**MAJOR X-CLASS SOLAR FLARE FROM EARTH-FACING
ACTIVE REGION AR12887 ON OCTOBER 28, 2021
AND FIRST COSMIC RAY GLE 73 IN SOLAR CYCLE 25**

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This work is dedicated to the 80th anniversary of the discovery of solar cosmic rays on February 28, 1942, and their confirmation a week later on March 7, 1942.

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Abstract

A phenomenological study of the new Ground Level Enhancement GLE 73 of cosmic rays (CRs) on October 28, 2021 is presented in this work. The investigated GLE 73 appears as one of the first major events of the Sun in the new solar cycle 25 (2019–2030). The recent GLE 73 occurred as a result of an X-class solar flare and was measured on the surface of both the Earth (by Neutron Monitors) and PAMELA satellite-borne instruments.

This GLE occurs as a result of massive acceleration of charged particles in the solar corona and interplanetary space. Usually such event provides quite a soft spectrum of energetic particles, but sometimes the spectrum is sufficiently hard so that the initial solar protons can generate secondary nucleons that can be detected as an increase in the cosmic ray flux at ground level. Such exceptional event represents the studied GLE 73. These GLEs of cosmic rays are numbered consecutively from the first events that were detected on February 28, 1942 (GLE 1) and March 7, 1942 (GLE 2) exactly 80 years ago. During the past 80 years of GLE studies some fundamental results of space physics have been achieved.

Analyzing the list of all GLEs registered until now in the period (1942–2021) some characteristics that are important parameters can be determined.

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The quantification of GLEs in different solar cycles is presented by calculating the frequency of GLE occurrence in solar cycles 17–25.

Key words: galactic and solar cosmic rays (CRs) and ground level enhancements (GLEs), solar activity, X-class solar flare

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Introduction. Ground Level Enhancements (GLEs) are sudden increases in the cosmic ray (CR) intensity recorded by ground based detectors. GLEs are invariably associated with large solar flares [1–4] but the acceleration mechanism producing particles of up to tens of GeV is not understood – [Ground Level Enhancements \(csiro.au\)](https://www.csiro.au/ground-level-enhancements). To date there have been 73 GLEs recorded since reliable records began on February 28, 1942 (GLE 1) and a week later on March 7, 1942 (GLE 2) – exactly 80 years ago. The most recent event GLE 73 was recorded on October 28, 2021 and it will be the subject of this study.

For the different cases of ground level enhancements of CRs, the increases in ground based measurements range from a few percent of background to more than 50 times for the maximum GLE event till now on February 23, 1956 (GLE 5) – see <https://gle.oulu.fi/#/>. Here we use the international GLE database hosted by the University of Oulu, Finland. The rate of GLEs would appear to be about one per year but there may be a slight clumping around solar maximums. This issue will also be explored in the present paper on solar cycles 17–24, when GLEs were experimentally recorded. Although the large solar flare is associated with GLE, the flare itself may not be causally related to the production of high-energy protons and heavier nuclei.

Solar Energetic Particle (SEP) events are not rare and energetic protons are produced in common with Coronal Mass Ejections (CMEs) and interplanetary shocks. These protons do not have sufficient energy to produce secondary particles that reach ground level but are clearly observed by spacecrafts. Such CMEs and their associated shocks are most often produced without a solar flare. It is possible that there is a continuum to the acceleration process and that flares are a by-product of the most energetic events. Alternatively, there is a possibility that the flare itself produces a seed population of higher energy protons that are further accelerated to energies sufficient to produce a GLE.

A phenomenological study of the first ground level enhancement of the cosmic rays GLE 73 in the new solar cycle 25 is presented in this work. For this purpose, the solar activity in the period around the occurrence of GLE 73 will be analyzed.

Solar cycle 25. It is the current solar cycle of sunspot activity. It began in December 2019 and it is expected to continue until about 2030. As of April 2018, the Sun showed signs of a reverse magnetic polarity sunspot appearing and beginning of the new solar cycle 25 [5–8]. It is typical during the transition from one cycle to the next to experience a period where sunspots of both polarities exist (during the solar minimum 24/25). The polarward reversed polarity sunspots

suggest that a transition to cycle 25 is in process. The first cycle 25 sunspot may have appeared in early April 2018 or even December 2016 [5].

