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A pulsating-ejecting solar core model and the solar neutrino problem

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Abstract. It is pointed out that the solar neutrino problem is related to a remarkable series of astrophysical problems of the solar core. Even if the MSW effect in itself would be able to give account of the missing neutrinos, one could explain the possible time variation of the neutrino flux (as revealed by the chlorine solar neutrino experiment) only by a non-standard solar model, allowing time-dependent density variations in the core. For resolving all these problems, I suggest that the Sun does not work as a well-tempered fusion reactor, and I present a mechanism which can generate the solar activity by the core. Changing the commonly accepted hypothesis from the constancy of the solar core into its variation with the activity cycle under the pressure of newly accumulating evidences, here I explore some consequences of this theoretically and observationally supported assumption, also to the observed neutrino fluxes. Allowing very localized time varying densities, i. e. the presence of macroscopic flows, a simple mechanism is derived for the generation of local thermonuclear runaways in hot bubbles shooted out from the core. The model derived seems to be also appropriate for the interpretation of a whole list of tantalizing problems like the nitrogen enigma, the flare related chemical anomalies, the heavy element enhancement of the solar corona and the rigid rotation of the activity generating centres.

Key words: Sun: activity – Sun: abundances – Sun: flares – Sun: oscillations – Sun: interior

1. Tantalus' astrophysical menu

The existence of the solar activity, including the quasiperiodic appearance of the sunspots, flares, plages, spicules, coronal holes, streamers, mass ejections, noise storms, radio storms etc. is well known for centuries. Unfortunately, the nature of this activity is not understood well enough. It is thought to be of magnetic nature with an atmospheric origin, but there are no detailed theoretical models describing its most important characteristics, explaining its period, or forecasting the activity itself. "One may easily get the impression that the gap between theory and observations of solar activity has only widened in the last decades" (Petrovay, Szakaly 1993).

While in the recent years the standard solar model approximated a state apparently more and more compatible with the observations, a whole series of basic problems became known additionally, all being in possible connection with the solar activity. Here I mention sixteen (16) related problems, firstly listed here, some of them referred to in the literature as tantalizing problems. I refer to this remarkable list of solar activity-related problems as Tantalus' astrophysical menu. The main dish on this menu is the production of the activity-related phenomena, the problem of the cycle itself (1).

On this list you can find the solar neutrino problem (2), one of the central problems of the present day astrophysics, which is strengthened and doubled by the accumulating signs of its time variation (Problem 3, see e. g. Gavryusev, Gavryuseva 1994, Haubold, Mathai 1994). The time variation of the solar neutrino flux now seems to point at the solar cycle changes of the energy production of the Sun (Grandpierre, 1990 and below). Most of the researchers think that the neutrino problem can be explained in relation to the finite mass of the neutrino. Nevertheless, it is generally ignored or forgotten, that this seemingly purely physical problem (i. e. not astrophysical, assuming that the standard solar model satisfactorily describes all the related phenomena) is accompanied with a whole series of possibly and most probably core-related astrophysical problems. These are the solar cycle variation of the frequency shifts of the low degree p-mode oscillations (4), the puzzling difference between the frequency shifts of the even $l = 0, 2$ and odd $l = 1, 3$ p-modes (5), the activity-related rotation rate variations of the solar energy producing core (6), the spin-down of the solar core to the surface rate (7), the cycle-related global events (8), the flare-related chemical anomalies (9), the nitrogen enigma (10), the heavy element enhancement of the solar corona and the solar wind (11, 12), the rigid rotation of the activity-generating centres (13), and, without the aim of completeness, the cycle variation of the solar luminosity (14), radius (15), and oblateness (16). All these fundamental and tantalizing problems clearly show that our simplified understanding is not sufficient concerning the solar core. It is clear that any physical mechanisms (like the non-zero neutrino mass) cannot solve simultaneously the neutrino problem and the above listed astrophysical problems. This is why these problems are 'tantalizing'. Moreover, any basically atmospheric mechanism for the generation of activity phenomena is in contradiction with these new measurements. Each of the above problems in themselves, and all together at a highly increased rate, calls for a theory considering the "generic connection between the variations of solar activity and neutrino fluxes. This is the most exciting and very difficult problem" (Kocharov, 1992). It seems that even the slightest shadow of a detailed physical mechanism is not known that could generate the phenomena leading to the above problems.

2. The directives set up by the astrophysical problems

Recently Castellani et al. (1994a) pointed out that the neutrino measurements led to a result that, provided that the neutrinos are standard (massless), the pp chain is shifted towards the ppI branch in comparison with the SSM predictions. It means that either the cross section of the He^3 + He^3(He^3 + He^4) reactions has to be larger(smaller) or the central temperature of the Sun has to be smaller. The former case with varying the nuclear cross sections does not work (Castellani et al., 1994b). In the latter case the luminosity of the standard solar model should be lower than the observed one. Therefore, an overlooked possibility shows up, telling that some processes are necessarily present in order to produce the missing luminosity. These processes have to be able to produce the missing solar luminosity while they should produce less neutrinos (for a unit of produced energy) than the solar core at temperature $T = 1.5 \times 10^7$ K. High temperature is necessary for the effective production of high luminosity. Since the temperature in the solar core has to be smaller than in the standard solar model (SSM), this high temperature can only be supported locally, in very small volume. This process has to be explosive if the temperature is high enough to give high luminosity in small volume. This explosive process will not produce overcompensatingly large neutrino flux because of the very small volume involved. On the contrary, the neutrino flux remains relatively low, because the reactions producing neutrinos are not enhanced to the remaining ones, since at high temperatures all the energy producing nuclear reactions occur in the rate given by the fuel supply. Moreover, the neutrino production is suppressed due to the large time scale of the weak interaction. The quick depletion of the reaction constituents of these reactions and the relative enhancement of the much quicker reactions producing energy without neutrino production lead to a relative neutrino flux suppression.

All nonstandard solar models working simply with a smaller central temperature predict more reduction of the B^8 neutrino flux than the Be^7 neutrino flux. This fact seems to make cooler Sun models incompatible with the experimental data. The higher Kamiokande observed rate relative to the Homestake rate cannot be explained in that way because cooler Sun models reduce the expected B^8 flux more than the Be^7 flux (see e. g. Castellani et al., 1994b). Nevertheless, as it is first suggested by Turck-Chieze and Lopes (1993), and later worked out a step forward by Haubold and Mathai (1994), the only astrophysical explanation for the neutrino problem would be a greater reduction of temperature in the region of energy production in the vicinity of 0.1 solar radius, than just in the central part where the B^8 neutrinos are produced. Nevertheless, I have to point out, that these deviations from the temperature distribution predicted by the SSM have significant consequences. They are consistent with the observed solar luminosity only if a mechanism produces the missing part of the solar luminosity, arising as a result of the lower temperature, what is required for the (selective) suppressions of the neutrinos with different energies. Since energy production is a highly dependent function of the temperature, an explosive mechanism is needed to make the model luminosity consistent with the observed one. Haubold and Mathai (1994) showed that a spiky time development of the temperatures of some central layers of the Sun produces a neutrino flux with the observed characteristics, i. e. a shock-like rise and a slower decrease.

A fundamental problem is related to the frequencies of the low degree p-modes. Despite the current, widely accepted views, the SSM still seems somewhat fail to fit the observations. While the different measurements (Anguera-Gubau et al., 1992, Elsworth et al., 1991) agree within 0.1μHz (note: the observed amplitudes of the solar cycle related frequency shifts are around 0.46μHz), the difference from the closest theoretical value reaches 4-8μHz (40-80σ, see Table 9. of Turck-Chieze and Lopes, 1993) and the discrepancies of the measured frequencies of Toutain and Frohlich (1992) of the theoretical values reach still 60σ. As Turck-Chieze and Lopes (1993) noted, an opacity change of 15-20% leads to 3-4μHz in the frequencies. Nevertheless, the recent results of Baturin and Ajukov (1994) show that the data from solar seismology require even larger disrepancies to the SSM. They pointed out that the solar model which fits the helioseismological data is possible only with unnatural opacity changes in the core (60% $-$ 80% - so high!) and a decrease of the hydrogen content X in the centre to X=0.2. Somewhat expanding the solar models including the gradient of the chemical composition in the radiative zone ("diffusion" models) also would necessitate very large or even inconsistent opacity changes. These deviations from the SSM may be produced by some kind of extra energy transfer between the different layers not included in the SSM. A local explosive process is necessary to generate such kind of energy transfer.

