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NON-THERMAL LEPTOGENESIS IN QUASI-DEGENERATE NEUTRINOS MASS MODELS

Ng.K.Francis

Department of Physics, Tezpur University, Tezpur, India

ABSTRACT

We study the non-thermal leptogenesis in quasi-degenearte neutrino mass models (QDN) which predicts the current data of neutrino and baryogenesis. Majorana CP violating phases coming from heavy right-handed Majorana mass matrices (M_{RR}) are considered to determine the baryon asymmetry of the Universe, for QDN in normal and inverted hierarchical patterns. The effects of phases on QDN matrix obeying μ-τ symmetry predicts the results consistent with obvervations for (i) solar mixing angle(θ_{12}) below TBM, (ii) absolute neutrino mass parameters[m_{ee}] in $0\nu\beta\beta$ decay, and (iii) cosmological upper bound $\sum_i m_i$. Analysis is carried out through parameterization of light left-handed Majorana neutrino matrices (m_{LL}) using only two unknown parameters (ϵ, η) within μ-τ symmetry. We consider the charge lepton and up quark mass matrices as diagonal form of Dirac neutrino mass matrix (m_{LR}), and M_{RR} are generated using m_{LL} through inversion of Type-I seesaw formula. The predictions for baryon asymmetry of the universe are nearly consistent with observations for flavoured thermal leptogenesis scenario. The analysis in non-thermal leptogenesis shows that Type-IA in normal hierarchical mass pattern for charged lepton type of Dirac neutrino mass matrix is the only models consistent with baryon asymmetry. The predicted inflaton mass needed to produce the observed baryon asymmetry of the universe is found to be $M_\phi \sim 10^{10}$ GeV for reheating temperature $T_R = 10^6$ GeV. The analysis shows the validity of QDN with normal hierachical mass patterns more favourable than those of inverted patern. The predicted result is new and have important implications for future experiments.

Keywords: QDN models, absolute neutrino masses, baryogenesis.
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I. INTRODUCTION

Since the present neutrino oscillation data[1] on neutrino mass parameters are not sufficient to predict the three absolute neutrino masses in the case of quasi-degenerate neutrino (QDN) mass models [2-8], such mass scale is usually taken as input ranging from 0.1 to 0.4 eV in most of the theoretical calculations [9]. As the latest cosmological tighest upper bound on the sum of the three absolute neutrino mass is $\sum mi \leq 0.28$ eV [11], larger value of neutrino mass $m_3 \geq 0.1$ eV in QDN models, has been disfavoured. The

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upper bound on $m_{ee} \geq 0.2$ eV in $0\nu\beta\beta$ decay [11] also disfavour larger values of neutrino mass eigenvalues with same CP-parity. Some important points for further investigations in QDN models for both NH and IH patterns are searches for QDN models which can accomodate lower values of absolute neutrino masses $m_3 \geq 0.09$ eV, solar mixing angle which is lower than tri-bimaximal mixing (TBM) [12] and effects of CP-phases on neutrino masses. In this paper, we introduce a generalclassification for QDN models based on their CP-parity patterns and then parameterize the mass matrix within μ- τ symmetry, and finally numerical calculations are carried out.

II. PARAMETERIZATIONS OF NEUTRINO MASS MATRIX

A general μ-τ symmetric neutrino mass matrix [13,14] with its four unknown independent matrix elements, requires at least four independent equations for realistic numerical solution.

$$m_{LL} = \begin{pmatrix} m_{11} & m_{12} & m_{12} \\ m_{12} & m_{22} & m_{23} \\ m_{12} & m_{23} & m_{22} \end{pmatrix} \qquad (1)$$

The three mass eigenvalues m_i and solar mixing angles θ_{12}, are given by $m_1 = m_{11} - \sqrt{2}\tan\theta_{12} m_{12}, \quad m_2 = m_{11} + \sqrt{2}\cot\theta_{12} m_{12}, \quad m_3 = m_{22} - m_{23}$.

$$\tan 2\theta_{12} = \frac{2\sqrt{2} m_{12}}{m_{11} - m_{22} - m_{23}} \qquad (2)$$

The observed mass-squared differences are calculated as
$\triangle m^2_{12} = m^2_2 - m^2_1 > 0, \quad \triangle m^2_{32} = |m^2_3 - m^2_2|$. In the basis where charged lepton mass matrix is diagonal, we have the leptonic mixing matrix,

$U_{PMNS} = U$, where

$$U_{PMNS} = \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ \frac{\sin\theta_{12}}{\sqrt{2}} & \frac{\cos\theta_{12}}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{\sin\theta_{12}}{\sqrt{2}} & \frac{\cos\theta_{12}}{\sqrt{2}} & \frac{1}{2} \end{pmatrix} \qquad (3)$$

