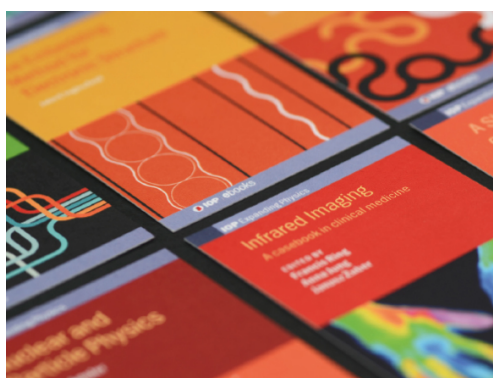


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Scalar triplet leptogenesis with S_3 symmetry

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Abstract. Extension of standard model with simplest discrete symmetry S_3 is considered to explain the neutrino masses and mixing consistent with the current observations. The particle content is extended by addition of right handed neutrinos and scalar triplets and explain the observed data in the neutrino sector. We mostly focus here on baryogenesis from the decay of a heavy triplets in the presence of right-handed neutrinos. The scenario also provides us the viability of TeV scale particles in the framework in the context of future collider searches of lepton flavor violation.

Albeit the success of standard model (SM), it fails to accommodate the explanation of certain experimental observations like neutrino mass, dark matter, matter-anti matter asymmetry etc. The current understanding is that there should be new physics (NP) beyond the SM and SM is the low energy effective theory of some higher theory, which is unknown. However, the search for direct or indirect detection of new physics beyond the standard model has not been successful so far. Nevertheless, the extension of SM is desired to justify the unexplained observations. Fortunately, there also exist few other observations in the flavor sector of the SM, where we have some kind of deviations from that of the SM expectations, although they cannot be construed as evidence of new physics. One can actually consider those deviations as smoking gun signals for possible new physics, which may lead to strong evidence of NP in the coming years or else may disappear with the accumulation of more data. Here we mention the possibility of lepton universality violation in the observables R_D and R_D^* , which are defined as

$$R_{D^{(*)}} = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)} \tau \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)} l \bar{\nu}_l)}, \quad (1)$$

where $l = e$ or μ . The SM predicted values for $R_D = 0.300 \pm 0.011$ and $R_D^* = 0.254 \pm 0.004$, and similar the observed values from different experiments are $0.340 \pm 0.027 \pm 0.013$ and $0.295 \pm 0.011 \pm 0.008$, respectively. The observed data for both the observables $R_D^{(*)}$ indicating the possibility that the τ leptons and rest other leptons (namely, e and μ) couple differently and lepton universality may have been observed to be broken in B decays. Although, it is difficult to say anything with certainty at this point of time, which in fact actually needs more careful study and, in particular, more precise experimental values with increased data set, but it has rekindled excitement in the community in the context of search for new physics beyond the SM.

Since our objective here is to study leptogenesis, we only take the clue from the above mentioned deviations in the flavor sector. If found to be true, then it will indicate that the τ lepton couples differently than the other leptons (e and μ). Looking at the neutrino sector, it is very well known that discrete symmetry has played an important role in the phenomenological



studies of observed neutrino oscillation data. In this context, one can find mention of S_3 , A_4 and other discrete symmetries. S_3 is the simplest discrete symmetry, where one makes an analogy with the doublet and singlet structures among the leptons and therefore the τ behavior could be different from the other leptons (μ and e).

Therefore, in the current framework, we include the simplest discrete symmetries S_3 and Z_2 along with the SM gauge group to explore the neutrino phenomenology and baryon asymmetry from leptogenesis [1]. The mentioned symmetries are widely discussed in the literature to explain neutrino masses and mixing with a specific flavor structure but very few are devoted towards the generation of lepton asymmetry from the decay of heavy triplets [2]. We extend the SM particle spectrum with three right-handed neutrinos, two Higgs doublets and two Higgs triplets to discuss the neutrino mixings compatible with current observation. Furthermore, we also explore the generation of lepton asymmetry from the decay of heavy triplets in the presence of right-handed neutrinos in two different mass scales [5].