Regulo et al. (1994) have shown that the correlation between the low degree solar oscillations and the solar surface is clearly present: "As the size of the effect is around 30% higher than the one found using high degree modes, other phenomena (probably related to magnetic fields) possibly occurring in the interior of the Sun may be involved in these solar cycle-related frequency shifts. Although low l p-modes also suffer the surface effect on their upper turning points, the higher variation found here would suggest that another effect is present. Presumably this effect will be active in the Sun's interior where the low-degree modes travel while the higher ones do not." This suggests that - contrary to the basic assumptions of the present day theories of solar activity - actually the core itself participates in the activity cycle, its density, temperature changes with the cycle. Taking into account the fact that the core is a highly sensitive system (see Sect. 6), and its energy production rate (and so its average temperature) sensitively depends on the local temperatures, even a few percent change in the macroscopic parameters of the core results in a change of local luminosity production comparable to the total one. So the presence of macroscopic, dynamic processes in the solar core are related to local explosive processes. The correlation of the frequency shifts of the low degree solar p-mode oscillations with the neutrino flux is shown to be statistically significant with more than 99.7% by Gavryusev and Gavryuseva (1994). This correlation is considered to be a tantalizing problem (Krauss, 1990). If the solar core shows activity related changes (Regulo et al., 1994, Delache et al., 1993, Goode, Dziembowski, 1991, 1993), its ultimate source has to be in the deep ranges, involving the energy producing core. The activity cycle of the solar core is necessarily based on explosive processes because of the high temperature sensitivity (Grandpierre, 1990). Then a mechanism is needed for the transportation of the changes from the core to the surface. If our conclusions are supported by the further analysis, the SSM will have to be extensively revised and completed.

Goode and Dziembowski (1991, 1993) have shown that the solar seismology data suggest that the rotation rate of the solar core changes in correlation with the surface activity. Although these results represent only marginal evidences yet, they refuse the still speculative assumption stating the constancy of the solar core in this respect, too, and so it seems to be worthwile to explore the possible consequences of these pioneering results, especially if other evidences point at similar conclusion. Elsworth et al. (1995) measured a slowly rotating solar core (440 nHz, or $T = 26^d.3$) from September 1992 to December 1993, a result which seems to be consistent with the correlation of the energy and neutrino production of the core with the surface activity, in agreement with the correlation curve that Goode and Dziembowski (1991) suggested (430 nHz for 1984 is consistent with 440 nHz for 1993). To change the rotation rates in the observed amount, a highly dynamical (and then explosive) process has to work within the solar core, in correlation with the surface activity cycle.

There are other signs showing that the energy producing solar core as a whole could, in some way, be coupled with the surface activity. Based on the standard theoretical model for the Sun, the solar core spin down is a slow process. The "best solar model" of Pinsonneault et al. (1989) shows that the rotation rate of the solar core at $r < 0.2R_0$ should be 4 - 15 times faster than the surface rate. In fact, despite the widespread trust in the SSM, in this respect, too, observations showing that the average core rotation rate (440 nHz) is similar to the surface rate (420 - 450 nHz) even for $r < 0.2R_0$ (e. g. Elsworth et al., 1995) indicate that the dynamics of the solar core is coupled to the solar wind in some direct way. As Dziembowski and Goode (1993) noted: " There is no satisfactory theory describing solar spin-down. The unsolved problem is the mechanism of the upward angular momentum transport in the radiative interior."

Oakley et al. (1994) pointed out, that the anticorrelation between the Homestake solar neutrino capture rate and magnetograph measured photospheric equatorial magnetic flux is stronger than the anticorrelation with the sunspot number, suggesting a direct connection between the line of sight surface magnetic flux and the line of sight neutrino production. Mordvinov and Tikhomolov (1994) have shown that perturbations originated from the radiative core generate global events on the Sun; sudden changes in the patterns of the giant cells set up simultenously with the rotation rate change of the background field, accompanied by the violent eruption of the solar and geomagnetic activity and the neutrino production.

The nitrogen enigma (Kerridge, 1989) states that the $^{15}N/^{14}N$ rate is enhanced by 50%, from a value 2.9×10^{-3} of 3×10^9 years ago to a present day value of 4.4×10^{-3} (Kerridge et al., 1991). It is just the opposite change of what the stellar evolution models predict. To produce the observed enhancement not only in the solar wind but also in the convective zone as a whole, would mean that the rate of this enhancement is so enormous that it exceeds the values by many orders of magnitude allowed by the standard models for the solar convective zone. This circumstance suggests that the solar surface is connected to the core by channels which are isolated from the convective zone, connecting the central regions with the subphotospheric regions directly. These central regions have to produce significant amount of heavy elements, like e. g. ^{15}N, which is possible only above $10^8 - 10^9$ K, i. e. in a local explosive process. The significance of the nitrogen-enigma is considered to be "similar to the neutrino problem" (Kerridge, 1989). Recent results suggest that the solar wind is supplied continuously with material of chemical composition different from that of the convective zone and the photosphere (Sect. 9).

Spence et al. (1993) pointed out that inhomogeneities exist like 'hot spots', sunspot-nests, (or 'pivot points'), which do not participate in the shift towards the solar equator of the solar activity patterns and at the same time they seem to generate the solar activity. The existence of these rigid rotating inhomogeneities has "such serious implications, as has the lack of solar neutrinos for our understanding of solar structure".

The solar diameter together with the neutrino flux data also shows anticorrelations with the acoustic mode frequency shifts. It was shown in a pioneering paper of Delache et al. (1993) that this correlation points to a close coupling between the dynamical processes detected in upper solar layers with perturbations inside the Sun, down to the core.

3. The case against the MSW mechanism

Until the recent results of the solar neutrino flux measurements it seemed that the best offered mechanism to solve the neutrino problem is the MSW effect. But now the results of the GALLEX (GALLEX 1992, 1994), Homestake (Davis, 1993), Kamiokande (Suzuki, 1994), and SAGE (Abdurashitov, 1994) measurements exclude the working parameter ranges with a high significancy. According to the recently measured average values in the $\Delta m^2 - \sin^2 2\Theta$ diagram, the until now allowed region for the MSW effect ($2 \times 10^{-6} < \Delta m^2 < 2 \times 10^{-5}$), decreases to a point-like area around $\Delta m^2 = 10^{-5}$ eV^2 and $\sin^2 2\Theta = 5 \times 10^{-2}$. Paterno and Scalia (1994) refer to this fact as "hypotheses on non-conventional neutrino properties are strongly disfavoured, except for the matter neutrino oscillations, the latter surviving within very narrow limits". The absence of the day-night effect (Turck-Chieze et al., 1993) seems to exclude with 90% confidence limit the parameter range $2 \times 10^{-6} eV^2 < \Delta m^2 < 2 \times 10^{-5} eV^2$ (their Fig. 6.2), which excludes the remaining part, as well (see also Schramm, Shi, 1994).

Krastev and Smirnov (1991) actually modified the SSM in order to get variations in the neutrino signals. Fitting the MSW calculation to a time variation of only 2 SNU of the chlorine detector (actually, it is observed as 2 SNU - 4 SNU), they had to allow a relative density variation in the range of 16%! It is remarkable that their results refer to perturbations situated in the inner part of the Sun ($r \simeq (0.2 - 0.4)R_0$, where R_0 is the solar radius). If the MSW theory needs a non-standard solar model for being consistent with the observed time variations of the neutrino fluxes, we have to ask first, whether the allowed deviancies from the SSM could cause alone the observed changes or not! If we find (as it will be shown here by our model calculations) that these changes in themselves are able to interpret all the observed data, we will not need the MSW at all. Actually, such a significant variation would be excluded by present-day helioseismology because such large discrepancy would lead to a measurable variation of the sound speed.

Gavryusev and Gavryuseva (1994) noted that "the GALLEX result (1992) is in sharp contradiction with the predictions based on the hypothesis that the solar magnetic field (the neutrino magnetic moment) is responsible for the time variation of the neutrino flux, and it is hence necessary to look more attentively at the processes taking place inside the Sun's core".