The mass parameters m_{ee} in $\nu\beta\beta$ decay and the sum of the ansolute neutrino masses in WMAP cosmological bound $Summ_i$, are given respectively by, $m_{ee} = |m_1 U^2_{e1} + m_2 U^2_{e2} + m_3 U^2_{e3}|$ and $m_{cosmos} = m_1 + m_2 + m_3$. A general classification for three-fold quasi-degenerate neutrino mass models [13] with respect to Majorana CP-phases in their three mass eigenvalues, is adopted here. Diagonalisation of left-habded Majorana neutrino mass

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matrix m_{LL} in equation (1) is given by $m_{LL} = UDU^T$, where U is the diagonalising matrix in eq.(4) and Diag=D$(m_1, m_2 e^{i\alpha}, m_3 e^{i\beta})$ is the diagonal matrix with two unknown Majorana phases (α, β).In the basis where charged lepton mass matrix is diagonal, the leptonic mixing matrix is given by $U = U_{PMNS}$ [14]. We then adopt the following classification according to their CP-parity patterns in the mass eigenvalues m_i namely Type IA: (+-+) for D=Diag$(m_1, -m_2, m_3)$; Type IB:(+++) for D=Diag(m_1, m_2, m_3) and Type-IC: for (++-) for D=Diag$(m_1, m_2, -m_3)$ respectively. We now introduce the following parameterization for μ-τ symmetric neutrino mass matrices μ_{LL} which could satisfy the above classifications[13].

III. NUMERICAL ANALYSIS AND RESULTS

For numerical computation of absolute neutrino masses, we take the following observational data: $\triangle m_{12}^2 = (m_2^2 - m_1^2) = 7.60x10^{-5}eV^2$, $|\triangle m_{32}^2| = |m_3^2 - m_2^2| = 2.40x10^{-3}eV^2$;and define the following parameters $\phi = \frac{|\triangle m_{23}^2|}{m_3^2}$ and $\psi = \frac{\triangle m_{21}^2}{|\triangle m_{23}^2|}$, where m_3 is the input quantity. For NH-QD, the other two mass eigenvalues are estimated from,$m_2 = m_3\sqrt{1-\phi}$; $m_1 = m_3\sqrt{1-\phi(1+\psi)}$ and for IN-QD from $m_2 = m_3\sqrt{1+\phi}$; $m_1 = m_3\sqrt{1+\phi(1-\psi}$. For suitable input value of m_3 one can estimate the values of m_1 and m_2 for both NH-QD abd IH-QD cases, using the observational values of $|\triangle m_{23}^2|$ and $\triangle m_{21}^2$.Table-1 gives the calculated numericalvalues for two models namely NH-QD and IH-QD for $|\triangle m_{23}^2| = 7.60x10^{-5}eV^2$ and $\triangle m_{21}^2 = 2.40x10^{-3}eV^2$.

Parameterizations: In the next step we parameterize the mass matrix eq.(1) into three types: **Type IA** withD=Diag$(m_1, -m_2, m_3)$. The mass matrix of this type [13,15] canbe parameterized using two parameters ϵ, η):

$$m_{LL} = \begin{pmatrix} \epsilon - 2\eta & -c\epsilon & -c\epsilon \\ -c\epsilon & \frac{1}{2} - d\eta & -\frac{1}{2} - \eta \\ -c\epsilon & -\frac{1}{2} - \eta & \frac{1}{2} - d\eta \end{pmatrix} m_0. \quad (4)$$

This predicts the solar mixing angle, $\tan\theta_{12} = -\frac{2c\sqrt{2}}{1+(d-1)\frac{\eta}{\epsilon}}$.ok When c=d=1.0, we get the tri-bimaximal mixings (TBM) $tan2\theta_{12} = -2\sqrt{2}(\tan^2\theta_{12} = 0.50)$ and the values of ϵ and η are calculated for both NH-QD andIH-QD cases, by using the values of Table-1 in these two expressions: $m_1 = (2\epsilon - 2\eta)m_3$ and $m_2 = (-\epsilon - 2\eta)m_3$.The results are given in Table-2 for $tan^2\theta_{12} = 0.50$.The solar angle can be further lowered by taking the values c ¡ 1 and d ¿ 1 while using the earlier values of ϵ and η extracted using TBM. For $\tan\theta_{12} = 0.45$ case the results are shown in Table-3.**Type-IB** with D = Diag (m_1, m_2, m_3): This type [13,15]of quasi-degenerate mass pattern is given by the mass matrix, okok

