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Statistical Analysis of Associated and Non Associated Type II Solar Radio Bursts during the Decreasing Phase of Solar Cycle 23

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Abstract Type II and Type III bursts are probably the most intensively studied form of radio emission in all of astrophysics. Immense effort has gone into the elucidation of both the observational and theoretical aspects. The bursts have captured the attention of plasma theorists because a considerable body of information exists on the plasma parameters and there is adequate space and time in the solar corona for the evolution of various particle and wave processes. Type II radio bursts are indicative of shock propagation in the corona and inner heliosphere, accompanied by electron acceleration. They are good indicators of shocks that eventually cause sudden commencement of geomagnetic storms. In our work, we have studied the type II bursts and their association with type III bursts during the decreasing phase after the peak phase of solar cycle 23. For the period 2002-2004, type II and type III bursts data of Culgoora observatory is referred. The parameters such as duration drift rate, shock speed, band width of these associated/non associated bursts are compared. Results indicate that except in the case of duration and bandwidth, the above parameters almost remain uniform for associated and non associated type II bursts.

Keywords Shock Speed, Drift rate, Plasma Frequency, Dynamic Spectrum

1. Introduction

Solar radio bursts were amongst the first phenomena identified as targets for radio astronomy. Solar radio bursts at frequencies below a few hundred MHZ have been extensively studied. Among the 5 types of solar radio bursts, the type ii and type III bursts are most important from the perspective of space weather prediction.

Type III bursts are the fast drift bursts which are an attractive tool to investigate fast acceleration processes, which is considered to be the cause of the high exciter velocities. They can be used as natural plasma probes traversing the corona and yielding information about different plasma parameters. Fast drift phenomenon provides an opportunity to study processes of different wave–particle and wave-wave interactions and has stimulated a considerable progress in developing in physical methods for a quantitative investigation. Therefore the type III bursts can be used as tracers of the magnetic field configuration and also other parameters in the coronal and solar wind. The investigation of the interplanetary medium through the analysis of the type III solar radio bursts at long wavelengths can in principle provide information about the structure and properties of active region streamers[8]. The type III phenomenon contains message about the interaction of beam with plasma and so it induced plasma physicists to study the possible mechanisms of such interactions and to study how plasma processes can give rise to the emission of electromagnetic radiation.

The main defining characteristic of type III bursts was recognized by Wild[38] and Wild & Mcready[36]; it is that their emission drifts rapidly from high to low frequencies. The drift rate is roughly 100MHz/s in the meter wave range, some 100 times faster than drifting bursts, such as type I chains and type II bursts. Of the various forms of radio burst emissions from the Sun, the type III bursts are most likely to be indicative of the escape of energetic particles from the Sun. These radio bursts exhibit a rapid frequency drift (~80 MHz/s at 100MHz) from high to low frequencies and have been shown to be due to disturbance propagating outward in the solar corona at speeds of ~c/3 (c is velocity of light)[36, 37]. Alvarez & Haddock[1] made the suggestion that bursts are caused by streams of electrons. These streams move out through the corona along the open field lines at a speed of about c/3 and their passage sets up plasma oscillations –

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Langmuir waves then radiate at their characteristic frequency. Because the electron density and consequently the plasma frequency decrease outward from the Sun, the emission frequency of the bursts does likewise. According to plasma hypothesis[38], type III emission at the plasma frequency is given by

$$f_p = 9 \times 10^{-3} N^{\frac{1}{2}}$$

N is the electron density in cm-3

It is clear that for the type III bursts extending to low frequencies the exciting agent escapes from the Sun. The nature of the exciting agent has been hypothesized to be both proton[9, 36] and electron streams[37]. There are theoretical grounds for the choice of proton streams as the excitation agent[11]. However, protons of the requisite energy (~50MeV) are rarely observed to be emitted by the Sun, and when they are emitted, they are not necessarily accompanied by type III radio emission but rather by type IV and type[19] raises the possibility that proton flux from a type III burst is too small to be observed above galactic cosmic ray background. Solar electros of ~c/3 velocity (~32keV) energy are frequently observed in the interplanetary medium. Almost every solar electron event of ~40keV is accompanied by such type III burst emission[19]. The plasma hypothesis was confirmed by interferometer measurements of the type III source height at different frequencies which showed successively lower frequencies being emitted from successively greater heights [37]. Interferometer observatio ns show that the average radial velocity varies from 0.2c to 0.8c between the 60 and 45 MHz plasma levels. Individual type III bursts observed over a frequency range from 200 to 12MHz, i.e. from $0.15R_o$ to $2R_o$ above the photosphere, have rift rates which correspond to radial source velocities ~c/3. Wang et al[34] studied type III groups and concluded that type III bursts may be caused by energetic electrons accelerated during a non linear reconnection process in the larger magnetic loop of solar corona. During the reconnection, the magnetic field will become more complex in local smaller area, there will be some explosive and fast instability, such as Tokamak instability, in the smaller area which might case the relevant change in induced electric field and cause acceleration of electrons.

The distinguishing characteristic of type III bursts is their harmonic structure; because this has been a subject of controversy and their circular polarization. Harmonic structures are exhibited by a significant proportion of type III bursts at meter and decameter wavelengths. The frequency ratio of harmonic to fundamental averages to 1.8:1 with a range from 1.6:1 to 2.0:1[36]. Type III bursts do not always drift down to very low frequencies. On many occasions bursts observed at metric wavelengths are not observed at decametric wavelengths, and similarly many bursts are not observed at hectometric and kilometric wavelengths which are seen by ground based observations which extend to decametric wavelengths[14]. The reasons for these cutoffs are not well understood. To study the possibility whether the exciting agent is impeded or dispersed in its progress outward through corona, Alvarez, et al[1] studied type III bursts which extend to kilometric wavelengths (frequencies ≤ 0.350MHz at height ≥ $50R_o$) and compared them with > 45KeV electron events observed at 1AU. They found that one to one correspondence exists between kilometric wavelength type III burst above a threshold of approximately 10-13 W/m2/Hz and >45Kev observed at 1AU. They concluded that streams of ~10-100keV electrons are the exciting agents for the type III bursts and that ~ 5 x 1032 electrons with energy > 100keV are emitted in a strong type III burst. A problem which remains is to explain the cutoff of many types III bursts before they reach kilometric wavelengths. They observed that such correlation may be due to stopping of the electron beam before it reaches 1AU. The time profiles of the radio emission contain important information about the particle streams and their interaction with the interplanetary medium. A study of the characteristic range of these parameters with distance from Sun can lead to a better understanding of the propagation and interaction of energetic particles in the interplanetary medium, Evans et al[7]. The time profile of type III solar bursts can be used for the determination of the coronal temperature if we assume that the decay of the emission is due to the damping of plasma oscillations by electron-ion collisions[17]. The temperature T is related to the damping constant through the formula

$$T = 0.65 \times 10^{-4} f^{\frac{4}{3}} \tau^{\frac{2}{3}}$$

f is the frequency in hertz

τ is damping constant in seconds.

The frequency drift rate at meter wavelengths according to Alvarez and Haddock (1973) is given by

$$\frac{df}{dt} = -0.01 f^{1.84}$$

Here f is in MHz and $\frac{df}{dt}$ is in MHz/s

The drift rates were converted to velocity by assuming that the bursts propagated along a coronal streamer possessing the density distribution of Newkirk streamer model[25].

