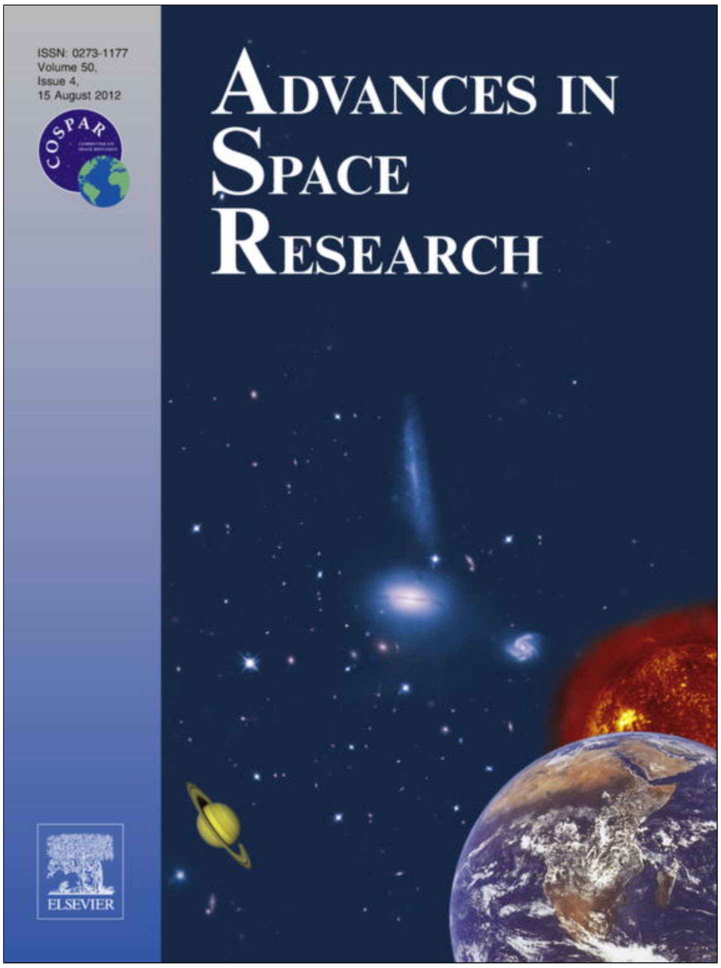
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Solar and interplanetary parameters of CMEs with and without type II radio bursts

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Abstract

We have analyzed 101 CMEs, and their associated ICMEs and interplanetary (IP) shocks observed during the period 1997–2005. The main aim of the present work is to study the interplanetary characteristics of metric and DH type II associated CMEs such as, shock strength, IP shock speed, ICME speed, stand off distance and transit time. Among these 101 CMEs, 38 events show both metric and DH type II bursts characteristics. There are no metric and DH type II association for 52 events. While DH type II alone is found in 7 cases, metric type II alone is found in 4 events. It is found that the mean speeds of CMEs increase progressively from CMEs without type II events to CMEs associated with metric and DH type IIs as suggested by Gopalswamy et al. (2005). In addition, we found that the speeds of ICMEs and IP shocks progressively increase in the following order: events without metric and DH type IIs, events with metric alone, events with DH alone and events with both metric and DH type IIs. Similarly the Mach number is found to increase in the same order. While there is not much change in the stand-off distance among these cases, it is minimum (~18 $R_\odot$) for CMEs with speed greater than 2200 km/s. The above results confirm that more energetic CMEs can produce both metric and DH type IIs for which the interplanetary parameters such as mean values of ICME speed and IP shock speed and Mach number are found to be higher.

Keywords: Coronal Mass Ejections; Flares; Radio bursts; Interplanetary shocks

1. Introduction

Coronal Mass Ejections (CMEs) are large scale expulsions of plasma ejected from the Sun into the interplanetary (IP) medium. Shocks generated by CMEs can be inferred from type II radio bursts in the corona and in the IP medium which are termed as metric and interplanetary type II bursts, respectively. The type II bursts are produced by plasma emission mechanism i.e., Langmuir waves are excited by electron beam produced in a propagating shock and the waves are then converted into escaping radio waves (see for example, Nelson and Melrose, 1985 and references therein; Cairns et al., 2003; Mann et al., 2003; Cho et al., 2005). The type II bursts are observed as slowly drifting features in the radio dynamic spectrum. It is well known that frequency drift rate of a type II burst is related to speed of the shock that produces the bursts and density gradient in the ambient medium (Gopalswamy et al., 2009). Since type II bursts are the earlier indicators of shocks, one should look at the radio emission characteristics near the Sun and in the IP medium (Gopalswamy et al., 2008a). The association of type II bursts with CMEs and their interplanetary counterparts have been investigated by several authors (e.g. Kahler et al., 1984; Sheeley et al., 1984; Cane et al., 1987; Aurass,