4. The magnetic torsional oscillations of the solar core

It was suggested by Goode and Dziembowski (1991), that the solar cycle changes of the rotation of the core are generated by the magnetic fields in the form of torsional oscillations. It is easy to estimate the rotational energy changes of the core in this picture. The rotational energy change is

$$\Delta E = (1/2) \times 2/5 m R_c^2 \times (\omega_1^2 - \omega_2^2) = 5.36 \times 10^{39} \text{erg}, \quad (1)$$

where we used for ω_1=445 nHz, ω_2 =420 nHz, m= 1.58×10^{33} g, R_c=0.4R_0= 2.8×10^{10} cm. It is a large value, since if it was really periodically given by the magnetic energy changes, in a volume of a sphere with 0.4R_0 , it would involve periodic magnetic field changes with an amplitude of 20 - 30 kG. Since the global field changes its polarity from one half of the cycle to the other half, the field has to dissipate in every half cycle. Actually, the reversal of the global field destroys the basic condition of the torsional oscillation of the core, namely, the constant presence of field lines connecting the different regions which are in torsional oscillation.

5. Radial mass movement as a possible cause of the variability of the core rotation rate

Recently Kocharov suggested (1992), that the changes in the core rotation rate are due to radial mass displacements from the centre to 0.3R_0 distance. A certain amount of mass with low angular momentum leaves the core, which makes the rotation of the core slower around 0.3R_0 and quicker around the centre. These turnovers (of unspecified origin) would also lead to the transport of beryllium from the active centre to less active parts of the core, which could be a mechanism for interpreting the periodic decrease of the neutrino flux behind the theoretically expected value. Here I estimate the necessary amount of masses involved to decelerate the rotation of the core in the observed rate. By using the conservation law of momentum,

$$\Theta_1 \omega_1 = \Theta_2 \omega_2 \quad (2)$$

$$\omega_1 / \omega_2 = (m + \Delta m)/m = 1.07 \quad (3)$$

it follows that

$$\Delta m = 1.1 \times 10^{32} \text{g}. \quad (4)$$

It means that the proposed mechanism could periodically decelerate and accelerate the rotation of the core in the observed rate only if the mass of the hypothesized turnovers amounts to 0.07 solar core mass and the mechanism works in transferring matter outwards in one half of the 22 years solar cycle period, and inwards in the other half. It is clearly a significant mass flow, and is related so directly to the reversal of the magnetic field, that at least its basical physics should be outlined.

6. The pulsating-ejecting core model

It is generally believed, that the luminosity of the Sun is directly connected to the central temperature and so to the neutrino flux. I point out, that the convective flare theory (CFT) works with an additional energy producing mechanism, therefore solar models free from this constraint of the SSM can be constructed.

The CFT predicted the existence of explosive processes in stellar cores on a purely theoretical basis (Grandpierre, 1984). These explosive processes are necessary to generate perturbations large enough in space and amplitude, for which the actual Rayleigh number is larger than the critical one, in order to be able to trigger the convection in the (outer) convectively unstable zone. This means that a kind of explosive flow shoots matter and energy from the core to the bottom of the outer convective zone (Grandpierre, 1991). The explosive process in stellar cores is the thermonuclear runaway, arising when mass movements and magnetic fields are simultaneously present in the core. The timescale of the runaways at the solar core is around 10^{-5} s (Grandpierre, 1990), while the time scale of the hydrodynamical expansion is much larger, it is around 10^2 s (Arnett, Clayton 1970). It is shown below that these runaways offer a modification of the SSM in a way to make it consistent with neutrino flux observations and the core-related astrophysical problems.

To present the power of the arguments for the existence of explosive jets in the solar core, now we approach (and reach) this conclusion in a different way from the above described ones. The magnetic field suppresses the thermonuclear reaction rates in two ways. First, the magnetic pressure makes the material less dense, thus reducing the number of the effective collisions. Consequently, less heat is produced in the same volume element, therefore the temperature begins to decrease which leads to an additional depression of the thermonuclear reaction rates. The positive feedback is not easily balanced by a compressive heating of the solar core, because the magnetic field also involves an additional pressure which the hydrostatic pressure first should overcome in order to be effective. In this way an infinitesimal effect of the magnetic field can lead to a finite temperature decrease of the core. On the other hand, the magnetic field acts to unidirect the paths of the charged particles, which also reduces the number of the effective collisions. Because the Lorentz force does not produce work, the increase of the parallel velocity components involves the decrease of the velocity components vertical to the field lines. The fact that the charges with similar signs accelerate in the same direction, leads to a contraselection of collisions with large impact factors, and so to an effective suppression of the reaction rates.

The magnetic field present in the solar core results in a process which modifies the distribution of the temperature. If the magnetic field is stronger around 0.1 solar radius, then it has to be cooler there. At the same time, this magnetic field coupled to an intruding flow, may generate explosive jets (Grandpierre, 1990) reaching until 0.4 solar radius (occasionally more, until the bottom of the convective zone, and then easily until the surface), where they produce local heating. Because of the fact that the core magnetic field anticorrelates with the global poloidal field, i. e. it correlates with the sunspot number, the core volume at solar maximum will be larger by the local heating of the edge of the solar core (as we will see later). Using the conservation law of momentum for the core we get a decrease of the rotation rate at the solar maximum.

The model works in the following way. We suggest that the core of the Sun consists of two parts with different characteristics. One is the main, quiet part of the core, which as a whole is cooled down by the effects of the magnetic field when approaching the maximum of the activity cycle. The other part of the core consists of hot bubbles produced by the thermonuclear runaways which are shooted out from the inner part of the core towards the edge of it. In these bubbles the temperature is much higher than in their surroundings, therefore thermonuclear reactions set up in them with much higher rate than in their environment, if the density inside is not low enough to compensate the effect. In fact, the contraselection of collisions by the magnetic field leads to a certain thermal shielding of the bubbles. Gorbatzky (1964) assumes that a thermalizing heat wave propagates from the hot bubbles, and increases their mass through heating their surroundings while travelling towards the stellar surface. Nevertheless, the shielding effect of the magnetic field, enveloping the bubbles and their pathways to the surface as channel walls, may decrease the rate of the energy exchange between the bubbles and their environment (see also Sect. 7). The preservation of the identities of the bubbles may be provided by the magnetic field of the bubble itself, when it forms a plasmoid (see e. g. Heritschi et al., 1989). The inner velocity field of the plasmoid may act also to conserve the bubble as a whole, as a consequence of the vortex conservation law.

In the model outlined here these hot bubbles are shooted out from the central regions and expand on their ways. Most of them are assumed to lose their surplus energy at the edge of the core around $0.4R_0$ to their environment. The dissipating agent at the core edge can be the factor causing the observationally suggested 'decoupling' of the edge of the core from the outer regions (Goode, Dziembowski, 1991). The luminosity of the Sun is produced by the 'core' and the 'bubbles' together,

$$L_0 \simeq L_c + L_b. \tag{5}$$

First let us use only the results of the chlorine detector! The high-energy boron neutrinos are produced (in the first approximation, averaged to the whole boron neutrino producing core) with the 18th power of the temperature. The neutrinos observed by the chlorine detector are mainly the beryllium neutrinos (their theoretical SSM value is 1.1 SNU) and the boron neutrinos (their theoretical SSM value is 6.1SNU). The observed neutrino flux varies between 1/100 (around 1980, activity maximum) and 1/2 (around 1986, activity minimum) of the value proposed by the SSM, depending on the phase of the solar cycle (see Table 1). We can take the average ratio of the observed and predicted neutrino flux as $R_{Cl} = 1/4$, and then

$$R_{Cl} = 0.25 = (T_c/T_{SSM})^{18} \tag{6}$$

$$L_c \sim T_c^4 \sim (1/4)^{4/18} L_0 = 0.735 L_0. \tag{7}$$

Accordingly, we assume that the missing luminosity is supplied by the hot bubbles.

$$L_b = L_0 - L_c = 0.265 L_0 = m_b \epsilon_b = 4\pi/3 \rho r^3 \epsilon_b. \tag{8}$$

Here ϵ_b is the specific energy production coefficient in the bubble, m_b is the mass within it, ρ is its average density for which we can take a value of 60 g/cm^3. Taking a plausible value for ϵ_b (Edwards, 1969), we can derive the mass of the bubble. Fixing the density gives the linear size of the bubbles.

$$\epsilon_b = 5 \times 10^{17} \text{ergs/g/s for the He-f lash at } T = 3 \times 10^8 \text{K}, \tag{9}$$

$$r_b(from\ R_{Cl}) = 2 \times 10^4 \text{cm}, \tag{10}$$

$$m_b = 1.8 \times 10^{15} \text{g}. \tag{11}$$

This m_b is the effective flaring mass participating in the runaway. It is easy to derive independently the size of the flaring volume by the convective flare theory (CFT). First let us assume, for simplicity, that only one site exists in the core where the thermonuclear runaway develops. The volume of the developing runaway grows until the actual Rayleigh number belonging

Table 1. The calculated temperature decrease of the quiet core relative to the SSM value, from the measured neutrino fluxes. Exp=26 means that the boron neutrino flux was calculated with $\cong T^{26}$ (otherwise with $\cong T^{18}$).

