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# High Energy Tau Neutrinos: Production, Propagation and Prospects of observations

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## Abstract

High energy tau neutrinos with energy greater than several thousands of GeV may be produced in some astrophysical sites. A summary of the intrinsic high energy tau neutrino flux estimates from some representative astrophysical sites is presented including the effects of neutrino flavor oscillations. The presently envisaged prospects of observations of the oscillated high energy tau neutrino flux are mentioned. In particular, a recently suggested possibility of future observations of Earth-skimming high energy tau neutrinos is briefly discussed.

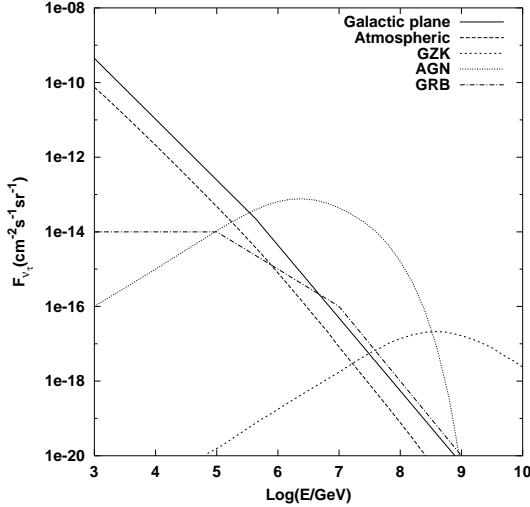
## 1. Introduction

High energy neutrino astronomy ( $E \geq 10^3$  GeV) holds great promise to unveil the microscopic details of the hitherto unexplored phenomena occurring in the cosmos around us [1,2]. In particular, a search for high energy tau neutrinos will not only bring unparalleled new information about the cosmos around us but also will indicate the existence of physics beyond the standard model of particle physics, namely the corroboration of the neutrino flavor mixing [3]. The essentially maximal neutrino flavor mixing implies the existence of high energy tau neutrino flux comparable to high energy muon neutrino flux [2].

## 2. High energy tau neutrinos

### 2.1. Production

The high energy tau neutrinos are produced in direct and indirect decays of  $D_S$  meson in  $p(\gamma, p) \rightarrow D_S + X$  considered to be occurring in cosmos around us. Here, the first  $p$  represents the accelerated cosmic rays. However, the intrinsic high energy tau neutrino flux is rather suppressed during its production relative to intrinsic high energy non tau neutrino flux in above interactions, such



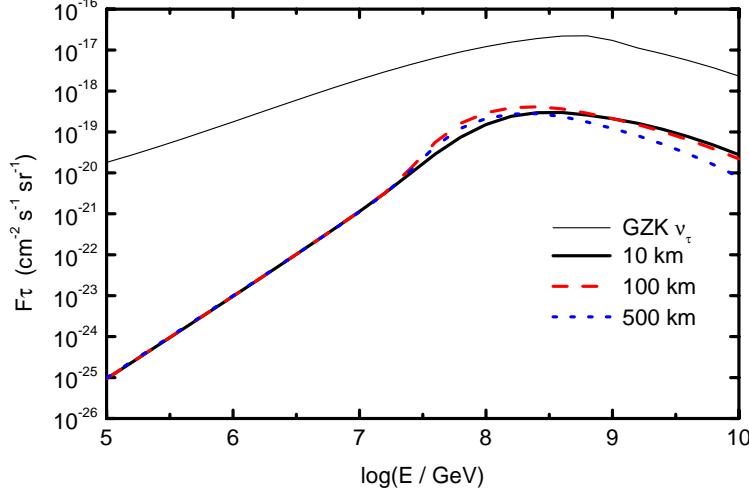
**Fig. 1.** Galactic plane, horizontal atmospheric and GZK high energy tau neutrino flux under the assumption of neutrino flavor mixing. For comparison, the oscillated high energy tau neutrino flux in a representative AGN model and in a fireball model of GRB is also shown.

as the intrinsic muon neutrino flux produced in the atmosphere of Earth in  $pA$  interactions.

