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Abstract. We investigate leptogenesis in the E_6 inspired Exceptional Supersymmetric Standard Model (E_6SSM). Right-handed (RH) neutrinos are singlets under the Standard Model gauge groups and the extra U_1 gauge group of the E_6SSM at low energies and are therefore not involved in gauge interactions. This allows them to have Majorana mass large enough for the seesaw mechanism and leptogenesis. In addition to canonical leptogenesis, the RH neutrinos may decay into exotic leptons and leptoquarks, the subsequent decays of which lead to extra lepton asymmetries. We find that the lepton asymmetry can be drastically enhanced as compared with that in the SM and MSSM?

1. Introduction

Leptogenesis from thermally produced Majorana RH neutrino decays is recognized as the most popular scenario for solving the Baryon Asymmetry of the Universe (BAU) problem. The heavy Majorana mass term of RH neutrinos violates lepton number, thus out-of-thermal-equilibrium CP asymmetric $\Delta L = 1$ decays of RH neutrinos could produce a net lepton number in the early universe. This net lepton number can be converted into baryon number via a sphaleron process above the electroweak scale.

The CP asymmetry in RH neutrino decays is critical in leptogenesis, and is defined as

$$\epsilon_{i,\ell_k} \equiv \frac{\Gamma_{N_i\to\ell_k+H} - \Gamma_{N_i\to\bar{\ell}_k+H^*}}{\sum_m \left(\Gamma_{N_i\to\ell_m+H} + \Gamma_{N_i\to\bar{\ell}_m+H^*}\right)} . \tag{1}$$

These CP asymmetries have been calculated in the SM [1] and the MSSM [2]. The final baryon number of the universe can be calculated by incorporating these CP asymmetries into the appropriate Boltzmann equations.

However, it is widely argued that applying constraints on the left-handed neutrino mass from the seesaw model and the reheating temperature of the universe, prevents enough lepton asymmetry from being produced. One possible solution is to extend the standard picture of leptogenesis by including more lepton number violating processes.

In the E_6 inspired Exceptional Supersymmetric Standard Model [3, 4], the RH neutrinos decay into ordinary leptons but also to an exotic lepton L' via Yukawa couplings. Additionally, when the model's extra Z_2^H symmetry is violated, extra decays must be considered, depending on how Z_2^H is broken; in both models I and II one has extra decays to "non-Higgs" particles, and in model II additionally decays to leptoquarks. We find that the lepton asymmetry can be drastically enhanced by these new channels. Assuming the maximal CP violating phase,

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successful leptogenesis can be achieved at a temperature as low as $T \sim M_1 \sim 10^6\,GeV$, where M_1 is the lightest RH neutrino mass.

2. The E$_6$SSM

The Exceptional Supersymmetric Standard Model is a superstring inspired E_6 model, which has the gauge breaking chain at high energies: $E_6 \to SO(10) \times U(1)_\chi\,, SO(10) \to SU(5) \times U(1)_\psi\,.$ At low energies only the combination $U(1)_N = \frac{1}{4}U(1)_\chi + \frac{\sqrt{15}}{4}U(1)_\psi$ survives, and the gauge symmetry is $SU(3)_C \times SU(2)_W \times U(1)_Y \times U(1)_N$. Three generations of the fundamental 27 representation of E_6 are included in the E$_6$SSM, providing three generations of regular leptons and quarks; RH neutrinos, N; Higgs bosons, H_1 and H_2; a gauge singlet S and exotic quarks $D, \overline{D}$, together with their supersymmetric partners. In addition, we also have exotic leptons L', $\overline{L'}$[1] with one generation, which is required for the gauge coupling unification. Gauge anomalies are canceled within each generation. To suppress tree level FCNC processes, a Z_2^H symmetry is introduced, under which all fields are odd except the third generation Higgs, $H_{1,3}, H_{2,3}$ and singlet S_3. Here $H_{1,3} = H_d, H_{2,3} = H_u$ are the down/up type Higgs, as in the MSSM. The superpotential with conserved Z_2^H is

