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PHENOMENOLOGICAL REPRESENTATION OF THE OCCURRENCE AND DEVELOPMENT OF THE LONG - TERM SOLAR ACTIVITY

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Abstract

The solar activity is presented as a set of the non-stationary power and dynamic processes periodically arising in the external layers of the Sun.

Keywords: The Sun, solar activity, the 11-year cycles

Various authors ambiguously approach to the problem of the nature of solar activity depending on properties of concrete phenomena chosen from a set of observable structures of various layers of the solar atmosphere. Their development is usually based upon those or other indexes of the solar activity. Therefore the various phenomena, such as structure and properties of the sunspots, prominences, fibrils, various types of flashes, features of the magnetic field, and many other parameters - are usually treated as several characteristics revealing the display of the solar activity. Actually, the observable processes are the only real display of the global course, origin, development and carrying out of the active structures from internal areas of the solar convection zone, and also their penetration into the external layers of the atmosphere. Long-term development and distribution of these structures provide that slow process which usually is perceived by researchers as the true display of the solar activity. However this approach does not allow revealing the reason of the global disturbances of the solar internal structure.

Actually, the nature of the solar activity is caused by the global magnetic hydrodynamics of the outer solar layers. Also it is impossible to exclude the solar system barycenter movement inside the Sun ($\Delta = (0.01 \div 2.19)\ R_o$,) on dynamics of its internal areas [Morozova, et al., 1999].

According to the theoretical results, obtained due to the development of the hydrodynamics applied to the rotating planets, and to the Sun as well, in the external layers of all these bodies a meridian current arises in which the inertial oscillation with a frequency ω at the latitude approaching the certain value, when the Coriolis parameter $f=2\omega_z$, (ω_z is the radial component) is equal ω, turns to the inertial oscillation described near this latitude by the Airy equation (Monin, 1972, 1988; Gill, 1986)

$$y'' - xy = 0 .$$

Practically it occurs at latitudes near 45-50°.

For various values of the argument the Airy function may be expressed by the Bessel functions. Following Abramowitz and Stegun, (1979) for the positive values of the argument

$$Ai(x) = \frac{1}{3}\cdot x^{\frac{1}{2}}\cdot\left[I_{-1/3}\left(\frac{2}{3}\cdot x^{\frac{3}{2}}\right) - I_{1/3}\left(\frac{2}{3}\cdot x^{\frac{3}{2}}\right)\right]$$

and for the negative

$$Ai(-x) = \frac{1}{3}\cdot x^{\frac{1}{2}}\cdot\left[J_{-1/3}\left(\frac{2}{3}\cdot x^{\frac{3}{2}}\right) + J_{1/3}\left(\frac{2}{3}\cdot x^{\frac{3}{2}}\right)\right]$$

The integral presentation of the Airy function looks like

$$Ai(\pm x) = \frac{1}{\pi}\cdot\int_0^{\infty}\cos\left(\frac{t^3}{3}\pm x\cdot t\right)\cdot dt .$$

According to the existing models, the solar convection zone is a large part of its atmosphere, where the meridian circulation occurs from the pole to the equator at the bottom level (about 0,7 $R_\odot$) and from the equator to the pole at the external part.

After the solar neutrino flux variations have been noticed (Haubold and Gerth 1983, Lanzerotti and Raghavan 1981, Sakurai 1979, Cleveland et al. 1998, Davis 2004) ; it has also been noticed the possible existence of their flux variations over the period equal to the duration of the solar activity cycle and its quasi-biennial changes, seen fig. 1 (Sakurai 1979). However the usual method of the spectral analysis cannot provide the correct detection of the character of these variations. The problem arises because the Airy functions are the quasiperiodical functions with decreasing (for negative argument) periods and amplitudes (Shefov and Semenov, 2006). Comparison of the cyclic variations and aperiodic quasi-biennial variations of the solar activity revealed by the F10.7 radio emission fluxes (Fadel et al. 2002), and later also by the sunspot numbers (Kononovich and Shefov, 2003) together with the neutrino fluxes data presented by Sakurai (1979) showed, that the variations occur in the ante phase. The observed variations of the neutrino fluxes occur for 1.4 years later with correlation factor about – 0.85 [Kononovich and Shefov, 2006]. This strongly testifies that such variations may be described by the Airy function and their source is located inside the Sun because the

reflected signal reaches the photosphere faster from the level at 0.7 solar radii, than from the more dense internal areas of the Sun about 0.2 solar radii where the neutrino particles are borne.

