On the global magnetic activity and dynamo of the Sun and solar-type stars

E.A. Bruevich [a] , I.K. Rozgacheva [b]

[a]Moscow State University, Sternberg Astronomical Institute, Russia
[b]Moscow State Pedagogical University, Russia
E-mail: [a]red-field@yandex.ru, [b]rozgacheva@yandex.ru

Abstract. The activity of the Sun as a result of cyclic changes of the global magnetic field is studied. As a consequence of the analysis of magnetic activity of solar-type stars the following power dependencies were found: the dependence between the rotation periods and the effective temperatures $P_{rot} \sim T_{eff}\ ^{-3,9}$, the dependence between the duration of the "11-year" cycles of activity and the effective temperatures $T_{11} \sim T_{eff}\ ^{-1,1}$ and the dependence between the duration of quasi-biennial cycles and the effective temperatures $T_2 \sim T_{eff}\ ^{-0,79}$. It is shown that the physical nature of these dependencies associated with the observed properties of solar-type stars and can be explained by the existence of internal Rossby waves around the base of convective shells of these stars.

KEY WORDS: the Sun, the magnetic activity, solar-type stars, "11-year" cycles, quasi-biennial cycles, solar dynamo, convection, Rossby waves.

1 The magnetic activity of the Sun

Magnetic activity of the Sun is called the complex of electromagnetic and hydrodynamic processes in the solar atmosphere. The analysis of active regions (plages and spots in the photosphere, flocculae in the chromosphere and prominences in the corona of the Sun) is required to study the magnetic field of the Sun and the physics of magnetic activity. This task is of fundamental importance for astrophysics of the Sun and the stars. Its applied meaning is connected with the influence of solar active processes on the Earth's magnetic field.

It is difficult to predict the details of the evolution of each active region in present time. However, the total change in active regions is cyclical. Long known "11-year" cycle of solar activity, the duration of which varies from 7 to 17 years. Quasi-biennial cycles of solar and solar-type stars magnetic activity were found (Vitinsky et al. 1986; Rivin 1989; Khramova et al. 2002; Kolah & Olach 2009; Bruevich & Kononovich 2011; Bruevich & Ivanov-Kholodnyj 2011; Bruevich & Rozgacheva 2012).

In the theory of the solar dynamo (Parker 1979; Monin 1980; Vanshtein et al. 1980; Makarov 1987; Berdugina et al. 2006) (Babcok - Layton $\alpha\Omega$-

dynamo model), the magnetic activity of the Sun is explained with the help of two main effects: first - production of azimuth (toroidal) field with help of a large-scale field (poloidal) due to the differential rotation of the convective envelope (Ω - effect); secondly - formation of the poloidal field with help of some local bipolar magnetic regions of the toroidal field (α - effect) due to differential rotation.

It is supposed, that in the maximum of the "11-year" cycle the old poloidal field, from which it was generated, a toroidal field, has already disappeared, and the generation of new poloidal field begins. In the theory of the solar dynamo the hypothesis of a strong turbulent convection in the under-photospheric layers is used. Strong turbulent convection is necessary requirement for the effective generation of magnetic fields. The theory of the solar $\alpha\,\Omega$ - dynamo well simulates the following phenomena of local magnetic activity on the Sun and the stars:

• the formation of strong local magnetic fields (of the order of 0,1 Tesla), the evolution of which leads to the appearance and evolution of spots and plages in photosphere and the energetic events in the chromosphere and corona, such as prominences, flares and coronal mass ejections;

• the cyclicity of magnetic activity (on the basis of the selection of the parameters of the turbulent viscosity tensor);

• the Shperer's law ("active latitudes" of spot's appearance during an "11-year" cycle move to the sun's equator, from helio-latitudes equal to $\pm 52°$ for beginners cycle's spots to helio-latitudes equal to $\pm 5°$ for the final cycle's spots);

• "11-year" cycles are closely connected with each other, and partially overlap, because near the minima of the activity, when the last spots of the old cycle are still visible at the equator of the Sun, the spots of a new cycle has already appeared on the high helio-latitudes;

• at the graph of dependence of the annual Wolf numbers on time, the duration of the branch growth cycle decreases with increasing amplitude of the cycle, and the area under the branch of the decline of the cycle increases with the amplitude of the cycle.

To the present time the following facts on the global magnetic activity of the Sun, which covers the whole of the outer layers of the Sun and has a complex evolution over time are known:

• active processes of the transformation of magnetic energy (plages, flocculi, flares) happen always and in all the outer layers of the Sun (Obrydko 1985; Obrydko 1999);

• there exist the "active longitudes", near to which there is high concentration of the spots. They are quasi-periodically distributed on the heliomeridians and over time, slowly moving during of the "11-year" cycle (Obrydko et al. 2009; Makarov et. al 2001; Schnerr & Spruit 2010); Also the "active longitudes" slowly movements during the 11-year cycle were detected in UV and X-rays by SOHO satellite observations (SOHO 1995-2012).

• duration of the "11-year" cycles are changed, and, the larger the amplitude of the cycle, the shorter the cycle;

• with the increasing of the amplitude of the "11-year" cycle the starting "active latitudes" will be increased (up to $\pm 60°$);

• there is the "Gnevyshev-Ol's rule" - in the 22-year magnetic cycle the amplitude of the initial 11-year cycle (even cycle) is always smaller than the amplitude of the final 11-year cycle (odd cycle);

• active cycle with a duration of 1,3 years on the background of the last eight of the "11-year" cycles was detected (Livshits & Obrydko 2006)

• analysis of cyclic variations of the chromospheric radiation of solar-type stars allows us to detect a set of cycles with duration from 2 years to 15 years (2-3 years, 5-6 years, 8-13 years) (Bruevich & Ivanov-Kholodnyj 2011);

• series of Wolf numbers observations for the majority of the cycles have two almost identical maximums;

• coronal holes, polar plages at the latitudes of $|\varphi| > 40°$ which are characterized by strong magnetic fields (the intensity of the magnetic fields is of the order to the kilogauss) are observed as features of high-latitude and polar activity;

• in the unperturbed chromosphere we can always observe spicules and supergranulation, number of spicules is the most of all at the poles (on 30% more, than at the equator) and least of all in the latitude of 35° (on 10% less than at the equator);

• the polar spicules are inclined to the equator, in the "active latitudes" spicules are inclined to the nearest pole (follow the direction of the magnetic field);

• the dipole component of the large-scale magnetic field during the maximum of local activity was detected. The axis of the dipole was located in the equatorial plane of the Sun;

• during the minima of the local activity the regions of opposite polarity of the magnetic field are observed. They alternate on longitude with prevailing wave number $m = 6$ (the giant convection cells).

