Analysis of Type II radio burst relationship with CME driven shocks

Raveesha K.H¹, Vedavathi P², Vijayakumar H Doddamani³

¹Department of Physics, CMR Institute of Technology, Bangalore -560037, India
²,³Department of Physics, Bangalore university, Bengaluru-560006, India

Email: hod.physics@cmrit.ac.in

Abstract- Type II radio bursts are known to be the signatures of coronal shocks. In this paper we examine the relationship between 129 type II bursts in the frequency range 35 – 450 MHz observed at Culgoora observatory during May 2002 – October 2015 and the associated CMEs. We apply Newkirk (1961) density model to determine the formation height of type IIs. We find that in 109/129 cases, type II bursts were preceded/ succeeded by CMEs. The CME associated type II events in which the CME height is above the type II burst source are categorized as group I events (91/129 cases). 91% of the bursts in this group are also associated with flares and 58% of these bursts originate during decaying phase of the flare. The correlation between CME speed and type II shock speed for limb events in this group is 0.33. The CME associated type IIs in which the CME height is below the type II source are categorized as group II (18/129 cases). CME driven shock could have been the exciter of these type II bursts. 88% of this group events are associated with flares and 62% of these bursts originate during the rising phase of the flare. The correlation between CME speed and type II shock speed for limb events in this group is 0.96. In 20/129 cases of our data set, type II bursts are not associated with CME and are categorized as group III. 90% of the bursts in this group are associated with flares. 77% of the bursts in the group are originating in the decaying phase of flares. Poor temporal association (9/69 cases) between type IIs and flares of X class during this period. Our results suggest that instead of temporal association with metric type II bursts, majority of the CME driven shocks (84%) are not successful in exciting type II bursts in 35–450 MHz domain. The type II bursts temporally correlated with CMEs and likely to have been excited by CMEs (type II height > CME height) are originating during the rising phase of the flares in majority of the events. In case of type II bursts temporally correlated with CMEs supposedly not excited by the CMEs (type II height < CME height), majority of them are originating in the decaying phase of flares.

Key words: Coronal Mass Ejection-shock-metric-observatory-flare-impulsive

1. INTRODUCTION

Solar type II radio bursts are known to be the signatures of magneto hydrodynamic (MHD) shocks propagating through the solar atmosphere. They are observed as slow drifting emission bands fundamental (F) and harmonic (H) with a frequency ratio of ≈1:2. The frequency drift from high to low frequencies (typically 0.5 MHz/s) is a measure of the decrease of electron density ($N_e$) with radial distance $r$ in the solar atmosphere. The observed drift rate can be utilized to find velocity if the dependence of $N_e$ on $r$ is known. The characteristics description of solar type II bursts can be found in Nelson & Melrose (1985), Mann et al. (1995), Aurass (1997), and Gopalswamy (2006). MHD shocks in the lower corona ($1-2R_o$) have been attributed to either solar flares or coronal mass ejections (CMEs) or combination of the two (Gopalswamy 2006; Mann & Vrˇsnak 2007; Pick & Vilmer 2008; Vrˇsnak & Cliver 2008; Nindos et al. 2008). CMEs occurring at the solar limb can be seen in coronagraph images than those near the center of the solar disk (Cliver et al. 1999; Gopalswamy et al. 2001).

Results obtained using radio spectral observations of metric type II bursts indicate that they can be excited by CME driven shocks (Lara et al. 2003; Cliver et al. 2004; Cho et al. 2005, 2007, 2008, 2011; Subramanian & Ebenezer 2006; Mancuso 2007; Gopalswamy et al. 2009a; Liu et al. 2009). Many of these works were carried out without positional information on the type II bursts. Radio heliograph data carry positional information of the type II bursts. Hence the spatial relationship with CMEs and flares can be verified using them. Type II bursts with positional information have been reported by authors (Dulk 1970; Stewart et al. 1974a, 1974b; Nelson & Robinson 1975; Kosugi 1976; Wagner & MacQueen 1983; Gergely et al. 1983; Gary et al. 1984; Gopalswamy & Kundu 1992; Maia et al. 2000; Magdalení´c et al. 2010; Ramesh et al. 2010; Nindos et al. 2011). These works consisted few selective events.
The relationship between type II bursts and coronal shock waves is established, the physical relationship among metric type II bursts, flares, and coronal mass ejections (CMEs) is not clear. The relationship between metric type II bursts and CMEs is debatable question (Cliver et al. 2004; Vršnak & Cliver 2008; Prakash et al. 2010), whereas for type II bursts at decameter and longer wavelengths there is a consensus that they are driven by CMEs (Cane et al. 1987; Gopalswamy et al. 2000). According to Vršnak and Cliver (2008) the source of the coronal wave is clear in some events with starting frequencies well below 100 MHz, where the CME is accompanied by a weak flare. They observed that for Moreton-wave-associated type II bursts at higher frequencies (>300 MHz for the harmonic emission), both the CME and the flare are observed. In these events, the CME and the flare are tightly related and, particularly during the impulsive phase, motions of the flare plasma take place together with the CME motions, and both phenomena are potential candidates for producing shocks (Vršnak & Cliver 2008; Magdaleníček et al. 2012). The study of the relationship between type II bursts and CMEs can be improved by observations of propagating brightness fronts in the extreme ultraviolet (EUV), so-called EUV waves (Moses et al. 1997; Thompson et al. 1998).

