8.7/1632–1741	N14E04

(18/400) of type IIs are found to be without mass ejections. Similar to this result, out of 265 type IIs observed by the Culgoora radio spectrograph during the period May 1979–October 1982, Sheeley *et al.* (1984) obtained 19 type IIs without CMEs (in Solwind). The fewer number of type IIs without mass ejections in the present study might be attributed to the high sensitivity of LASCO instrument in detecting CMEs, which were demonstrated by high observing rate of CMEs (which is a factor of two more than that of the earlier instruments, Cliver, Webb, and Howard, 1999).

From the investigations of this set of 18 events, we have found that there are no mass ejections corresponding to these events. But they are all related to flares and EIT brightenings. Out of these 18 cases, 2 events occurred beyond a longitudinal range of 45° for which any mass ejections would have been detected in SOHO/LASCO. The flare locations of the two events were near the limb (N10W72 on 27 July 2000, N15E90 on 2000 August 01). While there was a CME for the second event that appeared in LASCO C2 very late, there was no mass ejection in LASCO for the first event. This may imply that the type II-associated coronal shocks can be produced by flare blast-waves without any mass ejections. However, both events were associated with EIT brightening and expanding loop like structures as seen in the EIT images. Might this event represents the coronal shocks generated by flare-blast waves alone? If the answer to this question is "yes", classically-fundamental,

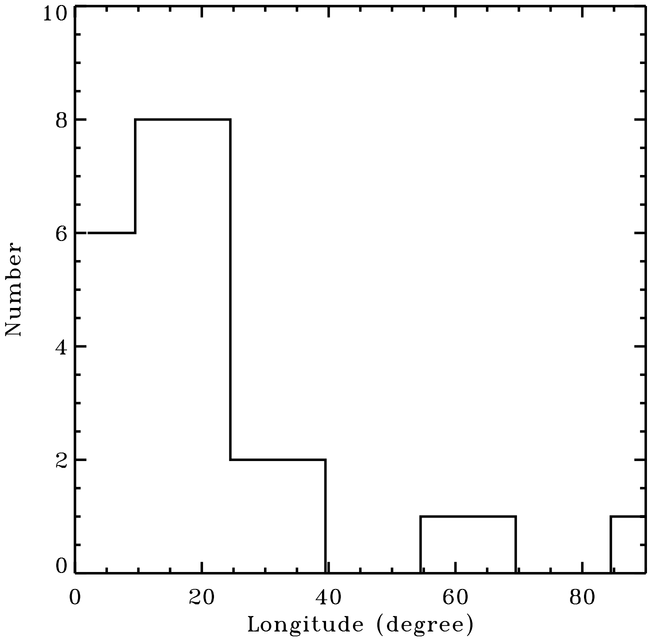

Figure 2. Histogram showing the distribution of longitudes of events in Table II.

