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Heart-shape Active Region 2529 Producing Strong M6.7 class Solar Flare and Gradual Coronal Mass Ejections

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ABSTRACT

The Centre of the Sun is very important to be study because this layer is where the nuclear reaction will be occurred. During large event pre-flare usually continues a few minutes and followed by impulsive phase about 3 to 10 minutes. Solar storms such as solar flare and Coronal Mass Ejections are frequently occurred on the area of the Sun that have strong magnetic field or known as active region The release of the stored free magnetic energy that probably drives a CME can take many forms including (predominantly) mechanical in the form of an expanding CME and erupting filament, electromagnetic emission in the form of a flare, and also in the acceleration of energetic particles, magnetic field reconfiguration and bulk plasma motion. In this study, the data of active region of the Sun was taken from official website of the Langkawi National Observatory. The image of the active region was observed by using 11-inch Celestron telescope with solar filter. This data confirms that there was a strong M class of solar flare during the day due to eruption of AR 2529 was occurred on 18th of April. From the x-ray flux data also, it can be observed that few days before M6.7 class solar flare occurred, there were several C classes of flare. The evolution of small AR 2529 to a big heart-shape forms an eruption that producing strong M6.7 class of flare and three gradual CMEs. This strong flare caused significant impact around the high technologies of Pacific Ocean by fading the signal at frequencies below 15 MHz.

***Keywords*:** Sun, solar flare, Heart-shape active region, X-ray region, Gradual Coronal Mass Ejections

1. INTRODUCTION

The Sun is divided two regions which are solar atmosphere and solar interior. The radius of the Sun is 69 600 km. Sun basically has three different physical regions. Centre of the Sun in which nuclear reaction will be occurred is named as core and it is extending to approximately $0.25R_\odot$ [1]. Nuclear reaction is a process where hydrogen fuses into helium with the associated release of energy. Radioactive zone energy is from $0.25R_\odot$ to $0.71R_\odot$ and the energy is transferred by the emission and the absorption of photons [2]. In the solar interior, dynamic action is the mechanism that generates Sun's magnetic field [3].

The consequences of the resulting magnetic field can be observed in the solar atmosphere even though the key physical process involve with this mechanism are hidden from the view. The energetic behaviours of the Sun reveals a variety of physical phenomena, some of which are still not at all or only barely understood due to the complexity of the structure of the Sun [4]. The large field of magnetic field can be characterised by the appearance of sunspot, region of intense magnetic field, the number of which varies with the cycle of approximately eleven years [5].

The phenomena called solar flare that been first discovered in 1859 by Carrington and Hodgson [6]. Flares can occur everywhere on the Sun, in active regions, penumbras, on the boundaries of the magnetic network of the quiet Sun, and even in the network interior [7]. Chromosphere and Corona of the Sun are the local regions where usually Solar flare occurred. In other words, flare is a process that huge energy and matter that release suddenly. Regular (large) flares, however, have preferred locations.

They occur in large active regions showing a complex geometry of the 3D magnetic field as revealed in photospheric vector magnetograms [8]. One of the most captivating aspects of solar flare is their acceleration of charged particle to high and supra-thermal energies. The heating of plasma to the temperature exceeding 10 MK is one of the characteristic to classify solar flare. Comprehensive observation of the hard X-ray emission from flares are crucial to obtain an understanding of the mechanism responsible for electron acceleration and heating [9].

Solar flares are magnetically driven explosions on the surface of the sun. A powerful burst of electromagnetic radiation in the form of X-ray, extreme ultraviolet rays, gamma ray radiation and radio burst arrives at Earth approximately 8 minutes after a solar flare occurs on the surface of the sun. Solar flares are produced when the magnetic energy that has built up in the solar atmosphere is suddenly released [10]. Around sunspots are active regions where intense magnetic fields build up and penetrate the photosphere linking the corona to the solar interior. According to Zhang et al. solar flares are formed mainly in two preferred longitude ranges; the active regions [11,12].

