Journal of Radiation and Nuclear Applications
*An International Journal*

http://dx.doi.org/10.18576/jrna/060110

# Statistical Evaluation of Solar Neutrino Associated with the Coronal Mass Ejections for Solar Cycle 23

*I. A. Hussain*[1*], *S. S. Salih*[2], *and W. H. A. Zaki*[2]

[1]Department of Physics, University of Mosul, Mosul, Iraq.
[2]Department of Physics, University of Kirkuk, Kirkuk, Iraq.

Received: 1 Oct .2020, Revised: 19 Nov .2020, Accepted: 29 Dec. 2020.
Published online: 1 Jan. 2021.

**Abstract:** Understanding solar neutrino will lead the researchers to understand the Sun. The present study is designed to track the associated solar neutrino with the solar cycle 23 and explore the statistical relations amongst the solar neutrino and solar activity through the correlation and regression.

The major solar energetic events like Coronal Mass Ejection (CME) and Sunspots for cycle (23) in the period of (1996 - 2007) were analyzed via the “Large Angle Spectroscopic Coronagraph experiments (LASCO) on board SOHO satellite”. The neutrino events were taken from “the Soviet American Gallium experiment (SAGE)” for the same epoch of time. All the obtained results were statistically analyzed via the statistical program SPSS.

The graphical results revealed the existence of complicated relations between the neutrino candidate events and solar activities as a function of time. Whereas the statistical results indicate that no relation is found between the CME and the neutrino events for the same period of time, while an indicated linear relation was found between the number of CME and the neutrino events within the down phase of the solar activity.

**Keywords:** Solar Neutrinos, Coronal Mass Ejection (CME); sunspot; SOHO-LASCOERNE: Data base.

## 1 Introduction

The Sun is one of the main sources of neutrino particles that reach the Earth as well as it is the main source of light and heat. Another source of the solar neutrino is from nuclear reactions in the solar Corona, in which the decay of the charged pion(π) particles will produce the electron neutrinos, anti-electron neutrinos, muon neutrinos and anti-muon neutrinos as in equation (1) [1,2]. This type of neutrino is known as solar flare neutrino and confirmed through its energy spectrum diagram shown in Figure (1).

The coronal mass ejections CME is a giant cloud of solar plasma confined by frozen magnetic field that expand away from the Sun into the interplanetary space. CMEs most often originate from active regions on the Sun's surface, such as groupings of sunspots. [3]

The Soviet American Gallium Experiment SAGE was made to measure the capture rate of solar neutrinos by the reaction, 71Ga + νe→71Ge + e-. The characteristic that differentiate the Ga experiment from all other solar neutrino experiments, that it has the lowest threshold energy of 233 keV.

$$p+p \quad \text{or} \quad p+\alpha \longrightarrow \begin{cases} \pi^+ + X \\ \pi^0 + X \\ \pi^- + X \end{cases} \qquad \text{...(1)}$$

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu \qquad \mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\pi^0 \longrightarrow 2\gamma$$

$$\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu \qquad \mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$

So, even the low energetic neutrinos from the Sun are detected. This detector is only sensitive to electron neutrinos (νe), and it can detect the most of solar neutrino spectrum including those (νe) associated directly with solar flares. The reaction transforms a stable gallium atom into a radioactive isotope of germanium. Exposures used in the experiments lasted for 4 to 6 weeks. Then, the 71Ge atoms produced are chemically extracted together with the germanium carrier from gallium [4]. This fact led to the monthly extracted data in the current study. SAGE operated till 2010, which limited the time period of this study.

*Corresponding author e-mail: imad_ahmad2003@yahoo.com

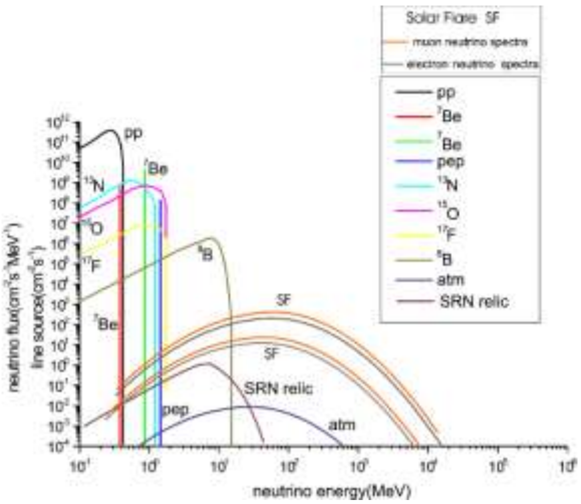


**Fig.**1**:** shows the spectrum of core generated solar neutrinos including electron and muon neutrinos from solar flares [5]

