Magnetic Activity of Solar-Type Stars

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Abstract: Here we described the origin of the magnetic-activity cycles of solar-like cool stars. On the basis of the atom-like structure of baryons, we calculated the ratios of the activity-cycle period to rotation period for the Sun and for the active and inactive branches. We also solved the coronal heating problem.

1. Introduction

Here we calculated how the magnetic-activity-cycle period depends on the rotation period of the solar-like stars defined as cool main-sequence dwarfs with the following effective temperatures

$$5{,}000 < T_{eff}\ [K] < 7{,}000.$$

On the assumption that just above the photosphere of the Sun are created two perpendicular vortices with rotating spins, one composed of electrons and the second of protons, we can calculate the 10.7-year sunspot cycle [1]. Most important is the relation which relates a characteristic/mean energy/mass in an interaction, $M_{Charact.,i}$, with period of rotation of a star on its equator, P_{Rot}, and with activity-cycle period, P_{Cyc},

$$P_{Cyc} = P_{Rot}\ M_{Charact.,i} / [2\ (e^+e^-)_{bare}]\ , \qquad (1)$$

where $(e^+e^-)_{bare} = 1.020814$ **MeV** is the bare mass of the virtual electron-positron pair [2] which is the characteristic mass in the electromagnetic interactions of the vortex of electrons. It means that activity-cycle period depends directly proportional on rotation period of star and characteristic mass in the nuclear strong interactions in the cores of stars. For the Sun is $P_{Rot,Sun} = 25$ **days** and $M_{Charact.,X+} = X^+ = 318.2955$ **MeV** is the mass of the electric charge inside the core of baryons [2].

The Sun at its maximum activity is presented in Figure 1.

Both vortices rotate. Responsible for the sunspot cycle is the rotation of the vortex of electrons. We must distinguish the period of spinning/rotation of the vortices or a star, P_{Rot}, from the period of rotation of the spin of the vortices, $P^*_{Rot-spin}$

$$P^*_{Rot-spin} = 2\ P_{Cyc}\ . \qquad (3)$$

The rotation of the vortex of protons is responsible for the changes in the solar polar magnetic field strength.

The vortex of electrons rises, then its magnetic axis turns 180 degrees, and next it vanishes, and so on – it rebirths each 10.7 years like a Phoenix from the ashes. When the spin of the vortex of electrons is antiparallel to the spin of the Sun, it is destroyed for very short time and until it is reborn with a spin parallel to the spin of the Sun, we have magnetic silence on the Sun.

Of course, the forces trying to rotate the perpendicular vortices act on both of them.

There is the maximum solar activity when the vortex of electrons has spin perpendicular to the sun's axis of rotation.

Probably the Maunder Minimum and other grand minima are the result of greater turbulence in the sun's photosphere which limited the separation of protons and electrons in the vortices. Thus, the minima are related to the greater nuclear activity of the Sun.

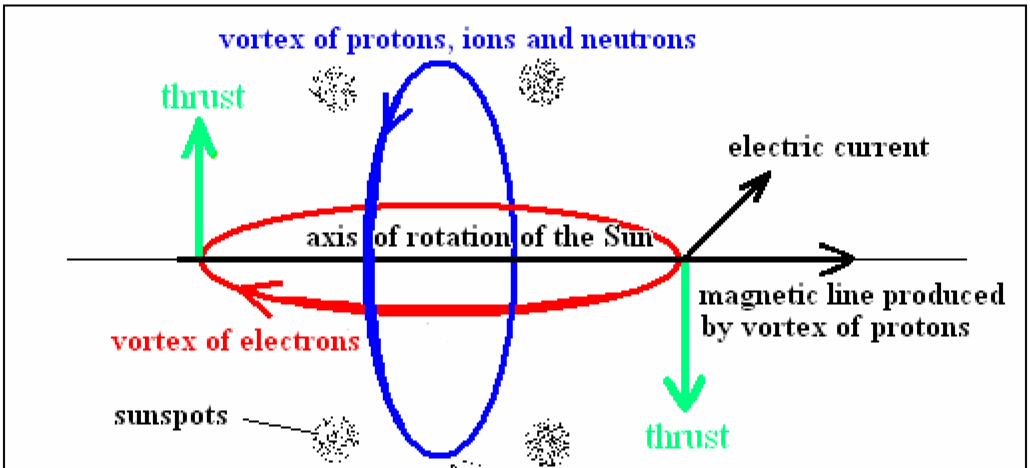

Fig.1
The Sun at its maximum activity.

