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Solar Neutrino Flux Variation and the Neutrino Energy Spectrum

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Solar neutrino flux determination from nuclear reactions inside the core of the sun is one of the main problem for the solar neutrino detectors. There is no doubt that the solar neutrino flux data detected by Homestake, Kamiokande-Superkamiokande, SAGE, and GALLEX-GNO are varying with the solar activity cycle. It is pointed out that the solar neutrino energy spectrum from different nuclear reactions inside the solar core must be reevaluated in order to be compatible with the observed solar neutrino flux from the existing solar neutrino detectors. Again, there is already a discrepancy in the neutrino energy spectrum above the neutrino energy 12 MeV from ^{8}B and ^{3}He + p neutrinos and cannot be explained by MSW neutrino oscillation mechanism .It is pointed out also that the recoil energy spectrum is indicated the stochastic nature of the solar core which may be due to temperature and density fluctuation inside the core of the sun. Considering the above observed fact it is suggested the solar neutrino spectrum from standard solar model (SSM) must be modified to explain the variations of solar neutrino flux with the solar activity cycle.

1. Introduction

Raychaudhuri[1] pointed out that standard solar model (SSM) are known to yield the stellar structure to a very good degree of precision but the SSM cannot explain the solar activity cycle, the reason being that the SSM does not include temperature and magnetic variability of the solar core. The temperature variability implied a variation of the energy source and from that source of energy magnetic field can be generated which also implies a magnetic variability. In the SSM the neutrino flux from the sun was calculated on the assumption of L_ν (neutrino luminosity) = L_γ (optical luminosity). The shape of the neutrino energy spectrum from the nuclear β-decay is very important to understand the temperature dependence of the solar neutrino flux from the various nuclear reactions which occur inside the solar interior and also to solve the solar neutrino problems. The solar neutrino spectrum is observing now five solar neutrino detectors: the pioneer Homestake detector with Chlorine[2], the Kamiokande- Superkamiokande and SNO with water Cerenkov detector[3,4] and two gallium detectors GALLEX_GNO[5] and SAGE[6] . Bahcall[7] pointed out that the shape of the ^{8}B neutrino energy spectrum is independent of whether the neutrinos are created in terrestrial laboratory or in the center of the sun. Thus, experimental evidence for the distortion of the ^{8}B solar neutrino spectrum from the laboratory shape would indicate the evidence of the new physics connected with neutrinos and also ^{8}B neutrino energy spectrum is not properly evaluated. Superkamiokande and SNO detectors are sensitive mainly to ^{8}B neutrinos. But all the above mentioned experiment do not give a coherent picture compatible with the standard physics, since we can understand easily why the Homestake detector leads to low neutrino flux than the Kamiokande-Superkamiokande and SNO detectors. The purpose of the paper is to suggest that we must remeasured and recalculate the β-decay spectrum from the nuclear reactions which occurs inside the core. Neutrino oscillation mechanism invoked to lower the solar neutrino energy spectrum for the solution of the solar neutrino problem. To explain the solar neutrino discrepancy it was suggested that part of the electron neutrino (ν_e) is transformed to muon neutrino (ν_μ) in the sun (MSW effect) or in vacuum. From the different experiments it is possible to determine the parameters: the mass difference and the mixing angle between the neutrinos. At present large mixing angle (LMA)(solution is favoured with parameters $\Delta m^2 = 6 \sim 8 \times 10^{-5}$ eV^2 and $\mathrm{Sin}^2\ 2\theta = 0.63 \sim 0.8$ [9]. This solution emerges if the sun is standard, the absorption cross sections are correct and all the experiments understood well. In this simplified approach ^{7}Be neutrinos must be largely suppressed, and the CNO neutrinos are well estimated but this is not demonstrated. It was thought that Superkamiokande detector can measure the shape of the high energy ($E_\nu > 5$ MeV) part of the solar neutrino spectrum which originates from the β-decay of ^8B produced on the sun. In the neutrino oscillation framework the energy spectrum of the Superkamiokande[4] indicate that there may not be any deviation at relatively low energy 5- 10 MeV but an important increase above 12 MeV comes from ^8B and ^3He+p neutrinos. It is not easy to make compatible such behaviors retaining only the neutrino oscillation mechanism [9].

Sudbury neutrino observatory (SNO) detectors detects ^8B neutrinos and ^3He+p neutrinos with energy ≥ 5 MeV through the reactions

$$\nu_e + d \rightarrow p + p + e^- \quad (CC) \qquad (1)$$

$$\nu_e + d \rightarrow n + p + \nu_e \quad (NC) \qquad (2)$$

$$\nu_e + e^- \rightarrow \nu_e + e^- \quad (ES) \qquad (3)$$

Although reported their findings which is almost in agreement with Superkamiokande detectors that also indicates that neutrino conversion is occurred. To embark on neutrino conversion mechanism we must confirm the result in the laboratory.