The first X-class solar flare of the cycle 25 took place on July 3, 2021, peaking at X1.59 (<https://www.spaceweatherlive.com/>).

On July 22, a total of six different active regions were seen on the solar disk for the first time since September 6, 2017, when the previous GLE 72 on September 10, 2017 exploded [9–11].

The second X-class flare of solar cycle 25 erupted on October 28, 2021, producing a CME and a S1 solar radiation storm (<https://www.space.com/>) (Fig. 1A, B). Reports initially predicted that the CME could graze Earth, however, the geomagnetic storm on 30–31 October only reached a moderate Kp index of 4. It was just a geomagnetic disturbance.

A big burst of solar activity on October 28, 2021. One of the largest bursts of solar activity took place on the Sun on October 28, 2021. Then 13 flares from class C, M and X were registered (Fig. 1C).

Almost all the events took place in two local parts of the Sun, in the active regions with numbers AR12887 and AR12891 (Fig. 1A, B), where powerful emissions of magnetic fields and the formation of a significant, about 30, number of sunspots were recorded. It is the magnetic fields that are formed in the depths of the Sun and then thrown onto its surface. For this reason, an increase in the activity of the Sun was expected the day before, however, its power and speed were completely unexpected.

The main active region AR12887 is located in the central sector of the Sun (Fig. 1A, B). Most solar flares associated with CMEs and GLEs are located in the western or central sector of the Sun where the Interplanetary Magnetic Field (IMF) is well connected to the Earth environment. It is rare to observe GLEs associated with flares to the east of the central meridian.

The largest outbreak of October 28, 2021 (Fig. 1A, B, C) was classified as X1.0. At the same time, the Sun is now close to the solar minimum, and, in principle, is not capable of producing extremely large flares. Against this background, the outbreak is unusually large. To assess the originality of what is happening, you can notice that over the past 4 years, since 2018, only two X-class flares have been recorded on the Sun, including the eruption now under consideration. All other events had lower scores.

GLE 73 on October 28, 2021. Such GLE events are characterized by an increase of the count rate of a world set of neutron monitors (NMs) appropriately located. The studied representative of GLE events was observed during 12–18 UT on October 28, 2021 (Fig. 2A, B) (www.nmdb.eu). During the GLE 73 event the magnitude of cosmic-ray flux, as measured by midlatitude and (sub)polar NMs was up to 15% (Fig. 2A, B).

According to space-borne measurements, there were a lot of solar energetic particles present during that time. A neutron detector onboard the PAMELA satellite-borne instrument also registered such increase.

Fig. 1. A. The image from NASA's spacecraft Solar Dynamics Observatory (SDO) shows the X1-class solar flare (in the circle on the central meridian) erupting from a sunspot AR12887 on October 28, 2021. SDO Atmospheric Imaging Assembly (AIA) 131 Angstrom (Image credit: NASA/SDO and the AIA, EVE, and HMI science teams). B. This movie of images from NASA's spacecraft Solar Dynamics Observatory (SDO) shows the X1-class solar flare erupting from a sunspot AR12887 on October 28, 2021. SDO Atmospheric Imaging Assembly (AIA) 304 Angstrom (Image credit: NASA/SDO and the AIA, EVE, and HMI science teams). C. GOES X-ray satellite 1 minute X-ray average in the 1–8 Angstrom passband on October 28, 2021 (from 0 to 24 UT). The 13 flares are clearly visible, as well as the major X1-class solar flare at 15:35 UT, which triggered GLE 73

Fig. 2. A. GLE 73 event on October 28, 2021. The measurements of 28 stations from world set of neutron monitors, located all over the earth, are shown. Source: GLE database (<https://gle.oulu.fi>). B. GLE 73 event on October 28, 2021. The measurements of 7 stations that registered the greatest effect (CALG, DOMB, DOMC, FSMT, PWNK, SOPB, SOPO) are shown. Source: GLE database (<https://gle.oulu.fi>). C. GLE 72 event on September 10, 2017. The measurements of 7 stations that registered the greatest effect (DOMB, DOMC, FSMT, JBGO, SOPB, TERA, THUL) are shown. Source: GLE database (<https://gle.oulu.fi>)

The previous GLE 72 event (4 years ago – on September 10, 2017) [9–11] had a 16% increase (Fig. 2C) (www.nmdb.eu). This allows for a comparison between GLE 72 and GLE 73 events, which turn out to be of almost the same magnitude.