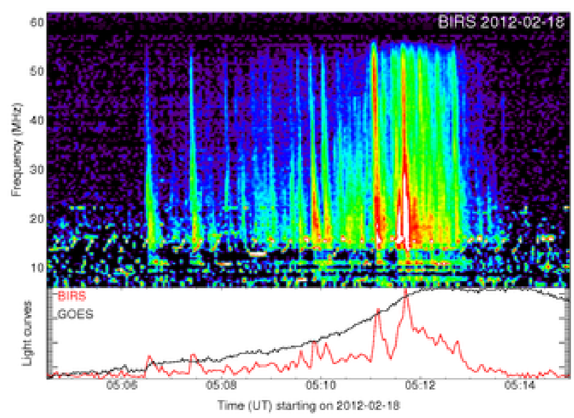


Figure 1. Typical example of Type III radio burst observed with BIRS observatory on 18/02/2012.The bursts begin at 05:50UT and are observed at till 06:14UT

The problem of exciter origin is not yet solved satisfactorily. The short duration of Type III bursts should provide valuable hints for the investigation of the related acceleration processes. Their special significance in relation to solar flares is their occurrence in compact groups of intense bursts lasting a minute or two; at the flash phase which marks the time of the basic flare explosion[36]. The drift rate and duration of type III bursts are known to be determined by the expressions given below

Duration = 60 / f $^{0.7}$

f is the drift rate MHz/s

Deceleration of exciter speeds is obtained from Fainberg (1971) as

$$D \text{ lob } V_e / d \log R = -0.38$$

V_e is the exciter speed in terms of velocity of light (Km/s)

R is the distance from the Sun in solar Radii

D is the Deceleration in Km/s^2

The position of type III burst radiation source is determined by the path of the exciting particles in space. Due to the smaller gyro radii, the electrons are forced to follow the magnetic field direction. The starting heights of the type III bursts may not be regarded as the actual heights where the acceleration is initiated; the location of the exciter origin is obscured. Zaitsev[41] concluded that in a spatially bound stream inspite of quasi linear relaxation plasma waves can be generated for a long time owing to faster particles escaping out of the front of the stream.

1.1. Type II Solar Radio Bursts

Payne-Scott observed large outburst of March 08, 1947 from Sun at three frequencies 10, 20 and 60MHz and found that the lower frequency emission was delayed with respect to higher frequencies. The Magneto Hydro Dynamic (MHD) Shock was found to be moving with speed 500-750km/s from higher to lower frequency plasma levels in the corona. Wild and Mcready[38] classified these outbursts as type II radio bursts in contrast to type I storms and the fast drifting type III. All these bursts are due to non thermal electrons and represent energy release in the corona. Type II bursts are the violent eruptions from the Sun that result in shock waves propagating through the corona and interplanetary medium. The origin of the shock waves in the solar corona that manifest themselves as solar type II radio bursts is one of the most important subjects of solar and terrestrial physics. A general picture of emission from type II shocks suggests that the emission mechanism is plasma emission near the fundamental and second harmonic[11, 24]. Langmuir waves are produced by beams produced in the shock. The excited Langmuir waves may be converted into escaping radio waves by non linear wave-wave processes[2, 4, and 11]. The study of type II is thus important for the understanding of the large scale structure and dynamics of the inner heliosphere. Since type II are good indicators of shocks that eventually cause sudden commencement of geomagnetic storms, their study is necessary for space weather predictions.

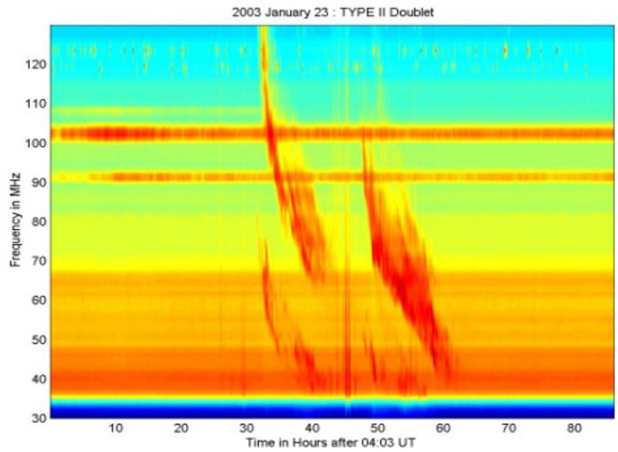


Figure 2. Typical example of type II radio doublets observed with the Gauribidanoor digital solar radio spectrograph on 23/1/2003. Two type II bursts are seen in sequence with the first one starting at 04:32 UT and the second one at 04:49UT. Both these bursts show the fundamental and harmonic structures

Type II bursts are observed in the meter wave regime at frequencies <150MHz. Ground based instruments observe type II down to ionospheric cutoff (~15MHz). Space borne radio instruments observe type II bursts at frequencies below ionospheric cutoff in interplanetary medium. WIND/ WAVES experiment[15] has detected type II bursts in the previously unexplored regime of 1-14MHz. Ulyssis spacecraft has detected type II bursts at a distance of several AU from the Sun. Dynamic spectrum is a plot of the observed radio intensity as a function of frequency and time. Radio interferometric observations give positional information of the bursts. Two dimensional interferometric arrays known as radio heliographs provide detailed information on the spatial structure and position of the radio bursts. The emission is observed in fundamental and harmonic modes. The rate at which the emission frequency changes is known as the drift rate and corresponds to the motion of exciting agency (an MHD shock) through the corona[37]. The typical drift rate is 0.1MHz/s. Using statistical analysis of type II bursts at frequencies >40MHz, Mann[22] found that the type II bursts have a drift rate of -0.16 +/- 0.11 MHz/s. The drift is negative because the bursts drift from higher frequency to lower frequencies. For the harmonic component the drift rate is 0.2MHz/s but when normalized to the central frequency of emission, the rates are same. Bursts starting at very high frequencies seem to have high drift rates. Mann[22] found a linear relationship

$$\frac{df}{dt} = 0.046\text{-}[0.002 /(s/f)]$$

s is the duration in seconds

f is the bandwidth in MHz.

Statistical studies have shown that duration of type II bursts is about 5-15 minutes. The radio emission is considered to be due to a plasma emission process which involves the following steps.

1. An instability condition is set up due to propagation of

an exciting agency through the corona resulting in the generation of high frequency plasma waves at the local plasma frequency f_p.

2. These plasma waves (Langmuir waves) scatter on the background ions resulting in electromagnetic waves of roughly the same frequency which propagate towards the observer and are detected as fundamental emission. Two plasma waves can coalesce resulting in an electromagnetic wave at a frequency 2fp which is observed as harmonic component. The condition for instability is maintained for the duration the agency passes through a given plasma layer. Once the agency leaves the layer, there is no more free energy available so the plasma waves decay to the thermal level and the generation of electromagnetic waves ends. The agency is a shock wave.

1.2. Fine Structure in Type II: (Band Splitting)

In the dynamic structure of type II, the F and H components are composed of two parallel lanes of emission. The frequency separation is about 10% of the central frequency .In the two dimensional images, the lower split bands originate higher in the corona than the upper side band. The band splitting seems to be related to the inhomogenity in the medium. Several studies are being made to find answers to questions on origin height of type II and type III bursts. Dulk et al (1971) pointed out that type II sources often appear in the same regions as the type III sources that precede them in the flash phase and also observed that the type II bursts are occasionally observed at frequencies as low as10MHz. The type II emission is generated behind the shock front-i.e., in the region of enhanced electron density. This means that the electron density of the source as derived from the fundamental frequency of emission does not refer to the undisturbed corona but to temporarily compressed regions. One may therefore expect that at a given frequency type II and type III bursts would be generated at different heights. There is no statistical evidence to support this prediction. This matter requires careful observational investigation since, if established, an equal height for type II and type III bursts may force one to seek type II models in which the radiation is generated ahead of shock front.

1.3. Association between Type II and Type III Radio Bursts

The association between type II and type III radio bursts are necessary in several aspects. In most of the cases, groups of type III radio bursts occur at the start of a flare. These type III radio bursts in most cases are followed by a type II radio bursts. Type III bursts are fast drifting bursts with duration of few seconds. Type II solar bursts can sometimes occur without preceded by type III radio bursts also. It is interesting to study whether the characteristics of type II bursts associated with type III bursts are different from those which are not associated with type III bursts. This will lead to the understanding of drivers of type II radio bursts. In our work, we have studied the type III bursts and their association with type II bursts. For the period 2002-2004, type III bursts data of Culgoora observatory is referred.

