Iranian Journal of Astronomy and Astrophysics
Vol. 9, No. 2, Autumn 2022
©Available online at http://journals.du.ac.ir
DOI:10.22128/ijaa.2022.680.1146

**Iranian Journal of Astronomy and Astrophysics**

# Correlation of the Flux of Energetic Rays and Particles with the Solar Cycle

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**Abstract**. A solar flare is a sudden flash that occurs near the solar surface. This results in the emission of an extensive range of energy from the surface of the Sun. These giant explosions generally contain X-rays and energy that tend to travel in all directions at the speed of light. Coronal mass ejections (CMEs) are types of explosions that occur on the solar surface. A CMEs releases a large amount of plasma and magnetic field. Our main goal in this research is to prove that the reason for the release of charged particles, protons, electrons and X-ray radiation, followed by the release of solar winds, is the occurrence of flares and CMEs. The occurrence of this phenomenon is related to other phenomena, such as the magnetic field of the Sun's surface, the cycle of the Sun's activity, sunspots, the emission of charged particles of electrons and protons from the solar corona, the rate of occurrence of CMEs from the corona, the average and maximum speed of CME and X-ray radiation in the category Class X, which is the highest energy category for X-ray radiation, is directly and closely related.

*Keywords*: Correlation, Solar Cycle, CME, Solar Wind, Magnetic Field

## 1 Introduction

Coronal mass ejections (CMEs) are types of explosions that occur on the surface of the Sun [10]. Mechanisms responsible for solar large-scale structures, such as flares and coronal mass ejections, might originate from small-scale energetic events [1,17,18]. A CME releases a large amount of plasma and magnetic field [5]. A solar flare is a sudden flash that occurs near the surface of the Sun [14–16]. This results in the emission of a very wide range of energy from the surface of the Sun. These giant explosions generally contain X-rays and energy that tend to travel in all directions at the speed of light. Instead of emitting X-rays and energy, a CME releases a large amount of plasma, and releases the magnetic field. It can be said that they are giant clouds of particles that are thrown into space. CMEs usually occur first and are often followed by solar flares [2]. Almost all CMEs are predicted to take 3 to 4 days to reach Earth [7,8] while slow and fast CME models predict 1.67 to 3.25 days. The CME started with an initial velocity of 1674 km$s^{-1}$ and reached 1 AU after 35.1 hours. [6] predicted 61.6 and 35.3 hours based on the slow and fast wind models respectively. While the flares travel at the speed of light, it only takes 8 minutes to reach the Earth. In order to distinguish between solar flares and CMEs, it should be noted that flares are flashes of light on the Sun, while a CME is an eruption that is ejected into space. CMEs also commonly occur in active regions, in sunspots. A CME is often immediately followed by a solar flare.

A solar flare is primarily an energy release, while a CME is often accompanied by a solar flare, a solar flare can occur without a CME present(see Table 1). CMEs are related with II-type radio bursts and SEP (solar energetic particle) [4]. Type II solar radio bursts are believed to be triggered by shock waves. They are often associated with shocks from solar eruption events, such as CMEs [3] and solar flares, and are characterized by a slow drift from high to low frequencies that is thought to reflect the speed of shock propagation from the Sun. The shock-induced emissions that show very little or no frequency drift are known to as " II-type stationary bursts". Fixed explosions of type II are sometimes interpreted as the end shock in solar flares. Basically, all explosions of type II in the Decametre-Hectometric (DH) wavelength range are associated with high-energy solar SEP (solar energetic particle) events. This is a significant result for space weather applications. Since if a CME originated in the Western Hemisphere with a DH-type burst II is associated, it is highly likely to trigger a SEP event. This is consistent with the idea that CME-based shocks accelerate both ions and electrons, so bursts of the type II especially those that occur at longer wavelengths, have become good indicators for SEP events [7].

In this research, we investigate flare positions concerning to CME craters for X-class, M-class, and C-class flare events separately (see Figures 11 and 15). It was found that the most frequent location of flares is in the center of the CME crater for all three classes, but this frequency is different for different classes. Many X-class flares are often located at the center of the associated CME, while C-class flares spread separately outside the CME crater. The spatial relationship between flares and CMEs contain information about the magnetic field settings involved in the eruption process and is therefore, essential for their modeling. Many flare-CME models are based on the magnetic reconnection model. The model requires that a flare occurs just below an erupting filament that eventually becomes the core of the CME associated with the flare. Usually, the core is the center of the CME.

## 2 Observations

in this research, we concentrate to find exactly relation between the magnetically activity, includes the Sun spot number and huge CMEs, according to the Goes and SDO/AIA simultaneous observations. For this purpose, we study the reason for the release of charged particles, protons, electrons, and X-ray radiation, followed by the release of solar winds. Flares and CMEs may be directly and closely related to other phenomena such as the magnetic field of the solar surface, the cycle of the solar activity, sunspots, the emission of charged particles of electrons and protons from the solar corona, the rate of occurrence of CME from the corona, the average and maximum speed of CME and X-ray radiation in the category Class X, which is the highest energy category for X-ray radiation. Therefore, in order to reach the time of occurrence of flares with high energy, we must first examine the relevant parameters that are related to our research process. We consider the time period from 2008 to 2019 for our research (which is in the 24th cycle of the solar activity), then we draw the graphs of the amount of mass leaving the Sun and the number of sunspots (see the Figures 8 ,15). Figures 1 and 2 show the diagram of mass outflow from the Sun from 2008 to 2019 (24th solar cycle) and monthly sunspot variations from 2008 to 2019, respectively (Mason). After drawing the graph of these two parameters, we can see that the limits of maximum and minimum are fully evident in this period. The outflow of mass from the Sun and sunspots in 2014 (maximum solar activity) are at their maximum level compared to other years. I found that there is a great connection between these phenomena, then definitely a high-energy flare happened in 2014. Also, the outflow of mass from the Sun and sunspots in 2019 (minimum solar activity) are at their minimum level compared to other

Table 1: Comparison between CME and Flare.

| CME | Flare |
|---|---|
| Eruption of matter into space | Sudden brightness near the solar surface |
| It releases a large amount of plasma and magnetic field | It emits X-rays and energy |
| The released particles take about one to three days for the CME to reach the Earth | It travels at the speed of light and therefore takes only 8 min to reach the Earth |

years. In this article, we have selected two flares, one flare erupted in 2014 (maximum solar activity) and the other flare in 2019 (minimum solar activity). Figures 3 and 4 indicate the diagrams related to the activity cycle of the Sun, and the diagram of the maximum speed of mass outflow from the Sun in 2014 (maximum solar activity), respectively.

# 3 Data analysis and Results

Our goal of receiving data and information about sunspots and CME speeds is to compare them with the information about charged proton particles taken from Goes satellite. We investigate when the number of sunspots and CMEs speeds reduces or increases, in the same time, the amount of corresponding energy (number of protons particles in the material coming out of the solar corona) reduces or increases. Figure 5 shows the diagram of the maximum velocity of mass leaving the Sun in 2019 (in minimum solar activity).