The above facts on the global magnetic activity indicate that, in the convective shell of the Sun work not less than two mechanisms $\alpha\ \Omega$ - dynamo. They have a variety of spatial scales and different characteristic times. These mechanisms should ensure the generation of several magnetic fields of different scales - the strong local magnetic fields, and weaker (to three orders of magnitude) large-scale global field.

In the framework of the hypothesis on one turbulent convective shell it is impossible to ensure sustainable separation of small-scale and large-scale hydro-magnetic dynamos. This hypothesis does not allow to explain the ordering of processes of activity in time (cycles) and in space ("active latitudes and longitudes", granulation and supergranulation). For example, Kolmogorov's spectrum of developed turbulence is not implemented for speed and size of granules (Nordlund et al. 1997). This requires the further development of the theory of $\alpha\ \Omega$ - dynamo (Spruit 1998; Spruit 2004).

At the present time the observational tests that can confirm or clarify the main hypothesis of the theory of the solar dynamo are necessary. So far the basic test is considered to be the existence of magnetic activity of the Sun.

A statistical analysis of the data on of the color indices, periods of rotation, the duration of activity cycles, the magnetic field, the age of solar-type stars is necessary. Such research will help to find a relation between the parameters of cycles such as the duration of activity cycles, the amplitude of the variations of the fluxes of radiation of different indices of activity with the physical parameters of the stars.

At present the observations of active atmospheres of solar-type stars are regularly held in the framework of the "HK-project" at Mount Wilson observatory (Baliunas et al. 1995; Radick et al. 1998; Lockwood et al. 2007)

In the work (Bruevich & Rozgacheva 2012) we published the results of processing of the observations of cyclic variations of chromospheric radiation of the 52 solar-type stars and the Sun in the form of a Table. In this Table an information about the periods of rotation and effective temperatures of stars, about the duration of their "11-year" and quasibiennial cycles is contained. The periods of cycles of activity are given according to the calculations of the authors of this work together with the definition of "11-year" periods with help the authors of "HK-project" (Baliunas et al. 1995).

In the present work for a sample of 52 stars from (Bruevich & Rozgacheva 2012) we found the statistically significant dependencies "the rotation period - the effective temperature" and "the duration of activity cycle - the effective temperature" (see below, section 2).

Next, in section 3 we give a physical interpretation of these dependencies on the basis of the hypothesis about the possibility of the existence of several layers in the convective shells of the solar-type stars.

Our physical interpretation is based on the assumption of the existence of not less than two layers located under the photosphere.

At the bottom level of convective zone the layer of the laminar convection is situated. This layer consists of giant convective cells. Due to differential rotation the Rossby waves with non-zero helicity are formed on the surface of this layer.

The formation of the laminar convection is a consequence of a strong heating of plasma with help of photons from the zone of radiant heat transfer and of the high radiant viscosity of fully ionized dense plasma. Radiant viscosity inhibits the directed motion of electrons more effectively than directed motion of protons. Therefore, the current appears in the Rossby waves, and this current generates the poloidal field. This field is a primary field for the whole of the magnetic activity of stars.

Above the layer of the laminar convection the layer of turbulent convention is situated. In the layer of turbulent convection primary poloidal field generates a toroidal field and starts the mechanism of generation of a strong local magnetic activity at the medium and equatorial latitudes of solar-type stars. Local and global magnetic activity are interconnected thanks to the existence of internal Rossby waves and thanks to the primary poloidal field.

2 Dependencies "the rotation period - the effective temperature" and "the duration of the cycle of activity - the effective temperature"

We used the data of observations of variations of chromospheric radiation of the Sun and of 52 solar-type "HK-project" stars from the Table, published in (Bruevich & Rozgacheva 2012) for statistical analysis and the search if there is a possible linear relationship between the periods of rotation Prot of the stars and their effective temperature T_{eff}. Diagram "the rotation period - the effective temperature" for 52 solar-type stars is shown in Fig. 1.

Linear regression equation has the following form:

$$\log P_{rot} = 15,7 - 3,87 \cdot \log T_{eff} \tag{1}$$

The linear correlation coefficient (Pearson's correlation coefficient) in the regression equation (1) is equal to 0,73. According to Pearson's cumulative statistic test (which asymptotically approaches a χ^2 -distribution) the linear correlation between the P_{rot} and T_{eff} is statistically significant at a 0,05 level of significance.

Thus our data set of the rotation periods and the effective temperatures of stars shows the following power-law dependence

$$P_{rot} \sim T_{eff}{}^{-3,9} \tag{2}$$

The diagram of "the duration of the cycle - the effective temperature" (T_{11} is the period of " 11-year" cycles) for 46 stars from Table, published in (Bruevich & Rozgacheva 2012) is shown in Fig. 2.

The linear regression equation for points of diagram at the Fig. 2 is of the form:

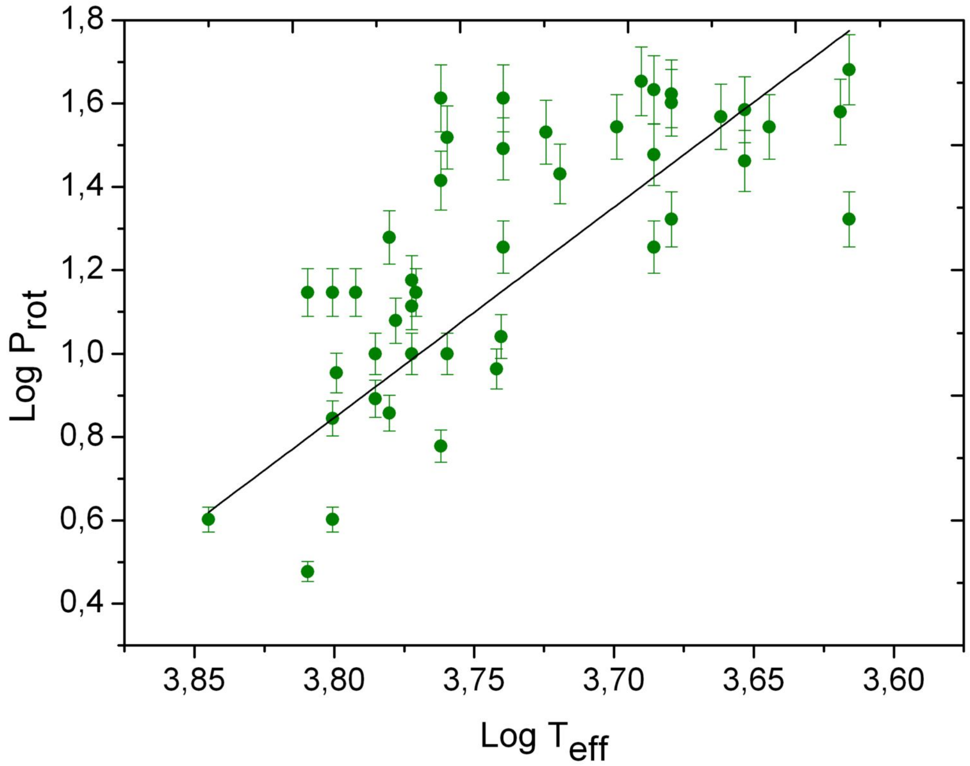

Figure 1: Diagram "the rotation period - the effective temperature". The line shows the linear regression on a data set

$$\log T_{11} = 5,15 - 1,11 \cdot \log T_{eff} \tag{3}$$

The linear correlation coefficient (Pearson's correlation coefficient) in the regression equation (3) is equal to (- 0,67). According to Pearson's cumulative statistic test (which asymptotically approaches a χ^2 -distribution) the linear correlation between the T_{11} and T_{eff} is statistically significant at a 0,05 level of significance.

Thus, for the investigated sample of stars the periods of "11-year" cycles T_{11} and their effective temperatures T_{eff} are connected in power-law dependence:

$$T_{11} \sim T_{eff}{}^{-1,1} \tag{4}$$

"The duration of the cycle - the effective temperature" diagram (T_2 is the period of quasi-biennial cycles) for 27 stars from Table, published in

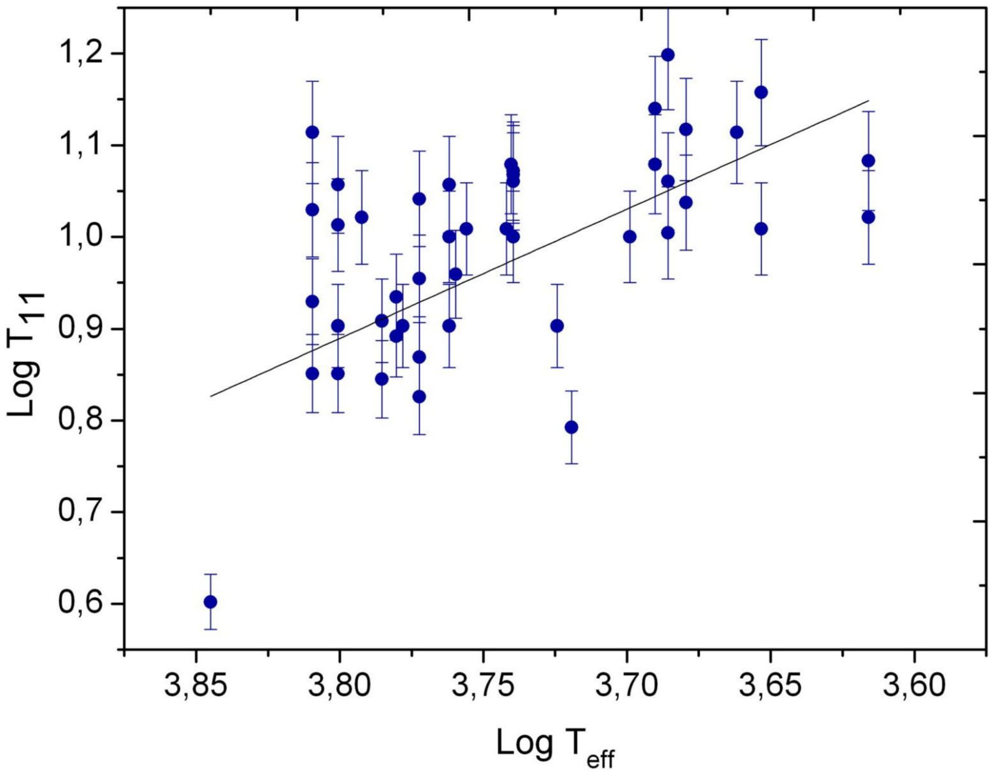

Figure 2: Diagram "the duration of the cycle T_{11} - the effective temperature T_{eff}" diagram. The line shows the linear regression on a data set

(Bruevich & Rozgacheva 2012) is shown in Fig. 3.

Linear regression equation for points of diagram at the Fig. 3 is of the form:

$$\log T_2 = 3,46 - 0,79 \cdot \log T_{eff} \tag{5}$$

The linear correlation coefficient (Pearson's correlation coefficient) in the regression equation (4) is equal to (- 0,51). According to Pearson's cumulative statistic test (which asymptotically approaches a χ^2 -distribution) the linear correlation between the T_2 and T_{eff} is statistically significant at a 0,1 level of significance.

Thus, for the investigated sample of stars their periods of quasi-biennial cycles T_2 and their effective temperatures T_{eff} are linked as power-law dependence:

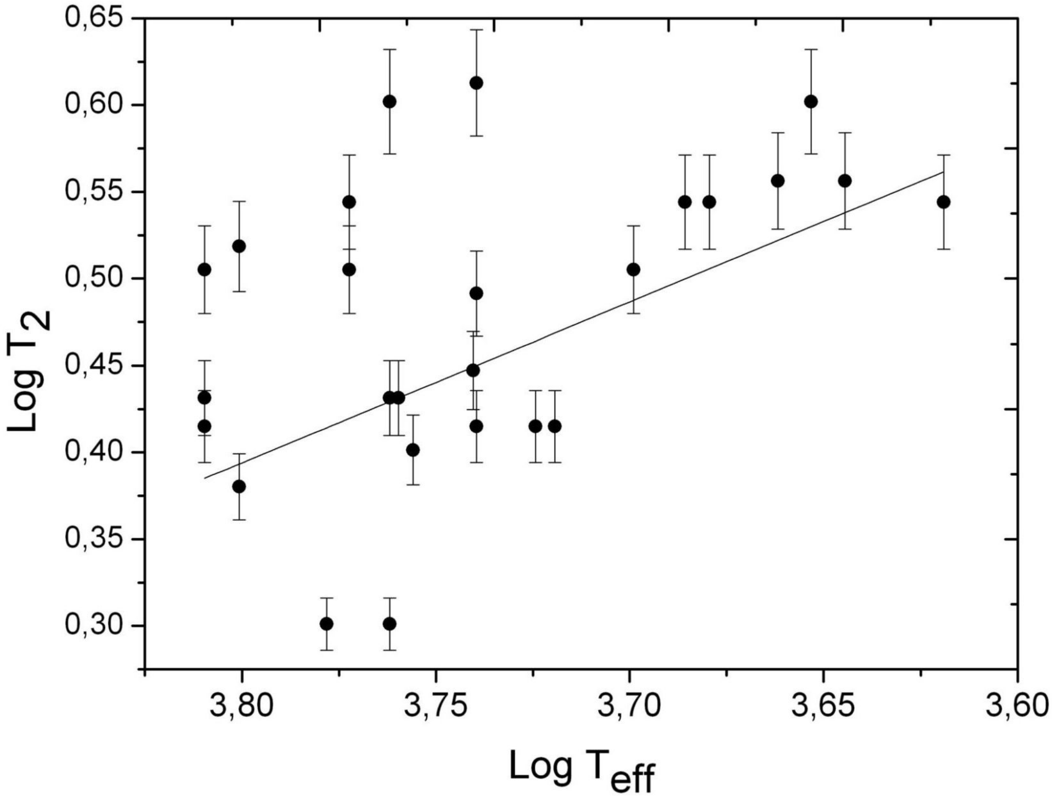

Figure 3: Diagram "the duration of the cycle T_2 - the effective temperature T_{eff}" diagram. The line shows the linear regression on a data set

$$T_2 \sim T_{eff}\ ^{-0,79} \tag{6}$$

3 Physical model of "the rotation period - the effective temperature" dependence

The connection between the rotation period and the effective temperature of the stars comes from the following facts:

Firstly, the continuous spectrum of radiation of the Main sequence stars at the Hertzsprung-Russell diagram is well approximated by the Plank's formula for the radiating plasma, which is in thermal equilibrium with its own radiation. Therefore, we use the Stefan - Boltzmann law for the luminance of the surface of the stars:

$$\frac{L_{star}}{L_{Sun}} = \left(\frac{R_{star}}{R_{Sun}}\right)^2 \left(\frac{T_{eff}{}^{star}}{T_{eff}{}^{Sun}}\right)^4 \tag{7}$$

where L_{star}, L_{Sun} - are the luminosities of stars and the Sun, R_{star}, R_{Sun} are the radii of the stars and the Sun, $T_{eff}{}^{Sun}$ - is the effective temperature of the Sun, $T_{eff}{}^{star}$ - are the effective temperatures of the stars.

Secondly, for Main sequence of stars there is dependence of the "mass of the star - luminosity of the star", which is well approximated by a power-law dependence:

$$L \sim M_{star}{}^{\alpha} \tag{8}$$

Where M_{star} is the mass of the star, the exponent α depends on the mass of the star and its spectral class, for stars with masses similar to the mass of the Sun $3,5 \leqslant \alpha \leqslant 4$.

In the third place, in the course of the evolution of the single stars of the Main sequence its angular momentum slowly decreasing due to the loss of weight, because of interactions with interplanetary plasma and to the planets. A significant decrease of the angular momentum comes slowly for billions of years.

In a relatively short time intervals, which are characteristic of magnetic activity, we can assume that the angular momentum is maintained.

In this case $M \cdot R_{star} \cdot \frac{2\pi R_{star}}{P_{rot}} \sim const$ where P_{rot} is the rotation period. We assume for simplicity P_{rot} of the Sun is P_{Sun}, P_{rot} of the star is P_{star}.

Therefore, we can write the relationship between mass, radius and period of rotation:

$$\frac{M_{star}}{M_{Sun}} = \left(\frac{R_{star}}{R_{Sun}}\right)^{-2} \left(\frac{P_{star}}{P_{Sun}}\right) \tag{9}$$

From the formulae (7) - (9) follows that there is the relationship of the period of rotation and the effective temperature:

$$\frac{P_{star}}{1year} = \left(\frac{T_{eff}{}^{star}}{1K}\right)^{-4} \left(\frac{M_{star}}{M_{Sun}}\right)^{\alpha+1} \tag{10}$$

Thus, at the diagram "the period of rotation of - the effective temperature" the solar-type stars should be placed near the line with the equation:

$$\log\left(\frac{P_{star}}{1year}\right) = -4\log\left(\frac{T_{eff}{}^{star}}{1K}\right) + const$$

So the above regression equation (1) agrees well within the errors with the theoretical formula (10).

4 Physical model of the dependency "the duration of the cycles of the stars - the effective temperature of the star"

In the work (Seehafer et al. 2003) a numerical MHD simulation of hydromagnetic dynamo was made. The authors have studied the fully turbulent and the fully laminar convective shells. They also studied the convective shell which consists of the shell of two layers: the turbulent convection and the laminar convection. Found that the numerical model of the solar dynamo is consistent with the observations of local magnetic activity, if in the convective envelope there are the layers both of the laminar and turbulent convection. Therefore it is likely that the convective shell of the Sun can be stratified into layers with different types of convection. We use this model result for the description of a physical nature of hydromagnetic dynamo of different scales.

The above properties of the global magnetic activity of the Sun and the power dependencies between the duration of cycles and effective temperatures of solar-type stars can be explained under the following scheme of physical processes in their convective shells:

(1) The process of magnetic activity begins with the formation of giant convective cells in the layer near the base of the convective envelope due to the heating of the plasma with help of photons coming from the radiation zone. In the work (Bruevich & Rozgacheva 2010) it is shown that near the base of convective envelope of the Sun the conditions for convective transfer from the account of the radiant viscosity of plasma only are fulfilled.