2. Temperature dependence of solar neutrino flux

Raychaudhuri[10] analyzing the solar neutrino flux data as measured in the existing solar neutrino detectors (e.g., Homestake, Kamiokande-Superkamiokande, SAGE, GALLEX-GNO0 suggested that all the neutrino flux data varies with the solar activity cycle with a very high level of statistical significance. Again it appears that solar neutrino flux data in Kamiokande-Superkamiokande ($E_\nu > 5$ MeV), GALLEX – GNO and SAGE have a tendency to be correlated with the sunspot numbers, whereas Homstake solar neutrino flux data is anticorrelated with the sunspot numbers with not a very high significant level but there is a tendency of anticorrelation with the sunspot numbers. Further it is observed that low order acoustic p-modes ($l \le 3$) data are correlated with the solar neutrino flux data from the Kamiokande-Superkamiokande, SAGE and GALLEX-GNO detectors with a time lag of ½ to 1 year but the neutrino flux data from Homestake detector is correlated with the low order acoustic p-modes ($l \le 3$)[10,11]. The variation of neutrino flux from solar core within the solar cycle may indicate the possible neutrino spectrum from the solar core. The observation suggests that the different parts of the neutrino energy spectrum from the nuclear reactions in the solar interior is not yet properly understood theoretically. Again, from the astrophysical point of view the temperature dependence of the neutrino energy spectrum is very important for the stellar interior. From the above observation it appears that the temperature dependence of the neutrino flux in

$\varphi\,(pp) \propto T^{-\alpha}$

$\varphi\,(pep) \propto T^{-\beta}$

$\varphi\,(^8B) \propto T^{\gamma}$ $\quad E_\nu < 5$ MeV

$\varphi\,(^8B) \propto T^{--\delta}$ $\quad E_\nu > 5$ MeV

$\varphi\,(^3He+p) \propto T^{-\lambda}$

$\varphi\,(^7Be) \propto T^{\chi}$

$\varphi\,(^{13}N) \propto T^{\rho}$

$\varphi\,(^{15}O) \propto T^{\sigma}$

where α, β, γ ,δ ,χ, λ, ρ, σ are positive and α , γ , δ etc. may not be the same as in standard solar model (SSM). The temperature dependence in $\varphi\,(pp) \propto T^{-\alpha}$ when ($E_\nu \le 0.42$ MeV), $\varphi\,(^8B) \propto T^{-\delta}$ when ($E_\nu > 5$ MeV) and $\varphi\,(^8B)$, $\varphi(^7Be)$, $\varphi\,(^{13}N)$, $\varphi(^{15}O) \propto T^{\gamma}, T^{\chi}, T^{\rho}, T^{\sigma}$ and $\varphi\,(pep) \propto T^{-\beta}$ when (0.5 MeV $< E_\nu <$ 5 MeV).The suggested temperature dependence of neutrino flux is needed to explain the variability of observed neutrino flux. This behavior is different from the standard solar model (SSM) calculation. It may suggest also that neutrino energy spectrum from the nuclear reactions in the hydrogen burning is not yet properly understood and probably because of this we have not only a discrepancy between the observed solar neutrino flux and the calculated neutrino flux from the SSM but also SSM does not suggest a in the solar neutrino flux with the solar activity cycle. Also, because of the discrepancy of observed neutrino flux with the calculated neutrino flux from SSM we have to invoke MSW mechanism. Again the intermediate energy (for 0.5 MeV to 2 MeV) neutrino flux is suppressed (i.e., from ^{7}Be, ^{13}N, ^{15} O etc.) it is possible that the neutrino absorption cross section for the detectors for neutrino energy ($0.5 < E_\nu < 5$ MeV) is lower, in comparison to electro-weak theory, than the cross section for neutrino scattering with detectors for neutrino energy ($E_\nu > 5$ MeV), particularly for $\nu_e + e^- \rightarrow \nu_e + e^-$ in Kamiokande-Superkamiokande detectors. It is possible that the neutrino flux is lower in this part of the neutrino energy. The above observation indicate also that we must remeasure all the cross section of neutrinos with matter. Again we can suggest from the above interpretation that the measurement of all the nuclear reactions participating in the hydrogen burning, which are accessible in the laboratory are necessary, and recalculate the neutrino energy spectrum of pp neutrinos, ^{7}Be neutrinos, ^{8} B neutrinos etc. Bahcall et al[12] derived the ^{8}B neutrino energy spectrum by averaging the usual β-decay allowed spectrum over the intermediate 2^+ states of ^{8}Be, as derived by the subsequent α-decay from ^{8}Be. It was thought also that β-decay spectrum play a fundamental role in constraining the uncertainties of the neutrino energy spectrum. In any case Superkamiokande detector suggests that theoretically calculated neutrino energy spectrum from ^{8}B decay is not compatible with the observational results.

