

# Investigation on the source location of flares associated with type II radio bursts using multi-wavelength observations

G Selvarani<sup>a\*</sup>, K Suresh<sup>b</sup> & A Shanmugaraju<sup>b</sup>

<sup>a</sup>Department of Physics, Sri Meenakshi Government Arts College for Women, Madurai 625 002, India

<sup>b</sup>Department of Physics, Arul Anandar College, Karumathur, Madurai 625 514, India

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In this paper, a set of 145 type II bursts-associated solar flares observed during the period November 1997 to December 2006 has been investigated. The radio bursts have been observed by Culgoora radio spectrograph and X-ray flares have been observed by GOES spacecraft. The main objectives are to study the distribution of locations of flares associated with type II bursts on the Sun and association of type II radio bursts with major solar flares and halo CMEs. Among the different latitudinal bins considered, more number of events occurred in the active latitude range 11-20° in both hemispheres. Shifting of dominance of type II-associated flare events from higher latitudes to equator has been seen from the butterfly diagram. Among the different longitudinal bins, more number of type IIs are found in the solar active longitudes around 50 degrees on both the eastern and western regions and in the range 10-20° west. That might be due to the favorable ambient/source conditions in the solar corona. In addition, the DH type II association with metric type IIs has been found to be nearly absent beyond the east longitude 50°. This east-west asymmetry in the low frequency type II bursts (DH type IIs) may be due to emission directivity of the low frequency radiations produced by CME-driven shocks.

**Keywords:** Solar activities, Coronal mass ejection, Solar flare, Type II radio burst

## 1 Introduction

Solar flares are believed to be generated by heating results from reconnection of field lines and they are observed in H-alpha and X-ray wavelengths. Coronal mass ejections (CMEs) are the plasma eruptions in the solar corona observed in white light by coronagraphs. Type II radio bursts are due to radio waves produced by the plasma oscillation due to flare-blast waves or CME-driven shock waves. They are observed as drifting signatures in the radio wavelength spectrum by radio spectrographs. The solar flares are sometimes associated with CMEs and metric type II radio bursts<sup>1-4</sup>. While a close temporal association between metric type II burst and flares was reported earlier<sup>5-8</sup>, recently, the positional relationship between the type II bursts and CMEs has been established<sup>9, 10</sup>. The occurrence rate and distribution of sunspots, solar flares and coronal mass ejections have been studied by several researchers<sup>2, 11-15</sup>. Garcia<sup>12</sup> investigated the N-S distribution of soft X-ray flares during solar cycle 21 and 22. It was concluded that the spatial distribution of flares varies within a solar cycle such that the preponderance of flares occurs in north during

early part of cycle and then moves towards south as the cycle progresses. Watari and Watanabe<sup>13</sup> found that the heliographic longitudinal distribution of the occurrence of coronal mass ejections (CMEs) was not uniform around the solar minimum of cycle 21, however, the distribution became uniform during solar maximum period. Kane<sup>14</sup> studied the latitude dependence of the variations of sunspot group numbers (SGN) and CMEs in cycle 23 and found that their peaks are not matching with each other in different latitudinal belts.

The distribution of various solar activity features with respect to heliographic latitudes as a function of time has been investigated<sup>16</sup>. It has been found that the flare activity dominates in the northern hemisphere during rising phase and this dominance shifted towards southern hemisphere after solar maximum of cycle 23. In the study of latitudinal distribution of CMEs, Peng-Xin Gao *et al.*<sup>17</sup> found that high latitude CMEs are slightly slower than the low latitude CMEs. Also, Shanmugaraju *et al.*<sup>18</sup> found that the CMEs were observed with less speed in higher latitudes than those of low latitudes. Motivated by these studies, in the present paper, the distribution of type II-associated flares on the sun for the period of

\*Corresponding author (E-mail: selvarani.ganesan@gmail.com)

November-1997 to December-2006 in solar cycle 23 has been investigated. Also, the association of the type II bursts with major flares and halo CMEs has been studied.

## 2 Data

We have collected a set of 145 type II radio bursts events which are associated with solar flares observed during the period of November 1997 to December 2006. The selection criteria for type IIs are as follows:

- (i) Starting and ending times and frequencies must be certain.
- (ii) The starting of type II is within 30 min after the starting of flare.
- (iii) Type II events observed with Culgoora radio spectrograph only.

