Frequency Drift Rate Investigation of Solar Radio Burst Type II Due to Coronal Mass Ejections Occurrence on 4th November 2015 Captured by CALLISTO at Sumedang-Indonesia

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Abstract. The formations type of solar radio bursts can be known base on the frequency range that is detected. The CALLISTO system works with a wide band of the frequency making it possible to detect several types of solar burst. Indonesia exactly at Sumedang, CALLISTO system detected the formation of solar radio bursts forms of type II for the first time on 5 November 2014. On the other side, CALLISTO spectrometer detects and traces the phenomenon of CME (Coronal Mass Ejections) which causes the solar radio burst type II occurrence. In this paper will be calculated frequency drift rate during the occurrence of solar radio bursts of type II phenomenon on 4th November 2015 at 03:30 UT. The results of these calculations will be discussed as a related study of drift rate during the phenomenon of burst type II radio bursts associated with CME. The obtained drift rate during the solar radio bursts events above 2.8 MHz / s with low drift rate so that the speed of the CME that occurred only about 790 km / s as shown from LASCO.

1. Introduction

In the field of radio astronomy, solar radio burst observation using low spectral range instrument and low spatial resolution can provide a crude spectrum of the light curve of whole flares and Coronal Mass Ejections (CMEs) which may consist of many sources with different characteristics. This is also to be one of the important role in monitoring the space weather. In related cases, solar radio burst type III plays a fundamental role in solar burst studies [1]. This is true not only in the determination of solar radio burst type II, but the types of other solar radio bursts can also specify an important role in space weather conditions. Like the same with solar radio burst type II in which the formation is influenced by the bursts of electron acceleration during coronal outward propagating shock front [2]. Solar radio burst type II were firstly identified [3] and is also observed as well as their classification as broadband [4]. The importance of the event is as an early indicator of the CME-driven shock. By taking the pattern of decreasing frequency of the signal, the motion of the shock can be observed. Shock generated by CME of type II radio bursts in the corona and in the interplanetary medium (IP), termed as metric and interplanetary type II bursts [5].

The CALLISTO spectrometer is a programmable heterodyne receiver built in the framework of IHY2007 and ISWI by former Radio and Plasma Physics Group at ETH Zurich, Switzerland [6]. The main applications are observation of solar radio bursts and RFI-monitoring for astronomical science, education and outreach. The instrument natively operates between 45 and 870 MHz using a modern, commercially available broadband cable-TV tuner CD1316 having a frequency resolution of 62.5 KHz. The data obtained from CALLISTO are FIT-files with up to 400 frequencies per sweep. The data are transferred via a RS-232 cable to a computer and saved locally. Time resolution is 0.25 sec at 200 channels per spectrum (800 pixels per second). The integration time is 1 msec and the radiometric bandwidth is about 300 KHz. The overall dynamic range is larger than 50 dB. For convenient data handling several IDL- and Python-routines were written.

Many CALLISTO instruments have already been deployed, including: 5 spectrometers in India (2 in Ooty, 1 in Gauribidanur, 1 in Pune, 1 in Ahmedabad), one in Badary near Irkutsk, Russian Federation, two in South Korea, three in Australia (Perth, Melbourne and Heathcote), two in Hawaii, two in Mexico, one in Costa Rica, two in Brazil, three in Mauritius, 5 in Ireland, one in Czech Republic, two in Mongolia, four in Germany, two in Alaska, two in Kazakhstan, one in Cairo, one in Nairobi, one in Sri Lanka, three in Trieste, one in Hurbanovo/Slovakia, two in Belgium, two in Finland, 8 in Switzerland, one in Sardinia, 4 in Spain, 5 in Malaysia, 3 in Indonesia, one in Scotland/UK one in Roztoky/Slovakia, one in Peru, one in Rwanda, one in Pakistan, 2 in Denmark, one in Japan, one in South Africa, two in Greenland, two in Austria and one in Uruguay (see figure 1). Through the IHY/UNBSSI and ISWI instrument deployment program, CALLISTO is able to continuously observe the solar radio spectrum for 24h per day through all the year. All CALLISTO spectrometers together form the e-CALLISTO network. CALLISTO in addition is dedicated to do radio-monitoring within its frequency range with 13'200 channels per spectrum. The frequency range can be expanded to any range by switching-in a heterodyne up- or a down-converter.

