

Study of Fast and Wide CMEs Associated with Kilometric Type II Bursts with Frequency below 100 kHz and their IP Shock Propagation

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Abstract

We have analyzed 67 CMEs and their associated flares and type II radio bursts observed during the 1997–2014. The main aim of the present work is to study the low frequency (below 100 kHz) solar radio type II bursts. Among these 67 CMEs, 14 events have type II burst end frequency of 100 kHz and the remaining 53 events have end frequency of below that. It is also found that all the 67 CMEs are fast and wide CMEs with mean speed of 1510 km s⁻¹ and many CMEs are associated with X-class and M-class flares. Further, we studied the range of km Type II radio burst and their arrival time estimation at 1 AU using SOHO/proton monitor for 33 events out of 67 events. The main findings of our study are that the all km type II events are associated with fast and wide CMEs with X-class and M-class flares. All these CMEs are produced interplanetary shocks. In the present study, we utilized the modified Empirical shock arrival model (Gopalswamy et al.2014) and IP shock arrival model (Manoharan et al. 2004) are very much useful in predicting IP shock arrival at 1 AU with high accuracy.

Keywords: - Coronal Mass Ejection – Solar flares – Type II bursts – IP shocks

INTRODUCTION

Coronal Mass Ejections (CMEs) are solar transients characterized by large expulsions of large plasma ejected from the Sun into the interplanetary (IP) medium. Shocks produced 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 radio bursts, respectively. These type II bursts are generated 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 (Nelson and Melrose, 1985, Mann et al., 2003, Cho et al., 2003, Mujiber Rahman et al., 2012). Further, solar radio bursts of type II are indicative of shock propagation in the corona and inner heliosphere, accompanied by electron acceleration (Wild and Mc Cready, 1950; Malitson et al., 1973). The type II bursts are detected as slowdrifting 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).

Solar corona ejects large violent eruptions of plasma and magnetic field. Type II

bursts are observed in the metric, decahectometer (DH) domains. DH type II radio bursts occurring in the decameter-hectometer wavelength are caused by shocks produced in the interplanetary space. They have frequencies in the range of 1 to 14 MHz (Gopalswamy et al., 2001). The radio emission of DH type II bursts originates roughly in the outer corona. These type II radio bursts which extend from DH wavelength are due to energetic CMEs which travel far into the interplanetary medium. Further, DH type II bursts associate with flares and CMEs, especially with solar eruptive events (Prakash et al., 2011). Generally, it is found to be faster and wider CMEs associated with DH type II bursts (Gopalswamy et al., 2000).

Gopalswamy et al. (2010) studied the characteristics for a set of 222 IP shock lacking type II events in solar cycle 23 period. They compared Radio Quiet and Radio Loud shock events. They found Radio Loud soft X-ray flare events were more energetic events than that of Radio Quiet events. Also they found that all the IP shock events were ICME driven events. They detected shock and ICME transit time using in-situ instruments. Further, they identified significant difference between Radio Quiet and Radio Loud

events. Manoharan et al. (2004) have studied the arrival of 91 IP shock events which were driven by ICMEs at the distance 1 AU. They first identified CME-CME interaction would affect IP shock/ICME propagation. Nearly 27% of events in their study were DH type II associated events. They also found significant relation between IP shock transit time and CME initial speed. In the mean time, the solar cycle 24 is comparably weaker than previous cycle. Manoharan (2012) found weak solar wind condition in the starting of solar cycle 24. Gopalswamy et al. (2014) have found solar activity reduction and their impacts on space weather.

Prasanna and Shanmugaraju (2017) studied the intensive flare events of solar cycle 23 and 24. They studied solar activities and their rate with respect to solar cycles. . They examined the solar activity reduction in solar cycle 24. In their study they also found huge reduction in solar type II radio emission generated from 10 MHz in the outer corona. However, the present work excludes the solar activity reduction between the cycles. We studied the kilometric type II radio bursts on or below 100 kHz for a set of 67 events from the year 1997 to 2014. The aim of the work is to know the properties of the

activities of CME, flare and Type II radio burst and the range of the shock and what mechanism controls the propagation of shock. In our study we utilized Leblanc density model (Leblanc et al. 2008) for measuring starting height of the shock. Similarly, Hybrid density model is used to measure end height of the shock. We also would like to know how many km Type II events arrived 1AU and how is their transit time behavior. Further, to know the importance of CME speed and flare locations are in estimating shock arrival time. This paper is organized as follows. Section 2 deals with data selection. Section 3 describes the results and discussion and in Section 4 we summarize the results of this study.

