Attention! **Article "Periods of "lowered" and "increased" solar activity: observant special features and key facts" by Ishkov V.N. is under the Table.**

Table. Cycles of Solar Activity 1-24

Number of cycle	Year of cycle beginning	W^*_{min}	Year of cycle max	Year of cycle min	W^*_{max}	Cycle duration, year	Increase branch, year	Decrease branch, year
	1610.8		*1615.5*			*8.2*	*4.7*	*3.5*
	1619.0		1626.0			15.0	*7.0*	8.0
	1634.0		1639.5			11.0	5.5	*5.5*
	1645.0		1649.0			*10.0*	*4.0*	*6.0*
	1655.0		1660.0			*11.0*	*5.0*	*6.0*
	1666.0		1675.0			*13.5*	*4.5*	*9.0*
	1679.5		1685.0			*10.0*	*5.5*	*4.5*
	1689.5		1693.0			*8.5*	*3.5*	*5.0*
	1698.0		1705.5			*14.0*	*7.5*	*6.5*
	1712.0		1718.2			*11.5*	*6.2*	*5.3*
	1723.5		1727.5			*10.5*	*4.0*	*6.5*
	1734.0		1738.7			*11.0*	*4.7*	*6.3*
	1745.0		1738.7		92.6	10.2	5.3	4.9
1	1755 III	8.4	1761 VI	1766 V	86.5	11.25	6.25	5.0
2	1766 VI	11.2	1769 IX	1775 V	115.8	9.0	3.25	5.75
3	1755 VI	7.2	1778 V	1784 VIII	158.5	9.25	2.92	6.33
4	1784 IX	9.5	1788 II	1798 IV	141.2	13.67	3.42	10.25
5	1798 V	3.2	1805 II	1810 VII	49.2	12.25	6.75	5.5
6	1810 VIII	0.0	1816 IV	1823 IV	48.7	12.75	5.67	7.08
7	1823 V	0.1	1829 XI	1833 X	71.7	10.50	6.50	4.0
8	1833 IX	7.3	1837 III	1843 VI	146.9	9.67	3.33	6.33
9	1843 VII	10.5	1848 II	1855 XI	131.6	12.42	4.58	7.83
10	**1855 XII**	**3.2**	**1860 II**	**1867 II**	**97.9**	**11.42**	**4.17**	**7.25**
11	**1867 III**	**5.2**	**1870 VIII**	**1878 XI**	**140.5**	**11.92**	**3.42**	**8.50**
12	**1878 XII**	**2.2**	**1883 XII**	**1890 II**	**74.6**	**11.33**	**5.0**	**6.33**
13	**1890 III**	**5.0**	**1894 1**	**1901 XII**	**87.9**	**12.08**	**3.83**	**8.25**
14	**1902 I**	**2.6**	**1906 II**	**1913 VII**	**64.2**	**11.67**	**4.08**	**7.59**
15	**1913 VIII**	**1.5**	**1917 VIII**	**1923 VII**	**105.4**	**10.08**	**4.0**	**6.08**
16	**1923 VIII**	**5.6**	**1928 IV**	**1933 VIII**	**78.1**	**10.25**	**4.67**	**5.58**
17	**1933 IX**	**3.4**	**1937 IV**	**1944 I**	**119.2**	**10.5**	**3.58**	**6.92**
18	**1944 II**	**7.7**	**1947 V**	**1954 III**	**151.8**	**10.25**	**3.25**	**7.00**
19	**1954 IV**	**3.4**	**1958 III**	**1964 IX**	**201.3**	**10.42**	**3.92**	**6.50**
20	**1964 X**	**9.6**	**1968 XI**	**1976 VI**	**110.6**	**11.83**	**4.08**	**7.75**
21	**1976 VI**	**12.2**	**1979 XII**	**1986 VIII**	**164.5**	**10.25**	**3.50**	**6.75**
22	**1986 IX**	**12.3**	**1989 VII**	**1996 V**	**158.11**	**9.58**	**2.92**	**6.66**
23	**1996 VI**	**8.0**	**2000 IV**	**2008 XII**	**120.7**	**12.7**	**3.83**	**8.87**
24	**2009 I**	**1.7**	**2014 IV**	*2021 IV-IX*	**81.9**	*12*	**5.4**	*7*