2. Activity-cycle period versus rotation period

How we should understand the term "characteristic energy/mass"?

The mean energy/mass of interactions depends on composition and temperature of the nuclear plasma in cores of stars.

When a mean energy/mass of interactions is equal to one, two or three characteristic energies/masses for the atom-like structure of baryons then we should observe a resonance – it should increase number density of stars. It is the reason that in Figure 2 we should observe the branches. Rotation period of stars strongly depends on the mean/characteristic energy/mass of interactions. The characteristic energy/mass of interactions must be electrically charged because only then are created the virtual electron-positron pairs which define the magnetic activity of stars.

Applying formula (1) to the characteristic masses for the atom-like structure of baryons, we can calculate the ratios $N_{Cyc/Rot} = P_{Cyc} / P_{Rot}$

$$N_{Cyc/Rot} = P_{Cyc} / P_{Rot} = M_{Charact.,i} / [2\,(e^{+}e^{-})_{bare}] \qquad (4)$$

for the solar-like cool stars.

There are many characteristic energies/masses $M_{Charact.,i}$ for the nuclear-plasma in the cores of stars: the helium nucleus $^4He^+$ = 3755.6 MeV, deuteron D^+ = 1877.8 MeV, proton p^+ = 938.27 MeV, charged core of baryons H^+ = 727.44 MeV, electric charge in the core of baryons X^+ = 318.30 MeV, the charged remainder $R^+_{d=4}$ = 187.57 MeV from the decay $S^{+,-}_{d=0} \rightarrow 4\pi^o + R^{+,-}_{d=4}$, relativistic charged pion $W^+_{d=1}$ = 215.76 MeV, relativistic charged pion in the ground state above the Schwarzschild surface for the nuclear strong interactions $W^+_{d=2}$ = 181.70 MeV, charged pion π^+ = 139.57 MeV, muon μ^+ = 105.66 MeV, charge of muon $\mu^+/2$ = 52.8 MeV, the electrically charged gluon loops with energy/mass $S^{+,-}_{d=0}$ = 727.44 MeV, $S^{+,-}_{d=2}$ = 298.24 MeV, $S^{+,-}_{d=4}$ = 187.57 MeV, and so on [2].

The big number of the characteristic energies/masses cause that in general, the stars in the diagram describing the dependence of magnetic activity on the star's rotation are scattered. But there are four masses that form two pairs, each composed of a gluon loop and a particle, with the same energies/masses of the components

A) $S^{+,-}_{d=0}$ = 727.44 MeV and H^+ = 727.44 MeV, – it leads to the boson-fermion resonance for the active branch (see Fig.2),
B) $S^{+,-}_{d=4}$ = 187.57 MeV and $R^+_{d=4}$ = 187.57 MeV – it leads to the boson-boson resonance for the inactive branch (see Fig.2). (5)

We should observe some increases in number densities of stars for the two resonant branches. Applying formula (4) we can calculate the distinguished ratios: $N_{Cyc/Rot}$ = 356 and 89. The two branches relate to the first and the last Titius-Bode orbits for the nuclear strong interactions [2].