The study and tracking of solar neutrino will allow the researchers to understand the structure, evolution, activities and associated nuclear reactions of the stars. As well as, it will allow studying the solar interior, the core of a collapsing star when it produces a supernova, testing the associated theories, and investigating the causes behind all the solar activities. [6]

Davis' has suggested that solar flares may have produced neutrino pulses. [7] In 1984, Raychaudhuri, by observing and statistically analyzing the sunspots for solar cycle 20 and solar neutrino data where the neutrino flux varies with time [8], while, J. N. Bahcall et.al, found the apparent correlation between them not strong [9]. Erofeeva et.al, calculated neutrinos and photons of energies > 10 MeV that are generated in large solar flares [10].

Tatsuya Shirai suggested that the solar neutrino fluxes may vary with about a 30-month period, depending on Super-Kamiokande data [11]. while P. Raychaudhuri and K. Ghosh found periods in months that are nearly similar epochs in the solar flares, Sunspot data, solar proton data (E>10 Mev) which shows that the solar activity cycle may be because of the changing nature of nuclear energy generation inside the sun, depending on SAGE and GALLEX-GNO data [12].

Sakurai and et. al. found that the solar neutrino flux is varying quasi- biennially. Indicating that the proton-proton and proton-proton III reactions of proton-proton chain are variable quasi- biennially simultaneously with an epoch of about 26 months [13].

Aharmim et. al, concluded that No correlations were found between neutrinos detected in Sudbury Neutrino Observatory experiment and solar flares. [14].

From Ice-cube detector Wasseige et.al, found direct relation between solar neutrino and solar flare events by time profile analysis using the Geant4 toolkit [15].

Fargion and Oliva tracked solar flare and their sudden neutrino (or anti-neutrino) flare that created by proton scattering and pion decays by way of Delta resonance production. According to them these indicators might be noticeable at largest flare by Hyper-Kamiokande HK through spectra up to tens-hundred MeV energy and by IceCube-PINGU at higher energies [16].

The main goal of this study is to track the solar neutrino and to explore the statistical correlation and relations among the solar neutrino and solar activity (the coronal mass ejections CME and Sun Spots) through the correlation and regression. The importance of this study lies in that since the neutrinos are the most penetrating particles and it can be travel huge distances without losing information. Neutrino provides all the information about the Sun, its interior, activity, magnetic field and solar reactions, as well as for the other stars.

## 2 Methodologies

### *2.1 Data Handling*

- The Neutrino Candidate Events counted per unit of time (i.e., month), for neutrino energy (E$\nu$=233 keV to 15 MeV) and 2293 candidate events are taken from the SAGE for a period of time from May 1996 to December 2007 [17].
- The13094 CMEs observed by SOHO/LASCO for the years 1996-2007. These data are filtered according to radial speed of ($\vartheta \geq 450$ Km/s), and angular width ($AW \geq 50°$), 2012 CME are to be left over as result of this filtration [18].
- From the logarithmic intensity- time profile of proton for resolution time of 1 hour from ERNE detector the CMEs events have been extracted and they were 112 events [19].
- Later each of the nominated CME events are added separately to give monthly data for the years (1996-2007) [20].

All the mentioned data ahead are statistically analyzed to explore the relation among the solar neutrino and the CMEs observations for the solar cycle (23). [21]

### *2.2 Statistical Analysis*

Statistical methods are a significant process to discover the correlation between data sets. All observation has been statistically examined by means of the statistical software (SPSS) program to discover relationships among neutrino candidate events and the solar wind as measured from SOHO/ERNE and GOES of solar cycle (23). The Pearson's coefficient that varies between 1 and -1 indicates the strength and direction of the relation, the positive sign indicates a positive correlation and vice versa.

