Available online at www.worldscientificnews.com

World Scientific News

WSN 35 (2016) 30-43 EISSN 2392-2192

The Formation of Fundamental Structure of Solar Radio Burst Type II Due X6.9 Class Solar Flare

N. H. Zainol[1,*], Z. S. Hamidi[1], N. N. M. Shariff[2], Marhana Omar Ali[1], Nurulhazwani Husien[1], S. N. U. Sabri[1], C. Monstein[3]

[1]School of Physics and Material Sciences, Faculty of Sciences, MARA University of Technology, 40450, Shah Alam, Selangor, Malaysia

[2]Academy of Contemporary Islamic Studies (ACIS), MARA University of Technology, 40450, Shah Alam, Selangor, Malaysia

[3]Institute of Astronomy, Wolfgang-Pauli-Strasse 27, Building HIT, Floor J, CH-8093 Zurich, Switzerland

*E-mail address: hidayahnur153@yahoo.com

ABSTRACT

A vigorous solar flare event marked on the spectrometer of the CALLISTO data, being one of the highest solar flare event that successfully detected. The formation of solar burst type II in meter region and their associated with X6. 9-class solar flares have been reported. The burst has been observed at the Blein Obsevatory, Switzerland, which detected by the Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) system in the range of 170-870 MHz in the two polarizations of left and right circular polarization. It occurred between 08:01 UT to 08:08 UT within 7 minutes. The Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory CALLISTO spectrometer is a solar dedicated spectrometer system that has been installed all over the world to monitor the Sun activity in 24 hours. The growth of this burst is often accompanied by abundance enhancement of particles which may take the form of multiple independent drifting bands or other forms of fine structure. Due to the results, the drift rate of this burst is 85.71 MHz s^{-1}, which is considered as a fast drift rate. The burst detected using CALLISTO also being compared to results detected by X-ray GOES data. Both different electromagnetic spectrum shows the exact time. The observations of the burst being discussed in details.

***Keywords*:** Sun; solar burst; type II; radio region; X-ray region; solar flare; Coronal Mass Ejections (CMEs)

1. INTRODUCTION

The Sun is the star at the center of our solar system and is responsible for the Earth's climate and weather. The average radius of the Sun is 695,508 km. At the Sun's core, energy is generated by nuclear fusion, as Hydrogen converts to Helium [1]. However, the corona is the most active region and beyond has a temperature millions of degrees which is still considered as mysteries properties [2,3]. Usually the solar radio bursts occur at the surface of the corona. There are five types of solar radio burst. All these solar radio bursts occur due to solar activity such as solar flare and Coronal Mass Ejections [4].

The Coronal Mass Ejections or called as CMEs is one of the event that causes of solar burst type II. It is an observable change in coronal structure that occurs on a time scale either in a few minutes or several hours. It can be recognized as a massive burst of solar wind and magnetic fields rising above the solar corona that can trigger huge disturbances in Earth's magnetosphere. Interplanetary (IP) shocks driven by coronal mass ejections (CMEs) are indicative of powerful eruptions on the Sun that accelerate particles to very high energies [5]. During CMEs, magnetic arcades overlaying magnetic neutral lines are hurled into the corona and the interplanetary medium, which in turn drive shocks by virtue of their speeds exceeding the local characteristic wave speeds [6]. CMEs affected by a huge plasma cloud produced by the plasma emission mechanism to leave the Sun which means it ejects large scale density waves turned into escaping radio waves out into space and after a few hours or days, it may enters the Earth and establish geomagnetic storm. Basically, solar radio burst was used to determine solar activity and level or radiation that received from the Sun. Type II is a slow drift from high to low frequency in dynamic radio spectra burst where it is more comparative rare and the rate of occurrence also small. The occurrence of this event is rare. However, the frequency emission may drift over hundreds of megacycles per second. Such radio emission is characterized by a narrow band of intense radiation that drifts toward lower frequencies with time [7]. Normally, the burst begins suddenly with fundamental and second harmonic beginning almost simultaneously. For us to know, the frequency drift rate of solar burst is a power law in the frequency of emission. Drift rate (*df/dt)* is a displacement of the peak in frequency per unit time. The absolute value of rate decreases with decreasing in frequency. It is determined by taking the start time to end time and start frequency to the end frequency of the solar burst Type II. The drift rate of the solar radio burst type II was defined as:

$$\text{Drift rate, } -(df/dt) = (f_e - f_s)/(t_e - t_s) \quad \text{[Unit: MHz/s]} \qquad (1)$$

where f_e is frequency of end time, f_s is frequency of start time, t_e is end time, t_s start time.

This power law was also valid when observations from different spectral domains [metric (m), decameter-hectometric (DH), and kilometric (km) wavelengths] are combined for the same events or for different events. Similarly, the power law was maintained when observations from different instruments and different epochs are combined. This universal nature of the power law suggests that the same shock should be involved in producing radio bursts at various spectral domains. Characteristically, type II bursts are basically due to electrons accelerated in shocks [8]. It can be seen that the small drift that originates in front of the CME is driven shock. The frequency drift from high to low frequencies (usually ~ 0.5 MHz s^{-1}) results from the decrease of electron density (N_e) with radial distance in the solar atmosphere. There are five sub-types of solar burst type II present such as narrow bandwidth, harmonic structure, band splitting, multiple bands, compound Type III-Type II Burst, Herring-bone structure and other fine structures. The burst is originated on the evolution of sunspot number and sunspot area. In this case of study, we focus on harmonic structure. In fact, the bursts represent radiation from oscillations induced in the coronal plasma by the outward passage of a disturbance [9]. They were quickly interpreted in terms of coronal shock wave accelerating electrons, driving Langmuir waves near the electron plasma frequency f_p and 2 f_p. This type II burst was definitely incorporated with Coronal Mass Ejections (CMEs), travelling shock waves, reflected electron, Langmuir waves and radiation approaches *fp* and 2 *fp*. Inner corona of the 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 start 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.

