Production of Coronal Mass Ejections in Relation With Complex Solar Radio Burst Type III Correlated With Single Solar Radio Burst Type III

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ABSTRACT

The complex solar radio burst type III is very related to generation of Coronal Mass Ejections (CMEs). In a previous study, they deduced that the burst was produced by electron beams accelerated in blast wave shocks and injected along open magnetic field lines, similar to the herringbone bursts at metric wavelengths. Usually, if there is another solar flare recorded during complex solar radio burst type III it should be type II burst. Different for this event, the single solar radio burst recorded occur 8 minutes 30 seconds before the complex solar radio burst type III. The Coronal Mass Ejections also recorded occurred 7 hours before the single and complex solar radio burst type III. It is noted that CMEs occurred several hours before this event recorded by the SOHO websites.It is proved that the production of coronal mass ejection contributed to the production of complex solar radio burst type III.

Keywords: Sun; Solar radio burst; type III; single Solar Radio Burst Type (SRBT) III; complex Solar Radio Burst Type (SRBT) III; Coronal Mass Ejection (CMEs); magnetic reconnection

1. INTRODUCTION

Type III burst is brief radio burst that drift very rapidly in spectrograph of frequency versus time. Because the emission is at the plasma frequency, the drift in frequency with time can be directly converted into a drift from high to low ambient coronal density with time. The type III burst emits the electron with energies up to tens keV. Such beams of electrons have long been known to be very efficient producers of electrostatic Langmuir waves via the bump-in-tail instability [1].

In-situ observation of Langmuir waves associated with type III burst were first taken by Gurnett and Anderson using the Helios spacecraft at around 0.5 AU [2]. These waves are then converted into the so-called type III radio burst which are freely propagating electromagnetic emission at plasma frequency [3].

The source of non-thermal electrons of complex type III burst have been debated extensively, flare blast waves [4], flares [5-8] or CMEs-driven shocks [9,10]. Recent results indicate that there is a 100% association between large solar energetic particle events and complex type III bursts [11].

The magnetic reconnection process leads to activities of the Sun. It converted the energy stored in the magnetic field to the kinetic and plasma energy. The type III burst is used as an indicator to detect the magnetic reconnection process on the Sun. It is reported that complex type III starts at much lower frequencies and definitely after the associated type II burst [9]. However, in the previous study, they found that some of a set of metric type II burst associated with shock accelerated events and found that about half of them were not associated with type III burst in the metric domain, contradicting the low-coronal origin for the shock-accelerated events [12]. CMEs-driven shocks are connected with the production of type II burst while the type III burst is associated with solar flare events. It is noted that the solar flare generated due to magnetic reconnection process.

The CMEs is a massive burst of solar wind and magnetic field rising above the solar corona that can trigger major disturbances in Earth's magnetosphere [13]. CMEs can be divided into two categories; flare related CMEs and CMEs associated with filament eruption. For the flare related CMEs, it is due to magnetic flux in the active region. Normally we could observe a type III and type II burst in this case. However, for the CMEs associated with filament eruption it is generated by the evolution of the sunspot or active region behavior. This evolution cannot understand well due to the complexity of this process.

2. MAGNETIC RECONNECTION OF THE SUN

Magnetic reconnection is the process in which the energy in plasma systems converted into high velocity plasma flows and energetic particles [14]. The process of magnetic reconnection is started when the tension force the magnetic lines to break and rejoin then the plasma are accelerated out of the dissipation points. Because of this outflow, the ambient plasma is drawn in. The inflowing plasma carries the surrounding magnetic field lines into the dissipating point. These magnetic field lines continue the reconnection cycle [15].

The other meaning of magnetic reconnection is the process of breaking and reconnecting of oppositely directed magnetic field lines in plasma. Plasma is a state of matter occurring at high temperatures where electrons are not bound to the nucleus. Magnetic

reconnection is at the heart of many spectacular events in our solar system. For example, solar flares which occur at near sunspot are believed to be powered by the magnetic reconnection. Solar magnetic activity, including flares may eject high energy particle into the space or these particles may reach the Earth. If this happened, it will disrupt the power grids and communication system and threaten the spacecraft and satellites.

There are many signatures of reconnection, including sudden plasma heating, the many manifestations of the presence of high energy particles like a radio emission and hard X-ray, fast plasma flows and changes in filed lines connectivity.