After examining the general graphs of mass outflow from the Sun, sunspots and, maximum speed, we see that in 2014 the considered parameters are at their maximum level compared to other years (maximum solar activity) and because there is a excellent connection between these phenomena, then a high energy flare definitely happened in 2014 (see Figures 6 and 7). Also, in 2019, the considered parameters are at their minimum level compared to other years (minimum solar activity), so definitely a flare with low energy happened in 2019 (see Figures 9 and 10). As we mentioned before, we have selected 2 flares, the first flare in 2014 (maximum solar activity, Figure 8) and the second flare in 2019 (minimum solar activity, Figure 15). We examine the diagrams of protons and electrons, using the site of [19], to find relationship between the amount of proton and electron charged particles leaving the solar surface with flares. Therefore, in the beginning, we check the graphs of 12 months of 2014. After viewing these graphs, when the energy of charged particles is high, it can be considered as the basis for the occurrence of flares. By reviewing the graphs of 2014, we see that in February 2014, there was an increase in energy for proton particles, the exact time of which is February 28, 26, 25, and 2 it should be noted that there are many examples of proton particle energy increase It existed in 2014, and we have chosen a sample to conduct our research, and therefore, we are moving forward with our research work using the site [22], which is related to the US Navy and the Lasco satellite, as well as the site [23]and the site [21], which is related to the SOHO satellite, it is possible to obtain an image of the flare occurrence and in this way, it is proven that the process of drawing the diagrams is correct. It is clear that there is a maximum of solar magnetic activity in 2014. To prove this, we can refer to the web page at [20] and check the video of the flare on the surface of the sun, which was prepared by the Solar Dynamic Observatory and the AIA instrument package at a wavelength of 171 Å. After watching this video, we can see the flares that have

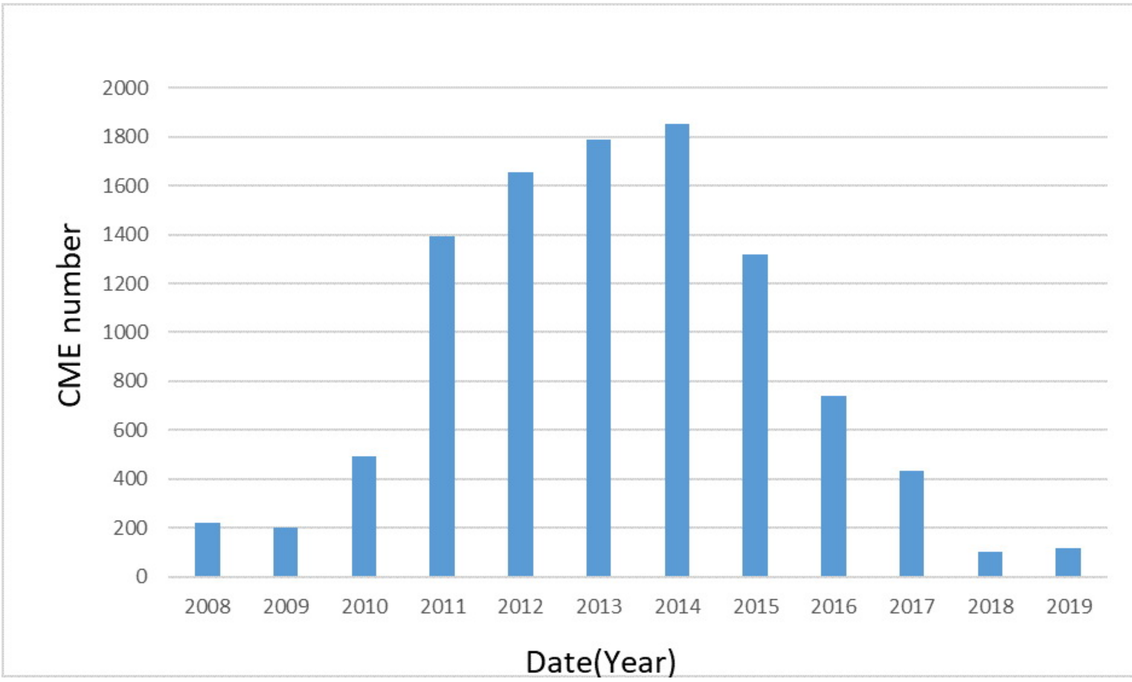


Figure 1: The diagram of mass outflow from the Sun from 2008 to 2019 (24th solar cycle).


Figure 2: Monthly sunspot variations from 2008 to 2019.

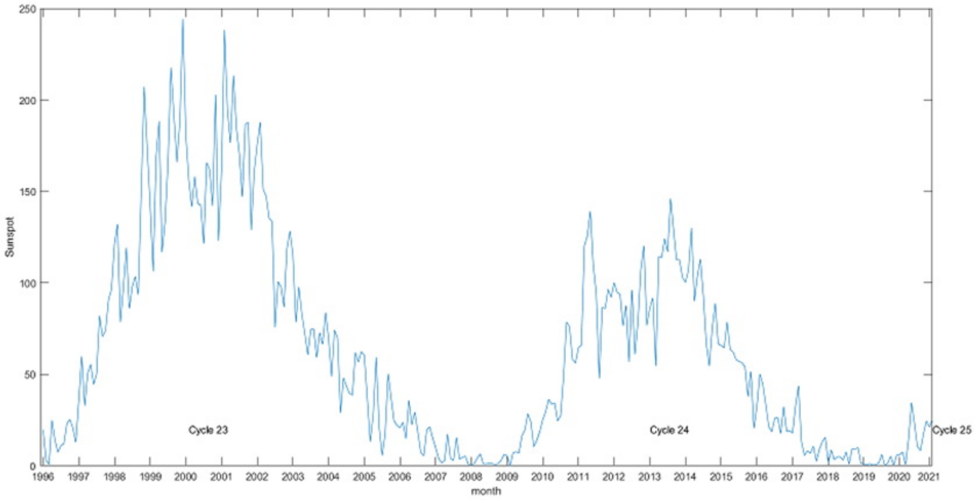


Figure 3: Diagram related to the activity cycle of the Sun

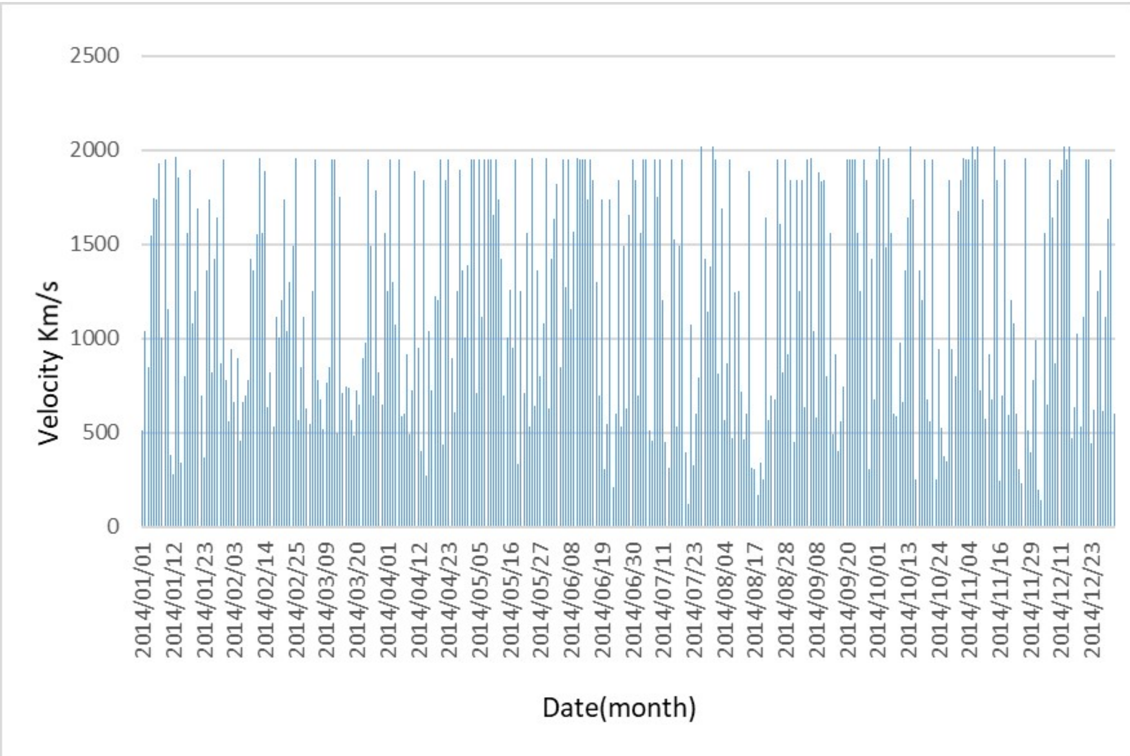


Figure 4: Diagram of the maximum speed of mass outflow from the Sun in 2014 (maximum solar activity)