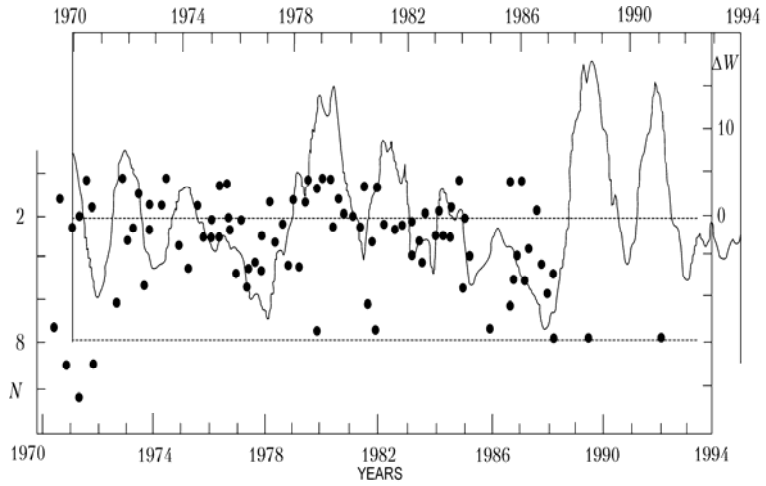


Figure 1. Comparison of the cyclic aperiodic (quasibiennual) variations of the solar activity ΔW (dark line) and the solar neutrino flux N (black dots) after [Sakurai, 1979], filtered by [Kononovich and Shefov, 2006].

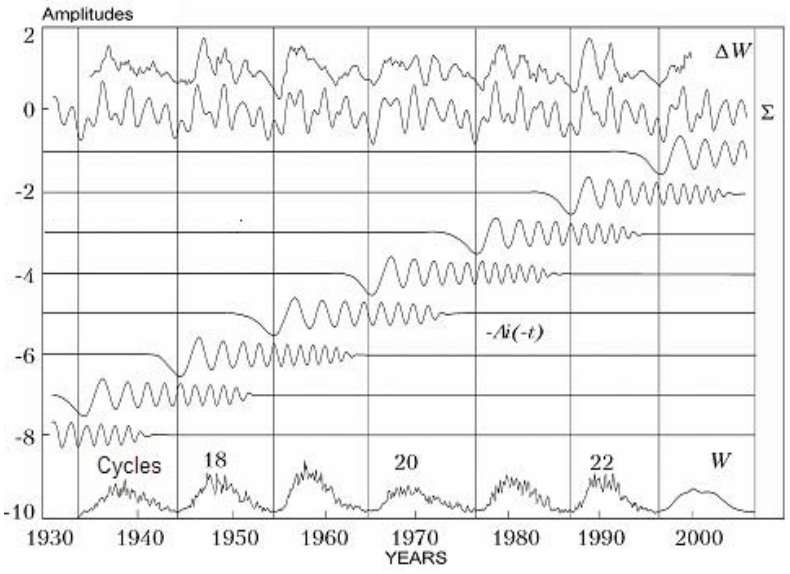


Figure 2. The lowest curve is the monthly mean Wolf numbers for the cycles 17 –22 and the prognosis of the cycle 23 in the right corner *W* [Khramova et al., 2000]. The upper curve Δ*W* is the filtered quasi biannual variations. Lower (**Σ**) is the summary of the 8 Airy functions for the cycles 17 – 22 presented below (*-Ai(-t)*).