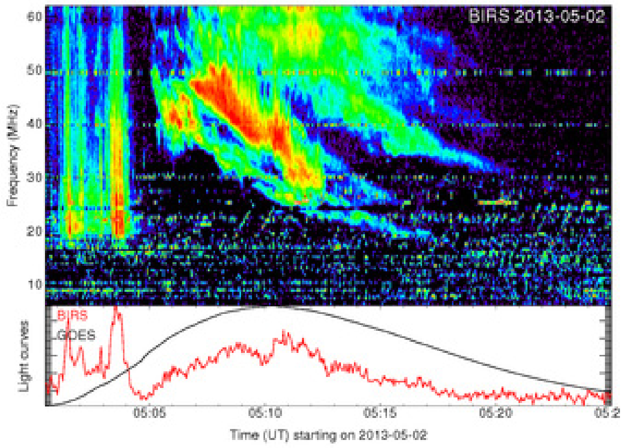


Figure 3. Typical type II and type III radio burst associated event observed with BIRS on 02/05/2013. The type III burst begins at 06:05UT and the associated type II begins at 06:15UT. Harmonic features of type II bursts are observed

2. Data Selection

In this study, we have used the data of type II radio bursts published by Culgoora radio observatory in the Solar Geophysical Data for the period January 2002 to December 2004. In our work, we have studied the type III bursts and their association with type II bursts. We have considered events in which type III and type II bursts are occurring with the time separation less than 30 minutes. A very large number of unclassified types of bursts exists in the decameter range. For our purpose, the bursts have been selected using the following criteria they have to be observed on at least two adjacent frequencies the delay between the bursts observed on the two frequencies must correspond to the normal frequency drift of type III bursts the bursts must be well isolated so that its time profile cannot be the superposition of different emissions. The observing period 2002-2004 being the decreasing phase of Solar cycle 23 close to the peak phase, the activity was moderate. Table 1 summarizes the data set for 2002- 2004.

Table 1.

Observatory	year	No of type II associated with type III	No of type II not associated with type III
Culgoora	2002	40	4
	2003	23	9
	2004	21	9

Typical examples of the non associated and associated type II radio bursts are shown in figure 2 and 3 respectively.

We have analyzed the following parameters from the data.

1. Total Duration
2. Start Frequency
3. End Frequency
4. Bandwidth
5. Drift rate
6. Estimated Shock Speeds (ESS)

3. Data Analysis

The radio parameters data for the events considered in our study is given below.

2002 Fundamental Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
6-Feb	3	57	65		8	0.044444444
16	5	57	90		33	0.11
20	6	75	95		20	0.055555556
27	9	65	85		20	0.037037037
1-Mar	4	57	65		8	0.033333333
12	2	57	80		23	0.191666667
4-Apr	12	57	90		33	0.045833333
9	2	110	200	900	90	0.75
12-Jan	2	57	70		13	0.108333333
	3	57	75	600	18	0.1
21-May	6	57	180		123	0.341666667
1-Jun	7	57	180		123	0.292857143
20-Jul	11	57	180	400	123	0.186363636
23-Jul	5	57	170		113	0.376666667
29-Jul	3	65	130		65	0.361111111
14-Aug	8	57	80		23	0.047916667
16-Aug	2	57	90		33	0.275
18-Aug	2	57	70		13	0.108333333
21-Aug	2	120	180	450	60	0.5
22-Aug	3	57	80		23	0.127777778
23-Aug	7	57	90		33	0.078571429
24-Aug	3	57	120		63	0.35
2-Sep	5	57	100		43	0.143333333
30-Sep	2	35	50		15	0.125
4-Oct	18	30	220		190	0.175925926
5-Oct	14	35	90		55	0.06547619
14-Oct	4	25	45		20	0.083333333
27-Oct	10	18	70		52	0.086666667
6-Nov	5	18	30		12	0.04
10-Nov	6	18	50		32	0.088888889
	14	18	80		62	0.073809524
4-Dec	4	60	130		70	0.291666667
	6	25	60		35	0.097222222
19-Dec	9	30	70		40	0.074074074
	10	30	80		50	0.083333333
	3	50	90		40	0.222222222
22-Dec	14	20	50		30	0.035714286
	4	20	60		40	0.166666667
	11	20	45		25	0.037878788

2002 Harmonic Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
14-Jan	3	85	180	1000	95	0.527777778
22	2	57	65		8	0.066666667
23	6	100	150	500	50	0.138888889
6-Feb	8	75	130	450	55	0.114583333
16-Feb	5	100	180	400	80	0.266666667
20-Feb	15	57	190	600	133	0.147777778
27-Feb	16	57	170	400	113	0.117708333
1-Mar	8	75	130	700	55	0.114583333
	3	65	160	1200	95	0.527777778
12-Mar	9	57	160	1000	103	0.190740741
4-Apr	14	57	140	400	83	0.098809524
9-Apr	2	220	400		180	1.5
12-Apr	4	95	130	400	35	0.145833333
	3	110	150		40	0.222222222
21-Apr	11	57	130	500	73	0.110606061
13-May	8	57	120	500	63	0.13125
16-May	15	85	290	400	205	0.227777778
21-May	16	57	160	500	103	0.107291667
1-Jun	10	70	350	750	280	0.466666667
12-Jun	13	57	100	450	43	0.055128205
20-Jul	10	110	400		290	0.483333333
23-Jul	7	57	280	950	223	0.530952381
	14	57	160	500	103	0.122619048
29-Jul	3	150	260	600	110	0.611111111
14-Aug	11	60	170	400	110	0.166666667
16-Aug	2	90	180	1700	90	0.75
18-Aug	6	57	140	1000	83	0.230555556
21-Aug	6	57	80	450	23	0.063888889
	1	240	280		40	0.666666667
22-Aug	6	57	160	800	103	0.286111111
23-Aug	10	65	180	550	115	0.191666667
24-Aug	8	190	190	850	0	0
2-Sep	7	60	180	750	120	0.285714286
8-Sep	16	57	260	650	203	0.211458333
16-Sep	5	60	90	750	30	0.1
17-Sep	17	57	100	900	43	0.042156863
30-Sep	4	57	100	950	43	0.179166667
4-Oct	25	35	460	500	425	0.283333333
5-Oct	22	65	180	250	115	0.087121212
14-Oct	4	50	100	1000	50	0.208333333
27-Oct	8	45	160	900	115	0.239583333
6-Nov	10	35	70	700	35	0.058333333
10-Nov	7	40	100	800	60	0.142857143
	14	40	160	600	120	0.142857143
4-Dec	13	45	260	900	215	0.275641026
	6	50	110	600	60	0.166666667
19-Dec	12	35	140	850	105	0.145833333
	4	57	180	550	123	0.5125
	3	100	180	550	80	0.444444444
20-Dec	2	90	140	550	50	0.416666667
22-Dec	14	40	100	450	60	0.071428571
	7	30	120	1300	90	0.214285714
	17	30	90	600	60	0.058823529

2002 Fundamental Not Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
3-Jan	6	57	75		18	0.05
25-Jan	7	57	85		28	0.0666
19-Sep	1	57	70		13	0.2166
	4	57	130		73	0.3041

2002 Harmonic Not Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
3-Jan	11	57	150	520	93	0.1409
31-May	11	57	85	400	28	0.0424
19-Sep	3	70	140	1000	70	0.3888
21-Sep	9	57	260	900	203	0.3759