Observational time span	Relative sunspot number R_Z	HOMESTAKE $\Phi_\nu(obs)/\Phi_\nu(SSM)$			KAMIOKANDE $\Phi_\nu(obs)/\Phi_\nu(SSM)$ calculated			
		measured	calculated	at ΔT_c	measured	with $\Phi_\nu(b)$	without $\Phi_\nu(b)$	at ΔT_c
1977 (min)	8	0.52 (1)	0.52	4%				
1979.5-1980.7	150	0.051 (1)	0.055	18%/ (15%,exp=26)				
1986.8-1988.3 (min)	6	0.53 (1)	0.52	4%	0.46 (6)	0.45 0.45	0.15 0.06	10%,p=15/17 5%,exp=26
1988.4-1990.3	153	0.32 (2)	0.32	7%	0.39 (6)	0.42	0.15	7%,exp=26
1991	143				0.59 (7)	0.58	0.40	5%
1991.5-1992.3	134							
1992	91	0.30	0.27	8%	0.61	0.59	0.40	5%
1993	54				0.41	0.40, q	0.27	7%

Observational time span	Relative sunspot number R_Z	GALLEX $\Phi_\nu(obs)/\Phi_\nu(SSM)$			SAGE $\Phi_\nu(obs)/\Phi_\nu(SSM)$		
		measured	calculated	at ΔT_c	measured	calculated	at ΔT_c
1977 (min)	8						
1979.5-1980.7	150						
1986.8-1988.3	6						
1988.4-1990.3	153				0.20 (4)	0.22	25%
1991	143				0.65 (5)	0.60	7%
1991.5-1992.3	134	0.63 (3)	0.60	7%	0.73	0.72	5%
1992.7-1993.9	85	0.59	0.60	8%			

to this size reaches the critical Rayleigh number (Grandpierre, 1984).

$$d_{crit} = 2\pi(\kappa\nu/g\alpha\beta)^{1/4} \quad (12)$$

$$= 2\pi$$

$$(2.64 \times 10^{11} \times 1.36 \times 10^{-13}/2.4 \times 10^3 \times 10^{-7} \times 4 \times 10^{-4})$$

$$= 2.45 \times 10^4 \text{cm} \quad (13)$$

Comparing Eq. (10) and Eq. (13), we see that the two explosion sizes, derived from independent data, are close to each other,

$$r_b(R_{Cl}) \simeq 2 \times 10^4\text{cm} \simeq r_b(CFT) \simeq 2.45 \times 10^4\text{cm}, \quad (14)$$

and also agree with the observed masses of the atmospheric flares. Now let us assume, that the rotation rate of the core decreases by the thermal expansion of the edge of the core around $0.4R_0$. Using the measured values of the core rotation rate changes, one can estimate the relevant rate of the volume expansion,

$$\Theta_1\omega_1 = \Theta_2\omega_2 \quad (15)$$

$$2/5m_1(R^2_{outer} - R^2_{inner})\omega_1 =$$

$$2/5m_2((R_{outer} + \Delta R)^2 - R^2_{inner})\omega_2 \quad (16)$$

$$\omega_1/\omega_2 =$$

$$m_2/m_1((R_{outer} + \Delta R)^2 - R^2_{inner})/(R^2_{outer} - R^2_{inner}). \quad (17)$$

With $\omega_1 = 450$nHz, $\omega_2 = 420$nHz, $m_1 = 1.58 \times 10^{38}$g, $R_{inner} = 0.3R_0$, $R_{outer} = 0.4R_0$, we will get $R_{outer} + \Delta R = 0.4062R_0$ and $\Delta V = 3.94 \times 10^{30}\text{cm}^3$.

This value is derived from the observed core rotation changes. On the other hand, using the assumption on the mechanism of this volume expansion, it is possible to derive independently a value for this volume expansion. When a hot bubble appears, and starts to move quickly outwards, it has to develop a channel behind itself, which may be maintained by the material flowing into it. A channel 'lives' a lifetime determined by the lifetime of the explosive source of the hot bubbles. These explosive processes, as deduced from the lifetimes of the surface active regions, may live for some months, occasionally more than a year. We can call them as the hot spots of the core. There are similar phenomena in the geophysics suggesting the existence of flow channels. We know that magnetic storms exist in the core of the Earth (Bloxham, Gubbins, 1989), producing magnetic spots which survive for hundreds of years in the core in a stabil configuration. These channels are the physical factors behind the constant positions of the 'hot spots', i.e. the vulcanoes which are observed not to be moving with the continents, as e.g. the hot spot producing the chain of the Hawaii-islands. These channels can be similar to the central channel of the tornadoes, which are probably produced by the electric heating of the air (Vonnegut, 1960). We can estimate, how much matter is transported in these channels in a 5.5 years period from the central part of the core to its edge.

$$\dot{M} = r^2 \pi v_{out} \times \rho = (2 \times 10^4 \mathrm{cm})^2 \pi \times 60 \mathrm{g/cm}^3 \times 200 \mathrm{km/s}$$

$$= 1.5 \times 10^{18} \mathrm{g/s}. \quad (18)$$

This happens if the ejection of the bubbles at reaching the critical size takes place at an average velocity of 200 km/s, a value near to the local sound speed of 400 km/s, because the temperature difference between the bubble and its surroundings is enormous, $T_b(start) = 4 \times 10^9$ K (Grandpierre, 1990). In this way, for the thermal expansion the volume change will take place during the half time of the eleven year period

$$\Delta V = (\dot{M} t R T / p)_{r=0.4R_0} \quad (19)$$

$$= (1.5 \times 10^{18} \times 5.5 \times 3 \times 10^7 \times 8.3 \times 10^7 \times 4 \times 10^{11}) /$$

$$(2.77 \times 10^{15}) = 3.12 \times 10^{30} \mathrm{cm}, \quad (20)$$

assuming that on the way to the core edge the temperature grows to 4×10^{11} K from the 4×10^9K value at the start. We can observe that

$$\Delta V(\omega) \simeq 3.94 \times 10^{30} \mathrm{cm}^3 \simeq \Delta V(\Delta T)$$

$$\simeq 3.12 \times 10^{30} \mathrm{cm}^3, \quad (21)$$

again an agreement between the independently derived data. The bubble heating of the core edge is a million times more effective process to decelerate the core rotation than the turnover of the central regions to transfer the low angular momentum material to the edge (Sect. 5). The pulsating-ejecting solar core model needs a mass transport M $\simeq 2 \times 10^{26}$g during the 5.5 years instead of the 1.1×10^{32} g, see Sect. 5. The mass supply $\dot{M}$ is maintained by the inflow to the bottom of the channel from the surroundings. The incoming matter is continuously heated by the presence of the local magnetic flux bundle and the electric field produced by the incoming flows. On the other hand, some fuel supply or entrainment is also possible on the way through the walls of the channel. One can treat this entrainment with the mathematics developed by Ulrich (1970). It can supply the fresh nuclear fuel for the explosive reactions all along the channel, and maintain its high temperature within it. In the hot bubbles the incoming fresh material burns quickly because of the large temperature and density. The largest will be the rate of the quickest reactions, and so the deuterium production as an extremely slow process (occurring through weak interactions) will become relatively rare. The hot pp or the explosive CNO cycle (Audouze et al., 1973), the explosive He-burning (Howard et al., 1971) and possibly some other reactions will be enhanced. The larger temperature makes the production of proton rich nuclei possible, because we are closer to the Coulomb barrier then. It is able to produce the observed ^{3}He/^{4}He enhancements, sometimes reaching a larger than 10^4 factor in solar flares (Kocharov and Kocharov, 1984). Anyhow, the specific neutrino production for the same amount of produced energy is smaller in the bubbles than in the quiet core, because in the bubbles the He burning competes with the H burning, and the He burning does not produce neutrinos.

