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ON THE PECULIARITIES OF CHAOTIC DYNAMICS OF SOLAR STRONG MAGNETIC FIELDS

I.G. Kostyuchenko[1] S.F.Timashev[1] Yu.S.Polyakov[2]
[1]Karpov Institute of Physical Chemistry, Moscow, Russia irkost@itep.ru; serget@mail.ru
[2]US PolyResearch, Ashland PA17921, USA, ypolyakov@uspolyresearch.com

Chaos is an order, which is organized by some complicate way.
The task is to characterize this complexity so that to know more about processes underlying a chaotic behavior of measured variable.

Here we use the approach, developed by **S.F.Timashev** (see ***Flicker-Noise spectroscopy : Information in Chaotic Signals, Fizmatlit, Moscow, 2007***).

The basic idea of Flicker- Noise spectroscopy (FNS) is the following: the main information hidden in dynamic signals $V(t)$, where t- time, is provided by specific "resonant" (or periodic) components as well as by **sequences of different types of irregularities such as spikes and jumps in the original signals, which have correlation links. Such irregularities represent the chaotic component of the measured variable.**

Thus in FNS all introduced information is related to **the autocorrelation function:**

$\psi(\tau) = \langle V(t)\, V(t+\tau)\rangle$ *, where τ is the time lag.* This function characterizes the correlation of values of a dynamic variable at higher and lower values of the argument. **Tools for the extraction and analysis of information are the transforms of this function :** the cosine-, transform of an autocorrelation function

$$S(f) = \int_{-T/2}^{T/2} \langle V(t)V(t+t_1)\rangle \cos(2\pi f t_1)\, dt_1$$

were f is frequency, and the difference moment, or structural function of the second order,

$$\Phi^{(p)}(\tau) = \langle [V(t) - V(t+\tau)]^p \rangle$$

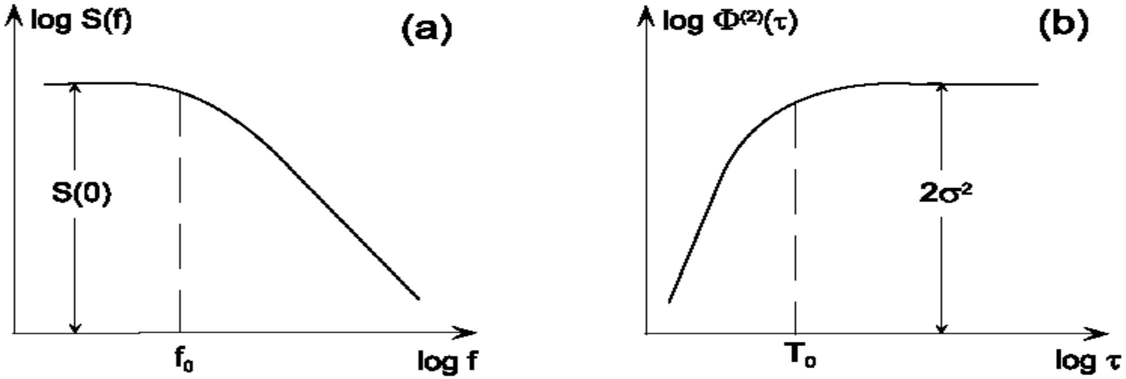
where p=2 and τ is the time lag. The angular brackets stand for the averaging over time interval T. The chaotic component of $\Phi^{(2)}(\tau)$ is formed by the jumps of a dynamical variable while the chaotic component $S(f)$ is formed by both spikes and jumps. **The intermittent character of the evolution dynamics accounts for the differences in the information contained in various irregularities.**

The simplified form of derived expressions for interpolation functions for $S(f)$ and $\Phi^{(2)}(\tau)$ are:

$$S_c(f) \rightarrow \begin{cases} 1/f^n, & if \quad f > 1/T_0 \\ S_c(0), & if \quad f < 1/T_0 \end{cases}$$

$$\Phi^{(2)}(\tau) \rightarrow \begin{cases} \tau^{2H_1}, & if \quad \tau < T_1 \\ 2\sigma^2, & if \quad \tau > T_1 \end{cases}, \quad \sigma^2 \equiv \langle V^2 \rangle - \langle V \rangle^2$$