DATA SELECTION

The long wavelength radio emission due to solar activities (solar flares, CMEs, CME-CME interactions) detection is achieved by wind/WAVES radio receiver for huge set of events in solar cycle 23 and 24 period. Nearly 511 Type II radio bursts with DH and km range are given in wind/WAVES Type II catalog in the website http://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html. The data list contains the details of Type II radio burst (start time, start frequency, end time, end frequency), flare (flare class, location) and

CME (CME on set date and time, width, speed) for the period 1997-2016. The events for our study are selected for the present work with the following criteria.

- i. Type II radio burst events with ending frequency with or below 100 kHz.
- ii. The CMEs should be front side flare located events.
- iii. All CMEs associated with solar flares.

From the Wind/WAVES data list, among the 511 events, first we excluded a group of 113 backside flare located events. Then we excluded a set of 316 Type II radio

burst events with ending frequency above 100 kHz. Further, we excluded 14 CME events with no frequency information available. Thus, we compiled a bunch of 67 events with ending frequency of 100 kHz and below that. The CMEs and their associated flare and radio type II burst details considered for the present study is given in Table 1. The CME data (date, CME onset time, speed, width) are given in column 2 to 5. The flare information (class, location) are given in the column 6 and 7. The km Type II below 100 kHz details (start frequency, start height, end frequency and end height) are given in column 8 to 11.

Table-1 List of events in cycle 23 and 24

	CME				Flare		Radio burst			
	Date	Time	Speed	Width	Class	Location	Start frequency	Start height*	End frequency	End height**
	yymmdd	hhmm	Km/s	deg	W/m ²		kHz	Rs	kHz	Rs
1	970512	0530	464	360	C1.3	N21W08	12000	2.5	80	67
2	971104	0610	785	360	X2.1	S14W33	14000	2.4	100	54
3	971106	1210	1556	360	X9.4	S18W63	14000	2.4	100	54
4	980420	1007	1863	165	M1.4	S22W90	10000	2.7	35	149
5	980616	1817	1484	281	M1.0	S22W90	12000	2.5	50	105
6	981105	2044	1118	360	M8.4	N22W18	5000	3.7	50	105
7	990604	0726	2230	150	M3.9	N17W69	14000	2.4	60	88
8	000208	0930	1079	360	M1.3	N25E26	12000	2.5	20	250
9	000217	2130	728	360	M1.3	S29E07	14000	2.4	100	54
10	000515	1626	1212	164	C7.8	S24W67	4800	3.8	40	130
11	000606	1554	1119	360	X2.3	N20E18	14000	2.4	40	130
12	000714	1054	1674	360	X5.7	N22W07	14000	2.4	80	67
13	000912	1154	1550	360	M1.0	S19W06	14000	2.4	60	88

14	001124	0530	1289	360	X2.0	N20W05	14000	2.4	100	54
15	010329	1026	942	360	X1.7	N20W19	4000	4.1	60	88
16	010409	1554	1192	360	M7.9	S21W04	12000	2.5	100	54
17	010410	0530	2411	360	X2.3	S23W09	14000	2.4	100	54
18	010415	1406	1199	167	X14.	S20W85	14000	2.4	40	130
19	010426	1230	1006	360	M1.5	N20W05	5000	3.7	20	250
20	010924	1030	2402	360	X2.6	S16E23	7000	3.2	30	173
21	010927	0806	669	138	C9.5	S15W40	4000	4.1	80	67
22	011019	1650	901	360	X1.6	N15W29	14000	2.4	30	173
23	011025	1526	1092	360	X1.3	S16W21	14000	2.4	30	173
24	011104	1635	1810	360	X1.0	N06W18	14000	2.4	70	76
25	011122	2330	1437	360	M9.9	S17W36	14000	2.4	40	130
26	020114	0535	1492	360	M4.4	S28W83	12000	2.5	100	54
27	020417	0826	1240	360	M2.6	S14W34	5000	3.7	40	130
28	020421	0127	2393	360	X1.5	S14W84	10000	2.7	60	88
29	020824	0230	1309	133	M2.3	N09W54	1000	11	30	173
30	020816	1230	1585	360	M5.2	S14E20	14000	2.4	60	88
31	020905	1654	1748	360	C5.2	N09E28	14000	2.4	30	173
32	021109	1331	1838	360	M4.6	S12W29	14000	2.4	100	54
33	031028	1130	2459	360	X17.	S16E08	14000	2.4	40	130
34	040725	1454	1333	360	M1.1	N08W33	1000	11	28	186
35	040729	1206	1180	360	C2.1	N00W90	1000	11	50	105
36	040912	0036	1328	360	M4.8	N03E49	14000	2.4	40	130
37	041107	1654	1759	360	X2.0	N09W17	14000	2.4	60	88
38	041203	0026	1216	360	M1.5	N08W02	10000	2.7	60	88
39	050115	2306	2861	360	X2.6	N15W05	3000	4.8	40	130
40	050117	0930	2094	360	X2.0	N15W25	14000	2.4	30	173
41	050119	0829	2020	360	X1.3	N15W51	5300	3.6	40	130
42	050120	0654	882	360	X7.1	N14W61	14000	2.4	25	201
43	050513	1712	1689	360	M8.0	N12E11	5000	3.7	40	130
44	050730	650	1968	360	X1.3	N12E60	9000	2.9	80	67
45	050822	1730	2378	360	M5.6	S13W65	12000	2.5	40	130
46	050905	0948	2326	360	C2.7	S07E81	1500	7.7	60	88
47	050909	1948	2257	360	X6.2	S12E67	10000	2.7	50	105
48	050913	2000	1866	360	X1.5	S09E10	1100	10	35	149
49	070125	0654	1367	360	C6.3	S08E90	14000	2.4	90	115
50	110529	2124	1407	186	C8.7	S19E72	16000	2.3	90	115
51	110824	0412	1315	360	M9.3	N19W36	13000	2.5	60	88
52	110922	1048	1905	360	X1.4	N09E89	14000	2.4	70	76
53	111126	0712	933	360	C1.2	N17W49	10000	2.7	50	105
54	120119	1436	1120	360	M3.2	N32E22	16000	2.3	100	54
55	120123	0400	2175	360	M8.7	N28W21	16000	2.3	40	130