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$$m_{LL} = \begin{pmatrix} 1-\epsilon-2\eta & c\epsilon & c\epsilon \\ c\epsilon & 1-d\eta & -\eta \\ c\epsilon & -\eta & 1-d\eta \end{pmatrix} m_3 \tag{5}$$

This predicts the solar mixing angle,

$$\tan 2\theta_{12} = \frac{2c\sqrt{2}}{1+(1-d)\frac{\eta}{\epsilon}}. \tag{6}$$

which gives the TBM solar mixing angle with the input values c = 1 and d = 1. Like in Type-IA, here ϵ and η values arecomputed for NH-QD and IH-QD, by using Table-1 in $m_1 = (1-2\epsilon-2\eta)m_3$, and $m_2 = (1+2-2\eta)m_3$. **Type-IC** with D = Diag$(m_1, m_2, -m_3)$: It is not necessary to treat this moddel [13] separately as it is silmilar to Type-IB except the interchange of two matric elements (22) and (23) in the mass matrix in eq.(10), and this effectively imparts an additional odd CP-parity on the third mass eigenvalue m_3 in Type-IC. Such change does not alter the predictions of Type-IB.Tables 2-3 present our numerical results for both $tan\theta_{12} = 0.5$ and 0.45 cases, in all types of QD models (Types-IA,IB). These results are consistent with observational bound from cosmological and both NH and IH patterns are valid within quasi-degenerate model.ok

IV. CONCLUSION

To conclude, we have studied the effects of Majorana phases on the prediction of absolute neutrino masses in three types of QDN models having both normal and inverted hierarchical patterns within mu-τ symmetry. These predictions are consistent with data on the mass squared difference derived from various oscillation experiments, and from the upper bound on absolute neutrino masses in $0\nu\beta\beta$ decay as well as upper bound of cosmology. The QD models are still far from discrimination and the prediction on solar mixing angle is found to be lower than TBM viz,$\tan^2\theta_{12} = 0.45$ which coincides with the best-fit in the neutrino oscillation data. The result shows the validity of NH-QD and IH-QD models. The results presented in this article are new and have important implications in the discrimination of neutino mass models.

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REFERENCES

[1] Schwetz, M.Tortola, J.W.F. Valle,hep-ph/08082016; M.C Gonzales-Garcia, M.maltonii, arxiv:0812.3161.

[2] or review, see A. Bandyopadhyay et.al., Rep. Prog.Phys.72,106201(2009).

[3] . S.Joshpura, Z.Phys. C64, 31 (1994); S.T. Petcov, A. Yu. Smirnov, Phys. lett B322. 109 (1994).

[4] . S.Joshipura and K.M Patel, arXiv:1005.004.

[5] . Barbieri, L.J.Hall, G.L.Kane, G.G.Ross, hep-ph/9901228.

[6] . Antusch and S.F.King. Nucl Phys B705, 239(2005),hep-ph/0402121.

[7] . Binetruy,S.Lavignac, S.T.Petcov, P.raymond, Nucl. Phys. B496, 3(1997) hep-ph/9610.

[8] . C.Branco, M.N.rebelo and J.I.Silva-Marcos, Phys.Rev Lett. 82, 683(1999),hep-ph/9810328; Phys.Lett.B428,136(1998), hep- ph/9802340.

[9] . M.Vazielas, G.G.Ross, M.Serna, Phys. Rev. D80. 073002(2009).

[10] haun A. Thomas, Filipe B. Abdalla, Ofer Lahav. Phys.Rev.Lett.105,031301 (2010).

[11] .Pascoli, S.T.Petcov, Phys. Rev D77, 11300392008).

[12] .F.Harrison, W.G.Scott, Phys.Rev Lett B547, 219(2002); P.F.Harrison, D.H.Perkins, W.G.Scott, Phys.Lett B530.167(200); P.F.harrison,W.G.Scott, Phys.Lett. B557.76(2003).

[13] .Altarelli and F.Feruglio, PHys.Rep.320.295(1999).

[14] Maki,M.nakagawa,S.Sakata,Prog.Theor.Phys.28,870(1962); B.Pontecovo, Zn, Eksp. Theor. Fiz.53.1717 (1968) [Sov. Phys. JETP 26(1968) 1984].

[15]. Nimai Singh, Monisa Rajkhowa, Abhijit Borah, J.Phys.G: Nucl.Phys.34.345(2007); Pramana J.Phys 69.533(2007); N.Nimai Singh, H.Zeen. Devi, Mahadev. Patgiri, arXiv:0707.2713.