Phenomenological aspects of A_5' modular symmetry on linear seesaw with leptogenesis

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Abstract

- The uniqueness of this work is that it employs the Linear Seesaw mechanism in **SUSY** to create a model that explains neutrino oscillation data under A_5' modular symmetry.
- The Standard Model (SM) is supplemented by three RH neutrinos (N_{R_i}) and three Sterile neutrinos (S_{L_i}), as well as one weighton that eliminates unnecessary components in the superpotential and maintains the model consistent.

Introduction

- **A_5' Modular Symmetry:** The utilisation of flavon fields is minimised with $\Gamma_5' \approx A_5'$ modular symmetry, and the modular group is the group of linear fractional transformations occurring on a complex variable. τ, used in expressing Dedekind eta-function $\eta(\tau)$.

$$\tau \longrightarrow \gamma\tau = \frac{a\tau + b}{c\tau + d}\ , \text{ where } a, b, c, d \in \mathbb{Z}$$

$$\text{and} \quad ad - bc = 1, \quad \mathrm{Im}[\tau] > 0,$$

$$\eta(\tau) = e^{\frac{i\pi\tau}{12}} \prod_{n=1}^{\infty} (1 - e^{2in\tau\pi}). \tag{1}$$

- The dimension of Γ_5' is $5k+1$ hence their are six basis vectors used is expressing lowest weight Yukawa coupling $Y_{\mathbf{6}}^{(1)}$

$$\begin{aligned}
\hat{e}_1 &= 1 + 3q + 4q^2 + 2q^3 + q^4 + 3q^5 + 6q^6 + \cdots, \\
\hat{e}_2 &= q^{1/5}\left(1 + 2q + 2q^2 + q^3 + 2q^4 + 2q^5 + \cdots\right), \\
\hat{e}_3 &= q^{2/5}\left(1 + q + q^2 + q^3 + 2q^4 + q^6 + \cdots\right), \\
\hat{e}_4 &= q^{3/5}\left(1 + q^2 + q^3 + q^4 - q^5 + \cdots\right), \\
\hat{e}_5 &= q^{4/5}\left(1 - q + 2q^2 + 2q^6 - 2q^7 + \cdots\right), \\
\hat{e}_6 &= q\left(1 - 2q + 4q^2 - 3q^3 + q^4 + 2q^5 + \cdots\right).
\end{aligned} \tag{2}$$

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

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

- The resulting mass formula

$$m_\nu = M_D M_{RS}^{-1} M_{LS}^T + \text{transpose}. \tag{3}$$

Model Framework

- The complete superpotential is given by

$$\begin{aligned}
\mathcal{W} \;=\; & A_{M_l}\left[(L_L l_R^c)_{\mathbf{3}} Y_{\mathbf{3}}^{k_Y}\right] H_d + \mu H_u H_d + G_d\left[(L_L N_R^c)_{\mathbf{5}} Y_{\mathbf{5}}^{(2)}\right] H_u + \\
& G_{ls}\left[(L_L S_L)_{\mathbf{4}} H_u \sum_{i=1}^{2} Y_{\mathbf{4},i}^{(6)}\right] \frac{\zeta}{\Lambda} + B_{rs}\left[(S_L N_R^c)_{\mathbf{5}} \sum_{i=1}^{2} Y_{\mathbf{5},i}^{(6)}\right] \zeta'.
\end{aligned} \tag{4}$$

Fields	e_R^c	μ_R^c	τ_R^c	L_L	N_R^c	S_L	$H_{u,d}$	ζ	ζ'
$SU(2)_L$	1	1	1	2	1	1	2	1	1
$U(1)_Y$	1	1	1	$-\frac{1}{2}$	0	0	$\frac{1}{2}, -\frac{1}{2}$	0	0
$U(1)_{B-L}$	1	1	1	-1	1	0	0	1	-1
A_5'	1	1	1	3	$3'$	$3'$	1	1	1
k_I	1	3	5	1	1	4	0	1	1

Table 1: The particle spectrum and their charges under the symmetry groups $SU(2)_L \times U(1)_Y \times U(1)_{B-L} \times A_5'$ while k_I represents the modular weight.

Mass matrices expression

$$M_D = \frac{v_u G_d}{\sqrt{30}} \begin{pmatrix} \sqrt{3}(Y_{\mathbf{5}}^{(2)})_1 & (Y_{\mathbf{5}}^{(2)})_4 & (Y_{\mathbf{5}}^{(2)})_3 \\ (Y_{\mathbf{5}}^{(2)})_5 & -\sqrt{2}(Y_{\mathbf{5}}^{(2)})_3 & -\sqrt{2}(Y_{\mathbf{5}}^{(2)})_2 \\ (Y_{\mathbf{5}}^{(2)})_2 & -\sqrt{2}(Y_{\mathbf{5}}^{(2)})_5 & -\sqrt{2}(Y_{\mathbf{5}}^{(2)})_4 \end{pmatrix}, M_{RS} = \frac{v_\zeta B_{rs}}{\sqrt{60}} \begin{pmatrix} 2\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_1 & -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_4 & -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_3 \\ -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_4 & \sqrt{6}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_2 & -\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_1 \\ -\sqrt{3}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_3 & -\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_1 & \sqrt{6}\left(\sum_{i=1}^{2} Y_{\mathbf{5,i}}^{(6)}\right)_5 \end{pmatrix}$$

