Confronting Heavy Tau Neutrinos with Neutrino Oscillations (Postprint)

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Abstract

If the tau neutrino is as heavy as 10 MeV which may have certain astrophysical implications, the neutrino mass pattern is studied so as to accommodate the new oscillation observations. It predicts that the electron neutrino has Marjorana mass around 0.05 eV. A supersymmetric model is described to realize the above scenario.

Full Text

Preamble

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Abstract

If the tau neutrino is as heavy as 10 MeV, which may have certain astrophysical implications, the neutrino mass pattern required to accommodate current oscillation observations is studied. The scenario predicts that the electron neutrino has a Majorana mass around 0.05 eV. A supersymmetric model is described to realize this scenario.

Keywords: tau neutrino, neutrino oscillation
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There are several motivations for a heavy . Cosmologically, 10 MeV ’ s could constitute cold dark matter in scenarios with low reheating temperature [1]. Theoretically, a 10 MeV is predicted in a supersymmetric (SUSY) model that explains the muon mass through sneutrino vacuum expectation values [2]. One astrophysical implication is that gamma-ray bursts may actually be supernova explosions [3]. In this model, mixes slightly with other neutralinos and decays to a light gravitino and photon with a very long lifetime of 10^{13} seconds. Consequently, distant supernova explosions that emit tau neutrinos would appear to us as gamma-ray bursts.

Neutrino oscillation observations must be carefully considered. The Super-Kamiokande (Super-K) data for the atmospheric neutrino problem (ANP) imply that mixes maximally with x (x = e,) with $\Delta m^2 \sim 3 \times 10^{3}$ eV^2 [4]. It has been claimed that the x = case is favored over the sterile neutrino [5]; however, Ref. [6] has argued that this claim is not yet reliable and that more careful analysis is needed. Nevertheless, as emphasized in Ref. [7], the x = sterile case is not ruled out on its own merits.

The Sudbury Neutrino Observatory (SNO) first results [8] for the solar neutrino problem (SNP) make it clear that mixing among active neutrinos is essential, although certain involvement of a sterile neutrino cannot be excluded [9]. Recent Super-K results [10] for the SNP show that solutions lie in the large mixing angle (LMA) region with $\Delta m^2 \sim 4 \times 10$ eV^2 or $\Delta m^2 \sim 7 \times 10$ eV^2.

In this Letter, we consider to be heavy (~10 MeV). The ANP is explained by introducing a sterile neutrino s, while the SNP is mainly due to e- mixing. In this scenario, there are three light neutrinos: e, , and s. Although this appears similar to the case of three light active neutrinos where several forms of the neutrino mass matrix are allowed by oscillation data [11], careful consideration reveals that the neutrino mass matrix is almost uniquely determined.

By introducing a sterile neutrino, one might naively expect a pseudo-Dirac mechanism for the ANP. However, this cannot explain the SNP, because even if e is taken to be degenerate with and s, large mixing between e and cannot be achieved. Requiring minimal parameter tuning, we arrive at the following neutrino mass matrix phenomenologically. In the (e, , s) basis, the leading-order mass matrix is given by Eq. (1). Note that the matrix elements (12) and (13) are not necessarily equal; the equality would be exact if the ANP is due to maximal mixing.

The following mass spectrum is obtained from Eq. (1): m = m = m, m = 0. Two neutrinos are degenerate and one is massless. Their mixing matrix is then determined accordingly. Therefore, both - s mixing (for the ANP) and e- mixing (for the SNP) are fixed to be maximal. The value of m is determined by the ANP to be 0.05 eV.

The degeneracy of and must be lifted as required by the SNP. Phenomenologically, a small perturbation m can be added to the mass matrix in Eq. (1). This splits and by m^2. The parameter takes different values for the Mikheyev-Smirnov-Wolfenstein (MSW) solution [12] and the LOW solution.

The fact that the SNP is due to large mixing rather than maximal mixing is explained by considering the charged lepton mixing matrix, which was taken as the unit matrix at leading order. It is then natural to expect the e- mixing angle to deviate from /4.

Let us discuss a SUSY model [2,13] that can produce the neutrino mass matrix of Eq. (1). The model is a SUSY extension of the standard model. Lepton number violation is introduced so that one of the left-handed sneutrinos gets a non-vanishing vacuum expectation value, v ~ few GeV, which results in a 10 MeV Majorana mass for the tau neutrino [2]. In addition, we introduce two heavy (N and N) and one massless (N) right-handed neutrino superfields. The relevant superpotential for N and N is generally written as

W , L H N , + L H N , + L H N , + M N N + M N N ,

where L (i = 1, 2, 3) are the SU(2) doublet superfields of leptons, H denotes one of the Higgs fields, and M , are the masses of N , . In the basis where the charged lepton mass matrix is diagonal, the lepton doublets are expanded as

L = (1/√6)(L + L - 2L),
L = (1/√2)(L - L),
L = (1/√3)(L + L + L).

In this basis,

W , L H N , + L H N , + L H N , + M N N + M N N .

One observation is that the term containing L is unnecessary because is already much heavier. It is natural to expect that the mass submatrix of e and in Eq. (1) arises from the seesaw mechanism via the other terms in the superpotential, with m ~ (few × 10 ²) eV.

We assume N couples dominantly to L : W = cL H N , with coupling c being very small, c ~ 10 . The smallness of c can be understood if N is a composite particle [14]. In the basis of L , L , and L , this leads to terms L H N + L H N . Again, the second term is unimportant for neutrino masses. The first term generates the (13) entry of the mass matrix in Eq. (1). Since N is essentially massless and has no self-coupling, the texture of the neutrino mass matrix in Eq. (1) is obtained.

One phenomenologically interesting consequence of introducing light N is that it interacts with other leptons through terms like L L E , where E denotes the SU(2) singlet charged lepton superfield. The superpotential results in interactions such as N , where N is the scalar component of N . After SUSY breaking, N becomes massive and decays to with possibly a long decay length. We wonder whether this might be related to the recent observation of the NuTeV Collaboration [15] or could be tested in future experiments.

Experimentally, the neutrino mass scenario proposed here can be tested in several ways. Besides direct measurement of the mass, confirmation of - s oscillation as the explanation for the ANP will be a serious challenge. The model predicts that the electron neutrino has a Majorana mass around 0.05 eV, which will be probed by neutrinoless double -decay experiments [16]. There is no room for the LSND result, but the scenario is compatible with the KARMEN experiment. The mixing element U can be vanishingly small without affecting the physics discussed in this paper.

When this work was written, we became aware of Ref. [17], which reports tau appearance in atmospheric neutrino observations at the 2 level.

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