The corresponding curves for S (f) (a) and $\Phi^{(2)}(\tau)$ (б) for chaotic component of signal V(t) are shown below:



The parameters, determined by fitting the derived expressions to experimental curves, are interpreted as the correlation times (T_0 and T_1) and parameters describing the rate of "memory loss" on these correlation time intervals for corresponding different irregularities (n and H_1 (Hurst constant)). It was derived, that **larger values of parameters n and H_1 correspond to a larger rate of the "memory loss".** The contribution of jumps to the S (f) is concentrated in its lower frequency band. The higher frequency band of S (f) is generated mostly by spikes. Because of the differences in the information contained in various irregularities, the common used relation $2H_1 + 1 = n$ **may be not valid.**

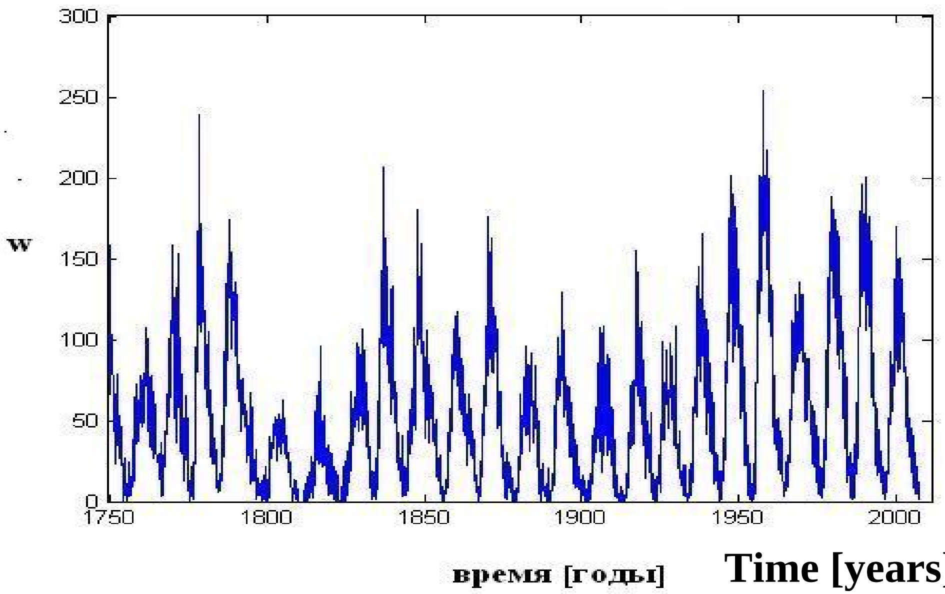
The values of parameters for some known processes are listed below :

– Classical flicker noise - $2H_1 = 0$, $n \sim 1$;
– Fickian diffusion - $2H_1 = 1$, $n = 2H_1 + 1 = 2$;
– Levi diffusion - $2H_1 = s$, $n = s + 1$ $(0 < s < 2)$ (case $½ < H_1 < 1$ correspond to super diffusion;
case $H_1 < ½$ – sub diffusion or diffusion with spatial restriction);
– «modified Levi diffusion» - $H_1 > 1$, $n > 3$;
– developed turbulence (Kolmogorov-Obukhov law), $2H_1 = 2/3$, $n = 5/3$;
– «turbulent» diffusion $2H_1 = 3$, $n = 4$.

The chaotic behavior of the solar activity indexes, which are directly associated with solar strong magnetic field of active regions were analyzed. They are:

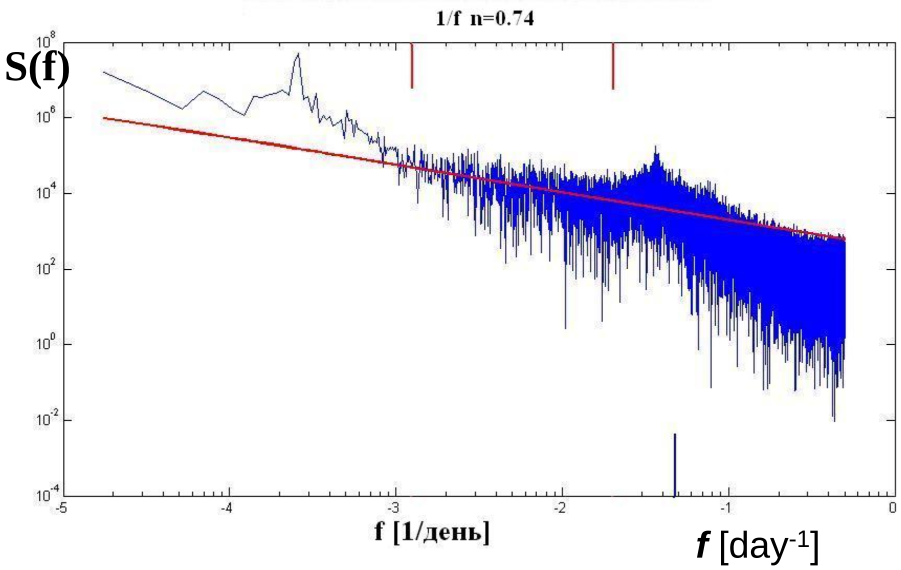
Sunspot index, Sunspot areas and solar Total radio flux at 2800MHz

The first task was the **analysis of chaotic dynamic of solar strong magnetic fields on the various time scale**. This is interesting for understanding nature of 11year periodic variations of solar activity. The longest time series- **Wolf numbers or sunspot index**, collected for almost 250 years, was used . Its dynamics characterize the property of process of emerge on the solar surface of strong magnetic fields .



Time [years]

Time series of monthly values of sunspot index. The 11-year periodic variation dominate.



Cosine transform of autocorrelation function for time series of daily value of sunspot index in log-log scale. **On all considerate time scales analyzed solar activity indexes demonstrate chaotic dynamic together with periodic variations**

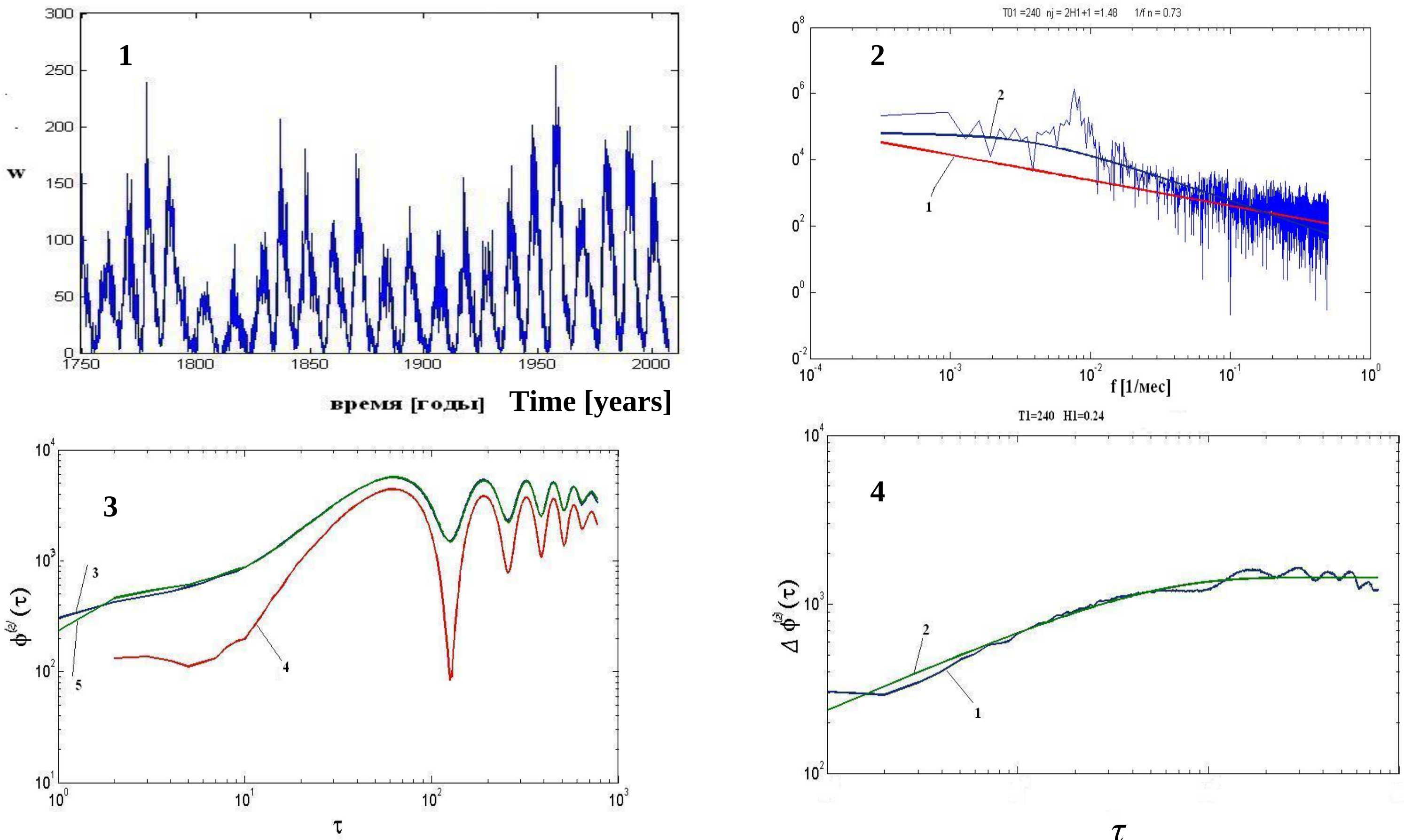
The change of the spectrum slope in the region of the solar rotation frequency of inverted 27days (pointed on the low ***x***-axis), to a more steep one is caused by mixing of temporal and spatial changes in the current state of the visible solar hemisphere. The solar rotation artificially increases the effective rate of relaxation of fluctuations within the frequency range of more than $(27\text{days})^{-1}$. This demonstrate the sensitivity of spectral index ***n*** to the change of character of chaotic dynamic.

