Large Angle Neutrino Mixing and Pseudo-Dirac Neutrinos

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Abstract

A possibility that the observed large angle neutrino mixing is caused by a set of pseudo-Dirac neutrinos is discussed. Since the recent Superkamiokande data disfavor to the large ν_μ-ν_s mixing, a model without a large ν_μ-ν_s mixing is also discussed.

1. Introduction

The most important clue to the unification of the quarks and leptons exists in the observed large angle neutrino mixing in the atmospheric neutrino data [1]. One of the possible interpretations is that such a large mixing is caused by a set of pseudo-Dirac neutrinos. This idea is very natural from the theoretical point of view. On the other hand, the recent Superkamiokande data [2] disfavor to the large mixing between ν_μ and ν_s. However, the idea is still attractive to me, because the large angle mixing is caused not as a result of parameter-adjustment, but as a result of an innate characteristic of the model.

2. Bowes-Volkas model

For such a model with light pseudo-Dirac neutrinos, first, I would like to give a short review on a model which has been recently proposed by Bowes and Volkas [3]. In their model, the neutrino mass matrix is given by

$$\left(\overline{\nu}_L \; \overline{\nu}_R^c \; \overline{N}_L \; \overline{N}_R^c\right) \begin{pmatrix} 0 & 0 & 0 & m_L \\ 0 & 0 & m_R^T & 0 \\ 0 & m_R & M_L & M_D \\ m_L^T & 0 & M_D^T & M_R \end{pmatrix} \begin{pmatrix} \nu_L^c \\ \nu_R \\ N_L^c \\ N_R \end{pmatrix} , \tag{2.1}$$

where N_L and N_R are neutral heavy leptons. For $M_D \gg M_L, M_R, m_L, m_R$, mass eigenstates are given by $\nu_\pm \simeq (\nu_L \pm \nu_R^c)/\sqrt{2}$ and $N_\pm \simeq (N_L \pm N_R^c)/\sqrt{2}$, with masses of the order of $m(\nu_\pm) \simeq m_L m_R / M_D$ and $m(N_\pm) \simeq M_D$, respectively. The explanation of the observed data is illustrated in Fig. 1.

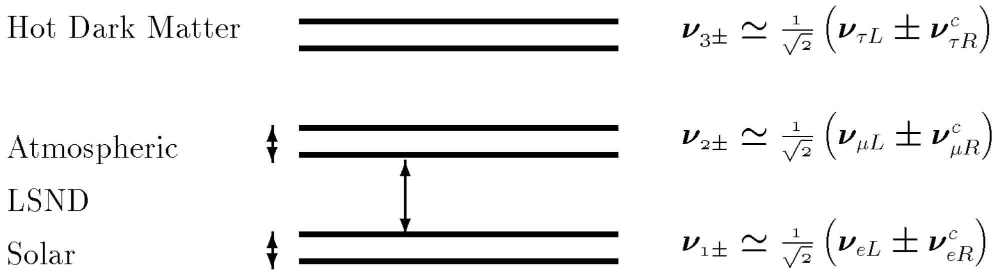

Fig. 1. Neutrino phenomenology in the Bowes-Volkas model

3. Universal seesaw model

Next, I would like to give a short review on a pseudo-Dirac neutrino model [4] within the framework of the universal seesaw (US) model [5]. In the US model, fermions belong to $f_L = (2,1)$, $f_R = (1,2)$, $F_L = (1,1)$, and $F_R = (1,1)$ of $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1)_Y$ where f_i $(i = 1,2,3;\ f = u, d, \nu, e)$ are conventional quarks and leptons, and F_i $(i = 1,2,3;\ F = U, D, N, E)$ are hypothetical heavy fermions. The mass matrix for (f, F) is given by

$$\begin{pmatrix} \overline{f}_L & \overline{F}_L \end{pmatrix} \begin{pmatrix} 0 & m_L \\ m_R & M_F \end{pmatrix} \begin{pmatrix} f_R \\ F_R \end{pmatrix} \ , \tag{3.1}$$

where m_L and m_R are universal for all quark and lepton sectors, and only M_F has a structure dependent on the families. Thus, quark and neutrino mass matrices can be described in terms of the charged lepton masses.

In this model, under $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1)_Y$, $F_L = (1,1)$ and $F_R = (1,1)$ cannot be distinguished from each other, and, hence, the mass matrix for the neutrino sector comes out as

$$\left(\overline{\nu}_L \ \overline{\nu}^c_R \ \overline{N}_L \ \overline{N}^c_R\right) \begin{pmatrix} 0 & 0 & m'_L & m_L \\ 0 & 0 & m^T_R & m'^T_R \\ m'^T_L & m_R & M_L & M_D \\ m^T_L & m'_R & M^T_D & M_R \end{pmatrix} \begin{pmatrix} \nu^c_L \\ \nu_R \\ N^c_L \\ N_R \end{pmatrix} \ . \tag{3.2}$$

For $M_D = M_L = M_R \gg m_R \simeq m'_R \gg m_L \simeq m'_L$, we obtain the same results with the Bowes-Volkas model except for the pseudo-Dirac neutrino assignment

$$\nu_{i\pm} \simeq \frac{1}{\sqrt{2}}\left(\nu_{iL} \pm \nu^s_i\right) \ , \quad \nu^s_i = \frac{1}{\sqrt{2}}\left(N_{iL} - N^c_{iR}\right) \ . \tag{3.3}$$

However, such a large ν_μ-ν_s mixing is disfavored by to the recent Superkamiokande data [2]. Therefore, I will propose a modified model without m'_L and m'_R within the framework of the US model.