Shock waves are an ubiquitous phenomenon in astrophysics. They accelerate electrons (Mann & Classen 1995; Miteva & Mann 2007; Schwartz et al. 2011) and ions (Thomsen et al. 1985; Sckopke 1995; Giacalone 2005). In the solar atmosphere, several kinds of shocks, which manifest as wave-structure in images are implied in the radio dynamic spectra. Type II radio bursts, following the eruption of coronal mass ejections (CMEs), are a kind of plasma emission with a slow frequency drift in the radio dynamic spectrum, and are generally known to be a signature of coronal shocks (Wild 1950; Zheleznyakov 1970). It is known that most of the interplanetary shocks (within 1 AU) are CME-driven (Cane et al. 1987; Reiner et al. 2001a, 2001b). However, the origin of the metric type II radio bursts is still an open question; they can be generated either by CME-driven shocks (Cliver et al. 2004; Liu et al. 2009; Chen 2011; Cho et al. 2013) or by flare-caused blast waves (Leblanc et al. 2001; Magdaleníček et al. 2008; Nindos et al. 2011).

Our present work utilizes a comparatively larger data set (129 events) in the frequency range 35MHz to 450 MHz. In this study we estimate the height of the CME driven shock at the onset of the type II radio bursts. 129 events are categorized as Group I (91/129) representing events with CME height at the onset of type II is above the Type II formation height. Group II (18/129) indicating events for which CME height is below the type II formation height and group III (20/129) for type II events not temporally associated with CMEs. We assume that coronal shocks producing metric type II radio bursts are driven by CMEs whose formation height is less than that of type IIs. We calculate the CME height at the type II onset by CMEs extrapolated back to the start time of the type II bursts assuming a constant speed of the CMEs. This approximation is reasonable as acceleration effect will be negligible at high velocities. The kinematics of type II shock is determined by adopting suitable coronal density models. In fact, the real density distribution at the lower corona varies with time and location and the observed CME kinematics might be different at the height where the type II bursts occur since the flare impulsive phase is often associated with CME acceleration phase (Bemporad et al.2003; Guhathakurta & Fisher 1998; Parenti et al. 2000; Zhang et al. 2001). This paper is organized as follows. Data set is provided in Section 2, data analysis and results are presented in Section 3, followed by a conclusion in Section 4.