7. The travel of the hot bubbles from the core to the surface

One can ask, how can a hot bubble reach the solar surface from the central regions, despite of the enormous distance, the dissipation etc. The answer is partly given by the calculations of Gorbatzky (1964), who has shown that a point explosion may reach the stellar surface in red dwarf stars. He calculated, that the initial temperature of the hot bubble in the centrum of the star is above 10^8K, its velocity is high, $10^5 - 10^6$ cm/s. I have to note here, that the hot bubble develops through the interaction of a macroscopic inflow into a magnetic field, therefore it seems to be plausible to assume that the hot bubble is involved in a magnetic structure, what later may somewhat isolate it from its surroundings, therefore making it easier to reach the solar surface regions. Moreover, the hot bubbles, while ascending in the energy producing core, may increase their temperature until around $0.4R_0$, because they are hotter than their surroundings, therefore the nuclear energy production may be enhanced inside them. The calculations tell us that the temperature increase within the hot bubble, from the initial temperature $T_1 > 10^8$K, at a distance r_0 from the center where $T = T_0$, grows to $T_2 > T_1$ in a rate given by the formula (Grandpierre, 1990)

$$T_2/T_1 = (1 - T_1^{\nu-1} \rho X^2 \epsilon_0 (\nu - 1) t) / T_0^{\nu} C_v)^{(1/1-\nu)} \quad (22)$$

By this formula the time scale of the heating of the bubble is

$$\tau = T C_v / \epsilon(\nu - 1). \quad (23)$$

Zel'dovich, Blinnyikov and Sakura (1981) already noted that all the stars seem to be thermally unstable against temperature perturbations, and actually the observed thermal stability is preserved by the negative heat capacity of the star as a whole. But they draw the attention to the circumstance that the thermal stability is maintained only if the star expands as a whole when reacting to the small perturbations. When this condition is not fulfilled, then instability and thermal explosion may easily arise. They give a formula, describing the development of the thermal instability, in case when energy production L_+ and also energy dissipation processes L_- are present (radiative or conductive):

$$T - T_0 = const. \times exp((dL_+/dT - dL_-/dT)/c)t. \quad (24)$$

As they showed, the heat dissipation processes are very insensitive to the temperature, the diffusion of radiation depends on the square-root of the temperature, while, when the Compton scattering is substantial, the dissipation of the heat is not sensitive to the temperature at all. Using their formula, substituting for $\epsilon = \epsilon(T_0) T^{\nu}$, working for the pp, CNO and 3α chain as well,

$$T - T_0 = const. \times exp(m_b \nu T^{(\nu-1)} t); \quad \nu >> 1 \quad (25)$$

This formula means that the stars, including our Sun, contrary to the widespread beliefs, are continuously in the state of local thermonuclear inequilibrium, while at the same time, they may be in the state of a global thermodynamic equilibrium. A similar conclusion is reached in a different way by Grandpierre (1984, 1990). These thermal instabilities create the hot bubbles which are shooted from the core outwards when their size is large enough to overcome the dissipation effects. It is pointed out, that for the ejection of material from the core a macroscopic inflow and a local magnetic field is necessary (Grandpierre, 1990).

Gorbatzky (1964) pointed out, that on the way of the bubbles towards the surface the inner energy surplus is transferred into volume expansion in a rate proportional to the 2/5th power of the ratio of the local pressures. From $0.4R_0$ until $0.7R_0$ the pressure decreases with a factor of ten in the SSM. Therefore if the temperature within the bubble at its start is larger than 10^8K, and on its way until the edge of the energy producing core at $0.4R_0$ it increases its temperature with a factor of ten or more, it may easily be able to reach the bottom of the convective zone, from where its ascension is much more easy until the photosphere.

8. Comparison of the theoretical and observed neutrino fluxes

In Table 1 and Fig. 1 the observational intervals, the ratios of the observed and SSM neutrino fluxes for the chlorine, Kamiokande-II(K II) and III(K III), the SAGE and the GALLEX experiments are shown. The neutrino flux produced by the quiet core is calculated in the usual way as $\Phi(pp) \sim (T_1/T_2)^4$, $\Phi(^7Be) \sim (T_1/T_2)^8$, and $\Phi(^8B) \sim (T_1/T_2)^{18}$, where T_1 is the actual, T_2 is the theoretical SSM temperature, or, to put it in an other way, T_1 and T_2 are the model temperatures based on the pulsating-ejecting solar core model and the SSM, respectively. These relations, with the coefficients given by Bahcall (1989, Tables 1.4 and 1.5), determine the value of T_1 in our pulsating-ejecting solar core model from the observed Φ_ν and the proposed T_2 values by the SSM. The values with $\Phi(^8B) \sim T^{26}$ are also shown for illustrative purposes indicating a stronger temperature dependence of the B^8 neutrinos and the effect of the central temperature, higher than in the SSM, as suggested by the measurements (see e. g. Kosovichev et al., 1994). I point out, that the relation $\Phi(pp) \sim T^{-1/2}$ is not valid if the luminosity constraint is not applicable, i. e. if the energy is liberated in the Sun not only through the pp cycle. These results suggest that the central temperature is significantly smaller than in the SSM just near to the central region, at $r \sim 0.1R_0$, and this discrepancy is smaller, or it has even an opposite sign in the more central region, where most of the boron neutrinos are produced.

To obtain an upper limit for the neutrino production of the bubbles, one can estimate that it is simply proportional to their electromagnetic luminosity. This would be the case if in the bubbles only H burning were occurring. The bubbles produce a part L_b/L_0 of the solar luminosity. Taking into account that they produce energy in hot CNO cycle (for $T \geq 10^8$K), in He-burning (also for $T \geq 10^8$K) and explosive He-burning reactions (for $T \geq 5 \times 10^8$K), and possibly some other unidentified chains, a part of them does not produce neutrinos, like e.g. the He-burning, we can say that only a part "p" ($p < 1$) of the reactions is accompanied by neutrino production. In this way the neutrino flux of the bubbles will be

$$\Phi(b) = p \times L_b/L_0 \times \Phi_\nu(SSM). \tag{26}$$

In the different phases of the solar activity we can estimate the central temperature change from the measured neutrino fluxes for each measurement (Table 1.). All the four neutrino experiments show a cyclical trend of the central temperature in anticorrelation with the sunspot number.

Gavryusev and Gavryuseva (1994) and Oakley et al. (1994) pointed out that the Kamiokande results are in reality consistent with the anticorrelation of the neutrino production rate and the solar cycle.

I calculated the temperature of the quiet core for the Homestake, Kamiokande, GALLEX and SAGE measurements. It is interesting to show, what temperatures can be seen in the solar core on these neutrino detectors. One can see from Table 1 and Fig. 1 that all measurements seem to show a definite variation of the core temperature with the solar cycle. Moreover, all the different kinds of measurements seem to be consistent. I had only two minor possibilities varying the calculated values, trying to fit to the observed data. One is to allow that the different types of detectors can see to different average depths into the solar core. This is one reason to calculate with the 26th power dependence of the boron neutrinos. Actually, since the Sun seems to deviate from the SSM in different rates and signs at different depths, and the neutrino spectra may be different from the one assumed in the SSM, the above described model in its present state does not account on these finer details, characterizing all these processes with two, but coupled, circumstances: the decreasing of the central temperature and the presence of hot bubbles. In our model the character of the temperature dependence of the neutrino fluxes

$$\Phi_\nu = \Phi_c + \Phi_b, \tag{27}$$

i. e. the neutrino production of the Sun Φ_ν is made up of the neutrino fluxes of the quiet core Φ_c and that of the bubbles Φ_b.

$$L_b = L_0 - L_c = L_0 - (T_2 - \Delta T)^4 L_0 = (1 - (T_2 - \Delta T)^4) L_0 \tag{28}$$

$$\Phi_b = p(1 - (T_2 - \Delta T)^4)\Phi_\nu(SSM), \tag{29}$$

expressing the circumstance that the neutrino production of the bubbles does not allow Φ_ν values less than 0.50 in the theoretical case if $n = 18$ and $p = 1$, therefore we had to use also $p < 1$ or $n = 26$ values, i. e. the relative underproduction of neutrinos by the hot bubbles or the stronger-than-SSM temperature around the centre, which is suggested by the theory and the measurements, as well. These parameters have to be used in three cases (Table 1.). It is remarkable, that most of the data (except the controversy between the SAGE and Homestake data for 1988.4 -1990.3) are in agreement within 1 σ of the neutrino flux measurements.

