COBIMAXIMAL NEUTRINO MIXING IN TYPE-I SEESAW MODEL WITH A_4 FLAVOR SYMMETRY

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ABSTRACT

Here we explore a minimal model to understand the cobimaximal (CBM) lepton mixing ansatz based on A_4 non-Abelain discrete flavor symmetry. Tiny neutrino mass and mixing are analyzed here relying on the type-I seesaw mechanism and study the associated phenomenology. Subsequently, we predict the absolute neutrino mass and effective neutrino mass parameter responsible for neutrinoless double beta decay. We further comment on the lepton asymmetry of the universe in the context of the present model.

INTRODUCTION

Current neutrino oscillation suggests, the mixing scheme known as Cobimaximal lepton mixing [1, 2] which predicts specific values for the atmospheric mixing angle ($\theta_{23} = 45°$) and Dirac CP phase ($\delta = -90°$) still remains as a viable option for the neutrino oscillation data. On the other hand, small neutrino mass triggers the idea of new physics such as seesaw mechanism. Here we study a type-I seesaw scenario guided by A_4 discrete symmetry to reproduce neutrino mass as well as CBM mixing pattern for leptons.

STRUCTURE OF THE MODEL

• We work in a type-I seesaw framework to explain the smallness of light neutrino masses in conjugation with A_4 discrete symmetry to obtain the lepton mass matrices.

	ℓ	α_R	H	N_R	ϕ_T	ξ	ϕ_S
A_4	3	3	1	3	1	1	3
Z_3	ω^2	ω^2	1	ω^2	1	ω^2	ω^2
Z_2	1	- 1	1	1	-1	1	1

Table 1: Symmetry and Particle content of the model

• Here along with the right-handed neutrinos (N_R) the Standard Model is extended by three gauge singlet scalar fields. The VEV alignment for these flavons are considered as : $\langle\phi_T\rangle = u_T$, $\langle\xi\rangle = v_\xi$ and $\langle\phi_s\rangle = (v_1, v_2, v_3)$.

• Presence of $Z_3 \times Z_2$ symmetry forbids unwanted contribution in the lepton mass matrices.
• In this construction e_R, μ_R, τ_R together forms a A_4 triplet α_R and yields a diagonal mass matrix for the charged lepton through $\bar{\ell}H\alpha_R\phi_T/\Lambda$.
• Lagrangian for neutrino sector :

$$-\mathcal{L}_\nu = y\left(\bar{\ell}N_R\right)_{\mathbf{1}}\tilde{H} + (y_x\xi + y_\phi\phi_S)\overline{N_R^c}N_R + h.c. \quad (1)$$

• This generates the Dirac (m_D) and Majorana (M) neutrino mass matrices as

$$m_D = vY_\nu = vy\begin{pmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{pmatrix}, M = \begin{pmatrix}x & \epsilon_2 & \epsilon_1\\ \epsilon_2 & x & z\\ \epsilon_1 & z & x\end{pmatrix}$$

where $x = 2y_x v_\xi$, $z = 2y_\phi v_1$, $\epsilon_1 = 2y_\phi v_2$, $\epsilon_2 = 2y_\phi v_3$.

COBIMAXIMAL MIXING

• The cobimaximal pattern for leptonic mixing is good approximation for the observed neutrino oscillation data.
• Under this mixing scheme the lepton mixing matrix satisfy the condition

$$|U_{\mu i}| = |U_{\tau i}| \text{ with } i = 1, 2, 3. \quad (2)$$

• Immediate consequances : $\theta_{23} = 45°$, $\delta = \pm 90°$ while the mixing angles θ_{12} and θ_{13} are free.

• The condition given in Eq. (2) can be easily realised through the condition [3]

$$SU = U^\star\mathcal{K}, \quad (3)$$

the transformation matrix S can be written as

$$S = \begin{pmatrix}1 & 0 & 0\\ 0 & 0 & 1\\ 0 & 1 & 0\end{pmatrix}, \quad (4)$$

and $\mathcal{K}$ is a diagonal phase matrix.
• Furthermore the Majorana phases take trivial values in this mixing scheme. Such trivial values of the Majorana phases play a decisive role in the prediction for $\nu 0\beta\beta$.

BASICS OF A_4 SYMMETRY

• Standard Model accompanied with non-abelian discrete flavor groups are widely popular to understand the lepton masses and mixings.

• Out of all the discrete groups employed in this purpose A_4 turn out to be the most popular one.

• It is a discrete group of even permutations of four objects with three inequivalent one-dimensional representations (1, 1′ and 1″) and a three-dimensional representation (3).