Instrument deployment including education and training of observers was financially supported by SNF, SSAA, NASA, Institute for Astronomy and North-South Center of ETH Zurich and a few private sponsors.

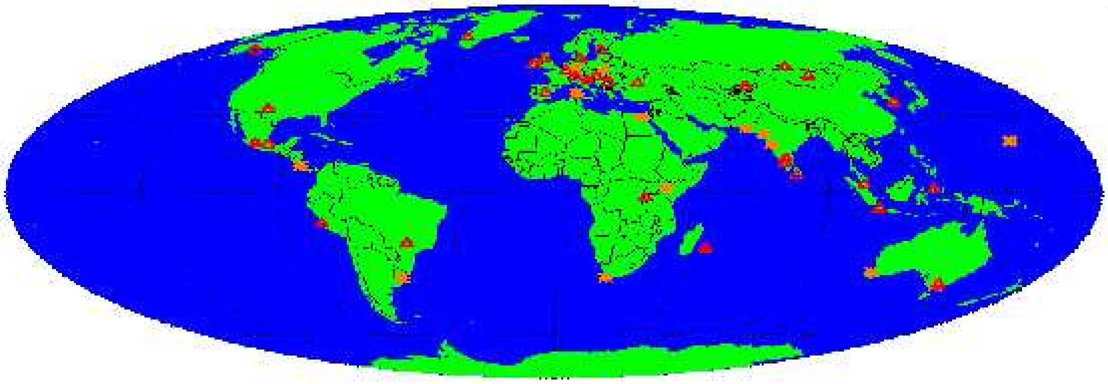


Figure 1. Map of current distribution of CALLISTO instruments in September 2016. Red triangles: locations provide data, orange star: locations do not provide data yet/anymore.

LAPAN (the National Institute of Aeronautics and Space) has some equipments to observe phenomena that occur on the sun, such as an optical telescope and radio spectrograph. Both of these instruments have been installed and operated in Sumedang observatory (6.91^{o}S, 107,84^o E) as one of the locations solar observations in Indonesia. Then around mid of July 2014, LAPAN also has installed a solar observation equipment system known as CALLISTO (Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory) spectrometer to monitor solar activity. This equipment uses a set of 21 elements of log-periodic antenna which capable to detect radio signals in the frequency range of 45 MHz -870 MHz. In the operation technically, particularly in the selection of frequency range to be received is based on the measurement of Radio Frequency Interference (RFI) around the site for optimum solar radio observations, so CALLISTO spectrometer then operated on two (2) separate frequency range of 45-80 MHz and 180-450 MHz. Detailed explanation of RFI measurement using CALLISTO installed in Sumedang [11].

Since 2014, LAPAN has been operated CALLISTO and develop three chain CALLISTO observation network covering 14 h daytime of observations time. The first location, CALLISTO was installed at Sumedang, West Java (6.91ºS, 107,84º E), the second CALLISTO was installed at eastern of Indonesia, Biak Island, Papua (6.9ºN, 107.84 ºE), and the newest CALLISTO had been installed at Tomohon, Manado, North Sulawesi (1.288394U, 124.913566E). The development of CALLISTO system with hardware configuration had been described briefly in [7], [8] and [10]. During the operation period the CALLISTO installed in Indonesia observed multiple Radio burst Type II. Indonesia exactly at Sumedang, CALLISTO system detected the formation of solar radio bursts forms of type II for the first time on 5 November 2014 at 09:43 UT [9] and for the second time on 4 November 2015 at 03:30 UT. On the other side, CALLISTO spectrometer detects and traces the phenomenon of CME (Coronal Mass Ejections) which causes the solar radio burst type II occurrence.

In this paper will be calculated frequency drift rate during the occurrence of solar radio bursts of type II phenomenon. The results of these calculations will be discussed as a related study of drift rate during the phenomenon of burst type II radio bursts associated with CME. The obtained drift rate during the solar radio bursts events above approximately 3.2 MHz / s with low drift rate so that the speed of the CME that occurred only about 376 km / s as shown from LASCO coronagraph.

