Impact of modular S_3 symmetry on neutrino mixing and leptogenesis with type III seesaw

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Abstract

Discrete symmetries are being preferred to explain the neutrino phenomenology, we chose the simplest S_3 group and explore the implication of its modular form on neutrino masses and mixing. Non-trivial transformations of Yukawa couplings under this symmetry, make the model phenomenologically interesting by reducing the requirement of multiple scalar fields. This symmetry imposes a specific flavor structure to the neutrino mass matrix within the framework of less frequented type III seesaw mechanism and helps to explore the neutrino mixing consistent with the current observation. Apart, we also discuss the preferred scenario of leptogenesis to explain the baryon asymmetry of the universe by generating the lepton asymmetry from the decay of heavy fermion triplet at TeV scale.

The Model

Fields	$SU(2)_L$	$U(1)_Y$	S_3	k_I
(E_{1R}, E_{2R})	1	−2	2	1
E_{3R}	1	−2	1	1
(L_1^c, L_2^c)	2	1	2	−1
L_3^c	2	1	1	−1
$(\Sigma_{1R}, \Sigma_{2R})$	1	0	2	−1
Σ_{3R}	1	0	1	−1
H	2	1	1	0
ρ	1	0	1	−2

Couplings	S_3	k_I
$(y_1(\tau), \ y_2(\tau))$	**2**	**2**
$y_3(\tau)$	**1**	**4**
λ_ρ	**1**	**8**

$$y_1^{(2)}(\tau) = \frac{i}{4\pi}\frac{\eta'(\tau/2)}{\eta(\tau/2)} + \frac{\eta'((\tau+1)/2)}{\eta((\tau+1)/2)} - \frac{8\eta'(2\tau)}{\eta(2\tau)},$$

$$y_2^{(2)}(\tau) = \frac{\sqrt{3}i}{4\pi}\left(\frac{\eta'(\tau/2)}{\eta(\tau/2)} - \frac{\eta'((\tau+1)/2)}{\eta((\tau+1)/2)}\right),$$

$$y_3^{(4)}(\tau) = [(y_1(\tau), \ y_2(\tau)) \otimes (y_1(\tau), \ y_2(\tau))]_1 = y_1^2(\tau) + y_2^2(\tau).$$

$$\begin{aligned} V &= \mu_H^2(H^\dagger H) + \lambda_H(H^\dagger H)^2 + y_3\mu_\rho^2(\rho^\dagger\rho) + \alpha''\lambda_\rho(\rho^\dagger\rho)^2 \\ &\quad + \beta'' y_3(H^\dagger H)(\rho^\dagger\rho). \end{aligned}$$

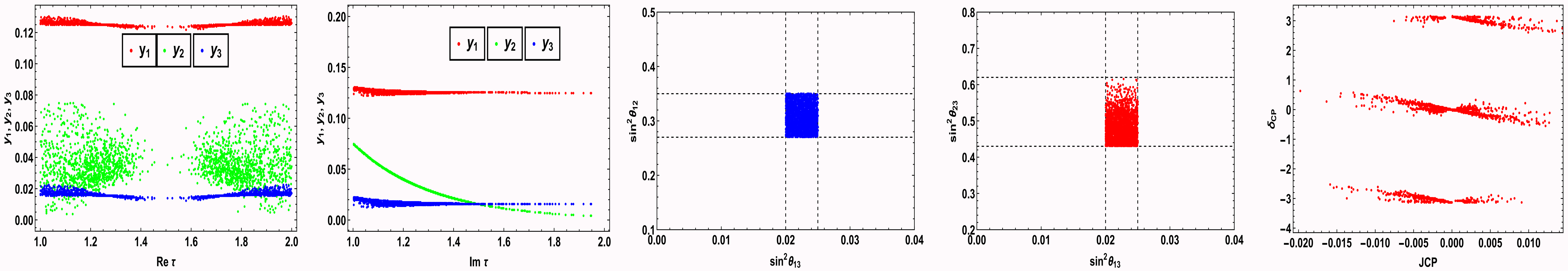
$$\begin{aligned} \mathcal{L}_l &= -y_e\left[\bar{L_1}HE_{1R} + \bar{L_2}HE_{2R}\right] - y_\tau\left[\bar{L_3}HE_{3R}\right] \\ &\quad - y_{SB}\left(\bar{L_1}HE_{2R} + \bar{L_2}HE_{1R}\right) + \text{ H.c.} \end{aligned}$$