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1997; Vršnak et al., 2001, 2002). They have established the relation between CMEs, flares, coronal shocks from the SMM and Solwind Coronagraphs in 1970s and 1980s. The higher speeds of CMEs associated with flares compared with CMEs not so associated was discussed by MacQueen and Fisher (1983). Recently during the SOHO/LASCO era with a large set of CMEs, the above relations have been further investigated by many authors (Classen and Aurass, 2002; Gopalswamy et al., 2001, 2005; Shanmugaraju et al., 2003, 2011; Cho et al., 2007). The interplanetary counterparts of CMEs are called as ICMEs, which have been mainly identified by in-situ observations, and most interplanetary (IP) shocks within 1 AU are driven by ICMEs. It was reported by many authors (Sheeley et al., 1985; Tsurutani et al., 1988; Bale et al., 1999; Gopalswamy, 2008) that ICMEs and IP shocks are associated with the CMEs. The interplanetary type II bursts are in the range of deca–hecta metric wavelength (DH type IIs) and they are found to be associated with solar energetic particle (SEP) events (Gopalswamy et al., 2005, 2008b). The type II bursts are due to non thermal electrons accelerated during solar eruptions. Further, the radio bursts thus provide important diagnostics of the solar eruption and the ambient medium through which the solar disturbance propagate (Gopalswamy, 2011). Interplanetary shocks arriving at 1 AU also compress the magnetosphere causing storm sudden commencement (SSC), which may be followed by a geomagnetic storm (Tsurutani et al., 1988; Gopalswamy et al., 2008a). Shocks can also be directly detected in situ in the solar wind data as a continuous jump in density, temperature, flow speed and magnetic fields.

Especially, Gopalswamy et al. (1999) and Cane and Erickson (2005) tried to establish the relationship between metric and DH type II bursts. The characteristics of CMEs associated with long wavelength type II (DH type II) were studied in detail by Gopalswamy et al. (2001, 2005, 2009). They found that the DH type II CMEs are wider and faster than the normal CMEs. The characteristics of CMEs associated with metric type II were investigated by several authors (e.g. Shanmugaraju et al., 2003). It has been reported that the CMEs associated with both the metric and DH type IIs are found to be energetic than any other CMEs. In addition, Gopalswamy et al. (2005) found that the CMEs associated with the m-to-km type II bursts were more energetic than those associated with bursts in any single wavelength regime. However, a combined study of the properties of CMEs, ICMEs and IP shocks of metric and DH type II associated events is performed in the present work. The main objective of the present work is to find the parameters of CMEs, ICMEs and IP shocks associated with metric and DH type II bursts for a set of 38 events and to compare these results with the parameters of events without metric and DH type IIs. In contrast to the earlier studies of statistical analysis of the properties of CMEs alone, the shock strength, stand off distance, IP shock speed and transit time of these events are analysed in the present work.

2. Data selection and analysis

In our present study, we considered a set of 101 CME events associated with ICMEs and interplanetary shocks observed during the period 1997–2005. Among these, the first 91 CME events are obtained from the list given by Manoharan et al. (2004) and the next 10 events are selected from the LASCO CME list (http://cdaw.gsfc.nasa.gov/CME_list/) according to the criteria used by Manoharan et al. (2004). In addition, the speed of CMEs should be greater than 2200 km/s. These 10 events are found to be associated with metric and DH type II bursts. The CMEs associated with flares and shocks are identified using LASCO (Large Angle Spectrometric Coronagraph) and EIT (Extreme Ultraviolet Imaging Telescope) on board Solar Heliospheric Observatory (SOHO) mission.

Identification and selection of IP shocks and ICMEs corresponding to the 91 CME events are already described in Manoharan et al. (2004). They investigated these events with a different concept of effect of interaction of CMEs in propagation through interplanetary medium. We utilised the data collected by them for a different purpose of studying the properties of CMEs, ICMEs, IP shocks in association with metric and DH type II bursts. Further, we obtained the data of IP shocks for the 10 events from the OMNI website (http://cdaweb.gsfc.nasa.gov/istp_public/) and interplanetary shock lists obtained from the Proton Monitor (PM) on board SOHO mission (http://umtof.umd.edu/pm/). Solar wind parameters associated with the shocks and CME at the near Earth spacecraft were obtained from Manoharan et al. (2004) and from the available online data using the website (http://nssdc.gsfc.nasa.gov/omniweb). For each event, we found the shock onset date, time, shock speed, Mach number (Alfvenic Mach number, Ma) and transit time as described below. The shocks are identified using sudden discontinuity in plasma parameters of proton density, flow speed and proton temperature. The shock speeds (see e.g. Douglas and Park, 1983) are calculated using density and speed from upstream and downstream of shock, $Vs = (v_1 n_1 - v_2 n_2)/(n_1 - n_2)$, v_1 and n_1 are speed and density before the shock front (upstream region), v_2 and n_2 are the speed and density after the shock front (downstream region). Alfvenic Mach (Ma) numbers (Velli and Prunetti, 1997) are calculated using magnetic field, density and velocity data at the shock front (Ma = upstream speed/Alfvenic speed). Transit time is represented by the time difference between the CME time in LASCO C2 image and shock time in WIND spacecraft data. By analysing the SOHO EIT and SOHO LASCO images and by considering the flare location, we have obtained the list of flares associated with all the 101 CME events. For the 101 CME events, 73 events are associated with X-ray flares and there is no report of X-ray flares for the remaining events. By considering the flare starting time as the reference, we have selected the metric type II association using a time window of ±30 min and a time window of 3 h for DH type II associations

