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The new approach to the mechanism of solar magnetic cycle

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Traditionally the $\alpha-\omega$-dynamo is regarded as a basic theory of solar activity (SA) cycle. Here the model of solar magnetic cycle based on the new MHD-solutions for the mean large-scale magnetic field is presented. The hypothesis of gyrotropic plasma turbulence and cyclic restoring of the poloidal magnetic field from the rising toroidal magnetic flux tubes due to the α-effect is not used (see Solov'ev and Kiritchek (2004)).

According to the model, two basic types of magnetic fields exist on the Sun.

The 1st type presents weak diffuse magnetic fields that immediately form the SA cycle (The strength of the mean large-scale magnetic field varies from 1 Gs for the poloidal to 100-200 Gs for the toroidal field). For these fields, the origin, the structure and the time-evolution are defined by the turbulence and the turbulent diffusion, which is rather rapid ($D_T \cong 2 \times 10^{13}$ cm$^2 \cdot$ s^{-1}).

The 2nd type of the magnetic fields is formed by the strong, regular, quasi-steady magnetic fields. According to the helioseismology data, fields of this type (with the strength of order of tens and hundreds of kGs) exist in the convective zone and do not appear at the surface of the Sun. These strong fields are not subject to the turbulent diffusion. Their dissipation, stipulated by the ordinary gas-kinetic conductivity, is extremely slow. The rotation rate and the asphericity of the convective zone are determined exactly by the magnetic fields of the 2nd type.

In the proposed model, every 22-years the magnetic cycle (Hale's cycle) is formed by a certain portion of diffuse magnetic flux (the 1st type fields), that was recycled by the turbulence in the convective zone into the large-scale dissipative structure. This field structure is described analytically by the solutions of diffusion problem, presented by the series:

$$\Psi(\tilde{r}, \theta, \tilde{t}) = B_{0,P} r_0^2 \sin^2\theta \sum_k M_k(\tilde{r}, \tilde{t}) P_k'(\cos\theta). \tag{0.1}$$

Here r_0 is the certain characteristic space scale of magnetic field, and $\tilde{r} = r/r_0$, $\tilde{t} = t/t_D(r_0)$; $t_D(r_0) = r_0^2/D_T$ is the diffusion time in the scale r_0. $\Psi = -\int B_\theta \sin\theta r dr$ is the poloidal magnetic flux, $P_k'(\cos\theta)$ is the $\cos\theta$-derivative of Legendre polynomial of order k, where $k = 0, 1, 2, 3...$. $B_{0,P} = const$ is the scale parameter for the poloidal magnetic field strength, and the function $M_k(r,t)$ satisfies the diffuse equation in the spherical geometry

$$\frac{\partial M_k}{\partial \tilde{t}} = \frac{\partial^2 M_k}{\partial \tilde{r}^2} - \frac{k(k+1)M_k}{\tilde{r}^2}. \tag{0.2}$$

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We have found the new regular solution of the equation (2). It has the form:

$$M_k(\tilde{r},\tilde{t}) = C_k^* \sqrt{r} \frac{\exp\left(\frac{-(\tilde{t}-\tilde{t}_{0,k})\tilde{r}^2/4}{\mu_k^2+(\tilde{t}-\tilde{t}_{0,k})^2}\right)}{\sqrt{\mu_k^2+(\tilde{t}-\tilde{t}_{0,k})^2}} J_{(k/2+1/4)}\left(\frac{\mu_k \tilde{r}^2/4}{\mu_k^2+(\tilde{t}-\tilde{t}_{0,k})^2}\right). \tag{0.3}$$

Here $J_{(k/2+1/4)}$ is the Bessel function; C_k^*, μ_k and $\tilde{t}_{0,k}$ are free parameters (constants). The main feature of this new solution is that the argument of the Bessel function contains both the radial distance and the time in the quadratic form. It provides the specific oscillating rate of the diffusion of the magnetic field. If we normalize the radial distances over the radius of the Sun: $\overline{r} = r/R$; and use the time normalized over the diffusion in the scale of the Sun, $\overline{t} = t/t_D(R)$, where $t_D(R) = R^2/D_T = const = 7.68$ year, then this solution can be presented in the other form which contains one less free parameter:

$$M_k(\overline{r},\overline{t}) = C_k \sqrt{\overline{r}} \frac{\exp\left(\frac{-\eta_k(\overline{t}-\overline{t}_{0,k})}{1+\eta_k^2(\overline{t}-\overline{t}_{0,k})^2}\frac{\eta_k\overline{r}^2}{4}\right)}{\sqrt{1+\eta_k^2(\overline{t}-\overline{t}_{0,k})^2}} J_{(k/2+1/4)}\left(\frac{\eta_k\overline{r}^2/4}{1+\eta_k^2(\overline{t}-\overline{t}_{0,k})^2}\right). \tag{0.4}$$

Here we specify:

$$C_k = \frac{C_k^*}{\mu_k}\sqrt{\frac{R}{r_0}}, \quad \eta_k = \frac{R^2}{\mu_k r_0^2}. \tag{0.5}$$

Since the diffusion equations are linear, and the choice of the parameters C_k, η_k, $\overline{t}_{0,k}$ in the solution (0.4) is arbitral, the superposition of the solutions of the linear equation allows us to write the expression (0.4) in more general form:

$$M_k(\overline{r},\overline{t}) = \sum_l \sum_j C_{k,l,j} \sqrt{\overline{r}} \frac{\exp\left(\frac{-\eta_{k,l}^2(\overline{t}-\overline{t}_{0,k,j})}{1+\eta_{k,l}^2(\overline{t}-\overline{t}_{0,k,j})^2}\frac{\overline{r}^2}{4}\right)}{\sqrt{1+\eta_{k,l}^2(\overline{t}-\overline{t}_{0,k,j})^2}} J_{(k/2+1/4)}\left(\frac{\eta_{k,l}\overline{r}^2/4}{1+\eta_{k,l}^2(\overline{t}-\overline{t}_{0,k,j})^2}\right). \tag{0.6}$$

Here the independent summing is conducted over the indexes l, j. This implies that in the solutions (0.1)-(0.6) the mode of the certain number k can contain the arbitrary number of summands having different amplitudes $C_{k,l,j}$ and different arbitral parameters $\overline{t}_{0,k,j}$, $\eta_{k,l}$.

This magnetic field configuration, described by (0.1)-(0.6), diffuses towards the surface of the Sun, and provides there all the observed SA phenomena. In 22 years it escapes the Sun due to the irreversible dissipation, and new topologically independent structure, having the similar physical parameters, occupies its place. The continuous supplement of the diffusion process is due to the winding up of the poloidal magnetic flux by the differential rotation in the upper layers of the convective zone (ω-effect).

The proposed model describes well the basic features of 22-years solar cycle (Hale's low, Maunder's butterflies, Waldmeier's rule), estimates correctly its duration and reveals the nature of the number of SA phenomena: torsional oscillations, meridional circulation, the reversals of global magnetic field and others. It also gives the latitudinal structure of the solar convective zone and the space distribution of the rotation velocity in that region which fits very well into the distribution obtained by the helioseismology methods.

References

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