2. Coronal Mass Ejection

A coronal mass ejection called as CME is unusually large phenomena that release a magnetic field and plasma from the solar corona. The event is being classified as Type II that causes of solar burst [12]. The CMEs generated a shocks wave as solar wind that can be inferred from type II radio bursts in the IP medium and in the corona which are termed as metric and interplanetary type II bursts, respectively [13]. The shock wave is an observable change in coronal structure that occurs on a time scale either in a few minutes or several hours and can be observed in coronagraph imagery. Its massive burst of shock wave and magnetic fields can rise through above the solar corona which possible to trigger main disturbances in the magnetosphere of the Earth [14]. Keeping consistent about the availability of free energy in the active region makes the speed of CMEs may not be higher than 3000 km/s [15]. The mechanism of the emission of plasma produce a huge plasma clouds of CMEs to leave the Sun within large scale density wave ejections converted into radio waves escaping out into the space toward and may enter the Earth and generate a geomagnetic storm after a few hours or days from the first shock or emission [16]. Basically, the changes of the electron density may vary the emission time duration [17]. Theoretically, solar activity level can be determined by solar radio burst type escape from the Sun [18]. Solar radio burst type II is rare comparative and has small of rate occurrence due to slow drift from high to low frequency in spectrum of radio electromagnetic. However, the frequency range of the emission can drift in the scale of hundreds of megahertz. Generally, the burst begins with fundamental and second harmonic simultaneously [19].

3. Solar Radio Burst Type II and Its Drift Rate

Figure 2a shows the event of solar radio burst type II detected by CALLISTO spectrometer at low frequency. The frequency drift rate of solar radio burst is a different of the frequency peak per unit time. It can be determined by taking both end and start time seen figure 2c and frequency of the solar radio burst type II seen in figure 2b. We use the 3rd order of curve fitting technique to fit the blue curve in figure 2c as the mean value of signal strength profile in every time scale. The estimation of both start and end time of solar radio burst even was derived by taken the absolute difference of each values. The frequency difference during the solar burst even can calculated by using the minimum and maximum frequency on the green line in figure 2b where the blue and the red curves shows the maximum value of signal strength profile in every frequency scale and its curve fitting based on the 3rd order polynomial fitting respectively. The drift rate of solar radio burst is expressed as equation (1):

$$\frac{d}{d} = \frac{f_a - f_b}{t_a - t_b}\left(\frac{M}{s}\right) \tag{1}$$

Equation (1) shows that the absolute value of rate is straight related to the frequency displacement where f_a is frequency of end time, f_b is frequency of start time, t_a is end time, t_b start time. Dynamic spectra of solar radio burst type II discovered as slowly drifting bands, often in pairs differing in frequency by a factor ≈ 2. They were quickly interpreted in terms of coronal shock wave accelerating electrons, driving Langmuir waves near the electron plasma frequency *fp* and 2 *fp.* This type II bursts was definitely incorporate with Coronal Mass Ejections (CMEs), travelling shock waves, reflected electron, Langmuir waves and radiation approaches *fp* and 2 *fp.* Inner corona of Sun presents an evolution of the CMEs. It undergoes a rapid acceleration in the beginning, after it starts from static as it erupts and reaches a maximum acceleration within the inner corona before being controlled by the aerodynamic drag. Langmuir waves starts from a disturbance (plasma) in the form of a longitudinal (electrostatic wave) that propagates in the plasma due to variations in the plasma's electron density. Specifically, Langmuir waves are collective oscillations of inhomogeneous bunches of electrons displaced from their natural equilibrium, in which the inertia of the relatively massive ions serves to establish an electrostatic restoring force that tries to bring the electrons back to their equilibrium positions.

4. Systems Configurations and Observations Methods

The whole CALLISTO system divided into two location indoor and outdoor devices as its function. The antenna and amplifier and filter devices as signal conditioner component placed in outdoor. The CALLISTO spectrometer and PC placed inside the control building. The geographic coordinate of the observation locate in Sumedang, Indonesia at (6.91°S, 107,84° E) that covered the range of frequency from 45-870 MHz [7, 9, 10].