(Gopalswamy et al., 2001; Vršnak et al., 2001, 2002; Shanmugaraju et al., 2003; Cho et al., 2005). Among the 73 flare associated events, there are 21 X – class flares, 26 M – class flares, 24 C – class flares and 2 B – class flares. However, we found that only 38 events out of 101 events showed both metric and DH type II bursts. Out of 38 events, it is found manually by inspecting the metric and DH spectrum plots that 23 events have extension of metric type II into the DH type II region.

The stand-off time of a CME at a distance is given by the time difference between the arrival of CME-driven shock disturbance and the CME at the given distance (see, e.g. Manoharan and Mujiber Rahman, 2011). That is, the stand off time is referred as the time difference between

Table 1a
List of CMEs associated with X-ray flares, metric and DH type II bursts ((i) Events without metric and DH type II bursts).

No.	Date yymmdd	CME Time hhmm	H/P	Speed kms^{-1}	Location	Type	Flare Start time hhmm	Peak time hhmm	End time hhmm
1	970106	1510	H	136	S18E06				
2	970207	0030	H	490	S20W04				
3	970830	0130	H	371	N30E17				
4	970917	2028	H	377	N30W10				
5	971119	1227	P	150	N20E05				
6	980125	1526	H	693	N21E25	C1.1	1429	1512	1700
7	980214	0655	P	123	S24E23				
8	980228	1248	P	176	S24W01				
9	980402	1830	P	155	S23E23	C1.8	1161	1659	1737
10	980609	0927	P	124	S25W20	B4.0	0835	0839	0846
11	980621	0535	P	192	N17W25	C2.7	0439	0512	0551
12	981015	1004	H	262	N22W01				
13	981104	0754	H	523	N17W01	C1.6	0713	0719	0731
14	981109	1818	P	325	N15W05				
15	990307	0554	P	835	S20E15				
16	990413	0330	H	291	N16E00				
17	990629	0731	H	634	N19E02I	C3.0	0624	0632	0643
18	990801	1927	P	1133	N25E13I				
19	990911	0154	P	266	S20W30				
20	990913	1731	P	444	N15E06	C2.1	1723	1732	1738
21	990920	0606	H	604	S20W05	C2.8	0546	0550	0610
22	991018	0006	P	247	S30E15	C1.0	0001	0004	0007
23	991025	1426	P	511	S20E05	C1.2	1440	1445	1512
24	000217	2006	H	600	S25W12				
25	000602	1030	H	442	N10E23	C2.4	0900	0939	1031
26	000620	0910	P	464	S30W30				
27	000707	1026	H	453	N17E10	C5.6	0842	0921	1011
28	000708	2350	P	483	N18W12				
29	000724	2354	P	320	N05W10				
30	000806	2306	P	597	S20W30				
31	000809	1630	H	702	N11W11	C2.3	1519	1622	1700
32	001002	2026	H	569	S09E07				
33	001103	1826	H	291	N02W02				
34	010215	1354	H	625	N07E12I	B8.8	1308	1416	1518
35	010228	1450	P	313	S02W12				
36	010316	0350	P	271	N11W09				
37	010319	0526	H	389	S05W00I				
38	010325	1706	H	677	N16E25I	C9.0	1625	1636	1710
39	010419	1230	P	392	N20W20	M2.0	1122	1135	1155
40	010809	1030	P	479	N05W05I				
41	010827	1726	P	408	N10W30				
42	010911	2130	P	646	S00E05	M4.5	2015	2036	2043
43	010927	0454	P	509	S20W27	C3.8	0422	0432	0448
44	011029	1150	P	598	N12E25I	M1.6	1130	1133	1137
45	020214	0230	P	473	N18E04	C4.5	0135	0142	0148
46	020320	1730	P	550	S17W20I	C4.0	1544	1808	1919
47	020507	0406	H	720	S10E27	M1.4	0337	0346	0407
48	020508	1350	H	614	S12W07	C4.2	1258	1327	1359
49	020517	0127	P	461	S20E05	M1.5	0055	0123	0130
50	020729	1207	H	556	N10W15I				
51	020729	2330	P	360	S10W10	C4.2	2238	2245	2257
52	020817	2230	P	254	S06W05I	M3.4	2039	2051	2057

Table 1b
List of CMEs associated with X-ray flares, metric and DH type II bursts.

