Thermal Leptogenesis in $SO(10) \times U(1)_A$ GUT

K.Shibata[1] (Speaker), N.Maekawa[2], M.Yamanaka[3]

[1]Nagoya Univ. E-lab, [2]KMI, [3]Hosei Univ.

We discuss thermal leptogenesis in SUSY $SO(10) \times U(1)_A$ GUT and show the contribution of second generation right-handed neutrinos.

Introduction

Problems in particle physics $\rightarrow$ Beyond Standard Model (BSM)

- Baryon asymmetry ($\eta_B \neq 0$)
- Neutrino mass ($m_\nu \ll m_q, m_l$) etc...

Grand Unified Theory(GUT) is a kind of BSM theory.

- Some GUTs introduce Right-handed neutrino (RHN:N) (example) $SO(10)$, E_6...

RHN explain two phenomena, so this is useful.

- $\eta_B \neq 0 \rightarrow$ Leptogenesis [1]
- $m_\nu \rightarrow$ Seesaw mechanism $\quad m_\nu = m_D M^{-1} m_D^\dagger$

We focus on leptogenesis in $SO(10) \times U(1)_A$ GUT.

$SO(10) \times U(1)_A$ Grand Unified Theory

In $SO(10)$ GUT, $N_i \in \Psi_i(\mathbf{16}, \mathbf{1})$ is natulally introduced.

$SO(10)$ GUT has some problems.

- predicting that all Yukawa matrices are same.

$$Y^{ij}\Psi_i\Psi_j H \ni \; Y_u^{ij}\Psi_i(\mathbf{16},\mathbf{10})\Psi_j(\mathbf{16},\mathbf{10})H(\mathbf{10},\mathbf{5}) + Y_d^{ij}\Psi_i(\mathbf{16},\mathbf{10})\Psi_j(\mathbf{16},\bar{\mathbf{5}})H(\mathbf{10},\bar{\mathbf{5}}) + Y_\nu^{ij}\Psi_i(\mathbf{16},\bar{\mathbf{5}})\Psi_j(\mathbf{16},\mathbf{1})H(\mathbf{10},\mathbf{5})$$

- Doublet-Triplet splitting problem

$$H_{\text{Doublet}} \text{ Scale} \ll H_{\text{Triplet}} \text{ Scale}$$

$\longrightarrow$ add new $U(1)_A$ symmetry + matter field $T(\mathbf{10})$[2]

Frogatt-Nielsen mechanism

- Frogatt-Nielsen field Θ

$$U(1)_A \text{ charge} : \theta = -1$$
$$\text{VEV} : \langle\Theta\rangle = \lambda\Lambda_G, \quad \lambda \sim 0.22$$

- If use this FN field, supression factor corresponding $U(1)_A$ charge appears (all term has $O(1)$ coefficient)

$$\left(\frac{\Theta}{\Lambda_G}\right)^{\psi_i+\psi_j+h}\Psi_i\Psi_j H \rightarrow \lambda^{\psi_i+\psi_j+h}\Psi_i\Psi_j H \qquad (1)$$

- using same mechanism, we can decide RHN mass matrix

$$\Lambda_G^{-1}\lambda^{2\psi_i+2\bar{c}}\Psi_i\Psi_i\overline{CC} \rightarrow M_i = \Lambda_G\lambda^{2\psi_i-c+\bar{c}} \qquad (2)$$

and neutrino Yukawa matrix. (including T effect Δ)

$$Y_\nu = \begin{pmatrix} \lambda^{2\psi_1+h} & \lambda^{\psi_1+\psi_2+h} & \lambda^{\psi_1+\psi_3+h} \\ \lambda^{\psi_1+\psi_3+h+\Delta} & \lambda^{\psi_2+\psi_3+h+\Delta} & \lambda^{2\psi_3+h+\Delta} \\ \lambda^{\psi_1+\psi_2+h} & \lambda^{2\psi_2+h} & \lambda^{2\psi_2+h} \end{pmatrix} \qquad (3)$$