### 2. DATA SET

In this work the type II radio data recorded by the Culgoora observatory (http://www.sws.bom.gov.au/Solar/2/5/1/) for the period May 2002 to October 2015 is referred. The detailed description is available at this site. The CME data provided by Large Angle Spectrometric Coronagraph (LASCO; Brueckner et al.1995) CME catalog http://cdaw.gsfc.nasa.gov/CME_list/index.html; Yashiro et al.2004; Yashiro et al.2004; Gopalswamy et al.2009b) on board the Solar Wind Heliospheric Observatory (SoHO) is used to examine whether the radio burst is associated with a CME. CMEs occurring within 20-30 minutes preceding/succeeding type II bursts have been considered and in most of the cases the temporal association is within 15 minutes. We identified all those Type II radio events for which adequate CME data is available. Few type II events with unclear start time/ end time, insufficient data have not been considered. Our final data set consists of 144 type II bursts categorized as Group I, II & III respectively are listed in table 1, 2 & 3. The columns in the table 1, 2 are : (1) type II date (2) start time (3) end time (4) drift rate (5) shock speed (6) associated flare peak time (7) flare location (8) associated CME detected time (9) CME height at type II formation height minus CME height. The columns in table 3 are: (1) type II date (2) start time (3) end time (4) drift rate (5) shock speed (6) associated flare peak time (7) flare location (8) type II formation height. The columns in table 4 are similar to the previous table along with X flare details. We use the flare data recorded by the low energy channel (0.5 – 4Å) of the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI; Lin et al.2002). Flares occurring within +/- 20-30 minutes from the onset of type II bursts are considered as associated flares. For most of the events in our data set, flares/CMEs are observed within 20 minutes from the type II event. Figure 1a shows the dynamic spectrum from Culgoora observatory recorded on 17/05/2012. The frequency range of the spectrometer is from 1800MHz to 18MHz. The fundamental type II burst started from about 40MHz at 01:32 and drifted to 18MHz at 01:40. The mean frequency drift rate of the type II is about 0.20MHz/s close to typical drift rate (~0.5MHz/s) of type IIIs reported by Mann (1995). The harmonic band starts at around 80 MHz at 01:32. As seen from the figure 1b, the early eruption of type II associated CME was observed by Large Angle and Spectrometric Coronagraph (LASCO – C2/C3) onboard the Solar and Heliospheric Observatory (SOHO) at 01:48. The first appearance of the CME was at 3.63Rₚ above the solar surface. The acceleration of the CME is -51.8km/s². The CME height at the onset of Type II
obtained by extrapolation is $1.45 R_o$ and is above the type II formation height $1.14 R_o$ found by applying Newkirk (1961) density model. This CME is likely to have not excited the type II shown in figure 1a. Figure 1c shows the height –time plot of the leading edge of CME from 01:20 to 04:40.

Figure 1d shows RHESSI X ray flux in the 6-12keV, 12-25keV channels. The associated flare commences at 00:23 reaches the peak at 01:48 close to the type II burst onset time 01:32. In addition, figure 1e shows an M class flare observed by the Geostationary Operational Environmental Satellite (GOES) with onset at 00:28.

![Image](image_url)

**Figure 1.**

(a) Dynamic spectrum of the type II radio burst observed by Culgoora observatory from 01:32-01:40 on 17/5/2012. The burst commences at 40MHz and drifts to 18MHz. Weak band splitting is observed.

(b) The type II associated CME observed by LASCO on 17/5/2012 detected at 01:48 at 3.61$R_o$ occurring 13 minutes after the onset of type II burst.

(c) Height –time plot of the leading edge of CME from 01:20 to 04:40


3. DATA ANALYSIS AND RESULTS

3.1 Type II - CME height relationship

The starting frequencies of type II bursts represent the heights of the radio sources: a higher starting frequency indicates a radio source closer to the solar surface because the frequency of the type II emission is proportional to the square root of the plasma density and the plasma density decreases as a function of radial distance. Most of the density models may differ significantly from the real case and affect the height calculation. In previous studies, the most commonly used density models are Newkirk (1961) and Saito et al. (1977). Since the use of Newkirk (1961) density model to estimate the radio source speed is compatible with radial shock motion [58], we have used Newkirk (1961) density model to determine the formation of height of type II bursts. The Newkirk (1961) density model is given by

\[ N_r = 4.2 \times 10^6 \times 10^{4.32(R_o/R)} \text{ cm}^{-3} \]

where \( R \) is the heliocentric distance and \( R_o \) is the solar radius.

The CME height at the onset of type II is calculated by back extrapolation assuming constant speed of CMEs.

CME height (at the onset of type II) = CME first appearance height \( +/- V_{CME} \times dt \)

Here \( dt \) is the start time difference between type II & CME.

Table 1 provides details of 91 group I events (type II height – CME height is negative). It is observed that the type II formation height is in the range of 1.005\( R_o \) to 1.36\( R_o \) for more than 83% of the events with an average of 1.16\( R_o \), close to the results of Cunha-Silva et al. (2015). The average start and end frequency are 201.8 MHz and 39.5 MHz respectively with an average bandwidth of 163.34 MHz. The average drift rate is 0.24 MHz/s close to the typical drift rate ( ~0.3 MHz/s) of type IIIs reported by Mann et al. (1995). The average shock speed is 776 km/s and the average duration is 10.7 minutes.

The CMEs observed in association with these 91 type II events are at heights above the type II formation heights (average height 3.59\( R_o \)). The average width and central position angle of these CMEs is 101.6 deg and 203.5 deg. The average speed of these CMEs is 695 km/s greater than typical speed of CMEs (450 km/s). 65% of CMEs showed deceleration in this group with an average of -5 km/s\(^2\). 27% of them are halo CMEs. Poor correlation (0.33) is observed between CME speed and type II shock speed for limb events supporting the argument that blast waves from flares could have excited these type IIIs.