When the plasma elementary volume is coming to light due to convection along the radial direction its path is rejected from the radial direction by the Coriolis forces. Figure 4. shows the directions of the Coriolis acceleration $\vec{W}_A$ of rising elementary volume of plasma at the point A and the Coriolis acceleration $\vec{W}_B$ of falling elementary volume at the point in the in the convective cell. Rising element of plasma in the point A is located closer to the equator than falling element of plasma at the point in the point B. The Coriolis accelerations are directed perpendicular to the radial plane, in which moves an elementary convective volume. The Coriolis acceleration in the point A is more than Coriolis acceleration at the point B, because the angular velocity of rotation increases with decreasing of latitude.

The rising element of volume creates a pressure gradient, the direction of this gradient depends on the direction of the velocity of the element and on the Coriolis acceleration, on the change of speed of rotation with the latitude (increasing of the speed of rotation in the direction of the equator or at the direction of the poles). The pressure gradient will be spread in the spherical shell along the lines of latitudes as Rossby wave.

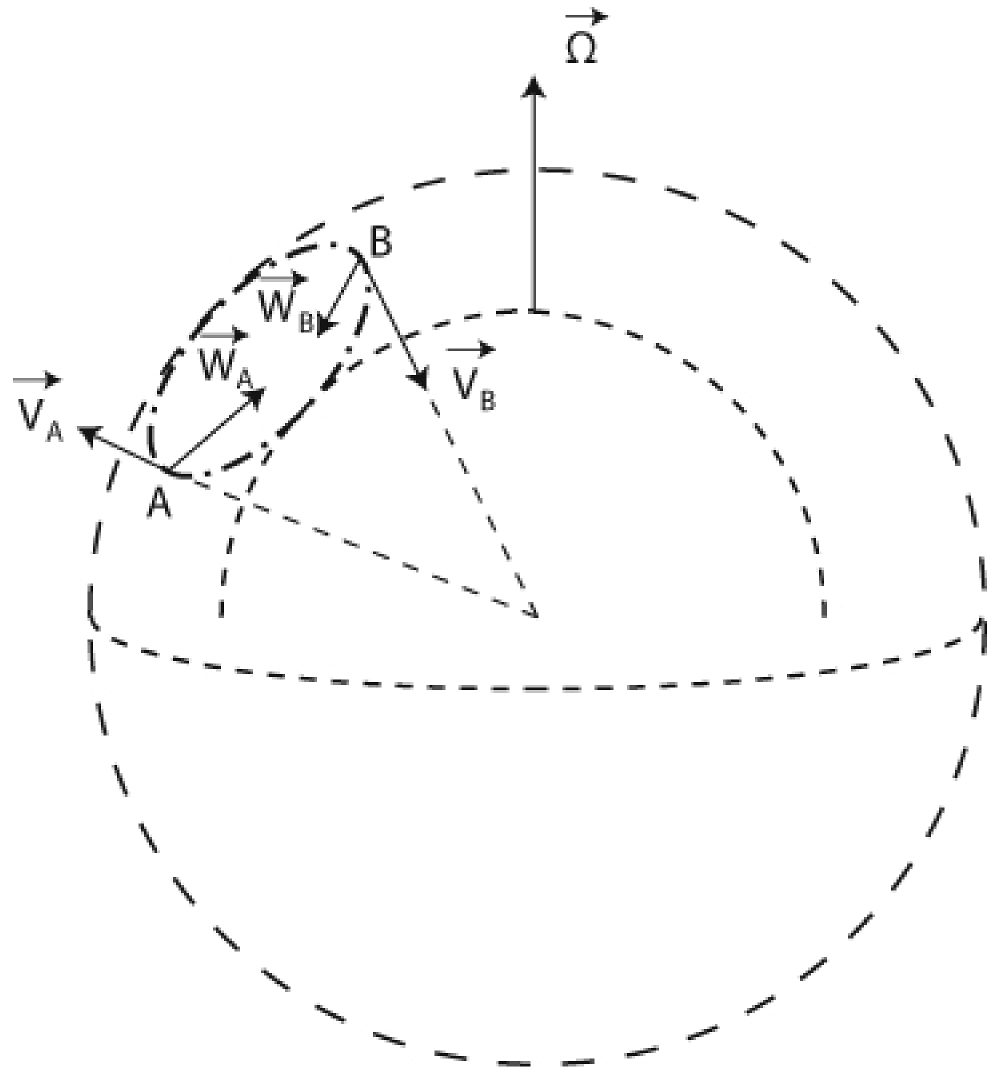

Figure 4: Scheme of the directions of the vectors of velocities ($\vec{V_A}$ and $\vec{V_B}$) and the vectors of the Coriolis accelerations ($\vec{W_A}$ and $\vec{W_B}$) in the convective cell

The first model with the use of Rossby waves in the theory of hydromagnetic dynamo was proposed in work (Gilman 1974). He considered that the Rossby waves were elements of spiral turbulence in the rotating convective shell, which occurs due to the latitudinal temperature gradient. Later this hypothesis was refined. In the total it was suggested to consider the Rossby waves, resulting from the vertical temperature gradient (Monin 1980).

In the work (Schmitt 1987) the solution of model equations for Rossby waves was found, thanks to which a toroidal field can be generated by a poloidal field.

Around the base of convective shell the plasma temperature reaches millions of degrees $T \approx 2 \cdot 10^6\ K$. Plasma is fully ionized at such temperatures. Interaction of radiation with plasma is carried out by the scattering of photons by electrons; if the characteristic energy of photons does not exceed kT (where k is the Boltzmann constant). The length of free photon scattering order $(\sigma_T n)^{-1} \approx 3 \cdot 10^2\ cm$ when concentration of plasma is equal about $n \approx 5 \cdot 10^{21} cm^{-3}$, where σ_T is the cross-section of Thomson scattering of photons by electrons.

The motion of the plasma in the Rossby wave is slowed by the radiant viscosity of plasma. This viscosity inhibits the directed motion of electrons (the characteristic time is a fraction of a second), faster than motion of protons. Therefore, in the Rossby wave the electric current appears. This current creates a poloidal field. Lines of force of this poloidal field have the wave-like structure. This field is concentrated around the base of convective envelope in the equatorial and medium-sized helio-latitudes. In the polar helio-latitudes lines of force of the poloidal field come to the atmosphere of the Sun (Fig. 5).

On the length of the latitude the whole number of Rossby waves is packed. Therefore, the length of these waves should be of the order of $\lambda \approx (1/m) 2\pi R_I \cos\phi$ where ϕ is the latitude of parallels, along which the wave applies, $R_I \approx 0,7 R_{Sun}$ is the radius of the base of the convective envelope, m is the integer number of Rossby waves. For giant cells which are observed in photosphere the wave number is of order $m = 6$ (Monin 1980).