W* - smoothed in 13 months relative number of sunspots. Reliable solar cycles are in **boldface** isolated, by **italics** – forecasted values and hypothetical characteristics of cycles to the numbered series (1610-1755). **Dark-blue** color isolated the solar cycles of the epoch of "lowered" solar activity; **violet** – the solar cycles of the epoch of "increased" solar activity; **red** - the solar cycles of transition periods. Cycles of solar activity 8 and 9 can be considered as the "conditionally reliable".

Periods of “lowered” and “increased” solar activity: observant special features and key facts

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Abstract. The modern period of solar activity (SA) decrease put on the agenda the studying the characteristics of the solar cyclicity, using only reliable series of relative sunspot numbers (timeline in ~180 – 16 solar cycles). These statistics leads to the scenario of the regular changes of magnetic field in the solar convection zone generation regime in the transition from the epoch of the "increased“ SA (8 – 10 and 18 – 22) to the epoch of the "lowered" SA and vice versa-from the epoch of the "lowered" to “increased" SA.

1. Introduction. At present moment the statistics of Wolf number series observations makes it possible to investigate the scenario of SA cycles, its property, characteristic and rule of the development on a reliable (1849 – 2014) series of Wolf numbers (Fig. 1) on the time scale in ~165 years – 14 total solar cycles (SCs). It is necessary to note that for such studies of SCs characteristics we in principle cannot use the restored series (1755 – 1848), since the reliable and restored series of the Wolf numbers have completely different spectral characteristics and significantly differ in the statistical parameters [Ishkov, Shibaev, 2005, 2012].

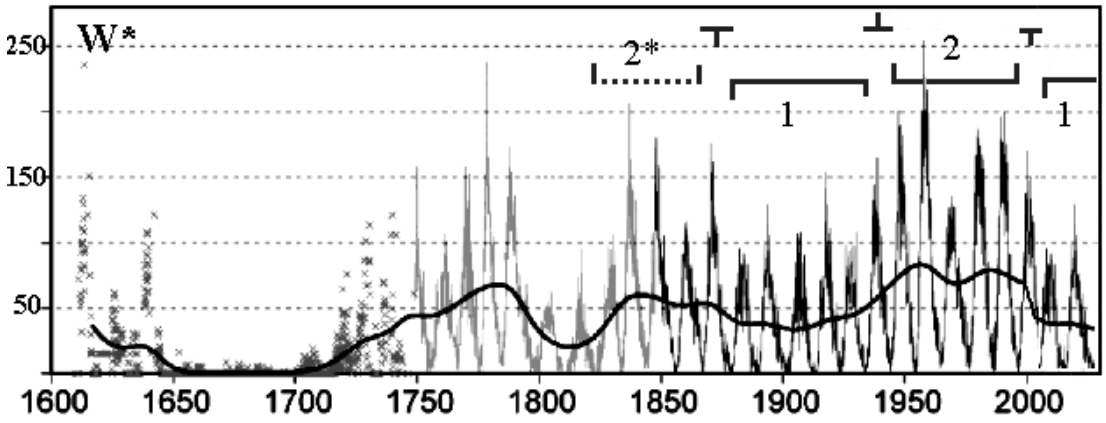

Fig. 1. Reliable (black) series of the relative sunspots numbers with the boundaries of the structural epochs of “lowered” (1) and “increased” (2) solar activity with the transition periods between them are shown. Probable epochs of “increased” solar activity (2*), which includes solar cycles 10 – 6. Probable cycle of solar activity 25th is added. The transformed drawing from Wikipedia – http://en.wikipedia.org/wiki/Sunspot.