Flares are associated in 91% of the events and 58% of these bursts originate during decaying phase of the flare. The drift rates of type IIIs associated with different classes of flares are studied for limb events (20/91) in this group. The average drift rate for type IIIs accompanying X, C and M class flares in this category is 0.27 MHz/s, 0.22 MHz/s and 0.17 MHz/s respectively. Higher drift rate for bursts associated with X class flares is possibly due to their higher energy. This probably leads to higher shock speed and corresponding higher Alfvén speed. This possibly could be one of the causes for the absence of association between Type II and X class flares. It may also be noted that drift rate corresponds to energy associated with the respective class of the flare.

Table 2 provides the details of 18 group II events (type II height – CME height is positive). It is observed that the type II formation height is in the range of 1.07\( R_o \) to 1.29\( R_o \) for more than 55% of the events with an average of 1.19\( R_o \). The average start and end frequency are 194.8 MHz and 36.3 MHz respectively with an average bandwidth of 158.5 MHz. The average drift rate is 0.20 MHz/s slightly less than the typical drift rate (~0.3 MHz/s) of type IIIs reported by Mann et al. (1995). The average shock speed is 745 km/s and the average duration is 11.14 minutes.

The CMEs observed in association with these 18 type II events are originating at a height lower than the type II formation heights (avg ht 1.19\( R_o \)). The average width and central position angle of these CMEs is 162 deg and 211.8 deg. The average speed of these CMEs is 1101 km/s which is almost 3 times greater than typical speed of CMEs (450 km/s). 74% of CMEs showed deceleration in this group with an average of -15 km/s\(^2\). 44% of them are halo CMEs. The strong correlation (0.96) between CME speed and type II shock speed for limb events is noticed. This supports the view that these type IIIs could have been excited by CME driven shocks.

Flares are associated in 88% of these events. Unlike group I events, 62% of these bursts originate during the rising phase of the flare. Average drift rate for type IIIs accompanying C and M class flares in this category is 0.16 MHz/s, 0.20 MHz/s respectively.

The details of group III type II events not associated with CMEs are given in table 3. It is observed that the type II formation height is in the range of 1.11\( R_o \) to 1.29\( R_o \) for more than 63% of the events with an average of 1.24\( R_o \). The average start frequency is 138 MHz significantly lesser than group I and II events. The average drift rate is 0.26 MHz/s. The average shock speed is 645 km/s which is lesser than the group I & 2 bursts. The average duration is 8.16 minutes. Flares are present in 90% of the events in this group. 77% of these bursts are originating in the decaying phase of the flare. Average drift rate for type IIIs accompanying C and M class flares in this category is 0.39 MHz/s, 0.31 MHz/s respectively. We repeated these calculations by applying Saito’s density model (Saito et al, 1977) of the form

\[ n(r) = 10^8 \times (0.0136r^{-2.14} + 1.68r^{-6.1}) \]

with a multiplication factor of 10 and obtained almost similar results.
3.2 Impulsive X class flare events and type II bursts

X class flares release large amount of energy. However type II bursts are not found to be associated with these flares in most of the cases. During the period 2002-2015, 70 Impulsive flares of X class are observed with sufficient data. We identified Type IIs and CMEs accompanying the X class flares. Neglecting events with unclear start/end time, insufficient data, our final data set contains 69 X class flares. These flares display sharp rising phase where as the decaying phase is exponential. The details of these flares and the accompanying type IIs & CMEs are provided in table 4. In 58/69 cases CMEs are temporally associated with flares. In 35/58 cases, the CMEs associated were found to be halo. The speeds of CMEs associated with X class are higher (avg 1259 km/s) than group I and II counterparts in agreement with results of Magdalenic et al.(2010). In 29/69 events, CME speeds are higher than 1000km/s.

It is interesting to note that only in 9/69 cases type IIs are observed. The characteristics of these 9 type IIs are studied. They possess higher drift rate (avg 0.51MHz/s). In most of these cases, the associated CMEs are ahead of type IIs supporting the opinion that high pressure blast waves caused by the flares could have been the excitors of type II bursts. However, the correlation between type II speed and CME speed is 0.56. We find that in 7/9 cases, the type II bursts are originating during rising phase of the flare and their average start frequency, bandwidth and velocity of type II shock waves are significantly higher than group I & II events. It was observed in few cases that type IIs accompanied C class flares rather than X class flares on a day when both the classes of flares were present.
Figure 2.