To test the hypothesis, the significance of the correlation should be equal or less than (0.01 or 0.05), for the Nell hypothesis (i.e. there is no statistically significant relationship between the two data sets) to be rejected and the alternative hypotheses (there is a statistically significant relation) accepted. The number of variables included in the analysis is given as N.

## 3 Results and Discussion

The total number of neutrino counts are taken per unit of time (month). As well as for the CME. Then the total yearly mean numbers for each of solar neutrino candidate events and solar activity are taken.

### *3.1 Month by Month Neutrino Tracking for the Solar Cycle 23*

Figure (2) show the variation in the number of the captured neutrino candidate events (blue colored) with CMEs (red colored) versus a given range of time. The red solid rectangular shapes were surrounding the directly associated peaks, between the neutrino events peaks in one hand and the CMEs on the other hand is observed.

Neutrino particles travel at speeds close to that of light regardless of the density of the medium it passes through due to its very small interaction cross-section, whereas the speed of the CME and SEPs are not close to the speed of light. According to this, a small shift in the peaks between each of neutrino events in one hand and CMEs in the other hand, will be true for periods of time in seconds, hours or even days. But since the period of time in the current study is in months this shift should not appear.

The correlation analysis for CME events with the neutrino candidate events as detected from SAGE experiment per month for the years 1996-2007 gave the following results, Table (4-1). A weak negative linear correlation between the number of candidate neutrino events and CME r (115) = -0.085, sig.= 0.366 (> 0.05) of 115 variables for statistically was not significant results.

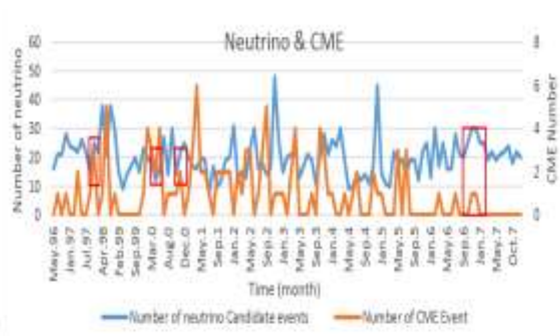


**Fig. 2:** The variation in the number of Candidate Neutrino Events and CME events with time.

### *3.2 The Three Main Regions of Solar Cycle 23*

The three main regions (rising phase (1996-1997), peak (2000) and the down phase (2006-2007)) of the 23rd solar cycle are tested to investigate for a short period relation between any of high energetic solar flares, SEP events and CME events with number of candidate neutrino events. As shown in figures (3,4 and 5) the periods of time where both lines were directly proportional (surrounded by solid red rectangular shapes), while during other periods of time they are inversely proportional (surrounded by dashed rectangular shapes).

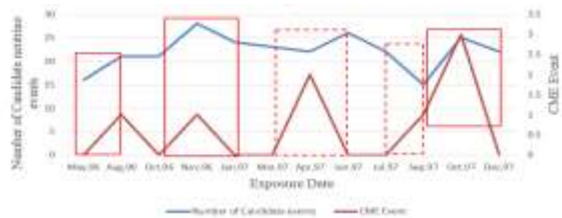


**Fig.3:** shows the variation in the number of Neutrino candidate events and CME events of the years (1996-1997).

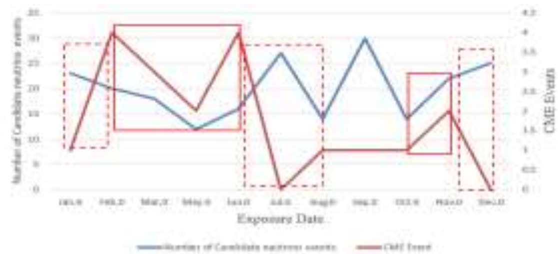


**Fig. 4:** shows the variation in the number of Neutrino candidate events and CME Events of the year 2000.

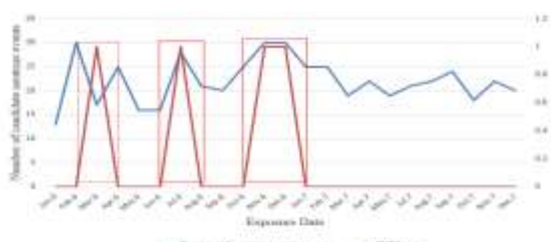

**Fig. 5:** shows the variation in the number of Neutrino candidate events and CME Events of the years (2006-2007).

From table (1), the correlation for the three main regions of solar cycle 23 was:

For the first two years the raising phase a positive weak linear correlation between the number of candidate neutrino events and the number of CME events of r (12) = 0.157. Sig.=0.626 (>0.05) that were statically not of significant results. For the raising phase peak in the year (2000) a negative weak linear correlation between the number of candidate neutrino events and the number of CME events, r (11) = -0.417. Sig.=0.201 (>0.05) that were statistically not significant results. For two years in the down phase (2006-2007) a positive linear correlation between the number of candidate neutrino events and the number of CME events, r (23) = 0.414. Sig. =0.050 (=0.05) that was statistically of a significant result.

**Table 1:** The correlation relation between number of Neutrino candidate events and the CMEs events.

| | | CME Events | | | |
|---|---|---|---|---|---|
| | | Years (1996-2007) | Years (1996-1997) | Year (2000) | Years (2006-2007) |
| Number of Candidate events | Pearson Correlation | -0.085 | 0.157 | -0.417 | 0.414 |
| | Sig. (2-tailed) | 0.366 | 0.626 | 0.201 | 0.050 |
| | N | 115 | 12 | 11 | 23 |

**Table 2.** The coefficients table of the linear regression equation for the number of candidate neutrino events as the dependent's variable and number of CME events as the independent variable.

| | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| CME Event | 5.039 | 2.419 | 0.414 | 2.084 | 0.050 |
| (Constant) | 21.211 | 1.009 | | 21.029 | 0.000 |

A further step was applied to estimate the describing equation by through regression. From table (2) the B value gave the "unstandardized" coefficients that determines the coefficients in the equation (2), and both coefficients were statically significant since their P value (i.e. sig.) was <= 0.05.

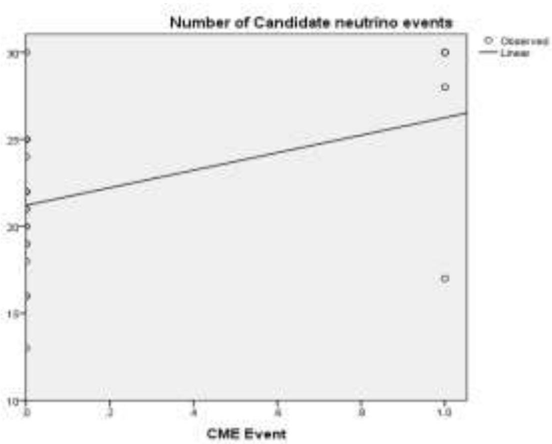


**Fig. 6:** represents the linear relation between the number of Candidate Neutrino Events (dependent variable) and CME events (independent variable).

While Figure (6) graphically shows the linear regression. The linear regression equation is,

$N_v = 21.211 + 5.039 * (N_{CME})$……(2)

Where;

$N_v$ : is the number of neutrino candidate events.

$N_{CME}$ : is the number of CME events.

### *3.3 Yearly Data Categories for Counting Neutrino*

To investigate how the yearly neutrino data are associated with the yearly different solar energetic events, figures (7) and (8) show a comparison between variation in the number of yearly mean value of captured neutrino events from SAGE and the yearly mean value for each of CME and Sunspots separately. As clearly shown in these resulted graphs there are periods of time where both lines are directly proportional (solid red rectangular shapes), while during other periods of time they are inversely proportional (dashed rectangular shapes).

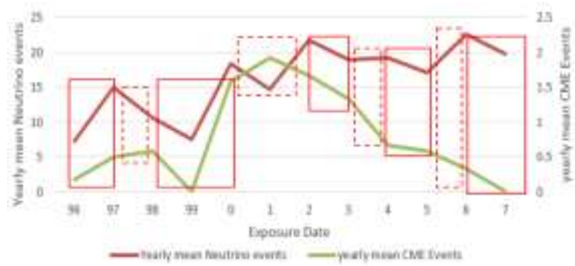


**Fig.7**: shows the comparison between the variation in candidate neutrino events and the yearly mean number of CMEs.

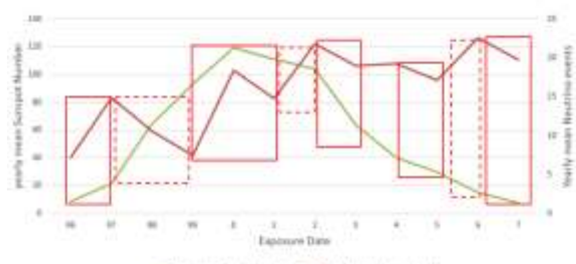


**Fig. 8:** shows a comparison between the variation in candidate neutrino events and the yearly mean number of Sunspots.