$$\begin{aligned} \mathcal{L}_\nu^\Sigma &= -y_1(\tau)\left[\bar{L_1}\Sigma_{2R}\tilde{H} + \bar{L_2}\Sigma_{1R}\tilde{H}\right]\alpha - y_1(\tau)\left[\bar{L_1}\Sigma_{3R}\tilde{H}\right]\gamma \\ &\quad - y_2(\tau)\left[\bar{L_1}\Sigma_{1R}\tilde{H} - \bar{L_2}\Sigma_{2R}\tilde{H}\right]\alpha - y_2(\tau)\left[\bar{L_2}\Sigma_{3R}\tilde{H}\right]\gamma \\ &\quad - y_1(\tau)\left[\bar{L_3}\Sigma_{1R}\tilde{H}\right]\beta - y_2(\tau)\left[\bar{L_3}\Sigma_{2R}\tilde{H}\right]\beta \\ &\quad - y_3(\tau)\left[\bar{L_3}\Sigma_{3R}\tilde{H}\frac{\rho}{\Lambda}\right]\alpha' + \text{ H.c.} \end{aligned}$$

Neutrino masses and mixing in the framework of type III seesaw

The Dirac mass matrices for charged leptons (M_ℓ) and neutral leptons (M_D) and the Majorana mass for the triplet (M_Σ) can be written as following.

$$M_\ell = \frac{v}{\sqrt{2}}\begin{pmatrix} y_e & y_{SB} & 0 \\ y_{SB} & y_e & 0 \\ 0 & 0 & y_\tau \end{pmatrix}, \quad U_{el} = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad M_D = \frac{v}{\sqrt{2}}\begin{pmatrix} \alpha y_2 & \alpha y_1 & \gamma y_1 \\ \alpha y_1 & -\alpha y_2 & \gamma y_2 \\ \beta y_1 & \beta y_2 & \alpha' y_3 \frac{v_\rho}{\Lambda} \end{pmatrix}, \quad M_\Sigma = \begin{pmatrix} M_0 y_2 & M_0 y_1 & 0 \\ M_0 y_1 & -M_0 y_2 & 0 \\ 0 & 0 & M_0' y_3 \frac{v_\rho}{\Lambda} \end{pmatrix}, \quad U_\Sigma = \begin{pmatrix} \frac{u_-}{\sqrt{N_-}} & \frac{u_+}{\sqrt{N_+}} & 0 \\ \frac{1}{\sqrt{N_-}} & \frac{1}{\sqrt{N_+}} & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$