Most of these signatures are not unique, for example, high energy particle can be accelerated by shocks, plasma flows can be generated by "buffeting" and plasma can be suddenly heated by compression or conduction [16]. A unique indicator of magnetic reconnection is a change in the connectivity of the magnetic field; in fact, this can be the definition of reconnection [17].

The change energy stored in the magnetic field will convert to the thermal and kinetic energy. The plasmas also will produce in this process. The solar radio burst type III is used as the indicator of the starting point of the magnetic reconnection [18]. The key points here are the plasma only will produce when the magnetic field occur that breaks the magnetic lines [19].
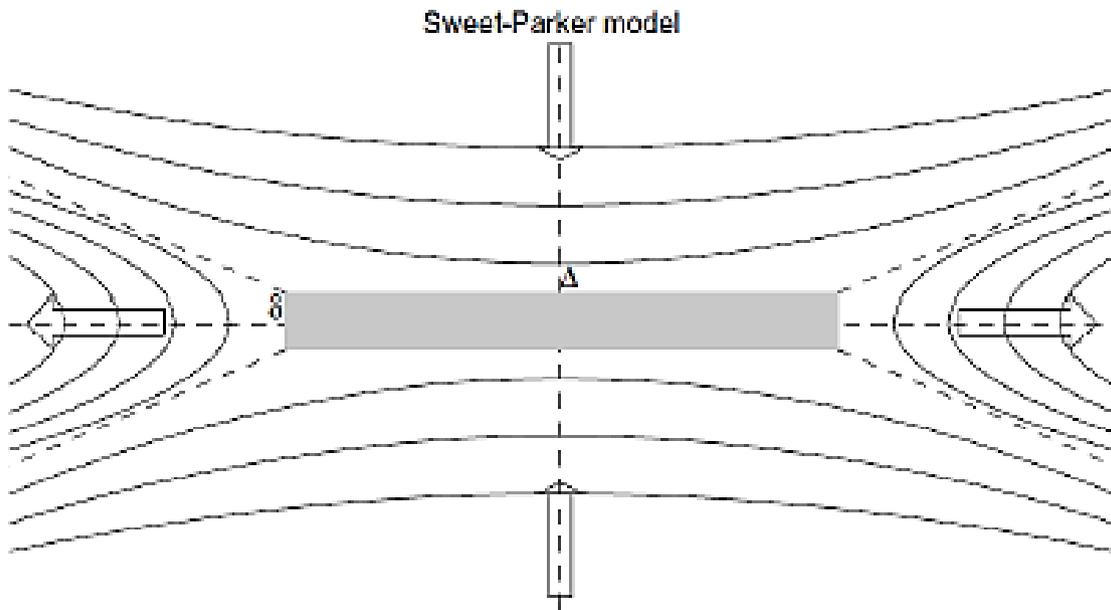

Figure 1. Geometry of the Sweet-Parker model.

The Figure 1 shows the Sweet-Parker models of two-dimensional. After this model, the Harry Petscheck has developed another new model. He said that the long and thin Sweet-Parker is replaced by an open configuration with a microscopic Sweet-Parker layer in the center. The magnetic energy conversion is mostly given due to standing slow shock waves outside the Sweet-Parker rather than diffusion inside as shown in Figure 2 [19].
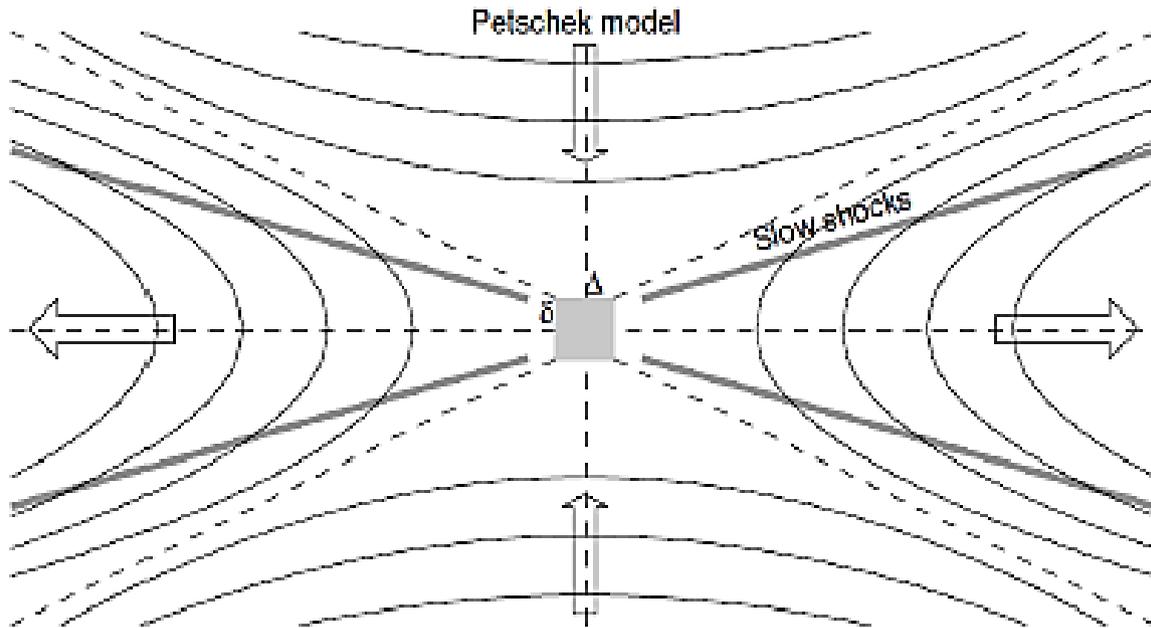
Figure 2. The geometry of Petschek reconnection model.

