

****TITLE****

*ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION***

****NAMES OF EDITORS****

High energy astrophysical neutrinos

H. Athar

Physics Division, National Center for Theoretical Sciences, 101 Section 2, Kuang Fu Road, Hsinchu 300, Taiwan

Abstract. High energy neutrinos with energy typically greater than tens of thousands of GeV may originate from several astrophysical sources. The sources may include, for instance, our galaxy, the active centers of nearby galaxies, as well as possibly the distant sites of gamma ray bursts. I briefly review some aspects of production and propagation as well as prospects for observations of these high energy astrophysical neutrinos.

1. Introduction

During¹ nearly past 50 years, the empirical search for neutrinos has spanned roughly six orders of magnitude in energy, from approximately 10^{-3} GeV up to approximately 10^3 GeV. The lower energy edge corresponds to solar neutrinos, whereas the upper energy edge corresponds to atmospheric neutrinos. The intermediate energy range include the terrestrial and supernova neutrinos. This search has already given us remarkable insight into neutrino interaction properties as well as its intrinsic properties such as mixing and mass. Here, I briefly review the possibility of having neutrinos with energy greater than 10^3 GeV. The upper energy edge for high energy astrophysical neutrinos is limited only by the concerned experiments. A main motivation to search for such high energy astrophysical neutrinos is to get more accurate information about the origin of observed high energy photons (and ultra high energy cosmic rays) that is presently not possible through conventional gamma ray astronomy. For instance, the observation of high energy gamma ray flux alone from active centers of nearby galaxies (AGNs) such as M 87 and distant sites of gamma ray bursts (GRBs) does not allow us to identify its origin in purely electromagnetic or purely hadronic interactions unambiguously. Sizable high energy astrophysical neutrino flux is expected if latter interactions are to play a dominant role. Search for high energy astrophysical neutrinos will thus provide us a complementary and yet unexplored view about some of the highest energy phenomenons occurring in the known universe. For a general introduction of the subject of high energy astrophysical neutrinos, see Bahcall & Halzen (1996), Protheroe (1999), Bahcall (2001). See, also Battiston (2002).

¹Talk given at IAU 8th Asian Pacific Regional Meeting, 2–5 July, 2002, Tokyo, Japan.

2. High energy astrophysical neutrinos

2.1. Production

The purely hadronic (such as pp or pn) and photo hadronic (such as γp or γn) interactions taking place in cosmos currently represent the main source interactions for the production of high energy astrophysical neutrinos. Examples of the astrophysical sites where these interactions (may) take place include our galaxy, the AGNs and the GRBs. In some model calculations for high energy astrophysical neutrino flux, the proton acceleration mechanism is considered to be the same as for electron acceleration at the astrophysical sites.

The accelerated protons in the above interactions in these sites produce unstable hadrons such as π^\pm and D_s^\pm that decay into neutrinos of all three flavors. The same interactions also produce π^0 that can contribute dominantly towards the observed high energy photons, whereas the escaping accelerated protons may (or may not) dominantly constitute the observed ultra high energy cosmic rays depending upon the finer details of the relevant astrophysical site. The absolute normalization of the high energy astrophysical neutrino flux is obtained by assuming that a certain fraction of the observed high energy photon flux has (purely) hadronic origin and (or) that the observed ultra high energy cosmic ray flux can dominantly originate from that class of astrophysical sites. Typically, the muon neutrino flux is twice the electron neutrino flux with essentially negligible tau neutrino flux at the production site. For a recent review article, see Halzen & Hooper (2002). High energy astrophysical neutrino production is in principle also conceivable in purely electromagnetic (such as $\gamma\gamma$) interactions taking place in cosmos, see Athar & Lin (2002).

The dedicated high energy neutrino detectors provide us a clue as well as a check for the absolute normalization of the high energy neutrino flux. For instance, the present upper bound from Antarctic Muon and Neutrino Detector Array (AMANDA) give value of $9.8 \cdot 10^{-6} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}$ for absolute flux of diffuse high energy neutrinos for the energy range between $5 \cdot 10^3 \text{ GeV}$ to $3 \cdot 10^5 \text{ GeV}$, see Ahrens et al. (2002). The AMANDA (B10) is at the south pole and its current upper bound is based on non observation. Its present cylindrical configuration searches for upward going high energy (muon) neutrinos covering the northern hemisphere with an effective area of $\sim 0.01 \text{ km}^2$ for (muon) neutrino energy $\sim 10^4 \text{ GeV}$.

2.2. Propagation

With three light stable neutrinos, as suggested by standard model of particle physics, neutrino flavor mixing is a dominant effect during high energy astrophysical neutrino propagation, once they are produced, see Athar, Jezabek, & Yasuda (2000). Since the average interstellar matter density is rather low, therefore the neutrino nucleon deep inelastic scattering (DIS) effects are usually negligible. These neutrinos thus restore the arrival direction and energy information starting from the production site. On the other hand, because of rather large unobstructed distances traversed by these neutrinos, typically greater than 1 pc, where $1 \text{ pc} \simeq 3 \cdot 10^{18} \text{ cm}$, the neutrino flavor mixing equally distribute the three neutrino flavors in the mixed high energy astrophysical neutrino flux. The present neutrino oscillation data implies that the deviations from these sym-