In the high-frequency band $0.04\,month^{-1} < f < 0.4\,month^{-1}$ (pointed on upper x-axis), where the linear interpolation for $S(f) \sim 1/f^{\,n}$ was made (red line), value $n = 0.74 \pm 0.04$.

In the low- frequency band $S(f)$ deviate significantly from red line. The sizable impact of the periodic 11-years variations presents in low frequency band.

One of the advance of the used method is the developed procedure of separation of the contribution of periodic (regular) and chaotic components. This procedure includes the following steps:

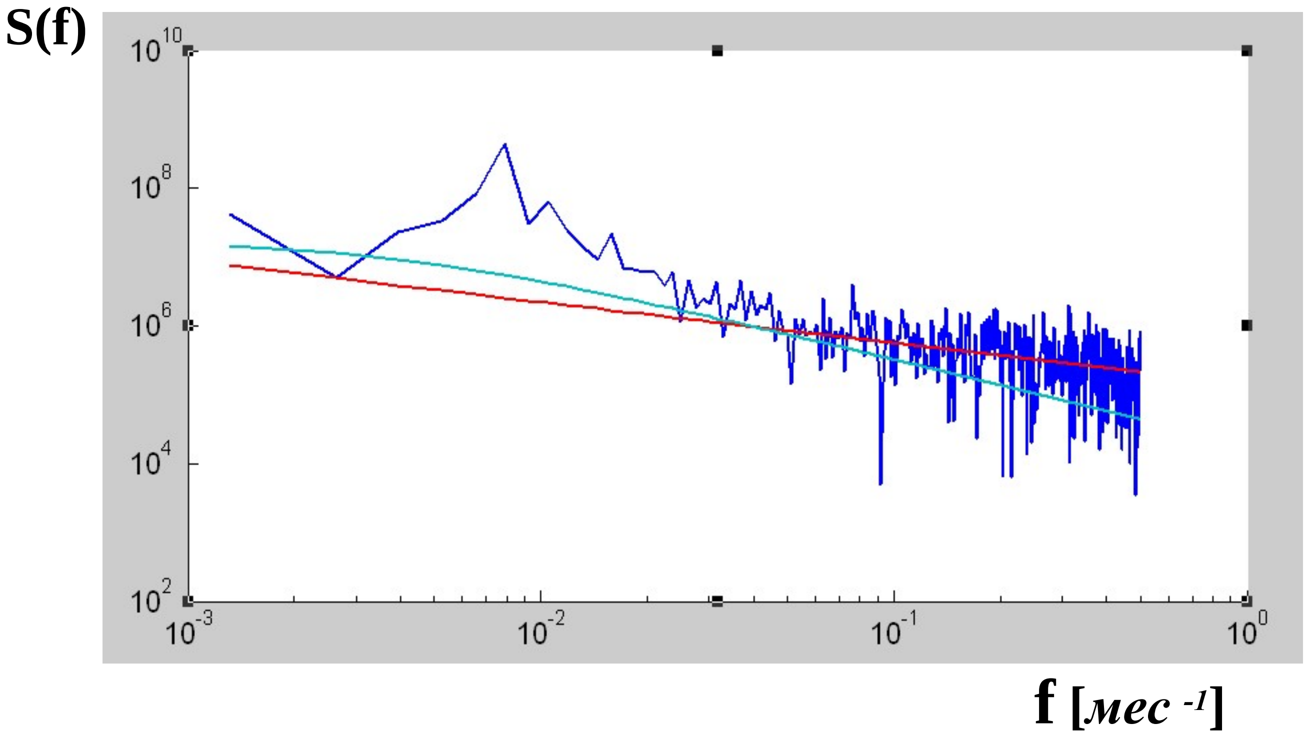
1 Extraction of the regular component from the source signal by using “incomplete” inverse cosine transform.
2. Calculation of the autocorrelation function and difference moment for the regular component.
3. Subtraction of the difference moment for the regular component from the difference moment of the source signal.
4. Parameterization of the remaining chaotic contribution to the transient difference moment



