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IMPROVED CALCULATION OF NON-FUSION SOLAR NEUTRINOS PRODUCED BY RUBAKOV EFFECTS

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ABSTRACT

We calculated the solar monopole abundance limit by comparing the observed solar neutrino flux and the calculation of non-fusion solar neutrino flux produced by Rubakov process in the solar core. We included the produced meson's enhancement effects by the surrounding ions in the solar core. We find that the monopole number $N_M < 1.9 \times 10^{20}(1mb/\sigma_0)$, where σ_0 is the characteristic proton decay cross section of Rubakov process. This is similar or stronger than strong limits obtained from neutron star's luminosity.

Key Words: monopole, solar neutrinos.

I. INTRODUCTION

If magnetic monopoles were produced at the early stage of the universe history. it is expected that they are nonrelativistic at present (For a review of magnetic monopole detectability and the flux limit, see Groom 1986). Some of them would have been trapped by the Sun's gravitation, if they are abundant enough. Once trapped by the Sun, monopoles are thermalized within a short period and they are practically rest near the solar center. Such monopoles in matter would catalyze protons to decay by Rubakov process with a typical cross section of order of strong interaction (Rubakov 1981, 1983; Callan Jr. 1982). We consider the non-fusion solar neutrino flux produced by such magnetic monopoles.

Detection of this neutrino flux is the unique way to identify the solar magnetic monopoles. Arafune and Fukugita (Arafune and Fukugita 1983, AF hereafter) pointed out the detection possibility of such neutrinos by Cl^{37} underground detector (Davis and Cox 1991; Bahcall 1989) and estimated a solar monopole abundance limit. But they used the average velocity of the hydrogen in the solar core and the average energy of the produced neutrino for the estimation of absorption cross section by Cl^{37}. In this paper we include the velocity spectrum of hydrogen by thermal motion to calculate the muon production rate by Rubakov process, and we encount the neutrino energy spectrum for the estimation of neutrino detection rate by Cl^{37} underground detector.

II. PRODUCED MESON'S AND MUON'S ENHANCEMENT IN THE SOLAR CORE

The supermassive monopoles captured by the Sun are easily thermalized in a short period and are concentrated in the solar core. So we will consider only the core region.

The main channel relevant to the production of electron neutrinos is muon decay which is produced directly in proton decay or indirectly through the π^+ decay and also by kaon decays.

$$p \rightarrow \mu^+ + \text{anything} \qquad p \rightarrow \pi^+, K + \text{anything}$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu, \qquad \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

The secondary's production rate is

$$F_m = N_M n_p \int \sigma(v) v W(v,T) dv,$$

where N_M is the total monopole number in the solar core region. We assume all the monopoles have unit magnetic charge. n_p is the proton number density. $W(v)$ is proton's velocity distribution function. We assume it has the Maxwell distribution.

$$W(v)dv = 4\left(\frac{m_p}{2kT}\right)^{3/2} \frac{v^2}{\sqrt{\pi}} \exp\left(-\frac{m_p v^2}{2kT}\right) dv,$$

v is the proton's speed and $T(\approx 1.5 \times 10^7 K)$ is the temperature of the solar core. $\sigma(v)$ is the cross section of the Rubakov proess. As pointed out by AF, it is $\sigma = \sigma_0(v/c)^{-2}$ for free proton case, where σ_0 is in order of GeV. But the neutrons are located in nucleus together with protons. So the effective neutron decay cross section would be complicated due to the nucleon's fermi motion in the nucleus. Nevertheless we assume all nucleons are free proton like. The hydrogen mass ratio in the solar core is $\simeq 36\%$ (Bahcal 1978, 1982). Although this assumption is crude, it would not largely affect the order of magnitude estimation of our final result. Then the secondary's production rate is rewritten

$$F_m = C_m N_M n_p r_{pm} \frac{2c}{\sqrt{\pi}} \left(\frac{m_p c^2}{2kT}\right)^{1/2} \sigma_0,$$

where C_m is a correction factor and r_{pm} is the branching ratio of proton decay into meson type m.

These mesons and muons are strongly affected by surrounding matter ($\rho \approx 160 g/cm^3$). And π^0 promptly decays into 2γ before further interaction, so its contribution is neglected. We may also neglect K_L contribution since it disappears by interaction with matter before decay (The mean free path $\lambda = 10^{(0-1)}$ cm while $c\tau = 1554$ cm, see the *Particle Data Book*). K_S has a comparable decay rate relative to interaction rate ($c\tau = 2.68$ cm). Charged pions have long life time ($c\tau = 780.4$ cm), but they lose the kinetic energies elctromagnetically and the actual path length is short. The energy loss rate is approximately 1Mev/(gcm^2). Therefore significant fraction of them decay at rest before further interaction. We incorporate the electromagnetic energy loss effect of charged particles in matter by a Monte Carlo simulation. And we find the average decay probabilities of $\pi^\pm$ and K_S are $0.2 - 0.5$. The major decay channel is the muon production. The branching ratio of the direct muon pair production from the Rubakov process is in order of 1%. And we neglect it.

