The Analysis of Solar Radio Burst Type III Associated with Solar Activities Due to Magnetic Reconnection from 2012-2017

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Abstract. Solar Radio Bursts Type III (SRBT III) and their correlation with solar flares always had been interesting issues. The objective of this research is to study the correlation of SRBT III related to solar flares to magnetic reconnection theory. The importance of this correlation is to enhance the understanding of the particles behaviour during the events over this burst. The data for both SRBT III can be obtained from the e - CALLISTO website. Meanwhile, the data for solar flares were obtained from the Solar Monitor website and Computer Aided CMEs Tracking website respectively. There are 44 data have been collected starting from 2012 until 2017. The Pearson Correlation Coefficient is a method used in obtaining the correlation of the variables of SRBT III and solar flares events. The value of R obtained for the peak flux and the starting frequency of SRBT III is +0.3364. The mean of the peak flux is $6.0 \times 10^{-5}$ W/m² which is in the M group with a magnitude of 6.0. From this study, they found that the single SRBT III is due to the single magnetic reconnection whereas for the storm and group SRBT III is due to the multiple magnetic reconnections.

1. Introduction

The Sun is considered as our nearest star which distances 149.5 million km from the Earth which is covered by a strong and complex magnetic field. The magnetic field of the Sun plays an important role in an exhibit all activities on the Sun’s surface when it breaks and re-join due to magnetic reconnection process [1]. This process occurred due to the instability of the magnetic field in the Sun surface stored the strong and energetic particles that flow inside the magnetic field lines. The process is called magnetic reconnection process which converted the magnetic energy into plasma kinetic energy. The magnetic field of the Sun has a large reservoir of energy and the energy released due to magnetic reconnection has been proposed to explain both large and small scale events. The large scale events refer to the solar flares. Meanwhile for the small scale phenomena, they usually refer to coronal and chromospheric microflares that probably heat and accelerate the solar wind [2]. This solar wind has a very strong connection with the climate change effect [3].

The high energetic particles, thermal and non-thermal emission ejected during the solar flare and CMEs which are a massive burst rising above the solar corona events will generate the emission that is known as the solar radio bursts [4-6]. There are five types of solar radio burst which are below
than two GHz that has been classified since the 1960s and they have their different related phenomena. These phenomena will provide the confirmation for the each of solar radio burst as they can be traced by the space and ground base antenna such as CALLISTO system [7, 8]. For example, Solar Radio Burst Type (SRBT) II and SRBT III are due to CMEs and solar flares events respectively [9].

The SRBT III is an indicator of the magnetic reconnection process as this type of burst usually relates to the solar flares. This burst is due to non-thermal emission process emitted by ejected energetic particles from solar events [10]. The solar flare that accompanied the outburst immediately caused short-wave radio interference, including the jamming of radio signals. Therefore, the objectives of this paper is to evaluate the statistical study of SRBT III accompanied by SRBT II based on start frequency and duration of the solar bursts. Type IV bursts are familiar by its broadband continuum turn as a hint of geomagnetic storm origination [11].

2. Magnetic Reconnection

There are estimated that 30,000 events take place on the surface of the Sun. These events were believed generated due to magnetic reconnection process. Magnetic reconnection process is the process where the magnetic lines of force break and re-join into a lower-energy configuration. This process is a fundamental process which converted the magnetic energy into plasma kinetic. The magnetic reconnections commonly occur within the magnetic legs of the departing CMEs. This provides strong evidence that the lift offs of Coronal Mass Ejections (CMEs) form the new magnetic loops. Majority of the halos CMEs happen at average speed of ~957 km/s [12]. The reconnection is seen as the most mechanism for coronal heating in most of Corona with the evidence by the surprisingly high line widths observed with the UVCS instrument on SOHO.

Furthermore, the other evidence of reconnection process on the corona has been captured by the Yohkoh satellite and SOHO satellite, especially the presence of cusps and interacting loops. X-ray jets, explosive events, EIT brightening and rotating macro spicules. Evidence of the magnetic reconnection process comes in the form of particles and fast outflows associated with solar phenomena such as solar flare and magnetospheric sub storms. The solar flares are the evidence of the magnetic field and chromospheric flares are closely associated with sunspots [13]. Once the upstream magnetic fields are asymmetric, the post-flare loop structure is distorted into a characteristic skewed candle flame shape [14]. Solar flares are a huge burst of radiation, and sometimes going with the release of a large amount of material from the solar atmosphere.

3. Methodology

At the first phase, all data of the SRBT III were obtained starts from 2012 until 2017 where the data can be extracted from the e - CALLISTO data to observe the Sun's activity in the radio wavelength [15]. The CALLISTO website provides the data starting from 2002 until present from 90 locations worldwide using the ground based antenna known as CALLISTO system [16, 17]. This system The system detects and accumulates radio signal for every day via internet and stored in a central data and has recognised to be a new tool for watching solar activity and for space weather study [18, 19]. The data of solar flares were obtained from the solar monitor and CACTus CME website respectively. These two websites used the special instruments to capture the image and measure the parameter of the solar phenomena. These instruments mounted on the spacecraft such as SOHO and LASCO. All these websites are the collaborations between the solar physics team from several countries with the support from NASA. To make sure the data are valid, all the data of the SRBT III related to the solar flares must be within one hour. It takes about 8 minutes to the ejected particles reach the Earth if they are Earth-directed. After all the processes have been completed, the data of the solar radio bursts could be obtained in FIT Files.