From the comparison of reliable and restored series it escapes:
− the nature of the behavior “instantaneous” frequencies and envelopes in interval of 1749 – 1849 strongly differs from a reliable series;
− an increase in the length of a series conducts to worsening in the permission of some significant spectral characteristics (usually vice versa);
− absence or the essential distortion “high-frequency” part of the spectrum.

As shown in the work [Shibaev, Ishkov, 2012], for the reliable cycles is present inverse correlation (−0.658) between the duration of the rising branch SC and the value of the maximum (hence Waldmeyer's rule) and absence of correlation (0.055) between the descending branch SC and the value of maximum. Another nature these connections bear for the restored cycles, where still the stronger inverse correlation (−0.898) between the first parameters it passes into the positive (+0.466) correlation for the second. Furthermore, by the consequence of poor restoration is the fact that in all reliable SCs the ratio of the cycle duration to the duration of the descending branch the more than 2, i.e., the rising branch is always less than the branch of the decrease, while of 9 restored

SC, the rising branch exceeded the descending branch in third SCs. From the comparison of the joint properties of the separate 11-year restored and reliable SCs in the first only three (3, 8 and 9) SCs most closely satisfy the characteristics of the reliable SCs. Therefore in the statistics of reliable SCs it is possible to conditionally include cycles of solar activity 8th and 9th, thus increasing statistics to 16 solar cycles (~180 years).

A reliable series of the sunspots relative numbers shows surprising constancy in the basic manifestations of separate 11- and 22- year SCs the development [Ishkov and Shibaev, 2005] and the structure of its cyclic recurrence, on this statistics (16 solar cycles), implies the periodic change of the epochs of "lowered" (cycles 12th – 16th) and "increased" (18th – 22nd) SA. Between these epochs are observed transition periods (11th, 23rd and 17th), during which changes the nature of spot-forming activity, i.e., the regimes of magnetic field generation in the spot-forming zone of the Sun. Observations show that last two SC (22nd and 23rd) were sufficiently uncommon according to their characteristics and into some of degree disrupted the prevailing picture of the SC development [Ishkov, 2012]. Current 24th SC is developed as the cycle of low value, whose flare activity substantially lower than all previous SC of the Space Age.

2. **Epoch of "increased" solar activity.** The reliable series of the Wolf numbers begins from last cycle (10) of the epoch of "increased" SA (SCs 6 – 10) *and observant data, practically they be absent besides strictly the Wolf numbers.* It is possible to note that inclusion in the statistics of solar cycles 8th and 9th, "the most plausible" from those restored, does not spoil the scenario in question, and they can be included in examination in the subsequent works. The second reliable epoch of "increased" SA includes 5 SCs (18 – 22), which became highest according to the numbers of Wolf and flare activity among the reliable cycles of SA. This epoch includes one super-cycle (19), three high (W*≥135 of − cycles 18th, 21st, and 22nd) and one SC of average value (85< W*< 135 – 20th), in which flare activity was at the high level, compared with the adjacent high solar cycles. Very important circumstance is the fact that space solar and interplanetary space research began in this epoch. Therefore the basic volume of knowledge about the solar activity is fallen precisely for this epoch of "increased" SA and transition period to the epoch of "lowered" (23) SA.

For a reliable epoch of "increased" SA the number of large sunspot groups with a complexes magnetic configuration significantly grows and, as a result, the number large and powerful solar flare events sharply grow. Parameters of the "increased" SA epoch solar cycles are specified in table 1.1. Fundamental characteristics these solar cycles (on the average) are the following:

− the higher initial values W*min (9.24);

– are shorter the duration of solar cycles (10.44^{y});

– the shortest rising branches (less than 3^{y});

– one and two apical phases of maximum, moreover the first peak is usually the maximum of cycle in the Wolf numbers (W*max), and the second coincides with the maximum of flare activity;