56	120307	0024	2684	360	X5.4	N17E27	16000	2.3	30	173
57	120310	1800	1296	360	M8.4	N17W24	14000	2.4	30	173
58	130315	0712	1063	360	M1.1	N11E12	14000	2.4	100	54
59	130830	0248	949	360	C8.3	N15E46	14000	2.4	50	105
60	130929	2212	1179	360	C1.3	N17W29	14000	2.4	60	88
61	131119	1036	740	360	X1.0	S14W70	14000	2.4	100	54
62	131212	0336	1002	276	C4.6	S23W46	12000	2.5	70	76
63	140107	1824	1830	360	X1.2	S15W11	14000	2.4	60	88
64	140225	0125	2147	360	X4.9	S13E82	14000	2.4	100	54
65	140402	1336	1471	360	M6.5	N11E53	14000	2.4	60	88
66	140909	0006	920	360	M4.5	N12E29	11000	2.6	100	54
67	140910	1800	1267	360	X1.6	N14E02	14000	2.4	100	54

*** 2 fold Leblanc density model (Leblanc et al. (1998))**

**** Hybrid density model (Vrsnak et al.(2004))**

RESULTS AND DISCUSSION

The statistical properties of the studied events and the IP shock arrival of some CME driven shocks at 1 AU are given in this section.

Study of CMEs and Flares

The CMEs listed in Table 1 shows that many events are wide CME events ($>120^\circ$) and most of them are halo type (360°). The distribution of CME width is shown in Figure 1. The average width of the CME events is found as 336° . Among this, nearly 86% ($=58/67$) of the events are halo type events. In the previous studies done by Shanmugaraju et al.(2003) found that the mean width of DH Type II associated CME events was 106 deg. They also found that DH Type II associated CME events are faster and wider than no DH

type II associated CME events. Wang and Calarinho (2014) found that the CMEs in cycle 23 were faster, massive and larger number of events than that of in cycle 24. Generally halo CME events are Earth directed. The energetic halo CME events can reach Earth earlier as suggested by Manoharan et al. (2004) Gopalswamy et al. 2010).

The distribution of CME speed is shown in Figure 2. It shows that there are more number of events in the range 1000 –1500 kms-1. The range of CME speed is 450 km s-1– 2800kms-1 and mean speed of the CME events is found to be 1510 kms-1. Gopalswamy et al.(2008) found that the CMEs associated with DH type II with mean speed of about 1115 kms-1 and mean speed of all kind of CME (with and

without DH - CME, SEP - CME, metric type II - CME etc.) is 470 kms-1 in SOHO era. Shanmugaraju et al. (2003) also found that mean speed of DH type II associated

CME events was 906 kms-1. The mean speed found in the present study is 1510 km s-1 which is comparably greater than the previous studies.