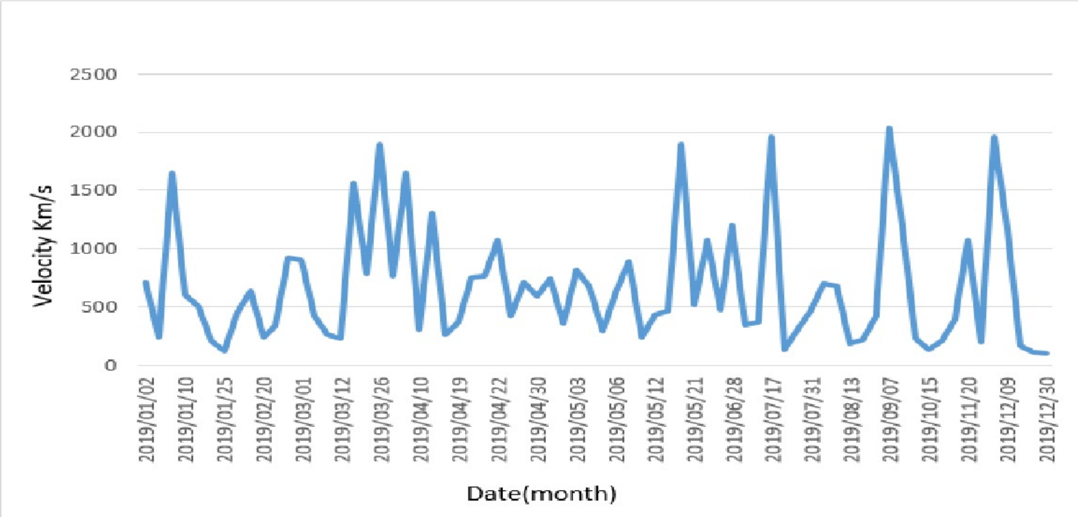


Figure 5: The diagram of the maximum velocity of mass leaving the Sun in 2019 (minimum solar activity)

Table 2: Properties of related to the occurrence of Flares

| Solar activity | Flare | Date of occurrence | Start time | Peak time | End time | The location and Area of the Spark |
|---|---|---|---|---|---|---|
| Maximum | X4.9 | 25/2/2014 | 00:39 | 00:49 | 01:03 | S15E86 AR:1990 |
| Minimum | C2 | 29/1/2019 | 21:17 | 21:29 | 21:48 | N06W61 AR:2733 |

the maximum energy in the relevant time frame, which is April 25, 2014. Table 2 , shows the date of occurrence of flares, the exact time of flares, class of flares, rise time of flares, the time of flares, location, and area of flare occurrence. The diagrams of protons (Figures 6, 9, 12, 16), electrons (Figures 7,10,13, 17), and X-rays (Figures 14, 18) also fluctuate in energy during this time. The vertical axis shows the flux of particles and by multiply to the each types of the energy spectrum gives the flux of total energy in each ranges. If we consider one of the flares, for example, on 02/25/2014 at 00:39, a class X flare occurred, now refer to the diagram of protons, electrons, and X-rays in this time frame. It is clear that this diagram also proves the occurrence of the flare. This was the result and goal that we were looking for. What we see in the graph expresses the same thing, the curve of the graph is drawn with more intensity towards its maximum value. After this time, the drawn graphs go downward, that is, there are flares in the class limit A, C, and M that occur until flares of class X. In the graphs for 2019, there will definitely not be a sharp rise and fall due to the lack of high-energy flares. In the chart related to X-ray radiation on February 25 and comparing it with the chart related to the proton chart on February 25, we can see that this electromagnetic radiation occurred about a day before the release of charged particles. Table 3 indicates the exact arrival time of X-rays, proton and electron particles caused by the explosion and the exact delay time between X-rays and proton and electron particles reaching the Earth.

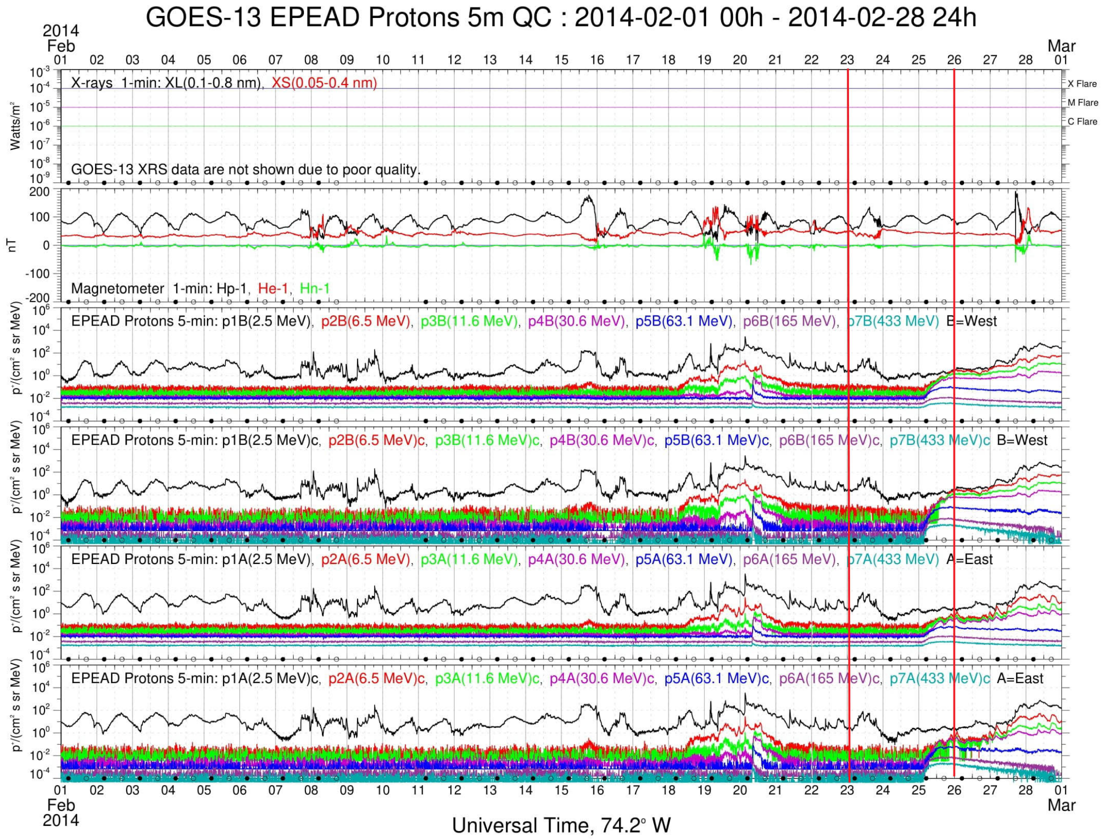


Figure 6: Proton particles diagram for February 2014 from the Goes 13 satellite. The two parallel red lines perpendicular to the time axis indicate the desired time range.

