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Solar flares and related phenomena

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1. O.M. Boyarkin, G.G. Boyarkina, Influence of solar flares on behavior of solar neutrino flux, Astropart. Phys. **85** (2016) 39.

2. O.M. Boyarkin, G.G. Boyarkina, Can we observe the new physics manifestations by the use of ultra-high energy cosmic neutrinos?, Astropart. Phys. **96** (2017) 18.

The SF represents itself the most powerful of all the solar activity events. The energy released during the SF is about $10^{28} - 10^{32}$ erg. It is now widely accepted that the magnetic field provides a main energy source of the solar activity including the SF's. A popular mechanism of the SF appearance is based on breaking and reconnection of magnetic field strength lines of neighboring spots (the magnetic reconnection model (K.Shibata, T.Magara, Living Rev. Solar Phys., 8 (2011) 6). Observations suggest that the magnetic field strength of big sunspots (d $\sim 10^5$ km) could reach 10^4 Gs while their geometrical depth is approximately 300 km. Then the total magnetic energy stored in such a sunspot is 4×10^{34} erg which is sufficient to produce even the largest flare.

According to the MRM, a change of magnetic field configuration in a sunspots group of opposite polarity might lead to the appearance of a limiting strength line (LSL) being common for whole group. Throughout the LSL the redistribution of magnetic fluxes takes place, which is necessary for magnetic field to have the minimum energy. The LSL rises from the photosphere to the corona.

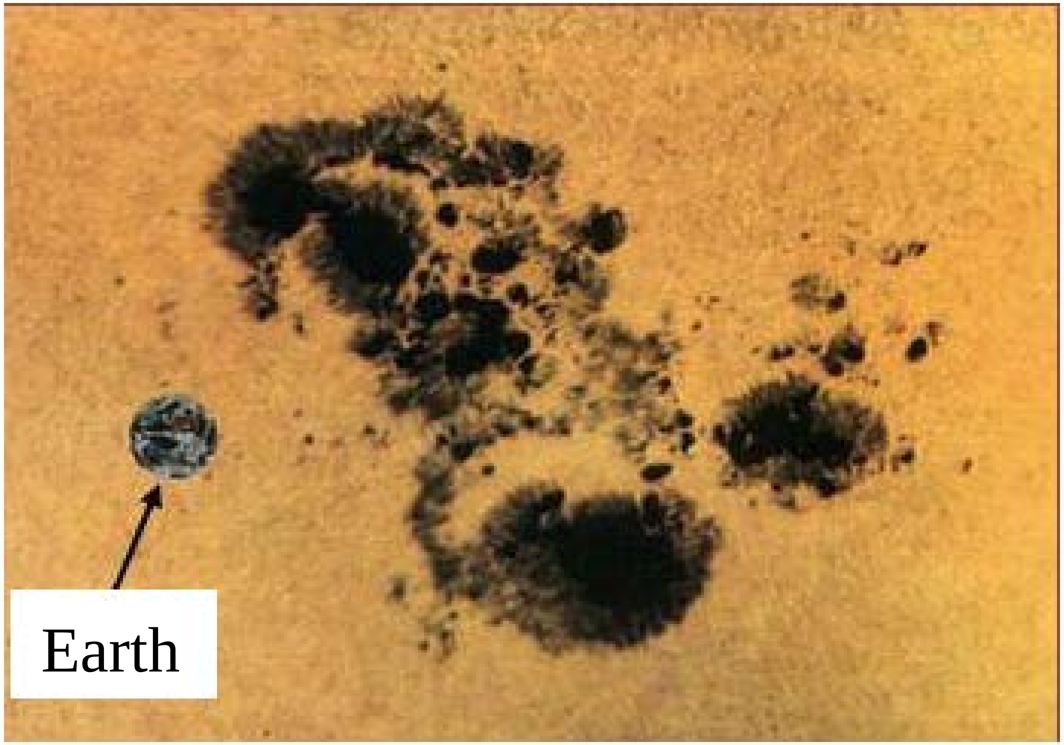
From the moment of this line appearance an electric field induced by magnetic field variations, causes current along the line, which due to the interaction with a magnetic field takes a form of a current layer. As the current layer prevents from the magnetic fluxes redistribution, the process of magnetic energy storage of the current layer begins. Duration of appearance and formation period of the current layer (initial SF phase) varies from several to dozens of hours.