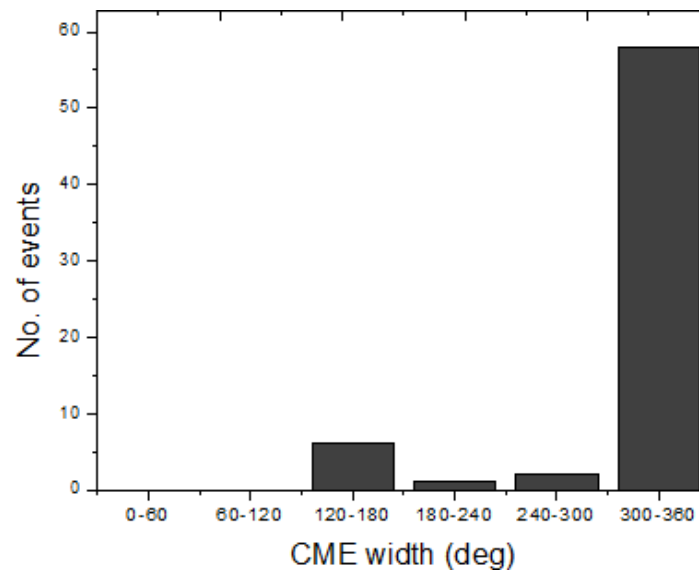


Fig 1 Distribution of CME width in LASCO FOV

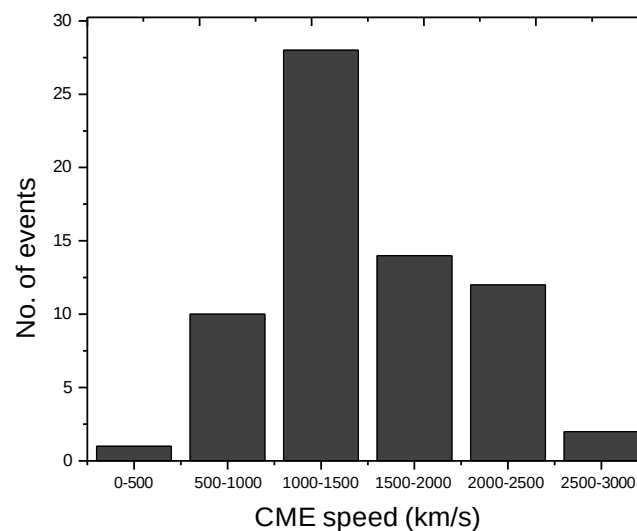


Fig2. Distribution of CME speeds shows all the CMEs are fast (>450 km/s) events.

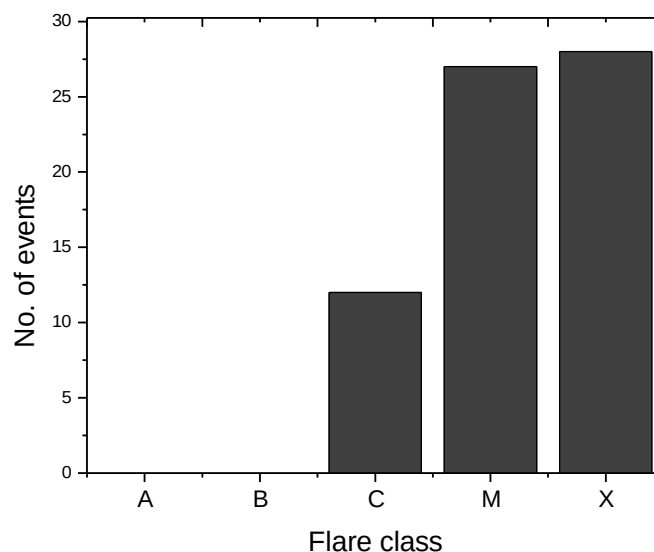


Fig 3 Distribution of X-ray flare class associated with CMEs

From Table 1, nearly 55% (=37/67) of events used in the study have start frequency 14 MHz or 16 MHz; it suggests that they may have the extension of metric Type II. If they are long wavelength Type II events (below 1 MHz) they may be called as M-km Type II bursts events. Gopalswamy et al. (2005) have found M-km Type II has mean speed 1490 km/s. The mean CME speed measured in our study (1510 km/s) is consistent with the Mkm mean CME speed (1490 km/s) found by Gopalswamy et al.(2005). All these suggest that the CME events listed in Table 1 are fast and wide. '

The distribution of solar flares is shown in Figure 3. It shows that many number of events with X-class and M-class. The

mean value of soft X-ray flare class flux is found to be X1.7. The flare events listed in Table 1 are nearly strong (>M5.0). Gopalswamy et al. (2010) investigated that radio loud IP shock events had associated with strong X-ray flares (M4.7). Their study stated that Type II radio emission in metric, DH and km frequency bands as radio loud events. But our studied events are km Type II events. Among them, some set of events are Mkm Type II events (Gopalswamy et al. (2010)). Such events would have strong flares as we found (X1.7). **The solar flares suggest that, these flares are very strong flares and they would have associated with fast and wide CMEs (Gopalswamy et al. 2010). It is normal that such potential**

flares and CMEs would affect space weather condition.