Table 3: The exact arrival time of X-rays, proton and electron particles caused by the explosion and the exact delay time between X-rays and proton and electron particles reaching the earth.

| Flare | Date of occurrence | Start time | Time of X-ray radiation reaching the Earth | The time when the proton flux reaching the Earth | The arrival time of the charge electron to the Earth | Delay time between proton and electron fluxes with X-rays |
|---|---|---|---|---|---|---|
| X4.9 | 25/2/2014 | 00:39 | 00:47 | February 26, 07:41, | February 26, 07:41 | 31/2 |
| M1.1 | 26/2/2014 | 14:52 | 15:00 | February 27, 21:54, | February 27, 21:45 | 31/2 |
| C8.3 | 4/3/2014 | 04:49 | 04:57 | Mars 5, 11:51 | Mars 5, 11:51 | 31/2 |
| M1 | 5/3/2014 | 02:06 | 02:14 | Mars 6, 09:06 | Mars 6, 09:06 | 31/2 |
| X1.39 | 25/4/2014 | 00:17 | 00:25 | April 26, 07:19 | April 26, 07:19 | 31/2 |

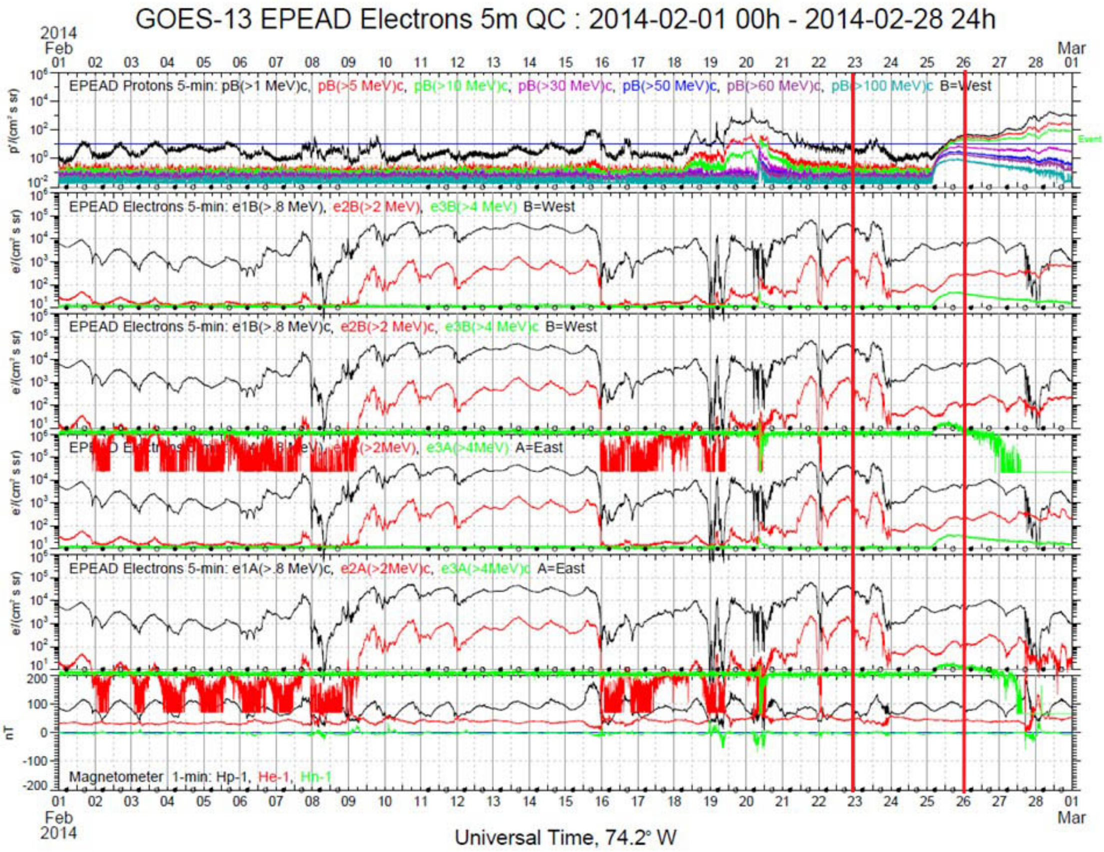


Figure 7: Electron particles diagram for February 2014 from Goes13. The two red parallel lines perpendicular to the time axis indicate the desired time range.

