SOLAR FLARE SUPER-EVENTS: WHEN THEY CAN OCCUR AND THE ENERGY LIMITS OF THEIR REALIZATION

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Abstract. For the successful development of terrestrial civilization it is necessary to estimate the space factors, including phenomena on Sun, which can ruin it or cause such catastrophic loss, that the restoration to the initial level can take unacceptably long time. Super-powerful solar flares are the only such phenomena. Therefore an attempt is undertaken to estimate the possibility of such super-event occurrence at this stage of our star evolution. Since solar flare events are the consequence of the newly emerging magnetic fluxes interacting with the already existing magnetic fields of active regions, are investigated the observed cases which lead to the realization of such super-events. From the observations of the maximal magnetic fluxes during the period of reliable solar observations, the conclusion is made that the super-extreme solar flares cannot significantly exceed the most powerful solar flares which have already been observed. On the statistics of the reliable solar cycles the sunspot groups, in which occurred the most powerful solar super-events (August-September 1859 – solar cycle 10; June 1991 – SC 22; October-November 2003 – SC 23) appeared in the periods of the solar magnetic field reorganization between the epochs of "increased" and "lowered" solar activity.

Keywords: Sun, solar activity, solar cycles, solar flare event.

Introduction

The technological development of the terrestrial civilization raise questions about the estimation of the space factors which in principle can destroy our civilization or inflict to it catastrophic loss, after which life on Earth can disappear, or the level of the development of civilization will sharply decline, and restoration to the initial level can take unacceptably long time. Events during the recent decades have given examples of sensible effects of space factors, both heliospheric (asteroid and comet hazards – the fall of fragments of Comet Shoemaker-Levy 9 on Jupiter in November 2001), and possibly galactic: galactic cosmic rays from the supernovas in our galaxy and ultrahard X-ray bursts from nonstationary galactic objects (the event of 27 December 2004).

In this work we limit our study to only to solar activity phenomena, among which the most powerful ones are solar flare events. *We must bear in mind* that the Sun is at present in the middle of the Hertzsprung-Russell diagram's main sequence – in the midway of its development, in a very stable state. Therefore no internal explosive processes can happen, which threaten the very existence of our star.

We examine the most powerful super-extreme solar flare events, both ones that have occurred and theoretically possible, and their potential effects on the near-Earth space which might be fatal for the civilization.

We define the near-Earth space as beginning at altitudes 50–60 km from the Earth's surface and stretching up tens of Earth's radii to the boundary with the heliosphere, and in which the matter filling it is still more connected with our planet than with the Sun or any other astronomical body. It is clear that in this region we mainly deal with natural plasma.

By the term "SPACE WEATHER" at present we denote the state (condition) of the upper layers of the Earth's atmosphere (mesosphere, thermosphere, troposphere), magnetosphere, ionosphere – all layers of the near-Earth space in any given time interval. The direct effect of solar activity phenomena on the near-Earth space is assumed to be evaluated by a five-grade scale according to three indicators (http://www.sec.noaa.gov/NOAAScales), in which the extreme events must have the highest grade in the respective type of influence:

Solar extreme events

The determination of solar extreme events completely and fully depends on those disturbances (significant deviations from the background values) in the near-Earth space or in any point of the heliosphere, produced by solar activity phenomena. Thus, it would be natural to define solar extreme flare events as large powerful solar flares, which are accompanied by the highest possible intensity bursts in all ranges of electromagnetic radiation, and by the most powerful dynamic manifestations of the flare energy release consequences (shock, MHD and surface waves, coronal mass ejections, etc.). After them, the most intense geophysical disturbances must follow as measured by all three indicators, i.e., R5, S5, G5 (Ishkov, 2007). However, the solar proton events (S) and the disturbances of the terrestrial magnetic field (G) strongly depend on the localization of the solar flare event on the visible solar disc. The geomagnetic disturbances and high-energy particles fluxes will be considerably lowered from the most powerful flares near the solar limbs (for example, 4.11.2003 – the largest flare event of solar cycle 23, which occurred on the western limb), since the entire energy of the coronal mass ejection and the maximum of the protons fluxes from these solar flare events will pass by the Earth. On the other hand, even solar flare events of simply large and even average X-ray class with complex structure of energy release, e.g. more than one moment of energy release, which are accompanied by the coronal mass ejections, can lead to interacting interplanetary disturbances which strengthen each other and cause magnetic storms of extreme intensity. The most expressive example is the greatest magnetic storm of the past 23th solar cycle, the extreme storm on November 20, 2003, whose source was the large flare event on November 18, 2003. This flare event included two X-ray bursts of average intensities (M3.9 and M4.5) and a solar filament ejection between them. Each energy release in this event was accompanied by a coronal mass ejection and their interaction led to a sharp increase in the intensity of the magnetic storm. However, its integral estimation corresponds to only a severe magnetic storm, by no means extreme. Therefore it is necessary to distinguish between solar flare extreme events per se and their effects on the near-Earth space.