The source location of solar flares associated with type II is taken from the location of  $H_{\alpha}$  flares. First, the heliographic distribution of metric type IIs is analysed in many aspects by drawing longitudinal and latitudinal distribution, butterfly diagram and solar cycle diagram. There are 75 and 70 events in the northern and southern hemispheres, respectively. As reported by Shanmugaraju *et al.*<sup>4</sup>, the flare-type II burst association is nearly 90% and hence the remaining type II bursts without flare are not considered in the present study.

## 3 Results and Discussion

### 3.1 Heliographic distribution of metric type IIs

The heliographic distribution of source location of 145 type IIs associated with flares is shown in Fig. 1(a). It shows that all the type II events are distributed within  $30^{\circ}$  latitude and spread up to  $90^{\circ}$  in longitude on both eastern and western sides. Majority of the events occurred in the latitudinal belt  $10-20^{\circ}$  on both the northern and southern hemisphere.

They seem to be active latitudes as reported by Zharkova and Zharkov<sup>15</sup>. The longitudinal distribution of the occurrence of type IIs in solar cycle 23 is shown in Fig. 1(b). It can be seen that there are longitudes surrounding  $50^{\circ}$  on both eastern and western regions and  $10-20^{\circ}$  on the western side where slightly excess number of events occurred. Nearly 40-50% of the events occurred close to these three regions. A slightly less number of activities on the western limb than the eastern limb is also noted here. Joshi and Pant<sup>16</sup> found in solar cycle 23 that

occurrence of more number of strong H-alpha flares (importance  $>1$ ) in specific longitudinal bands than the adjacent bands. For solar cycle 20, Dodge<sup>17</sup> observed maximum occurrence of type II source areas at  $30-40^{\circ}$  of both eastern and western hemispheres. On the other hand, Wright<sup>18</sup> suggested that the probability of association of type IIs with H-alpha of given magnitude is independent of longitude. Hence, there are no preferential longitudes for the production of type II radio bursts. The excess of events in selected regions may be due to the favorable source/ambient conditions (like fast CMEs, low Alfvén speed, CME-streamer interactions, etc.) in those regions to produce strong shocks and type II bursts.

The number of events in three different latitudinal bins ( $0-10^{\circ}$ ,  $11-20^{\circ}$ ,  $21-30^{\circ}$ ) in the northern and

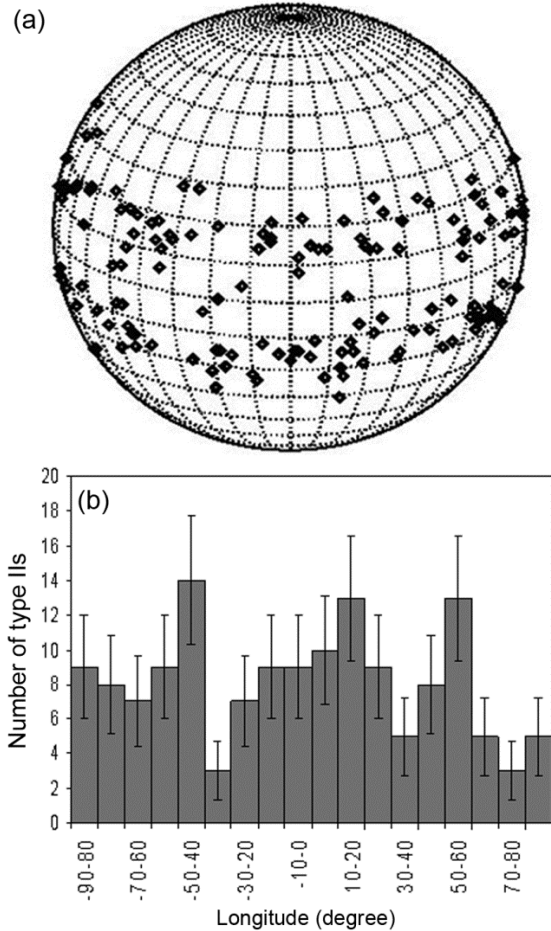


Fig. 1 – (a) Heliographic distribution of type IIs associated with flares for the period 1997 to 2006. (North is on top and East is on left), (b) plot according to bin wise (bin size is  $10^{\circ}$ , negative sign is given for eastern longitudes in x-axis). Error bars are drawn using  $\pm$  the square root of the number of events in each bin

