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Characteristic Features of the Cyclic Change of Solar Activity after 1610

Angel D. Bonov

The most characteristic feature of solar activity is its change in the course of time. The basic 11-year cycle was discovered by Schwabe during the past century.

After defining the relative number of solar spots of $R=K(10g+f)$, and collecting observations concerning them since 1610, Wolf determined more precisely the mean duration of the 11-year cycle. He noticed an interesting feature in the cyclic curve of the mean annual relative numbers of the solar spots: the consistent 11-year cycles form groups of two successive cycles, one of which is higher and the other one is lower. From this fact he drew the conclusion that there is a double cycle or a 22-year one (according to present terminology). Later on Turner [1] adduced arguments concerning the reality of the 22-year cycle.

The existence of the 22-year cycle became universally acknowledged only after the discovery of Hale's and Nicholson's [2] law of the change of sign of the magnetic polarity of solar spots. According to this law, the sign of the magnetic polarity of the bipolar groups changes in both hemispheres of the Sun (the Northern and the Southern ones) at the transition from one 11-year cycle to the next one.

In our opinion the change of sign of the magnetic polarity determines the special significance and the role of the 22-year cycle in the cyclic change of solar activity [3].

On using the Zürich numbering of the 11-year cycles and Wolf's mean annual numbers after 1700, Гневышев and Оль [4] pointed out that the even and odd 11-year cycles are closely connected with one another. They form an entity — the 22-year cycle. This is quite evident, for example, from [5], [6] and [7]. Indeed, the even and odd 11-year cycles cannot be separated from one another. *Their separation will mean to neglect the 22-year cycle whose existence is beyond dispute.*

Taking into consideration the fact that the interval from minimum to maximum (the growth — t) of the 11-year cycle is a parameter with which the basic cycle characteristics are closely connected, as pointed out by

Waldmeier [8], we calculate the sum $t_{2n}+t_{2n+1}$ for all 22-year cycles after 1610: (—12, —11), (—10, —9), ... (0, 1), (2, 3), ... (16, 17), (18, 19). Grouping them together two by two, as shown in Table 1, we calculate the value of the relation

$$S=\frac{(t_{2n}+t_{2n+1})'}{(t_{2n}+t_{2n+1})''}.$$

Table 1

Groups of 22-year cycles	22-year cycles	$t_{2n}+t_{2n+1}$	S
I	—12, —11	11.7	1.23
	—10, — 9	9.5	
II	— 8, — 7	14.0	1.56
	— 6, — 5	9.0	
III	— 4, — 3	13.7	1.57
	— 2, — 1	8.7	
IV	0, 1	11.6	1.90
	2, 3	6.1	
V	4, 5	10.3	0.84
	6, 7	12.4	
VI	8, 9	7.9	1.05
	10, 11	7.5	
VII	12, 13	9.5	1.02
	14, 15	9.3	
VIII	16, 17	8.4	1.25
	18, 19	6.7	

The change in S is presented graphically on Fig. 1. It shows directly some characteristic features of the cyclic change of solar activity after 1610, which is characterized by the index S.

The consistent 22-year cycles after 1610, grouped together two by two, form a new type of cycle, which may be conventionally called a 44-year cycle: (—12, —11, —10, —9), (—8, —7, —6, —5), (—4, —3, —2, —1), (0, 1, 2, 3), (4, 5, 6, 7), (8, 9, 10, 11), (12, 13, 14, 15), (16, 17, 18, 19). Безрукова [9], [10] has found indications for the existence of a 44-year cycle. But the data which she has used are few and they call in question the existence of the 44-year cycle.

Fig. 1 shows that the 44-year cycle is outlined clearly after 1610, which marked the beginning of toalescopic observations of solar spots.

In a paper which will be published we find an interesting dependence between the elements of the two 22-year cycles, which form the 44-year cycle. Further on we shall call them first and second 22-year cycles.

Let us introduce the following symbols: $\tau_{2n}+\tau_{2n+1}$ — the sum (in years) from the descending part of the two 11-year cycles, which form the first 22-year cycle; T''_{22} — the duration in years of the second 22-year cycle; ΣR_M — the sum of the mean annual Wolf numbers in the years of the maximum of the 11-year cycles, which form the 44-year cycle; ΣR — the sum of the mean annual Wolf numbers for the four 11-year cycles.

We compile Table 2 by using the data in [11].

Fig. 2 shows a definite dependence between $\tau_{2n}+\tau_{2n+1}$ and T''_{22}. For the correlation coefficient between these quantities, calculated from the data in Table 2, we obtain the value

$$r[\tau_{2n}+\tau_{2n+1},\ T''_{22}=+0.936.$$

In the above-mentioned investigation of the 44-year cycles after 1610 we point out that this value of r is not due to a mere chance. It is a consequence of the existence of a regression between $\tau_{2n}+\tau_{2n+1}$ and T''_{22} which is expressed by the equation

$$T''_{22}=+9.6+0.92(\tau_{2n}+\tau_{2n+1}).$$

Table 2 shows that the values of the quantities ΣR_M and ΣR for the consistent 44-year cycles alternate according to an interesting regularity: lower values of these quantities are followed by higher values, after which they are followed anew by lower values. If this regularity is preserved in the future, for the next 44-year cycle (20, 21, 22, 23) ΣR_M and ΣR will have considerably lower values in comparison with the 44-year cycle (16, 17, 18, 19). Actually, during the next 44-year cycle the activity of the Sun will be considerably lower in comparison with its level during the 44-year cycle (16, 17, 18, 19).

