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行政院國家科學委員會專題研究計畫期中報告
微中子天文物理之研究(2/3)
Selected Studies on Neutrino Astrophysics (2/3)

計畫編號：NSC92-2112-M-009-038
執行期限：92 年 8 月 1 日至 93 年 7 月 31 日
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計畫參與人員：Umeda 博士及碩博士生

一、中文摘要

在 10 到 100 GeV 能量之間，我們指出 Tau 微中子天文學的良機．經過微中子振盪分析，我們發現以上能量範圍內，大氣背景 tau 微中子流量遠小於大氣背景 muon 微中子流量．此背景值差異導致銀河系 tau 微中子遠比銀河系 muon 微中子容易觀測．此外太陽暗物質煙滅產生的 tau 微中子也是我們的關注焦點．

我們也即將完成一套模擬 tau 微中子及 tau 輕子在地球裏傳播的蒙地卡羅程式．只要給定初始 tau 微中子能譜，這套程式可以算出末態 tau 輕子衰變後的大氣粒子流．我們預備利用這套程式分析穿山微中子事例與超越標準模型物理的關聯性．

關鍵詞：微中子振盪、Tau 微中子、暗物質

Abstract

We point out the opportunity of tau neutrino astronomy for neutrino energies roughly between 10 and 100 GeV's. We demonstrate that, with neutrino oscillation effects taken into account, the atmospheric tau neutrino flux are highly suppressed compared to its muon neutrino counterpart. The flavor dependence in the background atmospheric neutrino flux leads to drastically different prospects between the observations of astrophysical muon neutrinos and those of astrophysical tau neutrinos. We illustrate this point by discussing the viability of observing tau neutrinos from the galactic-plane, produced by cosmic ray-matter scattering; and the sun, produced by possible dark matter annihilations.

We develop a full Monte-Carlo program for ν_τ and τ propagations inside the Earth. The program allows us to study air showers from tau lepton decays given a specific incoming high energy tau neutrino flux. This program could also accommodate new interactions for ν_τ/τ-nucleon scatterings and allows one to quantify new physics effects to the tau lepton event rate. We shall demonstrate that it is possible to test the enhancement of ν_τ-nucleon scattering cross section by observing the mountain-penetrating tau neutrinos.

Keywords: Neutrino Oscillation, Tau Neutrino, Dark Matter

二、緣由與目的

The studies on atmospheric and solar neutrino oscillations render useful information on the neutrino mass-square differences and mixing angles among different flavors [1, 2]. Both types of neutrinos come from sites with well known matter contents and densities. This is essential for one to extract neutrino mass and mixing parameters. The natural extension of such studies is to detect neutrinos from other astrophysical sites. Given our current understanding on the neutrino properties, the observation of astrophysical neutrinos provide complementary information on the specific astrophysical site to that obtained from conventional astrophysical means. In this regard, we discuss the viability of seeing the galactic-plane through detecting galactic neutrinos in the energy regime of Super-Kamiokande detector or its extension, i.e. from GeV to TeV energy scales. **Such detections shall open a new avenue for the**

neutrino astronomy. It is also worthwhile to point out that such an energy regime coincides with the energy scale of dark matter annihilations. Such annihilations could in principle take place inside the Sun and gives rise to a neutrino flux [3]. It is quite important to look for such a neutrino flux so that one can test various models for dark matter in the universe.

Besides studying neutrinos in the GeV energy scales, there have been existing efforts and new proposals to detect high-energy neutrinos ($E > 10^5$ GeV). Such studies are crucial to identify the extreme energy sources in the Universe, and possibly to unveil the puzzle of cosmic rays with energy above the GZK cutoff [4]. One way for detecting such neutrinos is to detect the air showers caused by the charged leptons produced by the neutrino-nucleon scatterings taking place inside the Earth or in the air, far away from the instrumented volume of the detector. This strategy includes the possibility of detecting quasi horizontal incident neutrinos which are also referred to as the Earth-skimming neutrinos. These neutrinos are considered to interact below the horizon of an Earth based surface detector.