Km Type II radio emission

As suggested by Gopalswamy et al. (2001b, 2005) and Reiner et al. (1998, 2005), the DH (16 MHz-1 MHz) and km (1 MHz-10 kHz) spectrum covers a heliocentric distance range of 2 Ro-215 Ro. The Type II radio emission in this frequency band is the generation of shock waves, which is driven by CME (Gopalswamy et al. 2005). One can view the shock driven by the CME in the LASCO field-of-view using C2 and C3 coronagraphs. That shock can be detected

in radio receiver in DH and km spectrum. The shock appearance time in the coronagraphs and Type II emission time given in wind/WAVES list are normally very close. It is valid examination for start frequency study. However for long wavelength Type II bursts, they have low frequency in km band and they are generated above the coronagraph 10 Rs. In support this, the end height of Type II burst events is in the range 54 Rs – 250 Rs as shown in Table 1. Also, some km Type II events associated with intensive flares ($M > 5.0$) were found to be travelled for short distance and low duration of Type II and vice-versa.

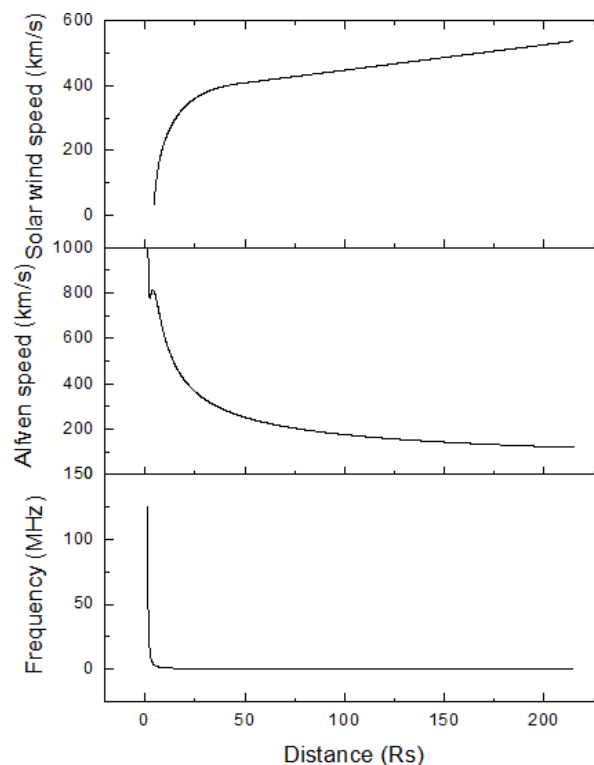


Fig 5 Alfvénic speed and solar wind profile in Sun-Earth line.

The study also estimates the Alfven speed and solar wind in Sun-Earth line. The solar wind speed, Alfven speed and Type II radio burst are plotted with respect to the height as shown in Figure 5. The coronal magnetic field is estimated using the study of Dulk and McLean al.(1978); the coronal density and Type II radio burst height by Leblanc density model (1998). By considering them, the Alfven speed is estimated using the relation,

$$\text{Alfven speed} = B/(\mu_0 \rho)^{0.5} \quad (1)$$

The condition when the CME speed is greater than the Alfven speed, a Type II radio emission would be generated as suggested by previous studies (Gopalswamy et al. (2001b, 2005) and Reiner et al. (1998, 2005). The Type II generation may be presence in leading

edge of the CME or flank position of the CME. Hence the present study suggests that the DH type II and km Type II are generated mainly due to CMEs only not by flares. This confirms that all the studied events are piston driven type shocks and they are driven by the CMEs. It supports the earlier studies Gopalswamy et al. (2001b, 2005), Shanmugaraju et al. (2003) and Reiner et al. (1998, 2005) etc. The solar wind measurement is done by using the study of Sheely et al. (1995). The solar wind speed near the sun it is low and the speed increases with increasing distance. The solar wind speed near Earth is ~400 km/s. The increasing solar wind with respect to height in Rs at Sun-Earth line as well as $V_{\text{CME}} > V_{\text{sw}}$, the solar wind would cause drag effect on the CME. Hence the CMEs would attain much deceleration due to this solar wind drag.