The wave length depends on the latitude. At different latitudes the various Rossby waves are generated, in each of which the electric current appears. These currents generate the poloidal magnetic fields. The ordered geometric structure of the spicules which are observed in the high helio-latitudes, points to the regularity of the poloidal field. Therefore, the lines of force of poloidal fields, created by Rossby waves, must be regular and not be entangled due to the large-scale convection.

It will be in that case, if the convective cells are big enough and are about the same, i.e. the convection around the base of convective envelope must be laminar. The length of the Rossby wave is approximately equal to the thickness of the shell of laminar convection.

We estimate the characteristic time of formation of the Rossby waves. The characteristic time of the convective ascent of the plasma element which is heated by photons from the radiation zone is equal:

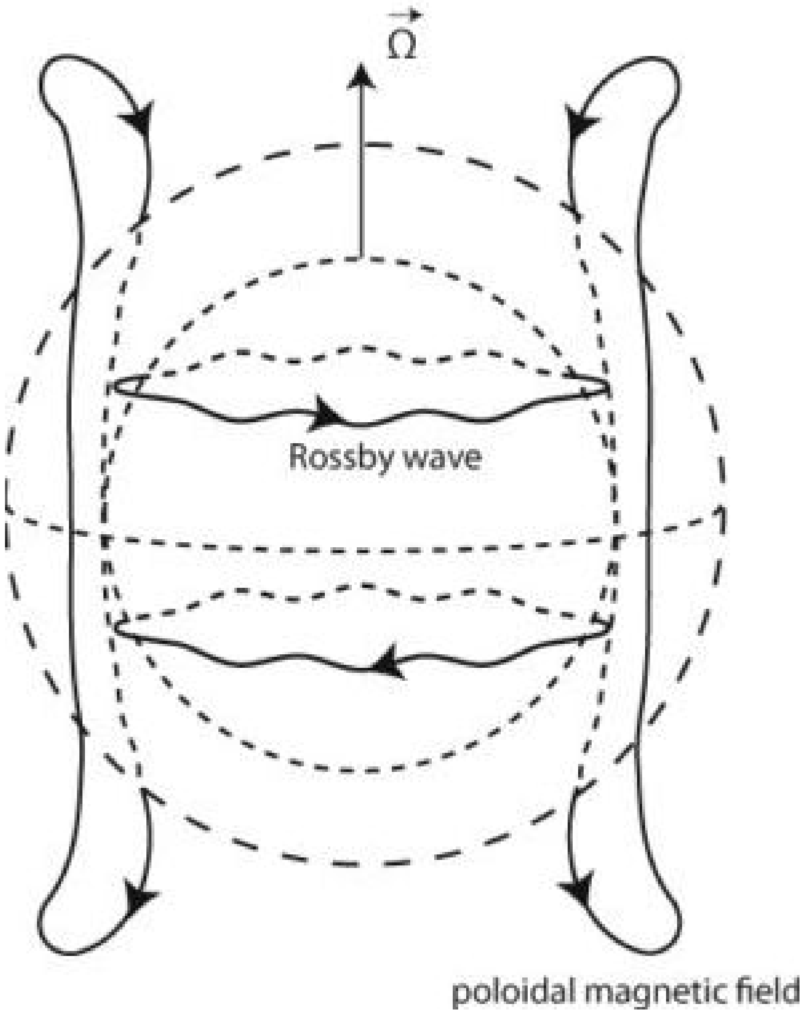

Figure 5: The scheme of Rossby waves and poloidal field

$$t \approx \frac{\nu}{gh\left(\frac{1}{\rho}\frac{\partial\rho}{\partial T}\right)\Delta T} \sim const$$

where ν is the coefficient of viscosity of the plasma, g is the free fall acceleration, h is the thickness of the shell of laminar convection, $\left(\frac{1}{\rho}\frac{\partial\rho}{\partial T}\right)$ is coefficient of thermal expansion of the plasma, ΔT is the gradient in the layer.

The average Archimedean acceleration of a plasma element is approximately equal to

$$a \approx g \left(\frac{1}{\rho} \frac{\partial \rho}{\partial T} \right) \Delta T$$

. Then the average Archimedean speed of a plasma element is $V \approx at \approx \frac{\nu}{h}$.

The Coriolis forces turn and stretch the convective cell along a parallel, so that the length of the path of element of the plasma is comparable with the length of parallels $l = 2\pi \cos\varphi$.

Average acceleration of the Coriolis force on this Parallels is in the order of magnitude is equal to $a_c = 2V\Omega_{Sun} \sin\varphi \approx 2\frac{\nu}{h}\Omega_{Sun} \sin\varphi$, where Ω_{Sun} is the angular velocity of rotation of the Sun around the base of convective shell.

The time interval which is necessary for the generation of Rossby waves (t_R) and poloidal magnetic field (t_g) on the order of magnitude is equal to:

$$t_g \approx \sqrt{\frac{2l}{a_c}} \approx \sqrt{\frac{\pi R_I \cos\varphi}{\frac{\nu}{h}\Omega_{Sun} \sin\varphi}} \tag{11}$$

For different latitudes the time of magnetic field formation is different: the less latitude, the longer the time of the formation. Therefore, the primary poloidal magnetic field should appear at high latitudes. It can stimulate the polar magnetic activity.

(2) In accordance with the hypothesis of the Babcock - Layton (Kichadinov 2005), we consider that the large-scale poloidal field, connected with Rossby waves have to be the primary for the whole complex of phenomena of magnetic activity.

From this poloidal field a toroidal field is generated due to the differential rotation of the convective zone. The direction of the magnetic force lines is the same as the direction of Rossby waves. It is formed in the middle turbulent layer of the convective zone. Here an $\alpha\Omega$ - dynamo model works. Magnetic tubes and loops of toroidal fields are generated as a consequence of turbulent convection and also due to the curves of the magnetic force lines of the primary poloidal field. Magnetic tube and loops of toroidal fields rise to the photosphere. Their intersection and reconnection stimulate the magnetic activity (Somov 2006).