It is also believed that the magnetic reconnection process will generate to the production of Langmuir wave. The Langmuir wave is known as rapid oscillations of the electron density in conducting media such as plasmas. Then the Langmuir wave will convert to the electromagnetic wave that will generate the mechanism of solar radio burst type III. It should be noted that from the observation, it shows that the Langmuir wave associated with solar type III radio burst are highly localized. The Langmuir wave spectrum can be classified into two components that are forward spectrum and backward spectrum. The forward spectrum is a beam that generated the Langmuir wave while the backward spectrum is a backscattered Langmuir wave. The SRBT III and SRBT II normally generated by plasma emission also lead by the magnetic reconnection process.

3. SOLAR RADIO BURST TYPE III

The Solar Radio Bursts Type (SRBT) III are short, strong burst with fast-drift rate cover frequency the range 10 kHz to 1 GHz. The largest SRBT III can start at frequencies in GHz. Ordinarily the SRBT III will start at 10s or 100s MHz and can onset at even lower frequency and the duration of SRBT III varies inversely as a function of frequency [2]. The associated phenomena for SRBT III are active region and flares. The SRBT III normally exists at vertical features because of the high drift rate from high to low frequencies [12].

The duration of SRBT III, frequency, extent and even how fast they drift varies from burst to burst. The duration of SRBT III increase with decreasing frequency [20].

Their size and intensity also different at different frequencies [2]. It is believed that the harmonic SRBT III occurred at a frequency above 100 MHz, while fundamental SRBT III occurred in frequency below 100 MHz.

Usually the complex SRBT III occurs in one to five minutes and it is associated with Coronal Mass Ejections (CMEs). In the previous study, 92% of the CMEs correlated with shock-accelerated (SA) events. On the other hand, only half of the SA events associated with front-side CMEs had microwave burst, while all they had interplanetary type II burst. So that, the presence of CME-driven shocks are essential for the SA events. This clearly brings CMEs into the picture of complex SRBT III. It is noted that all the fast CMEs have associated with complex SRBT III. However, some CMEs do not have SRBT III association; while some weak type III burst has no associated CMEs [12]. Although the presence of CMEs is essential for the complex type III bursts, it is still not clear whether they are accelerated by the CMEs-driven shocks or in the reconnection process taking place behind the CMEs [21].

In some cases, the complex type III burst starts at much lower frequencies and definitely after the associated type II [9]. However, it is generally believed that the CMEs-driven shocks are connected with the production of type II radio burst [22] whereas type III burst are associated with flares [23].