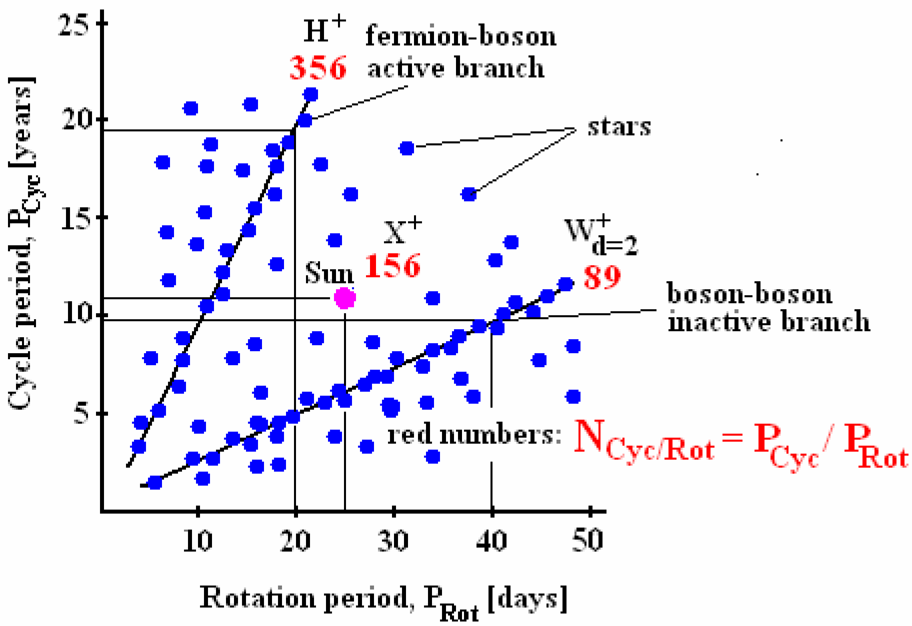

Fig.2
Activity-cycle period in years versus rotation period in days.

The distinguished ratios $N_{Cyc/Rot}$ for the solar-like stars are collected in Figure 2 – we present the activity-cycle periods in years versus rotation periods in days.

In Figure 2, as the effective temperature of stars drops, they migrate vertically downward.

Today the samples of the cool solar-like stars contain too few stars to conclusively confirm the existence of an active and inactive region, especially the active branch [3], [4], [5].

Emphasize also that higher characteristic mass means that also central temperature of star is higher.

3. The maximum solar magnetic field strengths for the polar direction and sunspots

The Biot-Savart law relates magnetic fields to the currents. The magnetic field (magnetic flux density), B, at centre of a current loop with a radius R is

$$B = \mu_o Q / (2 R P_{Rot}) , \tag{6}$$

where $\mu_o \approx 1.26 \cdot 10^{-6}$ **H/m** is the magnetic constant (the vacuum permeability), and Q is the total charge of the loop/vortex.

There are two cases in the Scale-Symmetric Theory (SST) when number of entangled neutrinos with lowest mass and non-rotating spin ($m_{Neutrino} = 3.3349306 \cdot 10^{-67}$ **kg**) is equal to K^4, where $K = 0.78967 \cdot 10^{10}$ [2]: it is for the charged core of baryons [2] and the predicted dark-matter particle [6] both with the masses equal to 727.4 MeV. In SST, the single or entangled neutrino-antineutrino pairs are the carriers of photons and gluons and 100% of the proton spin is from the entangled carriers of gluons [2]. Assume that the loop/vortex of electrons consists of $Z = K^4$ entangled electrons and that both vortices appear just above the photosphere of the Sun so their radii are equal to the photospheric radius of the Sun $R_{Sun} = 6.96340 \cdot 10^8$ **m**. The period of spinning of the vortex is equal to the $P_{Rot} = 25.0$ **days** $= 2.16 \cdot 10^6$ **s**.