On the other hand, due to constrain of the interference factors, the range of 45 MHz till 90 MHz had been chosen as selected data. The output of CALLISTO returns a standards FITS file format which describes a 2D diagram – frequency versus observation time, hence it is hard to determine the types of solar flare. Therefore, it needs to process the image to get a clear diagram that explain a specific radio signature of flare or CMEs.

Globally in the world, there are several CALLISTO spectrometer that has been successfully detected this kind burst between 03:30-03:36 UT on 4th November 2015 such as ALMATY Kazakhstan, GAURY India, KASI Korea, MRT1-3 Mexico, OOTY India and SSRT Siberia. Our CALLISTO in Sumedang also detected this burst at the same time. Using the data, we focus on the frequency range between 45 – 80 MHz seems this is the best range with a minimum of Radio Frequency Interference (RFI) [11]. According to the data, the burst is occurred within around four minutes.

5. Result and Discussion

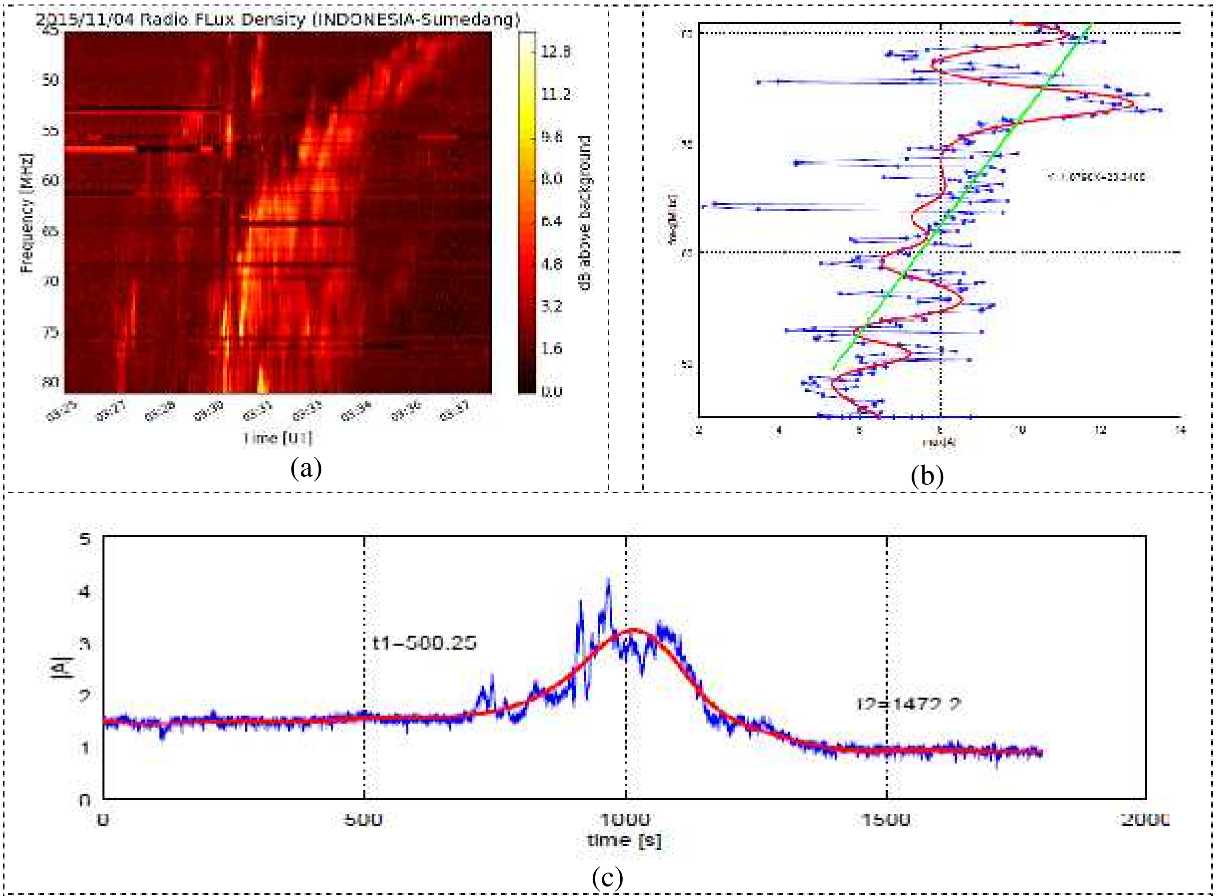
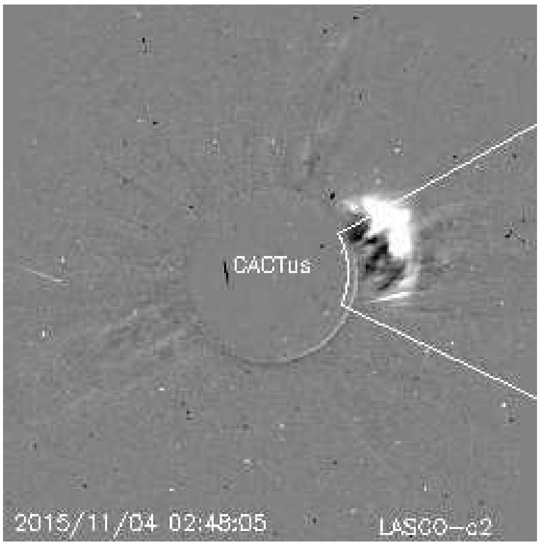