1- Monthly sunspot index (1749-2007yy). 2- Cosine transform of autocorrelation function in log-log scale: redline(1) - linear interpolation for $S(f) \sim 1/f^{n}$, $n = 0.73$; blue curve(2)-result of structural function analysis, $n = 2H_1 + 1 = 1.48$ 3- Structural function in log-log form: blue curve(3)-"experimental" $\Phi^{(2)}(\tau)$, red curve(4) –resonant interpolation, green curve(5)- resonant+chaotic interpolation; 4- blue curve- "experimental" $\Phi^{(2)}(\tau)$ minus resonant interpolation, green curve- chaotic interpolation.

-on the time scale 2 month < T < 2 year the common used relation $2H_1 = n-1$ is not valid; this can be explained by a sizable impact of large scale variations of analyzed solar activity indexes on the value of Herst constant.

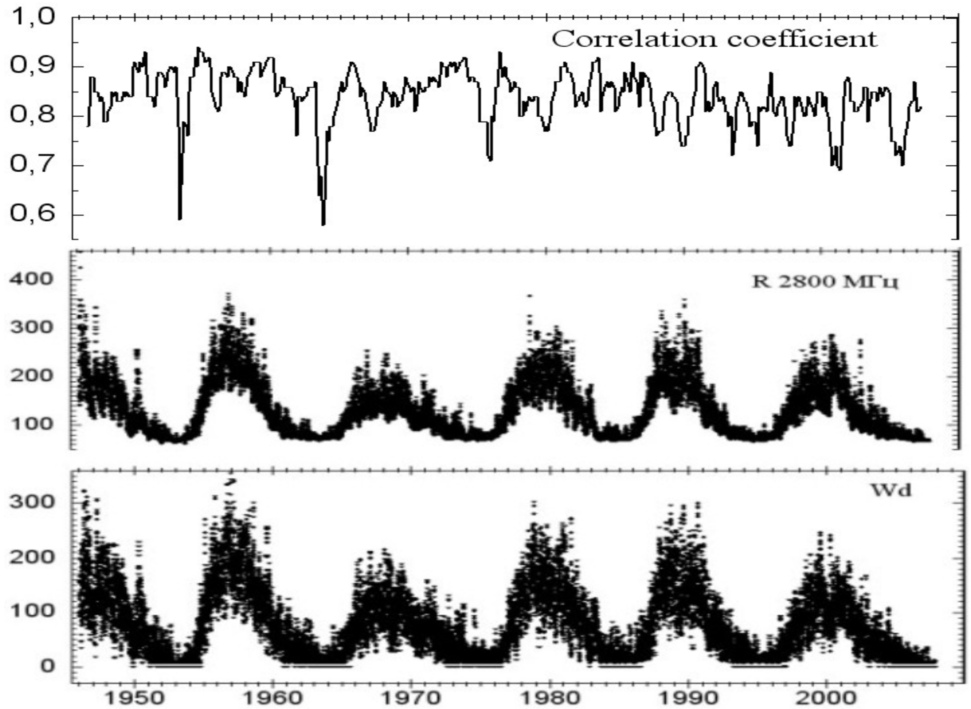
- the chaotic dynamic of emerge of strong magnetic fields on the solar surface changes significantly on a timescale of about 2 years. This can indicate the time non-stationarity of convection conditions in the solar convective zone.



