ULTRA-HIGH ENERGY COSMIC NEUTRINOS

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Several cosmologically distant astrophysical sources may produce ultra-high energy cosmic neutrinos ($E_\nu \geq 10^6$ GeV) of all flavors above the atmospheric neutrino background. I study the effects of vacuum neutrino flavor mixing on this cosmic neutrino flux. Prospects for observations of these ultra-high energy cosmic neutrinos in large underwater/ice neutrino telescopes are also briefly discussed.

1 Introduction

Search for ultra-high energy cosmic neutrinos ($E_\nu \geq 10^6$ GeV) will not only yield complemetary information about the highest energy phenomena in the universe with respect to conventional very high energy gamma ray astronomy but will also possibly address a fundamental aspect of particle physics, that is, to corroborate the neutrino flavor mixing[1].

This contribution is organized as follows: In section 2, I discuss in some detail the flux estimates, effects of vacuum neutrino flavor mixing and prospects for observations of ultra-high energy cosmic neutrinos. In section 3, concluding remarks are given.

2 Ultra-high energy cosmic neutrinos

2.1 Some flux estimates

A guarenteed source of ultra-high energy cosmic neutrinos is the interaction between ultra-high energy cosmic rays and the relic photon flux[2]. Here, the flux for ultra-high energy cosmic (muon) neutrinos, F^0_μ is obtained by folding the observed ultra-high energy cosmic ray (power law) flux spectrum with the relic (thermal) photon flux spectrum while integrating over the relevant differential cross-section and the kinematic variables. This flux peaks typically at, $E_\nu \sim 10^8$ GeV with $F^0_\mu \sim 5 \cdot 10^{-17}$ (cm^{2}s sr)$^{-1}$. The position and height of the peak depends on the assumed z distribution of the sources, $f(z)$, for ultra-high energy cosmic rays as well as the distance traversed by these. This generic feature of peaking of ultra-high energy cosmic neutrino flux also holds for other possible sources such as Active Galactic Nuclei (AGN) and Gamma Ray Burst fireballs (GRB), where the ultra-high energy cosmic rays produced within the source interact with the ambient photon field present in the vicinity of source. The E_ν value at the height of peak in F^0_μ depends on photon field spectrum shape. The recent AMANDA and SuperK searches for such ultra-high energy cosmic neutrino flux provide useful upper limits on this flux[3].

2.2 Effects of vacuum neutrino flavor mixing

In the context of three flavors, the currently preferred[4] flavor oscillation solutions to explain the solar electron neutrino deficit are the LOW and the LMA (MSW), whereas for the atmospheric muon neutrino deficit, the currently favourable solution is the maximal depth flavor oscillations of ν_μ into ν_τ. The present observational status, thus provides indirect clues for a (quasi) bimaximal neutrino mixing matrix. I will use the neutrino mixing parameters, $(\delta m^2, \sin^2 2\theta)$, corresponding to these solutions to estimate the final (downward going) ultra-high energy cosmic neutrino flux on earth, $F_\alpha\,(\alpha = e, \mu, \tau)$ due to vacuum neutrino flavor mixing. After averaging over the rapid oscillations, the flavor precession probability is

$$\langle P(\nu_\alpha \to \nu_\beta)\rangle \equiv \langle P_{\alpha\beta}\rangle \simeq \sum_{i=1}^{3} |U_{\alpha i}|^2 |U_{\beta i}|^2, \tag{1}$$

where $U_{\alpha i}$ and $U_{\beta i}$ $(\beta = e, \mu, \tau)$ stand for the relevant elements of 3×3 MNS neutrino mixing matrix which I will use in standard parameterization. F_α in terms of $\langle P_{\alpha\beta}\rangle$ and F^0_α, the intrinsic ultra-high energy cosmic neutrino flux is

$$F_\alpha \equiv \sum_\beta \langle P_{\alpha\beta}\rangle F^0_\beta. \tag{2}$$

The $\langle P_{\alpha\beta}\rangle$ matrix, in case of LOW solution for solar electron neutrino deficit alongwith the ν_μ to ν_τ flavor oscillations with maximal depth is

$$\langle P_{\alpha\beta}\rangle = \begin{pmatrix} 1/2 & 1/4 & 1/4 \\ 1/4 & 3/8 & 3/8 \\ 1/4 & 3/8 & 3/8 \end{pmatrix}. \tag{3}$$

Using Eq. (3) in Eq. (2), it turns out that starting from $F^0_e : F^0_\mu : F^0_\tau$'s as 1: 2: 0, one obtains F's as 1: 1: 1 at the level of F^0_e, irrespective of the flavor oscillations solution to the solar electron neutrino deficit. Thus, for instance, the flavor composition in the guarenteed flux for ultra-high energy cosmic neutrinos is expected to be equally distributed in ν_e, ν_μ and ν_τ.

If there is an incomplete or no averaging over the rapid oscillations, then there will be δm^2 and E_ν dependences in $P_{\alpha\beta}$ [see Eq. (1)]. In this situation, the effects of z distribution of the sources for ultra-high energy cosmic neutrinos should also be taken into account by calculating $f(z)$ weighted $P_{\alpha\beta}$ where $P_{\alpha\beta} = \int_0^{z^{max}} P_{\alpha\beta}(z) f(z) dz / \int_0^{z^{max}} f(z) dz$. It is relevant to note that the matter enhanced flavor oscillation effects are negligible for the δm^2 and E_ν values under discussion.

2.3 Prospects for observations

The typical km^2 effective surface area size neutrino telescopes which are currently under construction/planning may be able to search meaningfully for ultra-high energy cosmic neutrinos. For instance, the guarenteed ultra-high energy cosmic neutrino flux gives several events per kilometer per steradian in these neutrino telescopes. If the AGNs and GRBs are also sources of ultra-high energy cosmic neutrinos then the event rate is several orders of magnitude higher in the same neutrino telescopes depending on the model of the AGN/GRB. Moreover, in this case, even it is conceivable to identify the neutrino flavor content in the ultra-high energy cosmic neutrino flux.

3 Conclusion

For a comprehensive search of ultra-high energy cosmic neutrinos, (at least) km^2 effective surface area size neutrino telescopes should have to be deployed.

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References

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