The maximum magnetic field produced by the vortex of electrons (it is for sunspots) is defined by formula

$$B_{e,max} = \mu_o K^4 e / (2 R_{Sun} P_{Rot}) = 0.261 \text{ T} = 2610 \text{ G} , \tag{7}$$

where $e = 1.602 \cdot 10^{-19}$ **C** is the elementary electric charge. This value is the maximum magnetic field for the sunspots and is consistent with the observational data [7]

$$2{,}000 < B_{e,max,observational} \text{ [G]} < 3{,}000 . \tag{8}$$

On the assumption that spins of both vortices must be the same

$$Z_{proton}\, m_p (2 \pi R_{Sun} / P_{Rot}) R_{Sun} = Z\, m_e (2 \pi R_{Sun} / P_{Rot}) R_{Sun} , \tag{9}$$

we obtain

$$Z_{proton} = Z\, m_e / m_p . \tag{10}$$

From (7) and (10) we obtain that the maximum magnetic field in centre of the vortex of protons, $B_{p,max}$, is $N = 1836$ times lower than of the vortex of electrons

$$B_{p,max} = B_{e,max} / N = 1.42 \text{ G} . \qquad (11)$$

This value is very close to the observed maximum solar magnetic field strengths for the polar direction (~1.5 G) [8].

We can calculate the mean value for $B_{p,max}$. There is the sine function so the mean value is

$$B_{\mathbf{p,mean}} = B_{\mathbf{p,max}} \frac{\int_0^{\pi} \sin\alpha \, d\alpha}{\pi} = 0.905 \text{ G}$$

Mass of the vortices is $M = Z\, m_e = 3.54 \cdot 10^9$ **kg** so density is very low and their detection is difficult.

4. Coronal heating problem

This problem relates to the fact that the temperature of the sun's corona is too hot – it is about 2 million K, i.e. it is much hotter than the surface of the Sun.

Presented here mechanism is as follows.

Around the two perpendicular vortices/loops/currents produced on the surface between the convection zone and the photosphere (one is composed of electrons and the second of protons) are produced magnetic loops with different radii and they are composed of the entangled Einstein-spacetime components, i.e. of the non-rotating-spin neutrino-antineutrino pairs [2]. Such loops behave and interact similar to the dark-matter (DM) loops [9] but, contrary to the DM loops (they interact weakly), spins of the pairs in the magnetic loops are perpendicular to the loops so they can also interact electromagnetically.

The perpendicular vortices cause that the planes of the magnetic loops are perpendicular to the photosphere in such a way that a half or so of each of them is above the photosphere. Moreover, the vortices are orthogonal and the Sun rotates so the magnetic loops can be twisted.

Initially, each magnetic loop, due to the weak interactions, traps K^4 electrons – the electrons also are entangled so the magneto-electrical loops are the very stable structures. On the other hand, the magneto-electrical loops attract the positively charged chromospheric plasma. Such complex loops we call the coronal loops.

Range of the coronal loops is about 2460 km (see the calculations below) and next on the surface between the Transition Region and corona such coronal loops decay. During such decays, there is the transition from the cool laminar motions in the loops into the hot turbulent motions so there should appear the transverse motions as well [10]. The turbulent motions heat the plasma in corona to about 2 million K (see the calculations below).

The magnetic loops have the spin speed equal to the speed of light in "vacuum" c. The weak interactions of electrons with such magnetic loops can increase their spin speed (so also of the positively charged plasma along them) up to [9]

$$v_{Spin,plasma} = c\,(2\,\alpha_{w(electron\text{-}muon)})^{1/2} \approx 414 \text{ km/s} , \qquad (12)$$

where $\alpha_{w(electron\text{-}muon)} = 0.951108 \cdot 10^{-6}$ is the coupling constant for the weak interactions of electrons [2], and the factor 2 is for the electron-positron pairs that carry the interactions [9]. Such spin speed is consistent with observational data [10] – they detected cool plasma flowing in the coronal loops with speeds in the range $74 - 123$ **km/s**.

There are the different results for thickness of photosphere and chromosphere so we assume that they are as follows:

* the photosphere is about 300 km thick [11],
* the chromosphere is about 2000 km thick [11],
* the Transition Region is about 100 km thick.