Figure 2. Solar radio burst type II detected in Sumedang, Indonesia on 4th November 2015 at 03:30 UT

Figure 3 shows the CMEs detected by Large Angle and Spectrometric Coronagraph (LASCO). The CMEs speed needs to exceed the characteristic speed before it can produce a shock, and the combination of CME acceleration and the rapid change in the fast mode speed produces possibilities for shock formation and decay. The drift rate frequency of type II bursts in the solar radio dynamic spectra are related to the speed of the shock that produces the bursts and the density gradient in the ambient medium. By using equation (1), drift rate calculated was 2.8 MHz/s.

The CME height is to be the same as the shock height and the type II burst height. This is strictly not true because the shock is expected to be located ahead of the CME and the type II burst is located at the shock front. The frequency drift rate of the burst is related to the shock's velocity. The slow drift rate determines the lifespan for the particular solar radio burst type II. With a slow drift rate of 2.8 MHz/s, it has only short lifespan. The exciter of the type II burst is a shock wave (independent of any shock which may or may not have been associated with the earlier transient mass motion itself) which is generated at the site of and simultaneous with the impulsive phase of flare. Fast and wide CMEs do not drive shocks or they drive weak shocks that do not produce detectable radio emission. The X-ray region observation has a lot of advantages in the sense of observing the solar activity. This short wavelength can provide a starting point of the eruption. Then, it can show the major percentage of energy of the explosions. The CMEs characteristics in x-ray regions can provide a finding at early stage of the phenomenon as it has a short wavelength in the electromagnetic spectrum.



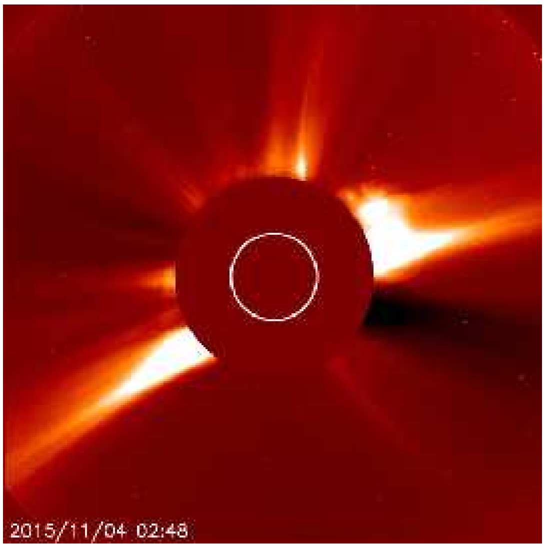


Figure 3. CMEs detected by Large Angle and Spectrometric Coronagraph (LASCO)

Figure 4 shows the details from National Oceanic and Atmospheric Administration (NOAA) were starts with Space Weather Message which issued an ALERT: activity increased to moderate levels (R1-Minor) on 04 November. At 04/0326 UTC, flare production with an associated Type II radio sweep. Wind parameters observed a rapid increase in winds speeds to an average of about 400 km/s with a peak of near 790 km/s early on 04 November. This event also produced an associated partial-halo coronal mass ejection (CME), first observed in LASCO C2.