- $U(1)_A$ charge

	Ψ_1	Ψ_2	Ψ_3	T	H	C	$\overline{C}$	A
$SO(10)$	**16**	**16**	**16**	**10**	**10**	**16**	$\overline{\mathbf{16}}$	**45**
$U(1)_A$	$\psi_1 = \frac{9}{2}$	$\psi_2 = \frac{7}{2}$	$\psi_3 = \frac{3}{2}$	$t = 5/2$	$h = -3$	$c = -4$	$\bar{c} = -1$	$a = -1$

Enhancement for the RHN Masses

By $\langle A \rangle = \lambda^{-a}, a = -1$, we can consider the following terms.

$$\lambda^{2\psi_1+2\bar{c}+2a}\Psi_1\Psi_1\overline{CC}A^2 \rightarrow \lambda^{2\psi_1+2\bar{c}+2a-2a}\Psi_1\Psi_1\overline{CC} = \lambda^{2\psi_1+2c}\Psi_1\Psi_1\overline{CC}$$

- This is same contribution of (2)
  $\longrightarrow$these terms increase the M_1.
- some bounds in this enhancement.
  - $\Delta m_{12}, \Delta m_{23}$.
  - $U(1)_A$ charge $2\psi_1 + 2\bar{c}$

Thermal Leptogenesis in $SO(10) \times U(1)_A$ GUT

- Thermal leptogenesis in minimal $SO(10)$ can't be realized.
  - Limitations of the mass hierarchy of N_is and Ibarra bound[3]
  - This study presents a new leptogenesis possibility in $SO(10)$ GUT
- Important parameters in thermal leptogenesis
  - z: time dependent parameter $\quad z := M_1/T$
  - ϵ_i: CP violation

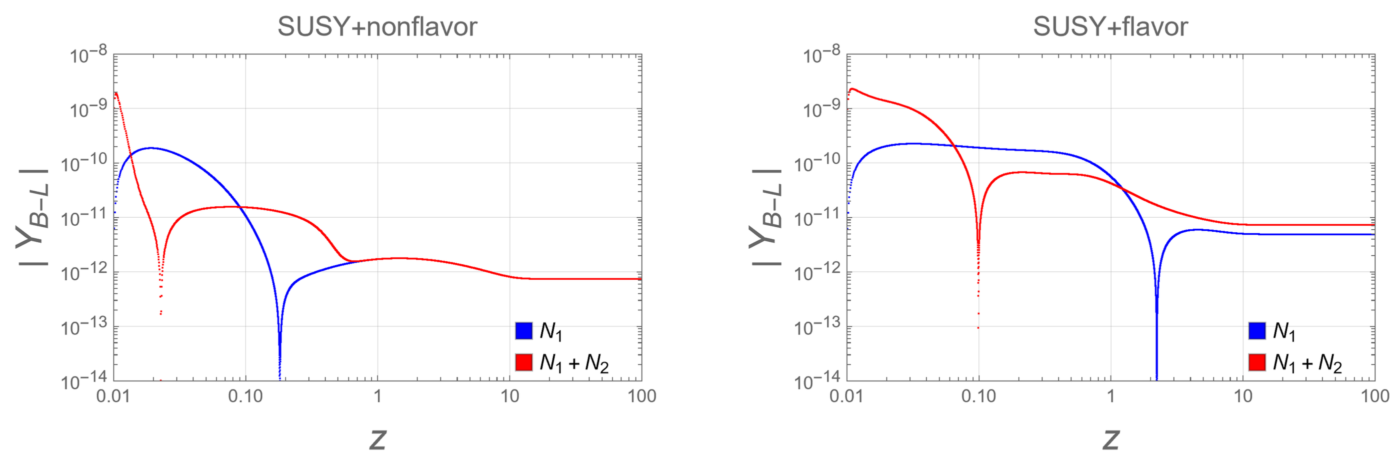
$$\epsilon_i := \frac{\Gamma_N - \overline{\Gamma}_N}{\Gamma_N + \overline{\Gamma}_N} = -\frac{1}{8\pi}\frac{1}{[Y_\nu^\dagger Y_\nu]_{ii}}\sum_j \text{Im}\left[(Y_\nu^\dagger Y_\nu)_{ij}^2\right] f\left(\frac{M_j^2}{M_i^2}\right) \propto M_i \qquad (4)$$