southern hemispheres is given in Table 1. Maximum number of events occurred in the region 11-20° on both the hemispheres. The type IIs started during flare rising time (impulsive phase) and decay time are counted and presented in the Table 1. It is seen that most of the type II events (65-75%) occur during impulsive phase of solar flare in all latitude bins of the northern region and 22-35% of type II events produced during decaying phase of solar flare in northern region. This is in agreement with the earlier results<sup>5-8, 22</sup> and signifies that more number of type II bursts are produced during the rising phase of flares. There are number of reports<sup>23</sup> for coincidence between the acceleration phase of CMEs and rising phase of flares. In contrast to the northern hemisphere, the number of metric type II events (49-58%) occurred in impulsive phase is only slightly greater than that (42-51%) in decaying phase of flare in the southern hemisphere. This shows that southern region is able to produce slightly greater number of type II events during declining phases of solar flare than in the northern hemisphere.

Gopalswamy *et al.*<sup>24</sup> compared the latitudinal distribution of prominence eruptions (PE) and CMEs as a function of time from 1996-2002. This study revealed that there is shift in dominance of PE and CMEs activity from northern to southern hemisphere after solar maximum in 2000. Similarly, Joshi *et al.*<sup>19</sup> reported that northern hemisphere to be dominant during the rising phase of solar cycle 23. This dominance of northern hemisphere shifted towards the southern hemisphere after solar maximum. The events in the present study also belong to same solar cycle 23. Figure 2 shows

the number of type II events in each year in the latitude range 0-30° during the entire solar cycle. It is seen from this figure that there is a shift of dominance of type II activities from northern to southern latitude. That is, the dominance of activities shifted from northern to southern after solar maximum.

**3.2 Association with major solar flares and halo CMEs**

Figure 3(a) shows the flare-associated type IIs (M and X class only) for the period 1997 to 2006. More number of type II-flares are there around 50° in east and west longitudes and in the central region. This plot also shows that there are nearly 50% of the type II-associated events occurred in these regions. Comparison of these three regions shows an excess of only 4 events occurred around east 50°. Similar peaks at both hemispheres were also present in the distribution of all type IIs shown in Fig. 1(b). But the distribution of all M and X class flares observed during the period 1997 to 2006 (given in Fig. 3(b)) shows a nearly equal distribution except the east limb. The comparison of these two plots shows that the distribution of type II-associated major flare is different from that of all major flares. As already mentioned, the excess of events in particular longitudes may be attributed to the favorable source/ambient conditions.

Using the locations of type II burst-associated flares, the latitudinal variation (butterfly diagram) for the entire solar cycle is plotted as given in Fig. 4(b). From this figure, it is clear that the events start at high latitude and as the time proceeds, the events move towards lower latitudinal bins. It also shows that there is more number of events between 11° to 20° latitudinal bins on both northern and southern

Table 1 – Distribution of source location of type II burst in northern and southern latitudes

Properties		Northern latitude		
		0-10°	11-20°	21-30°
Number of events (75)		18	43	12
Percentage of events	Impulsive phase	78%	65%	75%
	Decaying phase	22%	35%	25%
		Southern latitude		
Number of events (70)		12	47	9
Percentage of events	Impulsive phase	58%	49%	56%
	Decaying phase	42%	51%	44%