$$\begin{aligned} W_{\mathrm{E_6SSM}} \simeq\ & \lambda_i S(H_{1i}H_{2i}) + \kappa_i S(D_i\overline{D}_i) + f_{\alpha\beta}(H_d H_{2\alpha})S_\beta + \tilde{f}_{\alpha\beta}(H_{1\alpha}H_u)S_\beta \\ & + h_{ij}^U(H_u Q_i)u_j^c + h_{ij}^D(H_d Q_i)d_j^c + h_{ij}^E(H_d L_i)e_j^c + h_{ij}^N(H_u L_i)N_j^c \\ & + \frac{1}{2}M_{ij}N_i^c N_j^c + \mu'(L'\overline{L}') + h_{4j}^E(H_d L')e_j^c + h_{4j}^N(H_u L')N_j^c\,. \end{aligned} \tag{2}$$

Effectively one can regard L' has having one unit of lepton number. The breaking of Z_2^H gives extra terms in the superpotential:

$$W_N = \xi_{\alpha ij}(H_{2\alpha}L_i)N_j^c + \xi_{\alpha 4j}(H_{2\alpha}L')N_j^c\,, \tag{3}$$

where $\alpha = 1, 2$ represents the non-Higgs fields. In model I, the exotic quarks D are diquarks, carrying 2 units of baryon number and their superpotential is $W_1 = g_{ijk}^Q D_i\,(Q_j Q_k) + g_{ijk}^q \overline{D}_i d_j^c u_k^c$. In Model II, they are leptoquarks, carrying one lepton number and one baryon number, with a superpotential $W_2 = g_{ijk}^N N_i^c D_j d_k^c + g_{ijk}^E e_i^c D_j u_k^c + g_{ijk}^D\,(Q_i L_j)\,\overline{D}_k$. In this model, these Z_2^H violating Yukawa couplings are expected to be very small.

3. CP Asymmetry in the E$_6$SSM

When the Z_2^H symmetry is conserved, the new contributions to lepton number violating processes include RH neutrino decays to the new final state L': $N_1 \to L' + H_u$, $N_1 \to \widetilde{L}' + \widetilde{H}_u$, $\widetilde{N}_1 \to \overline{L}' + \overline{\widetilde{H}}_u$, $\widetilde{N}_1 \to \widetilde{L}' + H_u$. The CP asymmetries appear at one-loop,

$$\epsilon_{1,\ell_k} = \epsilon_{1,\widetilde{\ell}_k} = \epsilon_{\widetilde{1},\ell_k} = \epsilon_{\widetilde{1},\widetilde{\ell}_k} \simeq -\frac{3}{8\pi}\sum_{j=2,3}\frac{\mathrm{Im}\left[\left((h^{N\dagger}h^N)_{1j} + h_{41}^{N*}h_{4j}^N\right)h_{1k}^{N\dagger}h_{kj}^N\right]}{(h^{N\dagger}h^N)_{11} + |h_{41}^N|^2}\frac{M_1}{M_j}\,, \tag{4}$$

$$\epsilon_{1,L'} = \epsilon_{1,\widetilde{L}'} = \epsilon_{\widetilde{1},L'} = \epsilon_{\widetilde{1},\widetilde{L}'} \simeq -\frac{3}{8\pi}\sum_{j=2,3}\frac{\mathrm{Im}\left[(h_{41}^{N*}h_{4j}^N)^2 + (h_{41}^{N*}h_{4j}^N)(h^{N\dagger}h^N)_{1j}\right]}{(h^{N\dagger}h^N)_{11} + |h_{41}^N|^2}\frac{M_1}{M_j}\,, \tag{5}$$

where $k = 1, 2, 3$. And h_{4j}^N denotes couplings to the new L'. Note the important coupling is the Yukawa coupling of the *second lightest* RH neutrino, h_{42}^N. The lepton number of L' can be