For the case $M_R \gg M_L \sim M_D$, from (3.2) with $m'_L = m'_R = 0$, we obtain the effective mass matrix for (ν_L^c, ν_R)

$$M^{6\times 6} \simeq \left(\begin{array}{cc} -m_L M_R^{-1} m_L^T & m_L M_R^{T-1} M_D^T M_L^{T-1} m_R \\ m_R^T M_L^{-1} M_D M_R^{-1} m_L^T & -m_R^T M_L^{-1} m_R \end{array} \right) . \tag{3.4}$$

The phenomenology for a special case $O(M_L)/O(m_R^2) \sim O(M_R)/O(m_L^2)$ is illustrated in Fig. 2. The atmospheric neutrino data is explained by a maximal $\nu_{\mu L} \leftrightarrow \nu_{\tau L}$ mixing, while the solar neutrino data is explained by a small mixing between ν_{eL} and ν_{eR}^c.

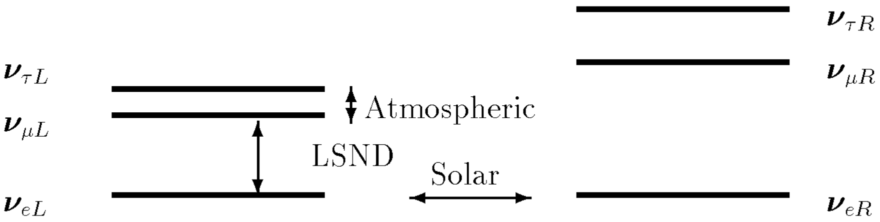

Fig. 2. Phenomenology in the modified universal seesaw model

4. Model without new fermions

Most physicists do not like hypothetical new fermions although they love a large number of SUSY particles. Most physicists do not prefer light sterile neutrinos because of the problem of big bang nucleosynthesis (BBN). Therefore, finally, I would like to propose a model without new fermions.

The basic idea is as follows: We assume that ν_{1R} is composed of a Majorana mass term $m_R \overline{\nu}_{1R}^c \nu_{1R}$, while ν_{2R} and ν_{3R} is composed of a kind of Dirac mass term $m_R\,(\overline{\nu}_{2R}^c \nu_{3R} + \overline{\nu}_{3R} \nu_{2R}^c)$, i.e., the Majorana mass matrix M_R for ν_R is given by

$$M_R = m_R \left(\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{array} \right) . \tag{4.1}$$

Then, the neutrino seesaw mass matrix $M_\nu \simeq -M_D M_R^{-1} M_D^T$ can give a large mixing between $\nu_{\mu L}$ and $\nu_{\tau L}$. For example, when we consider the following Dirac neutrino mass matrix

$$M_D = m_D \left(\begin{array}{ccc} 1+\varepsilon & \varepsilon' & 0 \\ \varepsilon' & 1 & \varepsilon \\ 0 & \varepsilon & 1 \end{array} \right) , \tag{4.2}$$

where $|\varepsilon| \ll 1$ and $|\varepsilon'| \ll 1$, we obtain the following mass-eigenvalues

$$\begin{aligned} m_1 &\simeq (m_D^2/m_R)[(1+\varepsilon)^2+\sqrt{2}\varepsilon'] \\ m_2 &\simeq (m_D^2/m_R)[(1+\varepsilon)^2-\sqrt{2}\varepsilon'] \\ m_3 &= -(m_0^2/m_R)(1-\varepsilon)^2 \end{aligned} \tag{4.3}$$

together with the mixing matrix U as

$$U \simeq \begin{pmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \end{pmatrix} . \tag{4.4}$$

Thus, we can obtain a desirable result $\Delta m^2_{atm} \simeq 4\varepsilon(m_D^2/m_R)^2$, $\sin^2 2\theta_{atm} \simeq 1$, $\Delta m^2_{solar} \simeq 4\sqrt{2}\varepsilon'(m_D^2/m_R)^2$ and $\sin^2 2\theta_{solar} \simeq 1$.

5. Summary

The idea that the observed large neutrino mixing may be caused by a set of pseudo-Dirac neutrinos is natural from the theoretical point of view. If it is true, then, the problem is who is the partner of $\nu_{\mu L}$. The candidates are as follows: (i) $\nu_{\mu R}$, (ii) $\nu^s_{\mu R} = (N_{\mu R} - N^c_{\mu L})/\sqrt{2}$, and (ii) $\nu^c_{\tau L}$. This question will soon be answered by coming data of the K2K experiment and other running and planed neutrino experiments.

References

[1] Y. Fukuda *et al.*, Phys. Lett. **B335** (1994) 237; Y. Fukuda *et al.*, Phys. Rev. Lett. *81* (1998) 1562.

[2] Y. Obayashi, *Neutrino Oscillations and their Origin*, Fujiyoshida, Japan, February 11-13, (2000) Universal Academy Press, Tokyo.

[3] J. P. Bowes and R. R.Volkas, J. Phys. **G24** (1998) 1249.

[4] Y. Koide and H. Fusaoka, Phys. Rev. **D59** (1999), 053004.

[5] references [1] in Ref.[4]. And also see Y. Koide and H. Fusaoka, Z. Phys. **C71**, 459 (1996); Prog. Theor. Phys. **97**, 459 (1997).

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