By a solar extreme flare event, usually a solar flare with emission intensity in the range of standard soft X-ray not less than 10^{-3} Wt·m^{-2} (X-ray class X10) is meant with integrated flux on the average of ≥2 J/m^{-2}, which is accompanied by a rapid coronal mass ejection (V_{CME} ≥ 1500 km/s) and by powerful radio bursts (Gopalswamy at al., 2005). Such solar flares events are accompanied by intensive dynamic radio bursts of II, IV and other types. These flare events, undoubtedly, exert very strong influence on the heliosphere both in the plane of the ecliptic and outside it, including the near-Earth space, if the Earth enters the zone of their action. But no extreme flare event is capable of inflicting to terrestrial civilization irreparable damage.

At present the class of solar flares is evaluated according to the value of the maximum flux of soft X-ray radiation in the standard range. If the maximum flux value of the flare emission is equal to or exceeds 10^{-4} Wt/m^2 , the X-ray is of class X, by an order lower - of class M, and further according to the same scheme are classes C and B. The situation is complicated by the fact that the standard detectors of the X-ray radiation aboard different GOES satellites had different thresholds of saturation, which hampers the straightforward comparisons of flare events. Until 1976 the threshold of the flux intensity was X≥5.4 ($5.4 \cdot 10^{-4}$ Wt/m^2) and therefore the famous, undoubtedly extreme flares on August 4 and 7, 1972 formally had X-ray class X≥5.4. Then, until 1996, the threshold of saturation became already X≥12.5, and afterward and up to now – X≥17.5. Accordingly, the X-ray class of the most powerful flares, whose rate of occurrence exceeded the indicated threshold, was determined tentatively: proportional to the time of the instrument cutoff.

It would be more objective to characterize the X-ray class of such flares by not only the threshold value of the device saturation, but also by the duration of the device cutoff period (τ). Whatever extrapolation, for example linear, for the very strong flares with prolonged saturation can hardly be justified. With such an estimation, the most intense X-ray flares in the entire period of observation were the super-events candidates on June 1 and 6, 1991 (τ = 26 min), and for three more flares of the same AR τ were ≥17min. This was well understood by researchers who first received information about these flares, and class X>12.5 was assigned to all these flares with the indication of the X-ray photometer cutoff time (Preliminary Solar Geophysical Data, № 822-824, June 1991). This was later forgotten and these flares in the literature have X-ray class X12. The extremely large solar flare of the past 23th solar cycle on November 4, 2003 (candidate for a super-event) had X-ray class X≥17.5 (τ = 11 min). According to quite approximate estimates its calculated X-ray class can be X28, and of the most powerful flare during the entire history of solar flare events observations, September 1859 – X40 (calculated from ionospheric observations). Taking account of the X-ray detectors' saturation time and their thresholds, the flare events on June 1 and 6, 1991 were the most intense ones in all times of observation in this range of X-ray radiation.

To characterize the active regions' flare productivity, the flare index XRI (X-ray region index) is used (Gaizauskas, McIntosh, 1984), which is calculated as the sum of the flares of class X and M, with a weight of 1 assigned to X class flares (X9.8 gives 9.8), and a weight of 0.1 to M class flares (M8.3 gives 0.83).

The largest manifestations of spot-forming and flare activity

In order to estimate the greatest possible solar flare event at this stage of our star's evolution, let us examine the largest manifestations of spot-forming and flare activity during the entire history of solar observations. In Table 2 the characteristics are given of the most flare-productive active regions from 1972 to 2012, since the time when it became possible to determine the X-ray class of the solar flares. Also given are the maximum disturbances of the near-Earth space caused by the solar flare events from these active regions.

The active region of June, 1991 is the undoubted leader for all history of solar observation as measured by the quantity and the power of solar flares. The active regions of October 2003 and March 1989 hold the second and third places, respectively. Therefore, we will consider the special features of energy release and the evolutionary characteristics of these sunspot groups, adding to them the sunspot group of

August/September 1859 in which were the most powerful flare events during entire history of solar observations occurred, and the record holder by area sunspot group of April 1947, in order to estimate the most powerful possible flare event at the present stage of the Sun's evolution (Table 3).

The understanding that powerful solar events significantly influence our life first came in the middle of the XIX century when the passing of a very big sunspot group on the visible disk of the Sun was observed in August - September 1859 (Fig. 1). Its area was 2300 msh and apparently it had been passing the visible solar disk for already a second rotation.

Table 1. NOAA Space Weather Scale.