The correlation analysis of the yearly mean number CME events with the yearly mean number of solar neutrino candidate events as detected from SAGE experiment for the years 1996-2007 gave the following result, as in Table (3).

A weak positive linear correlation between the yearly mean neutrino events and yearly mean CME events r (12) = 0.369, sig.=0.238 (> 0.05), statistically was not significant results.

A very weak negative linear correlation between the yearly mean neutrino events and yearly mean Sunspot number for 12 variables, r (12) = -0.021, sig.=0.947 (> 0.05) statistically was not of a significant result. According to "Raychaudhuri" the real start of a solar cycle starts before (about 2 years) the period of the relative sunspot minimum number and thus the temperature of the solar core began to growth before the sunspot minimum number, and temperature of the solar core began to reduce before (about one year) the sunspot maximum number [8]. Thus, in the present study, the peak in the solar neutrino could be related to the peaks of the solar cycle activities as in figures (6) and (7).

**Table 3:** The correlation between yearly mean number of neutrino candidate events and the yearly mean number of energetic events of the years (1996-2007).

| | | Yearly mean Neutrino events |
|---|---|---|
| yearly mean CME Events | Pearson Correlation | 0.369 |
| | Sig. (2-tailed) | 0.238 |
| | N | 12 |
| yearly mean Sunspot Number | Pearson Correlation | -0.021 |
| | Sig. (2-tailed) | 0.947 |
| | N | 12 |

The scientists Raychaudhuri (1984) [8], and Bahcal et. al. (1987) [7], separately in them researches compared the rate of neutrino and the sunspot numbers for an entire solar cycle as a function of time (i.e. years); by a direct comparison, they found no significant correlation. Because of the interaction of the solar core to the solar surface, Raychaudhuri, in his study, suggested that such variation in the neutrino may occur only during the sun spot maximum number to sunspot minimum number. Furthermore, he suggested that the biggest solar flare and maximum solar neutrino flux occur simultaneously. Their results are similar to the sunspot yearly mean part of the current study, figure (4-26), and Raychaudhuris' suggestion can explain the reason behind the unexplained outcome results.
The present study used the time scale of months and yearly for two reasons.
First: to escape the complexity of time shift between the solar neutrino, and solar flare neutrino (which are undistinguishable yet by SAGE and many other underground detectors) in one hand and CMEs in other hand.
Second: Gallium experiments do not directly count the neutrino events, but the exposure lasts for 4 to 6 weeks then the Germanium atoms are extracted and processed to know the final number of the candidate neutrino events for that period of time.
Since the present study included both core and solar surface neutrinos, the current results were varied from theirs.
The data analysis of the current study differs from the previous studies in

- Using statistical analysis to find the correlation, then the regression equation is used on the most correlated data to estimate the most descriptive equation in tracking neutrinos generated from solar activities.
- Searching for a relation for a long period of time (1996-2007), by taking the monthly summation for CMEs. While in the other studied the comparison was done for shorter periods and single.

## 4 Conclusions

The final outcome results lead to the following conclusions:
In the scale of months and later scale years for a long period of time (1996-2007), no significant relation was found between CME and solar neutrino events.
For short periods of time (two years or less) and through comparing the three main regions of the solar cycle (rising phase, peak and down phase) with the neutrino events, showed no significant relation between them. Except for years (2006-2007) a weak positive significant linear correlation exists. That leads to the conclusion that the solar core is not the only source for solar neutrino. The complex variation of magnetic fields during CMEs in the solar atmosphere at the down phase of solar cycle 23 is also a source for electron solar neutrinos.
In spite of statistically insignificant relations, the results obtained from graphics Figure (3) to (8) gave signs of the existence of very important relations between the solar neutrino data and the CMEs and the sunspots, but they are puzzling and complicated to explain.
There could be one or two unknown factors behind the variation in the number of emitted neutrinos. The solar magnetic field could be the main factor.
The variation in the number candidate neutrino events with time in scale of years is periodical. And this periodicity is repeated every 2 years, thus it is a “quasi-biennially”.