The first of these 11-year cycle characteristics is the aperiodic function. Therefore its time sequence cannot be presented by a harmonic function. Though the attempts to present the11-year cycle by a cosine function also were probed, they gave no opportunity to distinguish the nature of this dependence. Actually, analytical representation of the form of the11-year cycle can be described by three functions: they are:

1) The **exponential** function of a square argument,

$$G(t) = B \cdot t^{2k_G} \cdot \exp\left(-\frac{t^2}{T_G^2}\right),$$

2) The **lognormal** distribution

$$L(t) = \frac{A}{t} \cdot \exp\left[-\left(k_L \cdot \ln\frac{t}{T_L}\right)^2\right]$$

and

3) The **exponent** function of the cubic polynom

$$E(t) = H \cdot \exp\left[-k_E \cdot r_E \cdot (t - t_0) + \frac{D_T}{3} \cdot k_E^2 \cdot (t - t_0)^3\right].$$

The first distribution formally coincides with the Maxwellion one, the second - determines the process of diffusion of some component in a usual field of speeds [Klyatskin, 1994], the third - corresponds to the diffusion process of the heat transport [Polyanin, 2001]. One parameter of the last distribution characterizes depth of the location of the disturbance and has negative correlation with amplitude of the cycle maximum. On the average, the greater depth corresponds to the smaller cycle amplitude and greater its half width what is real and observed.

This apparently, means that these three functions display the properties of some more general dependence, and present special cases for the concrete time dependence lows.

The data of a special interest are the long-term cyclic variations of activity of the stars. The available data for stars of spectral classes F6-K7 [Baliunas et al., 1995; Bruevich, etc., 2001] specify existence of cyclic variations with the periods from 7 till 15 years having similarity to the 11-year periodicity of the solar activity. Thus it appears, that their properties depend on the temperature and the star sizes. However, the star observations are possible only at night, and thus the existing data have breaks of the time sequence, but the general time variations does not possess smoothness which absence forces to assume the presence of the maxima reviling the presence of the cyclic aperiodic variations, but without variations due to the spots and the star rotation. Undoubtedly, in these data should be found also the cyclic non-periodical variations which average period, probably, may be correlated with the period of the basic cycle.

These problems urgently demand to be solved for understanding the processes causing occurrence of the solar and star activity.

The important fact of the solar activity pattern is, that the non-periodical cyclic variations arise simultaneously with the beginning of the eleven-year cycle, but their duration is 22 years. Therefore the interference between the subsequent 11-year cycles creates additional maxima and minima on the background of the eleven-year cycle, which essentially depends upon the basic cycle duration [Kononovich and Shefov, 2003]. Therefore there is no recurrence of these small maxima in each consecutive 11-year cycle.

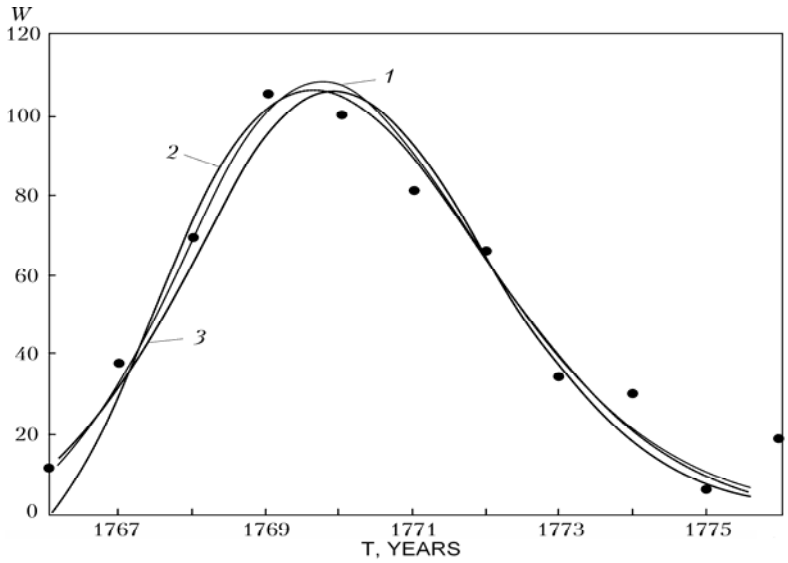


Figure 3. An example of the comparison of the yearly mean cycle 2 Wolf numbers (years 1766 – 1775, the dots) and approximating curves G(t), curve 1, L(t) curve 2 and E(t), curve 3. (Kononovich 2005).

