Application of Solar Radio Bursts Observation in Detecting Magnetic Reconnection Phenomenon

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Abstract. This study highlights the importance of solar activity observation in radio region which covers 45-870 MHz, which also provides clues on the appearance of magnetic reconnection. It was carried out by utilizing e-CALLISTO data from Glasgow station. On 9\textsuperscript{th} March 2019, intense solar radio bursts type III sparked off and were detected by Glasgow station in the UK at 12.29 UT, that lasted for 15 minutes. There were two bursts that were observed to appear separately by 1-minute interval. Accompanying the bursts formation was a B6.5 flare, the highest flare throughout the day and it was recorded by NOAA at 12.26 UT which was in the time frame of the bursts event. It is believed that the type III bursts were associated to the flare formation as radio emissions were emitted at the beginning of the flare during reconnection. From the analysis, results have shown that multiple magnetic reconnection process took place during the solar activity as indicated by a large group of bursts. However, no extended bursts formed for the rest of the day as well as lack of activity produced by the same region for the following days and that could be a hint of the decay phase of AR 2734. Detailed discussions on the bursts corresponding to the flare activity are discussed in this paper.

1. Introduction
Solar radio bursts are one of the techniques in monitoring solar activity in order to study on space weather. Furthermore, the variability of the energy emitted by the Sun is one of the main causes of climate change [1]. It was firstly carried out by J. S. Hey in 1944 following his discovery on radio waves emissions from the Sun [2]. Solar flares and coronal mass ejections (CMEs) are among solar activity which frequently happen on the Sun’s corona and extreme ones could activate solar storm which Earth would experience on. Solar flare is defined as an abrupt eruption of high energy radiation in which plasma are transported between corona and chromosphere by thermal conduction, non-thermal particle beams, radiation transport, and mass motions. Flares can take several hours to a few days to accumulate enough energy, but most flares need only some minutes to release their dynamism [3]. Intense flares may bring to disturbances to power grids, Global Positioning System (GPS) signal and increment of radiations in our atmosphere [4]. A fierce explosion of magnetic fields and mass particles from the Sun’s corona is called as CME. It is slightly different from flares where CMEs are also ejecting energetic plasma that will invade the Earth’s magnetosphere causing geomagnetic storm. When both of these events take place on the Sun, radio emissions are also produced and we detect them as solar radio bursts.
Solar radio bursts are enhanced by accelerated electrons translating to energies well above their thermal energy in the quiet corona [5]. They undergo a process which includes frequency space and varies with time [6]. Solar radio bursts are categorized into 5 different types and all of them are originated by either bremsstrahlung, gyrosynchroton or plasma radiations [7]. Type I bursts are classified as noise storm and they are not related to flares phenomena. Seemingly, they appear in narrow band events with a broader band continuum typically over frequency range of 100–400 MHz. Type II bursts look to be slow drift bursts [8] and act as the proxy in predicting earth-directed CMEs [9]. Next, type III bursts are the rapid drift bursts from high to low frequency and the most associated to solar flares. The emissions are produced as energetic particles escaping along the open magnetic field lines [10]. In monitoring active CMEs with speed of 1200 km/s and solar energetic particle events, type IV bursts can be as the indicator which are displayed in a broadband continuum. These bursts are caused by electrons trapped in closed field lines during flares events [11]. The last type of bursts, type V are the extended phase following type III bursts but at rather low frequencies. Type V emissions stay for a longer duration and defined as the decay phase of type III as the component appear to merge with type III component. As the Sun posses an unconstant complexity structure, there are still other bursts which are not classified under any types [12].

Magnetic reconnection is the essential process that pushes solar eruptive events to occur. The process undergoes energy release mechanism which takes place at certain distance up in the corona where plasma are effectively heated up and particles are accelerated [4]. Reconnection is primarily understood as the conversion of magnetic energy into kinetic energy as the consequence of the breaking and rejoining of magnetic field lines. The changing magnetic field converts magnetic potential energy into kinetic energy that can be detected by radio observation [13]. As kinetic energy becomes dominant, particles make their way out of the open magnetic field lines at the same time when electrons producing various radio bursts. Current sheet is a region where the energy is efficiently released from the changing in certain magnetic field components. For a long current sheet, magentic field lines break apart violently during reconnection process due to loss of the tearing stability [14]. The presence of magnetic reconnection can be detected from the results of solar radio bursts. Therefore, researchers have been utilizing metric radio observations data in learning the behaviour of magnetic reconnection associated to solar burst type III [15].