– of the descending branch sufficiently prolonged (6.96^{y}), but the phases of the minimum between high SCs are very short (34.25^{m}.). However, the phase of the minimum between SC of middle value (20) and high (21) proved to be anomalously (for this epoch) extended (69^{m});

– a quantity of spotless days around the phase of the minimum (or from the maximum to the maximum) in average 305^{d};

− the more extended zone of sunspot-formation ± of 45º (Fig. 2);

− the relative percentage of larger sunspots is significantly increased, the number of sunspot groups with the areas of ≥1000 msh in all SCs – 487 and the average summary smoothed area of the sunspot groups in curve maximum ~2100 msh [Janssen, 2014] (Fig. 3).

– the maximum value of a polar magnetic field (usually in 5 years after a polarity reversal, on solar cycles 20th and 21st) – ±250 mcT [Svalgaard, Kamide, 2012]

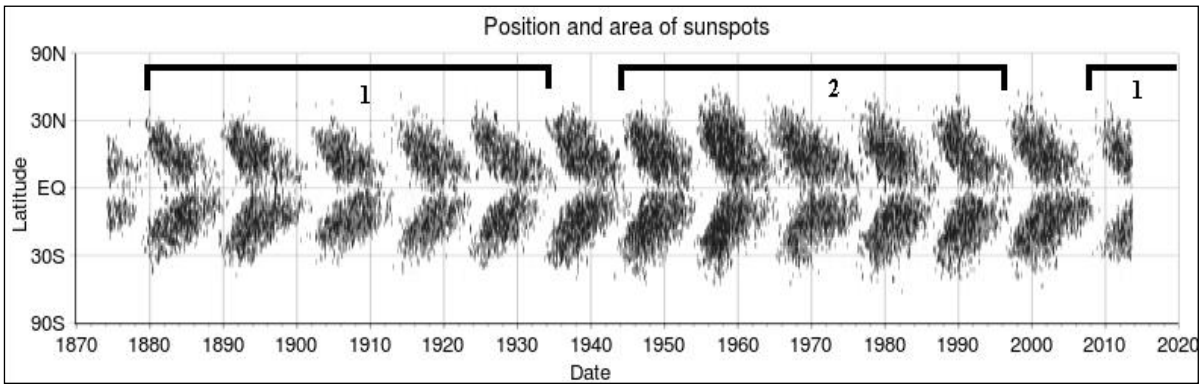

Fig. 2. Diagram of butterflies for position and area of sunspots with the boundaries of the structural epochs of "lowered" (1) and "increased" (2) solar activity. The transformed drawing from Wikipedia – http://en.wikipedia.org/wiki/Sunspot.

Table 1. The solar cycles of the Wolf number reliable series for the epochs of"increased" and "lowered" SA and transition periods of solar magnetic field reconstruction