The second stage (an explosion phase of SF) has a time interval of 1-3 minutes. At this stage magnetic energy of sunspots transforms into kinetic energy of matter emission, into energies of hard electromagnetic radiation and into fluxes of solar cosmic rays (SCR) which consist of protons, of nuclei with charges $2 < Z < 28$ and of electrons.

The concluding stage is characterized by existence of high temperature coronal region and can continue for several hours. The heating of dense atmospheric layers leads to an evaporation of large amount of gas, which favors a long-continued existence of a dense hot plasma cloud.

a significant solar flare erupting on june 10 2014

Sunspots are active regions in the solar photosphere. They represent themselves the tubes of the magnetic field strengths lines



The sunspots group compared with the Earth

The high-power SF's can be especially destructive when they appear to be aimed at the Earth, hitting the planet directly with powerful charged particles. Such SF's are potentially dangerous for satellites, power grids and astronauts. It is clear that the prediction of the SF at the initial phase is a very important task.

In 1995-1996 the series of works predicting existence of the correlation between the SF's and solar neutrino flux have been published

O.Boyarkin, D.Rein, Zeitschr. Phys. C, **67** (1995) 607.

O.Boyarkin, Phys. Rev. D, **53** (1996) 5298.

O.Boyarkin, Russ. Phys. J., **39** (1996) 597.

So, for the first time one was supposed to use the solar electron neutrinos for investigation of the solar flares. Of course the detection of the neutrino flux correlation with the SF will be possible only at the neutrino telescopes of the next generation where events statistics will increase on several orders of magnitude.

However solving the problem might come from the other hand, namely, from area of nuclear physics.

In recent years, a number of articles

J.H.Jenkins et al., Astropart. Phys. **32** (2009) 42.

J.H.Jenkins et al., Nucl. Inst. Meth. Phys. Res. A **620** (2009) 332.

E.Fischbach et al., Space Sci. Rev., **145** (2009) 285.

D.E. Krause et al., Astropart. Phys. **36** (2012) 51.

D.O'Keefe et al., Astrophys. Space Sci., **344** (2013) 297

presenting evidence that some beta decay rates are variable have been published. In so doing, this changeability was concerned with behavior of the solar neutrino flux (hypothesis of the ν_e-induced decays (see, for up-to-date review: T.Mohsinally *et al*. Astropart. Phys. **75** (2016) 29).

Investigated elements are Sr-90/Y-90, Rn-222, Eu-152, Ra-226, Si-32, Cl-36, Ag-108 ………..

Researchers have been examining variation in decay rates before SF's, as well as those resulting from Earth's orbit around the Sun and changes in solar rotation and activity. It should be noted that the changeability of the decay rate has been observed only for beta decays and electron capture processes.

Brookhaven National Laboratory

The experiments were conducted at the Brookhaven National Laboratory between February 1982 and December 1989. It was held 364 measurements of the decay rate for the Cl-36 and Si-32 samples.

Reference: P. A. Sturrock, E. Fischbach, Comparative Analysis of Brookhaven National Laboratory Nuclear Decay Data and Super-Kamiokande Neutrino Data: Indication of a Solar Connection

Physics building at Purdue University

Fischbach and the others conducted their own experiment lasting one month to measure the radioactivity of the isotope 54Mn at Purdue University.

Reference: Jere H. Jenkins and Ephraim Fischbach, Perturbation of Nuclear Decay Rates During the Solar Flare of 13 December 2006

Physikalisch-Technische Bundesanstalt

At the German PTB Center, experiments were performed for the samples Ag108, Ba133, Eu152, Eu154, Kr85, Ra226 and Sr90 from 1990 to 1996 and from 1999 to 2009.

Reference: P.A. STURROCK, E. FISCHBACH, AND J. JENKINS, ANALYSIS OF BETA-DECAY RATES FOR Ag108, Ba133, Eu152, Eu154, Kr85, Ra226 AND Sr90, MEASURED AT THE PHYSIKALISCH-TECHNISCHE BUNDESANSTALT FROM 1990 to 1996

Lomonosov Moscow State University

At the Moscow State University named after MV Lomonosov from August 2002 to February 2009, measurements were made for the Sr-90 / Y-90 samples.