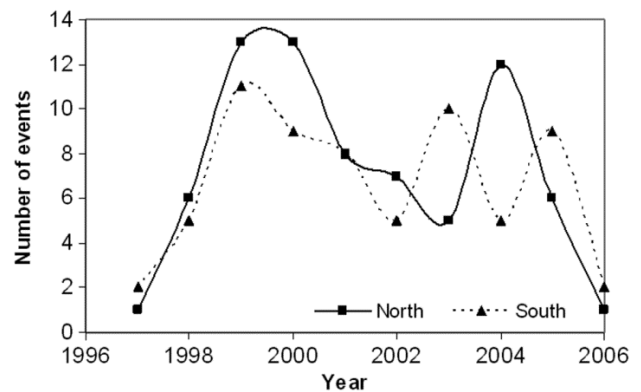


Fig. 2 – Number of type II events during the entire solar cycle (1997 to 2006) observed in the latitude range 0-30° of both northern and southern hemispheres

hemispheres. This plot is compared with the butterfly diagrams drawn using locations of all major flares of class M and X (Fig. 4 (a)), and using locations of flare-associated halo CMEs (Fig. 4(c)). Since the type II bursts association with flares and CMEs increases with the stronger flares and wider CMEs<sup>24</sup>, this comparison would be an appropriate one. It seems from this latitudinal variation, the type II-associated flares' distribution is similar to both the distributions of all major flares and halo CMEs and no conclusion can be arrived on the source of these type II bursts.

Hence, as an alternative approximate method, the total number of type IIs, major flares and Halo CMEs has been compared, because the type II burst association rate increases with the strong flares and

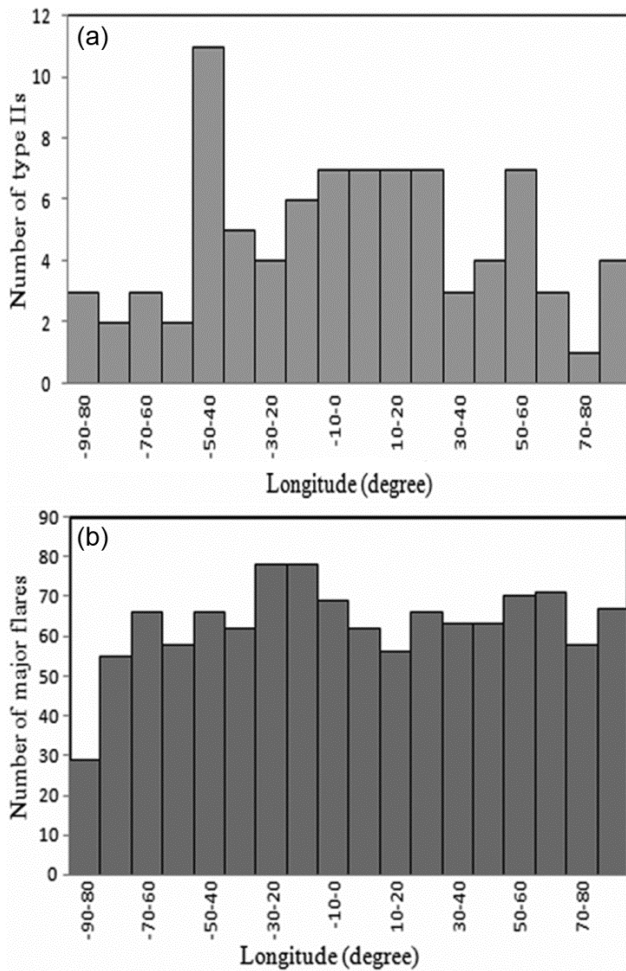


Fig. 3 – (a) Longitudinal distribution of type IIs associated with flares (M & X class) for the period 1997 to 2006. (bin size is 10°, negative sign is given for eastern longitudes in x-axis), (b) shows the longitudinal distribution of all major flares (M and X class)

faster/wider CMEs. Since the speed of fast CMEs associated with intensive flares can exceed the Alfvén speed, a strong shock can be formed which results in observable type II radio burst. In Fig. 5, the variation of number of type II bursts reported from 8 types of observatories over the entire solar cycle is compared