• The multiplication rules : $\mathbf{1'} \otimes \mathbf{1'} = \mathbf{1''}, \mathbf{1'} \otimes \mathbf{1''} = \mathbf{1}, \mathbf{1''} \otimes \mathbf{1''} = \mathbf{1'}, \mathbf{3} \otimes \mathbf{3} = \mathbf{1} + \mathbf{1'} + \mathbf{1''} + \mathbf{3_a} + \mathbf{3_s}$

• The product rule for this two triplets ($A = (a_1, b_1, c_1)^T$ and $B = (a_2, b_2, c_2)^T$) :

$$(A \times B)_{\mathbf{1}} \sim a_1a_2 + b_1b_2 + c_1c_2,$$
$$(A \times B)_{\mathbf{1}} \sim a_1a_2 + b_1b_2 + c_1c_2,$$
$$(A \times B)_{\mathbf{1'}} \sim a_1a_2 + \omega^2 b_1b_2 + \omega c_1c_2,$$
$$(A \times B)_{\mathbf{1''}} \sim a_1a_2 + \omega b_1b_2 + \omega^2 c_1c_2,$$
$$(A \times B)_{\mathbf{3_s}} \sim (a_2b_3 + a_3b_2, a_3b_1 + a_1b_3, a_1b_2 + a_2b_1),$$
$$(A \times B)_{\mathbf{3_a}} \sim (a_2b_3 - a_3b_2, a_3b_1 - a_1b_3, a_1b_2 - a_2b_1)$$

where $\omega = e^{2i\pi/3}$ is the cube root of unity.

RESULTS

• The light neutrino mass therefore takes the form

$$m_\nu = m_D M^{-1} m_D^T = \lambda\begin{pmatrix}x^2 - z^2 & \epsilon_1 - x\epsilon_2 & \epsilon_2 - x\epsilon_1\\ \epsilon_1 - x\epsilon_2 & x^2 - \epsilon_1^2 & \epsilon_1\epsilon_2 - x\\ \epsilon_2 - x\epsilon_1 & \epsilon_1\epsilon_2 - x & x^2 - \epsilon_2^2\end{pmatrix}$$

where $\lambda = v^2y^2/z(x^3 - x\left({\epsilon_1}^2 + {\epsilon_2}^2 + z^2\right) + 2z\epsilon_1\epsilon_2)$
• This matrix can be diagonalized through the relation

$$U^T m_\nu U = \text{diag}(m_1, m_2, m_3), \quad (1)$$

where m_1, m_2, m_3 are the three real positive neutrino mass eigenvalues and the unitary rotation matrix U is given by

$$U = \begin{pmatrix}U_{11} & U_{12} & U_{13}\\ U_{21} & U_{22} & U_{23}\\ U_{31} & U_{32} & U_{33}\end{pmatrix}$$

with

$U_{11} = \cos\gamma_{12}\cos\gamma_{13}$, $U_{12} = -\cos\gamma_{13}\sin\gamma_{12}$,
$U_{13} = -\sin\gamma_{13}$,
$U_{21,31} = \frac{1}{\sqrt{2}}(\sin\gamma_{12} \pm i\cos\gamma_{12}\sin\gamma_{13})$,
$U_{22,32} = \frac{1}{\sqrt{2}}(\cos\gamma_{12} \pm i\sin\gamma_{12}\sin\gamma_{13})$,
$U_{23,33} = \pm\frac{i}{\sqrt{2}}\cos\gamma_{13}$.

• Clearly, the lepton mixing matrix obtained here satisfy the condition presented in Eq. (1).
• Comparing U_{33}, U_{13} with 13 and 33 elements of standard form (U_{PMNS}) of the lepton mixing matrix we obtain :

$$\boxed{\theta_{23} = 45°, \delta = -90°}$$

• Similarly, comparing U_{11} with 11 element of U_{PMNS} we find $\gamma_{13} = \theta_{13}$ and $\gamma_{12} = \theta_{12}$.
• For a typical bench mark point the sum of the three absolute neutrino mass, $\sum_i m_i$ is found to be 0. 063 eV and the effective mass parameter appearing in $\nu 0\beta\beta$ is found to be 0.004 eV.

REFERENCES

[1] E. Takagusi K. Fukuura, T. Miura. 1999.
[2] P. F. Harrison and W. G. Scott. 2002.
[3] W. Grimus and L. Lavoura. 2004.

LEPTOGENESIS AND FUTURE DIRECTION

The lepton asymmetry parameter ϵ is proportional to $\text{Im}[(Y_\nu^\dagger Y_\nu)_{ij}^2]$. In our set-up $Y_\nu^\dagger Y_\nu \propto \mathbf{I}$ and it leads towards vanishing lepton asymmetry. However, allowed by the symmetry, if we include a higher order correction in the Dirac Yukawa coupling through $\bar{\ell}N_R\tilde{H}\phi_S\phi_S^\dagger/\Lambda^2$ one can obtain the complex off diagonal entries in $Y_\nu^\dagger Y_\nu$ and leptogenesis becomes viable.

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