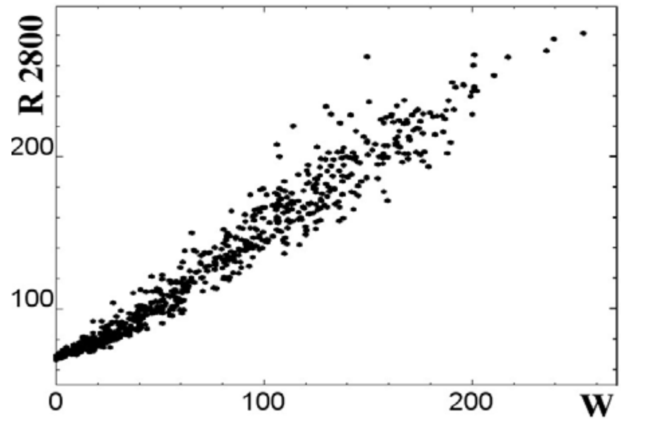
Cosine transform of autocorrelation function for time series of monthly values of sunspot areas in log-log scale; red line -the linear interpolation in the same high-frequency band ,

n =0.6±0.4 In the low- frequency band the same separation procedure was made.

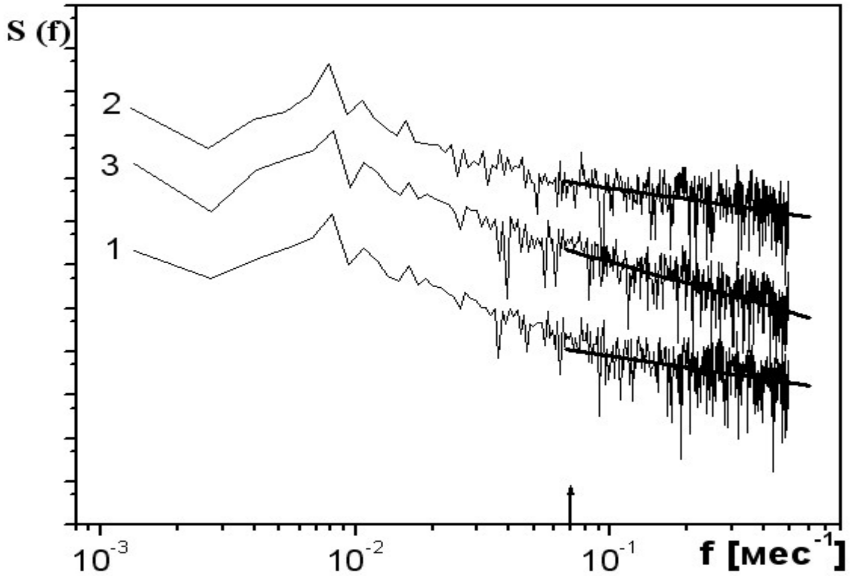
The analysis of chaotic dynamic of solar Total radio flux at 2800MHz