We can see that from the outer surface of the convection zone to the corona is about 2400 km which is consistent with the calculated below range of the magnetic loop interacting weakly with the K^4 electrons, i.e. with the range of the mass equal to

$$M_{Loop} = K^4 m_e = Z m_e = 3.54 \cdot 10^9 \textbf{ kg} = \textbf{const} . \qquad (13)$$

The equatorial radius of the baryons is $A = 0.6974425$ **fm** so range of loops created on such equator is $L_S = 2\pi A$. Assume that such a range relates to the mass of the Sun $M_S = 1.9885 \cdot 10^{30}$ **kg**. We know that range is inversely proportional to mass so range, L_{Loop}, of the mass M_{Loop} is

$$L_{Loop} = L_S M_S / M_{Loop} = 2460 \textbf{ km} . \qquad (14)$$

Orbital speed, $v_{Orbital}$, is defined as follows

$$v_{Orbital}^2 = G_i M / R_i , \qquad (15)$$

where G_i is a constant of interactions (it can be, for example, the gravitational constant G), M is the mass of source of interaction, and R_i is the radius of the orbit.

Orbital angular momentum is defined as follows

$$m v_{Orbital} R_i = \textbf{const.} , \qquad (16)$$

where m is the mass of a carrier of interactions.

Coupling constants, α_i , are defined as follows [2]

$$\alpha_i = G_i M m / (c \hbar) , \qquad (17)$$

where $\hbar$ is the reduced Planck constant (for example, m in the nuclear strong interactions decreases with increasing energy so the coupling "constant" for the nuclear strong interactions is the running coupling [2]).

The Wien's displacement law looks as follows

$$T_i \lambda_i = \textbf{const.} , \qquad (18)$$

where T_i is the absolute temperature, and $\lambda_i = 2\pi R_i$ is the wavelength peak.

From formulae (15) – (18), on the assumption that m is invariant (the M_{Loop} is invariant), results that temperature T_i of plasma is directly proportional to coupling constant α_i

$$T_i \sim \alpha_i . \qquad (19)$$

The radius of the fundamental gluon loop (FGL) which relates to the neutral pion (previously I called such a loop *the gluon large loop* but such term is not appropriate) [2] is

$$R_i = R_{FGL} = 2A/3 = 0.465 \ \mathbf{fm} \ . \tag{20}$$

From the Wien's law results that temperature of the FGL inside the core of baryons, which is responsible for the nuclear strong interactions at low energy ($\alpha_s = 1$ [2]), is $T_S = 9.92 \cdot 10^{11}$ **K**. Since in the coronal loops dominate the weak interactions of electrons so the characteristic temperature of the corona, T_{Corona}, should be

$$T_{Corona} = T_S \ (2 \ \alpha_{w(electron\text{-}muon)}) \ / \ \alpha_s = 1.89 \ \mathbf{million \ K} \ . \tag{21}$$

Both results, i.e. 2460 km and ~2 million K, are consistent with observational data.

5. The other experimental data consistent with the model presented here

All of presented here results follow from the Scale-Symmetric Theory [2]. The key roles in the SST plays the number K (see formula (7)) which leads to the phase transitions of the inflation field, and the Titius-Bode (TB) law for the nuclear strong interactions

$$R_i = A + d \ B, \tag{22}$$

where $B = 0.5018395$ **fm**, and $d = 0, 1, 2$ and 4 [2].

The phase transitions lead to the sizes characteristic for the core of baryons, i.e. to the radius of the FGL (it is responsible for the nuclear strong interactions inside baryons): $R_{FGL} = 2A/3 = 0.465$ **fm** (see formula (20)) and to the equatorial radius A of the core. The centre of the virtual or real FGL overlaps with the centre of baryons and its spin is parallel or antiparallel to the spin of baryons. On the other hand, formula (22) leads to the TB radii of the orbits for the nuclear strong interactions: $R_{d=0} = A \approx 0.7$ **fm**, $R_{d=1} = A + B \approx 1.2$ **fm**, $R_{d=2} = A + 2B \approx 1.7$ **fm** and $R_{d=4} = A + 4B = 2.7048$ **fm** – it and the phase transitions lead to the other gluon loops and to the other characteristic masses mentioned in Section **2**. The range of the nuclear strong interactions is $L_{Strong} = 2.9582$ **fm** [2].

There are experimental results that are equal or very close to the listed above sizes!