Reference: Peter A. Sturrock, Alexander G. Parkhomov, Ephraim Fischbach, Jere H. Jenkins, Power Spectrum Analysis of LMSU (Lomonosov Moscow State University) Nuclear Decay-Rate Data: Further Indication of r-Mode Oscillations in an Inner Solar Tachocline

In the result of thermonuclear fusion reactions in the Sun's core the total neutrino flux which falls on a terrestrial surface could be as large as

$$\Phi_\nu \approx 6\times 10^{10}\, cm^{-2} s^{-1}$$

So, we are living in the neutrino ocean. Then it should not be ruled out that some phenomena of our world might depend on neutrino behavior.

Establishing reasons of the ν_{eL}-induced decays is one of the basic task of the contemporary physics which is so far from the ultimate answer. Closeness of the typical solar neutrino energy ($0.14 < E_\nu^{solar} < 14$ MeV) and the nuclear binding energy per nucleon (7.6 Mev/nucl.) suggests following simple mechanism. Since a neutrino does not participate in strong interaction and has not electrical charge the bulk of the solar neutrinos penetrate unobstructed to nucleus. In so doing, neutrinos are not absorbed, while having given up a part of energy they pass through the nucleus. As a result, the decays of some elements of the periodic table become to be energy allowed. Therefore, if the **H**ν_{eL}**ID** is true, then we may state: some elements we belief that they are natural radioactive, in actuality, are artificial radioactive because of the solar neutrino flux bombardment.

- Let us find the evolution of the electron neutrino flux moving in the Sun. We shall work in two-flavor approximation. Recall that the flavor states are not mass eigenstates (physical states). They are mixing of the physical states, that is, in vacuum we have

$$\nu_e = \nu_1 \cos\theta_0 + \nu_2 \sin\theta_0$$

$$\nu_\mu = -\nu_1 \sin\theta_0 + \nu_2 \cos\theta_0$$

- Interaction of the electron neutrinos and muon neutrinos (tau lepton neutrinos) with matter electrons has different character

- $\nu_e + e^- \to W^* \to \nu_e + e^-$ $\qquad$ $\nu_\mu + e^- \to Z^* \to \nu_\mu + e^-$

  $\nu_e + e^- \to Z^* \to \nu_e + e^-$

- As a result the evolution equation in a Schrodinger-like form will look like

$$i\frac{d}{dz}\begin{pmatrix}\nu_e \\ \nu_\mu\end{pmatrix} = H(z)\begin{pmatrix}\nu_e \\ \nu_\mu\end{pmatrix}$$

$$H(z) = \frac{1}{2}\begin{pmatrix}-\Delta m^2 \cos 2\theta_0 + 2A & \Delta m^2 \sin 2\theta_0 \\ \Delta m^2 \sin 2\theta_0 & \Delta m^2 \cos 2\theta_0\end{pmatrix} \quad A = 2\sqrt{2} G_F E N_e \quad \Delta m^2 = m_1{}^2 - m_2{}^2$$

$$\sin^2 2\theta_m = \frac{(\Delta m^2)^2 \sin^2 2\theta_0}{(\Delta m^2 \cos 2\theta_0 - A)^2 + (\Delta m^2)^2 \sin^2 2\theta_0}$$

At $A = \Delta m^2 \cos 2\theta_0$ θ_m **reaches its maximal value** $\pi/4$

$\nu_e \to \nu_\mu$ resonance (MSW resonance)

Resonance condition: $H_{11} = H_{22}$

Let us complicate the problem. We consider the system consisting from $\nu_e, \nu_\mu, \bar{\nu}_e, \bar{\nu}_\mu$ and take into account interaction of neutrinos with electromagnetic fields in a preflare period. If neutrinos possesses the dipole magnetic and anapole moments then the Hamiltonian includes the additional term

$$H_{add} = 4\pi a_{\nu_k \nu_l} j_z + \mu_{\nu_k \nu_l} B_\perp - \delta_{el} \dot{\Phi}$$

$$B_x + iB_y = B_\perp e^{i\Phi}$$

For the case of the Majorana neutrino nature the evolution equation takes the view

$$i\frac{d}{dz}\begin{pmatrix}\nu_{eL}\\ \nu_{XL}\\ \overline{\nu}_{eL}\\ \overline{\nu}_{XL}\end{pmatrix} = \mathcal{H}\begin{pmatrix}\nu_{eL}\\ \nu_{XL}\\ \overline{\nu}_{eL}\\ \overline{\nu}_{XL}\end{pmatrix},$$