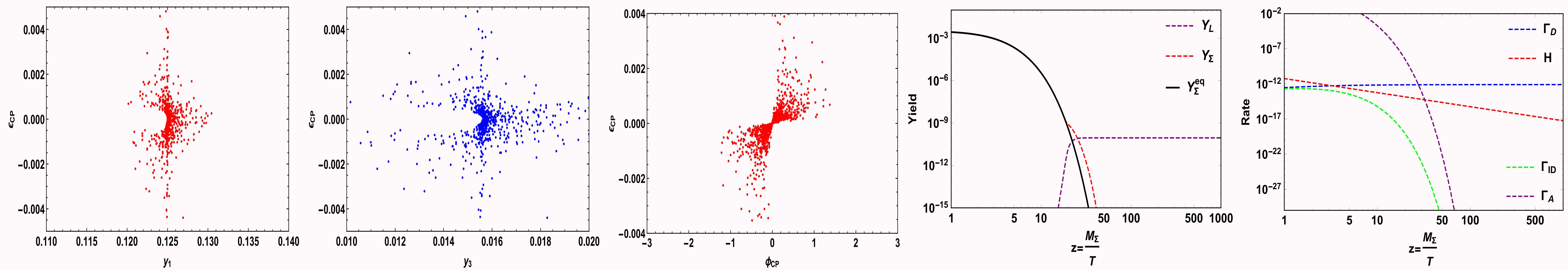
- We obtain the constraints on model parameters as per the 3σ neutrino oscillation data $\lesssim \ y_1(\tau) \lesssim 0.14$, $0 \lesssim \ y_2\ (\tau) \lesssim 0.08$ and $0.01 \lesssim \ y_3\ (\tau) \lesssim 0.03$ and $\delta_{CP} \in [-0.06, 0.06]$ and $[\pm 2.6, \pm 3.14]$ rad. By randomly varying the model parameters,

$$\text{Re}[\tau], \ \text{Im}[\tau] \in [1, 2], \quad \alpha, \gamma \in \ [0.005, 0.01], \quad \beta \in \ [0.02, 0.06], \quad \alpha' \in \ [0.1, 1], \qquad M_0 \in [10^2, 5\times 10^4], \quad M_0' \in [5\times 10^2, 10^6], \quad \frac{v_\rho}{\Lambda} = 0.1.$$

Resonant leptogenesis with fermion triplets

$$\epsilon_{CP}^\Sigma = -\sum_j \frac{3}{2}\frac{M_{\Sigma_i}}{M_{\Sigma_j}}\frac{\Gamma_{\Sigma_i}}{M_{\Sigma_j}}\frac{V-2S}{3}\frac{\text{Im}\left(\tilde{Y_\Sigma}\tilde{Y_\Sigma}^\dagger\right)_{ij}^2}{\left(\tilde{Y_\Sigma}\tilde{Y_\Sigma}^\dagger\right)_{ii}\left(\tilde{Y_\Sigma}\tilde{Y_\Sigma}^\dagger\right)_{jj}}, \quad S = \frac{M_{\Sigma_j}^2 \Delta M_{ij}^2}{(\Delta M_{ij}^2)^2 + M_{\Sigma_i}^2\Gamma_{\Sigma_j}^2}, \quad \text{with } \Delta M_{ij} = M_{\Sigma_j} - M_{\Sigma_i}, \quad V = \frac{2M_{\Sigma_j}^2}{M_{\Sigma_i}^2}\left[\left(1 + \frac{M_{\Sigma_j}^2}{M_{\Sigma_i}^2}\right)\log\left(1 + \frac{M_{\Sigma_j}^2}{M_{\Sigma_i}^2}\right) - 1\right].$$

$$sHz\frac{dY_\Sigma}{dz} = -\left(\frac{Y_\Sigma}{Y_\Sigma^{\text{eq}}} - 1\right)\gamma_D - 2\left(\frac{Y_\Sigma^2}{(Y_\Sigma^{\text{eq}})^2} - 1\right)\gamma_A, \qquad sHz\frac{dY_L}{dz} = -\gamma_D\left(\frac{Y_\Sigma}{Y_\Sigma^{\text{eq}}} - 1\right)\epsilon_{CP}^\Sigma - \frac{Y_L}{Y_L^{\text{eq}}}\left(\frac{\gamma_D}{2} + 2\gamma_W\right).$$



Conclusion

- We explore the neutrino phenomenology within the less frequented type III seesaw scenario with modular S_3 symmetry.
- We obtained the constraints on model parameters as per the 3σ neutrino oscillation data with a finite CP violating phase and reactor mixing angle.
- Resonant leptogenesis is discussed from the decay of heavy fermion triplets.