Table-2 Statistical measurents of CMEs, flares, km Type II parameters and IP shocks

Activity*	Mean value
CME speed (67)	1510 km/s
CME width (67)	336 deg
Flare class (67)	X1.7
Start Frequency (67)	11.1 MHz
Start distance (67)	3.23 Rs
End frequency (67)	108.9 kHz
End distance (67)	105.68 Rs
Shock TT (33)	45.6 hours

*** refers no. of events**

Shock arrival at 1 AU

Since the Type II events has long range (>0.5 AU), the study analyzed weather these events arrived at 1 AU by the help of SOHO proton monitor on board. The proton monitor can detect solar wind with high sensitivity. Generally continuity in solar wind speed, density, thermal speed and deflection flow angle refer the flow of solar wind. While a discontinuity in above solar wind parameters refers the arrival of IP shock. If sudden increase in all the parameters shows that the kind of shock is a fast forward shock. The sudden decrease in proton density, thermal speed and increase in speed in proton monitor indicates the arrival of a fast reverse shock. The IP shock may be driven by an ICME. Some driverless IP shocks are also detectable by proton monitor. That shocks are called CIR shocks. However this study

deals with ICME driven shocks only. Most of events were found to be ICME driven by several authors (Manoharan 2004, Gopalswamy et al (2005), Suresh et al. (2019)). Our study did not find the effect of pre-CME and steamer influences of shock arrival time.

The proton monitor instrument contains the details of shock, CME and associated flare. These association details are available for the period Mar 2001 – Dec 2017. We have checked our list given in Table 1 with pm IP shock list for our study period 1997-2014. Among them, we detected 33 events have arrived 1 AU. We have applied CME linear speed in modified ESA model developed by Gopalswamy et al. (2013) and IP shock arrival model (Manoharan et al. 2004).

Table-3 The list of IP shock events in cycle 23 and 24 detected by SoHO/pm detector. The shock arrival time is detected at discontinuous state in solar wind profile in the detector. The *Italic red colored font texts events are limb side flare originated events. (* indicates Limb events).*

	IP shock						LASCO				Flare	
	yymmdd	hhmm		Obs.TT	ESA	Mano	yymmdd	hhmm	VCME	w	Class	Loc.
1	010331	0314	X1.7	40.8	52.91	56.1	10329	1026	942	360	X1.7	N20W19
2	010411	1302	M7.9	45.13	40.88	48.7	10409	1554	1192	360	M7.9	S21W04
3	010411	1518	X2.3	33.8	17.07	28.1	10410	0530	2411	360	X2.3	S23W09
4*	010417	2357	X14.	57.85	40.60	48.5	10415	1406	1199	167	X14.	S20W85
5	010925	1915	X2.6	32.75	17.13	28.2	10924	1030	2402	360	X2.6	S16E23
6	011021	1605	X1.6	47.25	55.30	57.4	11019	1650	901	360	X1.6	N15W29

7	011028	0233	X1.3	59.11	45.20	51.5	11025	1526	1092	360	X1.3	S16W21
8	021106	0120	X1.0	32.75	24.11	35	11104	1635	1810	360	X1.0	N06W18
9	021124	0533	M9.9	30.05	32.50	42.5	11122	2330	1437	360	M9.9	S17W36
10*	020117	0551	M4.4	72.26	30.98	41.2	20114	0535	1492	360	M4.4	S28W83
11	020419	0758	M2.6	47.53	39.01	47.4	20417	0826	1240	360	M2.6	S14W34
12*	020423	0408	X1.5	50.68	17.20	28.2	20421	0127	2393	360	X1.5	S14W84
13	020818	1816	M5.2	53.76	28.65	39.2	20816	1230	1585	360	M5.2	S14E20
14	020907	1554	C5.2	46.33	25.22	36.1	20905	1654	1748	360	C5.2	N09E28
15	040726	2228	M1.1	31.56	35.72	45	40725	1454	1333	360	M1.1	N08W33
16*	040913	1929	M4.8	42.88	35.88	45.1	40912	0036	1328	360	M4.8	N03E49
17	041109	0905	X2.0	40.18	25.02	35.9	41107	1654	1759	360	X2.0	N09W17
18	041205	0704	M1.5	54.63	39.93	48	41203	0026	1216	360	M1.5	N08W02
19*	050121	1648	X7.1	33.9	56.46	58	50120	0654	882	360	X7.1	N14W61
20	050515	0219	M8.0	33.11	26.37	37.2	50513	1712	1689	360	M8.0	N12E11
21*	050801	0600	X1.3	23.16	21.66	32.6	50730	0650	1968	360	X1.3	N12E60
22*	050824	0534	M5.6	36.06	17.32	28.3	50822	1730	2378	360	M5.6	S13W65
23	050915	0825	X1.5	36.41	23.18	34.1	50913	2000	1866	360	X1.5	S09E10
24*	110925	1112	X1.4	72.4	22.57	33.5	110922	1048	1905	360	X1.4	N09E89
25*	111128	2127	C1.2	62.25	53.42	56.3	111126	0712	933	360	C1.2	N17W49
26	120124	1433	M8.7	34.55	19.17	30.1	120123	0400	2175	360	M8.7	N28W21
27	120308	1053	X5.4	34.48	15.35	27	120307	0024	2684	360	X5.4	N17E27
28	120312	0845	M8.4	38.75	36.98	45.9	120310	1800	1296	360	M8.4	N17W24
29	131002	0125	C1.3	51.21	41.41	49	130929	2212	1179	360	C1.3	N17W29
30	140129	1933	X1.2	49.15	23.77	34.7	140107	1824	1830	360	X1.2	S15W11
31*	140227	1617	X4.9	62.86	19.46	30.4	140225	0125	2147	360	X4.9	S13E82
32	140911	2302	M4.5	70.93	54.17	56.8	140909	0006	920	360	M4.5	N12E29
33	140912	1527	X1.6	45.45	38.01	46.7	140910	1800	1267	360	X1.6	N14E02