- **a:** Distribution of CME based on their height
- **b:** Type II and flare association for group I events
- **c:** Type II and flare association for group II events
- **d:** Type II and flare association for group III events
- **e:** Scatter Plot of CME speed and Type II speed for
- **f:** Scatter Plot of CME speed and Type II speed for Group I

**Legend:**
- (m) Number of events vs. Range of Shock speed (km/s)
- (n) Number of events vs. Range of Width (deg)
- (o) Number of events vs. Range of CME speed (km/s)
- (p) Number of events vs. Range of CME Acceleration (km/s²)
| Date       | Type II | Flare | CME      | Height (R$_\odot$) based on Newkirk model |
|------------|---------|-------|----------|------------------------------------------|
|            | start time (UT) | End time (UT) | Drift rate (MHz/s) | Shock speed (km/s) | peak time (UT) | Location | CME detected time (UT) | CME Height at the start of Type II | Type II start height | Type II -CME height difference |
| 24/5/2002  | 0322    | 0328  | 0.2306   | 2100 | 0330  | 1.1488 | -0.8012 |
| 31/5/2002  | 0304    | 0314  | 0.0317   | 2100 | 0326  | 2.13   | -0.7925 |
| 20/7/2002  | 2107    | 2137  | 0.0911   | 2100 | 2118  | 6.54   | -5.008  |
| 14/8/2002  | 0148    | 0209  | 0.0659   | 400  | 0207  | 2.08   | -0.9312 |
| 16/8/2002  | 0522    | 0554  | 0.0641   | 1700 | 0530  | 2.71   | -1.6242 |
| 21/8/2002  | 2124    | 2130  | 0.2306   | 2100 | 2154  | 1.577  | -0.4282 |
| 23/2/2003  | 0154    | 0200  | 0.0639   | 450  | 0144  | 3.58   | -2.2607 |
| 23/3/2003  | 0156    | 0202  | 0.3417   | 800  | 0152  | 2.52   | -1.4342 |
| 24/3/2003  | 0106    | 0114  | 0.2188   | 773  | 0113  | 2.46   | -1.3517 |
| 28/3/2003  | 0201    | 0252  | 0.25     | 718  | 2030  | 4.797  | -3.6196 |
| 8/9/2002   | 0152    | 0157  | 0.1167   | 900  | 0349  | -      | 0.0095 |
| 16/9/2002  | 0316    | 0321  | 0.1      | 750  | 0526  | -      | -6.056  |
| 19/9/2002  | 0521    | 0524  | 0.4611   | 1000 | 0554  | 1.61   | -0.4612 |
| 5/10/2002  | 0530    | 0539  | 0.0611   | -    | 0554  | 2.09   | -0.8107 |
| 27/10/2002 | 2505    | 2518  | 0.1404   | 850  | 2100  | 1.21   | -0.1242 |
| 27/10/2002 | 2509    | 2510  | 0.2526   | 720  | 2200  | 3.87   | -2.7556 |
| 19/10/2002 | 2139    | 2158  | 0.8097   | 900  | 2152  | 1.68   | -0.5942 |
| 21/1/2003  | 0227    | 0234  | 0.2143   | 700  | 0226  | 1.74   | -0.5712 |
| 23/1/2003  | 0448    | 0459  | 0.8984   | 324  | 0449  | 1.86   | -0.6206 |
| 12/2/2003  | 0151    | 0156  | 0.4567   | 700  | 0146  | 1.32   | -0.3091 |
| 23/4/2003  | 0102    | 0107  | 0.4767   | 679  | 0107  | 1.67   | -0.5969 |
| 5/24/2003  | 0530    | 0538  | 0.0667   | 800  | 0544  | 1.56   | -0.1103 |
| 26/4/2003  | 2340    | 2347  | 0.3524   | -    | 2336  | 2.76   | -1.682  |
| 29/5/2003  | 0106    | 0111  | 0        | 800  | 0102  | 2.4    | -1.8169 |
| 6/6/2003   | 2341    | 2351  | 0.075    | 415  | 2333  | 1.85   | -0.5263 |
| 17/6/2003  | 2248    | 2258  | 0.3      | 1000 | 2254  | 2.4    | -1.3387 |
| 17/6/2003  | 2003    | 2010  | 0.1667   | 1500 | 1956  | 5.85   | -2.793  |
| 7/1/2004   | 0406    | 0420  | 0.2726   | 692  | 0407  | 3.28   | -1.717  |
| 19/1/2004  | 0203    | 0214  | 0.2197   | 450  | 0407  | 3.03   | -0.9442 |
| 20/1/2004  | 0739    | 0750  | 0.2348   | 550  | 0741  | 1.42   | -0.3342 |
| 5/4/2004   | 0554    | 0606  | 0.1333   | 615  | 0546  | 5.1    | -3.926  |
| 16/6/2004  | 0423    | 0425  | 0.7917   | 2000 | 0433  | 2      | -3.8088 |
| 5/7/2004   | 2232    | 2243  | 0.0848   | 424  | 2306  | 2.22   | -0.9294 |
| 24/8/2004  | 2110    | 2134  | 0.0535   | 800  | 2107  | 3.17   | -1.9082 |
| 31/8/2004  | 0541    | 0554  | 0.0987   | 650  | 0533  | 2.09   | -0.8444 |
| 12/9/2004  | 0142    | 0148  | 0.1556   | 866  | 0049  | 9.82   | -8.5175 |
| 10/10/2004 | 2128    | 2138  | 0.3283   | 595  | 2157  | 1.52   | -0.5127 |
| 30/10/2004 | 0329    | 0344  | 0.0556   | 800  | 0326  | 2.65   | -1.3077 |
| 30/10/2004 | 0613    | 0631  | 0.0351   | 1800 | 0705  | 1.87   | -0.5463 |
| 15/1/2005  | 2234    | 2242  | 0.1354   | 1200 | 2257  | 1.51   | -0.2035 |
Table 2. Type II –Flare –CME parameters for GROUP II events