N	T_0	W^*_m	T_M	T_e	W^*_M	$T_Y\uparrow$	$T_Y\downarrow$	T_Y	$T1_m$	$T2_m$	Sp_{less}
1.1. The solar cycles of the reliable epoch of "increased" SA											
18	1944 II	7.7	1947 V	1954 III	151.8	3.2	7.0	10.2	33^m	33^m	444
19	1954 IV	3.4	1958 III	1964 IX	201.3	3.9	6.5	10.4	33^m	38^m	221
20	1964 X	9.6	1968 XI	1976 VI	110.6	4.1	7.8	11.8	38^m	69^m	269
21	1976 VI	12.2	1979 XII	1986 VIII	164.5	3.5	6.8	10.2	69^m	33^m	*273*
22	1986 IX	12.3	1989 VII	1996 V	158.1	2.9	6.7	9.6	33^m	40^m	*308*
Σ		9.2			157.26	3.52	6.96	10.44	41.2^m		302
1.2. The solar cycles of the reliable epochs of "lowered" SA											
12	1878 XII	2.2	1883 XII	1890 II	74.6	5.0	6.3	11.3	65^m	59^m	732
13	1890 III	5.0	1894 I	1901 II	87.9	4.5	8.2	12.1	59^m	77^m	937
14	1902 I	2.6	1906 II	1913 VII	64.2	4.1	7.6	11.7	77^m	59^m	1045
15	1913 VIII	1.5	1917 VIII	1923 VII	105.4	4.0	6.1	10.1	59^m	48^m	526
16	1923 VIII	5.6	1928 IV	1933 VIII	78.1	4.7	5.6	10.3	48^m	54^m	666
Σ		3.4			82.44	4.5	6.5	10.9	61^m		781
24	2009 I	1.7	2013 XI-14II	2020 V-IX	72	5±0.2	5.9	11.3	68m	59^m	
1.3. The solar cycles of the reliable periods of solar activity reorganization											
10	1855XII	3.2	1860 II	1867 II	97.9	4.17	7.25	11.42	38^m	34^m	402
11	**1867 III**	**5.2**	**1870 VIII**	**1878 XI**	**140.5**	**3.42**	**8.50**	**11.92**	**34^m**	**65^m**	**1025**
16	1923 VIII	5.6	1928 IV	1933VIII	78.1	4.7	5.6	10.3	48^m	54^m	666
17	**1933 IX**	**3.4**	**1937 IV**	**1944 I**	**119.2**	**3.6**	**6.9**	**10.5**	**54^m**	**33^m**	**262**
22	1986 IX	12.3	1989 VII	1996 V	158.1	2.9	6.7	9.6	33^m	40^m	308
23	**1996 VI**	**8.0**	**2000 IV**	**2008 XII**	**120.7**	**3.8**	**8.9**	**12.7**	**40^m**	**68^m**	**821**

T_0 – began SCs; W^*_m – initial value of the smoothed Wolf numbers; T_M – the time of maximum SCs; W^*_M – maximum value of the smoothed Wolf numbers; $T_Y\uparrow$ − the duration of the rise branch in the years; $T_Y\downarrow$ − the duration of the decrease branch in the years; T_Y – duration SCs in the years; $T1_m$, $T2_m$ – the length of the minimum phase before and after this SC in the months; Sp_{less} – a quantity of spotless days in the corresponding phases of minima; Σ – average values on the epochs. Basic solar cycles of transition periods are highlighted in bold type.

3. Epochs of "lowered" solar activity. The first epoch of "lowered" SA includes 5 SC (Table 1.2), three of which were low (W*≤80 – cycles 12th, 14th, 16th) and two average values (13th, 15th). The second epoch of "lowered" SA begins from current 24th SC. During these epochs small, quiet, short-lived sunspot groups with a simple magnetic configuration prevail, level of flare activity is lowered (for 24th SC). The number of powerful solar flare events significantly smaller.

The main characteristics of "lowered" SA epoch solar cycles in comparison with "increased" SA epoch, (on the average):

− the lower initial values W*min (3.38);

− their large duration, (11^{y});

– are more prolonged, ($4{,}5^{y}$) the branch of rise;

– multimodal of a maximum phases for low solar cycles and an accurate single-peak for solar cycles of average size;

– are shorter the branch of the decrease (6.5^{y});

− the narrower zone of sunspot-formation on the latitude of ±35°;

– a quantity of spotless days around the minimum phase – 781^{d};

− as can be seen from Fig. 3, the average smoothed area of the sunspot groups of ~1200 msh;

− the number of the sunspot groups with the areas of ≥1000 msh in all cycles of epoch – 147 [Janssen, 2004] without SC 24th;

– the tightened phases of the minimum between the SC (61^{m}) and, especially, before low SC, and in two cases of three (23–24 and 13–14) – the most extensive phases of the minimum;

– the maximum value of the polar magnetic field of ±100 mcT [Svalgaard, Kamide, 2012].

