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A NEW METHOD FOR DETECTION OF DISTANT SUPERNOVA NEUTRINO BURSTS

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We suggest a new method for detection of neutrino bursts generated by distant supernovas in our galaxy and in the local group of galaxies.
This new method is based on the detection of neutrons produced in the inelastic scattering of ν_μ and ν_τ neutrinos with nuclei via the neutral current channel. The advantages of such a detector are (1) the enhancement of neutrino scattering cross sections due to nuclear collective effects, (2) the selective detection of ν_μ and ν_τ supernova neutrinos, and (3) the existence of large geological deposits of suitable neutrino detector materials in nature.

1. INTRODUCTION

The astrophysical neutrino detectors used in the past and planned for future experiments for observing supernova neutrino bursts are based either on the charged current neutrino capture or charged plus neutral current scattering of neutrinos on single nucleons, electrons, or deuterons. These weak interactions have typical cross sections of the order of $\leq 10^{-42}$ cm^2.

It was recently shown that collective effects in nuclei can increase the neutral current neutrino inelastic cross sections on nuclei by at least one order of magnitude for $E_\nu \gtrsim 30$ MeV over single particle values [1-4]. We propose to use the neutrino inelastic scattering with subsequent neutron emission from the excited nucleus as the basis of an astrophysical neutrino detector

$$\nu_x + N(Z,A) \rightarrow N(Z,A-1) + n + \nu_x' \qquad (1)$$

where $\nu_x = \nu_e, \nu_\mu, \nu_\tau$, N(Z,A) is the nucleus of mass number A with Z protons, n the emitted neutron, and ν_x' the scattered neutrino.

The above reaction has a threshold energy, and the ν_e neutrinos generated in supernovae have an energy spectrum below this threshold, while the energy spectrum of ν_μ and ν_τ neutrinos is well above the threshold. Thus the detector based on the above reaction has a selective detection capability for ν_μ and ν_τ supernova neutrinos.

The additional advantages of this detector are the already mentioned enhancement of the neutrino inelastic scattering cross section due to nuclear collective effects, and the possibility to use large geological deposits existing in nature, such as $CaCO_3$ or NaCl formations, as detector medium, thus increasing the volume of the detector by orders of magnitude as compared to the current and planned detector designs.

2. CROSS SECTION CALCULATION

We have modeled the inelastic neutrino-nucleus scattering with a scaled-up version of charged current interactions, fitted the model to the shell model calculations of Haxton[4], and used this model to calculate cross sections for

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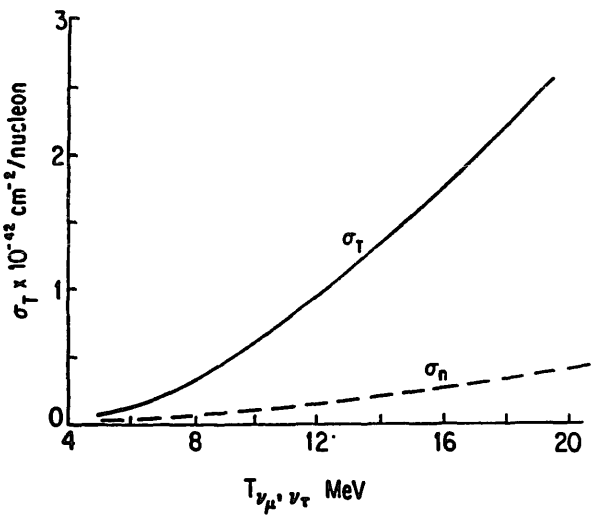

FIGURE 1

neutral current neutrino-nucleus interactions. Fig 1 shows the ν_μ, ν_τ neutrino cross sections per nucleon for total neutral current scattering, σ_T, and single neutron production, σ_n, computed for the excitation of ^{40}Ca to 24.15 MeV by inelastic neutrino nucleus scattering, averaged over neutrino black body spectra at Temperature T_{ν_μ}, ν_τ. We can see the rapid rise of the cross section above T_{ν_μ}, ν_τ ~5 MeV, corresponding to 15 MeV neutrino energy, the above mentioned "threshold" energy for reaction (1). The corresponding cross sections for carbon and oxygen are close to that of calcium.

Based on these calculations we obtained a flux averaged total inelastic cross section for $CaCO_3$ of σ_T ~1.10^{-42} cm^2 per nucleon, and for neutron production of σ_n ~2.10^{-43} cm^2 per nucleon for neutrinos emitted by a black body at T = 10 MeV.

3. THE DETECTOR DESIGN

A possible neutrino detector configuration using a geological $CaCO_3$ formation as the detector medium is shown in Fig. 2. Cylindrical BF_3 neutron detectors of radius r_1 are surrounded by a neutron thermalizing material [$n(CH_2)$] of radius r_2 and inserted into the $CaCO_3$ medium. Optimizing the efficiency of this configuration leads to an overall neutron detection efficiency of ~20% with r_1 = 20 cm, r_2 = 22 cm, and r_3 = 60 cm.

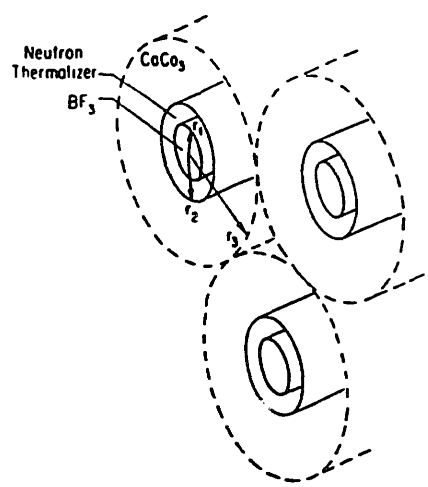

FIGURE 2

It can be shown[6] that this detector of size 10 m x 10 m x 10 m detects about 50 counts in a typical time interval of (10-20) seconds for a typical supernova in our galaxy (R ~ 20 kpc), well above the background count of (1 - 10) in the same time interval in limestone as calculated from recent neutron flux measurements at the Gran Sasso Laboratory. A detector of 100 m x 100 m x 100 m gives, however, only about 20 counts in the same time interval for a typical supernova in the local group of galaxies (R ~ 1000 kpc), far below the calculated background of 10^3-10^4 counts. This shows that the background is the major limitation to extend the range of the $CaCO_3$ detector to the local group, and we have to find purer target materials to achieve this goal.

If materials of low background can be found, the technique described in this paper could lead to the possibility of detecting a cosmologically significant ν_μ or ν_τ mass, if it exists.

In addition to this, if detectors of this large size are built, it will become quite essential to operate them in coincidence with gravitational wave detectors. A clear neutrino signal would significantly help the search for a gravity wave, and a gravity wave detected will determine the initial time of the neutrino burst.

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