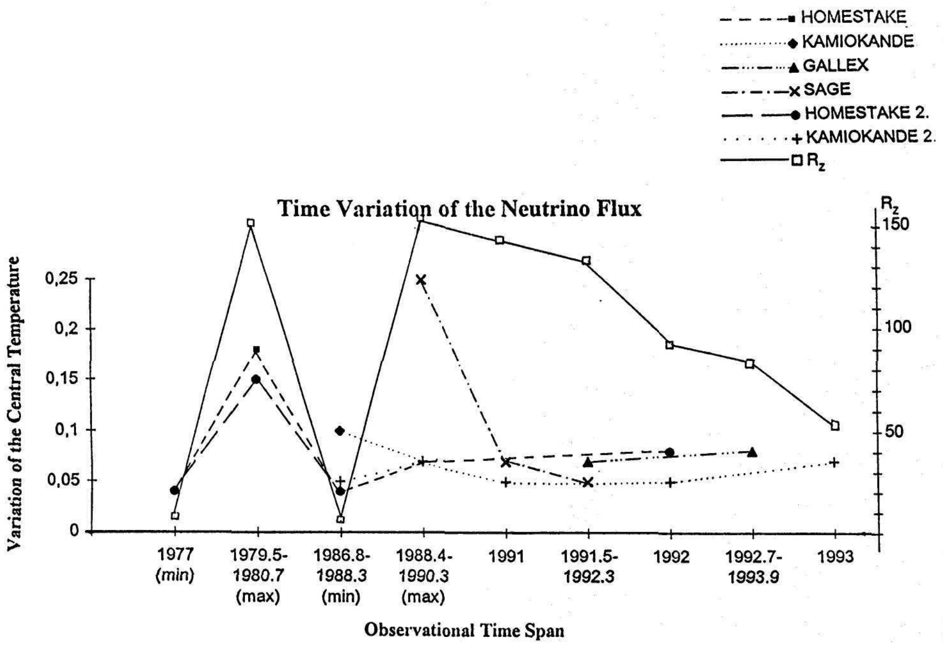

Fig. 1.

The effect of the bubble neutrino flux is to smooth out the solar cycle variations for the Kamiokande detector. The Kamiokande sees the bubbles around solar maximum, when the neutrino flux is of the quiet core is at minimum. The neutrino flux of the quiet core and the bubbles together changes much less than that of the quiet core alone (see Table 1). Of course, the dependence of the neutrino fluxes on the central temperature is not direct, as it is based on the local values of the magnetic field, flow velocities, depth etc. Nevertheless, Fig. 1 shows that the presence of core cooling *in parallel* to the appearance of explosive hot bubbles is clearly demonstrated.

9. Chemical anomalies in the atmosphere as evidences for deep origin

It is a basical challenge of the present day astrophysics that while the $^{15}N/^{14}N$ ratio should have to decrease by the present day stellar evolution theories, the observations found that this ratio actually increased by 50% in the last 3×10^9 years (Kerridge, 1989). Kerridge calls this effect the nitrogen-enigma, and he sees its significance as fundamental as comparable to the problem of the missing solar neutrinos. The most probable mechanism to produce extra ^{15}N is the explosive CNO cycle. It works at temperatures $T \geq 1 \times 10^8$K and $\rho \geq 0.1\text{g cm}^{-3}$ (Audouze et al., 1973 and Dearborn et al., 1978). Producing a 50% effect during 3×10^9 years needs a number of 2×10^{33} of ^{15}N producing reactions per sec, which is only 5 orders of magnitudes less than the total number of the nuclear reactions per sec.

The ^{15}N enhancement of the lunar surface is shown to be originated by the solar wind. But there are other strange chemical anomalies, related especially to flares. Waljeski et al. (1994) presented new results from measurements of soft X-rays (SXR) line and broadband intensities. They showed that for the observed active region the absolute abundances of the low first-ionization-potential (FIP) elements (Fe, Mg) are enhanced in the corona relative to the photosphere by a factor of 6 to 31, in a way that the abundances of the high FIP elements (Ne, O) are also enhanced by a factor larger than 1.75! There are other signs indicating that something is wrong in the standard picture of the production of the elements in the solar-like stars. For example, while the C^{13}/C^{14} rate decreases with the distance from the center of our Galaxy, the He^3/He^4 distribution is just the opposite (Balser et al., 1994). Also, the abundances of C, N and O in the Sun appear to exceed those found in the young Population I objects in the vicinity of the Sun by factors of 2.5 to 1.5, a result that goes counter to expectations given the approximately 5 Gyr age of the Sun (Sofia et al., 1994).

Mazur et al. (1993) have shown that in the large solar particle events the Fe is 4 times enhanced, while in the less impulsive ^{3}He-rich flares the Fe is 20 times enhanced in comparison to the photosphere, and in the large impulsive flares the Fe-enhancement is still larger. Sterling et al. (1993) have shown that in the solar flares the Ca/H ratio is in average two times larger than its photospheric value, and it changes from flare to flare, but not during one flare eruption. This circumstance suggests that the Ca-enhancing mechanism has to operate before the flare starts, otherwise the Ca enhancement would vary during the flare. Since the atmospheric acceleration mechanisms start at the flare onset, the enhancing mechanism should have to act before the flare begins.

As Kocharov and Kocharov (1984) write: the origin of the solar cosmic rays remains an open question. It is a question, because its chemical composition is different from the photospheric one. Recently Waljeski et al. (1994) have shown that the coronal active regions are enhanced both in low-FIP and high-FIP elements in comparison to the photosphere. This fact gives a possibility to interpret the differencies in chemical composition between the photosphere and the corona/solar wind.

Within the standard picture of the solar surface activity the flare phenomenon is generated in the corona. It is widely believed that the observed heavy element enhancement in the flares is a result of some selective acceleration processes acting locally in the solar atmosphere (Fisk, 1978, Miller, Vinas 1993), preferentially accelerating the heavier elements with larger ionic charges by ion cyclotron waves. Nevertheless, this selective acceleration should result in a depletion of heavy elements in the corona, chromosphere and photosphere during the lifetime of the Sun, because in this case the heavy elements would leave the Sun. If the observed atmospheric heavy element enhancement is absolute, and not relative, it has to originate from the central region, and it should produce the opposite effect than the one assumed implicitly by the Fisk (1978) and Miller, Vinas (1993) models; not a depletion, but an enhancement of the solar wind and corona in heavy elements. The observations tell us that the composition of the solar atmosphere at flare sites is enhanced not only relatively but absolutely (Sterling et al., 1993, Waljeski et al., 1994) in heavy elements. This means that the material of the chromosphere is supplied continuously from a source which is enhanced in heavy elements. Any selective preheating mechanism would have in the long run just the opposite effect to the observed one. This central source may supply the solar atmosphere and the solar wind with heavy elements. This mass supply may be the ultimate reason for the seemingly continuous enhancement He^3/He^4 ratio in the solar wind. The chemical composition of the meteorites, as referring to an era nearly 5 billion years earlier, show a $He^3/He^4 = 1.5 \times 10^{-4}$, based on a critical review of C1 chondrites (Anders, Ebihara 1982). While the ancient value of the He^3/He^4 of the solar gas implanted in lunar regolith samples is already 3.3×10^{-4}, today we measure 4×10^{-4}, which is actually a further 20% increasement (Kerridge et al., 1991). This continuous He^3/He^4 enhancement on the astronomical time scale seems to give an independent proof in favour of the deep origin of the mass supply of the solar atmosphere.