4. METHODOLOGY

The data used in this paper for spectrograph were obtained e CALLISTO website. CALLISTO is a worldwide network system first built by the engineer from ETH Zurich, Cristian Monstein.
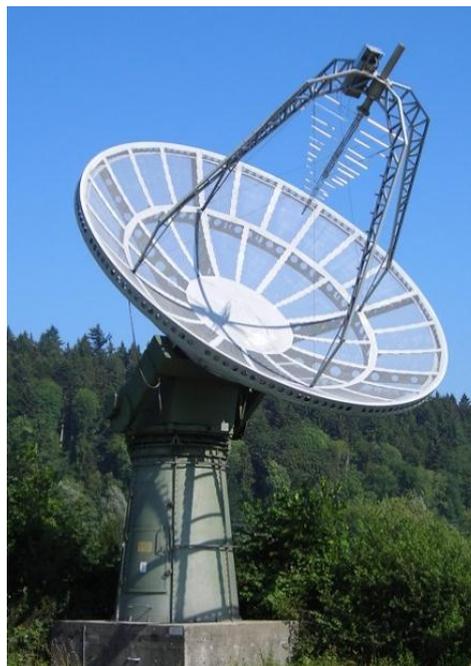

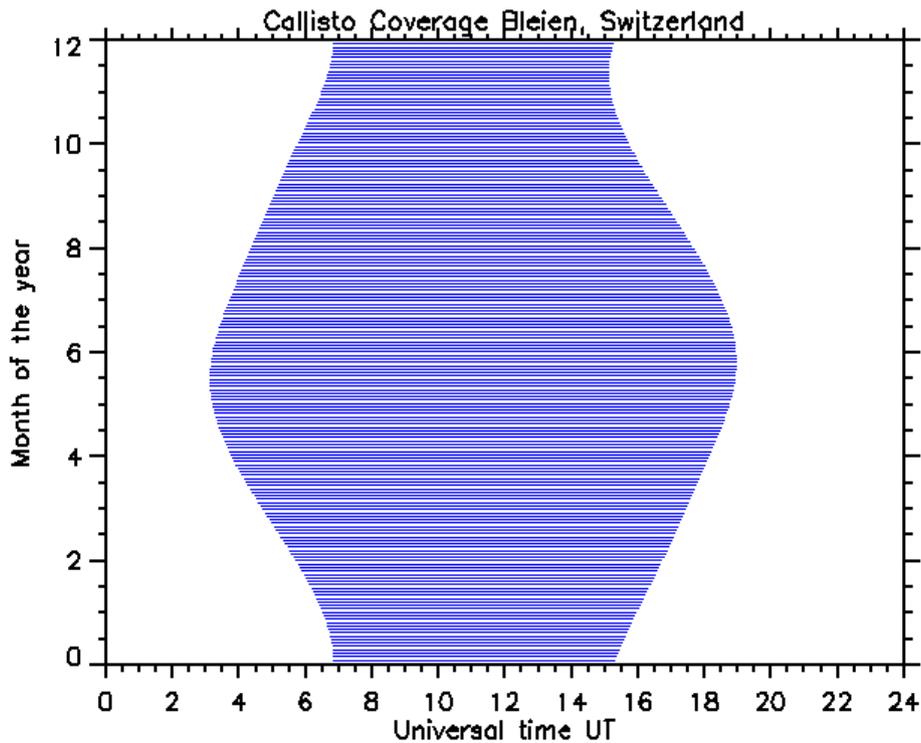**Figure 3.** The antenna in Bleien Switzerland (Credit to CALLISTO website).

Figure 4. The CALLISTO coverage for Bleien, Switzerland (Credit to CALLISTO website).

The aim of this system is to study the dynamics of the solar corona and to carry out the meter and decimeter wavelength radio observation to diagnosis the solar atmosphere progression [24]. The major characteristics of CALLISTO it is the lowest price for hardware and software, short assembly time, both two or more orders of magnitude below existing spectrometer [25].

The CALLISTO spectrometer covers the frequency channel in the range 45 MHz to 870 MHz. The promotions of collaborating with 22 countries all around the world contribute to the monitoring the Sun activities for 24 hours per day as each country receives the direct sunlight in different time every day. However, the number of e-CALLISTO stations is still growing as redundancy is desirable for maintaining full 24 hours coverage of the solar radio spectrum and the frequency coverage in various regions [26].

The data of 13th April 2015 in Figure 3 & 4 obtained from the Bleien, Switzerland used antenna othe 7m parabolic dishsh. The CALLISTO coverage per day in Bleien different in every month and the longest duration it receives the direct sunlight is in June. The system started when the antenna detects the frequency of the burst, then send it to the system to be interpreted. The processed data finally appeared on the screen of the computer.

The instrument automatically collects and send the data from all stations are gathered in a database. The data then can be achieved from the live website by browsing the link http://www.e-callisto.org/.