The FIT Files obtaining from the system. The data will be saved in FIT Files for every 15 minutes time interval. The data then tabulated and analysed using the Pearson Correlation Coefficient. The Pearson Correlation Coefficient is a tool used to measure how strong the correlation between the two parameters. The symbols positive shows that these two parameters have a positive correlation. If the one parameter increases the other one parameter will be increased. The negative value shows that these two parameters have a negative correlation which means if the one parameter increase the other
one parameter will be decreased. On other hand, if the magnitude of the Pearson Correlation Coefficient is perfectly 0, they have no correlation. If the magnitude is +1, they are perfectly positive correlate and if the value is -1, they are perfectly negative correlate.

4. Results and Discussion
There are 74 data of SRBT III accompanied by SRBT II within 6 years of data collection starting from 2012 until 2017. However, all the data must be related to the solar flares events. The SRBT III will be discussed from different context which are frequency profile and duration of the solar radio bursts. These data were tabulated and analyzed using Pearson Correlation Coefficient to observe how well they are correlated based on different parameters. Table 1 shows the data of SRBT III for 2012 until 2017.

Table 1. Data of SRBT III for 2012 until 2017.

| Date         | Time start (UT) | Time end (UT) | Frequency start (MHz) | Frequency end (MHz) | Date         | Time start (UT) | Time end (UT) | Frequency start (MHz) | Frequency end (MHz) |
|--------------|-----------------|---------------|-----------------------|---------------------|--------------|-----------------|---------------|-----------------------|---------------------|
| 24/04/2012   | 7:41:14         | 7:42:21       | 65.625                | 46.000              | 30/03/2014   | 11:51:04       | 11:51:57      | 173.188                | 165.625              |
| 17/05/2012   | 1:30:40         | 1:30:46       | 383.313               | 328.750             | 18/04/2014   | 12:48:47       | 12:54:42      | 57.375                 | 39.500               |
| 08/06/2012   | 3:03:35         | 3:03:38       | 202.500               | 234.625             | 22/08/2014   | 10:13:55       | 10:16:07      | 67.500                 | 27.188               |
| 09/06/2012   | 16:48:53        | 16:52:44      | 765.625               | 366.688             | 24/08/2014   | 12:03:20       | 12:06:28      | 46.938                 | 21.688               |
| 02/07/2012   | 5:04:53         | 5:05:36       | 157.875               | 110.000             | 25/08/2014   | 15:00:39       | 15:03:08      | 37.625                 | 22.125               |
| 04/07/2012   | 16:35:53        | 16:39:46      | 54.438                | 20.063              | 10/09/2014   | 17:10:18       | 17:10:23      | 181.063                | 114.688              |
| 08/07/2012   | 16:24:32        | 16:27:44      | 61.063                | 28.813              | 23/09/2014   | 23:06:29       | 23:08:17      | 269.313                | 271.313              |
| 27/07/2012   | 17:09:08        | 17:10:53      | 81.813                | 14.875              | 01/11/2014   | 3:48:28        | 3:50:09       | 167.750                | 45.000               |
| 13/11/2012   | 2:01:44         | 2:03:50       | 279.25                | 53.063              | 05/11/2014   | 9:37:16        | 9:37:17       | 259.938                | 221.813              |
| 13/01/2013   | 8:36:30         | 8:36:58       | 432.613               | 227.675             | 11/03/2015   | 16:19:20       | 16:19:39      | 384.250                | 278.188              |
| 02/05/2013   | 5:02:24         | 5:05:04       | 61.063                | 21.188              | 23/04/2015   | 9:16:33        | 9:16:44       | 41.375                 | 33.563               |
| 14/05/2013   | 1:05:41         | 1:05:44       | 348.125               | 234.625             | 06/05/2015   | 11:46:54       | 11:47:59      | 240.125                | 200.068              |
| 31/05/2013   | 19:55:04        | 19:56:24      | 163.500               | 115.625             | 13/05/2015   | 18:15:42       | 18:16:31      | 80.750                 | 58.438               |
| 18/06/2013   | 15:17:07        | 15:17:28      | 45.875                | 22.813              | 28/08/2015   | 6:16:29        | 6:23:08       | 50.750                 | 24.438               |
| 26/10/2015   | 9:24:10         | 9:28:43       | 233.313               | 200.000             | 16/10/2015   | 13:21:05       | 13:22:13      | 75.188                 | 59.375               |
| 02/11/2015   | 4:40:55         | 4:43:43       | 330.313               | 45.000              | 04/11/2015   | 13:40:44       | 13:41:38      | 46.938                 | 38.063               |
| 06/11/2015   | 13:42:57        | 13:44:04      | 454.813               | 199.500             | 09/11/2015   | 13:00:18       | 13:02:00      | 42.438                 | 31.625               |
| 19/11/2015   | 10:23:15        | 10:25:09      | 82.125                | 58.688              | 19/12/2015   | 12:52:11       | 12:52:13      | 141.688                | 136.375              |
| 20/02/2016   | 7:39:41         | 7:39:47       | 76.750                | 35.438              | 16/03/2016   | 6:36:59        | 6:39:09       | 60.000                 | 16.563               |
| 24/02/2016   | 12:01:18        | 12:05:07      | 72.938                | 53.000              | 02/05/2016   | 8:34:52        | 8:36:36       | 86.938                 | 79.000               |
| 28/03/2014   | 23:46:12        | 23:49:06      | 66.188                | 45.000              | 04/05/2016   | 13:40:46       | 13:49:25      | 64.625                 | 20.063               |
| 29/03/2014   | 17:45:58        | 17:48:48      | 76.250                | 37.125              | 06/09/2017   | 12:00:14       | 12:00:44      | 428.863                | 376.550              |