## References

[1] G. De Wasseige. Search for GeV Neutrinos from Solar Flares with the IceCube Neutrino Observatory. M.A. thesis, Universite Libre de Bruxelles, Belgium., (2014).

[2] G. De Wasseige, P. Evenson, K. Hanson, N. Van Eijndhoven, and K. L. Klein. Evaluation of Expected Solar Flare Neutrino Events in the IceCube Observatory, The 34th International Cosmic Ray Conference, Proceeding of Science, The Hague, Netherlands., 236(2015).

[3] W. H. A. Zaki , and A. Al-Sawad. Tracking the Evolution of Successful Coronal Mass Ejections CMEs, Verlag Publisher, Germany., (2016).

[4] V. N. Gavrin. The Russian-American gallium experiment SAGE, Physics-Uspekh.i, **54(9)**, 941-949, (2011).

[5] D. Fargion Anti-Neutrino Imprint in Solar Neutrino Flare, Physica Scripta., **T12**7, 22-24(2006).

[6] S. S. Salih. Studying and Tracking the Activity of Solar Neutrino for Solar Cycle 23. M.A. thesis, University of Duhok ., (2018).

[7] Jr. R. Davis. A review of measurements of the solar neutrino flux and their variation. Nuclear Physics B - Proceedings Supplements., 48(1–3), 284-298(1996).

[8] P. Raychaudhuri. Solar neutrino data and the 11-year solar activity cycle, Solar Physics., ,**93**, 397-401(1984).

[9] J. N. Bahcall, G. B. Field, and W. H. Press. Is Solar Neutrino Capture Rate Correlated with Sunspot Number?, Astrophysical Journal., **320**, L69-L73(1987).

[10] I. N. Erofeeva, S. I. Lyutov, V. S. Murzin, et al., High Energy Neutrinos from the Solar Flares, Proceedings of the 20th International Cosmic Ray Conference Moscow., **4**, 355(1987).

[11] T. Shirai. Time variation of the solar neutrino fluxes from Super-Kamiokande data, Solar Physics., **222**, 199–201(2004).

[12] P. Raychaudhuri and, K. Ghosh. Time Variations of the solar neutrino flux data from sage and GALLEX-GNO detectors obtained by Rayleigh power spectrum analysis, 29th International Cosmic Ray Conference Pune., **9,** 119-122(2005).

[13] K. Sakurai, H. J. Haubold, T. Shirai. The Variation of the Solar Neutrino Fluxes over Time in the Homestake, GALLEX(GNO) and Super-Kamiokande Experiments, Space Radiation., **5**, 207-216(2008).

[14] B. Aharmim, et. al.. A Search for Astrophysical Burst Signals at the Sudbury Neutrino Observatory, Astroparticle Physics., **55**, 1-7(2014).

[15] B. Aharmim, et al. Search for periodicities in the 8B solar neutrino flux measured by the Sudbury Neutrino Observatory, Phys. Rev. D., **72**, 8(2005).

[16] D. Fargion and P. Oliva, Korea and in IceCube, Cornell University Library, High Energy Astrophysical Phenomena, 5 pages., 2017.

[17] J. N Abdurashitov, V. N. Gavrin, V. V. Gorbachev, P. P. Gurkina, T. V., Ibragimova, A. V. Kalikhov , and et al. Measurement of the solar neutrino capture rate with gallium metal. III. Results for the 2002–2007 data-taking period, Physical Review C., **80(1)**, (2009).

[18] SOHO LASCO CME CATALOG. https://cdaw.gsfc.nasa.gov/CME_list/ .

[19] ERNE Data Finder Applet, https://srl.utu.fi/erne_data/datafinder/df.shtml.

[20] National-center for environmental information NOAA, https://www.ngdc.noaa.gov/stp/space-weather/solardata/solar-features/solar-flares/x-rays/goes/xrs/.

[21] SolarMonitor, 2017, https://www.solarmonitor.org/forecast.php?date=20170426.