2002 Start time difference and End Time Differences of Type III & Type II

date	Start time difference(min)	End Time Difference(Min)	Duration(Min)	BW(Mhz)	df/dt(MHz/s)
6-Feb	6	2	4	193	0.8041667
16	6	6	6	203	0.5638889
20	7	5	2	343	2.8583333
27	4	3	11	123	0.1863636
1-Mar	12	9	3	343	1.9055556
12	13	13	0	250	Data insufficient
4-Apr	14	14	0	123	Data insuddicient
	5	-22	27	123	0.0759259
9-Apr	2	0	2	83	0.6916667
12	10	1	9	540	1
	3	2	1	123	2.05
21-Apr	6	1	5	323	1.0766667
21-May	6	0	6	1243	3.4527778
12-Jun	12	9	3	123	0.6833333
1-Jun	2	1	1	1743	29.05
20-Jul	2	-2	4	273	1.1375
23-Jul	1	-3	4	1243	5.1791667
29-Jul	0	-1	1	300	5
14-Aug	1	-1	2	103	0.8583333
16-Aug	46	-88	2h14m	33	0
18-Aug	13	3	10	1543	2.5716667
21-Aug	2	0	2	643	5.3583333
	5	1	4	1243	5.1791667
23-Aug	6	4	2	83	0.6916667
24-Aug	6	3	3	123	0.6833333
	6	4	2	1540	12.833333
2-Sep	4	3	1	1243	20.716667
30-Sep	6	1	5	832	2.7733333
4-Oct	3	-1	4	502	2.0916667
5-Oct	4	2	2	90	0.75
14-Oct	4	1	3	150	0.8333333
27-Oct	7	-12	19	92	0.0807018
6-Nov	20	-12	33	162	0.0818182
10-Nov	4	-2	6	457	1.2694444
	10	4	6	457	1.2694444
4-Dec	5	-4	9	482	0.8925926
19-Dec	1	0	1	233	3.8833333
	3	-12	15	342	0.38
	2	2	0	180	0

2003 Fundamental Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
21-Jan	6	40	75		35	0.097222222
	6	40	70		30	0.083333333
23	11	30	85		55	0.083333333
	12	20	65		45	0.0625
12-Feb	8	50	160		110	0.229166667
9-Apr	1	57	70		13	0.216666667
23-Apr	5	30	150		120	0.4
	9	27	60		33	0.061111111
26-Apr	5	27	100		73	0.243333333
27-May	8	50	300	900	250	0.520833333
29-May	5	30	90		60	0.2
31-May	7	30	90		60	0.142857143
1-Jun	8	57	100		43	0.089583333
	8	57	180		123	0.25625
9-Jun	14	30	180		150	0.178571429
17-Jun	7	20	50		30	0.071428571
19-Jul	4	35	50		15	0.0625
6-Oct	5	45	65	500	20	0.066666667
26-Oct	8	30	160		130	0.270833333
	8	60	430	850	370	0.770833333
1-Nov	10	30	150		120	0.2
3-Nov	4	35	100		65	0.270833333
4-Nov	5	20	45		25	0.083333333

2003 Harmonic Associated

date	**duration (min)**	**starting frequency(MHz)**	**ending frequency(MHz)**	**ESS(Km/s)**	**Bw(MHZ)**	**df/dt(MHz/s)**
21-Jan	5	60	130	700	70	0.233333333
	6	60	140	700	80	0.222222222
23	2	57	160	450	103	0.858333333
	6	35	140	450	105	0.291666667
12-Feb	8	100	320	600	220	0.458333333
9-Apr	10	57	140	350	83	0.138333333
23-Apr	5	60	300	1500	240	0.8
	9	50	130	550	80	0.148148148
26-Apr	7	60	220	800	160	0.380952381
27-May	4	10	180		170	0.708333333
29-May	5	50	170	800	120	0.4
31-May	12	35	180	800	145	0.201388889
1-Jun	11	57	210	650	153	0.231818182
	10	70	350	750	280	0.466666667
12-Jun	13	57	100	450	43	0.055128205
9-Jun	14	60	360	550	300	0.357142857
17-Jun	10	35	180	1000	145	0.241666667
19-Jul	5	60	100	500	40	0.133333333
6-Oct	5	100	130		30	0.1
25-Oct	3	60	100	200	40	0.222222222
26-Oct	8	57	330	1100	273	0.56875
	6	330	1000		670	1.861111111
1-Nov	13	35	290	1000	255	0.326923077
3-Nov	5	50	200	500	150	0.5
4-Nov	7	23	90	500	67	0.15952381

2003 Fundamental Not Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
24-Jan	10	35	120		85	0.14166667
31-Jan	8	25	50		25	0.05208333
4-Apr	19	30	70	350	40	0.03508772
22-Apr	8	30	65		35	0.07291667
2-Jun	7	30	90		60	0.14285714
24-Jul	7	27	50		23	0.0547619
21-Oct	5	20	50		30	0.1
25-Oct	3	30	50		20	0.11111111
18-Nov	12	35	130	450	95	0.13194444

2003 Harmonic Not Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
24-Jan	15	50	260	600	210	0.233333333
31-Jan	19	35	110	550	75	0.065789474
22-Apr	16	45	160	800	115	0.119791667
25-Jun	17	60	180	700	120	0.117647059
24-Jul	9	50	100	500	50	0.092592593
21-Oct	5	40	110	1000	70	0.233333333
25-Oct	3	60	100	1200	40	0.222222222
18-Nov	11	80	280		200	0.303030303

2003 Time difference in start and End Times

date	Start time difference(min)	End Time Difference(Min)	Duration(Min)	BW(Mhz)	df/dt(MHz/s)
21-Jan	3	2	4	462	1.925
	6	6	3	732	4.0666667
23	2	5	0	122	0
	5	3	5	832	2.7733333
12-Feb	4	9	10	442	0.7366667
19-Mar	1	13	0	160	0
9-Apr	13	14	3	150	0.8333333
23-Apr	0	2	0	397	0
	4	0	3	162	0.9
26-Apr	2	1	11	532	0.8060606
27-May	2	2	7	1380	3.2857143
	6	1	6	982	2.7277778
31-May	3	0	1	650	10.833333
1-Jun	0	9	0	180	0
	2	1	1	1743	29.05
12-Jun	12	-2	3	123	0.6833333
9-Jun	2	-3	3	650	3.6111111
17-Jun	3	-1	14	780	0.9285714
19-Jul	6	-1	4	150	0.625
6-Oct	15	8	5	162	0.54
26-Oct	9	3	7	82	0.1952381
	0	0	2	362	3.0166667
1-Nov	0	1	1	312	5.2
3-Nov	16	4	10	322	0.5366667
4-Nov	1	2	11	34	0.0515152

2004 Fundamental Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
7-Jan	23	18	230	700	212	0.153623188
12-Jan	7	57	130		73	0.173809524
18-Jan	14	35	230		195	0.232142857
19-Jan	11	35	100		65	0.098484848
20-Jan	11	25	95		70	0.106060606
5-Apr	11	27	95	750	68	0.103030303
8-Apr	8	25	75		50	0.104166667
10-Apr	3	27	45		18	0.1
27-Apr	13	23	90		67	0.085897436
27-May	8	50	300	900	250	0.520833333
29-May	5	30	90		60	0.2
2-Jun	11	23	75		52	0.078787879
23-Jun	7	30	57		27	0.064285714
24-Jun	5	35	80		45	0.15
	4	30	50		20	0.083333333
5-Jul	6	27	57		30	0.083333333
13-Jul	3	57	150		93	0.516666667
24-Aug	11	18	45		27	0.040909091
30-Aug	8	20	70		50	0.104166667
	5	23	40		17	0.056666667
30-Oct	5	35	80	850	45	0.15
	11	25	140		115	0.174242424
	10	20	65	800	45	0.075
31-Oct	5	40	65	750	25	0.083333333
1-Nov	8	30	100		70	0.145833333
6-Nov	3	30	35		5	0.027777778
10-Nov	12	18	65		47	0.065277778
2-Dec	2	45	90		45	0.375
30-Dec	20	18	90		72	0.06