In our opinion, the reason for GLE 73 is related to X-class flare from the Sun on October 28, 2021. This is confirmed by the data from GOES-16 satellite (Fig. 1C). On this day, 13 flares were recorded on the Sun, including ten C-class flares (C1.1, two C1.2, C1.6, C2.3, three C3.2, C3.3, C3.9), two M-class flares (M1.4 and M2.2) and one maximum X-class flare (X1.0) in 15:35:00 UT, which in our understanding is the source of solar CRs. This X1 solar flare is detected also by the GOES Solar Ultraviolet Imager (SUVI). The GOES-16 and 17 satellites each house the SUVI, which is an extreme ultraviolet telescope that detects photons that are not detectable from the Earth's surface.

This type of X1 solar flare can affect Earth's conditions. This solar flare is associated with a strong R3 radio blackout in which high frequency radio communication can be impaired. The NOAA Space Weather Prediction Center (SWPC) is responsible for observing and forecasting such flares.

GLEs in the previous solar cycle 24. Seventy GLEs were registered from February 28, 1942 (GLE 1) to December 13, 2006 (GLE 70). In the cycle 24 (which started in January 2009) the first GLE and sub-GLEs were registered at the beginning of 2012 (Table 1). This time delay (more than 3 years) reflects the specific properties of cycle 23 (in particular, the long lasting solar minimum) and, correspondingly, the unusual character of cycle 24 [12].

Solar cycle 24 has been the weakest in the space era according to the measured sunspot number (SSN). The average SSN over the first 73 months of cycle 24 was ~ 46 , compared to 76 over the same epoch in cycle 23. This corresponds to a decrease of $\sim 40\%$ [13]. The solar activity has already entered into the declining phase, but the number of high-energy solar energetic particle (SEP) events has remained very low.

During cycle 24 there were only two ground level enhancements [1–4, 9–11]: May 17, 2012 and September 10, 2017 (Table 1). While there were 16 GLE events in cycle 23. Thus the reduction in the number of GLEs is significant, much higher than that in SSN. The number of SEP events, emitting particles with energies > 500 MeV, was also higher in cycle 23 [13].

Besides GLEs, four more solar energetic proton events are included in Table 1. Two of them occurred in the beginning of 2012 (January and March) and two in

January 2014 and October 2015. They have a significant increase of the integral proton fluxes with energies > 500 MeV, registered by the data from subpolar neutron monitors. As it was found these events were followed by minor cosmic ray enhancement up to a few percent at several subpolar and high latitude neutron monitors. Nevertheless, these events may contain some contribution to solar cosmic rays in the ground level observations. All four events may be considered sub-GLE events. In the works [1–4] they are called Contenders for GLE, or they are considered quasi GLE (qGLE).

Two cases of Anisotropic Cosmic Ray Enhancement (ACRE) events from June 2015 and August 2018 are also included in Table 1 [14–17]. In the works [14, 16] they are also denoted by ACRE, but they are named Anomalous Cosmic Ray Enhancement or ACRE (not a GLE) [16].

T a b l e 1

List of GLEs, Sub-GLEs and ACREs during solar cycle 24

Event No	Event date		Baseline date (YYMMDD)
Sub-GLE	27 January	2012	120127
Sub-GLE	07 March	2012	120306
GLE 71	17 May	2012	120517
Sub-GLE	06 January	2014	140106
ACRE	07 June	2015	150607
Sub-GLE	29 October	2015	151029
GLE 72	10 September	2017	170910
ACRE	26 August	2018	180826

Distribution of GLEs during solar cycles 17–25 (1942–2021). Analyzing the list of all GLEs (1942–2021) [3, 4] and GLE database (<https://gle.oulu.fi>), we can determine some characteristics, which are important parameters. The quantifying of GLEs in different solar cycles is presented in Table 2. Here the frequency of occurrence of GLEs in solar cycles 17–25 is calculated.

Discussion and conclusion. A major solar flare erupted from the Sun on October 28, 2021 in one of the strongest storms of our star’s current cycle 25. The Sun fired off an X1-class solar flare, its most powerful kind of flare, that peaked at 15:35 GMT (Fig. 1C), according to an alert from the US Space Weather Prediction Center, which tracks space weather events.