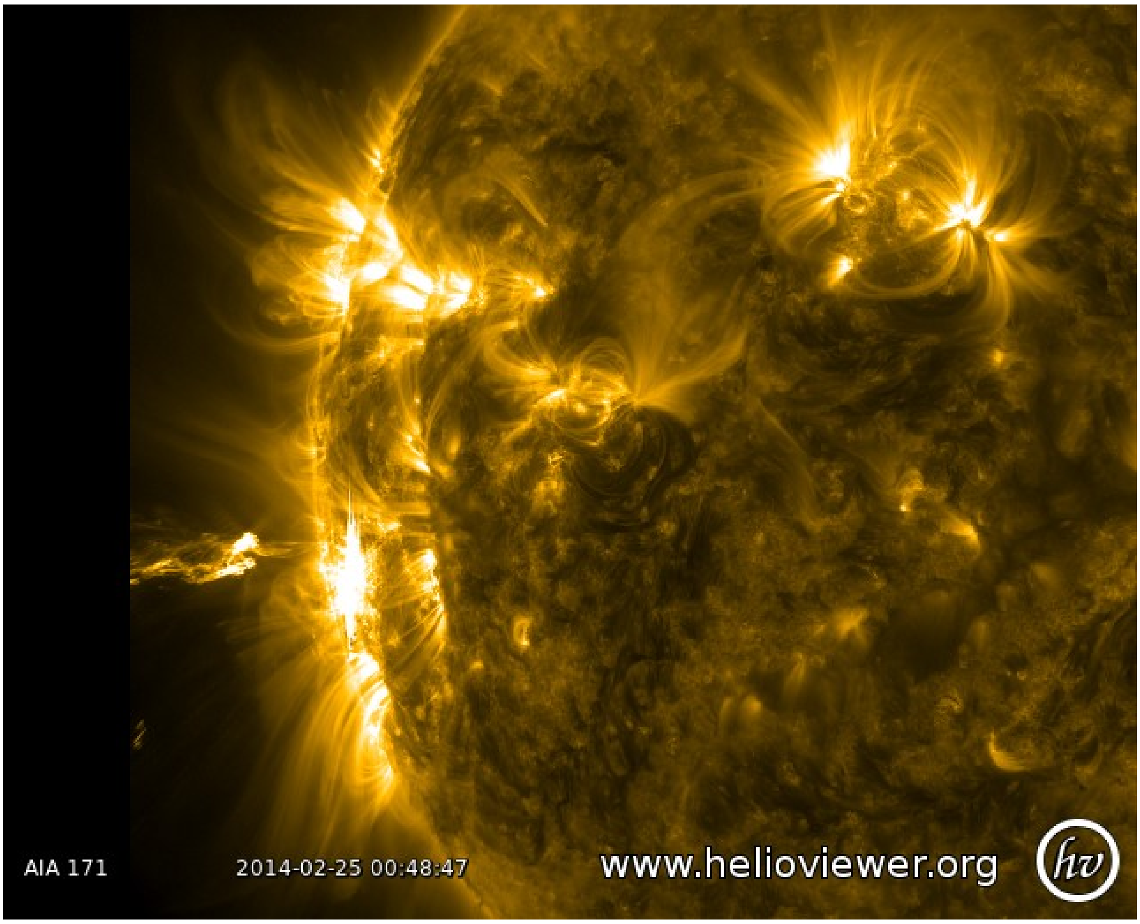


Figure 8: The explosion on the solar surface, on February 25, 2014

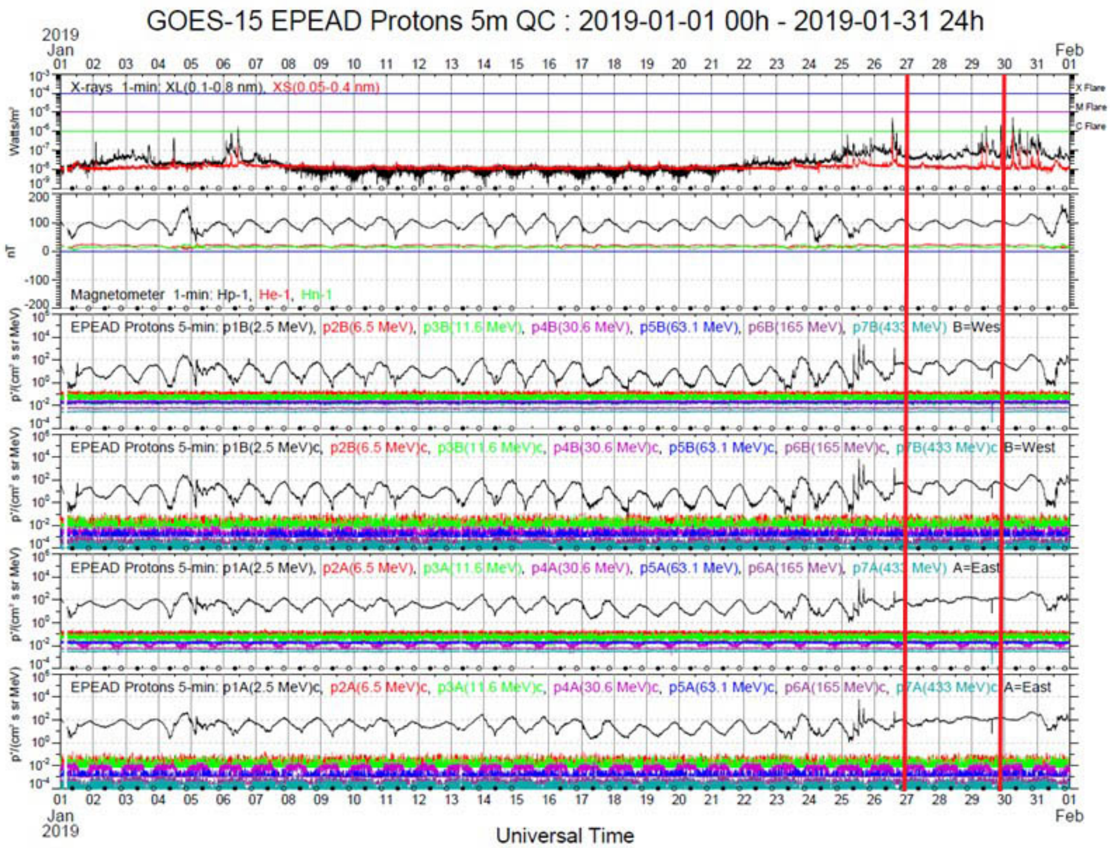


Figure 9: January 2019 proton particles diagram from Goes15. The two parallel red lines perpendicular to the time axis indicate the desired time range.

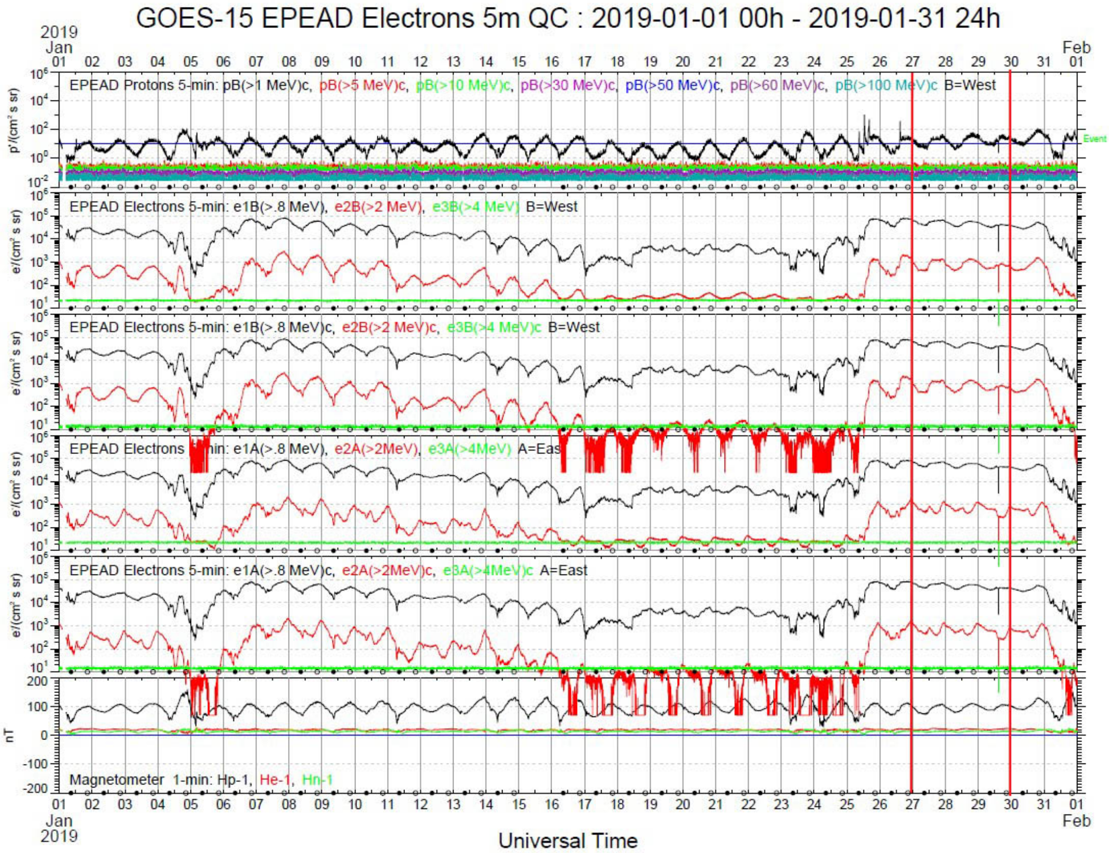


Figure 10: Electron particles diagram for January 2019 from Goes15. The two parallel red lines perpendicular to the time axis indicate the desired time range.