where

$$\mathcal{H} = \begin{pmatrix}\mathcal{H}_{\nu\nu} & \mathcal{H}_{\nu\overline{\nu}}\\ \mathcal{H}^{\dagger}_{\nu\overline{\nu}} & \mathcal{H}_{\overline{\nu}\ \overline{\nu}}\end{pmatrix},$$

$$\mathcal{H}_{\nu\nu} = \begin{pmatrix}\delta_c^{12} + V_{eL} + 4\pi a_{\nu_e\nu_e} j_z & -\delta_s^{12} + 4\pi a_{\nu_e\nu_X} j_z\\ -\delta_s^{12} + 4\pi a_{\nu_X\nu_e} j_z & -\delta_c^{12} + V_{XL} + 4\pi a_{\nu_X\nu_X} j_z\end{pmatrix},$$

$$\delta_{c(s)}^{12} = \frac{m_1^2 - m_2^2}{4E}\cos 2\theta_\nu (\sin 2\theta_\nu), \qquad V_{eL} = \sqrt{2}G_F(N_e - N_n/2),$$

$$V_{XL} = -\sqrt{2}G_F N_n/2, \qquad \mathcal{H}_{\nu\overline{\nu}} = \begin{pmatrix}0 & \mu_{\nu_e\overline{\nu}_X} B_\perp e^{i\Phi}\\ -\mu_{\nu_e\overline{\nu}_X} B_\perp e^{i\Phi} & 0\end{pmatrix},$$

$$\mathcal{H}_{\overline{\nu}\ \overline{\nu}} = \mathcal{H}_{\nu\nu}(V_{lL} \to -V_{lL}, j_z \to -j_z),$$

When the neutrino is a Dirac particle $\mathcal{H}_{\nu\overline{\nu}}$ should be replaced by the expression

$$\mathcal{H}_{\nu\overline{\nu}} = \begin{pmatrix}\mu_{\nu_e\overline{\nu}_e} B_\perp e^{i\Phi} & \mu_{\nu_e\overline{\nu}_X} B_\perp e^{i\Phi}\\ \mu_{\nu_e\overline{\nu}_X} B_\perp e^{i\Phi} & \mu_{\nu_X\overline{\nu}_X} B_\perp e^{i\Phi}\end{pmatrix}$$

and assume V_{lL} equal to zero in the expression for $\mathcal{H}_{\overline{\nu}\ \overline{\nu}}$.

Let us discuss the possible resonance conversions only for left-handed electron neutrino. In the case of the Majorana neutrino we have:

(i) $\nu_{eL} \to \nu_{XL}$ is the MSW resonance, which is realized at the condition

$$-2\delta_c^{12} + V_{eL} - V_{XL} + 4\pi(a_{\nu_e\nu_e} - a_{\nu_X\nu_X}) j_z = 0. \qquad (1)$$

while the transition width is as follows $\delta N_e(\nu_{eL} \to \nu_{XL}) \simeq \frac{\sqrt{2}(\delta_s^{12} + 4\pi a_{\nu_e\nu_X} j_z)}{G_F}.$

(ii) $\nu_{eL} \to \overline{\nu}_{XL}$ is the resonance with flavor and spin flipping which happens provided

$$-2\delta_c^{12} + V_{eL} + V_{XL} + 4\pi(a_{\nu_e\nu_e} + a_{\overline{\nu}_X\overline{\nu}_X}) j_z - \dot{\Phi} = 0. \qquad (2)$$

Corresponding expressions for the transition width will look like

$$\delta N_{en}(\nu_{eL} \to \overline{\nu}_{XL}) \simeq \frac{\sqrt{2}\mu_{\nu_e\overline{\nu}_X} B_\perp}{G_F}.$$

When the neutrinos have the Dirac nature the resonance conversion $\nu_{eL} \longrightarrow \overline{\nu}_{eL}$ takes place in addition to above mentioned ones. It will proceed when

$$V_{eL} + 4\pi(a_{\nu_e\nu_e} + a_{\overline{\nu}_e\overline{\nu}_e}) j_z - \dot{\Phi}/2 = 0 \qquad (3)$$

and the transition width is as follows $\delta N_{en}(\nu_{eL} \to \overline{\nu}_{eL}) \simeq \frac{\sqrt{2}\mu_{\nu_e\overline{\nu}_e} B_\perp}{G_F}.$

To estimate the order of terms entering into (1)- (3) we shall use

$$\sqrt{2}G_F N_e = 4 \times 10^{-20} \rho y_e \ (\mathrm{MeV})$$

where ρ is a matter density expressed in $\mathrm{g/cm^3}$, and y_e is the number of matter electrons in the atomic mass unit (y_e is changed from 0.9 in the Sun center up to 0.7 for the big values of the solar radius).