2004 Harmonic Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
7-Jan	24	18	110		92	0.063888889
12-Jan	9	57	260	600	203	0.375925926
18-Jan	14	65	440	600	375	0.446428571
19-Jan	11	70	180	450	110	0.166666667
20-Jan	11	50	180	550	130	0.196969697
8-Apr	16	35	160	800	125	0.130208333
10-Apr	13	35	90	1000	55	0.070512821
27-Apr	19	27	190	600	163	0.142982456
27-May	4	100	180		80	0.333333333
29-May	5	50	170	800	120	0.4
23-Jun	11	45	110	500	65	0.098484848
24-Jun	6	60	160	750	100	0.277777778
	9	35	100	850	65	0.12037037
5-Jul	12	27	100	700	73	0.101388889
13-Jul	3	100	300	1000	200	1.111111111
24-Aug	24	23	95	800	72	0.05
30-Aug	10	40	140	650	100	0.166666667
31-Aug	13	35	100	650	65	0.083333333
30-Oct	10	45	280	850	235	0.391666667
	10	40	140		100	0.166666667
1-Nov	10	45	250	1000	205	0.341666667
3-Nov	11	45	140	700	95	0.143939394
	12	30	120	750	90	0.125
6-Nov	4	57	80		23	0.095833333
10-Nov	16	18	130	1100	112	0.116666667
2-Dec	5	60	190	1000	130	0.433333333
30-Dec	24	27	180	600	153	0.10625

2004 Fundamental Not Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
12-Sep	6	30	57		27	0.075
10-Oct	15	23	180		157	0.17444

2004 Harmonic Not Associated

date	duration (min)	starting frequency(MHz)	ending frequency(MHz)	ESS(Km/s)	Bw(MHZ)	df/dt(MHz/s)
12-Sep	6	60	110	900	50	0.1388
10-Oct	16	50	750	900	700	0.729

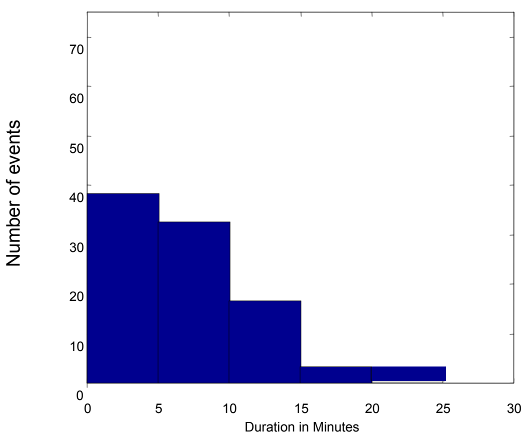
2004 Start and End time Difference

date	Start time difference(min)	End Time Difference(Min)	Duration(Min)	BW(Mhz)	df/dt(MHz/s)
7-Jan	2	-1	3	282	1.5666667
12	4	-2	6	132	0.3666667
18	3	1	2	782	6.5166667
19	3	2	1	110	1.8333333
20-Jan	6	0	6	602	1.6722222
5-Apr	11	-7	4	342	1.425
8-Apr	3	-4	3	150	0.8333333
10-Apr	9	5	4	260	1.0833333
27-Apr	4	-1	3	100	0.5555556
27-May	2	-5	7	1380	3.2857143
29-May	6	0	6	982	2.7277778
2-Jun	10	7	3	212	1.1777778
23-Jun	11	0	12	182	0.2527778
24-Jun	6	5	1	150	2.5
5-Jul	0	5	3	65	0.3611111
13-Jul	3	-2	5	1782	5.94
24-Aug	12	7	5	162	0.54
30-Aug	8	4	4	303	1.2625
31-Aug	4	2	2	155	1.2916667
30-Oct	7	4	3	102	0.5666667
30-Oct	2	-5	7	262	0.6238095
	2	-3	5	642	2.14
31-Oct	10	8	2	282	2.35
1-Nov	3	1	2	1282	10.683333
3-Nov	15	15	0	450	0
	0	-1	1	160	2.6666667
6-Nov	12	11	1	182	3.0333333
10-Nov	8	-2	10	162	0.27
2-Dec	5	2	3	1280	7.1111111
30-Dec	9	9	0	30	0

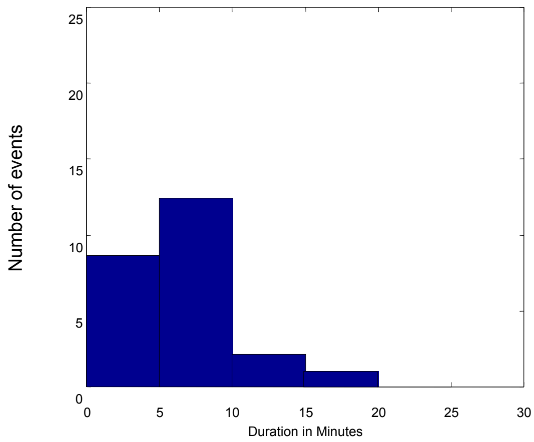
4. Analysis

From the statistical analysis, the following graphs were obtained.

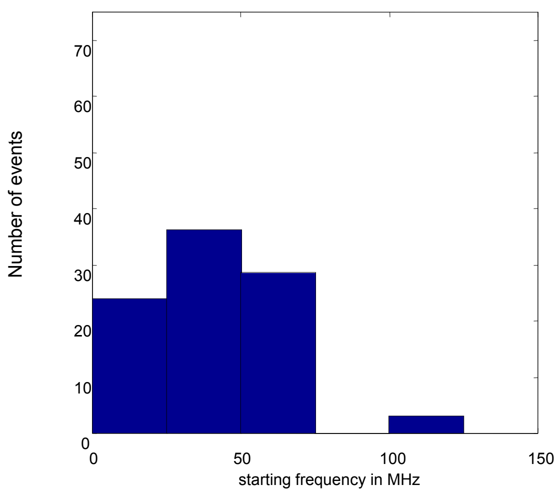
Fundamental- Duration of Type II associated with Type III for the years 2002 to 2004



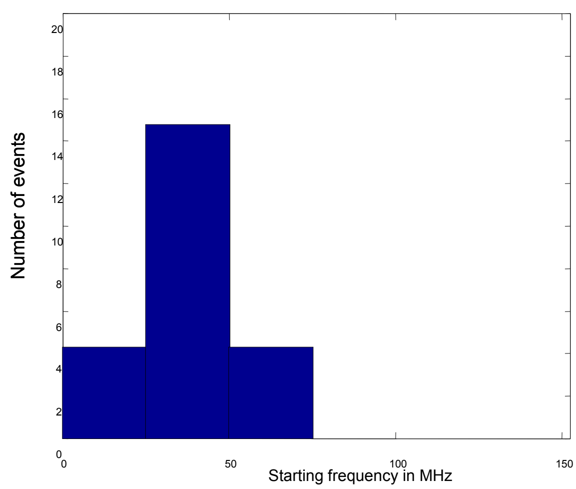
Fundamental - Duration of Type II NOT associated with Type III for the years 2002 to 2004



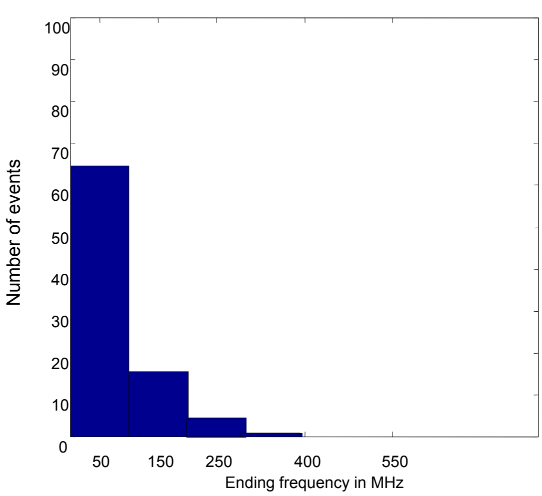
Fundamental- starting frequency of Type II associated with Type III for the year 2002 to 2004