1. The model framework

Addition of only scalar triplets are not enough to explain neutrino mixing and hence we include the right-handed neutrinos to explore the neutrino phenomenology with a type $I+II$ seesaw framework. The $SM \otimes S_3 \otimes Z_2$ invariant Lagrangian for type $I+II$ Yukawa interaction in the

Fields	$(L_e, L_\mu), L_\tau$	$(E_{1R}, E_{2R}), E_{3R}$	$(N_{1R}, N_{2R}), N_{3R}$	$(H_1, H_2), H_3$	Δ_1	Δ_2
G_{SM}	$(1, 2, -1)$	$(1, 1, -2)$	$(1, 1, 0)$	$(0, 2, 1)$	$(0, 3, 2)$	$(0, 3, 2)$
S_3	$2, 1$	$2, 1$	$2, 1$	$2, 1$	1	1
Z_2	$+$	$+$	$+$	$+$	$+$	$+$

Table 1. Particle contents and quantum numbers under SM and S_3

charged and neutral lepton sector, in the isospin basis of scalar triplet is given by [1]

$$\begin{aligned} \mathcal{L} \supset & -h_1 \left[\overline{L}_e \tilde{H}_2 N_{1R} + \overline{L}_\mu \tilde{H}_1 N_{1R} + \overline{L}_e \tilde{H}_1 N_{2R} - \overline{L}_\mu \tilde{H}_2 N_{2R} \right] - h_3 \left[\overline{L}_\tau \tilde{H}_1 N_{1R} + \overline{L}_\tau \tilde{H}_2 N_{2R} \right] \\ & - h_4 \left[\overline{L}_\tau \tilde{H}_3 N_{3R} \right] - \frac{1}{2} \overline{N}_{iR}^c M_{iR} N_{iR} - \frac{1}{2} \overline{N}_{3R}^c M_{3R} N_{3R} - y_{l2} \left[\overline{L}_e H_2 E_{1R} + \overline{L}_\mu H_1 E_{1R} + \right. \\ & \left. \overline{L}_e H_1 E_{2R} - \overline{L}_\mu H_2 E_{2R} \right] - y_{l4} \left[\overline{L}_\tau H_1 E_{1R} + \overline{L}_\tau H_2 E_{2R} \right] - y_{l5} \left[\overline{L}_e H_1 E_{3R} + \overline{L}_\mu H_2 E_{3R} \right] \\ & + y_{t_i} \left[\overline{L}_e^c i\tau_2 \Delta_i L_e + \overline{L}_\mu^c i\tau_2 \Delta_i L_\mu \right] + y_{t_i}' \left[\overline{L}_\tau^c i\tau_2 \Delta_i L_\tau \right] + \mu_i \left[\tilde{H}_1^\dagger \Delta_i^\dagger H_1 + \tilde{H}_2^\dagger \Delta_i^\dagger H_2 \right] \\ & + \mu_i' \left[\tilde{H}_3^\dagger \Delta_i^\dagger H_3 \right] + h.c. \quad (i = 1, 2) \end{aligned}$$

The charged neutral lepton mass matrices can be constructed from the above Lagrangian. The rotation and redefinition of the Higgs fields along with the diagonalization and parameterization of the mass matrices are discussed in detail in [5].