Table 1. Phase of Flare

1. **Pre-flare**	2. **Impulsive**
• In the free flare phase the coronal plasma in the flare region slowly heats up and is visible in soft x-rays and EUV.	• A large number of energetic electrons (up to 10^38) and ions (with the similar total energy) is accelerated when most of energy is released. • Some high energy particles and trapped and produced intensive emission in the radio band. • The thermal soft x-ray and Ha emissions finally reach their max the impulsive phase.
3. **Flash**	4. **Decay**
• The rapid increase in Ha intensity • It coincides largely with the impulsive phase.	• The coronal plasma returns nearly to its original state except in the high corona where magnetic reconfiguration, plasma ejections, and shock waves continue to accelerate particles causing meter wave radio burst and interplanetary particle events.

Table 1 shows the phase of flare. During large event pre-flare usually continues a few minutes and followed by impulsive phase about 3 to 10 minutes [13]. Afterwards the flash phase 5 to 20 minutes and decay for hours [14]. As mention earlier, in the explosion of flare the X-Ray emission grows evidently and it also related with the Coronal Mass Ejections (CMEs) [15].

The solar X-Ray flux has been measured in two bandpasses by these instruments: 0.5 to 4.0 Å and 1.0 to 8.0 Å. The x-ray flux is given on a logarithmic scale with A and B levels as typical background levels depending upon the phase of the cycle, and C, M, and X levels indicating increasing levels of flaring activity [55]. The Generally X-Ray flares are divided into five classes which are A,B,C, M and X-class according to peak flux of soft x-rays. According to Marusek et al. (2007), There are three main categories of solar flare which are as follows [9,7]:

1) X-class flares that are major events which can trigger worldwide radio blackouts and radiation storms in the upper atmosphere.

2) M-class flares that are medium-sized which can cause brief radio blackouts in the polar regions and,
3) C-class flares that are very small and can produce few noticeable effects on earth.

Harsh, B and et al., (2012) stated that another classification is based on Hα spectral observations that use intensity as well as emitting surface [9].