The solar radio burst Type II occur at around the time of the soft X-ray peak in a solar flare and are identified by a slow drift to lower frequencies with the time a dynamic spectrum, the frequent presence of fundamental and splitting of each of these bands into traces [10,11]. The emission of the type II radio burst is assumed to be a plasma emission at the plasma frequency and harmonics [12].

The observed frequency drift rate can be converted into a velocity if the dependence of electron density n_e on height is known, and it is found that a typical speed is of order 1000 kms^{-1} [13,14]. It is said to be bigger than the Alfven speed in the corona[15]. For this reason, Type II is agreed to be evidence for shocks in the corona, rendered visible by the radiation of the electrons that they accelerate [16]. Since the local plasma frequency decreases with radial distance away from the Sun, the plasma frequency in the radio-emitting region of the shock decreases with time. So, the emission of the shock drifts to lower frequencies with time at the local plasma frequency. Thus, if the density variation in the source path was known, the frequency drift rate of type II solar radio burst can be converted into the speed of the radio source.

2. METHODOLOGY

CALLISTO spectrometer is a programmable receiver built to observe or detect solar radio burst that occur at each particular time and location. The main applications of CALLISTO program are observation of solar radio bursts and Radio Frequency Interference (RFI) -monitoring for astronomical science, education and others. The instrument operates between 45 to 870 MHz using a modern, commercially available broadband cable-TV tuner having a frequency resolution of 62.5 KHz. Based on the data, Type II burst occurred within ten minutes. The data are transferred via a cable to a computer and saved locally. The time resolution is 0.25 Sec at 200 channels per spectrum (800 pixels per second). The overall dynamic range is larger than 50 dB. Many CALLISTO instruments have already been deployed in India, Switzerland, United Kingdom, Russia, South Africa, Australia, Malaysia, Indonesia and many more. Callisto in addition is constructed to do radio-monitoring within its frequency range.

The solar radio emission as observed from ground-based telescopes at the meter and decimeter wavelengths poses still has many challenges and potential treasures after many decades of study. When examining the result or data using the Callisto spectrometer device, there are two types of Type II burst pattern which is (i) harmonic structure and (ii) herring-bone structure (doubling both fundamental bands results in thick band). The appearance of Herring-born structure leads in which slow drifting band of Type II burst appears to be a source from which rapidly drifting elements diverge towards lower and higher frequency.

The instrumental parameters used in CALLISTO were stated in the Table 1 below.

Table 1. The table of parameter of the CALLISTO system.

Parameter	**Specification**
Frequency range	45.0 MHz to 870 MHz
Frequency resolution	62.5 KHz
Radiometric bandwidth	300 KHz/-3Db
Dynamic range	-120 dBm to -20 dBm (depending on gain voltage)
Sensitivity	25 Mv/Db +/-1 Mv/dB
Noise figure	<10 dBm
Sampling frequency	Internal clock 800 s/sec max, external clock 1000 s/sec max
Number of channels	1 to 500, nominal 200 frequency per sweep
Supply	12V +/- 2V / 225Ma
Weight	~800 grams
Dimensions	110 mm x 80 mm x 205 mm
Material cost	<200$ (material only)
Input	3 configuration files (config, frequency, scheduler)
Output	2 files (FITS-file and logfile)

3. RESULTS

We now discuss on how the observational results presented below can be used to understand the drift rate spectrum of the type II bursts over the entire range of frequencies where type II radio bursts occur.