Both the models are used to predict shock arrival time with high accuracy. Generally CME sky-plane speed is used as input parameter for the shock/ICME arrival models. The CME sky-plane speed is available for halo CMEs in SOHO/LASCO catalogue. Our events have both halo and non-halo CME events. So we are unable to estimate sky-plane speed for non-halo CME events. Recently Suresh et al. () have used linear speed and

sky plane speed for IP shock arrival time estimation. There are no large errors in arrival time estimation by applying both of them. Here we applied CME linear speed in arrival models to estimate the shock arrival time. The modified ESA model is given by Gopalswamy et al. (2013) as,

$$TT = AB^U + C \quad (1)$$

Here $A = 151.002$, $B = 0.998625$, $C = 11.5981$, TT is transit time in hours and U

is CME speed in km/s. The IP shock arrival model equation is stated in the study by Manoharan et al. (2004) as,

$$TT = 3.9 - 2 \times 10^{-3} V + 3.6 \times 10^{-7} V^2 \quad (2)$$

Here V is linear CME speed in km/s and TT is shock transit time in days.

The shock transit time detected by proton monitor and model detected transit times are listed in Table 3. It contains 33 IP shock events and it is remember that all the events are long wavelength Type II events. Also, these events are called as

radio loud events as suggested by Gopalswamy et al. (2010). In arrival time prediction, the origin of CME is important. Limb side events took longer time than disc centre events (Gopalswamy et al. (2010)). The mean shock TT for disc centre events is ~43 hours and the same for limb side events is ~51 hours. Also, the average shock transit time error between observed value and modified ESA model for disc centre events is $\sim \pm 10$ hours. Similarly the average error for limb side events is found as ± 20 hours.