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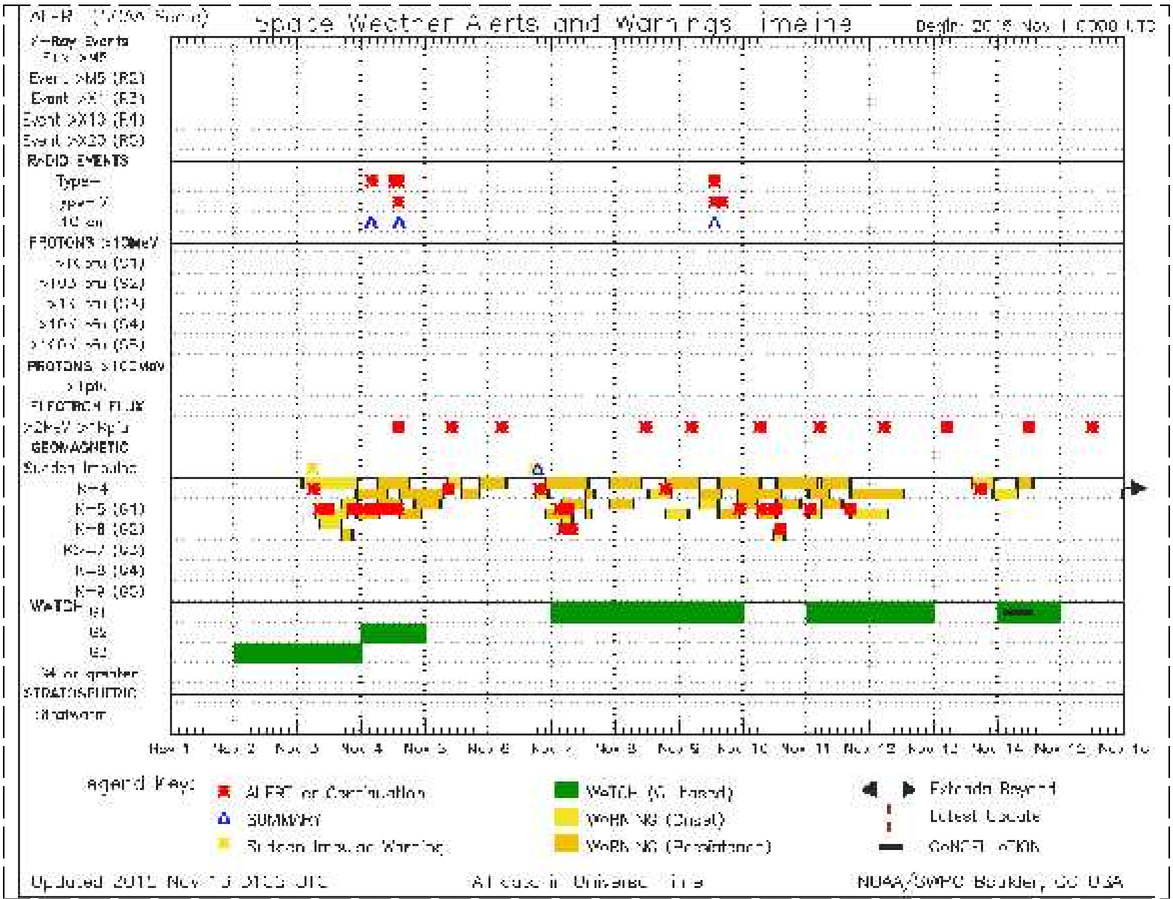