This flare originated from a sunspot called AR12887 currently positioned in the centre of the Sun and facing the Earth, based on its location (Fig. 1A, B).

The sunspot was responsible for two moderate M-class solar flares earlier in the day, according to Space Weather: <https://www.SpaceWeather.com>, which also tracks daily solar weather.

A new active sunspot, called AR12891 (Fig. 1A, B – to the east of the central meridian), also recently fired off an M-class flare as it rotated toward the Earth-

T a b l e 2

Quantifying the GLEs in solar cycles 17–25 and the corresponding occurrence rates η for 80-year period (1942–2021)

Solar cycle No	Started	Finished	Duration (years)	Number of GLE	GLE occurrence rate η , yr ⁻¹
17	1933.09.	1944.01.	10.4	(2)	(0.192)
18	1944.01.	1954.02.	10.1	2	0.198
19	1954.02.	1964.10.	10.7	10	0.935
20	1976.05.	1986.08.	10.3	13	1.262
22	1986.08.	1996.08.	10.0	15	1.500
23	1996.09.	2008.12.	12.2	16	1.131
24	2009.01.	2019.12.	11.0	2+4+(2)	0.545(0.727)
25	2019.12.	(2030)	(11)	(1)	

facing side of the Sun. It is currently making its way across the face of the Sun, as seen from Earth, a process that will take about two weeks.

This paper presents a phenomenologically studied last GLE 73 of cosmic rays on October 28, 2021 as the following more important results were obtained:

1. The reason for this GLE is related to X-class flare from the Sun on the same day and time. This is confirmed by the data from GOES-16 satellite (Fig. 1C).
2. A comparison with the two GLEs in the previous 24th solar cycle (Table 1) shows that all three: GLE 71, GLE 72 and GLE 73 have almost the same magnitudes – 17.4% for May 17, 2012, 16% for September 10, 2017 and up to 15% for October 28, 2021 (Fig. 2A, B, C), respectively.
3. This is because solar cycles 24 and 25 are almost comparable and weaker than cycles 19–23 in the beginning of space era. For example, for the previous 23rd solar cycle, the magnitude of GLE 70 from December 13, 2006 is 92%, the magnitude of GLE 69 from January 20, 2005 is $\sim 4800\%$ (International GLE database <https://gle.oulu.fi>).
4. However, the 23rd solar cycle (as well as the 21st and 22nd) is much more powerful, almost two times larger SSN than during the 24 and (maybe) 25 cycles (Solar Terrestrial Activity Report: <https://solen.info/solar/>).
5. To better study the cosmic rays of the Sun over the last ten years, a useful classification in Table 1 of GLEs, Sub-GLEs and ACREs during solar cycle 24 has been made.
6. Analyzing the list of all 73 events of GLEs registered until now in the last 80 years some characteristics and parameters (Duration of solar cycles in

years, Number of GLEs in the cycles, etc.) are determined. The calculation of GLE occurrence rate η , yr^{-1} in different solar cycles is presented in Table 2.

7. Table 2 shows that during the powerful solar cycles 19–23 the GLE occurrence rate η is from 1 to 1.5 yr^{-1} , while during the weaker 24th cycle η falls to 0.545 yr^{-1} . The sunspots number SSN decreases almost as many times, i.e. $\eta \sim \text{SSN}$.
8. During the 17th and 18th solar cycles, the global Neutron Monitor network did not yet exist, so the results are not representative. We can assume that rather weak and medium GLEs were not registered in the early years of observations due to technical and methodical difficulties. If the average occurrence rate of the GLEs is $\eta \geq 1.0 \text{ yr}^{-1}$, the number of omitted events in 1942–1955 could be considerable [4]. Really in 1942–1955 the average GLE occurrence rate is $\eta = 4/14 = 0.286 \text{ yr}^{-1}$.

It should be noted that CRs and GLEs initiate nucleonic-electromagnetic cascades in the atmospheres of Earth, planets and their satellites [18–20], affecting their physicochemical properties and ion balance [21,22]. These events are one of the sources of geophysical disturbances in the Earth’s environment – together with coronal mass ejections and geomagnetic storms [23–27].