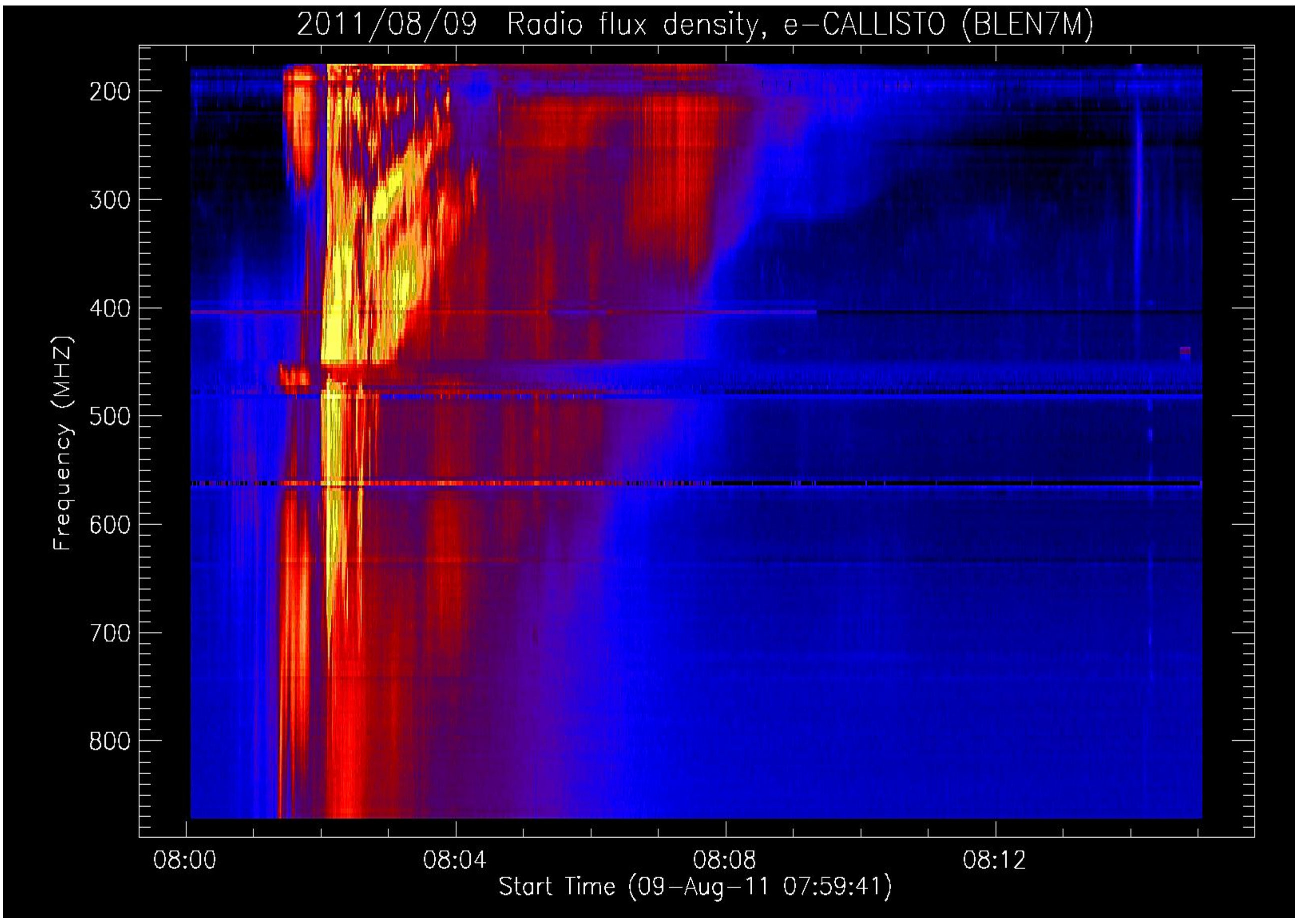

Figure 1. Details of e-CALLISTO spectrometry of selected events.

Based on e-CALLISTO spectrometry in Figure 1, structure of the Type II radio burst is presented. This event occurred on 9th August 2011 with a starting frequency was at 800 MHz on a time of 08:01 [UT] to end frequency of 200 MHz of 08:08 [UT]. The event is very clearly recorded by the e-CALLISTO using Bleien 7 meter dish radio telescope. The solar wind recorded during this event is 551.5 km/Sec and the density of proton recorded is 0.1 protons/cm^3.

Those data were updated for every 10 minutes by the Space Weather website. They are obtained from real-time information transmitted to Earth from Advanced Composition Explorer (ACE) spacecraft located between Earth and Sun enables it to give a one hour advance warning of impending geomagnetic activity and reported by NOAA Space Environment Center.

The graph above plots the type of solar flares for three days starting on 7th August 2011 until 9th August 2011. Among these three days, solar flare reaches to the highest peak on 9th August 2011 with X6.9 class followed by M2.5 class detected using GOES15 satellite with 1.0Å to 8.0Å.

The X6.9 flare is a very large flare as it has power per unit area is between 10^{-4} Watt/m^2 to 10^{-3} Watt/m^2 compared to M2.5 flare which has medium-sized flare with power per unit area of 10^{-5} Watt/sec to 10^{-4} Watt/sec. The magnetic field of the flare was 4.6 nT.

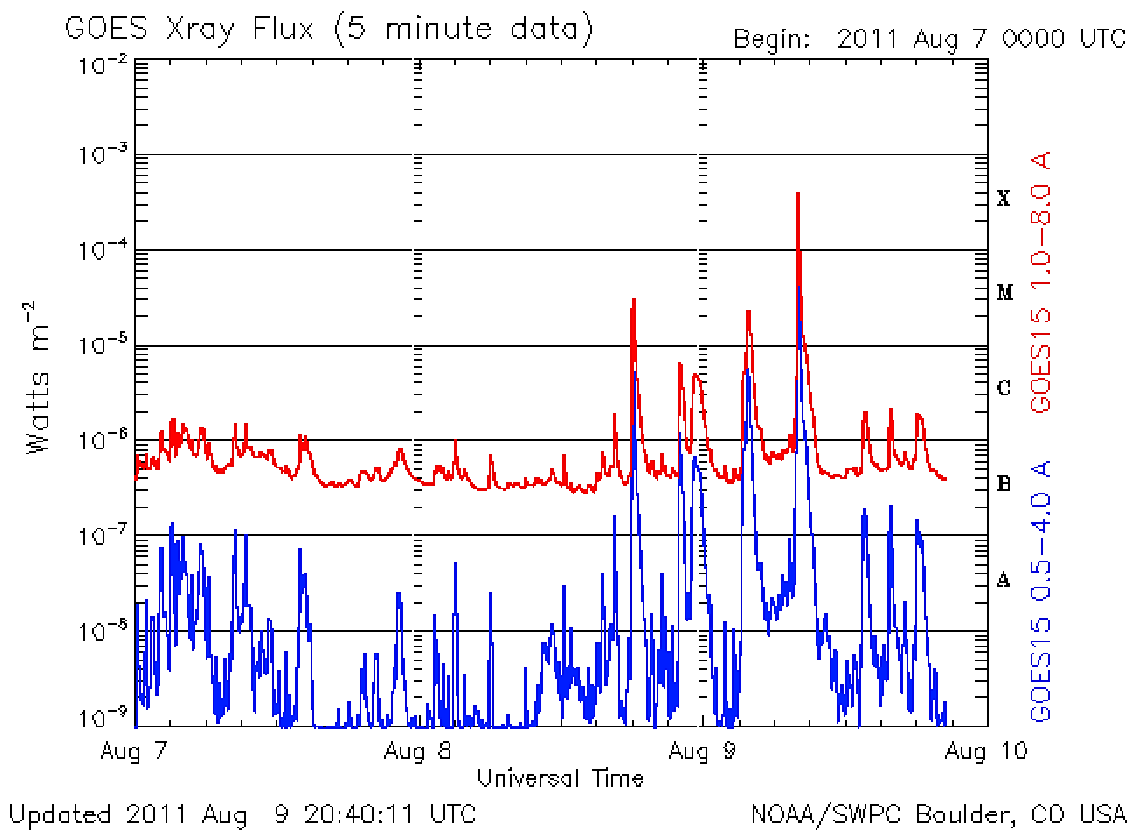

Figure 2. The graph shows a series of solar flares detected by NOAA satellite (Credited to SolarMonitor).