[1] These notations differ from that of Ref [3][4] from the extra 27 and $\bar{27}$, where these new leptons are called H', $\overline{H'}$.

released into ordinary leptons via the decay $L' \to L + H_u$. When Z_2^H is violated, decays with the "non-Higgs" in the final states are included: $N_1 \to L_k + H_{2\beta}$, $N_1 \to \widetilde{L}_k + \widetilde{H}_{2\beta}$, $\widetilde{N}_1 \to \overline{L}_k + \overline{\widetilde{H}}_{2\beta}$, $\widetilde{N}_1 \to \widetilde{L}_k + H_{2\beta}$, $N_1 \to L' + H_{2\beta}$, $N_1 \to \widetilde{L}' + \widetilde{H}_{2\beta}$, $\widetilde{N}_1 \to \overline{L}' + \overline{\widetilde{H}}_{2\beta}$, $\widetilde{N}_1 \to \widetilde{L}' + H_{2\beta}$, where $\beta = 1, 2$.

In model II, leptoquarks also contribute to the generation of lepton asymmetry: $N_1 \to D_k + \widetilde{q}_j$, $N_1 \to \widetilde{D}_k + q_j$, $\widetilde{N}_1 \to D_k + q_j$, $\widetilde{N}_1 \to \widetilde{D}_k + \widetilde{q}_j$. Notice D, $\overline{D}$ have the R parity -1. The lepton number of D can be released into SM leptons via consequent decays such as $D_k \to L_i + \widetilde{q}_j^\dagger$.

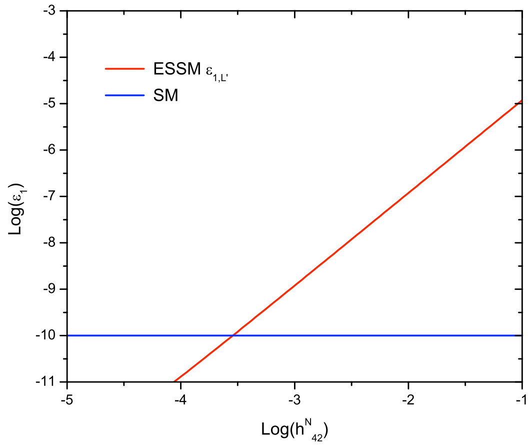

Figure 1. CP asymmetry versus the Yukawa coupling h_{24}, assuming maximal CP phases. We set $M_1 = 10^6\,GeV$, $M_2 = 10^8\,GeV \ll M_3$. The blue line indicates the total CP asymmetry in standard leptogenesis.

CP asymmetries are illustrated in Figure (1). The final BAU should be calculated using flavour dependent Boltzmann Equations. In this proceedings, we estimate the efficiency factor η_e using [5]. η_e achieves its maximal value ~ 0.1 for the parameter $K \equiv \Gamma_{N_1}/H(M_1) \sim 1$, where $H(M_1)$ is the Hubble constant at temperature $T \sim M_1$, which requires $h^N_{k1} \sim h^N_{41} \sim 10^{-5}$. A successful baryon asymmetry can then be acheived for $h^N_{42} \sim 0.03$ giving $n_b = A\,\eta_e \epsilon_{1,\ell_4}/g_* \sim 0.1 \times 10^{-6} \times 10^{-2} \sim 10^{-9}$, where $A \sim 1$ and $g_* \sim 100$ are the sphaleron rate and the number of particle degrees of freedom respectively.

4. Conclusion

New contributions to leptogenesis in the Exceptional Supersymmetric Standard Model are considered. We have presented CP asymmetries in the RH neutrino decays, and found that they can be drastically enhanced. We have estimated the efficiency factor converting CP asymmetry to final baryon asymmetry, and the result indicates that the right amount of lepton asymmetry can be achieved for successful baryogenesis.

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