Inverse Seesaw under A_5' Modular symmetry

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Abstract

- The ingenuity of this work is to build a model that explains neutrino oscillation data under A_5' Modular symmetry making usage of Inverse Seesaw mechanism.
- The Standard Model (SM) is extended by three RH neutrinos (N_{Ri}) and three Sterile neutrinos (S_{Li}) along with one flavon field which eliminates unwanted terms in the superpotential and keeping the model consistent.

Introduction

- **A_5' Modular Symmetry:** A_5' modular symmetry has 120 elements divided into 9 conjugacy classes denoted as $\mathbf{1}, \hat{\mathbf{2}}, \hat{\mathbf{2}}', \mathbf{3}, \mathbf{3}', \mathbf{4}, \hat{\mathbf{4}}, \mathbf{5}$ and $\hat{\mathbf{6}}$ by their dimensions for $N = 5$ and τ being the complex variable given by

$$\tau \longrightarrow \gamma\tau = \frac{a\tau + b}{c\tau + d}, \text{ where } a, b, c, d \in \mathbb{Z}$$
$$\text{and } ad - bc = 1, \ \ \text{Im}[\tau] > 0$$

- **Inverse Seesaw:** The light neutrino mass matrix under the inverse seesaw in the flavor basis of (ν_L, N_R, S_L^c) is expressed as

$$\mathbb{M} = \begin{pmatrix} 0 & M_D & 0 \\ M_D^T & 0 & M_{RS} \\ 0 & M_{RS}^T & M_\mu \end{pmatrix}, \tag{1}$$

- The resulting mass formula

$$m_\nu = M_D \, M_{RS}^{-1} \, M_\mu \, (M_{RS}^{-1})^T \, (M_D)^T + \text{transpose}. \tag{2}$$

Model Framework

- The particle content of the model and their Quantum nos are given in Table 1.
- Thus, one can write the interaction Lagrangian for the **Charged Lepton, Dirac, Mixing of Heavy fermions** N_R **&** S_L **& Majorana mass term** are given in Eqns. **??, ??, ??, ??** respectively

$$\mathcal{W}_{\mathcal{M}_l} = \alpha_l \left[(\overline{L_L} e_R)_{\mathbf{3}} Y_{\mathbf{3}}^{(2)} \right] \mathcal{H}_d + \beta_l \left[(\overline{L_L} \mu_R)_{\mathbf{3}} Y_{\mathbf{3}}^{(4)} \right] \mathcal{H}_d + \gamma_l \left[(\overline{L_L} \tau_R)_{\mathbf{3}} \left\{ \sum_{i=1}^{2} Y_{\mathbf{3},i}^{(6)} \right\} \right] \mathcal{H}_d, \tag{3}$$

$$\mathcal{W}_D = \mathcal{H}_u \left[(\overline{L_L} \, N_R)_{\mathbf{4}} \sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)} \right] Diag(g_{D_1}, g_{D_2}, g_{D_3}), \tag{4}$$

$$\mathcal{W}_{\mathcal{M}_{RS}} = Diag(\alpha_{RS_1}, \alpha_{RS_2}, \alpha_{RS_3})[(\overline{S_L} N_R)_{\mathbf{5}} Y_{5,1}^{(6)} + (\overline{S_L} N_R)_{\mathbf{5}} Y_{5,2}^{(6)}]\zeta, \tag{5}$$

$$\mathcal{W}_\mu = \mu_0 \overline{S_L^c} S_L. \tag{6}$$

Fields	e_R	μ_R	τ_R	$\overline{L_L}$	N_R	S_L	$\mathcal{H}_{u,d}$	ζ
$SU(2)_L$	1	1	1	2	1	1	2	1
$U(1)_Y$	1	1	1	$-\frac{1}{2}$	0	0	$\frac{1}{2}, -\frac{1}{2}$	0
$U(1)_{B-L}$	-1	-1	-1	1	-1	0	0	1
A_5'	1	1	1	3	$3'$	$3'$	1	1
k_I	2	4	6	0	6	0	0	0

Table 1: Particle content of the model and their charges under $SU(2)_L \times U(1)_Y \times U(1)_{B-L} \times A_5'$ where k_I is the number of modular weight.