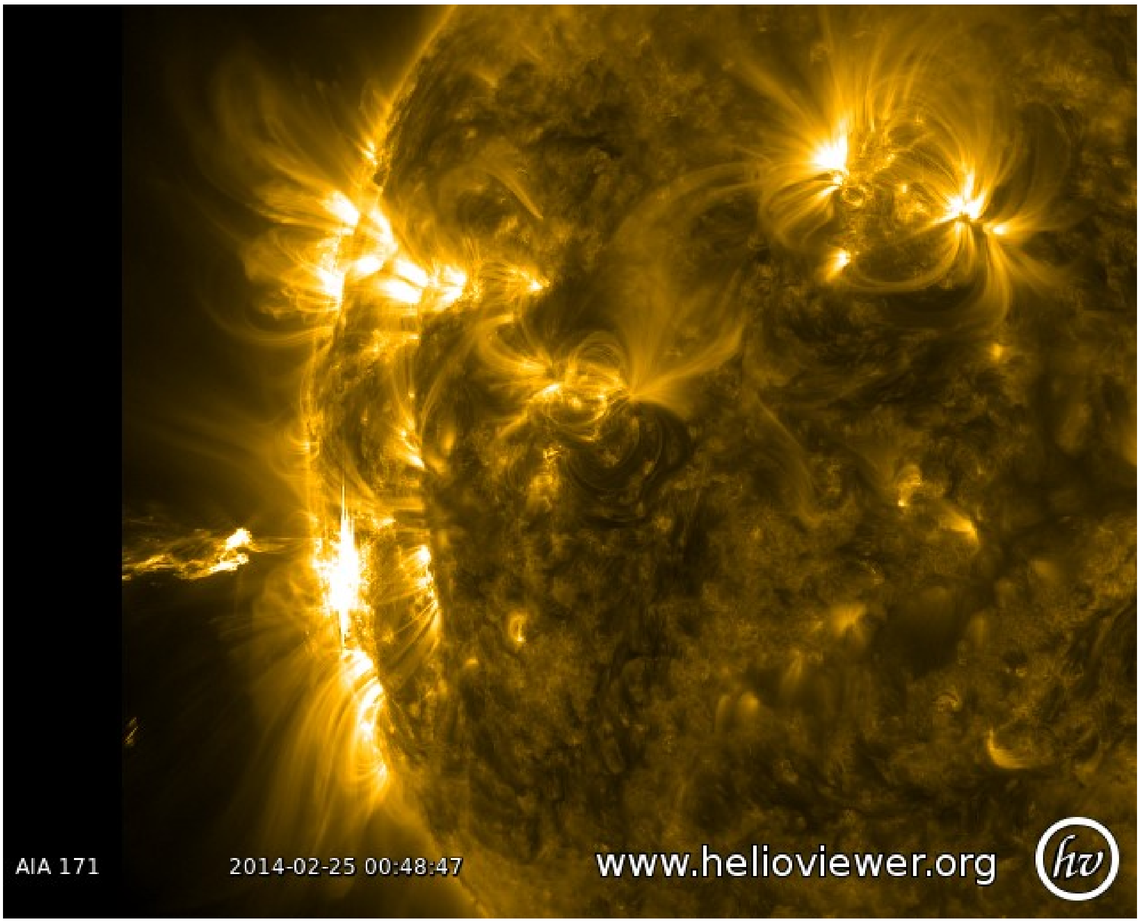


Figure 11: Flare class X4.9 on 2/25/2014

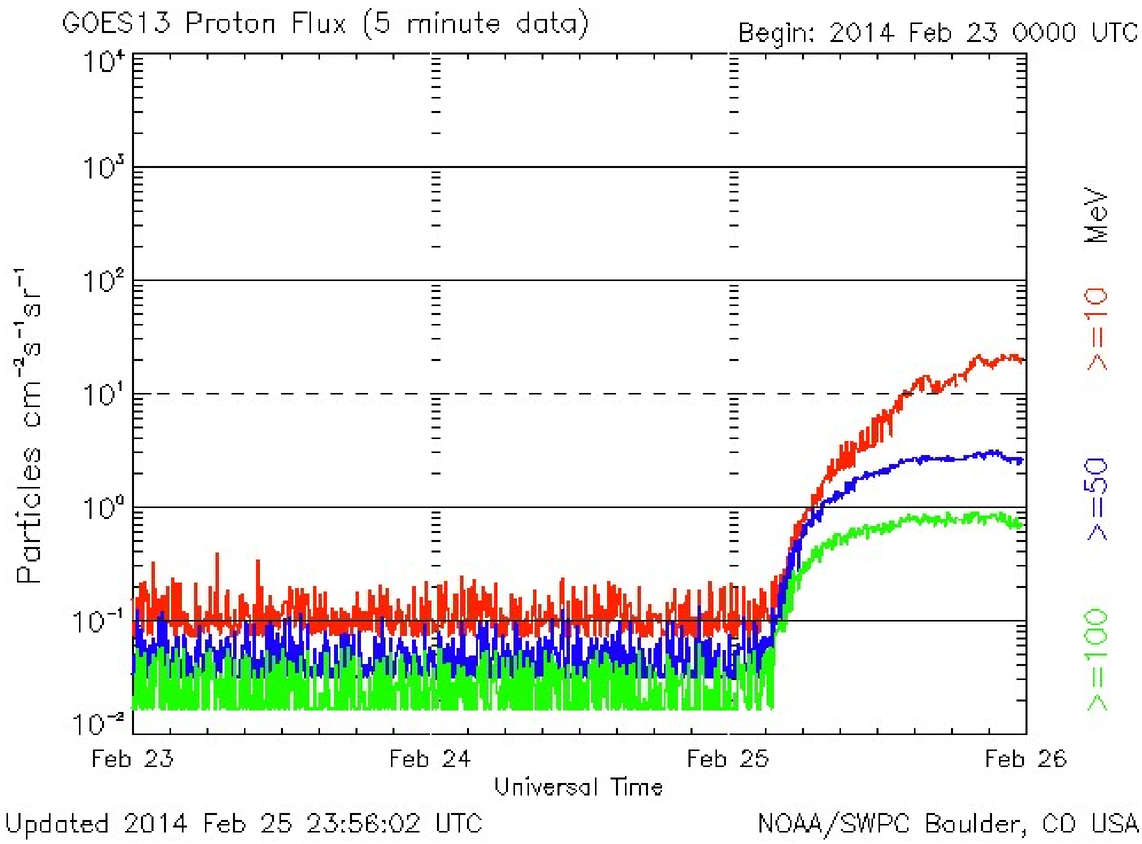


Figure 12: Proton particles diagram for February 25, 2014

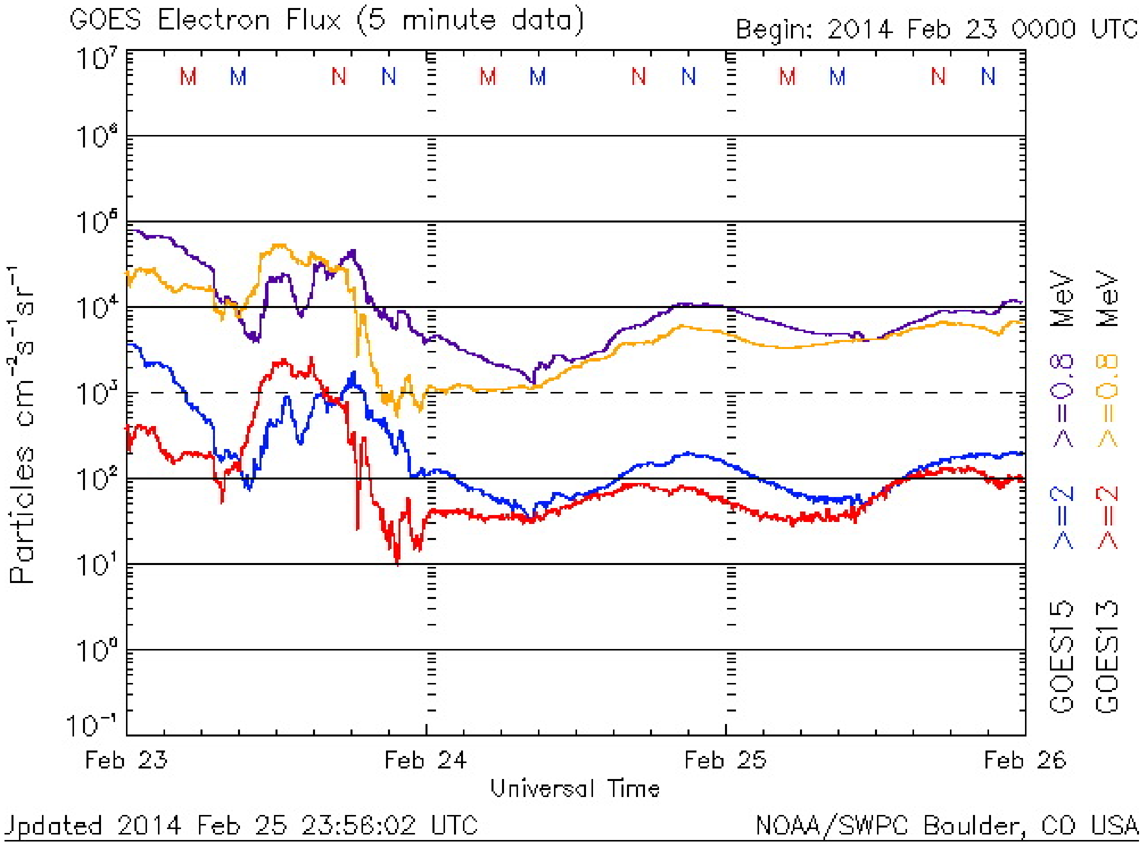


Figure 13: Electron particles diagram for February 25, 2014

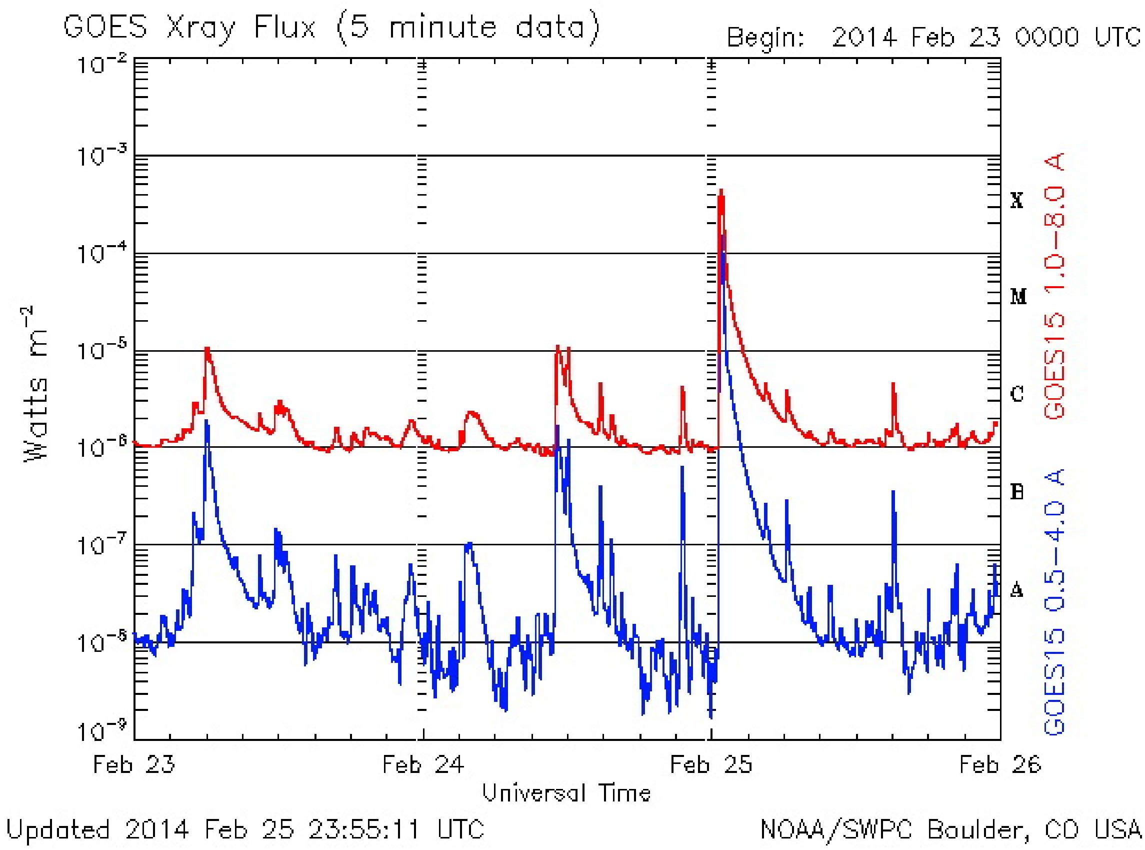


Figure 14: X-ray diagram for February 25

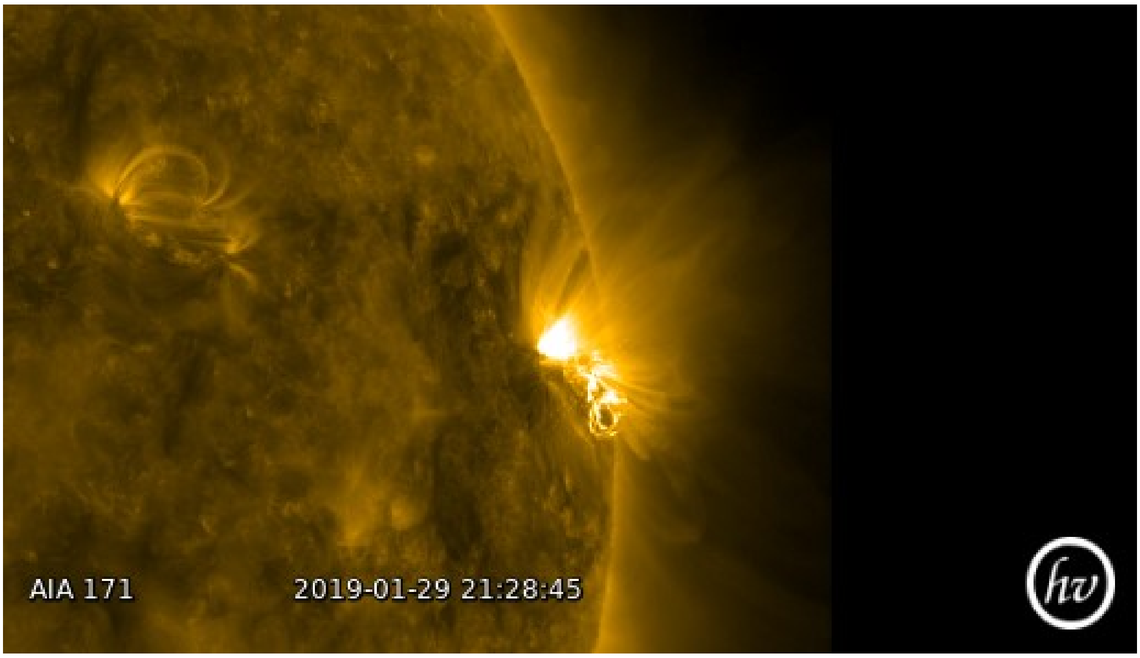


Figure 15: Flare class N06W61 on 1/29/2019

# 4 Conclusion and discussion

The Sun's magnetic field plays the main and essential role in the occurrence of all solar phenomena. Movements and currents of the Sun's magnetic field cause the plasma and charged particles of the Sun to flare up. If there is no or low activity of the magnetic field, the solar plasma will not gain momentum and energy, and solar phenomena will not occur. The activity period of the Sun and the number of sunspots that appear in this cycle in the solar photosphere are not unrelated to the occurrence of CMEs and flares. When the number of spots reaches its maximum, CMEs also go through this process and the opposite of this also happens. Magnetic connections occur more continuously and when the magnetic flux systems are in conflict with each other or in conflict with the currents created under the photosphere, this connection consistently produces magnetic shock waves. Also, the occurrence of a solar halo mass consists of a huge explosion of the solar prominence that produces a wave that transports the backscatter forward to such an extent that it is sometimes repeated by a radio burst of the type II be released our leading goal of conducting this research is to prove that the main cause of the emission of solar winds and charged particles of protons and electrons are the occurrence of high-energy flares and CMEs, and CMEs are accompanied by radio bursts of the type II and SEP energetic events are related. Solar radio bursts type II are excited by shock waves. They are often associated with shocks from solar erupted events such as coronal mass ejections (CMEs), and solar flares, and are characterized by a slow drift from high to low frequencies that are thought to reflect the speed of the shock propagation from the Sun. All explosions of type II in the decametre-hectometric (DH) wavelength range, they are associated with high-energy solar SEP events [9,13]. Type II radio bursts of the first indicators are shocks from solar flares and hence provide information on solar energetic particle (SEP) events, fast and widespread CMEs (FW), and in situ detected shocks.