| Date       | Start time (UT) | End time (UT) | Drift rate (MHz/s) | Shock speed (Km/s) | Peak (UT) | Location | CME detected time (UT) | CME Height at the start of Type II | Type II start height | Type II - CME height difference |
|------------|-----------------|--------------|-------------------|--------------------|-----------|----------|------------------------|-----------------------------------|---------------------|-------------------------------|
| 30/5/2002  | 2312            | 2344         | 0.061             | -                  | -         | -        | 2326                   | 0.9                              | 1.0884                           | 0.1884                      |
| 23/8/2002  | 0549            | 0611         | 0.093             | 530                | -         | -        | 0625                   | 1.04                             | 1.0585                           | 0.0458                      |
Table 3. Type II – Flare parameters for GROUP III events

| Date       | Type II start time (UT) | Type II end time (UT) | Drift rate (MHz/s) | Shock speed (Km/s) | Flare peak (UT) | Location |
|------------|-------------------------|-----------------------|--------------------|--------------------|----------------|----------|
| 16/7/2002  | 2201                    | 2206                  | 0.26               | 557                | 2141           | -        |
| 19/7/2002  | 0331                    | 0333                  | 0.24               | 325                | 0246           | -        |
| 25/8/2002  | 0225                    | 0329                  | 0.23               | 484                | 0323           | -        |
| 2/9/2002   | 0012                    | 0014                  | 0.79               | 1897               | ...            | -        |
| 8/9/2002   | 0156                    | 0203                  | 0.07               | 500                | 0136           | -        |
| 30/9/2002  | 0225                    | 0242                  | 0.11               | 1000               | 0420           | -        |
| 14/10/2002 | 0003                    | 0008                  | 0.31               | 1000               | 0005           | -        |
| 31/1/2003  | 2208                    | 2226                  | 0.07               | 505                | 2241           | -        |
| 19/7/2003  | 0139                    | 0143                  | 0.06               | 551                | 0136           | N16W20   |
| 20/1/2004  | 0748                    | 0757                  | 0.12               | 850                | 0741           | S14W22   |
| 27/4/2004  | 0716                    | 0735                  | 0.14               | 600                | 0723           | -        |
| 24/6/2004  | 0619                    | 0626                  | 0.24               | 565                | 0605           | S11W53   |
| 31/8/2004  | 0547                    | 0554                  | 0.13               | 400                | 0536           | N03W88   |
| 18/8/2006  | 2357                    | 2359                  | 0.75               | 630                | 2326           | -        |
| 19/2/2007  | 0018                    | 0024                  | 0.16               | 500                | 0013           | S12E04   |
| 3/3/2011   | 0343                    | 0350                  | 0.24               | 900                | -              | 1.1444   |
| 30/9/2011  | 0252                    | 0256                  | 0.07               | 676                | 0249           | N13W29   |
| 13/12/2011 | 0316                    | 0323                  | 0.15               | -                  | -              | 1.1412   |
| 15/12/2013 | 2027                    | 2042                  | 0.09               | 600                | -              | 1.2165   |
| 22/6/2015  | 0600                    | 0607                  | 0.07               | 325                | 0518           | -        |