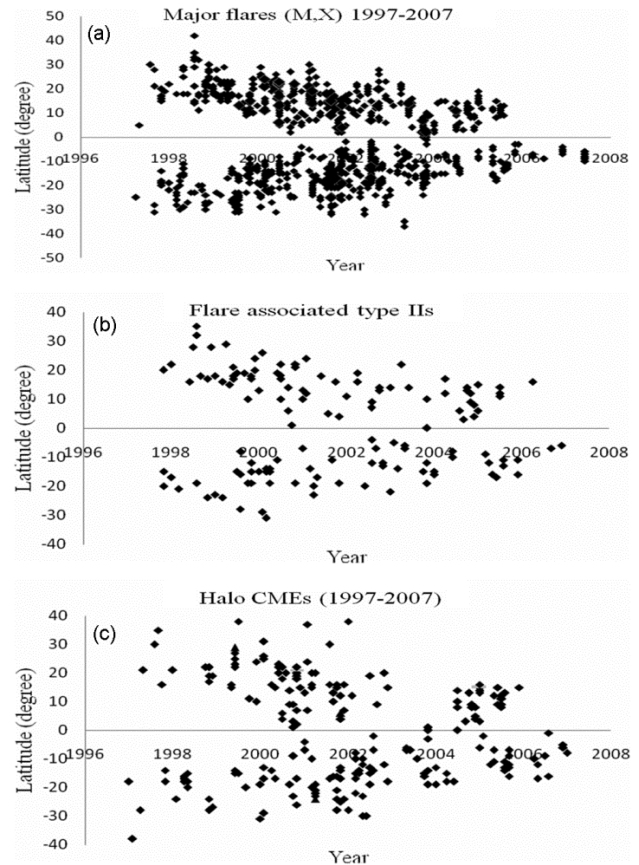


Fig. 4–Butterfly diagram drawn for : (a) major flares, (b) flare associated type IIs and (c) Halo CMEs observed during the period 1997 to 2007

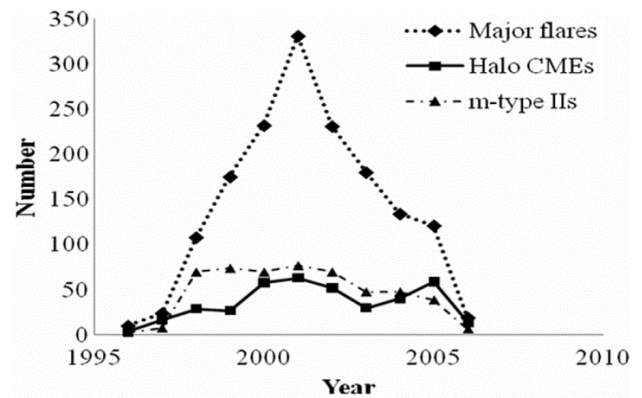


Fig. 5 – Number of metric type II events during the entire solar cycle (1996 to 2006) compared with the number of major flares and halo CMEs

with the numbers of major flares and halo CMEs. The reporting stations are Potsdam ( $52^\circ$  N,  $13^\circ$  E), San Vito ( $41^\circ$  N,  $18^\circ$  E), Izmiran ( $55^\circ$  N,  $37^\circ$  E), Learmonth ( $22^\circ$  S,  $114^\circ$  E), Hiraiso ( $36^\circ$  N,  $140^\circ$  E), Culgoora ( $30^\circ$  S,  $150^\circ$  E), Palehua ( $21^\circ$  N,  $204^\circ$  E), and Sagamore Hill ( $42^\circ$  N,  $289^\circ$  E). The longitudinal distribution of different observing station is such that there is a continuous observation of the sun over a period of 24 h throughout the entire period of the solar cycle 23 (1997 to 2006). The list of 145 type IIs from Culgoora considered earlier in the present study is a subset of around 500 metric type IIs reported by all the above observatories.

Figure 5 shows the number of type IIs over the entire solar cycle which typically follows the number of halo CMEs. Of course, the number of major flares is nearly 6 times that of type IIs/ halo CMEs during the solar maximum. The CME data gap during June-October 1998 (when SOHO was temporarily disabled) should be noted. Figure 5 seems to support roughly the CME origin of metric type II bursts. The subject of origin of metric type II bursts<sup>25</sup>, i.e., whether they are driven by CMEs or flares, has been a longstanding debate. In the past, there were many reports in favor of flares rather than CMEs<sup>6, 8, 26, 27</sup>. As discussed earlier, CME supportive results for the metric type IIs have been published in the recent decades<sup>9,10</sup>. Quite recently, Park, Moon and Gopalswamy<sup>28</sup> reported that solar proton occurrence probability depends on CMEs rather than flares and it also depends on longitude.