There are four active regions (AR) present during this event which are AR11263, AR11266, AR11267 and AR 11268. However, the active region AR11263 is more active compared to other active regions. This active region produces the two outstanding large flares X-class and M-class. The X-class flares are large size of flare and they are major events that can trigger planet-wide radio blackouts and long-lasting radiation storms. **M-class flares** are medium-sized; they can cause brief radio blackouts that affect Earth's polar regions. Minor radiation storms sometimes follow an M-class flare.

Jan Karlovsky in Hlohovec, Slovakia detected a sudden ionospheric disturbance which was made by strong X6.9 class solar flare by their VLF receiver tuned on DHO38 (23.4kHz) and GQD (22.1kHz). (Source from spaceweather.com)

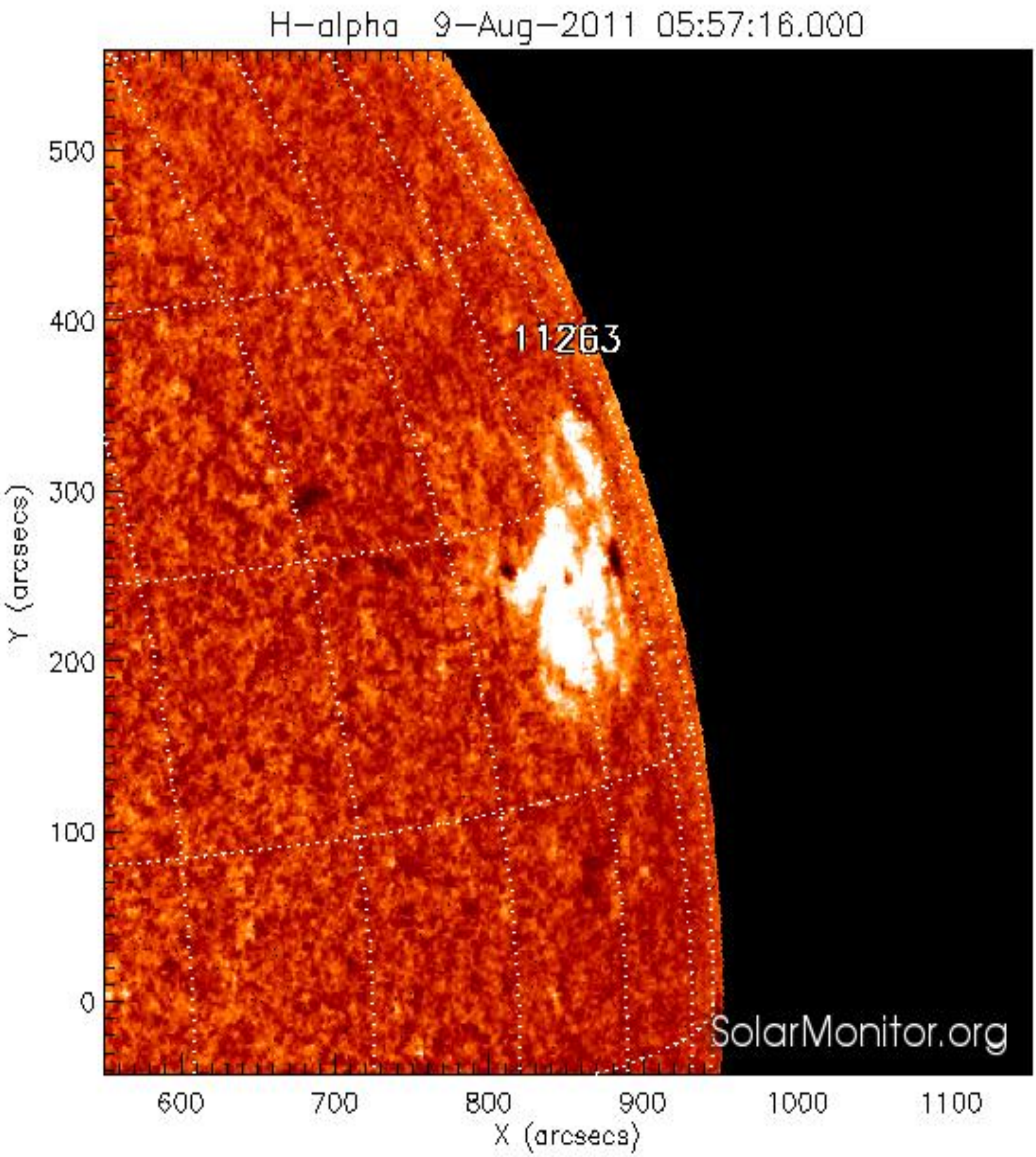

Figure 3. Sunspots of active regions present on 9th August 2011 (credited to SolarMonitor.org)