$$M_{LS} = \frac{v_u}{2\sqrt{6}}\left(\frac{v_\zeta}{\sqrt{2}\Lambda}\right) G_{ls} \begin{pmatrix} 0 & -\sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_3 & -\sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_2 \\ \sqrt{2}\left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_4 & -\left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_2 & \left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_1 \\ \left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_1 & \left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_4 & -\left(\sum_{i=1}^{2} Y_{\mathbf{4,i}}^{(6)}\right)_3 \end{pmatrix}. \tag{5}$$

Leptogenesis

- To account for leptogenesis, a higher dimensional mass term for the Majorana fermion (N_R) is introduced as in eqn.(6), resulting in a tiny mass splitting between the heavy fermions, where G_R is the coupling.

$$\mathcal{W}_{M_R} = -G_R\left[\sum_{i=1}^{2} Y_{5,i}^{(4)} N_R^c N_R^c\right] \frac{\zeta'^2}{\Lambda}. \tag{6}$$

Boltzmann equations

$$\begin{aligned}
\frac{dY_{N^-}}{dz} &= -\frac{z}{sH(M_1^-)}\left[\left(\frac{Y_{N^-}}{Y_{N^-}^{\rm eq}} - 1\right)\gamma_D + \left(\left(\frac{Y_{N^-}}{Y_{N^-}^{\rm eq}}\right)^2 - 1\right)\gamma_S\right], \\
\frac{dY_{B-L}}{dz} &= -\frac{z}{sH(M_1^-)}\left[\epsilon_{N^-}\left(\frac{Y_{N^-}}{Y_{N^-}^{\rm eq}} - 1\right)\gamma_D - \frac{Y_{B-L}}{Y_\ell^{\rm eq}}\frac{\gamma_D}{2}\right].
\end{aligned} \tag{7}$$

Here, s denotes the entropy density, $z = M_1^-/T$ and the equilibrium number densities are given by

$$Y_{N^-}^{\rm eq} = \frac{135 g_{N^-}}{16\pi^4 g_\star} z^2 K_2(z), \quad Y_\ell^{\rm eq} = \frac{135\zeta(3) g_\ell}{8\pi^4 g_\star}. \tag{8}$$

Conclusion

- We investigated the linear seesaw mechanism under modular A_5' symmetry and the local $U(1)_{B-L}$, which aids in the prohibition of needless terms and the constraint structures of crucial Yukawa interactions.
- In addition, our model is good enough to handle Leptogenesis.

Results

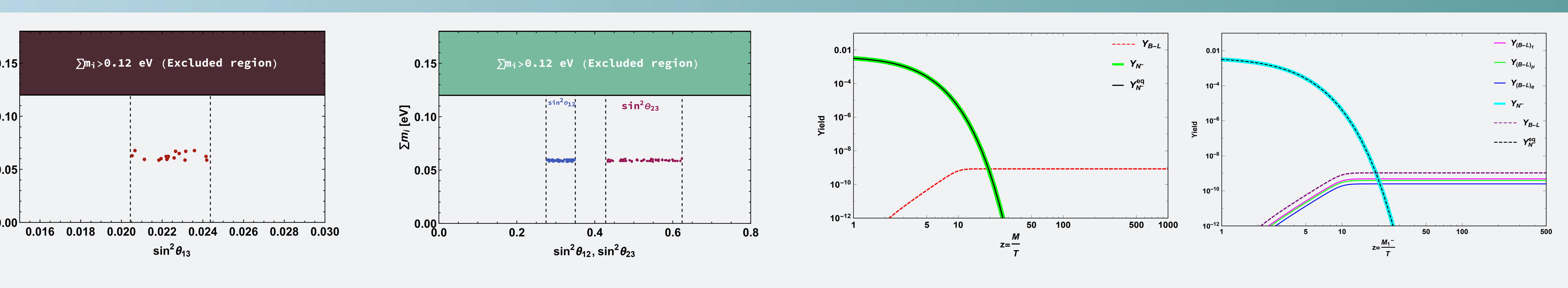

Figure 1: Extreme left plot represents $\sin^2\theta_{13}$, ($\sin^2\theta_{12}$ and $\sin^2\theta_{23}$) (middle) versus Σm_i[eV], right middle and extreme right plot shows evolution of Y_{B-L} (dashed) as a function of $z = M_1^-/T$ for one flavor approximation and flavoured case respectively.

References

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