The usual β-decay allowed spectrum averaged over the intermediate 2^+ states of ^{8}Be as derived by subsequent α-decay from ^{8}Be is possibly not the way to find the details of the ^{8}B neutrino energy spectrum. By averaging , it is possible that some of the details of neutrino spectrum from ^{8}B has lost. So it is necessary to calculate the details of the neutrino energy spectrum from ^{8}B decay. Again it should be pointed out that from laboratory experiment we should try to find the ^{8}B neutrino energy spectrum.

3. Recoil electron energy spectrum

(a) The recoil energy spectrum from elastic scattering of electrons with neutrinos (i.e., $\nu_e + e^- \rightarrow \nu_e + e^-$) are reported by Superkamiokande group for 1496 days of data set an upper limit of 7.3×10^4 cm^{-2} sec^{-1} for the neutrino flux from ^{3}He+ p neutrinos. They have displayed the DATA/ SSM in fig.1. We have analyzed the data for recoil electron energy spectrum and found that after 12 MeV the data are significantly (with more than 98.5% C.L.) distorted from the average recoil electron energy spectrum. We have fitted the data by the equation

$$\begin{aligned} \text{DATA/SSM} = {} & 0.440 + 0.043 \exp[-(E-7.5)^{2/} / 1.5\ \text{MeV}^2] + 0.036 \exp[-(E-9.5)^2/0.4\ \text{MeV}^2] \\ & +0.445 \exp[-(E-11.5)^2/1.2\ \text{MeV}^2] + 0.280 \exp[-(E-15.5)^2/3.7\ \text{MeV}^2]. \end{aligned}$$

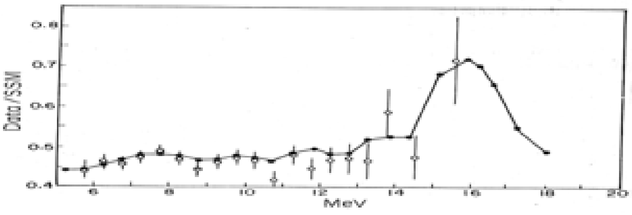

Figure 1. Recoil electron energy spectrum from 5 MeV to 20 MeV in the Superkamiokande detector. The diagram shows the ratio DATA/SSM of the measured number of electron to the number of electrons expected from SSM. The continuous curve here represent our estimate of ^{8}B electron recoil energy spectrum from equation.

The very nature of the curve shows Gaussian in nature indicating the stochastic nature of the solar core which may be due to temperature and density fluctuation of the interior sun where nuclear burning occurs. From Fig.1 we have analyzed the data and found that the solar neutrino from ^{3}He+p neutrino is about 1.50 times the observed upper limit reported by Superkamiokande group[13].

(b) we have analyzed also the data for recoil electron energy spectrum from SNO detectors and found that after 10.5 MeV the data are significantly distorted from the average recoil electron energy spectrum. We have also fitted the data by Gaussian distribution as in Superkamiokande which indicate that solar core is stochastic in nature.

4. Discussion

The usual β-decay allowed spectrum averaged over the intermediate 2^+ states of ^{8}Be as derived by subsequent α-decay from ^{8} Be is possibly not the way to find the details of the ^{8}B neutrino energy spectrum. Again it should be pointed out that from laboratory experiment we should try to find the ^{8}B neutrino energy spectrum. Recently Berkeley weak interaction group are currently designing the experiment which will measure the β-decay spectrum from ^{8}B (http://weakophysics.berkeley.edu/weakint/research/boron8/Boron.htm). It may be possible that in β-decay there may be two channels of neutrinos i.e., (ν_e and ν_μ) so that neutrino energy spectrum can be composed of the distribution of the above two neutrinos and may help not only to understand the neutrino energy spectrum but also to explain the solar neutrino puzzle[14,15]. It may be that in β-decay main part of the neutrino energy spectrum is due to ν_e and a small part of the neutrino energy spectrum is due to ν_μ.. Infact if ν is a mixture of ν_e and ν_μ then the flux of ν can be written as

$$\varphi(\nu) = \varphi(\nu_e) + \varphi(\nu_\mu)$$

Considering the cross section is the same for electro-weak interaction then if $\varphi(\nu_\mu)/\varphi(\nu_e) = 5/2$ for $E_\nu > 0.5$ MeV and $\varphi(\nu_\mu)/\varphi(\nu_e) = 1/3$ for $E_\nu < 0.5$ MeV, then the observed solar neutrino flux from Homestake, Superkamiokande, SNO, SAGE, GALLEX-GNO can be explained.

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