1.1. Lepton asymmetry from the decay of triplet with mass $\mathcal{O}(10^{10})$ GeV

We realized that the diagonal structure of the triplet Yukawa leads to a vanishing CP contribution from the lepton mediated loop. But still the CP asymmetry can be generated from the Higgs mediated self energy and right-handed neutrino vertex diagrams, which are provided below [2].

$$\epsilon_\Delta^h \approx \frac{3}{16\pi^2} \frac{3y_{t1}' y_{t2}' (\mu_{1L} \mu_{2L}^*) \sin \phi_{\text{cph}}}{\Gamma_{\Delta_1} M_{\Delta_1}} g \left(\frac{M_{\Delta_1}^2}{M_{\Delta_2}^2} \right), \quad \epsilon_\Delta^N \approx \frac{-1}{4\pi} \frac{M_{\Delta_1}^2}{M_{3R}} \frac{\mu_{\Delta_1} y_{t1}' y_{\nu_3}^2 \sin \phi_{\text{cph}}}{M_{\Delta_1}^2 \text{Tr}(Y_{\Delta_1}^\dagger Y_{\Delta_1}) + |\mu_{\Delta_1}|^2}. \quad (\text{For } M_{iR} \gg M_{\Delta_1}) \quad (2)$$

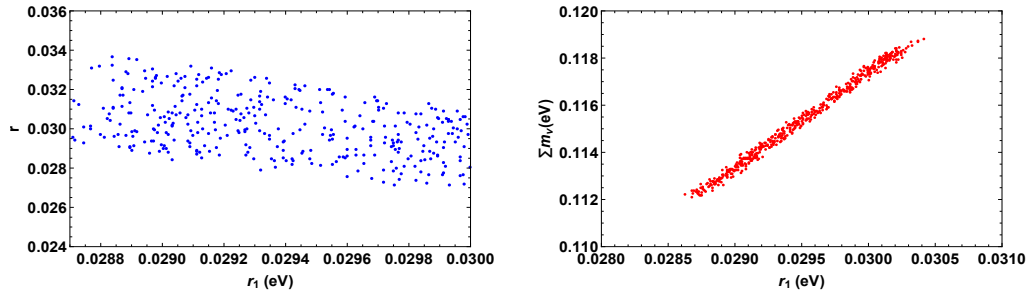


Figure 1. The left panel displays the variation of ratio of solar to atmospheric mass squared differences with r_1 and the right panel shows the variation of total active neutrino mass with the same. These plots constrain the parameter space of r_1 as per the current neutrino oscillation data.

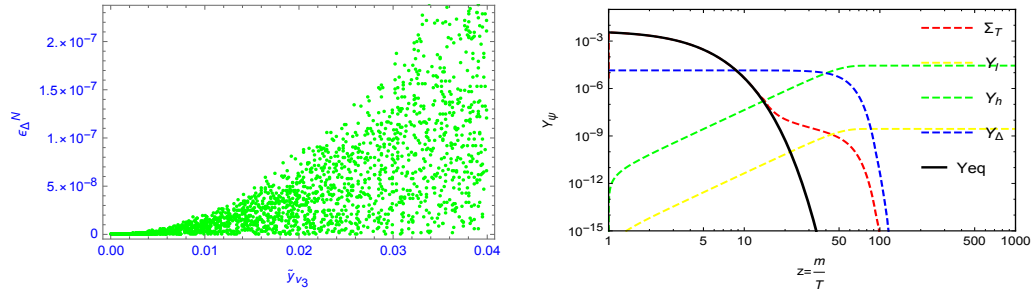


Figure 2. The left panel shows the variation of Yukawa coupling with the CP asymmetry and the right panel represents the solution of Boltzmann equations, which gives rise to the required lepton asymmetry compatible with the observed baryon asymmetry.

2. Resonant enhancement of CP asymmetry with TeV scale triplets

We consider the standard scenario of resonant leptogenesis, where the self energy enhancement is done by fixing the mass difference between the two heavy triplets [2].

$$\epsilon_{CP} = \frac{1}{2\pi} \frac{\text{Im} \left[Y_{\Delta_1} Y_{\Delta_2}^\dagger \mu_{\Delta_1}^* \mu_{\Delta_2} \right]}{M_{\Delta_1}^2 (Y_{\Delta_1}^\dagger Y_{\Delta_1})_{ii} + \mu_{\Delta_1}^2} \frac{M_{\Delta_1}^2 \delta M_{12}^2}{(\delta M_{12}^2)^2 + M_{\Delta_1}^2 \Gamma_{\Delta_2}^2}, \quad \delta M_{12}^2 = M_{\Delta_2}^2 - M_{\Delta_1}^2. \quad (3)$$