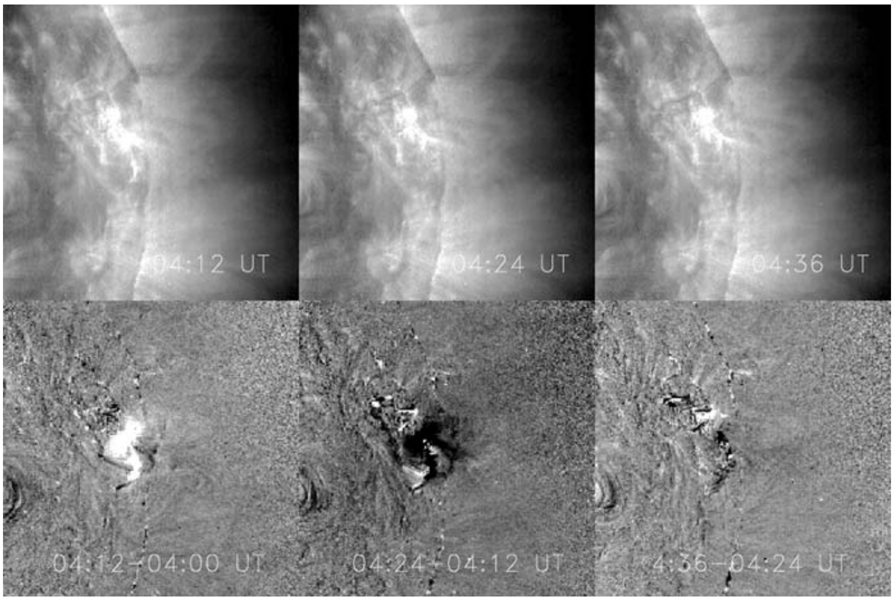

Figure 3. *Top row*: SOHO/EIT images corresponding to the event on 2000 July 27. *Bottom row*: EIT running difference images.

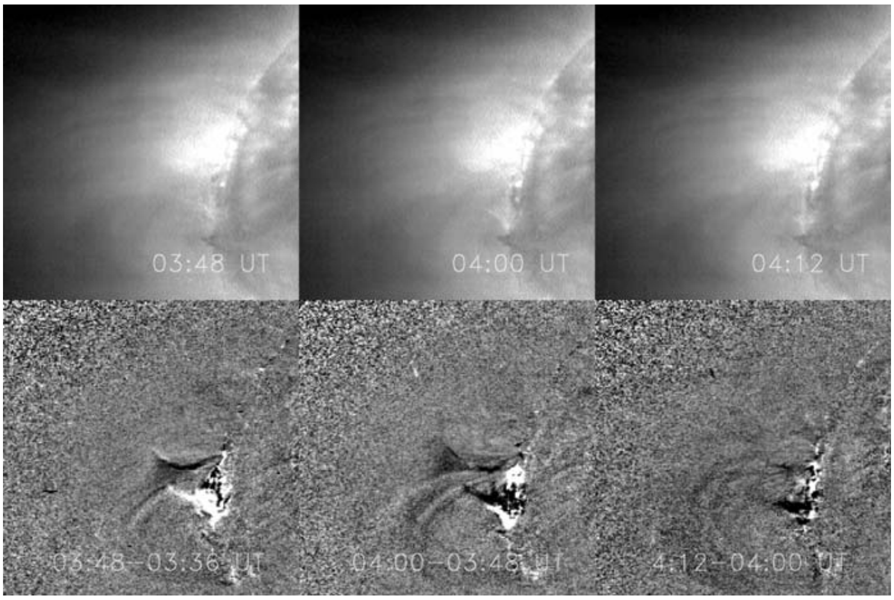

Figure 4. *Top row*: SOHO/EIT images corresponding to the event on 2000 August 01. *Bottom row*: EIT running difference images.

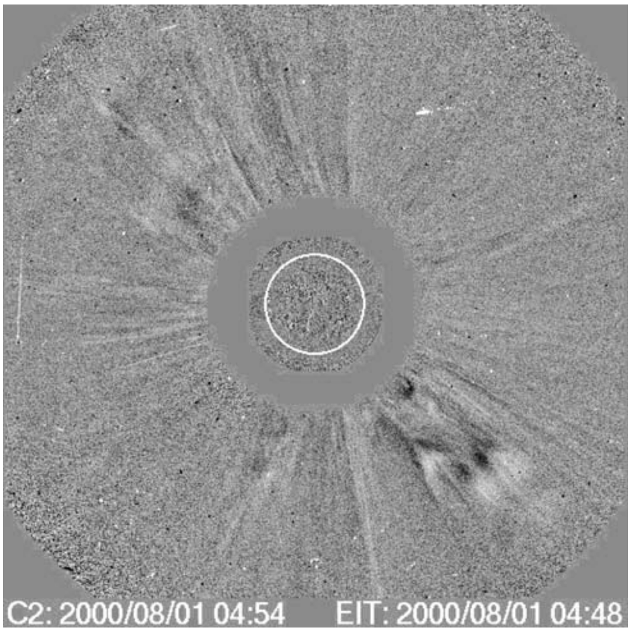

Figure 5. SOHO/LASCO C2 difference image on 2000 August 01 at 04:54UT. EIT running difference image is superimposed at the *center*. The *white circle* represents the photosphere.

self-similar blast wave Sedov theory (reviewed by Dryer *et al.*, 1974a; Dryer, 1974b) might be appropriate to explain this phenomenon. In such cases, only the surrounding corona would be set into motion with no mass ejected from the flare source.