The CALLISTO software produces several output files and the most important are the data files which use the Flexible Image Transport System (FITS) file format. The FITS file typically produced at 15 minute intervals throughout the specified observation period [26].
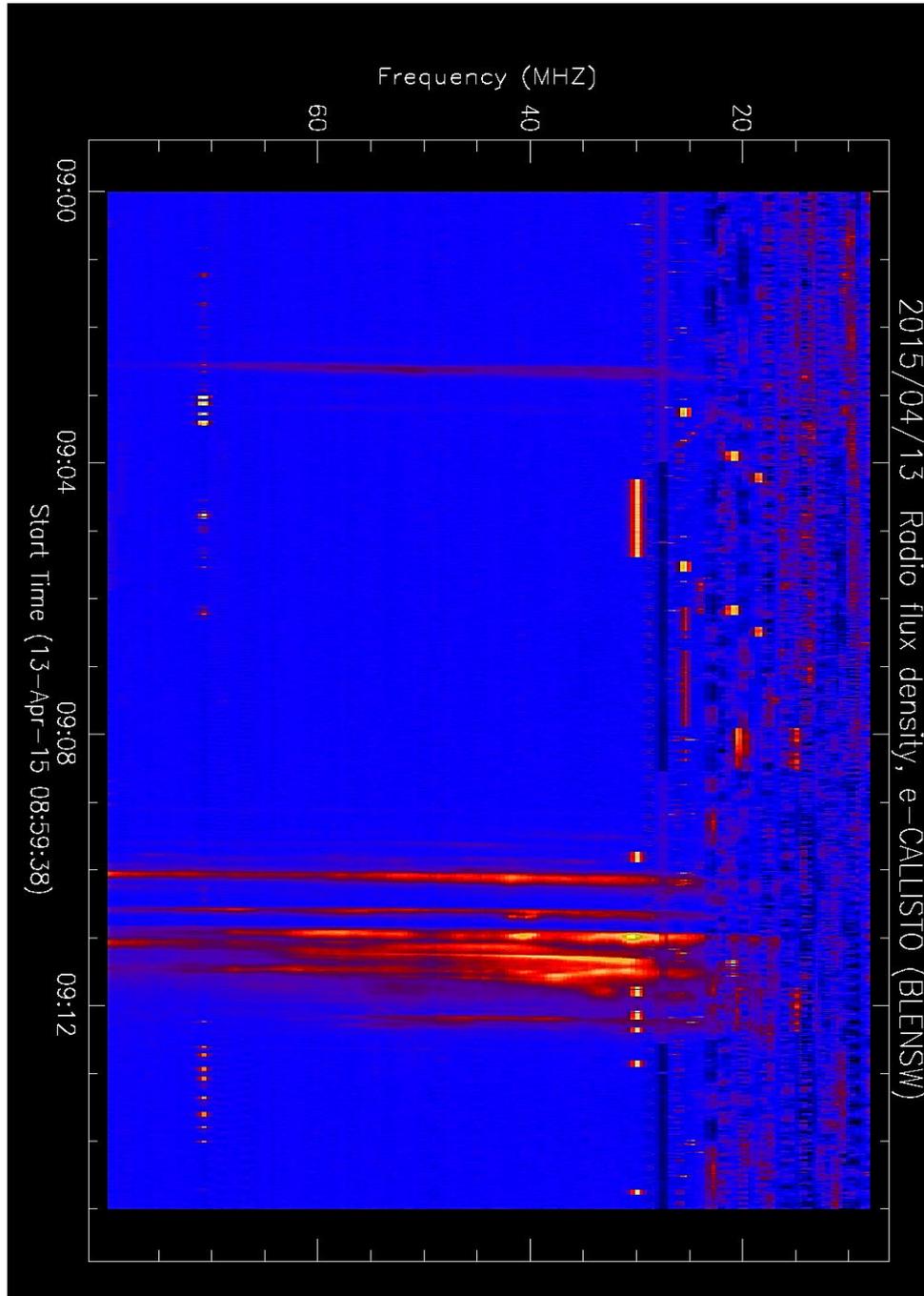
5. RESULTS

Figure 5. The single and complex solar radio burst type III (Credit to e CALLISTO website).