		RADIO BLACKOUT	**S**PE	**G**EOMAGNETIC STORMS
Scale	Descriptor	**R** – X-ray peak brightness by class and by flux (intensity)	**S** – Pr >10 МэВ (intensity)	**G** – MS – Ap(Kp) (intensity)
R1, S1, G1	Minor	≥ M1 (10^{-5}Wt/m^2)	≥ 10 pfu	≥ 48 nT (Kp 5)
R2, S2, G2	Moderate	≥ M5 ($5x10^{-5}$Wt/m^2)	≥ 100 pfu	≥ 80 nT (Kp 6)
R3, S3, G3	Strong	≥ X1 (10^{-4}WT/m^2)	≥ 1000 pfu	≥ 140 nT (Kp 7)
R4, S4, G4	Severe	≥ X10 (10^{-3} WT/m^2)	≥ 10 000 pfu	≥ 240 nT (Kp 8, 9–)
R5, S5, G5	Extreme	≥X20 ($2x10^{-3}$WT/m^2)	≥ 100 000 pfu	≥ 400 nT (Kp 9)

– electromagnetic shock (RADIO BLACKOUT) – the impact of electromagnetic radiation during the development of a solar flare mainly on the ionosphere (R5 – blackout of several hours), which is evaluated according to the intensity of the soft X-ray radiation in the standard range (1 ÷ 8 Å = 12.5 ÷ 1 keV);

– solar proton events (SPE) – arrival to the near-Earth space of the solar charged particles, which affect mainly the radiation situation in the vicinity of the Earth, cause an increase in the electron concentration above the polar caps, disrupting radio communication on the polar routes (S5 –this flux of protons has not been observed so far, the maximum flux of protons was detected in August 1972 – $8.6 \cdot 10^4$ pfu);

– geomagnetic field disturbances (MAGNETIC STORMS) – the consequence of the arrival to the Earth of solar plasma streams with increased density, velocity and temperature with intensive magnetic field (G5 – the magnetic storm with Ap> 400 nT).

Table 2. The most flare-productive AR 1972 – 2012.

№	CMP	AR	φ^0	L^0	Sp max	R, S, G	XRI	M±y
1	09 06 1991	6659	N31	248	2300	R5/S4/G4	>86.5	+2
2	29 10 2003	10486	S17	354	2610	R5/S4/G5	>62.56	+3.5
3	12 03 1989	5395	N34	257	3600	R5/S4/G5	>57.0	-0.5
4	14 09 2005	10808	S09	229	1430	R5/S3/G3	49.21	5.5
5	08 06 1982	3763	S08	086	1270	R4/S2/G2	42.4	+2.5
6	04 07 1974	0433	S14	156	1334	R4/S3/G5	≥41.4	+5.5
7	16 12 1982	4025	S06	089	500	R4/S2/G3	36.7	+3
8	23 03 1991	6555	S23	188	2530	R4/S4/G4	32.6	+1.5
9	15 07 1982	3804	N14	322	2960	R4/S4/G5	31.6	+2.5
10	14 07 1978	1203	N18	170	1600	R5/S2/G2	29.7	-1
11	10 04 2001	9415	S22	359	880	R4/S3/G4	28.73	+1
12	08 08 1989	5629	S17	076	1320	R5/S4/G4	≥26.8	-0.5
13	04 08 1972	0331	N12	010	1330	R5/S4/G5	≥26.0	+3.5
14	11 11 1980	2779	S11	098	2000	R3/S1/G4	25.9	+1
15	28 03 2001	9393	N20	152	2440	R5/S2/G5	>25.74	+1
16	17 05 1990	6063	N34	321	940	R3/S3/G2	23.1	+1
17	12 01 1989	5312	S31	308	1800	R3/S1/G2	22.4	-0.5
18	15 01 2005	10720	N13	179	1630	R4/S3/G4	21.5	+4.5
19	11 12 2006	10930	S06	009	680	R4/S3/G4	21.44	+6.5
20	28 04 1984	4474	S13	334	2160	R5/S3/G3	21.2	+5

CMP - time of the central meridian active region passage; AR - number of the active region in NOAA system; φ^0-average heliolatitude of the active region; L^0 - average Carrington longitude of active region; SP max – maximum sunspot area; XRI - the X-ray flare index (XRI; R, S, G - classes of the strongest events in the near-Earth space from flares in the given active region t; M±y - lag in years relative to the solar cycle maximum (accuracy 0.5 years).

Table 3. Evolutionary and flare characteristics of active regions – generators of the most powerful solar flare events, candidates for solar super-events.