Table 4. X class flare – Type II – CME parameters

| Date       | Flare peak time (UT) | Flare location | Flare class | Type II start time (UT) | Type II end time (UT) | Drift rate (MHz/s) | CME detected time (UT) | Speed (Km/s) |
|------------|----------------------|----------------|-------------|-------------------------|-----------------------|--------------------|------------------------|--------------|
| 27/5/2003  | 0028                 | S07 W20        | X1.3        | 2302                    | 2310                  | 0.52               | ...                    | ...          |
| 29/5/2003  | 0057                 | S07W46         | X1          | Insufficient data       |                       |                    | 0127                  | 1237         |
| 9/6/2003   | 2139                 | N12W32         | X1.7        | 2138                    | 2152                  | 0.392              | ...                    | ...          |
| 10/6/2003  | 0002                 | N12W36         | X1.4        |                         |                       |                    | 0056                  | 730          |
| 15/6/2003  | 2356                 | S07E85         | X1.3        |                         |                       |                    | 2354                  | 2053         |
| 19/10/2003 | 1649                 | N06E53         | X1.1        |                         |                       |                    | 1708                  | 472          |
| 23/10/2003 | 0826                 | S16E70         | X5.4        |                         |                       |                    | 0854                  | 511          |
| Date       | Code   | Latitude | Longitude | Data       | Insufficient data |
|------------|--------|----------|-----------|------------|-------------------|
| 26/10/2003 | 0839   | S06E10   | X1.2      |            |                   |
| 28/10/2003 | 1110   | S07E04   | X17.2     |            |                   |
| 29/10/2003 | 2049   | S16W11   | X10       | 2042       | 2050 0.562        |
| 2/11/2003  | 1720   | S17W62   | X8.3      |            |                   |
| 3/11/2003  | 0952   | N08W82   | X3.9      |            | 1006 1420         |
| 4/11/2003  | 1949   | S17W89   | X17       |            | 1954 2657         |
| 26/2/2004  | 0203   | N14W27   | X1.1      |            |                   |
| 30/10/2004 | 1146   | N14W25   | X1.2      |            | 1230 427          |
| 7/11/2004  | 1602   | N08W22   | X2        |            | 1654 1759         |
| 10/11/2004 | 0207   | N08W62   | X2.5      | Insufficient data | 0226 3387 |
| 1/1/2005   | 0031   | N05E21   | X1.7      | 29 50      | 0.555 0054 832    |
| 15/1/2005  | 2252   | N13W03   | X1.2      |            | 2306 2861         |
| 17/1/2005  | 0952   | N13W30   | X3.8      |            | 0954 2547         |
| 19/1/2005  | 0818   | N14W56   | X1.3      |            | 0829 2020         |
| 20/1/2005  | 0657   | N14W70   | X7.1      | 636 800    | 0.175 0654 882    |
| 14/7/2005  | 1055   | N12W97   | X1        |            |                   |
| 30/7/2005  | 0635   | N12E52   | X1.3      |            | 0650 1968         |
| 7/9/2005   | 0739   | S12E83   | X17       |            |                   |
| 8/9/2005   | 2102   | S09E67   | X5.4      |            |                   |
| 9/9/2005   | 1952   | S09E67   | X5.4      |            | 1948 257          |
| 10/9/2005  | 2202   | S09E44   | X1.1      |            | 2152 1893         |
| 13/9/2005  | 1927   | S11E04   | X1.5      |            | 2000 1866         |
| 15/9/2005  | 0838   | S11W22   | X1.1      |            |                   |
| 5/12/2006  | 1026   | S06E72   | X9        |            |                   |
| 6/12/2006  | 1847   | S05E60   | X6        |            |                   |
| 13/12/2006 | 0241  | S05E33   | X3.4      |            | 0254 1774         |
| 14/12/2006 | 2215  | S05W47   | X1.5      |            | 2230 1042         |
| 9/3/2011   | 2323   | N09W12   | X1.5      |            | 2305 332          |
| 9/8/2011   | 0754   | N17W81   | X6.9      |            | 0812 1610         |
| 6/9/2011   | 2220   | N14W18   | X2.1      |            | 2305 575          |
| 7/9/2011   | 2238   | N14W32   | X1.8      |            | 2305 792          |
| 22/9/2011  | 1101   | N17E76   | X1.7      |            | 1048 1905         |
| 24/9/2011  | 0940   | N12E47   | X1.9      |            | 0948 1936         |
| 3/11/2011  | 2027   | N18E57   | X1.9      |            |                   |
| 27/1/2012  | 1839   | N29W88   | X1.7      |            | 1827 2508         |
| 5/3/2012   | 0409   | N17E41   | X1.1      |            | 0400 1531         |
| 7/3/2012   | 0024   | N17E15   | X5.4      |            | 0024 2684         |
| 12/7/2012  | 1657   | S16W09   | X1        |            | 1648 885          |
| 23/10/2012 | 0317   | S12E43   | X11       | 317 321    | 1.417 …..         |
| 13/5/2013  | 0215   | N12E81   | X2.8      | 212 227    | 0.106 0200 1270   |
| 14/5/2013  | 0113   | N11E66   | X3.2      | 107 120    | 0.262 0125 2625   |
| 15/5/2013  | 0144   | N11E66   | X1.2      | Insufficient data | 0148 1366 |
| 25/10/2013 | 0801   | S09E63   | X1.7      |            | 0812 587          |
| 28/10/2013 | 0203   | N06W81   | X1.0      | Insufficient data | 0224 695         |
| 5/11/2013  | 2212   | S11E38   | X3.3      | Insufficient data | 2236 562         |
4. CONCLUSIONS