The start frequency of solar radio bursts is significant to study as they correspond to the mechanical energy of the ejected particles and also represent the location of the start emission in forming the solar radio bursts on the spectrograph of CALLISTO system. For the 44 data collected, the SRBT III tabulated based on their start frequency range as shown in Table 2.
Table 2. SRBT III tabulated based on their start frequency range.

| Start Frequency Range (MHz) | No. of Type III Bursts |
|-----------------------------|------------------------|
| 1 – 100                     | 24                     |
| 101 – 200                   | 6                      |
| 201 – 300                   | 6                      |
| 301 – 400                   | 4                      |
| 401 – 500                   | 3                      |
| 501 – 600                   | 0                      |
| 601 – 700                   | 0                      |
| 701 – 800                   | 1                      |
| 801 – 900                   | 0                      |
| 901 – 1000                  | 0                      |

From 44 data on 2012 until 2017 the frequency of SRBT III recorded are in between 10 MHz until below than 800 MHz. The lowest start frequency is 41.375 MHz recorded on 23rd April 2015 while the highest start frequency of SRBT III recorded is 765.625 MHz which is occurred on 9th June 2012. Most of SRBT III recorded in the range of 1 MHz until 100 MHz which are 24 events. The least is in the range of 701 MHz until 800 MHz with only an event on this range of frequency. The start frequency is important to study as they represent the location of the emission process take place and the mechanical energy carried by the ejected particles. As a consequent of the start frequency SRBT III is in MHz, all these SRBT III are start to emit by the electrons in the corona region of the Sun with a distance of 2 Rʘ. The Figure 1 shows the graph of SRBT III against their range of start frequency. The longer the duration of the solar bursts indicates the higher mechanical energy in the ejected particles that continuously emit the EM until these particles lost the energy and being stable. The high energetic particles are very dangerous to the Earth that it may causes a blackout, damage the satellite system and causes another dangerous impact on the life on Earth.

The data obtained then used to study; the relationship between solar flares and the starting frequency of SRBT III. As mention in previous the start frequency of the solar bursts is closely related to the origin or the locations of the electrons emission and the mechanical energy of the electrons during the events. For each class of flare, they have 9 scales of logarithmic categories. For example, the C class they have C1 until C9. It is noted that the C2 flare has peak flux twice than the C1. The value of each magnitude of class flare should be multiplied by the value of peak flux to get the actual value of each flare. For example, the value of the peak flux of M2.8 is 2.8 x 10^-5 W/m².

The value of R obtained for the peak flux and the starting frequency of SRBT III is +0.3364. Since the value of R is between +0.3 and +0.49, this relation has moderate degree positive correlation. The mean of the peak flux is 6.0 x 10^-5 W/m² which is in the M group with a magnitude of 6.0. If the value of the peak flux is higher than this value, it will be considered as higher peak flux while if it has the value lower than this peak flux it is said to be lower peak flux. For the start frequency of SRBT III, the mean value has been mention, where the value is 170.93 MHz. It should be noted that the value of the R, mean value of the peak flux and the start frequency of SRBT III in this only valid for the data of 2012 until 2017.
5. Conclusion

If the magnitude of the Pearson Correlation Coefficient is perfectly 0, they have no correlation. If the magnitude is +1, they are perfectly positive correlate and if the value is -1, they are perfectly negative correlate. From the value of R, the correlation of this parameters were concluded. The higher the peak flux of solar flares, the higher the starting frequency of SRBT III. As mention before, the starting frequency is significant to study where the location of each burst take place in the interstellar atmosphere can be determined. The higher value of peak flux will contribute to the higher starting frequency. This is consequent due to higher peak flux of solar flare and the start frequency has the higher mechanical energy of the ejected particles. The event with high peak flux will start to emit the radiation at the lower corona region with higher start frequency due to their strong mechanical energy of the particles.

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