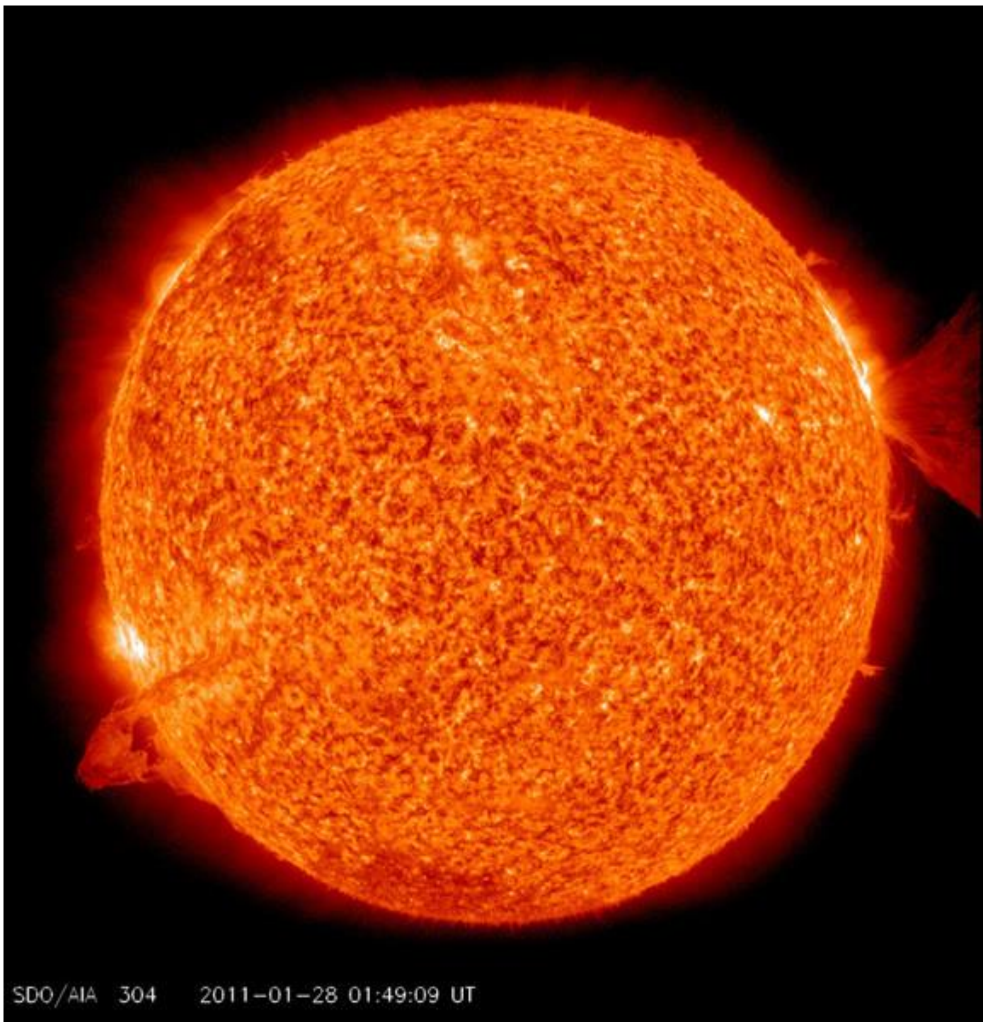


Figure 1. Solar Flare (Credit to NASA/SDO)

The Coronal Mass Ejections (CMEs) ejected from the sun is one of the main solar phenomena. The Earth-directed CMEs are very crucial, since they can produce geomagnetic storms as the consequences of this violent event. Howard et al., stated that usually these CMEs are seen as Halo CMEs. Many researcher has been studied the relation between CMEs and the other Sun activities. This research field has become topic of interest till this new era. Early measurements of the CMEs speeds have helped to advance our understanding of the physical processes in the solar corona [16].

Table 2. Classification of Solar Flare Intensity.

Class	Peak flux (WM-2) (100-800 Pico meter X-r\Rays near earth)	Class	Peak flux (WM-2) (100-800 Pico meter X-Rays near earth)
M_1	1×10^{-5} WM^{-2}	X_1	1×10^{-4} WM^{-2}
M_2	2×10^{-5} WM^{-2}	X_2	2×10^{-4} WM^{-2}
M_3	3×10^{-5} WM^{-2}	X_3	3×10^{-4} WM^{-2}
M_4	4×10^{-5} WM^{-2}	X_4	4×10^{-4} WM^{-2}
M_5	5×10^{-5} WM^{-2}	X_5	5×10^{-4} WM^{-2}
M_6	6×10^{-5} WM^{-2}	X_6	6×10^{-4} WM^{-2}
M_7	7×10^{-5} WM^{-2}	X_7	7×10^{-4} WM^{-2}
M_8	8×10^{-5} WM^{-2}	X_8	8×10^{-4} WM^{-2}
M_9	9×10^{-5} WM^{-2}	X_9	8×10^{-4} WM^{-2}

Coronal Mass Ejections (CMEs) are powerful explosions in the atmosphere of the Sun that bring massive magnetised plasma (1012-1013 kg) into the interplanetary medium. Their velocities range from 10 to 2000 kms^{-1} [10]. Wild et al. (1963) derived speed values of 500–1000 km/s from their observations of metric type G bursts and they concluded that these flare-associated bursts were produced by shock waves moving out through the interplanetary medium [17]. There are some favourite measured properties of CMEs include their occurrence rates, locations relative to the solar disk, angular widths, speeds and accelerations, masses, and energies [18].

The release of the stored free magnetic energy that probably drives a CME can take many forms including (predominantly) mechanical in the form of an expanding CME and erupting filament, electromagnetic emission in the form of a flare, and also in the acceleration of energetic particles, magnetic field reconfiguration and bulk plasma motion [19]. There are two classes of CMEs, namely flare-related CME events and CMEs associated with filament eruption are well reflected in the evolution of active regions, flare related CMEs mainly occur in young active regions containing sunspots and as the magnetic flux of the active region is getting dispersed, the filament eruption related CMEs will become dominant [20]. Figure 2 shows that the classification of CME.