In this paper we study the relationship between type II bursts and CMEs. We find that in the metric domain in 70% of the events in our data set, the type II formation height is below the CME height indicating that CMEs are less successful in exciting type II bursts in the metric domain. The main results of the paper are summarized as follows.

1. We apply the Newkirk density model to determine the type II bursts and compare it with CME height at the onset of type II.

2. We classify the events as group I, II & III depending whether type height - CME height is positive, negative or CME is not present respectively. We have found that type II parameters are slightly higher for group I events than group II events. Type II bursts not associated with CMEs possess lesser shock speed, bandwidth and duration. In 83% of type II events, our results suggest that despite temporal association, majority of the CME driven shocks are not successful in exciting type II bursts in 35-450 MHz domain.

3. CME parameters are greater for group II events than group I events. This supports the earlier results which indicated that CMEs successful in exciting type II bursts are stronger with greater speed & width.

4. Fairly equal amount of flare association exists in group I, II & III events. Despite poor correlation is observed between type IIs and X class flares, such type IIs possess higher drift rates. Majority of X class flares are accompanied by CMEs which possess higher speed (avg 1259 km/s).

5. The type II bursts likely to have been excited by CMEs are originating during the rising phase of the flares in majority of the events and in case of type II bursts supposedly not excited by the CMEs, majority of them are originating in the decaying phase of flares.

6. We applied Saito (1977) density model and obtained similar results.

ACKNOWLEDGEMENTS

We are deeply indebted to authorities of Indian Institute of Astrophysics, Bangalore, CMR Institute of Technology, Bangalore and Bangalore university, Bangalore for the support and encouragement. We are grateful to the authorities of Culgoora observatory, SOHO and RHESSI teams for their open data policy.

REFERENCES

1. Aurass, H., 1997, Coronal Physics from Radio and Space Observations, edited by G. Trottet, Springer, Berlin, p.135, 1997.

2. Bemporad, A., Poletto, G., Suess, S. T., Ko, Y. K., Parenti, S., Piley, P., Romoli, M., & Zurbuchen, T. Z. 2003, ApJ, 593, 1146.

3. Brueckner, G. E., et al. 1995, Sol. Phys., 162, 357.

4. Cane, H. V., Sheeley, N. R., Jr., and Howard, R. A.: 1987, J. Geophys. Res. 92, 9869.

5. Chen, P.F.: Living Reviews in Solar Physics, Volume 8, Issue 1, article id.1, 92 pp

6. Cho, K.-S., Lee, J., Gary, D. E., Moon, Y.-J., & Park, Y. D. 2007, ApJ, 665, 799.

7. Cho, K.S., et al. 2011, Astronomy & Astrophysics, Volume 530, id.A16, 5 pp

8. Cho, K.-S., et al. 2005, J. Geophys. Res., 110, A12101.

9. Cho, K.-S., et al. 2008, A&A, 491, 873.

10. Cho, K.-S., et al, Lee, J., Gary, D. E., Moon, Y.-J., & Park, Y. D. 2007, ApJ, 665, 799.

11. Cho, K.-S., et al, 2013, Solar Physics, Volume 284, Issue 1, pp.105-127.