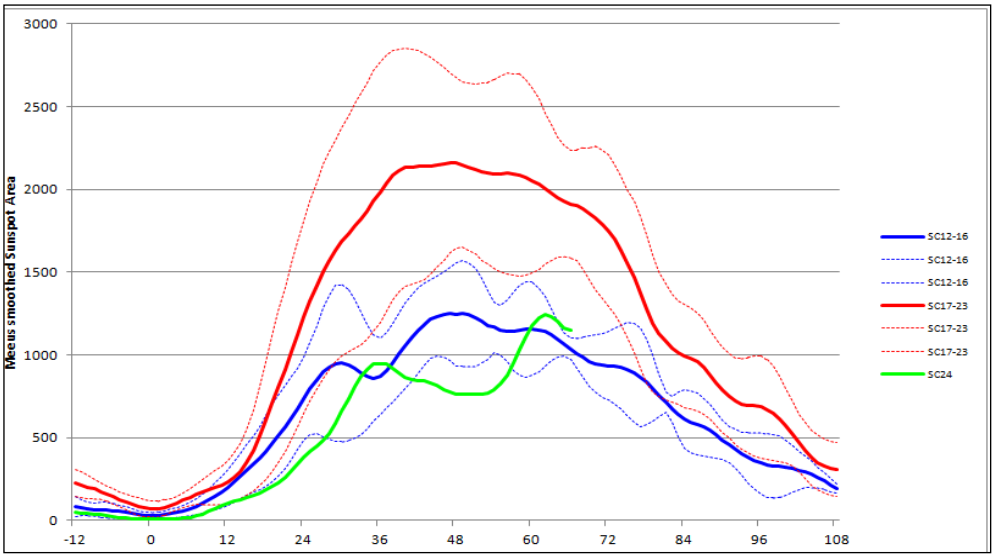

Fig. 3. Smoothed average areas of sunspots group for the epoch of "increased" (red curve) and for the epoch of "lowered" SA (blue curve) with the boundaries of the spread of values. The first curve besides SC 17 – 23, that somewhat possible reduces the values of areas the epoch of "increased" SA. Green curve isolated current 24 SC. Figure from http://users.telenet.be/j.janssens/SC24web/SC24.html

4. Periods of the solar magnetic field reorganization between the epochs of "increased" and "lowered" SA.

Before each such epoch there is a change of a magnetic field generation mode in a sunspot-forming zone of the Sun and conducts to essentially different picture of sunspot group formation (Fig. 3). The reorganization periods, which last 1±0.5 SC, lean on one basic solar cycle, but include, as showed 22 – 23 SCs, and the adjacent parts of the neighboring SCs when processes of a mode change begin or continue. It should be noted that these statistics during the transition from "lowered" to "increased" SA starts in the previous basic SC (10 – **11** and 22 – **23**), and the periods of transition from "increased" to "lowered" – continue in the following (17 – 18) SC.

Table 1.3 gives the basic parameters SC of reorganization periods. In reliable SCs this first period, apparently, could be observed in cycle 11^{th} (pour data), when occurred reconstruction of the magnetic field generation regime to the first reliable epoch of "lowered" SA. In a cycle 17th the

period of magnetic fields reorganization by an epoch of "increased" SA and as a possible consequence, on a growth branch of the 18th solar cycle for the first time and the only time for all the time of SA observation, there were sunspot groups of the gigantic areas (4 – $6 \cdot 10^3$ msh) was appeared. The second period of magnetic field reconstruction to the epoch of "lowered" SA began from maximum 22nd and on the end of 23rd cycles.