Carrington 520 (N20W12L085, CMP 31,6.08.1859; Sp^{max} = 2300 msh, γ, R2)	**AR6659** (N31L248; CMP 09,5.06.1991) Sp^{max} = 2240 msh; FKC; δ; ***XRI = >86.5***; $X_6^{>12.5}+M_{26}+C_{39}$; $4_1+3_3+2_6+1_{20}+S_{73}$; PFER I (**21h**) 1 – 2.06.1991 – X_1+M_2; PFER II (**46h**) 4 – 6.06 – X_2+M_2; PFER III (**67h**) 9 – 11.06.1991 – X_2+M_{11} PFER IV (**39h**) 13 – 15.06. – X_1+M_8
Greenwich 1488603 (S24.5L084, CMP 07,5.04. 1947 Sp^{max}=6132 msh, R4)	
AR 5395 (N34L257, CMP 12,7.03.1989); Sp^{max} = 3600 msh, FKC, δ; ***XRI >61.5***: $X_{11}^{>17.5}+M_{48}+C_{47}$;$3_5+2_{21}+1_{37}+S_{132}$; PFER I (**42**h) – 6 – 7.03 – $X_2^{>12.5}+M_6^{5.7}$; PFER II (**70**h) – 9 – 12.03 – $X_4^{4.5}+M_{18}^{9.7}$; PFER III (**44**h) – 12 – 14.03 – $X_2^{1.2}+M10^{6.3}$; PFER IV (**48**h) – 16 – 17.03 – $X_3^{6.5}+M_9^{8.4}$	**AR 10486** (S17L283, CMP 29,3.10.03); Sp^{max} = 2610 msh, FKC, δ; ***XRI>62.56:*** $X_7^{>17.5}+M_{16}+C_{16}$; $4_1+3_2+1_7+S_{49}$; PFER (**59h**) – 22 – 24.10 – $X_2^{5.4}+M_6^{9.9;7.6}$; PFER II (**59h**) – 27 – 29.10 – $X_2^{17.4}+M_4^{5;6.7}$; PFER III **(63h)** – 02 – 05.11 – $X_2^{8.3;>17.5}+M_6^{5.3}$

Record of the basic evolutionary and flare characteristics of active regions (Ishkov 2008):

AR - number of the active region in NOAA system; heliocoordinates (latitude, Central Meridian Passage); area Sp^{max} in units of msh (a millionth of the solar hemisphere), evolutionary and magnetic classes of the sunspot group at the moment of maximum development, age in the solar rotations; flare index XRI, number of solar flares of y class X+M, where the lower sign is the number of flares of this class, and the upper sign - the X-ray class of largest flare; number of solar flares of optical importance with the same lower sign and upper sign; date, time, duration and a number of flares of these flare energy release periods (PFER).

The fundamental characteristics of this sunspot group are given in (Newton, 1943). On September 1.09, 1859 the English amateur astronomer R. Carrington was making the regular sketches of sunspots when his attention was drawn by four small bright knots in the mentioned gigantic sunspot group. This was the first observation of a very powerful solar flare (Carrington, 1860). After 17 hours and 40 minutes, serious disturbances continued several hours of the wire telegraph communication (underwater and underground system), were registered in America and Europe. Aurorae were observed in Havana and in Hawaii. With the known time of the maximum of the flare (knots of solar flare in "white" light are visible at the moments of the maximum flare energy release) it is possible to say that the propagation of the disturbance from this flare to the Earth was very short – the second shortest after the August 4, 1972 solar flare event.

It is believed that this was the most powerful solar flare in the entire history of observations which besides happened in a place of a solar disk, convenient for maximum influence on the Earth (W12°). It should be noted that on August 28, 1859 another strong aurora was registered, which was also observed in the equatorial part of Atlantic Ocean. This means that one more flare occurred on August 28 in the same sunspot group, which was not weaker than the event on September 1, since it occurred in a longitudinal interval (~E55°) which was more inconvenient for the influence on the Earth. These were the only two cases when aurora was observed near the equator, which makes it possible to indirectly estimate the magnetic storms from the given flare events as the most powerful ones during the entire history of geomagnetic observations. Thus, this sunspot group produced not less than two super-extreme flare events.

One of the sunspot groups with the biggest area in the last 4 solar cycles, AR5395 (N34L257) was formed on the invisible side of the Sun in the space between two coronal holes (in the previous rotation) and appeared on the eastern limb on March 6, 1989 during a powerful period of the flare energy realization (PFER), continuing to develop. During this PFER I and the following PFER II, powerful flare events of very large duration occurred: the X-ray class X>12,5/3B (*X15*, CME) flare on March 6, which lasted more than 6, and the flare on March 10 (X4.5/3B) which lasted 7.5 hours, and moreover the level X4 was held for not less than 45 minutes. This active region is a good example of the opportunity to track the fast consecutive emergences of four new large bipolar structures (sunspot groups) directly in the active region location (Fig. 2). Each emergence of a new magnetic flux led to PFER (Tab. 3) so that large and middle class flares were occurring all the time while this AR was on the visible part of the solar disk (Ishkov, 2013).

The sunspot group, already in state of the first most powerful period of flare energy release when it appeared on the visible solar disc, was formed from structures I and II (Fig. 2). After March 10 in the middle part of the sunspot group structure III started forming which after March 12 forced the sunspot group rapidly to be extended along its axis from 14° on March 10 to 20° on March 13. Since March 14 structure IV began to form, whose development extended the sunspot group up to 23° by March 17. As the rate of these magnetic structures emergence was more than "evolutionary", each of them had its own period of large flares with duration of about 40 hours.