The data used in this section is complex solar radio burst type III recorded by e CALLISTO in Bleien, Switzerland on 13th April 2015. The frequency of plasma electron during the event is in the range of 5 MHz – 75 MHz at 9:10 UT until 9.13 UT. However, there is also single type III radio burst occurred between 9:02 UT until 9:03 UT with low intensity. The solar wind speed recorded in this complex event is 293.2 km/Sec while the density of protons is 5.8 protons/cm^3. The total magnetic field recorded during this event is 1.9nT.
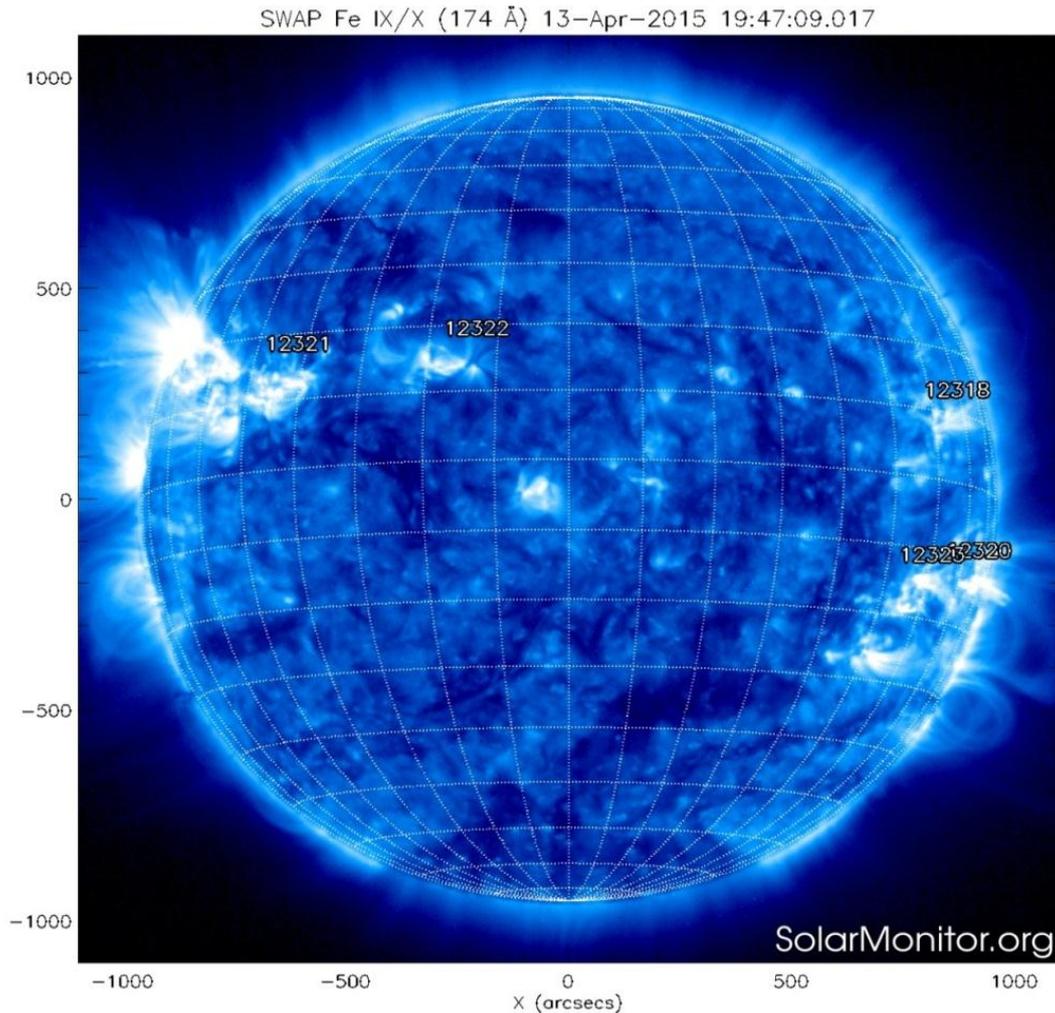

Figure 6. The number of sunspot recorded during this event (Credit to SolarMonitor).

There are five sunspots of active region detected during this event which are AR12318, AR12320, AR12321, AR12322 and AR12323. The all sunspot has contributed to the C-class solar flare except for the AR12318. The highest C-class recorded was C9.0 at 17:58 UT.