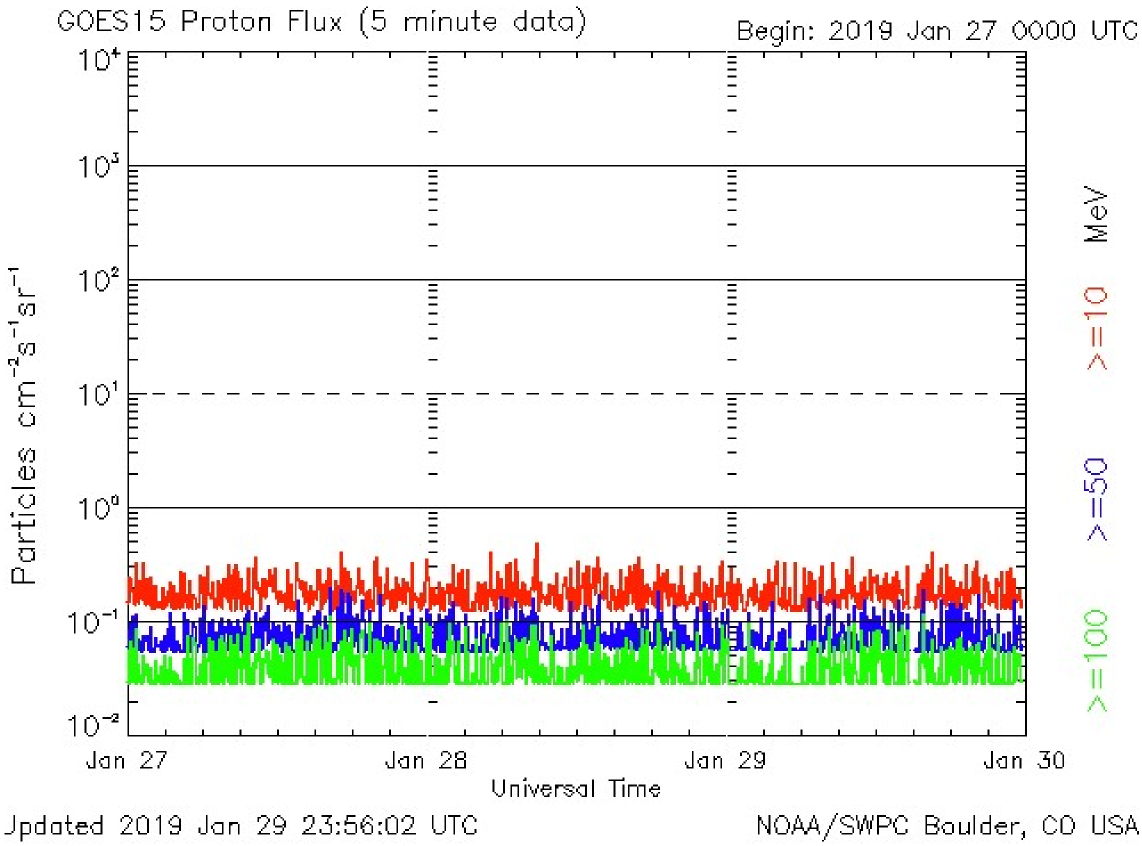


Figure 16: Proton particles diagram for January 29, 2019

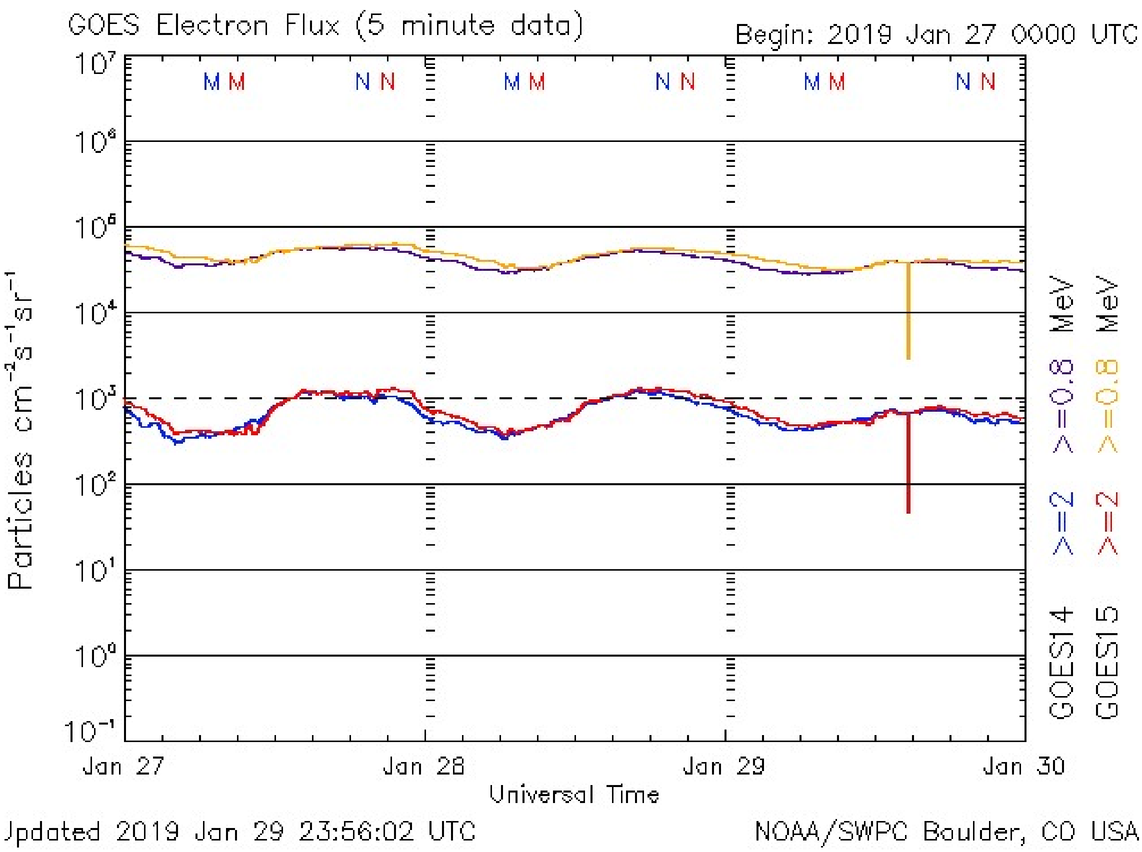


Figure 17: Electron particles diagram for January 29, 2019

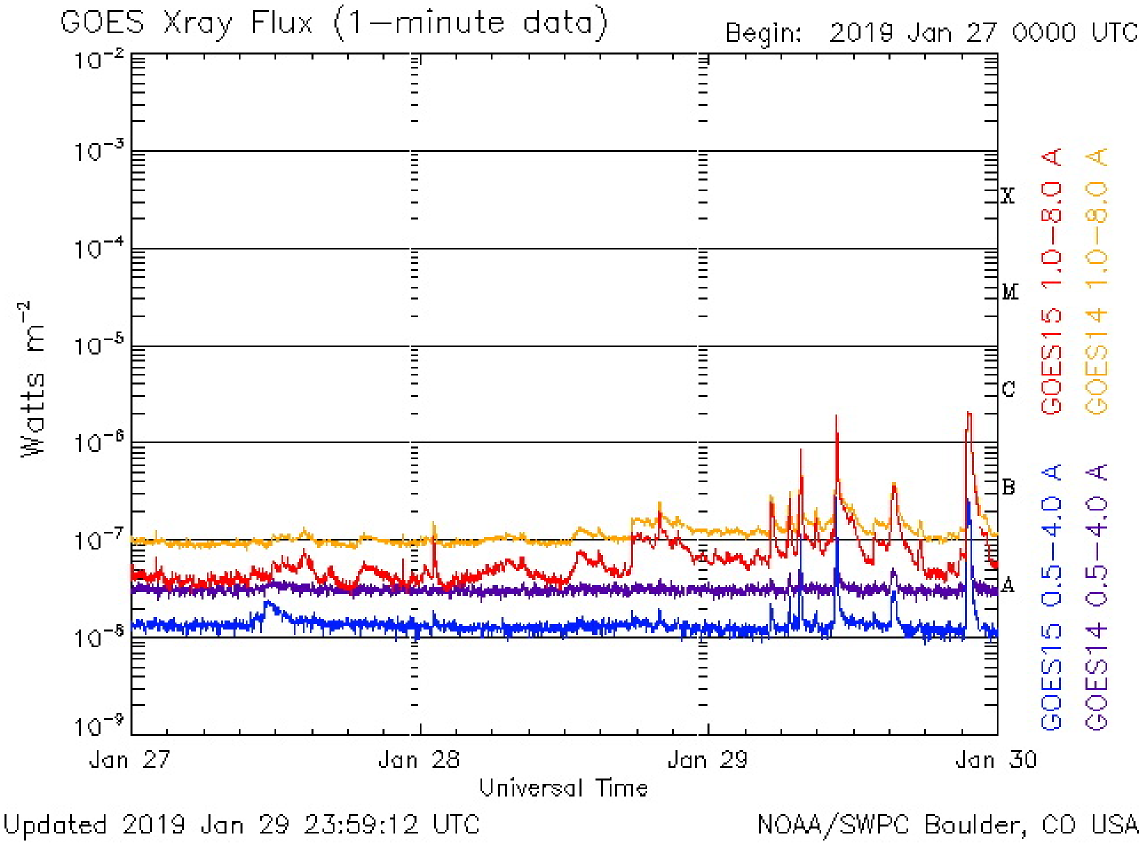


Figure 18: X-ray diagram for January 29, 2019

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