The above detection strategy is proposed only recently [5, 6, 7]. **In a result obtained last year [8], we calculated the energy spectrum of tau leptons induced by the high energy Earth-skimming tau neutrinos.** We have taken AGN, GRB, and GZK incident neutrino fluxes for our analysis. Our calculation takes into account all interactions of ν_τ/τ inside the Earth. The only approximation in our approach is the treatment of tau-lepton energy loss. We have taken such an energy loss to be a deterministic rather than stochastic process [9]. Since the deterministic approach works well only in the lower energy, say less than 10^9 GeV, it is therefore desirable to use stochastic approach for analyzing tau lepton spectrum resulting from Earth-skimming GZK neutrinos. In this regard, we develop a full Monte-Carlo code for ν_τ and τ propagations inside the Earth, adopting the stochastic approach for the tau-lepton energy loss. We shall apply this code not only for Standard Model interactions but also for Beyond-Standard-Model interactions that enhance the neutrino-nucleon scattering cross section [10]. It is argued that the enhanced neutrino-nucleon scattering cross section in fact decreases the tau lepton event rate induced by the Earth-skimming tau neutrinos, due to the Earth absorption effect [10]. **On the other hand, we observe that [11] the same anomalous neutrino-nucleon scattering cross section enhances the tau-lepton event rate induced by mountain-penetrating rather than Earth-skimming tau neutrino (the propagation distances of ν_τ/τ in the former case is smaller than the latter). This is very important information for neutrino-telescope experiments and deserving careful studies by full Monte-Carlo simulations.**

三、結果與討論

We found drastically different drastically different prospects between the observations of astrophysical muon neutrinos and those of astrophysical tau neutrinos, due to much smaller background atmospheric tau neutrino flux compared to the muon neutrino case. **Specifically the galactic-plane tau neutrino flux dominates over the atmospheric tau neutrino flux for neutrino energy beyond 10 GeV. Hence the galactic plane can in principle be seen through tau neutrinos with energy greater than 10 GeV [12].** In a sharp contrast, the galactic muon neutrino flux does not dominate over its atmospheric counterpart until the energy of 10^6 GeV. For neutrino energy greater than 10^6 GeV, the galactic-plane muon neutrino flux is already too suppressed to be observed, despite its dominance over atmospheric background! To establish the above difference between tau neutrino and muon neutrino astronomy, we make use of the atmospheric neutrino mixing parameters $\sin^2(2\theta) = 1$, $1.3\cdot10^{-3} < \delta m^2/\mathrm{eV}^2 < 3\cdot10^{-3}$. **For the neutrino flux from the dark matter (assumed to be the SUSY LSP) annihilations, we have so far finished the cross-section calculations for neutralino annihilating into neutrinos. The dark**

matter trapping rate is yet to be determined [13].

We are rather close in completing the Monte-Carlo code for ν_τ and τ propagations inside the Earth with the Standard-Model ν_τ/τ-N interaction cross sections [14]. The tau-lepton range obtained by taking the stochastic energy loss has been compared to its counterpart obtained by taking the simplified deterministic energy-loss approach. The former is 25% smaller than the latter for $E_\tau=10^9$ GeV. Further tests on this Monte-Carlo code are underway.

四、計畫成果自評

The on-going projects mentioned above are rather extensive. Each of them takes much longer time than anticipated. Fortunately, the work on tau neutrino astronomy has been just completed and we are currently working on the first draft of the paper [12]. The result is very interesting! **It indicates that one is hopeful to establish the tau neutrino astronomy in the energy window of 10-100 GeV accessible by the Super-Kamiokande detector.** This is in a sharp contrast to the muon neutrino case. We have submitted this work to **International Conference on Neutrino Physics and Astrophysics (Neutrino 2004)** to be held in Paris this June. My student, **Fei-Fain Lee**, is expected to present this work. I will also present this work in **International Symposium on Multi-particle Dynamics (ISMD 2004)** to be held this July in Rohnert Park, California. **The work on dark-matter annihilations into neutrino fluxes is in good progress and is expected to be completed before September [13].**

The Monte-Carlo code for ν_τ and τ propagations inside the Earth will be completed this July, as the **Master Thesis** of my student, **Chan-Hin Iong**. **The immediate application of this code is to study new physics enhancement in the event rate for mountain-penetrating ultrahigh-energy tau neutrinos. This work is expected to be completed in late September [14]. The result will be very relevant to neutrino-telescope experiments such as Ashra-NuTel collaboration [15, 16].** In fact, Ashra-NuTel project is the only experiment which detects both Earth-skimming and mountain-penetrating tau neutrinos. The Earth-skimming detection strategy has more tau-lepton event rate compared to the mountain-penetrating strategy. On the other hand, the latter strategy is sensitive to the new physics effect that enhances ν_τ-N scattering cross sections. **Our Monte-Carlo simulation will be one of the important elements of full simulation analysis in the Ashra-NuTel collaboration mentioned above [15, 16].**

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