This paper is aimed to study the type of magnetic reconnection presence in solar radio bursts type III which occurred on 9th March 2019. Methods applied in acquiring data are discussed in the next section followed by results and discussion and finally conclusion.

2. Data acquisition
Solar radio bursts type III result was obtained from e-CALLISTO website. It is an open database which provides solar radio bursts data that are recorded by various stations across the globe. The database was fed by a device called CALLISTO whereby it processes the signals from the Sun collected by an antenna. The entire system was pioneered by Christian Monstein from Institute of Astrophysics, ETH Zurich, Switzerland [16]. The system was installed in 2002, and its network has covered many locations across the globe ever since, providing researchers and individuals with plenty of bursts data [17]. Currently, there are more than 159 instruments have been implemented at more than 98 locations worldwide. This large-scale project has set a goal to monitor solar activity every day throughout the year with the extensive installation of the device.

Other than e-CALLISTO, we also obtained data from NASA, NOAA SWPC and Solar Monitor as well as Space Weather as a reference.

3. Results and discussion
On 9th March 2019, Glasgow station has detected solar radio bursts type III which was emitted at 1229 UT and settled down 15 minutes later as shown in Figure 1. The bursts were formed as a storm component which are seemed to appear separately. The first bursts storm occurred at 1230 UT and ended at 1233 UT followed by a single burst at 1234 UT before another major storm coming in at 1235 UT. Their formation is kind of intermittent as the bursts cover a wide range of frequency from 40 until 80 MHz.
Figure 1. Solar radio bursts type III on 9\textsuperscript{th} March 2019. The bursts were detected by Glasgow station initiated at 1230 UT.

We believe that these bursts are associated to the peak of solar activity on that day with B6.5 flare by AR 2734. The flare erupted 12.15 UT and ceased at 1237 UT which was parallel to the duration of bursts formation. During the flare, radio flux has exceeded 72 sfu with proton density of 5.1 protons/cm\(^3\). Figure 2 shows the progression of soft X-ray flux for 3 consecutive days by GOES satellite. These bursts were predicted to appear as on previous day, C class flare was formed at the same region which indicates the possibility of another flare to set off on the next day accompanied by radio emissions. However, there was no activity recorded on the next day as the active region started to shift to its quiet mood and less active.

Figure 2. Soft X-ray flux recorded by GOES satellite on 7\textsuperscript{th}, 8\textsuperscript{th} and 9\textsuperscript{th} March 2019.

By referring to radio emissions formation, we can immediately identify the magnetic reconnection process that takes place at the beginning of any solar activity. Ideally, a single burst indicates first magnetic reconnection and if another line of emission appears, it implies second magnetic reconnection. Meanwhile, a large group of bursts shows the presence multiple reconnection process. As obtained in Figure 1, we can deduce that magnetic field lines at AR 2734 continuously snap off during multiple reconnection process which then the electrons emit radio emissions in a form of large bursts. Based on solar activity report, AR 2734 has changed its magnetic structure from $\beta$ on the previous day into $\alpha$ on March, 9th and remained that structure for the next 3 days before disappeared from the visible disk. It is believed that AR 2734 has come to its decay phase and its last activity was on March, 9th with the emission of type III bursts. Supposedly, active region with $\alpha$ magnetic classification is a stable structure which rarely produces solar activity. Since, AR 2734 was about to decay at this moment, it releases its last amount of free energy stored during the flare. Figure
3 shows the structure of AR 2734 covered by twisted magnetic field lines. The image was captured by one of SDO instruments; Atmospheric Imaging Assembly (AIA), in 193\text{	extdegree}.

Despite what has been captured, the condition of the active region was not shown during the flare. It was taken about 3 hours after the event and as observed, the magnetic loops formed at the region are seemed to be a little bit relax and less intense. During this time, no energy was released as the region was settling down.

4. Conclusion
In conclusion, solar radio bursts type III occurred on 9th March 2019 is due to B6.5 flare that formed on the same day. From the spectrograph, multiple magnetic reconnection process took place at the beginning of the flare which prompted the radio emissions by electrons. The event was hosted at AR 2734 which we believe was moving into its decay phase as the flare on this day was the last one and no extended bursts detected on the following days. The application of e-CALLISTO system is very useful and helpful in understanding the pattern of solar radio bursts with respective to the current behaviour of the Sun.

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