On the other hand, all the 12 events in Table I are associated with some kind of mass ejections. The ejections are weak and narrow and some times diffused. Keeping this in mind, naturally one can raise doubt about the 18 events in Table II on the basis of whether the mass ejections corresponding to these events got diffused before reaching the initial height of LASCO C2 coronagraph.

But there are reports in the literature about flares without CMEs (for example, Green *et al.*, 2002; Feynman and Hundausen, 1994). It seems that these events were not associated with type IIs. Also there are reports for a lack of nearly 30% association between type IIs and CMEs (for example, Sheeley *et al.*, 1984; Lara *et al.*, 2003). As suggested by Svestka (2001), the physical characteristics of mass ejections may vary depending on the strength of the magnetic field in the region of the field line opening. Interestingly, the flares associated with most of the events in Tables I and II are of less strength and short duration (<20 min). As reported by many authors (for example, Kahler, Reames, and Sheeley, 2001), the ejections associated with impulsive flares are mostly weak and narrow. Furthermore, when the CMEs are directed far from the plane of the sky, as already pointed out, they are unlikely to be identified due to reduced Thomson scattering (Thompson *et al.*, 2000). According to these studies, the CMEs corresponding to the events in Table II may either be actually absent, or not be identified in LASCO imagery.

In Table II, except for the two events, all others occurred within the central region of the solar disk. As proposed by Cliver, Webb, and Howard (1999), it can be assumed that any mass ejections for these events might have gone undetected, perhaps because of reduced Thomson scattering near the center of the disk (Andrews, 2002). Only two events are found to have occurred beyond a longitudinal range of 45°. Among these two cases, at least one event is found to have occurred at the limb and associated with a CME. The other event occurred within 15 degrees from the limb, but without any associated CME. As suggested by Cliver and Hudson (2002), if there are type IIs associated with limb-flares but without CMEs, they might represent the sources of coronal shocks generated by flares. Though this event may perhaps be considered as the representative case for the coronal shocks of flare origin, more evidence is needed to confirm the generation of coronal shocks by flare blast-waves alone, i.e., coronal shocks without mass ejections.

On the other hand, these results may give more evidence for the existence of strong metric type II – CME relationship (Reiner *et al.*, 2003; Mancuso and Raymond, 2004; Cliver *et al.*, 2004; Cho *et al.*, 2005). For example, Gary *et al.* (1984) found that the type II burst sources and hence the shock were located within the dense, ejecta material for the event on 1980 June 29 (0233UT). The presence of mass ejections in many cases may either be considered as driver of the shocks, or they are essential for the flare-blast waves to seek high density regions (that is, low-Alfven speed regions, Uchida, 1974) to steepen into fast mode MHD shocks.

5. Conclusion

In this paper, we have presented the analysis of several events of coronal shocks observed during the period April 1997 – December 2000. From a large sample of shock-associated type II bursts reported during this period, we have obtained a sample of 30 events that satisfied several criteria. These events were analyzed in detail using the multi-wavelength observations from Radio (metric wavelength), X-ray, white light, etc. Among these events, nearly 40% (12 out of 30) might be associated with weak and narrow mass ejections that were not reported earlier. Then a clear set of 18 events were considered and found that there are no mass ejections corresponding to all events except one. But they are all related to flares. Out of 18 cases, 2 events occurred beyond a longitudinal range of 45 degree for which any mass ejections would have been detected in SOHO/LASCO. There is a variety of signatures (EIT brightening/dimming) in the EIT images of both these events. While there was an unrelated backsided CME for one event (2000/08/01) which appeared late in LASCO C2, no mass ejection was observed for the second event (2000/07/27). Though this event suggests that the type II-associated coronal shocks might have been generated by flare-blast waves without any mass ejections, more evidence is needed to confirm this result. Alternatively, these results may imply a strong type II – CME relationship.

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