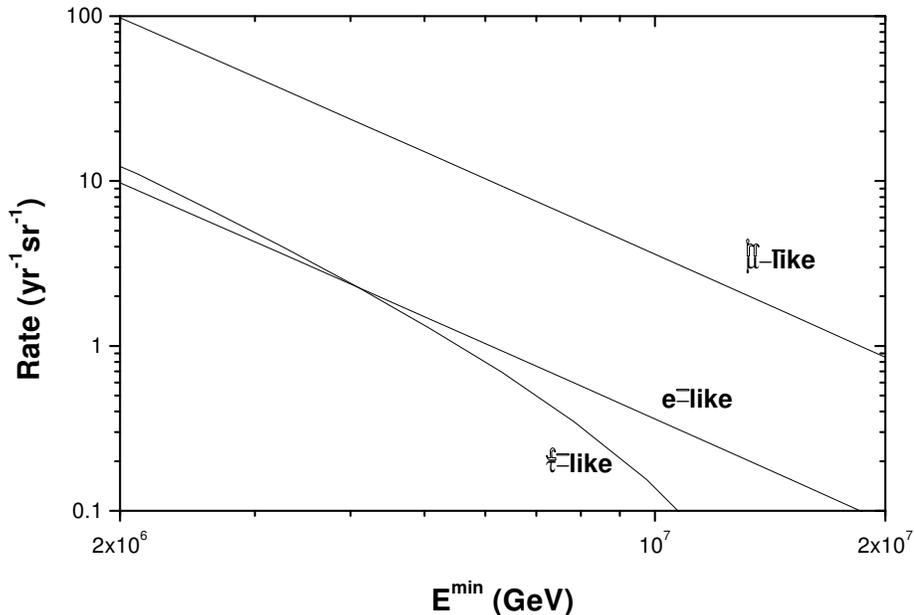


Figure 1. Expected downward going e -like, μ -like and τ -like event rate produced by AGN neutrinos as a function of minimum energy of the corresponding charged lepton in a large km^3 volume ice or water neutrino detector. Three flavor neutrino mixing is assumed.

metric distributions are not more than a few percent. The absolute level of (downward going) high energy astrophysical electron neutrino flux, arriving at the detector, is essentially independent of the relative ratio at the production, as it is least effected by neutrino oscillations, see Athar & Lin (2001).

2.3. Prospects for observations

Typical high energy astrophysical neutrino observation can be achieved by attempting to observe the Cherenkov radiation from the associated charged leptons and/or showers produced in DIS occurring near or inside the detector. For simplicity, here I ignore a possible observational difference between neutrinos and anti neutrinos.

The mixed high energy astrophysical neutrino flux arrives at an earth based detector in three general directions. The downward going neutrinos do not cross any significant earth cord while reaching the detector. In Fig. 1, the downward going event rate for the three neutrino flavors is displayed under the assumption of neutrino flavor mixing in units of $\text{yr}^{-1} \text{sr}^{-1}$ as a function of minimum energy of the corresponding charged lepton produced in charged current DIS occurring near or inside the detector. The different levels and energy dependencies of the rates reflect the differences in the associated charged lepton ranges, in a large (under construction) km^3 volume ice or water detector such as the proposed

extension of AMANDA (B10), although as mentioned in the last subsection, the three neutrino flavors arrive at the detector in almost equal proportion. The contained e -like event rate is obtained by rescaling the μ -like event rate for illustration. A diffuse AGN neutrino flux model is used here as an example where pp interactions are considered to play an important role, see Szabo & Protheroe (1994). The event topology for each flavor can possibly be identified separately in km^3 volume water or ice detector within the energy range shown in Fig. 1. For details, see Athar, Parente, & Zas (2000).

The near horizontal neutrino flux crosses a small earth cord before reaching the detector. Several proposals are under study to construct a specific detector for such type of neutrinos, see Hou & Huang (2002). The upward going neutrino flux crosses a significant earth cord before reaching the detector, and is therefore absorbed by the earth to a large extent for energy typically greater than $5 \cdot 10^4$ GeV, see, for instance, Hettlage & Mannheim (2001). Above this energy, the earth diameter exceeds the charged current DIS length. In addition to attempting to measure the Cherenkov radiation, several other alternatives are also presently being explored. See, for instance, Chiba et al. (2001).

3. Conclusion

Several astrophysical sources such as center(s) of our as well as other nearby galaxies may produce high energy astrophysical neutrino flux with energy around or above 10^4 GeV, compatible with the observed high energy gamma ray and ultra high energy cosmic ray flux above the atmospheric neutrino flux. This implies need for a more meaningful search.

The author thanks Physics Division of National Center for Theoretical Sciences for financial support.

References

- Ahrens et al. [The AMANDA Collaboration] 2002, arXiv:astro-ph/0206487
 Athar, H., Jezabek, M., & Yasuda, O. 2000, Phys. Rev. D, 62, 103007
 Athar, H., Lin, G.-L. 2001, arXiv:hep-ph/0108204
 Athar, H., Lin, G.-L. 2002, arXiv:hep-ph/0203265
 Athar, H., Parente, G., & Zas, E. 2000, Phys. Rev. D, 62, 093010
 Bahcall, J. N. 2001, Int. J. Mod. Phys. A, 16, 4955
 Bahcall, J. N., Halzen, F. 1996, Phys. World, 9, 41
 Battiston, R. 2002, arXiv:astro-ph/0208108
 Chiba, M. et al. 2001 in AIP Conf. Proc. 579, Radio Detection of High Energy Particles, ed. D. Saltzberg & P. Gorham (New York: AIP), 204
 Halzen, F., Hooper, D. 2002, Rept. Prog. Phys., 65, 1025
 Hettlage, C., Mannheim, K. 2001, Nucl. Phys. Proc. Suppl., 95, 165
 Hou, G. W., Huang, M. A. 2002, arXiv:astro-ph/0204145
 Protheroe, R. J. 1999, arXiv:astro-ph/9907374
 Szabo, A. P., Protheroe, R. J. 1994, Astropart. Phys., 2, 375