On the other hand, the atmospheric selection mechanisms suggested by Fisk (1978) and Miller, Vinas (1993) seem to be challenged strongly by the recent measurements. Luhn et al. (1987), who determined the average mean ionic charge of energetic Si emitted in He^3 rich flares for the first time, got the result that the mean charge of Si would be expexted by the Fisk-mechanism around 8-9, while the measured value is 14. Also, the selective heating by ion cyclotron waves, by the more detailed investigations of Luhn et al. (1987), does not seem to have a significant effect on the ions heavier than He, contradicting to the Fisk (1978) model. Mason et al. (1994) showed that their observations may indicate that the particles are energized in solar coronal locations only if there are enhancements of heavy ions already. They also pointed out, that the predicted Fe/C ratios by the mechanism suggested by Miller and Vinas (1993) are far in excess of the observed values. The observed isotopic composition and the simultaneous acceleration of all the heavier than He elements contradict to the Miller and Vinas (1993) model. I point out, that the enhancement of the coronal flare sites in heavy elements has to occur just at the flare onset based on these results, suggesting that the heavy elements are directly transported to the flare site from below just at the flare onset. Let us keep in mind the flare energy and particle number problem (Holman, 1985, Grandpierre, 1989), stating that there is not enough energy and mass locally at flare sites, and the observed densities at the magnetic loop-tops which are the primary flare sites, are at least 2-3 magnitudes higher than in the flux tube models (Grandpierre, 1989, 1995b). As Zirin (1988) notes: "What is the significance of the loop-tops, where much of the energy release seem to occur? It is really hard to understand how density can peak at loop tops." Meyer (1985) remarks that the iron-enhancement is most frequently the largest at flare onsets. These facts seem to give further support for our suggestion about the mass supply of flares from below the convective zone.

Now we can reach the same conclusion starting from the observed atmospheric iron enhancement. For a clear picture, we would need data on the absolute element abundances at the different layers of the solar atmosphere, photosphere, chromosphere, corona and solar wind, and in the meteorites. In all these layers we should study the abundances at different sites, i. e. in relation to large solar energetic particles, flares, active regions and sites far from active regions. Unfortunately, to construct such a table the present day data are not sufficient. Nevertheless, one can subtract some conclusions even from the available data set. For example, the large solar particle events show a photospheric iron abundance of $A_{Fe/H} = 4.66 \times 10^{-5}$ (Mazur et al., 1994), in the solar wind the same value grows to 10^{-4}, while it is only 3.20×10^{-5} in the meteorites (Anders, Grevesse 1989). We also know, that the non-active photospheric regions show an iron abundance of 3.20×10^{-5} (Biemont et al., 1991), or 4.57×10^{-5} (Pauls et al., 1990). The iron abundance in coronal active regions is much larger, 3.16×10^{-4} (Waljeski et al. 1994) and it varies from photospheric composition values to the typical coronal values found for solar energetic particles, by an enhancement factor of ten between structures and within different regions (Saba, Strong, 1994). One can speculate that the meteorites preserve the composition of the protosun, while the observed enhancements of the flare sites in heavy elements are slowly enhance also the solar atmosphere, first the corona and the solar wind, then the chromosphere and, much slowly, the photosphere. This line of thought seems to be substantiated by the protosolar value of $r = He^3/H^1 = 1.1 \times 10^{-5}$, while in the flares $r = 3 \times 10^{-5}$ (Trottet et al., 1993).

Realizing that the atmospheric iron enhancement means an absolute abundance increasement (Waljeski et al., 1994), and that it is far too large to be produced in the atmosphere, we find its source only in the deeper regions. Knowing that the production of Fe is possible only in temperatures $\geq 10^9$K, and that it needs high densities (≥ 0.1g/cm^3), one can deduce that the material of the flares has to come from dense and hot regions. Regions with these characteristics cannot develop in the solar atmosphere (note: only Ambartsumian's idea (1957) on the explosive atmospheric decay of superdense prestellar material would lead to the appearance of such regions), so they have to come from the deep solar interior, from below the convective zone. The additional production of heavy elements as compared to the SSM has to involve a significant part of the total solar luminosity, because the energy production is a very sensitive function of the temperature. In this way, from this fact alone, we are led directly to the conception of thermal runaways in the solar core.

10. The production of energy and heavy elements in the hot bubbles

It is easy to estimate the nuclear transmutation rate in the hot bubbles. Assuming that the bubble transmutation rate $\dot{m}_b$ is proportional to the core transmutational rate $\dot{m}_0$ in the ratio of the luminosities,

$$\dot{m}_b \sim (L_b/L_0)\dot{m}_0. \tag{30}$$

$$For \quad L_b/L_0 = 1/2 \quad we\ get \quad \dot{m}_b = 1.5 \times 10^{14}\text{g/s}, \tag{31}$$

$$while\ for\ L_b/L_0 = 1/10, \quad \dot{m}_b = 3 \times 10^{13}\text{g/s}. \tag{32}$$

During the last 5×10^9 years the bubbles produced

$$\Sigma Z = 4.5 \times 10^{30} - 2.25 \times 10^{31}\text{g} = 0.2\% - 1\% M_0. \tag{33}$$

This is comparable to the value given by the SSM for the amount of produced heavy elements for the same time as 0.7%. This extra heavy element production can cause the observed difference in the chemical composition of the solar atmosphere and the average composition of the solar system.

The explosive CNO cycle works above 10^8K, burning hydrogen to helium (Audouze et al., 1973). The helium burning starts similarly above 10^8K, the explosive He burning above 5×10^8K (Howard et al., 1971). The iron is produced above 10^9K. At such a high temperature the energy production is extremely quick and the elements can easily deplete if there is not enough support of fresh nuclear fuel. The time scale of the nuclear depletion of the bubble can be estimated as

$$\tau_d = QA/\epsilon_b, \tag{34}$$

where Q is the heat energy produced in the dominant reaction per nucleon, A is the number of the nuclei participating in the reaction per gram, and ϵ_b is the rate of the energy production in the bubble. If there is no fuel supply into the bubble, and Q$\simeq$7 MeV, the depletion time would be around 14 sec. During that time the bubble with a velocity of 200km/s can travel only 1% of the centre-core edge distance. It is much more plausible to assume, that a channel develops, in which the matter is hot and is shooted upwards, and the continuous nuclear processing is supplied through the channel walls and/or from below. The energy production of the channel is equivalent with that of an idealized bubble with $\epsilon_b = 5 \times 10^{17}$ergs/g/s. This means that $\epsilon_{ch} \approx 10^{12}$ergs/g/s because the total volume of the channel is around 10^6 times larger than that of the bubble. One can imagine that a bubble is shooted upwards from the bottom of the channel. It is clear that a very moderate entrainment is enough to feed the burning of the channel wall. For the production of the observed iron enhancement in a flare $10^{12}g$ iron is needed, i. e. 10^{34} iron producing reactions. One flare with atmospheric nuclear reactions can produce only $3 \times 10^6 g$ of deuterium (Terekhov et al., 1993), i.e. it is undereffective for the observed iron and nitrogen flare anomalies by a factor of 10^6. In the hot bubbles around 10^{38} reactions/s occur. For the nitrogen anomaly 2×10^{33} N^{15} producing reactions/s are needed. Ibrahimov and Kocharov (1975) and Heritschi et al. (1989) suggested that the flare-related He^3/He^4 enhancement is the result of He^3 transport from the solar deep interior. The He^3/He^4 ratio is the largest, when the He^3 flux is lower by 3 magnitudes (Kocharov and Kocharov, 1984). As Ibrahimov and Kocharov (1975) pointed out, flares that arise successively in the same active region, produce less and less He^3 enhancement. These circumstances may be related to the fact that a flare starting with a larger energy surplus from the core may reach the disrupting magnetic gradient/sonic boom treshold lower below the photosphere, therefore its explosive character in the corona will be more damped, its chemical materials may reach the coronal regions with a much less probability. Indeed, the so-called gradual flares generally have a tendency to possess larger energies, slower time development and lower rate of chemical anomalies. The observations of He-enhancement give us a way to estimate also the amount of He^3 showing up in a large solar flare. Using a value for the mass of a flare 10^{15}g, the mass of the He^3 may reach a mass of 10^{12}g, also too large for an atmospheric origin.