Rossby wave interacts with the local magnetic fields which float due to the convection up to the photosphere. This interaction compresses the region of localization of the fields, increases the intensity of magnetic fields and stimulates the formation of spots (Bissengaliev et al. 2010). So Rossby waves lead to the formation of "active latitudes" (Monin 1980). Offset of local fields with help of the waves leads to the formation of "active longitudes" with almost periodic distribution along the helio-meridians.

The meridional fluxes around the base of convective zone are directed from the poles to the equator (Kichatinov 2005). They move Rossby waves closer to the equator. The consequence of this will be the slope of the lines of force of poloidal field in the direction to the equator. Generally speaking, the shifts of the currents which are in the Rossby waves change the orientation of poloidal fields in space: the axis of symmetry of the poloidal field turns and may be situated in one of the surfaces of the equatorial latitudes.

The meridional fluxes around the base of convective zone are transmitted to magnetic tubes of toroidal field due to the magnetic viscosity of plasma. The consequence of this is observed in the photosphere the "Shpherer's law " which describes the local magnetic activity on low helio-latitudes (each new cycle begins at high latitudes in both hemispheres, gradually shifting to the equator as the cycle unfolds).

In both hemispheres of the Sun photospheric bipolar magnetic regions of toroidal fields are stretched, reconnected and form the poloidal field of opposite polarity in relation to the primary poloidal field. Then a toroidal field disappears. The first half of the cycle of magnetic activity ends.

(3) New poloidal field interacts with the primary poloidal field. Because these fields have the opposite direction, so the reconnection of lines of magnetic takes place. At this time, there appeared a magnetic activity above the middle latitudes. As a result of this the processes of activity there are all over the surface of the Sun.

Because of the rotations of the primary poloidal field a large-scale field, which is formed by adding of two poloidal fields, may have a complex structure, for example, quadruple structure.

In the general case a poloidal field is not completely destroyed due to the polar activity. However, the new poloidal field becomes weaker due to the polar activity.

The new toroidal field, which appears as a consequence of $\alpha\Omega$ - dynamo from weakened poloidal field, will be weaker than the previous one toroidal field, which appeared from the primary poloidal field. Therefore, the local magnetic activity, which will be caused by this toroidal field in the second half of the magnetic cycle, will also be weaker.

This is a new a toroidal field which is directed opposite to the direction of Rossby wave propagation. It weakens the electric currents that exist in these waves. This leads to a weakening of the primary poloidal field.

(4) At the end of the previous stage of the magnetic activity before the disappearance of the toroidal field the poloidal field appears thanks to the $\alpha\Omega$- dynamo.

The direction of this poloidal field is close to the area of primary poloidal field; if the latter does not experienced significant changes. In this case, the primary poloidal field will increase. From this poloidal field will be generated a toroidal field, which will be stronger than the previous toroidal field. Its evolution in a turbulent layer of the convective shell will lead to a local activity in the medium and equatorial helio-latitudes. This activity will be stronger than in the previous cycle. Therefore, the "Gnevyshev-Ol's rule" comes from the contribution of the primary poloidal field in the evolution of the toroidal fields.

If the primary poloidal field has experienced a significant turn, the "Gnevyshev-Ol's rule" would be broken, as it was for 22 and 23 of the "11-year" cycles.

The rotation of the primary poloidal field can lead to the emergence of secondary maxima of magnetic activity. These maxima are connected with the processes of the reconnection of the lines of force of a primary poloidal field, caught in the middle latitudes, and the lines of force of a toroidal field (Fig. 6).

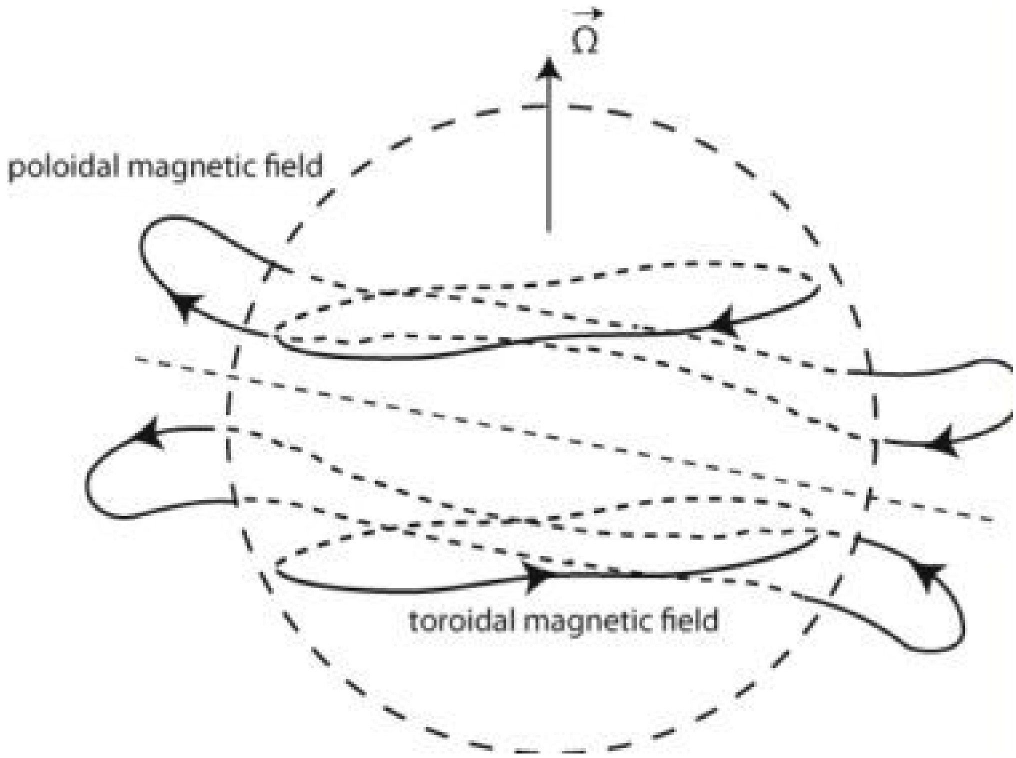

Figure 6: The intersection of the toroidal field and the turned primary poloidal field

(5) Energy of the global magnetic activity is determined by the energy of the Rossby waves. Therefore, the Rossby waves are gradually fade in the course of evolution of the primary poloidal field. Poloidal fields can also

disappear because of the high-latitude activity. The beginning of a new cycle will move away up to moment of formation of new Rossby waves. This may explain the different durations of the "11-year" cycles.