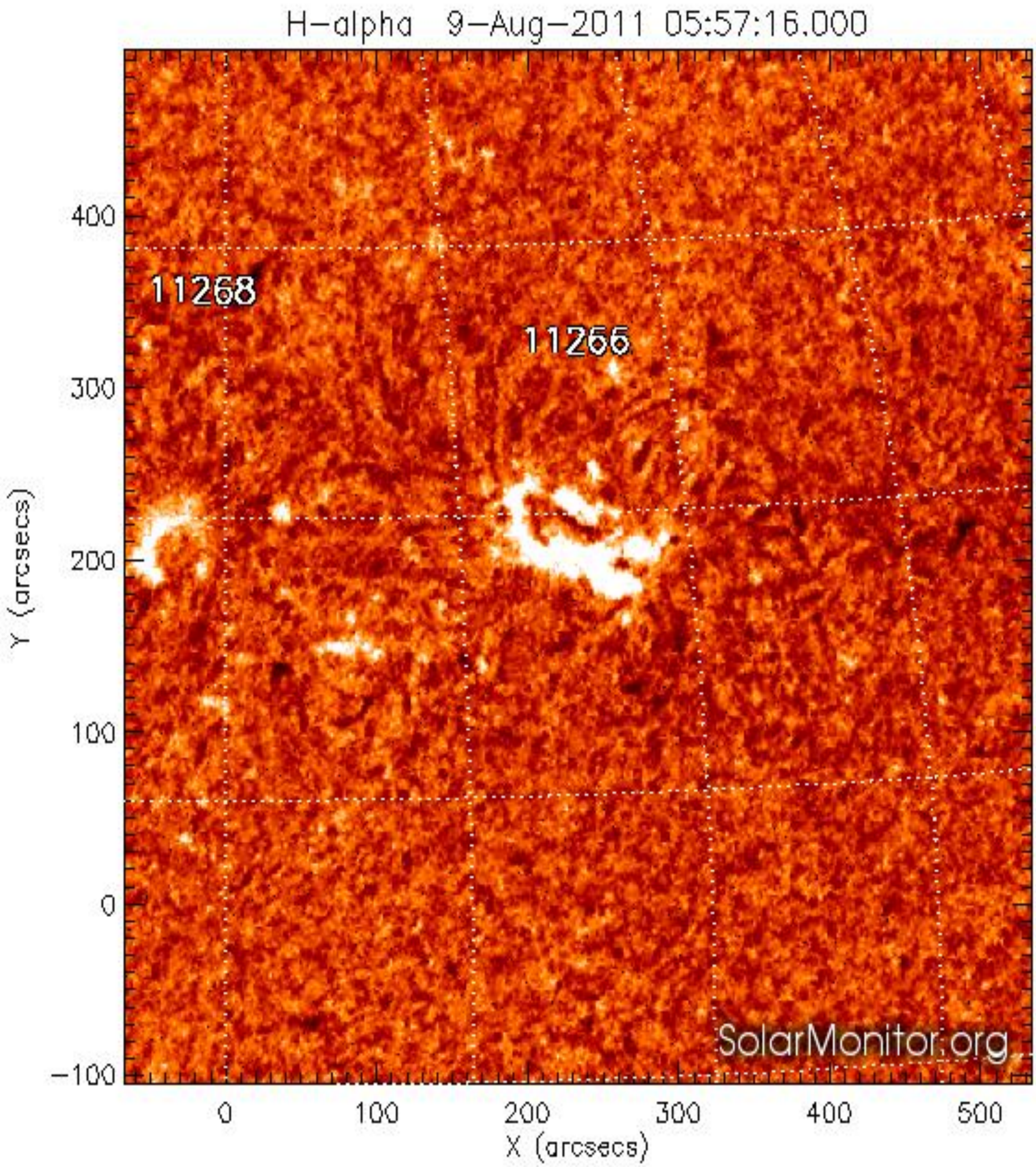

Figure 3(continue). Sunspots of active regions present on 9th August 2011 (credited to SolarMonitor.org)