Mass Matrix and mixing angles expression

$$M_\ell = \frac{v_d}{\sqrt{2}} \begin{pmatrix} \alpha_l \left(Y_{\mathbf{3}}^{(2)}\right)_1 & \left(Y_{\mathbf{3}}^{(4)}\right)_1 & \left(\sum_{i=1}^{2} Y_{\mathbf{3},i}^{(6)}\right)_1 \\ \left(Y_{\mathbf{3}}^{(2)}\right)_3 & \beta_l \left(Y_{\mathbf{3}}^{(4)}\right)_3 & \left(\sum_{i=1}^{2} Y_{\mathbf{3},i}^{(6)}\right)_3 \\ \left(Y_{\mathbf{3}}^{(2)}\right)_2 & \left(Y_{\mathbf{3}}^{(4)}\right)_2 & \gamma_l \left(\sum_{i=1}^{2} Y_{\mathbf{3},i}^{(6)}\right)_2 \end{pmatrix}, \quad M_D = \frac{v_u}{2\sqrt{6}} \begin{pmatrix} 0 & -\sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{3}} & -\sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{2}} \\ \sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{4}} & g_{D_2}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{2}} & -\sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{1}} \\ \sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{1}} & \left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{4}} & -g_{D_3}\left(\sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right)_{\mathbf{3}} \end{pmatrix},$$

$$M_{RS} = \frac{v_\zeta}{\sqrt{2}} \begin{pmatrix} 2\,\alpha_{RS_1}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_1 & -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_4 & -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_3 \\ -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_4 & -\sqrt{6}\,\alpha_{RS_2}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_2 & -\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_1 \\ -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_3 & -\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_1 & -\sqrt{6}\,\alpha_{RS_3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_5 \end{pmatrix},$$

$$M_\mu = \mu_0 \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}.$$

$$\sin^2\theta_{13} = |U_{13}|^2, \quad \sin^2\theta_{23} = \frac{|U_{23}|^2}{1 - |U_{13}|^2}, \quad \sin^2\theta_{12} = \frac{|U_{12}|^2}{1 - |U_{13}|^2}. \ [U \text{ diagonalizes matrix (1)}]$$

Results

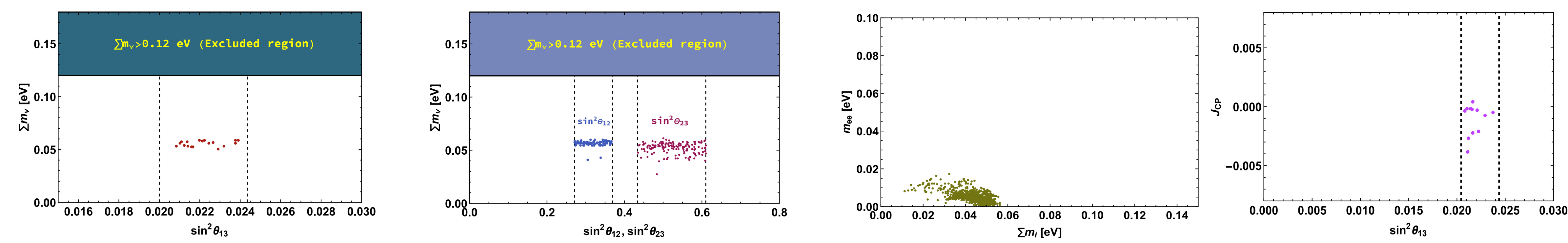

Figure 1: These plots express mixing angles $\sin^2\theta_{13}$ (left), $\sin^2\theta_{12}$ and $\sin^2\theta_{23}$ (left middle), m_{ee}[eV] (right middle) versus Σm_i[eV] and J_{CP} versus $\sin^2\theta_{13}$(right).

Conclusion

- We have studied the inverse seesaw mechanism under modular A_5' symmetry along with the $U(1)_{B-L}$ local symmetry, forbidding unnecessary terms and restrict structures of relevant superpotential terms.
- We were able to successfully explain the observed neutrino oscillation data (mixing angles and the mass-squared differences) as well as the cosmological bound on neutrino masses i.e., $\Sigma m_i \leqslant 0.12$ eV.

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References

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