Thus, the character of the long-term cyclic variations permit us to assume, that at the moment of the cyclic aperiodic variations described by the Airy function origin at the convective zone bottom, there is a disturbance at the latitudes about 45-50^{o}, having the eleven-year period. It has the form of a swelling (in the meridian section), which diffuses in the photosphere and simultaneously travels to the equator, apparently, due to the centrifugal forces. It carries spatial structures and cyclic none periodical variations. The occurrence of such structures in the external layers of the Sun is displayed as latitude drift, and also as the position, change also the sunspot Wolf numbers which is well illustrated by the Maunder butterfly diagram. Evidently the initial depth of the spot appearance is displayed both by the intensity, and by the eleven-year cycle duration: the deeper the cycle, the weaker and longer the upward motion due to losses by the long-term upward diffusion movement.

It is rather important, that this motion in the solar atmosphere does not terminate in the photosphere, but proceeds into the solar corona. It was revealed by Apostolov and Letfus

(1985) from variations of the green coronal line λ 530.3 nanometers. According to the estimations it corresponds to the heights about 100000 km, occurs to delay approximately for three months. This corresponds to the average speed ~ 5 km/s. A similar situation is observed for the radio emission flux at 10.7 cm. Therefore it is interesting to find out, how far such movement in the corona is traced.

An interesting conclusion comes from the results presented by Kononovich (2005). Three types of the empirical approximation of the eleven-year cycle with accuracy about 10 % have been tested. All of them present aperiodic functions. Therefore their time sequence cannot be described by a harmonic array. Though attempts to present the 11-year solar cycle by the cosine function were probed they did not provide an opportunity to understand the nature of this phenomenon. Actually, the analytical presentation of the 11-year cycle form can be attained using one of three functions, namely: the gamma function depending upon a square of the argument, the lognormal distribution and the exponential function depending upon a cubic polynom. The first distribution actually coincides with the Maxwellian one, the second one – presents a diffusion process of a component in a chaotically field of speed, the third one - corresponds to a diffusion process. A parameter of the last distribution characterizes the depth of a disturbance and has a negative correlation with the cycle maximum amplitude. On average, the greater depth corresponds to a smaller cycle amplitude and greater its half width, what is really observed.

This, apparently, means that these three functions accumulate the properties of the more general common functional dependence, and are the special cases for the most suitable concrete time dependences.

The item of a special interest provides the data of the long-term cyclic variations for the other star activity. The available data for stars of the spectral classes F6-K7 (Baliunas et al., 1995; Bruevich, etc., 2001) specify the existence of cyclic variations with the periods from 7 till 15 years similar to the 11-year periodicity of the solar activity. Thus it appears, that the cyclic variations properties depend on temperature and the star sizes. However, because the star observations are possible only at night, the existing data have time breaks though the general view of the variations does not possess smoothness which forces us to assume the presence of the maxims connected to presence of the non periodical cyclic variations, instead of those due to variation of the spot activity of the star caused by rotation. Undoubtedly, in these data must be presented also cyclic aperiodic variations which average period, probably, should correlate with the period of the basic cycle.

The considered problems must be solved urgently. They are connected to the mechanism of the cyclic non-periodical solar activity variations, namely the quasibiannual and the 11- year variations. Their generation is provided near the bottom of the convection zone and connected to the meridian circulation from the poles to the equator.

Рассмотренные выше проблемы связаны с механизмом циклических апериодических вариаций солнечной активности, а именно, квазидвухлетних и 11- летних. Их генерация происходит у основания конвективной зоны и обусловлена меридиональной циркуляцией от полюса к экватору.

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