No.	CME						Flare				Metric type II				DH type II	
	Date yymmdd	Time hhmm	H/P	Speed kms^{-1}	Location	Type	Start time hhmm	Peak time hhmm	End time hhmm	Burst	freq MHz	Start time hhmm	End time hhmm	Start time hhmm	End time hhmm	freq MHz
(ii) Events only with metric type II bursts																
53	000725	0330	H	528	N06W08	M8.0	0243	0249	0254	II/1	178-68	0249	0252			
54	001009	2350	H	798	N01W14I	II/1	25-65	2338	2354							
55	010928	0854	H	846	N10E18	M3.3	0810	0830	0910	II/3	84-25	0830	0838			
56	021106	0606	P	485	S13E13	C7.2	0505	0532	0614	II/2	63-25	0538	0546			
(iii) Events only with DH type II bursts																
57	970407	1427	H	878	S28E19I	C6.8	1350	1407	1419					1430	1730	11-1.00
58	971226	0231	P	197	N24E14									0700	1400	0.2-0.07
59	980502	1406	H	938	S15W15	X1.1	1331	1342	1351					1425	1450	5-3.00
60	000711	1327	H	1078	N17E27	X1.0	1212	1310	1335					1300	1330	12-1.00
61	020315	2306	H	907	S08W03	M2.2	2209	2310	0042					2245	2330	14-6.0
62	020415	0350	H	720	S15W01	M1.2	0305	0355	0506					0335	0415	11-1.5
63	020715	2130	H	1300	N19W01I	M1.8	2103	2132	2148					2115	0500	5-0.175
(iv) Events with both metric and DH type II bursts																
64	970512	0630	H	464	N21W08I	C1.3	0442	0455	0526	II/2	80-30	0454	0503	0515	1600	12-0.08 l
65	980429	1658	H	1374	S18E02I	M6.8	1606	1637	1659	II	40	1622	1632	1630	1700	10-2.00 n
66	981105	2044	H	1118	N22W18	M8.4	1900	1955	2012	II	75-25	1951	1957	2200	0800	5-0.05 n
67	000118	1754	H	739	S19E11I	M3.9	1707	1727	1744	II/2	80-30	1719	1731	1731	2200	14-0.5 l
68	000208	0930	H	1079	N25E26	M1.3	0842	0900	0918	II/3	80-35	0857	0916	0905	0220	12-0.02 n
69	000210	0230	H	944	N30E04	C7.3	0140	0208	0239	II/2	80-30	0148	0158	0155	0200	14-8 n
70	000212	0431	H	1107	N26W23I	M1.7	0351	0410	0431	II/1	80-30	0406	0417	0355	0920	4-0.4 n
71	000606	1554	H	1119	N20E15I	X2.3	1458	1525	1540	II	146-25	1523	1527	1520	0900	14-0.04 n
72	000714	1054	H	1674	N22W07	X5.7	1003	1024	1043	II/3	80-35	1020	1026	1030	1430	14-0.08 e
73	000912	1154	H	1550	S12W18I	M1.0	1131	1213	1313	II/1	48-25	1143	1152	1200	1220	14-0.06 e
74	000916	0518	H	1215	N14W07	M5.9	0406	0426	0448	II/2	180-25	0417	0425	0430	1030	14-0.4 e
75	001124	0530	H	994	N20W05I	X2.0	0455	0502	0508	II/3	180-25	0502	0509	0525	1500	14-0.1 e
76	001124	1530	H	1245	N22W07I	X2.3	1451	1513	1521	II/3	80-30	1512	1523	1525	2200	14-0.2 e
77	010329	1026	H	942	N14W12I	X1.7	0957	1015	1032	II	65-2	1003.3	1007	1012	0600	4-0.06 e
78	010409	1554	H	1192	S21W04	M7.9	1520	1534	1600	II/3	80-30	1527	1552	1553	0100	12-0.1 e
79	010410	0530	H	2411	S23W09I	X2.3	0506	0509	0542	II/3	80-30	0513	0517	0524	2400	14-0.1 e
80	010411	1331	H	1103	S22W27I	M2.3	1256	1326	1349	II	64-29	1303	1311	1315	1415	14-1.5 e
81	010426	1230	H	1006	N17W00	M7.8	1126	1312	1319	II	84-25	1334	1340	1240	0500	5-0.02 n
82	010924	1030	H	2402	S12E23I	X2.6	0932	1038	1109	II	270-35	0940	1030	1045	2000	7-0.03 e
83	011009	1130	H	973	S28E08	M1.4	1046	1113	1149	II/2	180-25	1054	1102	1115	1600	8-0.2 e
84	011019	1650	H	901	N15W29	X1.6	1613	1630	1643	II/2	180-25	1624	1642	1645	1640	14-0.03 l
85	011022	1506	H	1336	S21E18	M6.7	1427	1508	1531	II/2	142-25	1453	1513	1515	1740	8-1.2 e
86	011025	1526	H	1092	S16W21	X1.3	1442	1502	1528	II/1	180-66	1455	1500	1530	2300	14-0.03 n
87	011104	1635	H	1810	N06W18	X1.0	1603	1620	1657	II/2	180-29	1610	1621	1630	1100	14-0.7 l
88	020516	0050	H	600	S22E14	C4.5	0011	0035	0118	II/1	290-90	0028	0045	0150	0330	9-2 n
89	020718	0806	H	1111	N19W30	X1.8	0724	0744	0749	II/2	92-25	0747	0753	0755	0845	14-1.5 e
90	020816	1230	H	1459	S14E20	M5.2	1132	1232	1307	II/2	40-25	1205	1208	1220	2100	14-0.06 e
91	020905	1654	H	1657	N04W28	C5.2	1618	1706	1735	II/2	180-32	1635	1649	1655	1622	16-0.03 e
92	031102	1730	H	2598	S14W56	X8.3	1703	1725	1739	II/3	180-25	1714	1787	1808	1910	12-0.25 e
93	031104	1954	H	2657	S19W83	X17.4	1929	1953	2006	II/3	90-23	2003	2010	2000	2400	10-0.2 l
94	041110	0226	H	3387	N09W49	X2.5	0159	0213	0220	II/3	260-70	0215	0230	0225	0340	14-1 e