There is no direct relationship between CMEs and flares. Many CMEs are associated with solar flares but many are not, just as most flares are not associated with mass ejection. When CMEs and flares occur together, the CME onsets seem to precede the flares in many cases, and the CMEs contain far more total energy than that radiated by the flare itself [13].

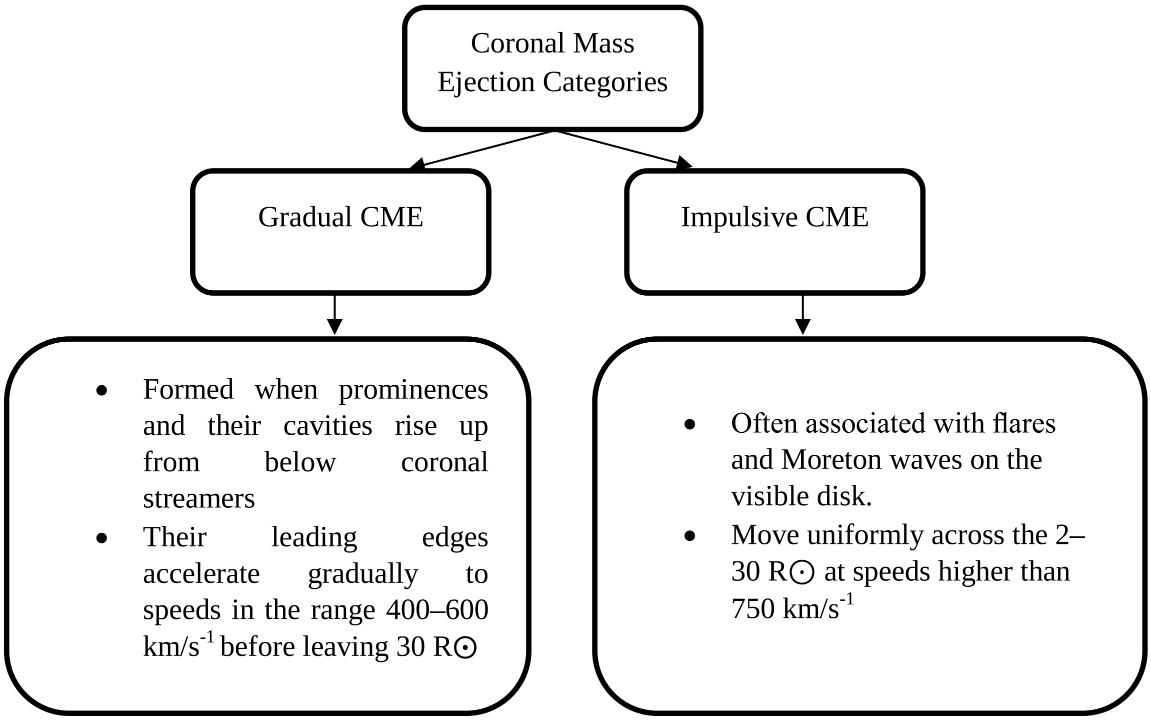


Figure 2. Categories of CMEs

For a better understanding of the effects of the propagation of a CME, multi-point observations between Sun and 1 AU are required [21].

Solar storms such as solar flare and Coronal Mass Ejections are frequently occurred on the area of the Sun that have strong magnetic field or known as active region. Active region is usually indicated by sunspot however not all active regions have sunspot. The plentiful of magnetic field can reach 1000 times stronger in the active region as compared to the average magnetic field of the Sun. Active regions are frequently observed when the Sun's magnetic field is tremendously disturbed during peak of the sunspot cycle. There are also other types of solar dramatic activities that also frequently occurred around active regions such solar prominence and coronal loops.