Therefore the muon production rate is

$$F_\mu \simeq (C_\pi r_{p\pi} r_{\pi\mu} + C_K r_{pK} r_{K\mu}) N_M n_p \frac{2c}{\sqrt{\pi}} \left(\frac{m_p c^2}{2KT}\right)^{1/2} \sigma_0.$$

Secondary or tertiary muons produced by π or K decay have long lifetime to lose the total kinetic energies. So most of them decay at rest. Therefore the produced electron type neutrinos from the stopped μ^+ decay have the following energy spectrum.

$$y(x) = 12x^2(1-x), \quad \text{where} \quad 0 < x \equiv \frac{2E_\nu}{m_\mu c^2} < 1.$$

It is worthwhile to comment that the electron type neutrino spectrum is different from the electron spectrum, since the matrix element of the muon decay is proportional to $(p_\mu \cdot p_{\nu_e})(p_e \cdot p_{\nu_\mu})$. It is symmetric under the exchange of muon neutrino and electron. So only the muon type neutrino spectrum is same with the electron spectrum. AF mistakenly used the energy spectrum of muon type neutrinos. But this mistake is not a significant factor for the estimation of order of magnitude because $\langle E_{\nu_e} \rangle = 30$ MeV while $\langle E_{\nu_\mu} \rangle = 35$ MeV.

IV. NEUTRINO CAPTURE RATE BY UNDERGROUND DETECTORS

The capture rate of solar neutrinos by a target atom in an underground detector is

$$I = \frac{F_\mu}{4\pi R^2} \int \sigma_{cap} y(x) dE_\nu$$

$$= (C_\pi r_{p\pi} r_{\pi\mu} + C_K r_{pK} r_{K\mu}) N_M \sigma_0 \left(\frac{m_p c^2}{2\pi kT}\right)^{1/2} \frac{2cgn_p}{4\pi R^2}$$

where $g \equiv \int \sigma_{cap} y dE_\nu$ and $R = 1$ A.U. is the distance between the Sun and the Earth. And $\sigma_{cap}(E)$ is ν_e absorption cross section. We apply this calculation to Cl^{37} underground detector. We incorporate the theoretical calculation (Bahcall and Ulrich 1988) for the ν_e absorption cross sections at several energies and use interpolation and extrapolation to cover whole neutrino energy up to 53MeV. We get $g = 7.5 \times 10^{-41} cm^2$.

If $C_\pi r_{p\pi} r_{\pi\mu} + C_K r_{pK} r_{K\mu} = 0.1$, $\sigma_0 \simeq 1$ mb and $I \simeq 2.23$ SNU the detected solar ν_e flux (Davis and Cox 1991) then $N_M \simeq 4.3 \times 10^{20}$, where 1 SNU = 10^{-36}capture/(atom $\cdot$ sec). It is very unrealistic if all the observed solar neutrinos are produced by Rubakov process. Therefore if we take 1 SNU as the upper bound for an excess neutrino capture rate, then we obtain $N_M < 1.9 \times 10^{20}(1mb/\sigma_0)$. This value is smaller than the AF calculation by two orders of magnitude.

The Ga^{71} case has similar value, $g = 8.7 \times 10^{-41} cm^2$. But since the reported value of solar neutrino detection by Ga^{71} detector obtained by SAGE group (Abazov *et. al* 1991) is bigger than the value by Cl^{37} detector. Therefore this SAGE value (= 20 SNU compared to the expected theoretical value 132 SNU) gives no stronger limit for the solar magnetic monopole abundance. Furthermore this SAGE value is highly uncertain and controversial. So we avoid further discussion of the SAGE result in this paper.

V. CONCLUSION

In conclusion, we calculated the solar monopole abundance limit. If the characteristic cross section of the Rubakov process is in order of 1 mb, the solar monopole abundance is $N_M < 1.9 \times 10^{20}$.

But our limit also depends on the solar neutrino oscillation effect such as MSW mechanism (Wolfenstein 1978; Mikheyev and Smirnov 1986). Only a small fraction of Rubakov neutrinos is below 5.9 MeV which is the critical ν_e energy for not undergoing the oscillation into ν_μ in the Sun. Therefore if MSW mechanism is the right theory, our monopole flux limit should be at least two orders of magnitude higher.

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