However, it is reported from Spaceweather websites that the AR12321 is the most active area which has 'beta-gamma-delta' magnetic field that harbors the energy that contributed to X-class flares. It is dangerous as this active region of the sunspot turning towards the Earth. The data recorded by NOAA/USAF were recorded in Table 1.

Table 1. The table of properties for each sunspot (Credit to SolarMonitor).

Group Number	Location	Hale Class	McIntosh Class	Sunspot Area	Number of Spot	Flares History
12320	S14W78 (908",-211")	β/βγ	Dao/Dai	0050/0090	06/12	C1.2(07:26) C1.9(10:06) C2.3(11:28) C1.4(13:14) /C2.2(16:31)
12321	N13E40 (-600", 286")	βγδ/βγ	Ekc/Eac	0610/0200	11/05	C2.1(02:39) /C2.9(08:11) C1.7(14:39) C9.0(17:58) C6.4(23:24)
12322	N14E12 (-193", 322")	β/β	Dro/Cro	0030/0020	03/02	C4.3(04:02) C1.6(06:35) C4.7(08:21) /C2.3(19:34)
12323	S16W62 (813", -219")	β/β	Dro/Bxo	0030/0010	04/04	/C1.3(15:11) C2.0(21:20) C2.9(22:16)
12318	N08W66 (866", 171")	/α	/Axx	/0010	/01	-

Table 2. The parameter calculated for single SRBT III and complex SRBT III.

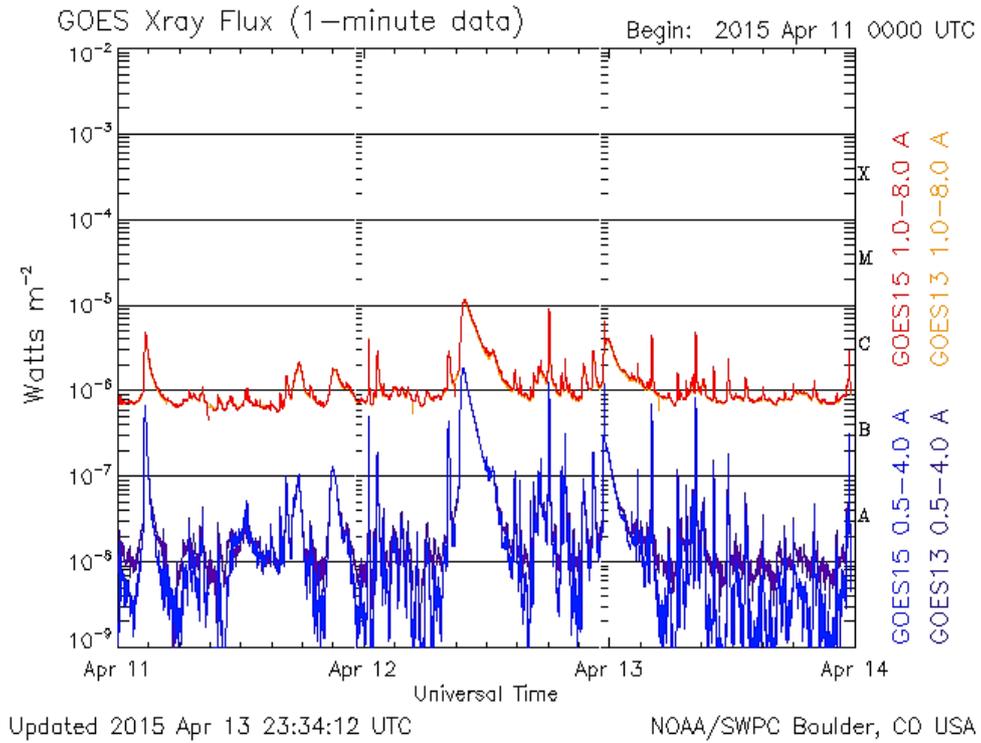| Parameter	Single SRBT III	Complex SRBT III
Electron Density (kg/m^3)	2.809×10^{15}	4.044×10^{13}
Drift Rate (MHz/s)	1.9	0.38
Photon energy (MeV)	$E_1 = 3.099 \times 10^{-13}$ $E_2 = 1.529 \times 10^{-13}$	$E_1 = 3.305 \times 10^{-13}$ $E_2 = 9.504 \times 10^{-14}$