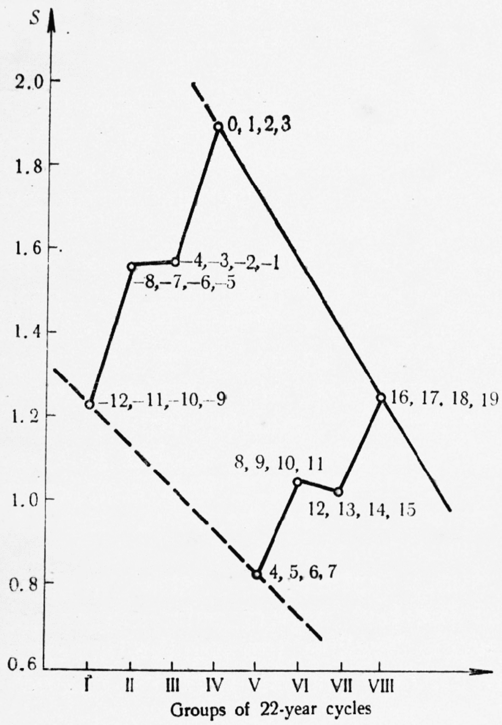

Fig. 1

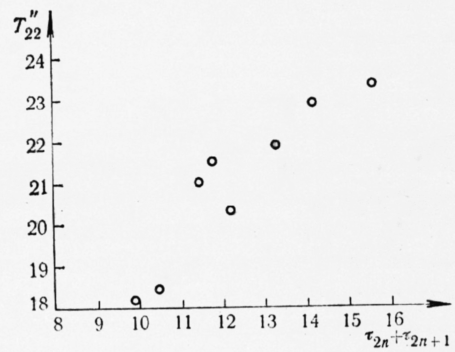

Fig. 2

Fig. 1 shows that after 1610 the activity of the Sun, characterized with the index S, is presented by two *supersecular cycles:*

The first one begins in 1610 and ends in 1784,7. Its duration is 174 roughly years.

The second one begins in 1784,7 and ends in 1964,7. Its duration is 180 years.

The duration of the 11-year cycle, as well as the duration of the 22-year cycle, is not constant. That is why the duration of the supersecular

Table **2**

44-year cycle	$\tau_{2n}+\tau_{2n+1}$	T''_{22}	ΣR_M	ΣR
—12, —11, —10, —9	11.5	21.0		
— 8, — 7, — 6, —5	10.5	18.5		
— 4, — 3, — 2, —1	11.8	21.5	354	1673
0, 1, 2, 3	9.9	18.2	430	2158
4, 5, 6, 7	15.6	23.3	296	1772
8, 9, 10, 11	14.2	22.9	498	2535
12, 13, 14, 15	13.3	21.9	316	1677
16, 17, 18, 19	12.2	20.4	534	2752

cycle discovered by us cannot be constant either. We call it conventionally a 180-year cycle.

Fig. 1 shows that the supersecular cycle consists of eight 22-year cycles or of four consecutive 44-year cycles. It is evident that the consecutive 44-year cycles are grouped together two by two and form a new cycle, which may conventionally be called an 88-year cycle. In fact this is the well-known "secular" cycle.

Гневышев, Оль [4] noticed that during the 22-year cycle (4, 5) there appeared a 'catastrophic' decrease of solar activity. We believe this is due to the transitional epoch in the supersecular run of solar activity. Actually, it comes at the end of the one supersecular cycle and at the beginning of the next one. This is evident from Table 1.

Taking into consideration that the new supersecular cycle begins with the 22-year cycle (20, 21), we draw the conclusion that there will soon come a new 'catastrophic' decrease of solar activity. This conclusion is confirmed to a certain extent on the basis of the following observations: the maximum of the 11-year cycle No. 20 is approximately two times smaller than the maximum of the 11-year cycle No. 19. Actually, until the end of the 20th century the solar activity will be considerably weaker in comparison with its level during the 22-year cycle (18, 19). This conclusion is in agreement with the conclusion drawn on the basis of the 44-year cycle.

Fig. 1 shows clearly another interesting feature: the straight lines which join the beginnings and the ends of the two supersecular cycles are approximately parallel and have a considerable incline toward the abscissa axis. This fact points out that the 180-year cycle is a part of a much longer supersecular cycle of solar activity.

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Характерные особенности циклического изменения активности Солнца после 1610 г.

А. Д. Бонов

(Резюме)

Наиболее характерной особенностью активности Солнца является ее циклическое изменение во времени. Основной цикл — одиннадцатилетний. Закон смены знака магнитной полярности биполярных групп солнечных пятен доказывает существование двадцатидвухлетнего цикла. Он состоит из двух последовательных циклов с четным и нечетным номером согласно Цюрихской номерации.

Принимая во внимание, что нарастание (t) одиннадцатилетнего цикла является параметром, тесно связанным с характеристиками этого цикла, мы вычисляем для всех двадцатидвухлетних циклов после 1610 г. величины

$$S = \frac{(t_{2n}+t_{2n+1})'}{(t_{2n}+t_{2n+1})''}$$

и группируем их по двум последовательным циклам.

Изменение S, представленное на рис. 1, показывает интересные особенности цикличности солнечной активности после 1610 г.

1. Хорошо прослеживается „сорокачетырехлетний цикл".
2. Два последовательных сорокачетырехлетних цикла группируются в один цикл со средней продолжительностью 88 лет („вековой" цикл).
3. После 1610 г. активность Солнца представлена двумя сверхвековыми циклами (сверхвековые „стовосемьдесятлетние" циклы, как их называем условно).
4. После окончания одного „стовосемьдесятлетнего" цикла и начала следующего активность Солнца катастрофически падает. До конца XX века активность Солнца будет значительно слабее по сравнению с ее уровнем в двадцатидвухлетнем цикле [18, 19].
5. Видно, что стовосемьдесятлетний цикл является частью цикла солнечной активности много большей продолжительности.

Department of Astronomy
Bulgarian Academy of Sciences

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