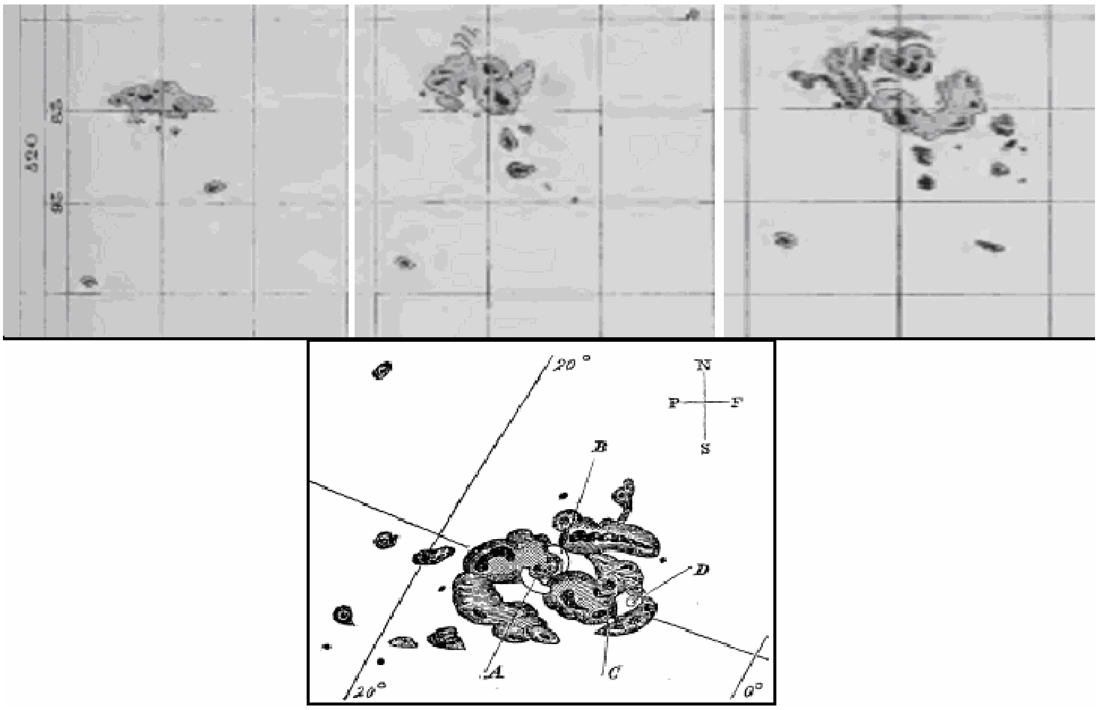

Fig. 1. Sunspot group of August-September 1859: upper row drawings of the sunspot group for 26, 28 and 31 August [Carrington, 1863]; lower figure a drawing of the sunspot group and flare in white light (knots A, B, C, D) of 1 September 1859. [Carrington, 1860].

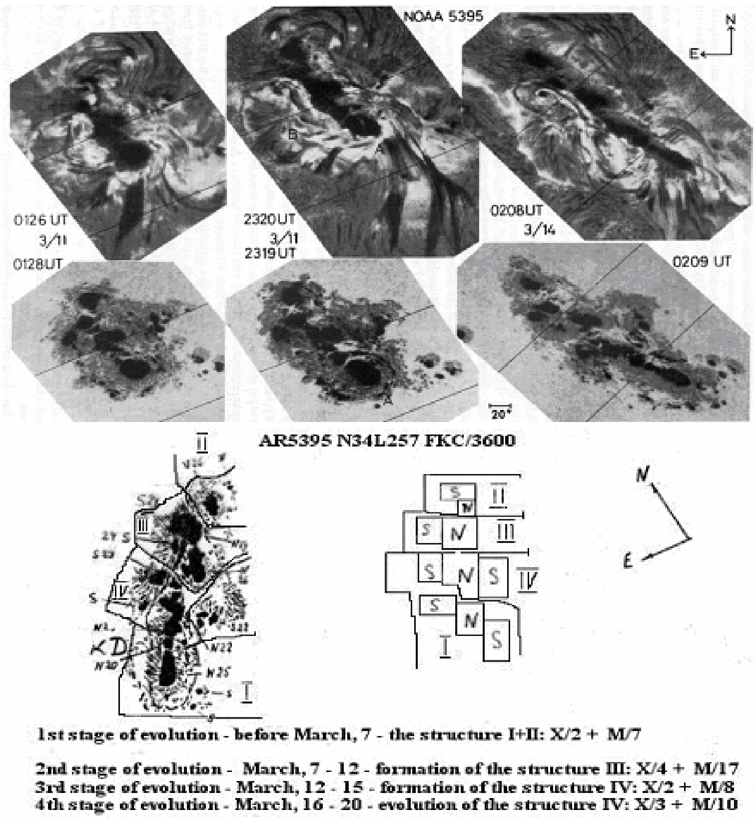

Fig. 2. Images, evolution and flare activity of sunspot group of March 1989, AR 5395. (images of sunspot group by G. Yakunina, GAISH MSU, Moscow). The scheme represents evolutionary sequence of development of this AR.