Figure 4. X-ray region of Space Weather Alerts and Warnings Timeline from National Oceanic and Atmospheric Administration (NOAA)

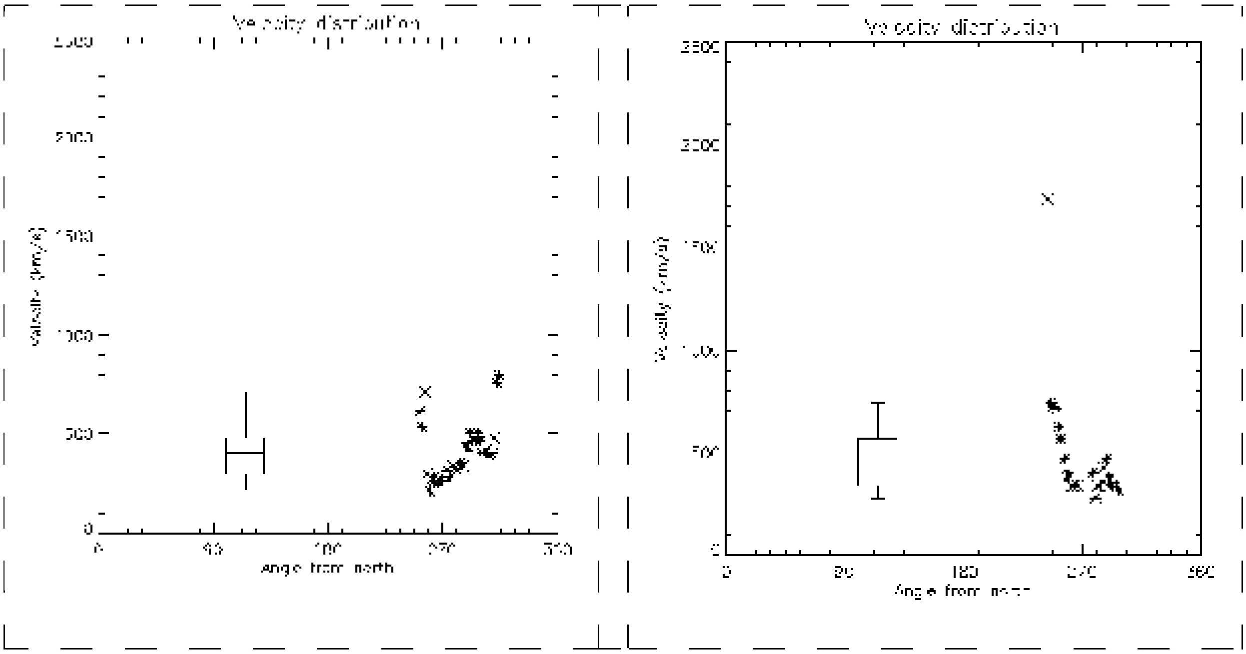

Figure-5: The velocity distribution of CMEs at the first stage (left) and at the during explosion (right) from LASCO or SECCHI.

Figure 5 shows the velocity distribution of Coronal Mass Ejections at the first stage and during the explosion. As can be seen in Figure 5 left side, there is clearly a beginning of the evolution of CMEs explosion. The structure of CMEs tends to be formed. The velocity also starting to increase from 300 km sec-1. It should be noted that this evolution occurred within a few minutes with a complex mechanism that not easy to be understood. This means that the tendencies of a huge explosion are very high and could be dangerous to the magnetic field of the Earth. This is a motivation for us to know more detail in understanding the mechanism of the explosion.

Here, we used the data from LASCO2 to obtain a clearer picture on the range of distribution of the velocity of the CMEs. During that event, CMEs velocity also reached from 350-1800 kmsec-1. It shows a high acceleration of the particles from the thermal radiation. This parameter provided an alert with Sun's activity. The potential of a big explosion of CMEs during that period is considered very high.

6. Conclusion

CALLISTO spectrometer installed in Sumedang, Indonesia had detected the solar radio burst type II due to CMEs on 4th November 2015 which has low drift rate during the moment was around 2.8 MHz/s and the CMEs velocity was just about 790 Km/s according to the NOAA space weather alert.

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