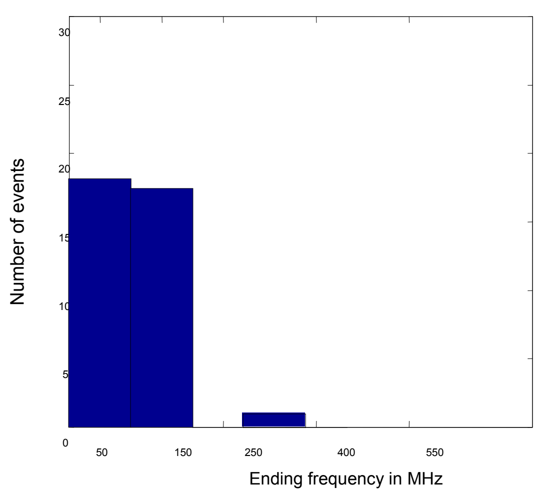
Fundamental-Starting frequency of Type II NOT associated with Type III for the years 2002 to 2004

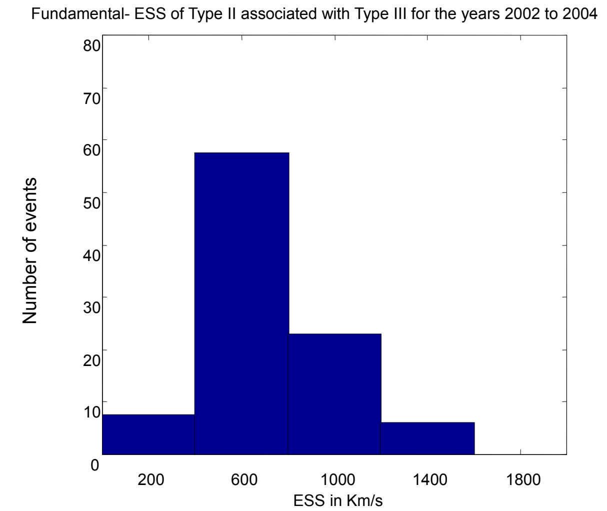


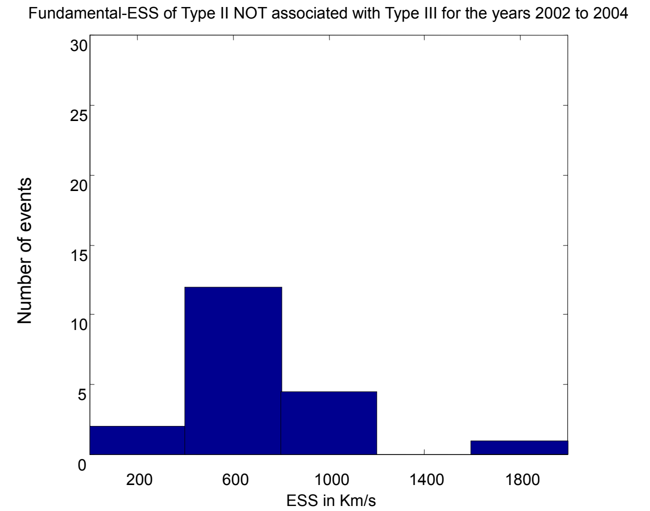
Fundamental- ending frequency of Type II associated with Type III for the years 2002 to 2004

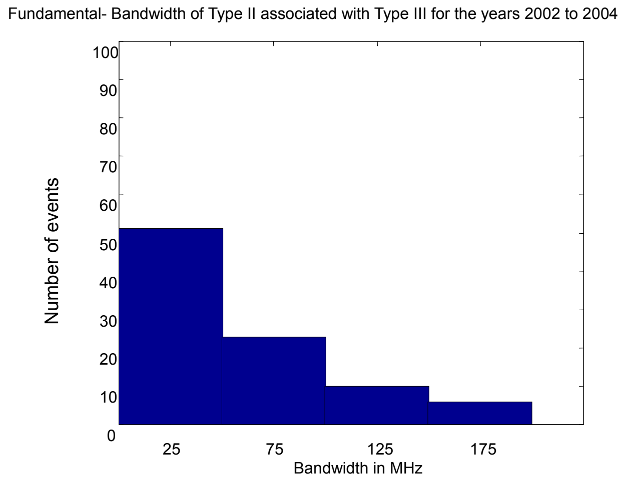


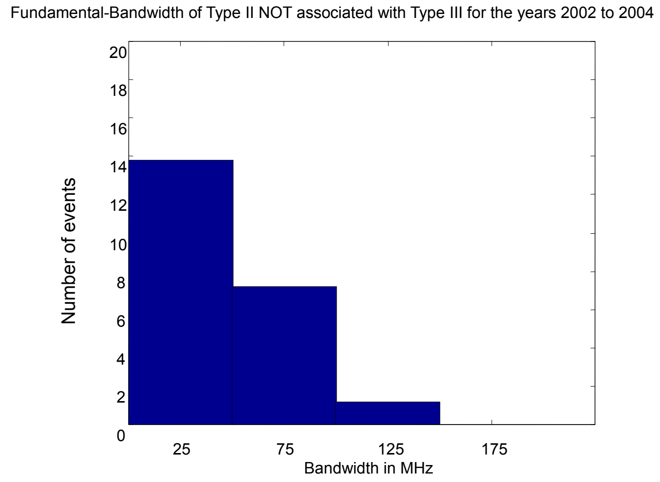
Fundamental - Ending frequency of Type II NOT associated with Type III for the years 2002 to 2004

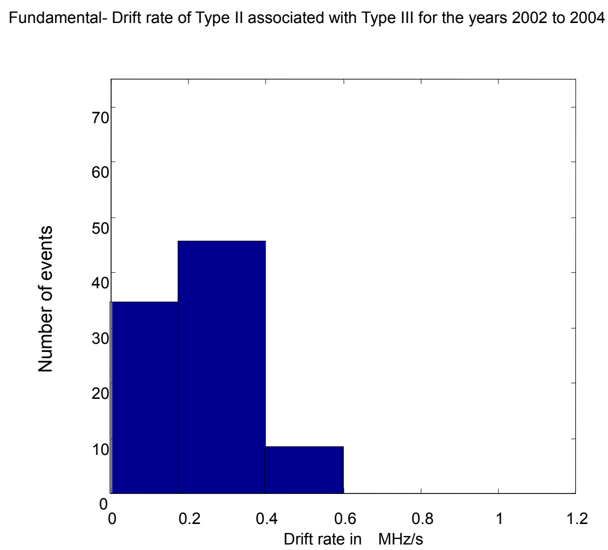


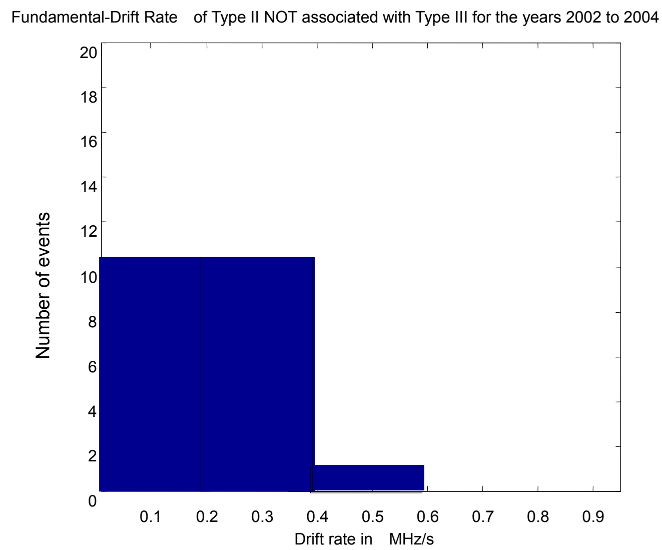

Fundamental- ESS of Type II associated with Type III for the years 2002 to 2004
Number of events
0 10 20 30 40 50 60 70 80
200 600 1000 1400 1800
ESS in Km/s