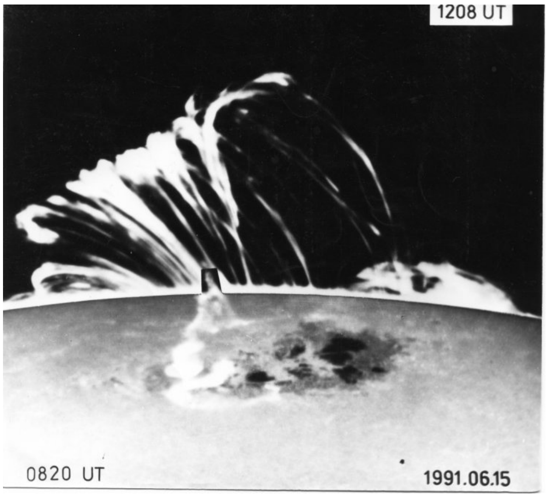

Fig. 3. June 1991 sunspot group (AR6559) near the western limb of Sun, 15.06.1991 (www.spaceweather.com)

Only the second PFER possibly combined two periods, but it is impossible to separate them. The distribution of extreme flares fits well with the advent of new large bipolar structures (under the normal conditions of separate sunspot groups) in the boundaries of the active region.

All four periods of large solar flares began within 24 - 48 hours after the emergence of new magnetic structures. This sunspot group showed the possibility in principle of large magnetic structures emergence in a developed active region with rates ensuring the realization of large flares.

On June 1, 1991 the most powerful flare-active region for the entire history of solar flares observation AR6659 (N31L248) rotated to the visible solar disc. 11 large flares occurred in this group in two weeks, among them 6 solar extreme flare events (Table 1). In the extreme flares of 1 and 6 June (X≥12.5, Φ= 4.44 J m^{-2} and X ≥12.5, Φ=2.55 J·m^{-2}, ^{o}n, respectively) the time of X-ray detectors saturation reached 26 minutes, moreover solar neutron flux was registered during the latter one. One of the most powerful γ- burst and solar neutron flux (^{o}n) was registered in the extreme flare event on June 6 with X-ray class X≥12.5 (Φ =3.53 J·m^{-2}, ^{o}n), with 19 minutes time of detector saturation After the extreme events of June 11 (X≥12.5, Φ =1.81 J·m^{-2}, τ= 17 min) and June 15 (X≥12.5 (Φ =2.85 J·m^{-2}, τ= 22 min) GLE events were registered by the ground-based monitors (Fig.3).

The flare activity reached its greatest concentration in the 23rd solar cycle in the period of October 19 – November 05, 2003 when three large and flare-active sunspot groups were passing together the visible disk of the Sun. However, extreme solar flare events (3) occurred only in AR10486 (S16L286) which came to the visible disk of the Sun on October 21 (Ishkov, 2006). It evolved into a large sunspot group on the invisible side of the Sun (Fig. 4). On October 24-25 the first observed powerful magnetic flux emergence in this active region occurred, which increased the sunspot group area by 800 mvh (Sp=2200 msh). The emergence of the following magnetic flux (October 27-28) increased the sunspot group area to the record for 23rd solar cycle value Sp=2610 msh, which led to two successive extreme flare events, on October 28 (X17.3/4B, Φ =1.80 J·m^{-2}, V_{CME}= 2459 km/s) and on October 29 (X10.0/2B, Φ =0.87 J m^{-2}, V_{CME}= 20^{29} km/s). The result of these events were an extreme solar proton event (S4 – 29500 pfu) and a very big magnetic storm (G5 – Ap=253). Ground-based neutron monitors registered GLE events from both these flare events.

The next period of flare energy release began on November 2 with a flare of class X8.3/2B (GLE, ^{o}n) and continued until November 4 with a flare of the class X>17.5/3B (X28, Φ =2.3 J·m^{-2}, V_{CME}= of 2657 km/s, ^{o}n), the most intense one in the 23rd solar cycle by soft X-ray radiation flux. The last flare events occurred near the western limb of the Sun and did not produce significant effects on the geomagnetic situation; however, the solar proton events occurred of class S3 and S2 (maxima on October 2 and 4, respectively). During this period the space observatories HESSI and KORONAS-F registered 8 hard X-ray bursts in the range 7 – 200 MeV. Three γ-bursts were observed in the extreme flare on October 28, and the generation of considerable background γ-emission began an hour prior to the beginning of the flare in the optical and soft X-ray ranges.

