NEUTRINO ASTRONOMY AND THE ATMOSPHERIC BACKGROUND

T.K. Gaisser and Todor Stanev
Bartol Research Foundation of the Franklin Institute
Uiversity of Delaware
Newark, DE 19716
USA

ABSTRACT

We illustrate some aspects of neutrino astronomy by calculating the neutrino-induced muon flux from Cygnus X-3. The signal depends primarily on the power in cosmic rays at the source and on the distance to the source, and only relatively little on details of the matter distribution in the neighborhood of the source.

1.Introduction. Cygnus X-3 is a binary X-ray source in which the compact partner apparently accelerates particles to high enough energy to produce multi-TeV secondaries in the envelope or debris of the companion star.[1] The 10^{12}-10^{16} eV photon spectrum can be accounted for in this way if protons are accelerated to 10^{17} eV and then produce neutral pions which decay to photons.[2] Charged pions and kaons will also be produced, and these will be a source of neutrinos. Muon neutrinos and anti-neutrinos will interact in the Earth to produce a signal of muons, which might be visible above the background of atmospheric muons at sufficiently large angles. The general idea of neutrino astronomy is well-known.[3] Detailed models of Cygnus X-3, coupled with numerous observations of signals from this and other sources, motivated us to carry out a detailed calculation of the neutrino flux and of the neutrino-induced signal from it.[4]

2.Calculation of Neutrino Flux. Assuming that the compact partner accelerates protons which collide with material of the companion star, we calculate in detail the hadronic cascade induced by the proton beam[5], including interaction, energy loss and decay of charged pions and kaons. This is done for a grid of primary energies and phases of the period of the binary system. For the matter distribution of the companion we assume a 2.8 solar mass main sequence star. Since this is undoubtedly an oversimplification, we later compare the results obtained for a variety of densities and thicknesses. Fig. 1 shows the resulting neutrino flux averaged over a period, assuming an isotropic luminosity in cosmic rays at the source (10 kpc) of 10^{39} erg/sec. For comparison we also show the atmospheric neutrino flux. The signal/background ratio exceeds one above about 1 TeV.

We next attenuate the produced neutrinos in the companion. Stecker et al. [6] have pointed out that deposition by neutrinos of too much energy in the interior of the companion would disrupt the system. This can be used to place a limit on the luminosity of such a system in high energy cosmic rays.

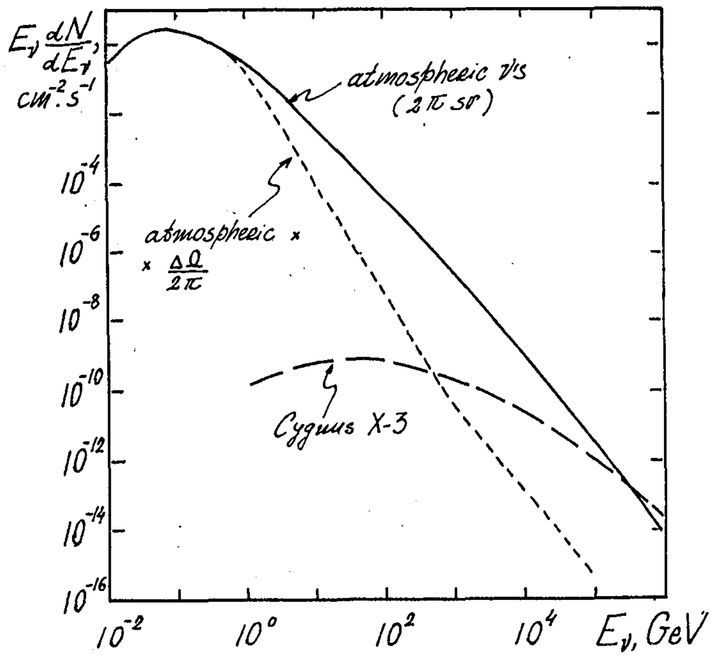

FIG. 1. Neutrino flux from Cyg X-3 compared to atmospheric flux. Dashed line is an estimate of atmospheric background assuming detector resolution of 1°. For E_ν below about 1 TeV angular resolution is dominated by scattering angle in charged-current neutrino interaction rather than by detector resolution.

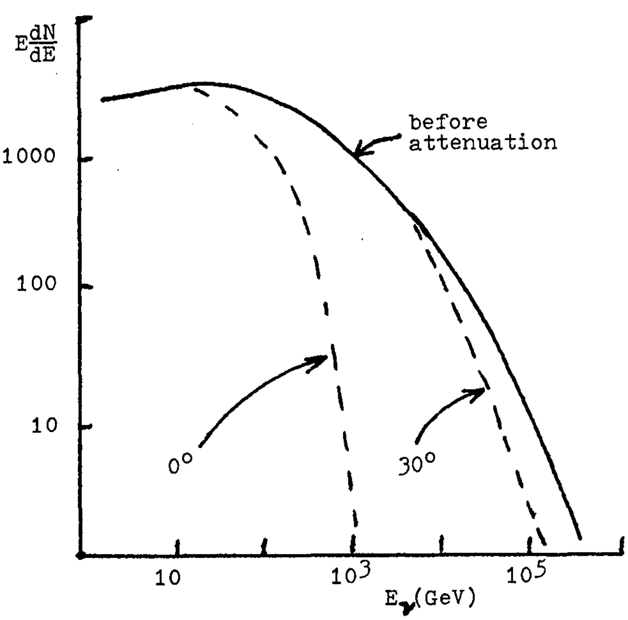

FIG. 2. Attenuation of neutrinos in the companion. Solid line shows neutrino flux before attenuation; dashed lines show transmitted flux at two angles relative to the surface of the companion.