## 2.2. Propagation

Neutrino flavor mixing seems to play a dominant role during the propagation of a system of mixed high energy neutrinos over cosmologically large distances. Fig. 1 summarizes the intrinsic high energy tau neutrinos flux,  $F_{\nu_\tau} \equiv dN_{\nu_\tau}/d(\log_{10}E)$  estimates from some representative astrophysical sites including the effect of (two) neutrino flavor oscillations [4].

A main background in observing high energy muon neutrinos from the cosmos is the atmospheric muon neutrino background. From Fig. 1, we see that this is **not** the case for high energy tau neutrinos as the oscillated high energy tau neutrino flux from the galactic plane is already above the relevant atmospheric tau neutrino background even for  $E$  as low as  $10^3$  GeV. Thus, above around  $10^3$  GeV, the high energy **tau neutrino** search can lead to identification of extra-atmospheric neutrino flux, in particular from the direction of galactic plane. This is in contrast to the situation for non tau neutrinos, where the atmospheric background tend to dominate up to  $10^5$  GeV for the same astrophysical site [5]. Thus, at least approximately a two order of magnitude **lower** energy tau neutrinos can probe same astrophysical site provided relevant tau neutrinos can be isolated from relevant non tau neutrinos in near future.



**Fig. 2.** The tau lepton energy spectrum induced by the rock-skimming GZK neutrinos for three different slant depth/matter density ratio values (see text for some more details). The incident tau neutrino flux is shown by thin continuous line.

### 3. Prospects of possible observations

#### 3.1. Downward going

For  $E \geq 5 \cdot 10^5$  GeV, the downward going high energy tau neutrinos can be separated from other two neutrino flavors via event topology characterization in water or ice based high energy neutrino telescopes. It thus might become possible to identify the down ward going high energy tau neutrinos through double shower technique. The first shower is from deep inelastic charged current high energy tau neutrino-nucleon interaction, whereas the second shower is from hadronic decay of the associated tau lepton, both showers are considered to occur inside the telescope. Some quantitative details of this idea for under construction km<sup>3</sup> ice or water based high energy neutrino telescopes are given in [6].

#### 3.2. Upward going

High energy tau neutrinos that cross the entire Earth or most part of it before reaching the detector are called upward going high energy neutrinos. In case of tau neutrinos, for  $E \geq 5 \cdot 10^4$  GeV, the upward going tau neutrino flux is exponentially suppressed [7,8].

#### 3.3. Quasi horizontal or Earth-skimming

It might become possible in near future that the dedicated high energy neutrino telescopes can be configured such that the Earth-skimming high energy (tau) neutrinos induced charged leptons as well as their associated radiations can

be measured [9].

Figure 2 gives the tau lepton flux induced by the Earth-skimming high energy GZK tau neutrinos as a representative example. This tau lepton energy spectrum is obtained by solving a coupled set of partial differential equations describing the simultaneous propagation of tau neutrinos and their induced tau leptons inside the Earth. This set of differential equations explicitly take into account the **inelasticity** of the neutrino-nucleon scattering and the tau lepton **energy loss** in contrast to previous relevant studies in this context [10]. The high energy GZK tau neutrino flux is given in Fig. 1. The presence of rather small tau lepton pile up around  $10^8$  GeV is a consequence of specific energy dependence of incident GZK high energy tau neutrino flux (see Fig. 1)[11].

#### 4. Conclusions

- The high energy tau neutrino flux can probe the cosmos around us such as the center of our galaxy even with energy starting from  $10^3$  GeV **above** the atmospheric high energy tau neutrino flux as a result of neutrino flavor oscillations. This is in **contrast** to the case for high energy muon neutrino flux.
- The energy spectrum of the tau leptons induced by the Earth-skimming high energy tau neutrinos is calculated by explicitly taking into account the **inelasticity** of the neutrino-nucleon interactions and the tau lepton **energy loss**.

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