The estimate of the greatest possible solar flare event

The present paradigm in solar physics is that the most probable mechanism of sunspot formation is the "dynamo" mechanism, which produces cyclic recurrence of magnetic flux appearance in the form of active regions with sunspots, sunspot groups, and new, "secondary" magnetic flux, responsible for all manifestations of flare activity. All evolutionary variety of magnetic formations can be considered as the consequence of the emergence of magnetic fluxes. The sizes and lifetimes of magnetic structures depend on the magnitude and rate of emergence of these fluxes. Fig. 5 presents the dependence of magnetic fluxes on the surface of the Sun and other sun-like stars on the luminosity in the range of soft X-ray (Pevtsov et al, 2003). The active region can be considered as the evolution of one or more magnetic fluxes (with magnitude ≥10^{13} Wb) emerging simultaneously or consecutively into the atmosphere of the Sun with medium or low rate of emergence (~10^{7} – 10^{8} Wb/s). During this period the active region evolves from the appearance of the first signs of a plage, through the stage of formation, development and disintegration of the sunspot group, to the complete disappearance of the plage. For a sufficient value of the emerging magnetic flux and/or duration of its emergence, we observe a sunspot group with a growing area. The biggest area of a sunspot group was observed in April 1947 (18th solar cycle), when on the third rotation the area of the sunspot group (Greenwich 1488603) reached the value of 6170 msh. Such "evolutionary" rate of new magnetic fluxes emergence leads to the formation and increase in the areas of sunspots and sunspot groups proper, without producing a significant increase in the flare productivity.

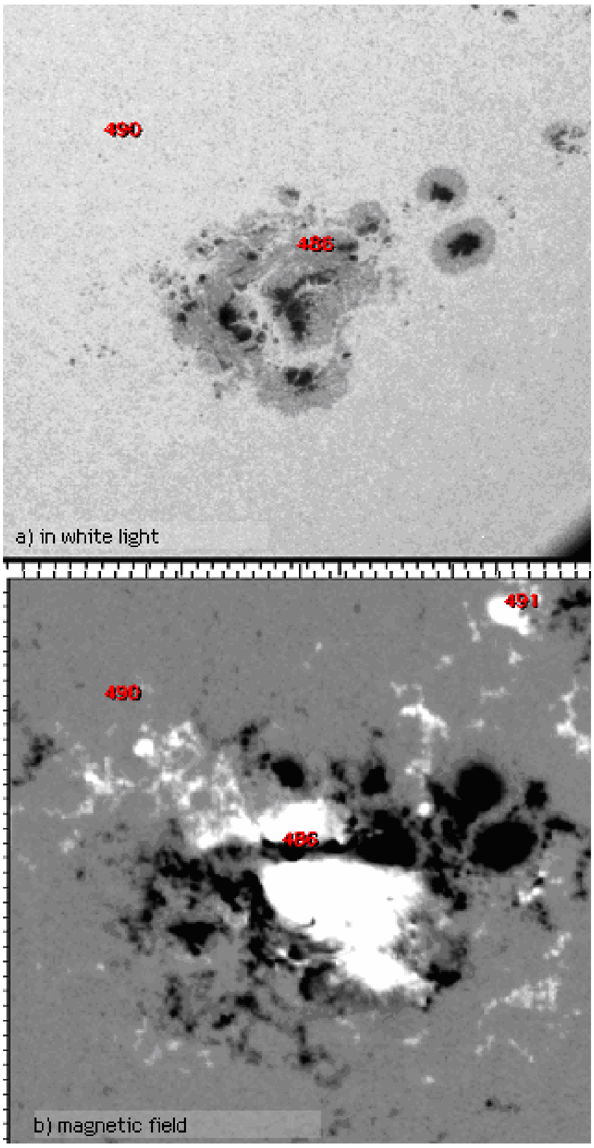

Fig. 4. October 2003 active region (AR 10486) picture taken on October 30, 2003: a) in white light (top), b) magnetic field (below), SOHO MDI.

The occurrence of large solar flares is an independent process inside the general evolution of an active region (Ishkov, 2001). This physical process has a very distinct beginning – the emergence of new magnetic flux inside the active region; maximum – the period during which a series of large and middle power flares occur; end – complete realization of the new emerging magnetic flux energy. Limited in the time, this process can accelerate the evolution of the active region, but, in the general case, this effect can be considered unessential, since only the energy brought namely by the new magnetic flux is expended. The statistically most substantiated time for a flare series preparation is the interval of 1 – 2 days since the first signs of new magnetic flux. For the realization of large geoeffective flares it is necessary that the new emerging magnetic flux is sufficient to large (> 10^{13} Wb) and the rate of its emergence is not less than 10^9 Wb/s (Ishkov, 2001). Therefore, for evaluating the most powerful possible flare event at this stage of Sun's evolution, it is necessary to assume that the maximum magnetic flux, derived from the observations, was emerging in the developed, very large, compact sunspot groups with a rate not less than 10^9 Wb/s.

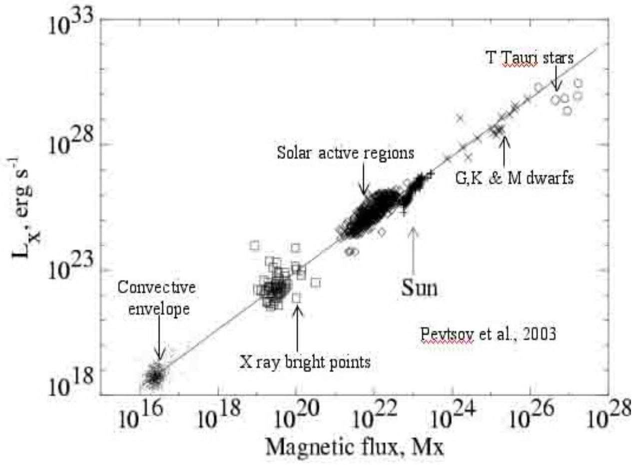

Fig. 5. Dependence of magnetic fluxes on the surface of the Sun and stars on which very powerful flare events are observed, on the luminosity in the range of soft X-radiation [Pevtsov et al, 2003].