(continued on next page)

Table 1b (*continued*)

No.	CME						Flare				Metric type II			DH type II		
	Date yymmdd	Time hhmm	H/P	Speed kms^{-1}	Location	Type	Start time hhmm	Peak time hhmm	End time hhmm	Burst	freq MHz	Start time hhmm	End time hhmm	Start time hhmm	End time hhmm	freq MHz
95	050115	2306	H	2861	N15W05	x2.6	2225	2302	2331	II/2	180-70	2234	2258	2300	2400	3-0.04 e
96	050117	0954	H	2547	N15W25	X3.8	0659	0952	1007	II/3	50-25	0915	0920	0925	1600	14-0.03 e
97	010402	2206	P	2505	N19W72	X20	2132	2151	2203	II/3	280-28	2152	2157	2205	0230	14-0.25 e
98	010924	1030	H	2402	S16E23	X2.6	0932	1038	1109	II	270-45	0940	1030	1045	2000	7-0.03 e
99	020421	0127	H	2393	S14W84	X1.5	0043	0157	0238	II/3	130-57	0119	0130	0130	2400	10-0.06 e
100	050822	1730	H	2378	S13W65	M5.6	1646	1727	1802	II	180-40	1655	1705	1715	1300	12-0.04 e
101	990604	0725	P	2230	N17W69	M3.9	0652	0703	0711	II	2000-40	0700	0710	0700	0100	14-0.06 n

the ICME and IP shock arrival time at 1 AU. The stand off distance is calculated using stand off time multiplied by the ICME speed.

CME date (yymmdd format), time, type (halo or partial halo), initial speed in LASCO field of view and location of the corresponding flare region are listed in the second to sixth column of Tables 1a and 1b. This table is arranged as follows: absence of both metric and DH type II bursts (event #1 to event #52), only metric type II events (event #53 to event #56), only DH type II bursts (event #57 to event #63) and presence of both metric and DH type II bursts (event #64 to event #101). These are obtained from SOHO LASCO CME online catalogue (http://www.cdaw.gsfc.nasa.gov). The flare associated data are obtained from the NOAA list (ftp://ftp.sec.noaa.gov/) available online. Metric and DH type II association is given in Table 1b for reference. Strength of the flare, start, peak and end times of the X-ray flares are listed in seventh to tenth column.

The coronal type II burst details are obtained from the available online NOAA list of RSTN (http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarradio.html),

Culgoora (http://www.ips.gov.au/main.php?catID=5/),

Hiras (http://sunbase.nict.go.jp/solar/denpa/index.html),

Potsdam (http://www.aip.de/groups/osra/index_en.html) and

Izmiran (http://helios.izmiran.rssi.ru/lars.html). The frequency range of observation, start time and end time of metric type II are listed in column 12–14. The start time, end time, frequency range of observation of interplanetary type II bursts are obtained by using WIND/WAVES spectrum (http://ssed.gsfc.nasa.gov/waves) and they are listed in column 15–17. Identification of the continuation of metric type II in the DH spectrum is done by stack plot using the spectrum from different observatories. In Table 1b, the letter 'e' denotes the extension (or continuation) of coronal type II into DH type II and, '*n*' denotes that there is no extension between metric type II and DH type II. The letter '*l*' denotes that the coronal type II is listed in the NOAA list but does not have enough spectrum data to identify its extension with DH type II. The letter '*I*' attached with the flare location denotes that they are interacting CME events.

3. Results and discussion

3.1. Flare and CME association

As mentioned above, out of 101 CME events 73 are X-ray flare associated events and only 38 events are associated with coronal and interplanetary type II bursts. It is evident from Table 1b that four X-class flares did not produce coronal type II burst but five C-class flares produced coronal type II bursts. While a CME with low initial speed (485 km/s) observed on 6 November 2002 with C-class flare is associated with a type II burst, there are several high speed CMEs without type II bursts. Cliver et al. (1999,