  - K_i: the strength of the interaction of RHN with SM particles

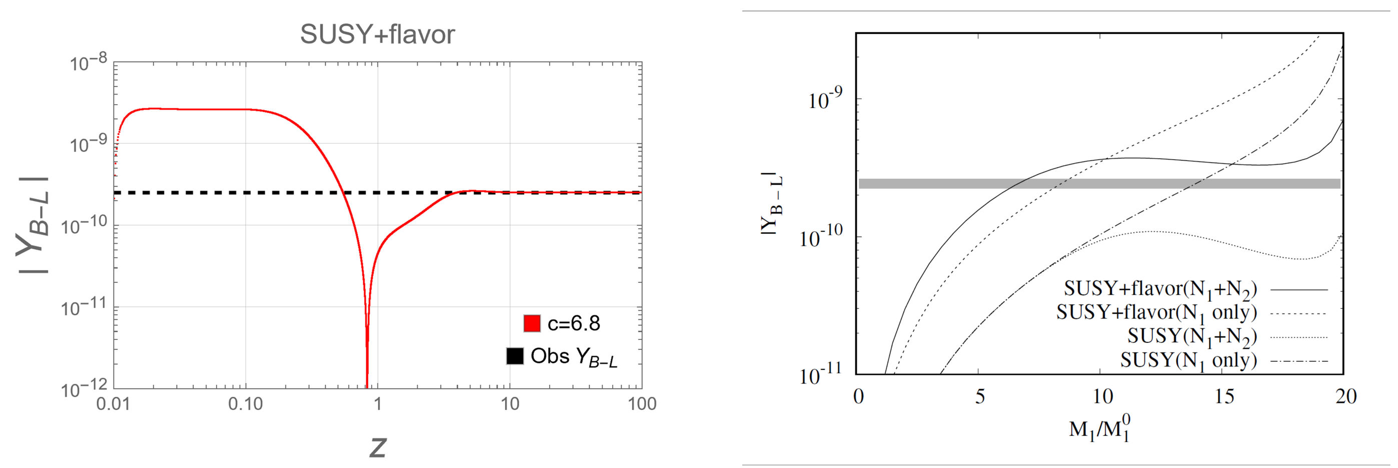
$$K_i := \frac{\Gamma_{N_i}|_{T=0}}{H|_{T=M_i}} = \frac{M_i}{8\pi}\left[Y_\nu^\dagger Y_\nu\right]_{ii}^2\left(\sqrt{\frac{4\pi^3 g_*}{45}}\frac{M_i^2}{m_{\text{pl}}}\right)^{-1} \propto M_i^{-1} \qquad (5)$$

- Lepton asymmetry is proportional to ϵ_i and maximized when $K_i = 1$
- Some effects
  - SUSY particle
  - lepton flavor
  - enhancement for M_1

  These effects increase lepton number
- We include 2nd generation RHN (N_2) contribution
  - In previous research, the contribution of N_2 is neglected.
  - When include lepton flavor effect, N_2 contribution cannot be neglected in this GUT.



- lepton asymmetry $\eta_{B-L} \simeq 2.5 \times 10^{-10}$[4]
  - M_1 consistent with η_L
    $\longrightarrow M_1 = 6.8 \times M_1^0 \simeq 1.748 \times 10^9$GeV



- This model predicts left-handed neutrino mass

$$M \overset{\text{seesaw}}{\longleftrightarrow} m_\nu$$

$\longrightarrow$It can be verified in future experiments

Conclusion and Future Works

Conclusion

- we considered leptogenesis in $SO(10) \times U(1)_A$ GUT
  - This study offers new possibilities for leptogenesis in $SO(10)$ GUT
- The contribution of N_2 is newly clarified in this framework.

Future Works

- The contribution N_3
  - This contribution needs other caluclation.

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