By the most probable signs of this reconstruction into 22nd and 23th SC of next:

– appearance on 22nd SC rising and maximum phases of the large flare-active sunspot groups on the high latitudes ($\geq 35°$);

– the realization of the most powerful solar flares in the phase of maximum;

– the complete absence of the X-ray flares class X (after October 1992) on the descending phase;

– the only in a sunspot reliable series case of the Gnevyshev-Ohl' rule violation;

– a drop in the tension of magnetic field in the umbra of sunspots in 2000 – 2012 (Fig. 4) because of significantly increased quantity of small sunspot groups [Nagovitsyn, et al, 2012];

– the maximum value of the polar magnetic field of ±200 mcT with a gradual decrease to 150 mcT at the beginning of the rising phase in SC 24th [Svalgaard, Kamide, 2012]

In both periods of reconstruction to the "lowered" SA strongly tightened branches of decrease (8.5 and 8.9 years) were observed and as a possible consequence, the quantity of the spotless days round a minimum phase sharply increased and made 1025^d (cycles 11 – 12) and 821^d (cycles 23 – 24). Before an epoch of "increased" SA this parameter sharply decreased – 262^d (cycles 17 – 18).

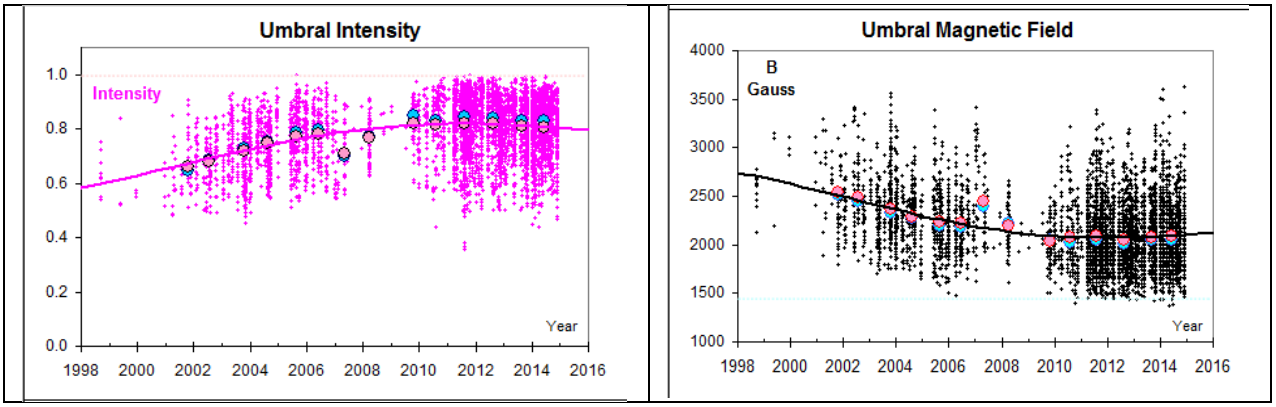

Fig. 4. Drop in the tension of magnetic field (left figure) and, correspondingly, an increase in the intensity in the umbra of sunspots (right figure) according to the observations on the observatory Kitt- Peak. Given in March 2015. http://www.leif.org/research/Livingston%20and%20Penn.png

5. **Discussion.** A reliable series of relative sunspot numbers gives the chance on new to look at the scenario of solar cyclicity. 11-year solar cycles are grouped in the families by forming an epochs of "lowered" and "increased" SA (~ on 5 cycles) which significantly differ from each other in parameters, evolutionary characteristics and manifestations of sunspot-forming activity. During epochs of "lowered" SA the average smoothed areas of sunspot groups are essentially lower; the number of sunspot groups big size and complexes on a magnetic configuration significantly decreases.

The consequence of this, as show the current 24th cycle, is noticeable reduction in the flare activity and, in particular, the observed significant decrease of large solar flares quantity [Ishkov, 2012]. Within the epoch's framework, on this statistics undoubtedly are occurred the observant rules of SC development, including such, as the Gnevyshev – Ohl' rule, the rule of the most powerful flare events on the decrease phases concentration. At the same time, the latter two SCs (22nd, 23rd) brought many observant surprises in their development, which designated how it is possible to now understand, the sequential period of the sunspot-formation regime reorganization.