2004) proposed that all metric type II shocks are CME driven. It is found that 17 X-class flare events are associated with both metric and DH type II bursts and CMEs of initial speed 900–2500 km/s. Out of 101 CMEs studied, 52 events had neither metric nor DH type IIs association. Among the 52 events without metric and DH type IIs, 35 events have CME speed less than 500 km/s, 23 events have CME speed less than 400 km/s. In these cases, the shock produced by the disturbance remains sub-Alfvenic and hence the production of type IIs is not possible. From these results, one can understand that the production of type II does not depend only on the intensity of the flare or on the speed of CMEs, but depend on special conditions like Alfven speed (Vršnak et al., 2001, 2002; Mann et al., 2003; Gopalswamy et al., 2009). In addition, the shock parameters are related with the properties of ambient medium such as magnetic field and density. For example, the band splitting of coronal and interplanetary type II bursts has been studied by Vršnak et al. (2001, 2002). Further, it is found that out of 101 events only 23 events have metric to DH extension. The absence of extension may be due to weakening of shocks in a certain height range of the corona (Gopalswamy et al., 1999, 2001). Irrespective of the several studies regarding the flare-CME-shock relation (Cliver et al., 1999; Gopalswamy et al., 1999; Shanmugaraju et al., 2003; Vršnak et al., 2004, 2008), the origin of coronal shocks is still under debate though the driver of interplanetary shocks are identified as CMEs.

We found an average speed of CMEs for flare associated events as 1108 km/s and for non flare associated events as 417 km/s. This result is in agreement with that of Moon et al. (2002) who studied the two types of CMEs: CMEs associated with flares and CMEs associated with eruptive filaments.

3.2. Distribution of the characteristics of CMEs, ICMEs and IP shocks

The distribution of CME speeds for two groups of events (absence of metric and DH type II bursts, presence of metric and DH type II bursts) is shown in Fig. 1. From this figure. we note that large number of events is spread into the high speed range in the case of both coronal and interplanetary type II bursts. But, in the case of absence of metric and DH type II events, there are no high speed CME events (CME speed $\geqslant$ 1500 km/s) and the average CME speed for this case is 449 km/s. The average speed of CMEs are 664 km/s and 853 km/s respectively for events with only metric type II and only DH type IIs. Hence, metric and DH type II events are produced predominantly by fast CMEs alone (e.g. Shanmugaraju et al., 2003; Cane and Erickson, 2005). As suggested by Gopalswamy et al. (2005), there is a clear trend of progressively increasing average values of CME speed from the absence of both metric and DH type II bursts to the presence of both (refer Table 2). Further, for 23 events which showed extension of metric type II range into DH type II range, the average CME speed associated with these events is exceptionally high (1856 km/s) as compared to all the above cases. In Table 2, the standard deviation values are also given for each parameter.

From Table 2, the average CME speed of events associated with both metric and DH type II is noted as 1594 km/s. This is more than four times that of average speed of normal CMEs reported around 428 km/s (Yashiro et al., 2004) or that of average speed of CMEs without any metric and DH type IIs (449 km/s). Hence we can understand that the CME's kinetic energy plays a vital role to produce the type II bursts in both coronal and interplanetary medium (see, e.g. Gopalswamy et al., 2005; Gopalswamy, 2008). Some exceptions are there: even with speeds >900 km/s and width >60 deg, some CMEs is not associated with type II bursts. As suggested by Gopalswamy (2008), the possible reasons are (i) the CME does not drive a shock, (b) the shock does not result into detectable radio emission and (c) the radio emission does not propagate to the observer.

Generally, ICMEs have a speed range of 200–1000 km/s (see, e.g. Kahler and Simnett, 2009). From the distribution of ICME speeds as shown in Fig. 2, we noted that for the presence of both metric and DH type II bursts, there are more events in the high speed range (>600 km/s) and the average ICME speed is found as 612 km/s. In the case of absence of both metric and DH type II events, the speed distribution is concentrated in the ~400–500 km/s range

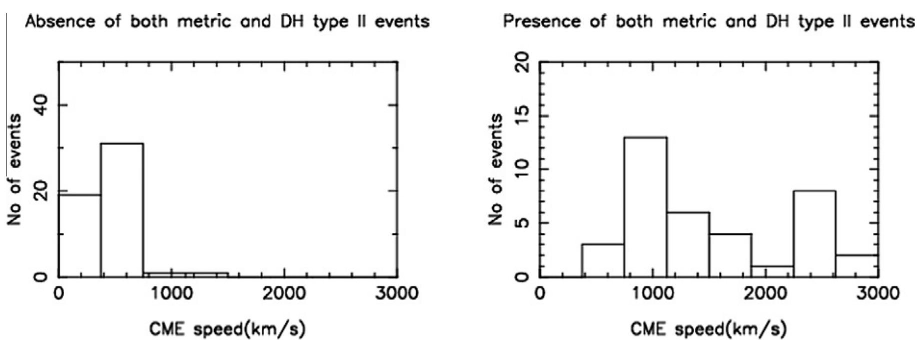

Fig. 1. Distribution of CME speeds for events with out (Left panel, number 1–52 in Table 1a) and with metric/DH type II bursts (Right panel, number 64–101 in Table 1b).

Table 2
Average values and standard deviation values of CME speed, ICME speed, IP shock speed, stand off time, stand off distance, Alfvenic Mach number (Ma) and Transit time (TT).