Parameters	M_{Δ_1} (TeV)	M_{Δ_2} (TeV)	$y_{t1}' \mu_{1L}$ (GeV)	$y_{t2}' \mu_{2L}$ (GeV)	$\sum m_\nu$ (eV)	ϵ_{CP}
BP1	2	20	7.2×10^{-10}	9×10^{-7}	0.023	0.06
BP1	2	20	6×10^{-10}	7.6×10^{-7}	0.02	0.1

Table 2. Benchmark points for the parameters satisfying the constraints from neutrino mass and observed baryon asymmetry.

2.1. Comments on Lepton flavor violation

Lepton flavor violating decay processes have received great attention in last few decades [3]. In this context, $\mu \rightarrow e\gamma$ is found to be an important process to be measured with less background from observation. The current experimental limit on this decay is $\text{Br}(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}$ from MEG collaboration [4]. In the framework of low scale leptogenesis, we can have extra contribution to rare decays $l_\alpha \rightarrow l_\beta\gamma$ due to the presence of right handed neutrinos and Higgs.

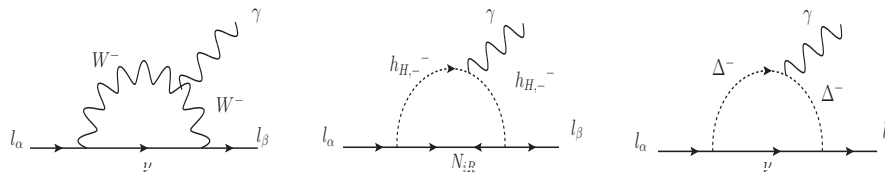


Figure 3. Feynman diagrams represent the Lepton flavor violating rare decays and muon $g-2$ anomaly in one loop level.

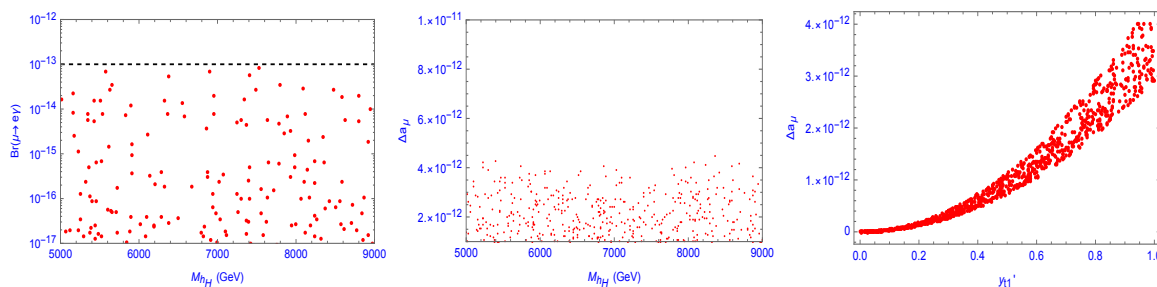


Figure 4. The left middle panel shows the allowed Higgs mass as per the experimental limit of LFV and muon anomalous magnetic moment, where, the right most panel represents the variation of triplet-lepton Yukawa with muon anomalous magnetic moment.

3. Summary

We discuss the neutrino masses and mixings with a non-vanishing θ_{13} in this framework and obtained constraints on the model parameters from current oscillation data. Leptogenesis from the decay of lightest heavy triplet is explored in detail with the S_3 symmetry in two different mass scales. The TeV scale triplet opens up the future scope for the collider searches. The presence of right handed neutrinos not only explains the neutrino sector but also contribute to the lepton asymmetry along with providing valuable insights into rare lepton flavor violating decays [5].

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