Fundamental-ESS of Type II NOT associated with Type III for the years 2002 to 2004
Number of events
0 5 10 15 20 25 30
200 600 1000 1400 1800
ESS in Km/s

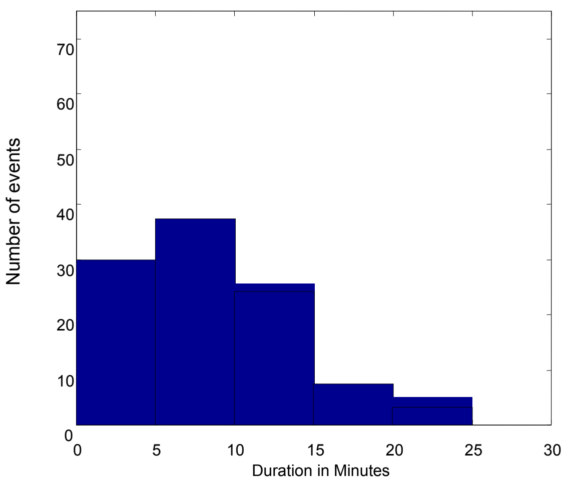

Fundamental- Bandwidth of Type II associated with Type III for the years 2002 to 2004
Number of events
0 10 20 30 40 50 60 70 80 90 100
25 75 125 175
Bandwidth in MHz


Fundamental-Bandwidth of Type II NOT associated with Type III for the years 2002 to 2004
Number of events
0 2 4 6 8 10 12 14 16 18 20
25 75 125 175
Bandwidth in MHz

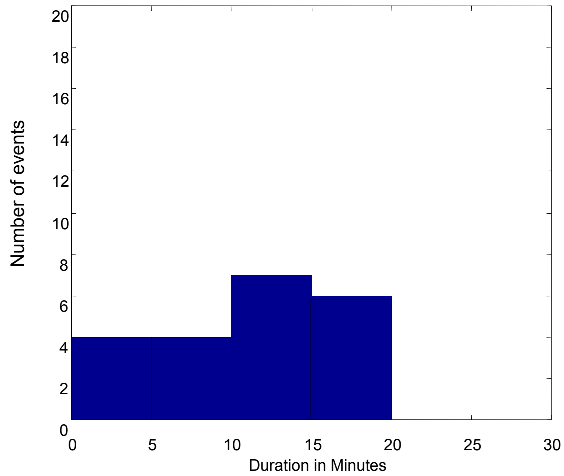

Fundamental- Drift rate of Type II associated with Type III for the years 2002 to 2004
Number of events
0 10 20 30 40 50 60 70
0 0.2 0.4 0.6 0.8 1 1.2
Drift rate in MHz/s


Fundamental-Drift Rate of Type II NOT associated with Type III for the years 2002 to 2004
Number of events
0 2 4 6 8 10 12 14 16 18 20
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Drift rate in MHz/s

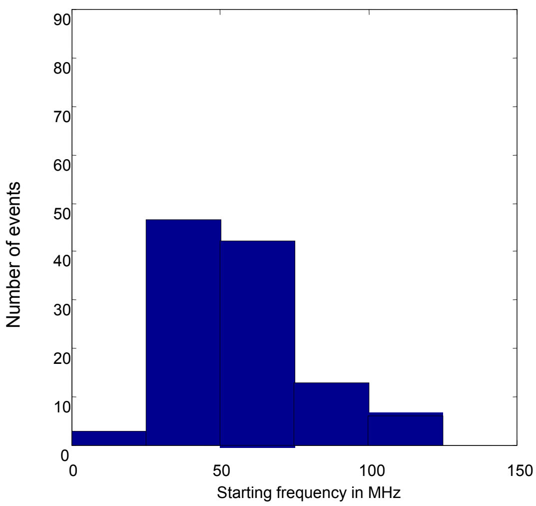
HARMONIC - Duration of Type II associated with Type III for the year 2002 to 2004



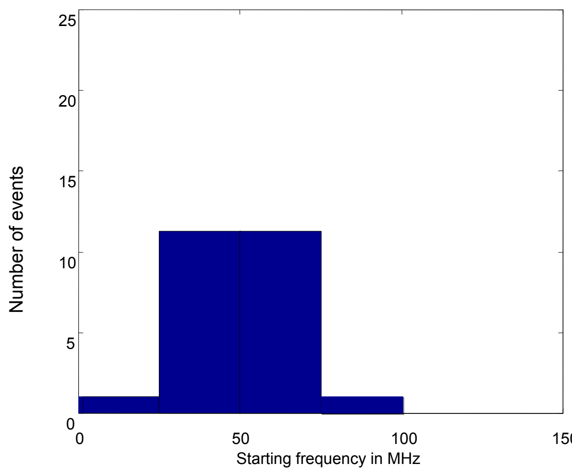
HARMONIC-Duration of Type II NOT associated with Type III for the years 2002 to 2004



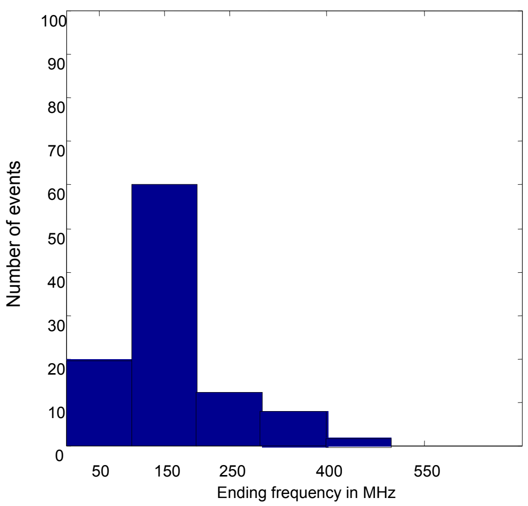
HARMONIC - Starting Frequency of Type II associated with Type III for the years 2002 to 2004



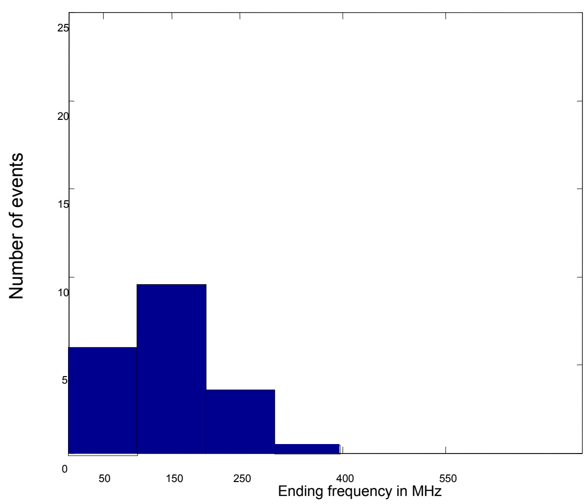
HARMONIC-Starting frequency of Type II NOT associated with Type III for the years 2002 to 2004