Figure 7. The X-ray graph on 13th April 2015 (Credit to SolarMonitor).
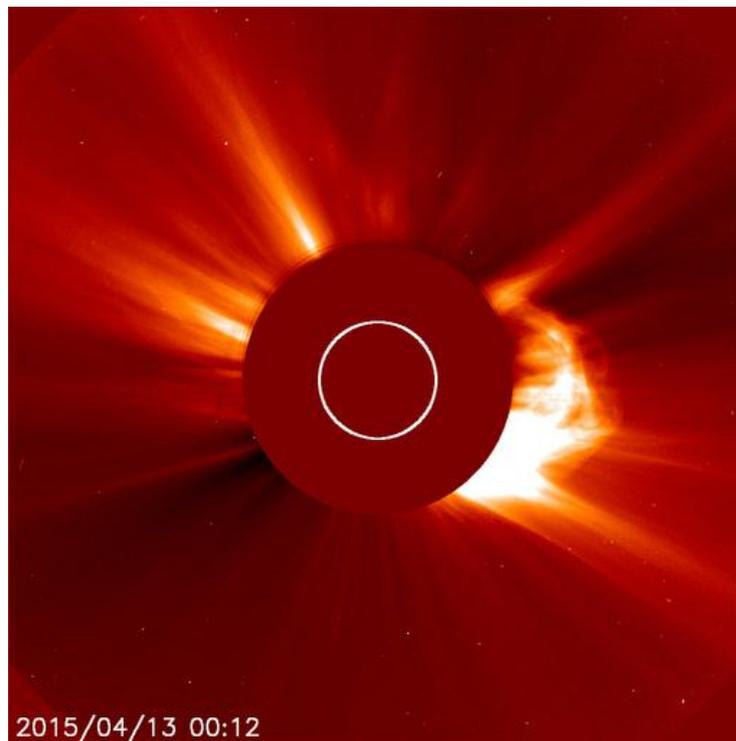

Figure 8. The CME recorded by SOHO (Credit to SOHO website).

On 13th April 2015, the C-class solar flares recorded in the table approved as it is showed the all of peaks are in the C-class. It is different from the Spaceweather website which reported that the M-class event also occurred during this event. The complex SRBT III recorded by spectrograph was occurring at 09:10 UT until 09:13 UT. The flares recorded nearer to this Universal Time (UT) were C2.9 and C1.9 at 08:11 UT and 10:06 UT respectively.

However, in a day before 13th April, which means about 12th April the X-ray classes of solar flares are quite high and reach to the M-class of solar flare. It has been recorded that the Coronal Mass Ejections occurred at 00:12 UT. The production of this CME is believed to generate the complex solar radio burst type III at 9:10 UT until 9.13 UT.

From these events, the parameter of electron density, drift rate, photon energy were calculated and tabulated in the Table 2 below.

6. DISCUSSIONS

This event is interested to discuss as the complex SRBT III occurred a few minutes after single SRBT III recorded. The time intervals for these two complex and single SRBT III is about 8 minutes 30 seconds. It is generally believed that the energy produced at the first single SRBT III may also contribute to the second SRBT III which is complex SRBT III. In some cases, the complex type III bursts start at much lower frequencies and definitely after the associated type II burst. But for this case, the complex radio burst type III comes after the production of single radio burst type III.

The SRBT III is used as the indicator of the magnetic reconnection process. The magnetic reconnection process is the process in which the magnetic field of the Sun breaks and rejoins into a lower-energy configuration which magnetic energy is converted to the plasma kinetic energy [27]. In this case, the stored energy in the magnetic field at the first event (single SRBT III) may contribute to the second event (complex SRBT III) 8 minutes 30 seconds later.

The drift rate calculated for single SRBT III is greater compared to drift rate of complex SRBT III. This may happen due to particle emitted during the single SRBT III is less compared to the complex SRBT III. So that, the plasma particle for single SRBT III can drift faster as the total mass of plasma particles during the single SRBT III is lighter.

It is noted that CMEs occurred several hours before this event recorded by the SOHO websites. The CMEs recorded is quite huge started to explode at 0:00 UT until 2:24 UT. After almost 7 hours later, the production of single SRBT III and complex SRBT III emerged at the spectrometer.

7. CONCLUSIONS

It can be concluded that, the energy during the production of single solar radio burst type III contribute to the production of complex solar radio burst type III at the ~9:08 UT until ~ 9:12 UT. It is proved that the production of coronal mass ejection contributed to the production of complex solar radio burst type III.

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