Fig. 2 shows the attenuation of the neutrino beam through the center of the companion (0°) and at 30°. For angles larger than 30° attenuation is negligible. For the case of spherically symmetric, 10^{17} eV monoenergetic protons, only about 0.5% of the total cosmic ray energy is deposited by high energy neutrinos in the interior of the companion. (This is for a spherically symmetric matter distribution with $R=1.4*10^{11}$cm and a scale height of 8000 km for the companion star. The distance between the centers of the stars is assumed to be not much larger than R.) As pointed out by Stecker et al., this will be further reduced to some extent when compression of the companion by the intense cosmic ray flux is accounted for. This is becuase of increased cascading (rather than decay) of energetic charged pions in the denser medium.

3.Neutrino-induced upward muons. To calculate the induced muon signal at such high energies it is necessary to account for the effect of the W-propagator in the charged-current neutrino cross sections, as well as for the appropriate range-energy relation for the muons. We have done this with two different sets of nucleon structure functions and find [7] the result shown in Fig.3, independent of details of the structure functions. P_ν in Fig. 3 is the probability that a muon neutrino aimed at the detector produces a muon through the detector (assuming neutrino/antineutrino=1.2). This probability is folded with the neutrino spectrum to obtain the signal.

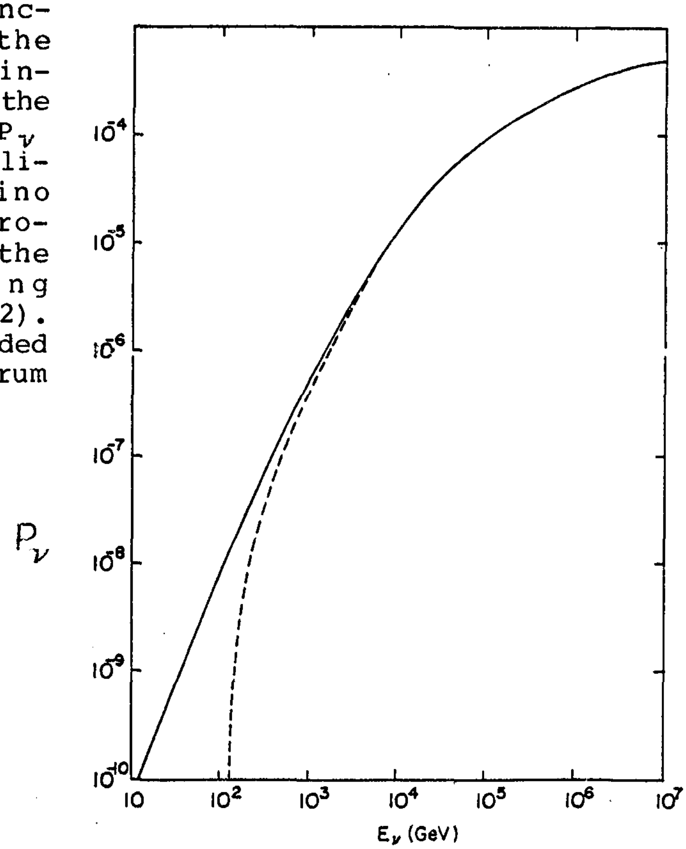

FIG. 3

Averaged over a period the result is

$$10^{-3} \text{ events}*\{L_{39}/(R_{10})^2\}m^{-2}yr^{-1}$$

where L_{39} is the luminosity of the source in units of 10^{39} ergs/sec and R_{10} is its distance in units of 10 kpc. Varying the density and thickness of target material in the region of the source changes this only by factors of two or three.

4. References

[1] David Eichler and W. Thomas Vestrand, Nature 307, 613 (1984).

[2] A.M. Hillas, Nature 312, 50 (1984).

[3] See e.g. David Eichler, Nature 275, 725 (1978); V.J. Stenger, Ap. J. 284, 810 (1984) and references therein.

[4] T.K. Gaisser and Todor Stanev, Phys. Rev. Letters 54, 2265 (1985).

[5] The calculation is similar to that for neutrino production by cosmic rays in the Earth's atmosphere. Only the incident spectrum and the stellar atmosphere are different. The atmospheric calculation is described by T.K. Gaisser, Todor Stanev, S.A. Bludman and H. Lee, Phys. Rev. Lett. 51, 223 (1983) and T.K. Gaisser and Todor Stanev in Proc. 11th Int. Conf. on Neutrinos and Astrophysics, ed. K. Kleinknecht and E.A. Paschos (World Press, Singapore, 1984), p.372.

[6] F.W. Stecker, A.K. Harding and J.J. Barnard, NASA/Goddard preprint, April 1985.

[7] T.K. Gaisser and Todor Stanev, Phys. Rev. D31, 2770 (1985).