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Letter to the Editor

The Sun as the source of VHE neutrinos

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Abstract. During the last decade proposals to build large underground/underwater neutrino detectors have been discussed actively. We argue here that the Sun is the source of very high energy (VHE) neutrinos which are the result of cosmic ray interactions with the solar matter. The ratio of the flux of the solar $\tilde{\nu}_\mu$ and ν_μ neutrinos to the Earth's atmospheric ones for the $\approx 0.5^\circ$ angular resolution detector is ≈ 1 for the energy range ≤ 200 GeV and is much greater then 1 for the energy >200 GeV. The possible applications of such measurements are discussed.

Keywords: The Sun, VHE Neutrinos, Cosmic ray interactions

1.Introduction. There are a lot of papers now in which authors have calculated the VHE neutrino flux from various astrophysical objects (e.g. Berezinsky V.S. et al. 1985, 1988; Auriemma G. et al. 1986; Tkaczyk W. et al. 1986). Detection of the neutrinos can provide useful information about powerful processes in these objects. However, the physical conditions in such objects (density of matter, particle flux and spectrum and so on.) are not known accurately; therefore the estimations of neutrino fluxes have large uncertainties. The Sun was considered as source of high energy neutrinos also, which could be produced by interactions of protons from solar flares at the opposite side of the Sun (Berezinsky V.S. et al. 1985). However, it is necessary to note that the time duration of a flare is very short and it should be very powerful to provide a detectable neutrino flux.

We have estimated the $(\nu_\mu+\tilde{\nu}_\mu)$ neutrino flux from the Sun which appears as a result of decay of pions and kaons produced by VHE cosmic ray interactions with the solar matter. Since the VHE cosmic ray flux near the Earth is well-known so the VHE neutrino flux could be calculated accurately.

2. VHE neutrinos from the Sun. The neutrino production spectrum by a power-law proton energy spectrum has been calculated (Berezinsky V.S. et al. 1985):

$$F_\nu(>E) = \varphi_\nu n_H \sigma_{pp}(E/f) kE^{-\gamma} \ [cm^{-3}s^{-1}sr^{-1}], \qquad (1)$$

where E is the neutrino energy, φ_ν is the neutrino yield function, n_H is the number density of the gas, $\sigma_{pp}(E/f)$ is the proton-proton inelastic cross section, f is the part of proton energy which the neutrino takes away, $kE^{-\gamma}$ is the integral flux of cosmic rays. For a thick layer of matter the neutrino intensity is (Berezinsky V.S. et al. 1988):

$$I_\nu(>E) = \frac{\varphi_\nu kE^{-\gamma}}{(1-\alpha^\gamma)} \ [cm^{-2}s^{-1}sr^{-1}], \qquad (2)$$

where α is the inelasticity coefficient of pp-interactions ($\alpha\approx 0.5$). The VHE neutrino flux near the Earth from the Sun is:

$$I_\odot(>E) = \pi I_\nu(>E) R_\odot^2/D^2 \ [cm^{-2}s^{-1}], \qquad (3)$$

where $R_\odot$ is the solar radius, D is the distance from the Sun, $\pi I_\nu(>E)$ is the neutrino flux near the solar surface. The underground neutrino flux from the cosmic ray interactions in the Earth's atmosphere (background) within the solid angle which covers the Sun is:

$$I_b(>E) = \pi \sin^2(0.25^\circ) I_\nu(>E) \ [cm^{-2}s^{-1}], \qquad (4)$$

therefore we obtain the estimation:

$$I_\odot(>E)/I_b(>E) = 1 \qquad (5)$$

for the Sun at all energies, as $R_\odot/(D \sin 0.25^\circ) = 1$. The value 1 is a lower estimate of the signal/background ratio, because at energies above 200 GeV the atmospheric neutrino flux becomes steeper (Allkofer O.C. et al. 1978), due to the fact that VHE $\pi^\pm$-mesons (produced during EAS developing) rather interact than decay. For the solar neutrinos this effect takes place at higher energies because the solar gas density is very low.

We also calculated the neutrino flux from the Galactic Center (GC) and compared it with the one for atmospheric neutrinos (for the same assumptions as for formula (5)):

$$I_{GC}(>E)/I_b(>E) = (1-\alpha^\gamma)x/\lambda \approx 2\cdot 10^{-3}, \qquad (6)$$

where x is the grammage in the direction of the Galactic Center, λ is the proton mean free path.

The calculated neutrino fluxes from the Sun and the GC and the background estimation for the $\approx 0.5^\circ$ angular resolution detector are shown in Figure 1. The dashed line is the solar and atmospheric neutrino fluxes (S&B) which have been calculated using formulae (3) and (4) for the following parameters: $k = 1$ $cm^{-2}s^{-1}sr^{-1}GeV^{1.7}$, $\gamma=1.7$ and for φ_ν we took value 0.023 (Berezinsky V.S. et al. 1985). The solar neutrino flux S (solid line) was calculated taking into account the neutrino absorption effect in the solar matter. In this calculation the solar matter density distribution was taken from Allen C.W. (1973) and the neutrino-nucleon cross section is equal $0.8\cdot 10^{-38}(E/GeV)\ cm^2$ up to an energy of ≈ 20 *TeV* (Eichler D. 1978). The solid line B is the atmospheric background flux. One can see that for the energy range ≤ 200 *GeV* the flux/background ratio for solar neutrinos is ≈ 1. For the energy range ≥ 200 *GeV* this ratio is increasing quickly, so the solar neutrino flux could be detected even with the $>0.5^{\circ}$ angular resolution detector.

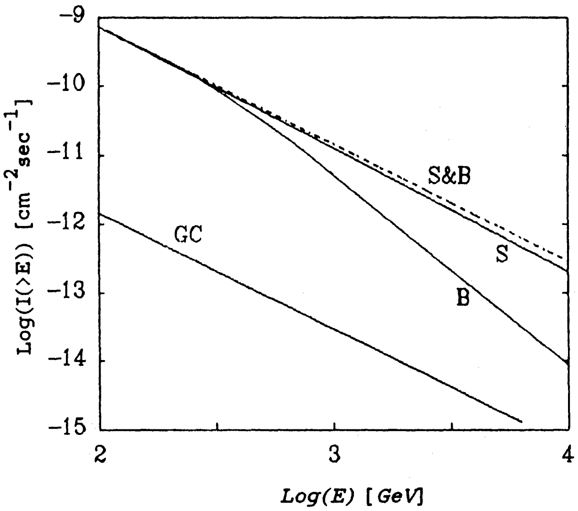

Fig. 1. The estimated integral neutrino fluxes from the Sun (S) and the Galactic Center (GC) and the atmospheric background (B) for the detector with 0.5° angular resolution (solid lines). The dashed line (S&B) is the same without the effects of neutrino absorption in the solar matter and of the steepening of the atmospheric neutrino flux.

3.Conclusion. At the present time the planned neutrino experiments (e.g. GRANDE) can reach 0.5° angular resolution (Haines T. 1989), so we hope that in near future VHE neutrinos from the Sun should be detected.

We suggest some possibilities to use the measured solar neutrino flux. First of all the solar neutrino flux could be used as a "standard neutrino flux" for the detector calibration. Secondly, one could use the neutrino flux to understand solar deep layers and nucleus. Thirdly, such observation could yield useful information about the behavior of the neutrino-nucleon cross section at very high energies.

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