Returning to other two transition periods, it is possible to note that they all were accompanied by the uncommon phenomena, among which the strongly tightened minimums, and the significant decrease of the parameter q= SU/S (ratio of the umbra area to the area of entire sunspot), which reached the observant minimum at the beginning of the 30's 20 of century, i.e., at the beginning of the 17th SC [Bludova et al,

2014], and the appearance of gigantic areas sunspot groups in the first half of cycle 18th, and the decrease of polar magnetic field during of 23rd SC. Furthermore, all known extreme solar flare super-events (VIII – IX of 1859 into 10th SC; VI of 1991 into 22nd SC; X – XI of 2003 into 23rd SC) they were occurrence precisely in the transition periods. The isolation of such transition periods can help to understand the physical picture of the solar activity development cycles. If the processes, connected with the theory of solar dynamo, are critical for the cyclic recurrence of SA, then appears the sufficiently rigid requirement of its realization – cyclic change of the solar magnetic field generation regime in the zone of the sunspots formation every five solar cycles.

The periods of the sunspot-forming activity reconstruction on these statistics, occupy the time interval of ~1.5 cycles, seizing adjacent with supporting solar cycles, and they ensure "calm" activity of the Sun inside each epoch at its level of activity. During the last epoch of "increased" began the era of space experiments with the great possibilities of the SA observations the diverse manifestations in all ranges of electromagnetic and corpuscular radiation. Practically all, that we know about the Sun, the interplanetary space and the sun-earth connections, all background values and statistical inferences relate precisely to this epoch (SCs 19 – 22) and period of transition from the regime of "increased" to the regime of "lowered" SA (cycles 22 – 23). Obtained data during this period, understanding possible change in the physical characteristics both entire Sun and nature of flare activity strongly enlarged. At present according to this scenario the Sun entered the second epoch of "lowered" SA, the study by which, practically, only begins. In the last phase of the minimum (cycles 23rd – 24th) we for the first time obtained background characteristics on the present of the quiet Sun, which was reconstructed to the epoch of unknown thus far to us "lowered" solar activity.

6. Conclusions. The statistics of reliable solar cycles (9 – 24) it is already sufficient in order to make the first conclusions about the fine structure of solar cyclicity, and the surprises of last passed SC (22nd, 23rd) make it possible to begin the consideration of transition periods. The solar cycles are grouped into the epochs of "lowered" and "increased" solar activity, about 5 SC, separate period of 1 – 1.5 SCs, when occurs reconstruction of the magnetic field generation regime on in the spot-forming region of the solar convective zone to the appropriate epoch. Epochs of "lowered" SA characterized by greater proportion of small, quiet sunspot groups and, accordingly, lowered flare activity. At low cycles significantly reduces the number of powerful solar flare events and, as a consequence, leads to a small number of severe and strong magnetic storms, but dramatically increases the number and duration of relatively quiet geomagnetic periods.

In the epochs of "increased" SA significantly increases the amount of magnetic fluxes with rapid evolution, which leads to the appearance of large flare-active regions, and there is a full set of powerful events to the Sun and in the near-Earth space. In these epochs the observant rules of the SC development and their alternation strictly work. In the transition periods can appear deviations from the observant rules and be achieved, apparently, the most extreme flare events (27.08 – 2.09. 1859 – 10th SC, 1 – 15.06.1991 – 22nd SC; 28.10 – 4.11.2003 – 23rd SC), including extreme solar proton event (proton fluxes $>10^4$ pfu) – of 10 registered events 9 were occurred in SC 22nd and 23rd, i.e., such SPE are improbable inside the epochs.

The current 24^{th} solar cycle will be low and beginning of the second epoch of "lowered" SA with all resultant consequences:

– the most powerful flare events will occur on the descending phase (2016 – 2018);

– 25th SC there will be that above current with size W*~100 – 120;

– SCs 24 – 28 will make the next epoch of "lowered" SA with realization of low and average size solar cycles.

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