The reviewed examples allow making power estimates of the most highly productive flare-active sunspot groups in which the most powerful flare events for all history of solar observations occurred.

(Gopalswamy et al.,2005) made an assessment of all types of energy for sunspot group AR10486 (October – November 2003):

volume ~ of 10^{31} cm^3 (300 x 300 x 300 $arcsec^3$),

potential energy (PE) ~ 4.57 x10^{33} erg,

total magnetic energy ~ of 2 x PE ~ 9.2 x10^{33} erg,

free energy ~ 4.6 x10^{33} erg.

Kinetic energy of the coronal mass ejection (ECME) ~ 1.2 x 10^{33} erg, i.e., ~1/4 of free magnetic energy is taken away by the CME.

The sum of all other forms of energy is an order of magnitude lower than ECME (Emslie et al., 2004; Thomas et al., 2005). We remind that the luminosity of the Sun is 3.83x10^{33} ergs/s.

For other considered sunspots groups, June 1991 and August – September 1859p the distribution of energies with approximately equal volume of the active region will have similar values. For AR 5395, March 1989 (Sp=3600 msh), the value of free energy will increase to 6 x 10^{33} ergs. The limit of the magnetic flux of the "evolutionary" type on the Sun which formed the April 1947 sunspot group is 1.8x10^{23} Mx that gives the value 1.1x10^{34} erg for free energy. If one assumes that such magnetic flux is of "flare" type with the rate of the emergence 10^{17} Mx/s and is realized in one flare, its total energy can be 3 x 10^{34} ergs. If the energy which was emitted in the Carrington`s flare and in the flare on 4.11.2003 (Emslie et al., 2012) was ~2.8x10^{33} -10^{34} ergs, the conclusion can be made that **super-extreme solar flares cannot significantly exceed the most powerful flares already occurred in the period of scientific observations.**

Conclusion

The scenario of solar cyclicity which follows from reliable (1849 – 2014) series of Wolf number is steady; the cycles of solar activity have sufficiently rigid characteristics and, based on this statistics, don't allow violation of the development scenario (Ishkov, 2013). All reliable cycles of solar activity are divided into the epochs (of five solar cycles) of "lowered" (12 – 16 cycles) and "increased" (18 – 22 cycles) solar activity, between which during ~ 1.5 solar cycles a regular change of the magnetic field generation regimes in the spot-forming zone of the Sun occurs. These epochs principally differ in the populations of the sunspot groups: the smoothed average values of the sunspot group areas in the epoch of "lowered" solar activity are almost twice less than in the epoch of "increased" activity. Inside the epochs, undoubtedly, all observational rules work, including the Gnevyshev – Ohl′ rule. The first epoch of "lowered" SA has already been observed in 12 – 16 solar cycles. A similar following period begins with the current 24th cycle and, with a high probability, will also last 5 sunspot cycles, when the low and the average amplitude solar cycles will be observed. Basic cycles of the reorganization periods were cycles 11, 17, and 23. Rich observation data are available for the last solar cycle (23) which provided its detailed investigation. The "strangeness" of the transition period began already in the maximum phase of solar cycle 22 and continued all the way to the beginning of an increasing phase of the current cycle 24.

Among the most significant signs of magnetic field reconstruction the only violation of the Gnevyshev – Ohl′ rule observed during the reliable cycles, and the tightened phase of the minimum with a very large number of spotless days can be noted. The most convincing phenomenon of the transition period became decrease in the umbral magnetic field strength observed between 1999 and 2010 (12 years) (Livingston, Penn, 2012), which reflects the restructuring of the magnetic field to the conditions to the following epoch of "lowered" solar activity. It can be speculated that in the solar cycle 17 – a basic transitional solar cycle from an epoch of the "lowered" solar activity to an epoch "increased" activity – the reverse process occurred of growth of the magnetic field strength in sunspots umbrae. A possible consequence of these processes was the appearance during the growth phase of solar cycle18 of gigantic sunspot groups, the biggest of which was Greenwich 1488603 (Sp_{max} = 6170 msh). Based on the statistics of reliable solar cycles, it can be supposed that the period of magnetic field reorganization from "increased" to "lowered" solar activity covers a part of the preceding solar cycle (22, 23 and 10, 11), and the transition period from "lowered" to "increased" activity – a part of the following cycle (17, 18). In that case all candidates for solar flare super-events occurred in periods of change of the magnetic field generation in the spot-forming zone of the Sun (27.08 – 2.09.1859 – 10 SC, 1 - 15.06.1991 – 22 SC, 28.10 – 4.11.2003 – 23 SC).

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