Notice that the arithmetic mean of the radius of the last TB orbit and the range of the nuclear strong interactions is

$$L_{Strong\text{-}d=4} = (R_{d=4} + L_{Strong}) \ / \ 2 = 2.8315 \ \mathbf{fm} \ , \tag{23}$$

so we can write down the two results as follows

$$L_{Theory,SST} = 2.8315 \pm 0.1267 \ \mathbf{fm} \ . \tag{24}$$

On the other hand, the result fitted to the STAR experimental data gives the following value of the source size [12]

$$r_{o,experiment,STAR} = 2.83 \pm 0.12 \ \mathbf{fm} \ . \tag{25}$$

We can see that our result is perfect!

So-called "hard core of nucleons" of an infinite strength was first introduced phenomenologically by Jastrow in 1950 [13]. We assume that it concerns the FGL.

When a beam is flowing in direction of the spin of a target (i.e. the spins of the target components are polarized) then we should obtain the radius of FGL – it is at the zero-temperature limit and it is the upper limit for the radius of the hard core of nucleons in our model

$$R_{\text{Hard-core,upper}} = R_{\text{FGL}} = 2A/3 = 0.465\ \mathbf{fm}\ . \tag{26}$$

On the other hand, for thermal nucleons (i.e. their spins are not polarized) we obtain the lower limit for radius of the hard core of nucleons. Along the x-axis and y-axis, the radius is R_{FGL} while along the z-axis the radius is zero so an approximate mean value that is the lower limit is

$$R_{\text{Hard-core,lower}} = (2\ R_{\text{FGL}} + 0)\ /\ 3 = 0.31\ \mathbf{fm}\ . \tag{27}$$

In paper [14], there are calculated the properties of a neutron star (NS) at zero-temperature limit (so spins of neutrons are polarized). They found the hard core radius for the baryons

$$0.425\ \mathbf{fm} < R_{\text{Hard-core,NS,[14]}} < 0.476\ \mathbf{fm}\ . \tag{28}$$

This result is consistent with our result – see formula (26).

In paper [15], authors claim that a comparison with the phenomenology of neutron stars implies that the hard-core radius of nucleons has to be temperature and density dependent. Their result for the hard-core radius of nucleons is

$$0.3\ \mathbf{fm} < R_{\text{Hard-core,NS,[15]}} < 0.36\ \mathbf{fm}\ . \tag{29}$$

This result is consistent with our result – see formula (27).

In the spin-triplet state, the effective range for the neutron-proton scattering is [16]

$$r_{ot} = 1.7606(35)\ \mathbf{fm}\ . \tag{30}$$

It relates to the $R_{d=2} \approx 1.7$ **fm** in our model.

In the spin-singlet state, the effective range for the neutron-proton scattering is [16]

$$r_{os} = 2.706(67)\ \mathbf{fm}\ . \tag{31}$$

It relates to the $R_{d=4} = 2.7048$ **fm** in our model.

Notice also that the experimental muon radius of proton [17] and its electron radius [18] indirectly lead to the radius $R_{d=1} = A + B \approx 1.2$ **fm** [19].

6. Summary

On the basis of the atom-like structure of baryons, we calculated the ratios of the activity-cycle period to rotation period for the Sun and for the active and inactive branches.

To see some increases in number density of stars on the branches in Figure 2, we need a sample of sun-like stars of about tens of thousands of them.

Since there is a big number of the characteristic energies/masses that follow from the atom-like structure of baryons so, generally, stars in Figure 2 are scattered. But there are four masses that form two pairs each composed of a gluon loop and a particle both with the same energies/masses so we should observe some increases in number densities of stars along two branches – it is for $N_{Cyc/Rot} = 356$ and 89.

On the assumption that on the surface of the Sun are created two perpendicular currents, we calculated the maximum solar magnetic field strengths for the polar direction and for the sunspots. Mass of the vortex/loop/current of electrons follows from mass of the core of baryons.

On the basis of the Scale-Symmetric Theory, we also solved the coronal heating problem.

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