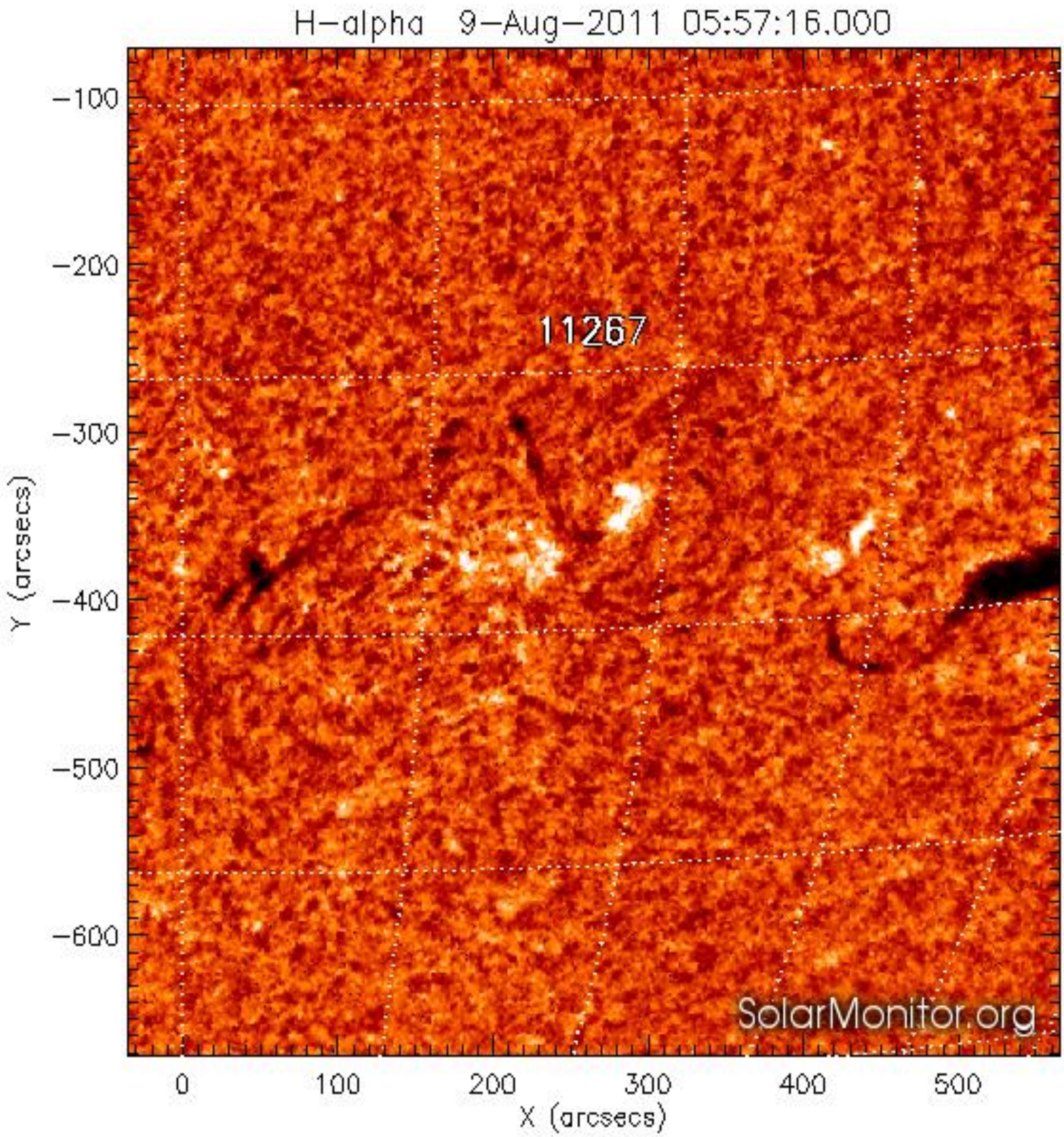

Figure 3(continue). Sunspots of active regions present on 9th August 2011
(credited to SolarMonitor.org)

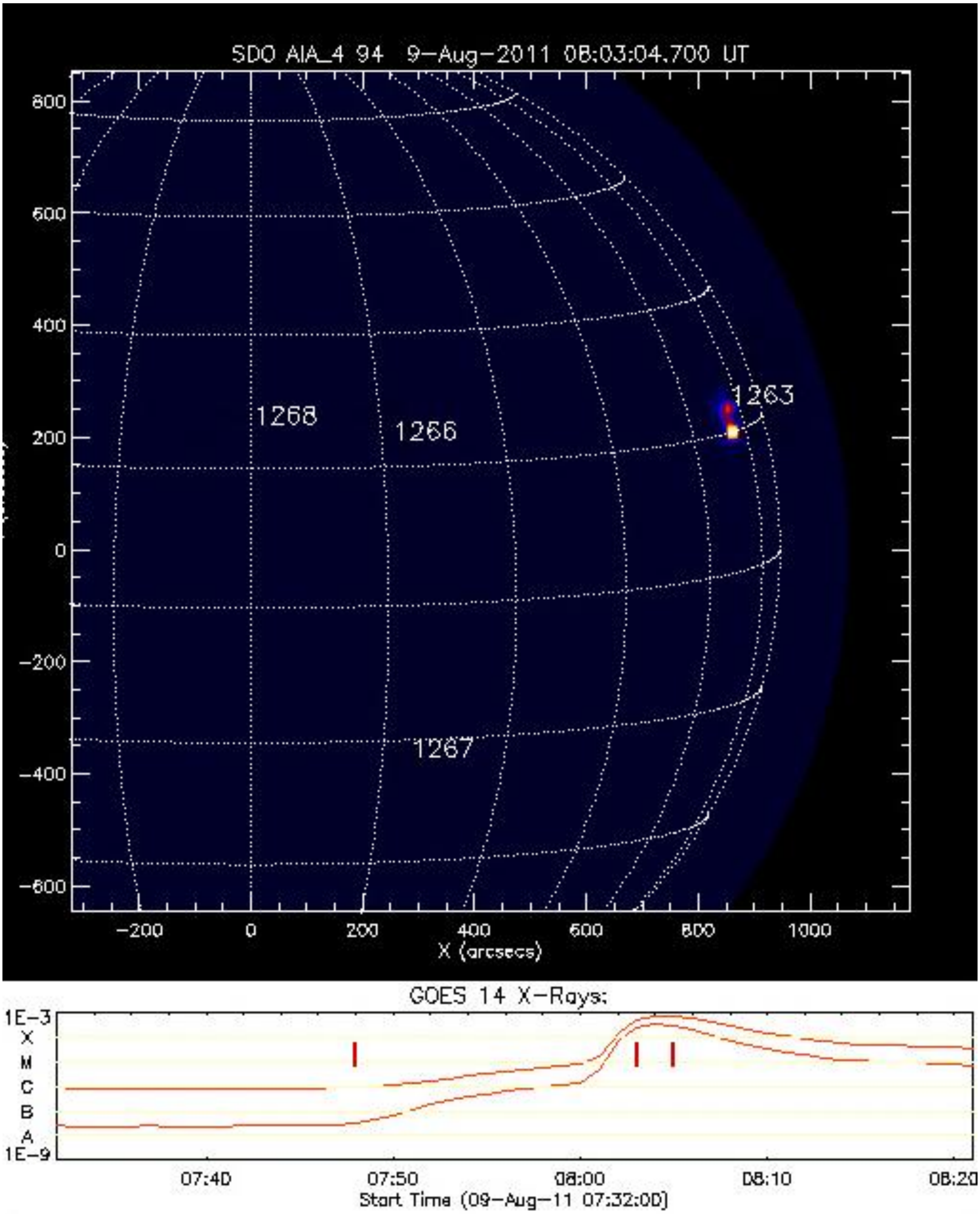

Figure 4. Sunspot of active region 11263 with present of X6.9 class X-ray solar flare (left) and M2.5 class X-ray solar flare (right)