11. Recent solar oscillation measurements

There are other independent measurements revealing the presence of extremely high temperature processes occurring in the solar core. Recently Christensen-Dalsgaard (1992) has shown by the analysis of the solar oscillation measurements that the edge of the solar core around $0.4R_0$ is less dense by 4% than in the SSM, while around $0.1R_0$ it is denser by 3%. It would be interesting to know the rate of change of this effect with the solar cycle. It is remarkable, that the anomalous behaviour of the temperature distribution occurs at $0.4R_0$, just at the radius where the core rotation rate changes set up. Since the bulk volume of the Sun has to be in hydrostatic equilibrium, these results suggest that the edge of the core is hotter and the central regions are cooler than in the SSM. But a 5% decrease of the central temperature diminishes the core luminosity by at least 20%, so a compensating mechanism is needed, which can supply the task of transferring a substantial part of the solar luminosity from the central regions directly to the edge of the core. Since the edge of the core cannot produce an appreciable part of the solar luminosity in the SSM, this mechanism has to produce a significant part of the solar luminosity at the central parts of the core and to transport it directly to the core edge.

Elsworth et al. (1990) presented evidence for solar cycle-dependent frequency shifts of the low degree ($0 \leq l \leq 2$) p-mode oscillations. Recently Rhodes et al. (1993) and Regulo et al. (1994) confirmed this evidence. The sign of the frequency shifts show expansion when the Sun is globally contracting, and vice versa. This is what sets up in our model. If the core is colder at solar maxima, the resonant cavity is larger then and the first order frequency shifts anticorrelate with the sunspot number as it is observed. Elsworth et al. (1990) note that the travel time of the neutrinos is maximum at solar minimum. The pulsating-ejecting model clearly suggests, that the cavity is larger at solar maximum. The observed shifts 0.46μHz suggest a rate of volume expansion $\Delta R \approx 4 \times 10^7$cm, which is an order of magnitude smaller than the linear expansion/contraction of the quiet core (as calculated here, $\Delta \mathrm{R} \approx 4 \times 10^8$cm).

One can think that a 14% temperature decrease in the solar core is not allowed by the solar seismology. Nevertheless, it is important to keep in mind, that the p-mode measurements and the neutrino detection have a complementary character (Bahcall and Ulrich, 1988). While the neutrino measurements are sensitive to the central temperature, the p-mode frequencies do not change significantly even for such a drastic change in nuclear energy generation as the switching off the ^{3}He + ^{4}He reaction, which produces 15% of the energy, increases the central H and ^{3}He by 10% and 54%, the central pressure by 3% and the caused relative frequency changes still remain less than 10^{-4}, i. e. less than 0.2 - 0.4 μHz.

Gavryusev (1994) pointed out, that it is not possible to deduce directly the central temperature from the solar seismological data.The solar model calculations did show that the sound speed is an average property of the whole star and can not be connected in any way to the "averaged temperature". The sound speed deduced from the solar oscillations is an "averaged sound speed" and it is a very stable value defined by global solar parameters (mass, radius, luminosity). Even significant changes in the inner solar model structure do not change it too much. Hence, by the model calculations, variations of the temperature with amplitudes of order 5% is possible in the small inner core of the Sun on time scales from months to years (Gavryusev, 1994). In reality, the central temperature cannot be measured by the p-mode oscillations, it can be only calculated from the radiative opacities. This radiative opacity is the one believed to be known with a precision of a few percent (Bludman et al., 1993). Nevertheless, the solar model calculations of Baturin and Ajukov (1994) show that the SSM fits the new helioseismological data only with unnatural opacity changes of 60% – 80%, allowing the determination of the central temperature only with a similar indeterminacy.

Another thing to take into account is that the above picture gives an average value of 7% temperature decrease. Concretely, in the last solar cycle, at minimum the chlorine detector saw a ΔT = 3%, at maximum ΔT = 7%. Still half of the average 5% value, 2.5% could work for this pulsating-ejecting solar core model, for an SSM like that of Turck-Chieze et al. (1988, 1993), with $\Phi_\nu(SSM)$ = 6 SNU and using the recent higher values for the Homestake detector.

It is important to note, that the opposite behaviour of the quiet core and the core edge acts as a significant compensating mechanism for the average temperature of the core. Even when the quiet core is 15% colder than in the SSM, the compensation can be so strong, that the average temperature of the whole core in the pulsating-ejecting solar core model is within 1% agreement with that of the SSM. The measured compensation effect is determined by the resolution of the oscillation measurements. It depends on the relative masses and sizes of the central core and the heated core edge. The pulsating-ejecting model is in much better agreement with the lowest degree oscillation measurements than the SSM.

The recent measurements of Regulo et al. (1994) point clearly to a direct connection between the solar core and the surface activity. They note the anomalous behaviour of the low l p-modes at 1991 August just when the GALLEX (and a month before the SAGE) measured anomalously large neutrino fluxes around 300 SNU. One interesting thing to note here, that in the time interval June 4-15, 1991 an extremely powerful, extraordinary activity was observed in the Sun. While until that time only 8 larger than X10 flares were observed all together during the last decades, in this one huge spot group during these nine days 6 such large flares were observed (B. Kalman, personal communication). Regulo et al. (1994) showed that the low l p-modes showed this anomalous behaviour in the period 1980 - 1993 only once, just in August 1991. This measurement points to an almost immediate and direct connection between the energy producing solar core and the surface activity.

The measurements of the solar cycle changes of the solar core, neutrinos and core structure, now are solidified, reinforced, and they cannot thought of as marginally observed (Delache et al., 1993, Gavryusev, Gavryuseva, 1994, Haubold, Mathai 1994, Regulo et al., 1994, Elsworth et al., 1995). It is interesting to note here, that the above described model is not only appropriate for interpreting all the above listed problems, but, at the same time, all the observed parameters and the direction of their changes, represented by the signs of the correlations, are also produced by the above model correctly without any further assumption. Each of these correlation signs contains basical physics. These coupled correlations together with the observed parameter values form an interconnected causality network. If we change one element of this network, all the other elements will change accordingly. I think it is a rare occasion in the history of astrophysics, when such a long list of independent data can be described with a simple assumption, the parameters of which are derived from only one data set. This circumstance gives a plausibility and a heuristic power to our model.

There is a need for more detailed pulsating-ejecting solar core models. One point where we can improve the model could be to describe the production of electromagnetic fields and currents, and the generated heating when a macroscopic flow intrudes into a magnetic field by numerical calculations (Grandpierre, 1995a). This calculation can be used to describe the atmospheric flares, too (Grandpierre, 1989). One missing point of the above outlined model is to calculate precisely the nuclear reactions occurring within the bubbles and the related neutrino production. This step can be made if we modify the SSM.

The thermal runaways can work not only in the solar core. The flare activity can be related to them in general. Especially, the young flare stars, the T Tau type stars can trigger first their nuclear reactions by the runaway at a temperature where the proton-proton cycle cannot be triggered yet. This mechanism is so basical, that it has to play a significant role in all types of stars, and possibly, in other celestial objects.

12. Conclusions

It is firstly pointed out, that there is a whole chain of fundamental and 'tantalizing' problems of the present day solar physics, all of which seem to be related to the physics of the solar core. This sequence of failures of the SSM expresses our accumulated but not yet understood knowledge. In this paper I proposed a simple model for the dynamics of the solar core, which seems to give a promising base for approximating all of these problems. The suggested model is based on a simple plausible assumption, what is also indicated by new measurements, showing the possible presence of a magnetic field and a macroscopic flow in the solar core. The model is able to describe the full range of parameters observed using only one set of them (the data of one neutrino detector). The pulsating-ejecting solar core model gives a plausible explanation of how to generate the solar cycle in the core (from the core magnetic field and macroscopic flow changes), and at the same time the same mechanism produces a direct connection between the core and the surface. The heating of the core edge, the solar cycle variation of the core rotation rate, the nitrogen enigma, the flare related chemical anomalies, the rigid rotation of the activity generating centres, the failure of the SSM to predict exactly the observed low degree frequencies and their shifts together with the solar cycle variation of the core structure are such kind of facts, that each in itself would be enough to unveil the presence of localized extremely hot regions in the solar core and their self-preserving transfer to the surface by a channeling mechanism. All these phenomena were interpreted by the pulsating - ejecting solar core model, which was constructed here from the data supplied by the separate neutrino measurements.

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