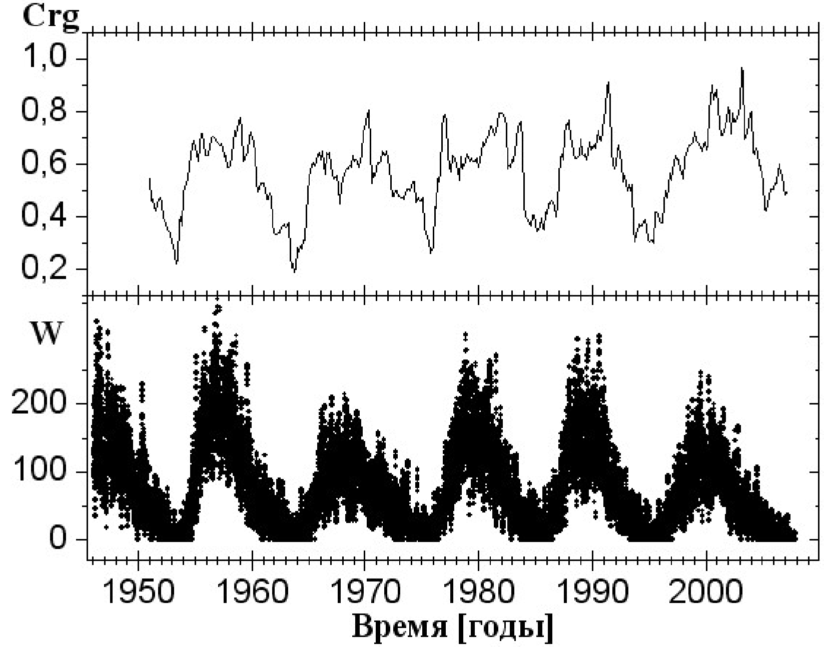
Time series of daily value of sunspot index Wd, total radio flux at 2800 MHz
and coefficient of correlation between them



Relation W-R2800 for the monthly values



Cosine transform of autocorrelation function for time series of monthly values of : 1- sunspot index (***n***=0.7), 2- sunspot aries (***n*** =0.6), 3- solar total radio flux at 2800MHz (***n*** =1.4) in log-log scale. Straight lines- interpolation by $S(f) \sim 1/f^{n}$ in frequency band $f > (15\text{month})^{-1}$



Regression coefficient Crg for relation R2800 ~Crg*W, calculated in sliding window 365 days and time series of daily value W

The sunspot index and solar radio flux at 2800MHz demonstrate significantly different chaotic dynamics on a timescale lower than 1-1.5 year, in spite of high level of correlations of their time variations. This can be explained, if one suggests, that the solar radio flux at 2800MHz reflects to a larger extent, than the sunspot index or sunspot square, the strength of magnetic fields, the topological complexity and diversity of local magnetic structures of active regions. Stress, that the value of regression coefficient does not depend onthe amplitude of solar activity maximum. This can indicates the limit on possible values of the mentioned characteristics of solar active regions.

CONCLUSIONS

-the analysis of chaotic component of variations is useful

-on all considerate time scales analyzed solar activity indexes demonstrate chaotic dynamic together with periodic variations and spectral index n is sensitive to the changes in character of chaotic dynamics.

-on the time scale 2 month < T < 2 year the common used relation $2H_1 = n-1$ is not valid; this can be explained by a sizable impact of large scale variations of analyzed solar activity indexes on the value of Herst constant.

- the chaotic dynamic of appearance of strong magnetic fields on the solar surface changes significantly on a timescale of about 2 years. This can indicate the time non-stationarity of convection conditions in the solar convective zone.

-sunspot index and solar radio flux at 2800MHz demonstrate significantly different dynamics on a timescale lower than 1 year, in spite of high level of correlations of their time variations. This can be explained if one suggests, that the two mentioned indices reflect different properties of active regions evolution with solar cycle: the sunspot index characterizes mostly the dynamics of emerge on the solar surface of strong magnetic fields, while the solar radio flux at 2800MHz reflects to a larger extent the strength of magnetic fields, the topological complexity and diversity of local magnetic structures of active regions.

- indication on the limit of possible values of size and topological complexity of solar active regions is received.


THANK YOU