The information obtained from our analyses can be used for a number of practical purposes, for example for forecasting space weather and space climate [21].

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REFERENCES

- [1] VELINOV P. I. Y. (2016) On the distribution of Ground Level Enhancement (GLE) events during solar cycles 17–24, *C. R. Acad. Bulg. Sci.*, **69**(7), 897–904.
- [2] VELINOV P. I. Y. (2016) Different groups of ground level enhancements (GLEs). Collective and recurrent GLEs due to solar energetic particles, *C. R. Acad. Bulg. Sci.*, **69**(9), 1195–1202..
- [3] VELINOV P. I. Y. (2016) Expanded classification of solar cosmic ray events causing ground level enhancements (GLEs). Types and groups of GLEs, *C. R. Acad. Bulg. Sci.*, **69**(10), 1341–1350.
- [4] VELINOV P. I. Y. (2016) Extended categorisation of solar energetic particle events rising to ground level enhancements of cosmic rays, *Aerospace Res. Bulg.*, **28**, 3–20. BAS Publishers, Sofia, ISSN:1313-0927.
- [5] PHILLIPS T. (2018) A sunspot from the next solar cycle. SpaceWeather.com. Retrieved 13 December 2018. <https://spaceweatherarchive.com/2018/11/20/a-sunspot-from-the-next-solar-cycle/>.

- [6] VELINOV P. I. Y., Y. TASSEV, D. TOMOVA, L. MATEEV (2018) Analysis and characteristics of unpredictable G2 – moderate geomagnetic storm on April 20, 2018 in solar cycle 24 minimum, *C. R. Acad. Bulg. Sci.*, **71**(10), 1357–1365.
- [7] TASSEV Y., P. I. Y. VELINOV, D. TOMOVA (2019) Forecast of solar activity geo-effectiveness in May 2019. Does the solar cycle 25 begin?, *C. R. Acad. Bulg. Sci.*, **72**(9), 1234–1243.
- [8] VELINOV P. I. Y., Y. TASSEV, D. TOMOVA (2020) Study of unpredicted first geomagnetic storm of 2020, due to interaction of ICME with Near-Earth Space on April 20, *C. R. Acad. Bulg. Sci.*, **73**(11), 1571–1578.
- [9] TASSEV Y., P. I. Y. VELINOV, D. TOMOVA, L. MATEEV (2017) Analysis of extreme solar activity in early September 2017: G4 – Severe geomagnetic storm (07–08.09) and GLE72 (10.09) in solar minimum, *C. R. Acad. Bulg. Sci.*, **70**(10), 1437–1444.
- [10] TOMOVA D., P. I. Y. VELINOV, Y. TASSEV (2017) Energetic evaluation of the largest geomagnetic storms of Solar cycle 24 on March 17, 2015 and September 8, 2017 during Solar maximum and minimum, respectively, *C. R. Acad. Bulg. Sci.*, **70**(11), 1567–1574.
- [11] VELINOV P. I. Y., Y. TASSEV (2018) Long term decrease of stratospheric ionization near the 24-th solar cycle minimum after G4 – Severe geomagnetic storm and GLE72 on September 8–10, 2017, *C. R. Acad. Bulg. Sci.*, **71**(8), 1086–1094.
- [12] ABUNINA M., A. ABUNIN, A. BELOV, S. GAIDASH, Y. TASSEV et al. (2014) Properties of magnetic fields in coronal holes and geoeffective disturbances in solar cycle 24, *C. R. Acad. Bulg. Sci.*, **67**(5), 699–704.
- [13] GOPALSWAMY N., P. MAKELA, S. YASHIRO, H. XIE, S. AKIYAMA et al. (2015) High-energy solar particle events in cycle 24, *J. Phys.: Conf. Ser.*, **642**, 012012, doi: 10.1088/1742-6596/642/1/012012.
- [14] DORMAN L. I., P. I. Y. VELINOV, D. TOMOVA, A. MISHEV, L. MATEEV (2018) Anomalous Cosmic Ray Enhancement (ACRE) during G3 geomagnetic storm on 26.08.2018 in special position of Sun-Earth-Moon system, *Proc. SES 2018, Institute for Space Research and Technology – BAS*, 43–48 (ISSN:2603-3313).
- [15] GIL A., G. KOVALTSOV, V. MIKHAILOV, A. MISHEV, S. POLUIANOV et al. (2019) Anisotropic Cosmic-ray Enhancement (ACRE): Case Studies of 07-Jun-2015 and 26-Aug-2018, *Proc. of Science*, **358**, 36th Int. Cosmic Ray Conf. (ICRC2019) - SH - Solar & Heliospheric, DOI: <https://doi.org/10.22323/1.358.1081>.
- [16] VELINOV P. I. Y. (2019) Anomalous Cosmic Ray Enhancement ACRE (not a GLE) during G3 – Strong geomagnetic storm on August 26, 2018 associated with Forbush effect, *C. R. Acad. Bulg. Sci.*, **72**(3), 375–382.
- [17] VELINOV P. I. Y. (2019) Study of strongest geomagnetic storm for 2018 – the surprise synagermós G3 storm on August 26, 2018 in special position of Sun-Earth-Moon system, *C. R. Acad. Bulg. Sci.*, **72**(2), 226–233.
- [18] VELINOV P. I. Y., M. BUCHVAROVA, L. MATEEV, H. RUDER (2001) Determination of electron production rates caused by cosmic ray particles in ionospheres of terrestrial planets, *Adv. Space Res.*, **27**(11), 1901–1908.
- [19] USOSKIN I., L. DESORGHER (2009) Ionization of the Earth’s atmosphere by solar and galactic cosmic rays, *Acta Geophysica*, **57**(1), 88–101.
- [20] GRONOFF G., C. MERTENS, J. LILENSTEN, L. DESORGHER, E. FLUECKIGER et al. (2011) Ionization processes in the atmosphere of Titan. III – Ionization by high-Z cosmic rays, *Astron. Astrophys. (A&A)*, **529**(5), A143–A146.

