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HOW IS THE SUN WORKING?

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Abstract. I assume that at the solar core finite amplitude flows are generated by some process for which a candidate can be the planetary tides. I assume also that there are some local magnetic flux bundles at the solar core with a strength larger than 10^3 G. The aim of this paper is to show that these assumptions involve an electric field generation which then produces local thermonuclear runaways which shoot up convective cells to the outer layers. Within certain conditions these primal convective cells erupt in the subphotospheric layers which phenomenon can produce high-energy particle beams which when injected into magnetic flux tubes appear as flares. I suggest these processes for solving the neutrino problem, and also to interpret the spiky character of the solar neutrino flux and the correlation of the energy production of the Sun with its atmospheric activity.

It was suggested first by Zatsepin ans Kuzmin (1964) that the nuclear energy production of the Sun has an 11 year periodicity of undescribed origin. Later the idea got support by Kocharov and Starbunov (1966), Sheldon (1969), Raychaudhuri (1971, 1986), Chistyakov (1975), Kocharov (1977), and Sakurai (1979). The idea traces back to the conception of Ambartsumian (1957) by which the material from stellar cores can reach the surface by some undefined explosive process. This was probably the background of the paper of Gorbatsky (1964) who calculated how the material from stellar cores can travel through the star in the form of a hot bubble generated by some point explosion at a stellar core site. Later the idea of flares deep inside the Sun was introduced by Kocharov (1971, 1977).

This idea now has experimental support. Davis *et al.* (1990) have presented new observations that show the correlation of the observed neutrino flux with sunspot number and with the diameter of the Sun, and also with coronal hole areas. Basilevskaya *et al.* (1982) have shown first experimentally the correlation of neutrino flux with surface activity and with solar cosmic rays.

It is plausible to assume the existence of a strong fossil magnetic field at the solar core. If the material of the protosun is sufficiently ionized during the contraction, the central fossil magnetic field can be 10^{10} G (Cowling, 1965). Solar seismological measurements also show megagauss magnetic field of fossil origin deep inside the Sun (Dziembowski and Goode, 1988).

It was Öpik (1972) who calculated first the tidal flows on the Sun induced by the Earth, Venus, Mercury, and Jupiter. He got a value for the velocity of the solar tidal flows of about 100 cm s^{-1} which gives for a half rotation period a horizontal tidal shift of about 560 km. I make the rather plausible assumption here, that some kind of flows of undefined origin – for which one candidate can be just the tidal flows – arise at the solar core and there they meet with local magnetic flux bundles with a magnetic field strength of $B > 10^3$ G.

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The plasma generates electric field by moving in magnetic fields,

$$E = 1/c(v \times B)\,, \tag{1}$$

so assuming 1 cm s^{-1} flow we need a $B = 10^8$ G for the generation of $E = 1$ V cm^{-1}. For $v = 10^5$ cm s^{-1}, 10^3 G is sufficient for the same electric field. The planets act as outer sources for the work of driving the dynamo in the solar core.

The generated electric field then accelerates the charged particles to a high speed. The acceleration length is

$$l(a) = U/eE\,, \tag{2}$$

where U is the energy of the particle after the acceleration. If we want to use the value $U = 200$ keV as Martens (1988) used for solar flares, we have an acceleration length $l = 10^5$ cm with $E = 2$ V cm^{-1}. The mean free path of the protons at the solar core is given as

$$l(\mathrm{mfp}) = U^2/(n\pi e^4 \ln \Lambda)\,, \tag{3}$$

where n is the number density of protons, $\ln \Lambda$ is the Coulomb logarithm ≈ 20. So we got the mean free path of protons as

$$l(\mathrm{mfp}) = 5 \times 10^{-4}\ \mathrm{cm}\,. \tag{4}$$

This means that the protons while accelerated in the electric field are colliding frequently and, therefore, the electric field heats locally the solar plasma at the solar core to very high energies. For $U = 200$ keV the related kinetic temperature is

$$T = 3 \times 10^9\ \mathrm{K}\,. \tag{5}$$

This temperature – which arises locally at the flux bundles of the central fossil magnetic fields – is larger than the temperature at the peak of the He-flash $T = 3 \times 10^8$ K (Schwarzschild and Harm, 1962) by an order of magnitude. So we can expect that local thermonuclear runaways will be established. The time scale can be estimated by solving the energy conservation equation, calculating only the thermonuclear energy for the heating:

$$c\ \mathrm{d}T/\mathrm{d}t = \varepsilon_{pp} = \rho x_1^2 \varepsilon_0 (T/T_0)^{\nu}\,, \tag{6}$$

where c is the specific heat coefficient at constant volume, T is the temperature, ε_{pp} is the energy produced by the proton–proton cycle per gram per second, ρ is the density, x_1 is the concentration of the protons, ε_0 is a factor introduced by Reeves (1965), and ν is the exponent of the temperature dependence. This is an equation of Bernoulli type, which can be solved with the substitution of a new variable $T\exp(1 - \nu)$. The solution is

$$T_2 = T_1/\{1 - [\rho x_1^2 \varepsilon_0(\nu - 1)]/C_v T_1]t\}^{(1-\nu)^{-1}}. \tag{7}$$

The time-scale of the nuclear heating is then

$$\tau_h = 3/2(RT)/(\rho\mu x_1^2 \varepsilon_0(\nu - 1)). \tag{8}$$

This scale for the quiet regions of the solar core is

$$\tau_1 = 10^{15}\ \mathrm{s} \approx 3 \times 10^7\ \text{years}, \tag{9}$$

while for the regions of the thermonuclear runaways we can use

$$\varepsilon_{pp} = 5 \times 10^{17}\ \mathrm{ergs\ g^{-1}\ s^{-1}} \tag{10}$$

given by Edwards (1969). Then the local time scale of the thermonuclear runaway is about

$$\tau_{\mathrm{r.a.}} = 6 \times 10^{-5}\ \mathrm{s}. \tag{11}$$

When a thermonuclear explosion starts, it cannot generate convection until it reaches a size for which the size-dependent critical Rayleigh number exceeds the local value of the actual wave number (Grandpierre, 1984). The criterion for this is

$$d > 2\pi \times ((\kappa\nu)/(g\alpha\beta)) \exp(\tfrac{1}{4}), \tag{12}$$

where d is the linear characteristic size of the thermonuclear runaway area, κ, ν, α, β are the coefficients of the heat conduction, viscosity, volume expansion, and the inverse temperature gradient and g is the local gravitational acceleration. When d satisfies (12), the exponentially growing thermonuclear runaway begins to rise as a primal convection. The significant buoyant force accelerates the cells to a high speed. With an average speed $v = 10\ \mathrm{km\ s^{-1}}$ the primal convective cells reach the solar surface within a day. At the solar photosphere the local sound speed is about 8 km $\mathrm{s^{-1}}$. Therefore, they can explode just near the photosphere, running into the pressure wall of the sonic boom (Grandpierre, 1981). The 3-dimensional numerical simulations of Deupree supported the suggestion that the convection can approximate the sound speed but cannot surpass it in stellar envelopes (Deupree, 1983, personal communication).

The sonic boom then destroys the convective cells and the surplus inner energy, together with the kinetic energy of the cell, is transformed into the sharp front of the shock wave. This means that high-energy particle beams are locally generated which run into the magnetic flux tube apexes above them and generate optical and other phenomena (Grandpierre, 1986). This mechanism makes it possible to solve the energy problem, the

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particle number problem, and other problems of the magnetic flare theories (Grandpierre, 1989, 1990).

In the above picture the convection regulates effectively the nuclear instabilities developing at the solar core. As the hot matter travels out, cooler material flows to the place of the runaway, and there will be a certain local mixing, which together with the effect of the runaway has the result of lower average neutrino production. It is also known that making on average the proton–proton chain twice as fast, which can be a result of the thermonuclear runaways, resolves the neutrino discrepancy (see, e.g. Plaga, presentation at this Colloquium).

The above mechanism – in the frame of the assumptions made – gives a natural explanation for the many-sided correlation of the observed solar neutrino flux and its atmospheric activity. A prediction of this theory is that the neutrino flux is much more spiky than the observations now show, and temporarily very high-energy neutrinos appear.

One can be satisfied with a proposed solution of a basic problem only if the solution raises up deeper new problems then it solves. Therefore, I can say in this sense that I am satisfied with the perspective of the above conception.

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