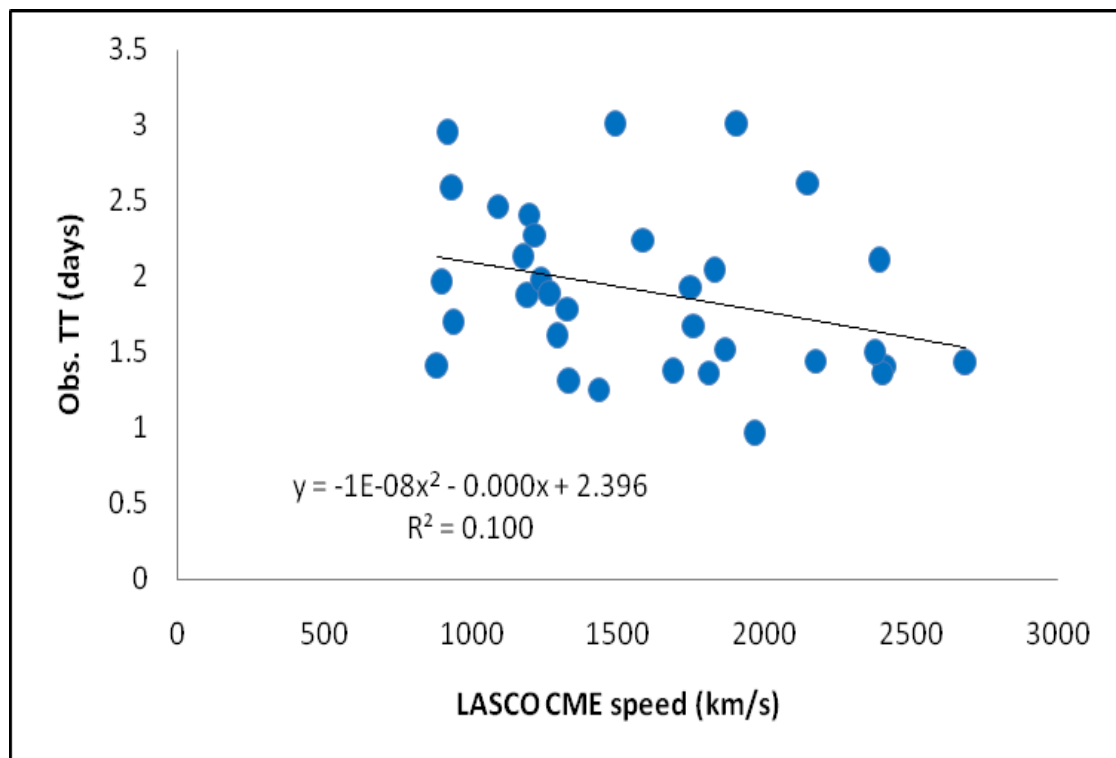


Figure 6 The Observe shock transit time distribution given in days with respect to CME initial speed given in km/s.

The Figure 6 shows the distribution of shock TT as a function of CME linear speed. It shows that the shock TT increases with decreasing CME speed. The long arrival time points >60 hours are belongs to limb side flare originated IP shock events. Table 3 also shows that the events in italic red colored texts are limb side events. The list of events given in serial number 10, 12, 24 and 31 has large arrival time error with ESA model (Gopalswamy et al. (2013)) and IP shock model (Manoharan et al. 2004). Since our study did not use sky plane speed as suggested by ESA model. If we consider sky plane speed for arrival time estimation, the error would be reduced. However, we found some significant difference in arrival time estimation for limb side and disc centre events. The arrival time estimation has minimum error within 10 hours between observed and model TT for disc centre events when we use linear speed as a function. The study suggests that both modified ESA model and IP shock model (Manoharan et al.(2004) can give exact accuracy arrival time with less error. The IP shock function response in the study is found as,

$$TT = 2.396 - 0.0003 V - 1E-08 V^2 \quad (3)$$

The slight dissimilar in the IP shock function parameters between equation 2 and 3 is mainly due to solar cycle variation, fast CMEs (>450 km/s) in Table 3.

CONCLUSION

A set of 67 km Type II events with ending frequency on or below 100 kHz during 1997-2014 is considered for the study. The CME and flare properties are studied along with Type II radio bursts. We used SOHO/LASCO, GOES, WIND/WAVES data. The Alfvén speed and solar wind study are carried out along with radio analysis. The important results obtained in this work are:

- 1) The detection rate of km Type II below 100 kHz during the period 1997-2015 is found to be followed the sunspot cycle. The km Type II radio burst events are flare and CME associated events. The X-ray flares are much intense (>M5.0) and the CMEs are fast and large wide.
- 2) The DH and km Type II radio bursts are generated due to CME only. However, the burst existence and duration are mainly controlled by ambient magnetic field and density [Gopalswamy et al. (2001b, 2005),

Shanmugaraju et al. (2003) and Reiner et al. (1998, 2005)]. Any streamer or pre CME movement before a shock during would affect the Type II radio emission [Gopalswamy et al. (2001a)].

- 3) Km Type II events are strong flare associated events. They are fast and wide. They can cause ICME driven shocks. The CME initial kinematics (speed, width) cause major roles in driving the IP shocks (Manoharan et al. 2004, Gopalswamy et al. 2010).
- 4) The modified Empirical shock arrival model (Gopalswamy et al. 2014; Suresh et al. 2019) and IP shock arrival model (Manoharan et al. 2004) are very much useful in predicting IP shock arrival at 1 AU for all kind of CMEs (slow or fast).
- 5) The IP shocks associated with limb side flare located km Type II events took longer time than disc centre flare located IP shock events.
- 6) The km Type II burst activities follow sunspot cycle. The study confirms weak solar wind and activity reduction in solar cycle 24 (Manoharan 2012, Gopalswamy et al. 2014; Prasanna and Shanmugaraju 2016)

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