There is a region on the Sun that massive with magnetic field and most solar surface activities like sunspots, solar flares and coronal mass ejections (CMEs) frequently form in these regions, which is known as active region. This region appears bright in X-ray and ultraviolet images [15]. Solar active regions form where the tops of loops of magnetic flux, shaped like the Greek letter omega, emerge into the solar atmosphere where they can be seen [14-16]. In 1979 Parker suggested that the active region flux tubes are believed to rise due to buoyant force[16]. This regions come and go, and their lifetime be influenced by large extent on their size [14].

The long-term evolution of ARs confirmed that the evolution of an active region in each and every detail reflects the evolution of its magnetic field. It was found that flares mainly occur when the magnetic field of the AR has the highest complexity and magnetic flux density, and this is when the variability of AR cores are the highest, too [17].

However, the decades-old identification of ARs with sunspots still has a strong influence: NOAA (National Oceanic and Atmospheric Administration) assigns a number to an AR when/as long as it contains at least one sunspot visible in white-light [17]. t is generally believed that energetic activity like solar flares in the solar atmosphere is driven by magnetic reconnection in the vicinity of active regions (ARs) [18]. The aim of this paper is to discuss how the active region AR2529 could trigger strong M6.7 class flare and gradual coronal mass ejections.

2. INSTRUMENTS FOR OBSERVATIONS

In this study, the data of active region of the Sun was taken from official website of the Langkawi National Observatory. The image of the active region was observed by using 11-inch Celestron telescope with solar filter. The information of activities and events such eruptions and solar flares on the Sun were retrieved from spaceweather.com [22]. Spaceweather.com is an official website that provides news and information about Sun-Earth environment. Meanwhile, Coronal Mass Ejection data and images were retrieved from Large Angle and Spectrometric Coronagraph (LASCO) online database. LASCO is an instrument of 11 instruments included on the joint NASA/ESASOHO (Solar and Heliospheric Observatory) spacecraft [23].

Table 3. Specification of 11-inch Celestrone Telescope.

Diameter	11-inch
Focal Length	2800 mm
Focal Ratio	f/10
Optical Tube Length	580 mm
Visual Resolution	0.5’’’
Limiting visual magnitude	14.7

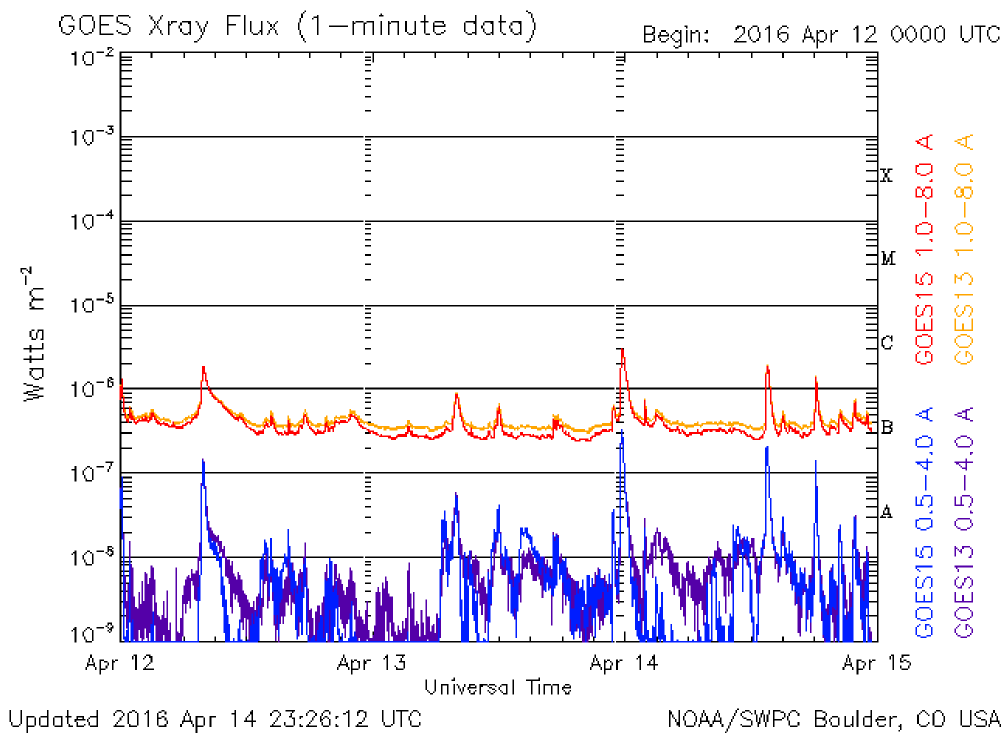
The data of X-Ray flux which observed by GOES satellite was retrieved from Space Weather Prediction Centre official website. This website provides alerts and warnings for any disruptions that might affect people and equipment working in space and earth to the nation and the world.