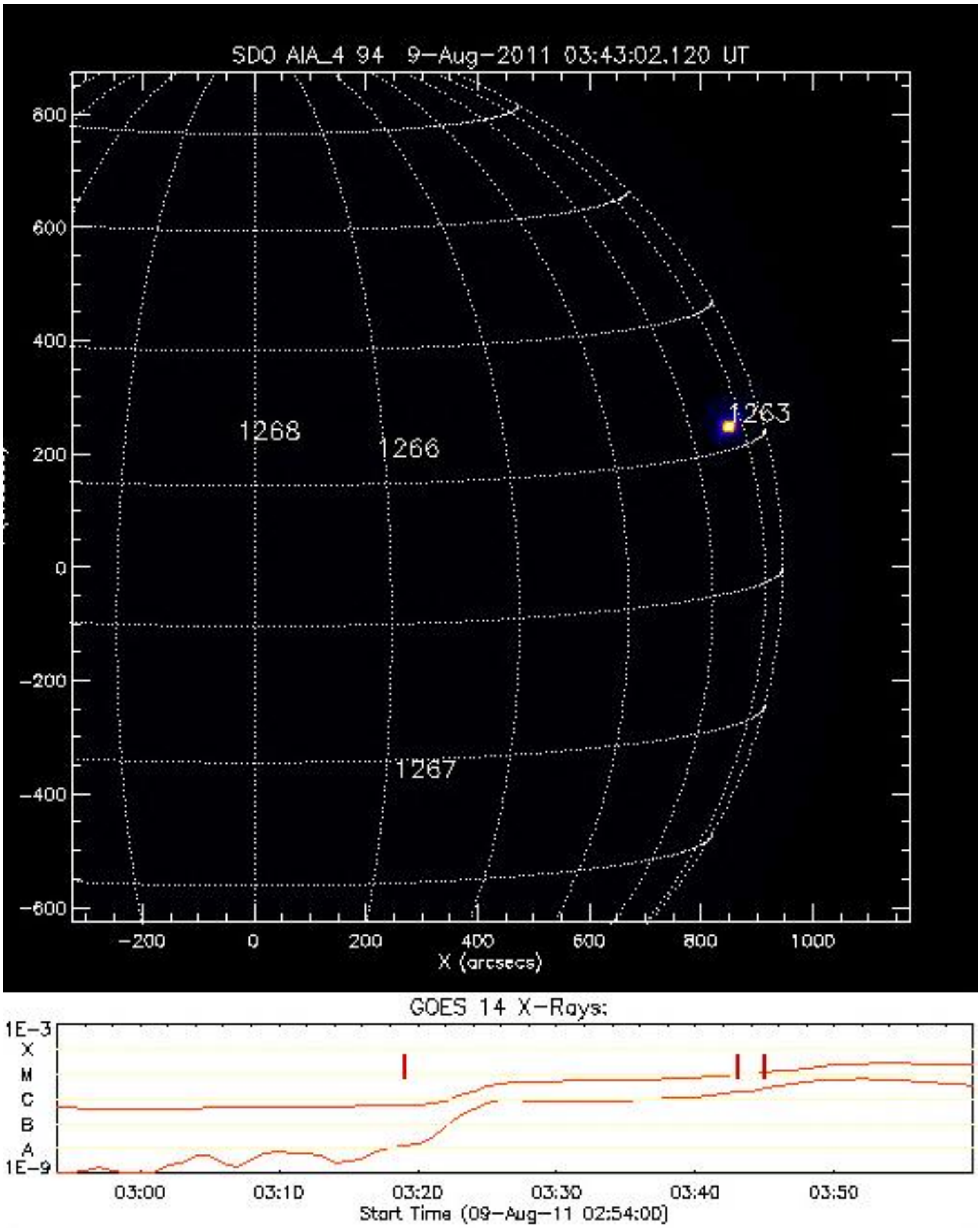

Figure 4(continue). Sunspot of active region 11263 with present of X6.9 class X-ray solar flare (left) and M2.5 class X-ray solar flare (right)

The most active region was AR11263 produced one X class flares, two M class flares and 8 C class flares. The probabilities for all these three classes were 13% of X class, 41% of M class and 54% of the C class.

There are two outstanding solar flares where first one was the major solar flare happened X6.9 class started at 07:48 [UT] until 08:08 [UT] with peak at 08:05 [UT]. It is the third X-flare of new Solar Cycle 24 and the most powerful so far. Secondly was M2.5 class solar flare began at 03:19 [UT] ends at 03:54 [UT] where peak at 03:45 [UT]. There are two outstanding solar flares where first one was the major solar flare happened X6.9 class started at 07:48 [UT] until 08:08 [UT] with peak at 08:05 [UT]. It is the third X-flare of new Solar Cycle 24 and the most powerful so far. Secondly was M2.5 class solar flare began at 03:19 [UT] ends at 03:54 [UT] where peak at 03:45 [UT]. In addition, the activity level was high which has one X class flare, to M class flare and 10 C class flare in the previous two days.

The impact of the explosion was not directed to the Earth. However, a minor proton storm is in progress around our planet which could affect satellite in high-altitude orbits.

The most active region was AR11263 produced one X class flares, two M class flares and 8 C class flares. The probabilities for all these three classes were 13% of X class, 41% of M class and 54% of the C class. There are two outstanding solar flares where first one was the major solar flare happened X6.9 class started at 07:48 [UT] until 08:08 [UT] with peak at 08:05 [UT]. It is the third X-flare of new Solar Cycle 24 and the most powerful so far. Secondly was M2.5 class solar flare began at 03:19 [UT] ends at 03:54 [UT] where peak at 03:45 [UT]. In addition, the activity level was high which has one X class flare, to M class flare and 10 C class flare in the previous two days. The impact of the explosion was not directed to the Earth. However, a minor proton storm is in progress around our planet which could affect satellite in high-altitude orbits.

4. DISCUSSION

Solar radio bursts of type II are characterized by a narrow band of intense radiation that drifts toward lower frequencies with time. It has been observed with maximum emission near the frequency 550 MHz. The burst is often accompanied by numerous form of independent drifting bands. The main band of the burst produce from the Zeeman Effect where it split a spectral line into several components in the presence of a static magnetic field. The peak flux exceeds up to 102 sfu. This splitting is associated with the increasing phase of the flare. We have compared the data with solar flare from Geostationary Operational Environmental Satellites (GOES15) data. From the analysis, this burst is ejected and appears at the same point of the X-6.9 class solar flare event.