(6) The existence of Rossby waves at different helio-latitudes may lead to the existence of cycles of different duration, because the characteristic time of these waves and poloidal fields formation depends on helio-latitudes (the Coriolis acceleration is depended on the latitudes)

Energy of giant convective motions at the lower laminar layer is spent on:

- heat transfer in turbulent layer convection,
- the longitudinal transfer of momentum to maintain of the differential rotation of the Sun,
- generation of Rossby waves.

The observed magnetic activity of the Sun has the quasistationary character, therefore, between these branching in the process of the distribution of energy of the convection, apparently, remains a dynamic equilibrium. If, for example the formation of Rossby waves will slow down in the mid-latitudes due to the penetration of turbulent motions to the lower laminar layer, it will lead to the acceleration of the meridional transport momentum that will speed up the rotation of the mid-latitudes. The increase of the angular velocity of rotation will lead to the reduction of the time of Rossby waves formation (11). As a result, they will resume after a short time.

Quantitative value of the characteristic time of Rossby waves formation (11) depends on the thickness of the layer laminar convection and plasma viscosity in it. We estimate the value of viscosity, with the help of formula (11), if the time of the of waves Rossby formation is approximately equal the duration of the activity cycle. Taking into account that

$$h \approx \lambda \approx \frac{l}{m} 2\pi R_I \cos\varphi \approx \frac{1,4\pi}{m} R_{Sun} \cos\varphi$$

find the coefficient of viscosity:

$$\nu \approx \frac{0,49\pi^2 R_{Sun}^2 \cos^2\varphi}{m\Omega_{Sun} t_g^2 \sin\varphi} \approx 1,6 \cdot 10^{12} \left(\frac{m}{6}\right)^{-1} \left(\frac{t_g}{1year}\right)^{-2} \frac{\cos^2\varphi}{\sin\varphi} \frac{sm^2}{sec} \qquad (12)$$

For "active latitudes" the value of the viscosity (11) can be compared with the value of the coefficient of viscosity ν_γ around the base of convective envelope (c is speed of light):

$$\nu_\gamma \approx \frac{1}{3} \frac{c}{n\sigma_T} \approx 3 \cdot 10^{12} \frac{cm^2}{sec} \qquad (13)$$

It is a coincidence speaks in favor of the above-described the physical nature of the global magnetic activity. Approximately the same value of turbulent viscosity is used in the $\alpha\Omega$- dynamo model.

The model of multi-layered laminar convection using viscosity of radiant plasma (13) is described in (Rozgacheva & Bruevich 2002).

Rossby waves at different solar latitudes and with different wavelengths generate a very complex structure and evolution of the poloidal field. So check the physical picture of this poloidal field formation according to the observations of the Sun only is difficult.

Come to the aid of the study of solar-type stars. Using formula (11) to assess the relationship between the duration of activity cycle and the effective temperature of the stars.

Consider, first, that the angular velocity of rotation of the star connected with star's effective temperature as ratio $\Omega \sim T_{eff}{}^{4}$, which follows from the formula (10).

Secondly, we take into account that for fully ionized hydrogen plasma its concentration depends on the temperature, as $n \approx T^{\frac{3}{2}}$. Then the viscosity depends on the temperature, see (13) as $\nu \approx \nu_{\gamma} \sim \frac{3}{2}$. In this case, we can use the formula (11), and so we obtain the following connection between the star's duration of the activity cycle and its effective temperature:

$$T_{cyc} \approx t_R \sim T_{eff}{}^{-\frac{5}{4}} \tag{14}$$

The ratio (14) is consistent with the power relationships (4) and (6) within the limits of errors. This speaks in favour of the above-described the physical nature of the global magnetic activity of the Sun.

For the quantitative analysis of the proposed physical picture it is necessary to conduct the numerical experiments of the magnetic hydrodynamics of a multilayer convective shell of the Sun. It is the purpose of one of the following of our work.

5 Conclusion

In this paper, the following results were obtained:

1. It is shown that the dependence of "the rotation period - the effective temperature" (2) is a natural law for Main sequence stars, for which Stefan - Boltzmann law (7), the ratio of "mass - luminosity" (8) and conservation of angular momentum (9) are applicable.

2. We offer the physical picture of the interrelationship of observed properties of the local and global magnetic activity of the Sun. The main new element in this picture is a hypothesis about the possibility of the existence of several layers of the convective shell of the solar-type stars. T here must

be at least two layers. Around the ground level the convective shell is the laminar convection layer, which consists of a giant convective cells. Thanks to the rotation on the surface of this layer Rossby waves are formed.

These waves have spiral structure due to differential rotation. The formation of the laminar convection is caused by a strong heating of plasma photons from the zone of radiant heat transfer and high radiant viscosity of fully ionized dense plasma. The radiant viscosity of plasma effectively inhibits the directed motion of electrons more than directed motion of protons. Therefore, in the Rossby waves the current appears, and this current generates the poloidal field. This field is a primary reason of the whole magnetic activity of stars. Above the layer of the laminar convection the layer of turbulent convection extends. In the layer of turbulent convection the primary poloidal field generates a toroidal field of starts and process of generation of a strong local magnetic activity solar-type stars in the medium and equatorial latitudes starts. Local and global magnetic activity are interconnected thanks to the existence of internal Rossby waves and the primary poloidal field.

3. It is shown that in the framework of the proposed hypothesis about the existence of internal Rossby waves you can explain the dependence of "the duration of the activity cycles - the effective temperature" for 11-year and quasi-biennial cycles, see (4) and (6). The duration of the activity cycles according to the order of magnitude is equal to the characteristic time of generation of Rossby waves.

These results refer to the main problems of hydrodynamics of the Sun - differential rotation and solar dynamo. They point to the fact that, apparently, the model of a one-layer of turbulent convection and the model of turbulent theory of generation of the magnetic field and the magnetic activity are characteristic of young rapidly rotating stars. These stars may intensively lose the substance due to the strong magnetic activity. Their outer layers are not yet fully formed.

In the later stages of the evolution the inner layer laminar convection is formed, because, firstly, the speed of rotation is reduced, and, secondly, and, secondly, a strong turbulent diffusion of plasma fluxes reduces the heterogeneity of rotation and gradually the convection passes from turbulent state to the laminar state. Due to this layer the phenomena of magnetic activity acquire the properties of orderliness, observed on the Sun.

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