3. OBSERVATIONS AND DISCUSSIONS

After few days of its appearances, Active region (AR) 2529 starts to produce explosions. This active region had evolved till it forms a heart shape and it was reported in spaceweather.com that this active region had erupted and producing a strong M6.7 class solar flare on 18th of April 2016. This heart-shape Active region was observed by Karzaman Ahmad of the Langkawi National Observatory in Malaysia and he photographed the active region on April 13th 2016. The active region was photograph by using 11-inch Celestron telescope with solar filters. Figure below shows the heart-shape AR2529 taken from Langkawi National Observatory.

Figure 3. AR2529 (Credit to the Langkawi National Observatory)

During 18th of April was the climax of this active region whereby it erupted and producing a strong M6.7 class solar flare. Due to this event, shortwave radio communications over the daylit side of our planet were disrupted. Besides, some high technology activities around the Pacific Ocean such mariners, aviators, and ham radio operators had noticed fading signal at frequencies below 15 MHz. Figure above shows X-Ray flux data that retrieved from space weather prediction centre from 17th to 20th of April. This data confirms that there was a strong M class of solar flare during the day due to eruption of AR 2529 was occurred on 18th of April. From the X-ray flux data also, it can be observed that few days before M6.7 class solar flare occurred, there were several C classes of flare. Thus from the observations, it can be hypothesized that the emergence of constant small C class of flare might be the indicator for the larger class of flare to be occurred which can cause significant impacts on our earth.


GOES Xray Flux (1-minute data)
Begin: 2016 Apr 12 0000 UTC
Watts m-2
X
M
C
B
A
GOES15 1.0-8.0 A
GOES13 1.0-8.0 A
GOES15 0.5-4.0 A
GOES13 0.5-4.0 A
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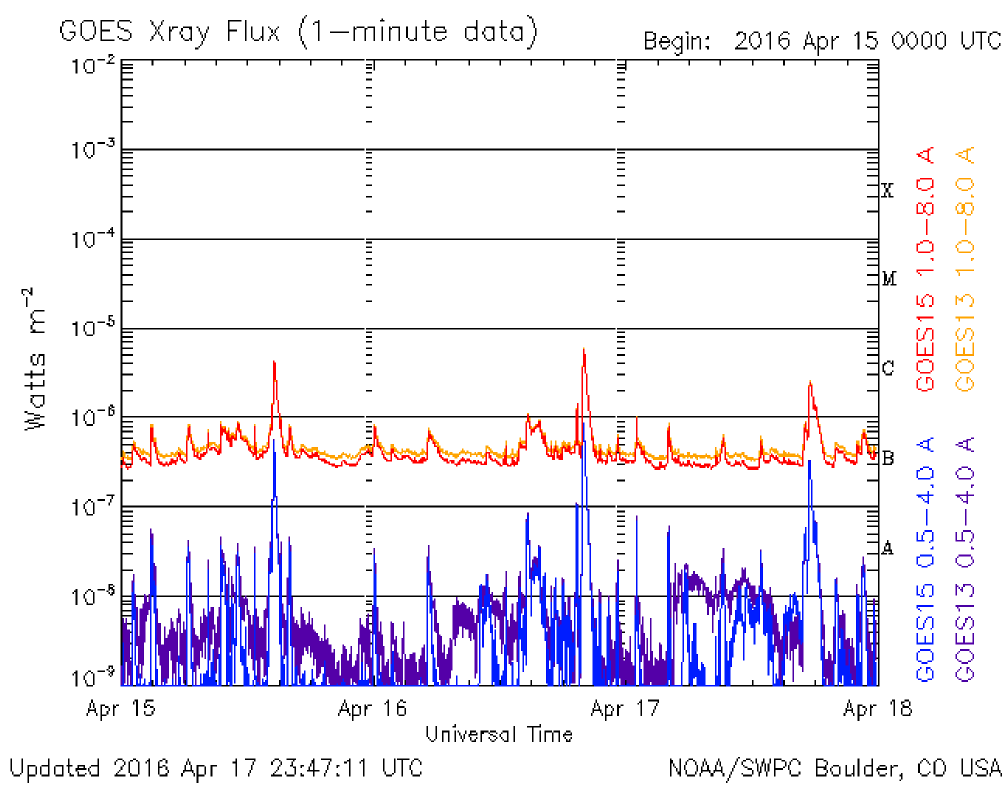
Universal Time
Updated 2016 Apr 14 23:26:12 UTC
NOAA/SWPC Boulder, CO USA