Properties (average values)	Absence of both metric and DH type II bursts (52)	Only metric type II bursts (4)	Only DH type II bursts (7)	Presence of both metric and DH type II bursts(38)	Metric type II extend to DH region events (23)	CME speed $\geqslant$ 2200 km/s events (12)
CME speed (km/s)	448 ± 61	664 ± 184	853 ± 359	1594 ± 141	1856 ± 725	2564 ± 306
ICME speed (km/s)	446 ± 9	442 ± 71	525 ± 108	612 ± 26	661 ± 641	673 ± 147
IP shock speed (km/s)	507 ± 3	581 ± 151	597 ± 200	693 ± 39	687 ± 210	742 ± 166
SOT (hours)	11 ± 1	12 ± 6	13 ± 5	9 ± 3	9 ± 6	5 ± 4
SOD ($R_\odot$)	27 ± 3	26 ± 10	35 ± 12	27 ± 8	24 ± 17	17 ± 14
Ma	2 ± 0.02	3 ± 3	4 ± 2	4 ± 0.7	4 ± 2	5 ± 2
TT(hours)	73 ± 2	72 ± 11	58 ± 15	46 ± 4	44 ± 10	39 ± 7

SOT – Stand off Time, SOD - Stand off Distance.

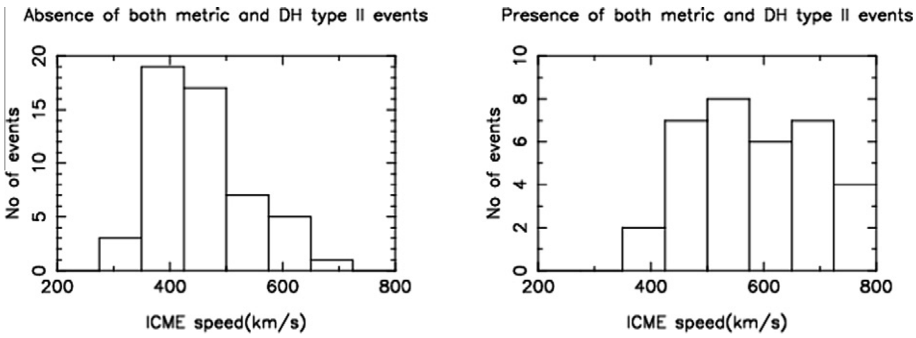

Fig. 2. Distribution of ICME speeds for events with out (Left panel, number 1–52 in Table 1a) and with metric/DH type II bursts (Right panel, number 64–101 in Table 1b).

and the average speed is 446 km/s. We found that the average ICME speeds are 443 km/s, 526 km/s, 662 km/s respectively for events with only metric, only DH and extension of metric to DH type II (see Table 2).

From Table 2, the average of interplanetary shock speed is found to be 687 km/s for events associated with both metric and DH type IIs. As shown in Fig. 3, one can see a large number of events with IP shock speed ranging from 300 km/s to 800 km/s in the case of both metric and DH type II bursts. On the other hand, it is seen that very few events are distributed in the high speed range for events without metric and DH type IIs. Sheeley et al. (1985) studied the connection between CMEs and IP shocks and reported that metric type II bursts are neither necessary nor sufficient for the occurrence of interplanetary shocks. In the present study, a few events with only metric type II bursts indicate that radio emission is produced only near the Sun and the shocks remained sub-critical for the rest of the Sun–Earth distance. The IP shocks associated with purely metric type II bursts correspond to the lower CME kinetic energy (Gopalswamy et al., 2008b).

The average stand off distance is found to be $\sim$18 $R_\odot$ for CMEs whose initial speeds are very high ($\geqslant$2200 km/s). However, we found an average stand off distance $\sim$25 $R_\odot$ for events which showed extension of metric and DH type II events. The average stand off distance is 27 $R_\odot$ for events without metric and DH type IIs which is higher than the previous cases. From the distribution diagrams (Fig. 4),

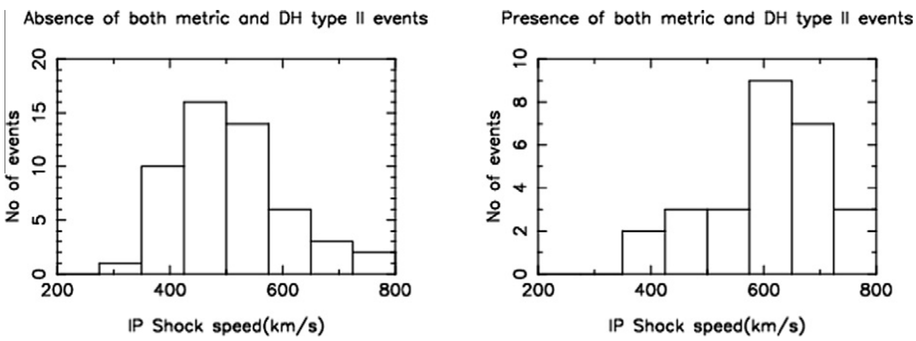

Fig. 3. Distribution of Interplanetary shock speeds for events with out (Left panel, number 1–52 in Table 1a) and with metric/DH type II bursts (Right panel, number 64–101 in Table 1b).

we note that there are more events around 20 R⊙ for events with metric and DH type IIs. For the case of only metric type II events the stand off distance value is 26 R⊙ (see Table 2). In contrast to all the above cases, stand off distance is maximum (35 R⊙) in the case of only DH type II events. From this analysis, it seems that the standoff distance is less for fast CMEs. Recently, Gopalswamy and Yashiro (2011) have pointed out that the standoff distance is the thickness of the shock sheath (difference between the shock and flux rope heights). The least value of standoff distance for fast and energetic CMEs reveals that the shock sheath is thin, i.e., the shock and flux rope are spatially closer.