The broad features of solar radio waves are illustrated in Figure 1 in terms of frequency versus time in the spectrogram. Based on the analysis, the duration of the formation of the burst is long lasting until 7 minutes, which quite long for burst to burst out. Then, the drift rate of 85.71 MHz/s was quite high, thus produced a very strong and complex characteristics of type II, solar radio bursts which result from the excitation of plasma waves in the ambient medium by a shock wave propagating outward from the Sun. Fast drift makes type II burst cannot form the harmonic structure. The simplest is sharp-featured and continue their curved sweep towards increasing frequencies as far as the lower frequencies observable, their duration decreasing with decreasing frequency.

5. CONCLUSIONS

This burst is a one of the examples where the type II burst is not always associated with CMEs event. It is related to solar flare phenomena. The combination of radio and x-ray region give a complete view of the solar flare eruption from an active region AR11263. Both different electromagnetic spectrum shows the burst occur at an exact time. Other interesting results is that this type II burst is not associated with CMEs as usual, but due to the very high solar flare event with a fundamental formed at more than 550 MHz.

ACKNOWLEDGMENT

We are grateful to CALLISTO network, STEREO, LASCO, SDO/AIA, NOAA and SWPC make their data available online. This work was partially supported by the 600-RMI/FRGS 5/3 (135/2014) and 600-RMI/RAGS 5/3 (121/2014) UiTM grants and Kementerian Pengajian Tinggi Malaysia. Special thanks to the National Space Agency and the National Space Centre for giving us a site to set up this project and support this project. Solar burst monitoring is a project of cooperation between the Institute of Astronomy, ETH Zurich, and FHNW Windisch, Switzerland, Universiti Teknologi MARA and University of Malaya. This paper also used NOAA Space Weather Prediction Centre (SWPC) for the sunspot, radio flux and solar flare data for comparison purpose. The research has made use of the National Space Centre Facility and a part of an initiative of the International Space Weather Initiative (ISWI) program.

References

[1] Goldman, M.V. and D.F. Smith, *Physics of the Sun*. Vol. 2. 1986: Dordrecht: Reidel.

[2] Hamidi, Z.S., *Probability of Solar Flares Turn Out to Form a Coronal Mass Ejections Events Due to the Characterization of Solar Radio Burst Type II and III.* International Letters of Chemistry, Physics and Astronomy, 2014. 16.

[3] Z.S. Hamidi, N.N.M.S., Z.A. Ibrahim, C. Monstein, W.N.A. Wan Zulkifli, M.B. Ibrahim, N.S. Arifin, N. A. Amran, *Magnetic Reconnection of Solar Flare Detected by Solar Radio Burst Type III.* Journal of Physics : Conference Series 539 (2014) 012006.

[4] White, S.M., *Solar Radio Bursts and Space Weather.* Asian Journal of Physics, 2007. 16: p. 189-207.

[5] N. Gopalswamy1, H.X., P. Mäkelä2, S. Akiyama2, S. Yashiro3, M. L. Kaiser1, and R.A.H.a.J.-L. Bougeret5, *Interplanetary shocks lacking type II radio bursts.* 2007.

[6] N. Gopalswamy, M.R.K., P. K. Manoharan, A. Raoult, and P.Z. N. Nitta, *X-Ray And Radio Studies Of A Coronal Eruption: Shock Wave, Plasmoid, and Coronal Mass Ejection.* The Astrophysical Journal, 1997

[7] E-Aguilar-Rodriguez, N.G., R. MacDowall, S. Yashiro and M.L Kaiser, *A Study of Drift Rate Type II Radio Burst At Different Wavelengths.* 2005.

[8] Z. S. Hamidi, Z.Z.A., Z. A. Ibrahim, N. N. M. Shariff and C. Monstein, *Observations of Coronal Mass Ejections (CMEs) at Low Frequency Radio Region on 15th April 2012.* 2013.

[9] Z. S. Hamidi1, N. N. M. Shariff2, C. Monstein3, *Type II Solar Radio Burst with a Split and Herring − Bones During a Minimum Solar Activity.* International Letters of Chemistry, Physics and Astronomy, 2014.

[10] Gopalswamy, N., et al., *Type II radio bursts and energetic solar eruptions.* Journal of Geophysical Research, 2005. 110(A12).

[11] Hamidi, Z., N. Shariff, and C. Monstein, *Type II Solar Radio Burst with a Split and Herring− Bones During a Minimum Solar Activity.* International Letters of Chemistry, Physics and Astronomy, 2014. 13(2): p. 104-111.

[12] Gopalswamy, N., et al., *Relation between type II bursts and CMEs inferred from STEREO observations.* Sol. Phys., 2009b. 259: p. 227-254.

[13] Hamidi, Z., et al., *Theoretical Review of Solar Radio Burst III (SRBT III) Associated With of Solar Flare Phenomena.* International Journal Physical Fundamental Sciences, 2013. 3(2): p. 20-23.

[14] Hamidi, Z., N. Shariff, and C. Monstein, *Fundamental and Second Harmonic Bands of Solar Radio Burst Type II Caused by X1. 8-Class Solar Flares.* 2014.

[15] Aguilar-Rodriguez, E., et al., *A Study of the Drift Rate of Type II Radio Bursts at Different Wavelengths*, in *Solar Wind 11/SOHO*. 2005. p. 393-396.

[16] Hamidi, Z., N. Shariff, and C. Monstein, *The Tendencies and Timeline of the Solar Burst Type II Fragmented.* 2014.

(Received 20 December 2015; accepted 06 January 2016)