(A)


GOES Xray Flux (1-minute data)
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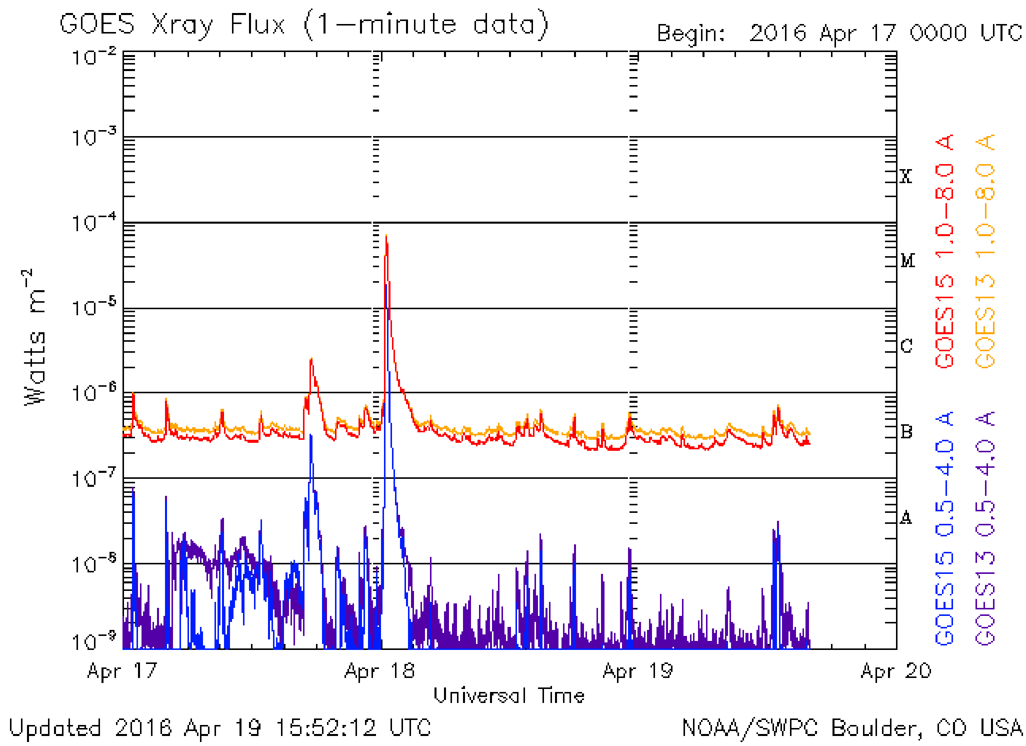
(B)