For the lower border of the convective zone we have $\rho \sim 10^{-2}\ \mathrm{g/cm^3}$

while for photosphere and chromosphere the matter densities are

$\rho \sim 2 \times 10^{-7}\ \mathrm{g/cm^3}$ and $\rho \sim 3 \times 10^{-12}\ \mathrm{g/cm^3}$, respectively.

Then, using the upper limit on the anapole moment $a_{\nu_l \nu_l'} = 6.7 \times 10^{-33}$ cm^2

we come to the following result. The term $\frac{4\pi}{c} a_{\nu_l \nu_{l'}} j$ has the energy dimensionality (erg). So this quantity will have the same order as the matter potential in chromosphere provided

$$\frac{4\pi}{c} a_{\nu_l \nu_{l'}} j \simeq 10^{-26} eV \qquad (4)$$

From (4) it follows

$$j \simeq 10^{-6} \frac{A}{cm^2}$$

On the other hand the term $\mu_{\nu_l \nu_{l'}} B_\perp$ is comparable to the chromosphere matter potential when

$$B_\perp \simeq 5 \times 10^4 \text{ Gs}$$

where we have used the upper bound on the neutrino magnetic moment (A.Beda *et al*., [GEMMA Collaboration] Advances in High Energy Physics **2012** (2012) 350150)

$$\mu_{\nu_l \nu_{l'}} \leq 2.9 \times 10^{-11} \mu_B$$

CONCLUSION

1. The evolution of the solar neutrino flux has been considered. In the convective zone the electron neutrinos undergo the $\nu_{eL} \rightarrow \nu_{XL}$ resonance (MSW). When the electron neutrinos pass the SF region in pre-flare period they are subjected to additional resonance conversions. For the Majorana neutrino we have the $\nu_{eL} \longrightarrow \bar{\nu}_{XL}$ conversion, while for the Dirac neutrino apart from that we have the $\nu_{eL} \longrightarrow \bar{\nu}_{eL}$ conversion. So, when the SF is absent a terrestrial detector records the electron neutrino flux weakened at the cost both of vacuum oscillations and of the MSW resonance conversion only. On the other hand, the electron neutrino flux passed the SF region in pre-flare period proves to be further weakened by additional resonance conversions.

2. The transition widths (TW's) of the resonances $\nu_{eL} \longrightarrow \bar{\nu}_{XL}$, $\nu_{eL} \longrightarrow \bar{\nu}_{eL}$ and $\nu_{XL} \rightarrow \bar{\nu}_{XL}$ proves to be proportional to the DMM. However, the MESM predicts the DMM value close to zero. Therefore, these resonances must not be observed from the point of view of this model.

3. The analysis has shown that the most probable scenario is the existence only of the $\nu_{eL} \longrightarrow \overline{\nu}_{eL}$ and $\nu_{eL} \longrightarrow \overline{\nu}_{XL}$ -resonances. So, when the solar neutrino flux moves through the SF region in the pre-flare period, the $\overline{\nu}_{eL}$ and $\overline{\nu}_{XL}$ neutrinos appear. Then, terrestrial detectors could record these particles with the help of the reactions

$$\overline{\nu}_{eL} + p \to n + e^{+} \qquad \overline{\nu}_{\mu L} + p \to n + \mu^{+}.$$

4. Existence of $\nu_{eL} \longrightarrow \overline{\nu}_{eL}$ and $\nu_{eL} \longrightarrow \overline{\nu}_{XL}$ resonance transitions will confirm the Dirac nature of the neutrinos.

5. It should be stressed that the phenomena of reducing the number of the electron neutrinos, emerging the $\overline{\nu}_{eL}$ and $\overline{\nu}_{XL}$ neutrinos, and decreasing the beta decay rate for some elements will be not only forerunners of the SF, but they also will be the convincing arguments in favour of the Physics beyond the SM.

«The completion of the discussion»
An author is not known