### 3.3 Association with DH type IIs

When we extended our study to look into the association of deca-hectametric (DH) type II bursts with the metric type IIs, we found some interesting results. Out of 145 metric type IIs, 38 events are associated with DH type IIs and their source locations are obtained from the H-alpha flare locations listed in the Wind/WAVES catalog ([http://cdaw.gsfc.nasa.gov/CME\\_list/radio/waves\\_type2.html](http://cdaw.gsfc.nasa.gov/CME_list/radio/waves_type2.html)). The heliographic distribution of metric type II associated DH type IIs is shown in Fig. 6. It shows that the extension of metric type IIs into the DH domain is found within  $50^\circ$  east longitude and beyond that DH type IIs are unlikely to be detected. This is similar to the result of Sakurai<sup>29</sup> who found the east-west asymmetry in the extension of type III bursts from metric to hectometric range. As suggested by him, the reason would be the poor connectivity of the events near the eastern limb to the Earth. That is, the

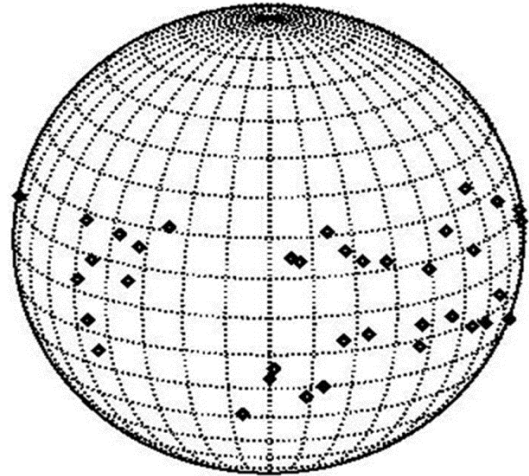


Fig. 6 – Heliographic distribution of metric type IIs associated with Deca-hectametric (DH) type IIs. (North is on top and East on left)

east-west asymmetry in the low frequency type II bursts (DH type IIs) may be due to emission directivity of the low frequency radiations along the path of accelerated electrons by the CME-driven shock. However, as pointed out by Wright<sup>18</sup>, if the conditions for the metric type II bursts to occur, it might be observable irrespective of the longitude. In addition, there is only less than 30% of DH type II association found on the eastern region.

## 4 Conclusions

The latitudinal and longitudinal distributions of 145 solar flares associated with metric type II events during the period November 1997 to December 2006 are analyzed. These type II bursts were observed by Culgoora spectrograph. The distribution of these type II-associated flares in latitude and longitude are studied using the locations of associated H-alpha flares. Most of these events occurred in the latitudinal range  $0-30^\circ$ . Maximum number of events found in the latitudinal range of  $11-20^\circ$  in both northern and southern regions revealed the active latitudinal belts similar to that reported in other solar cycles. In the northern region, nearly 65-80% of type II events produced during impulsive phase of solar flare and 20-35% of type II events produced during decaying phase. On the other hand, nearly equal numbers of cases are found in the southern region.

The shifting of dominance of type II-associated events from higher latitudes to equator is seen by the butterfly diagram and shifting of dominance of activities from northern to southern hemisphere is revealed from the solar cycle diagram. The

distribution of type II-associated flares in longitude displays slightly excess number of events in the longitudes around  $50^\circ$  on both the eastern/western and central regions. That might be due to the favorable ambient conditions in the corona such as, high density streamers or low Alfvén speed regions, high speed mass ejections, etc. to produce type II bursts. According to the butterfly diagram, there is no distinction between the distribution of type II-associated flares and that of major solar flares (M and X) and halo CMEs. However, when the total number of type IIs are considered, frequency of occurrence of type IIs is similar to that of halo CMEs. This result is in support of literature that radio-loud CMEs are wider and such CMEs have more chances of facing streamers of high density and low Alfvén speed regions where the possibility of strengthening the shocks is greater.

There is an east-west asymmetry in the heliographic distribution of DH type II associated with metric type IIs and DH type IIs are almost absent beyond the east longitude of  $50^\circ$ . It may be attributed to emission directivity of these low frequency radiations by the CME-driven shock.

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