(C)

Figure 4(A,B,C). GEOS X-ray Flux from 12th – 20th April 2016l
(Credit to solarmonitor.org)

Table 4. Properties of CMEs on 18th April 2016 (Credit to CACTUS)

#CME	Onset time	Median velocity	Lowest velocity	Highest velocity
0048	23:36	0534	0117	1121
0047	22:36	0496	0214	0664
0046	05:12	0544	0172	1736

Active region 2529 also producing three associated CMEs on 18th April 2016 which each of them were distinguished by number in sequence. AR2529 has developed a 'beta-gamma' magnetic field that harbors plenty of energy for this kind of explosion.

CME number 46 is the fastest among all CMEs during the day with the average velocity of 544 km/s^{-1}. All of the CMEs were classified as gradual CMEs since their speed were within the range of 400-600 km/s^{-1}.

From Figure 5, it obviously shows that, the number 46 CME is bigger than the others. It is to be noted that the emergence of AR2529 was producing M6.7 X-Ray class solar flare with gradual CMEs.

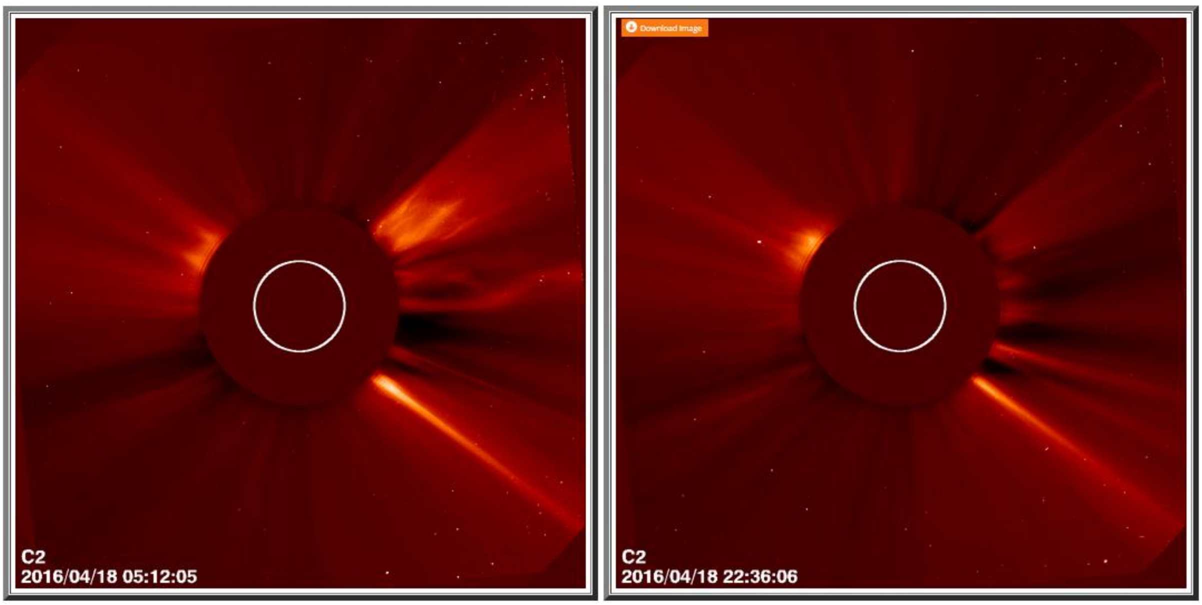


Figure 5. Image of #46 and #47 CME (Credit to LASCO C2)

4. CONCLUSION

The evolution of small AR 2529 to a big heart-shape forms an eruption that producing strong M6.7 class of flare and three gradual CMEs. This strong flare caused significant impact around the high technologies of Pacific Ocean by fading the signal at frequencies below 15 MHz. Based on the data provided by space weather prediction centre, it can be hypothesized that small C class of flare might be the indicator for the larger class of flare to be occurred since it occurred before strong M class flare was observed.

Acknowledgement

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