- [²¹] TSAGOURI I., A. BELEHAKI, N. BERGEOT, C. CID, V. DELOUILLE et al. (2013) Progress in space weather modeling in an operational environment, J. Space Weather & Space Clim., **3**, A17, 72 pp.
- [²²] KILIFARSKA N., V. BAKMUTOV, G. MELNYK (2020) The Hidden Link Between Earth's Magnetic Field and Climate, Elsevier Sci. Publ., ISBN: 9780128193464, 228 pp.
- [²³] MISHEV A., P. I. Y. VELINOV (2016) Ionization effect due to cosmic rays during Bastille day event – GLE 59 on short and mid time scales, C. R. Acad. Bulg. Sci., **69**(11), 1479–1484.
- [²⁴] MISHEV A., P. I. Y. VELINOV (2015) Determination of medium time scale ionization effects at various altitudes in the stratosphere and troposphere during GLE 70 due to solar cosmic rays on 13.12.2006, C. R. Acad. Bulg. Sci., **68**(11), 1427–1432.
- [²⁵] MUKHTAROV P., R. BOJLOVA (2017) Influence of solar and geomagnetic activity on the ionosphere over Bulgaria, C. R. Acad. Bulg. Sci., **70**(9), 1289–1297.
- [²⁶] BOJLOVA R., P. MUKHTAROV (2019) Response of total electron content to the three G4-severe geomagnetic storms in January 2005 associated with cosmic ray events GLE 68 and GLE 69, C. R. Acad. Bulg. Sci., **72**(9), 1244–1250.
- [²⁷] BOJLOVA R., P. MUKHTAROV (2020) Relationship between the critical frequencies of the ionosphere over Bulgaria and geomagnetic activity, C. R. Acad. Bulg. Sci., **73**(8), 1113–1122.

URL addresses:

Ground Level Enhancements (csiro.au) https://www.atnf.csiro.au/pasa/18_1/dulldig/paper/node6.html

International GLE database (<https://gle.oulu.fi>)

Real-Time Database for high-resolution Neutron Monitor measurements (<https://www.nmdb.eu>)

Solar Terrestrial Activity Report: <https://solen.info/solar/>

Space: <https://www.space.com/>

Space Weather: <https://www.SpaceWeather.com>

Space Weather Live: <https://www.spaceweatherlive.com/>

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Space Weather | NASA: <https://www.nasa.gov/>

Space Weather Prediction Center, NOAA, USA: <https://www.swpc.noaa.gov/>

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