In Fig. 5, the distribution of transit time (CME travel time from Sun to Earth) is plotted along with number of events. It can be seen that a large number of events are distributed between ~50 and 90 h in the case of absence of metric and DH type II bursts, and the average transit time is found to be as high as 73 h (refer Table 2). But, the events which produce both metric and DH type II show maximum number of events around the transit time of 40–50 h. Further, the average transit time is found to be ~45 h for the metric type IIs which extend into the DH regions. From this particular analysis of transit time, it is evident as expected that high speed CMEs have the least transit time as given by Manoharan et al. (2004).

4. Summary

In the present study, we have analyzed 101 CMEs, their associated ICMEs and IP shocks. These events are studied with respect to their association with metric and deca–hecta metric type II bursts. It is found that among the 101 CME events, only 38 events produced both coronal and IP type II bursts. Among the 38 events, extension of coronal type II into DH spectrum is found for 23 events. It is also found that there are no metric and DH type II associations for 52 events. Mainly the interplanetary parameters of these events such as, speeds of ICMEs and IP shocks, Mach number and stand-off distance are examined and they are compared.

The mean speeds of CMEs increase in the same manner as suggested by Gopalswamy et al. (2005) from events without metric type IIs to events with metric and DH type IIs. In addition, we found that the speeds of ICMEs, IP shocks and Mach number also progressively increase in the following order: events without metric and DH type IIs, events with metric alone, events with DH alone, events with both metric and DH type IIs. This result confirms that the above properties are greater for more energetic CMEs. On the other hand, the mean travel time decreases from ~75 h (for events without both metric and DH type IIs) to 47 h (for events with both metric and DH type IIs).

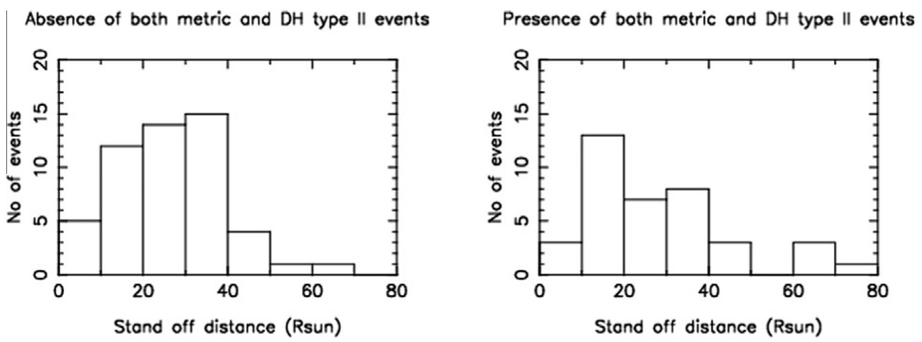

Fig. 4. Distribution of stand off distance for events with out (Left panel, number 1–52 in Table 1a) and with metric/DH type II bursts (Right panel, number 64–101 in Table 1b).

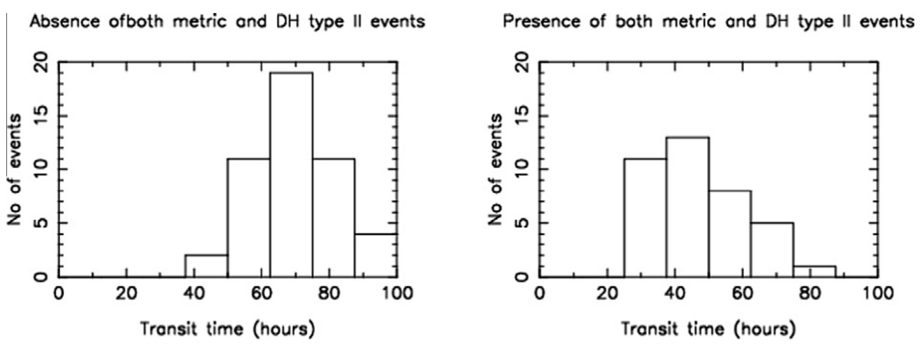

Fig. 5. Distribution of transit time for events with out (Left panel, number 1–52 in Table 1a) and with metric/DH type II bursts (Right panel, number 64–101 in Table 1b).

Though there is not much change in the stand-off distance among these cases, we found that the stand-off distance is minimum (18 $R_{\odot}$) for CMEs with speed greater than 2200 km/s.

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