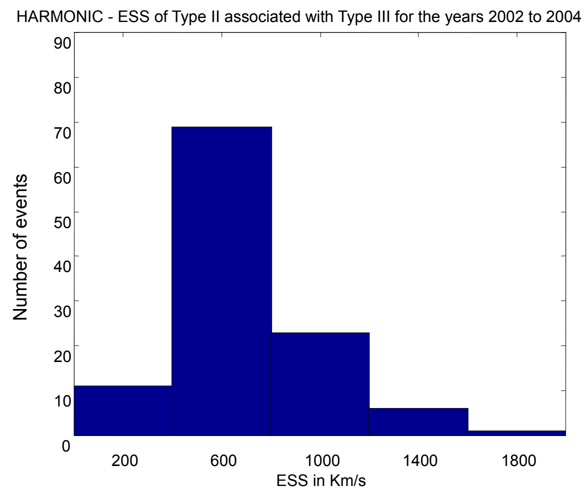


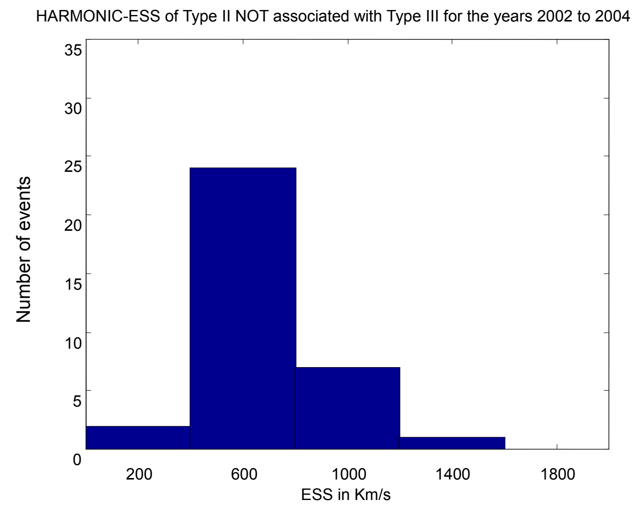
HARMONIC - Ending Frequency of Type II associated with Type III for the years 2002 to 2004

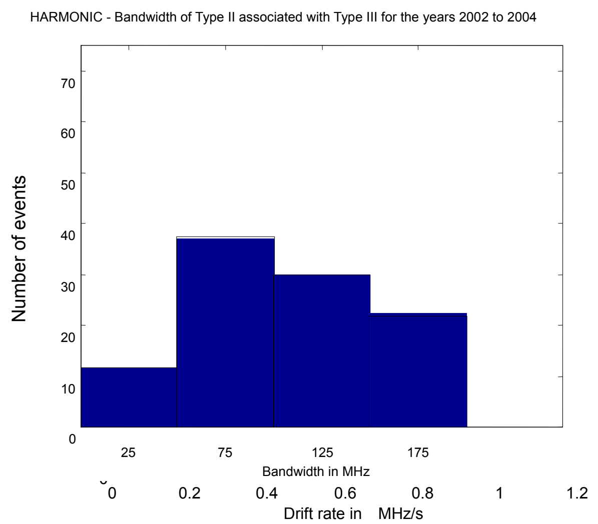


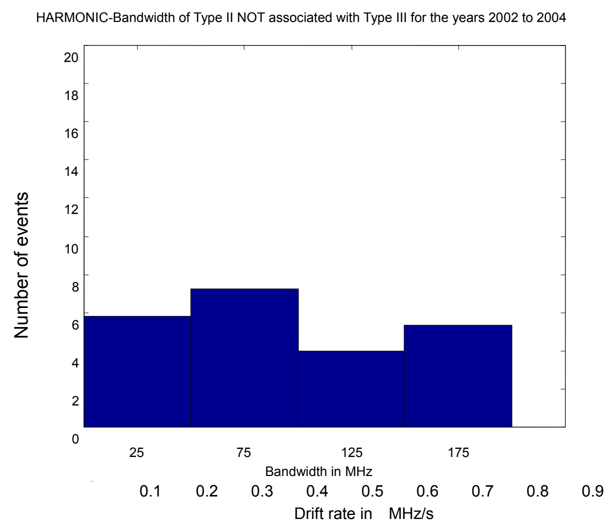
HARMONIC-Ending frequency of Type II NOT associated with Type III for the years 2002 to 2004











Harmonic - Drift rate of Type II associated with Type III for the years 2002 to 2004

Harmonic - Drift Rate of Type II NOT associated with Type III for the years 2002 to 2004

5. Results and Discussion

1.The time profile of a burst at a given frequency is believed to represent the passage an electron stream through the plasma frequency level and the temperature of the corona at different heights (Aubier et al.1972). The burst duration at each level is believed to be related to the duration of excitation (i.e. the time required for the exciter to cross the level) rather than the response of the medium; it increases with time , which indicates an increase of the exciter length with the distance traversed by the beam due to dispersion(Poquerusse et al.,1984).

In the case of fundamental emission, the number of associated type II radio bursts with a duration of 1-5 minutes is almost same as (39 out 92 events) the bursts with duration between 5-10 minutes (32 out of 92 events) and similar pattern is observed with harmonic emissions (30 out of 103 events in the range of 1-5 minutes 36 out of 103 events with duration 5-10 minutes). In the case of type II radio bursts not associated type III radio bursts, 7 out of 22 bursts had the duration in the range 1-5 minutes in the case of fundamental emissions and 4 harmonic emissions had the duration of 1-5minutes. 13 out of 21 bursts had duration in the range 11-20minutes.

2. The starting frequencies of majority of associated type II radio bursts lie in the range of 25 to 75 MHz (88 out of 90 events in case of associated fundamental emissions and 90 out of 103 events in case of harmonic events). With Non associated events, a similar pattern was observed (25 out of 25 fundamental bursts and 23 out of 24 harmonic bursts). The ending frequencies are in the range 50-200MHz (86 events out of 91 in associated fundamental events and 80 out of 103 in harmonic events).With non associated bursts, most of the bursts possessed ending frequencies in the range 50-200MHz (20 out of 21 fundamental events and 15 out of 21 harmonic events).

3. The Estimated shock speeds (ESS) of associated type II radio bursts are in the range of 400 to 800 km/s in more than half the cases (56 out 94 events). In the case of non associated type II radio bursts also, the ESS is in the range of

400 to 800 km/s in most of the cases (12 out of 19 events). In very few cases, a higher ESS of 2000km/s (1 out of 94 cases including associated and not associated events) is noticed.

4. Bandwidth of associated bursts is less than 50 MHz for fundamental emission (in 51 cases out of 90) where as for harmonic emission; it increases up to 100 MHz (50 out of 100 cases). It is observed that bandwidth of equal number of bursts is in the range of 100 – 200MHz. In the case of non associated bursts, 22 out of 23 fundamental bursts had bandwidth in the range of 1-100MHz. Interestingly 13 out of 22 not associated harmonic bursts possessed a bandwidth of 1-100MHz and 9 out of 22 events were in the range 100-200MHz.

5. Less half of the associated bursts (36/88) had a drift rate in the range of 0.01-0.099MHz/s where as in 45 out 88 events, the drift rate was in the range 0.1 to 0.4 MHz/s. In 7 cases, it was above 0.4MHz/s. Drift rate of majority of harmonic emissions is in the range 0.1 -0.4 MHz/s (67 out 105 events) and hence is higher than the fundamental emission. In the case of not associated type II bursts, 24 out of 25 fundamental events, the drift rate was in the range of 0.01-0.4MHz/s and 6 out of 12 harmonic events had the drift rate in the range of 0.1 -0.4MHz/s.

6. Conclusions

Based on association of type II radio bursts and type III radio bursts, the variation in the parameters such as duration , bandwidth, ESS, drift rate of type II radio bursts associated/non associated with type III radio bursts during the decreasing phase after the peak phase (2002 & 2004) of solar cycle 23 are explained. The time structure characteristics of type III radio bursts associated with type II radio burst is carried out. The results of this study have been obtained by an extensive analysis of several data sets. Using the available data we have concluded that:

1. Although the sources and origin processes of type II bursts and the type III bursts are different, the plasma parameters remain almost uniform and variation in the plasma parameters of associated and non associated events is very marginal except in the case of duration and bandwidth. The difference in plasma parameters is noticeable in their duration and bandwidth. Relatively higher fraction of non associated type II radio bursts have more duration than the associated type II radio bursts. Also higher fraction of non associated bursts possessed greater bandwidth than the associated bursts. Since the duration of our study and the number of events is not fairly large, this observation needs further examination.

2. The dynamic spectra of events associated with interplanetary solar energetic particles are very complex and rarely show well defined type II bursts i.e. slowly drifting, harmonically-related pairs of narrow bands. The type II features that are observed appear to be composed of limited frequency type III bursts. The dominant feature is overlying wideband type III emission.

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