Leptogenesis and Flavour Symmetries

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Works in collaboration with:
G.C.Branco, R. González Felipe, N.M.Rebelo, HS, PRD (2009)
R. González Felipe, HS, PRD (2010)
I. de Medeiros Varzielas, R. González Felipe, HS, PRD (2011)

FLASY, Valencia, 14 July 2011

See-saw models

Type-I see-saw: addition of heavy singlet fields, ν_R.

$$-\mathcal{L}_{High} = \overline{\ell_L} Y_D \tilde{\phi} \nu_R + \frac{1}{2} \overline{\nu_R^c} M_R \nu_R + \text{H.c.}$$

Type-II see-saw: addition of heavy scalar triplet fields, Δ.

$$-\mathcal{L}_{High} = \frac{1}{2} \overline{\ell_L^c} Y_\Delta \Delta \ell_L + M_\Delta^2 \text{Tr}\left(\Delta^\dagger \Delta\right) + \mu \tilde{\phi}^T \Delta \tilde{\phi} + \text{H.c.}$$

Low-Energy:

$$\mathcal{L}_{eff} = \frac{1}{2} \overline{\nu_L} m_\nu \nu_L^c + \text{H.c.}$$

$$[m_\nu]_I = m_D M_R^{-1} m_D^T \,, \quad [m_\nu]_{II} = v_\Delta^* Y_\Delta^*$$

See-saw models and Leptogenesis CP asymmetry

Sakharov conditions: $\not{B}$, $\not{C}$ and $\not{CP}$ and Out of thermal equilibrium

Type-I: (ϵ_k^α)

$$\frac{\Gamma\left(N_k \to \ell_\alpha \bar{\phi}\right) - \Gamma\left(N_k \to \bar{\ell}_\alpha \phi\right)}{\Gamma\left(N_k \to \ell_\alpha \bar{\phi}\right) + \Gamma\left(N_k \to \bar{\ell}_\alpha \phi\right)}$$

$$\epsilon_k^\alpha \propto \mathrm{Im}\left[m^\dagger_{D,k\alpha} m_{D,\alpha m} H_{km}\right] \quad \textit{flavoured}$$

$$\epsilon_k = \sum_\alpha \epsilon_k^\alpha \propto \mathrm{Im}\left[H^2_{km}\right] \quad \textit{unflavoured}$$

with $H = m_D^\dagger m_D$

Type-II: $(\epsilon_a^{\alpha\beta})$

$$2 \times \frac{\Gamma(\Delta_a^* \to \ell_\alpha \ell_\beta) - \Gamma(\Delta_a \to \bar{\ell}_\alpha \bar{\ell}_\beta)}{\Gamma_{\Delta_a} + \Gamma_{\Delta_a^*}}$$

$$\epsilon_a^{\alpha\beta} \propto \mathrm{Im}\left[\mu_a^* \mu_b Y^b_{\alpha\beta} Y^{*a}_{\alpha\beta}\right] \quad \textit{flavoured}$$

$$\propto \mathrm{Im}\left[\mathrm{Tr}\left(Y^b Y^{\dagger a}\right) Y^b_{\alpha\beta} Y^{*a}_{\alpha\beta}\right]$$

$$\epsilon_a \propto \mathrm{Im}\left[\mu_a^* \mu_b \mathrm{Tr}\left(Y^b Y^{\dagger a}\right)\right]$$

unflavoured

Symmetry of Matrices

C.S.Lam, PRD (2006)
W. Grimus, L. Lavoura, P.O. Ludl, JPG (2009)

S.F. King, C. Luhn, JHEP (2009)

We shall focus on 3×3 matrices:

- **Hermitian Matrices:**

$$G^\dagger M G = M\,, \quad M = U d U^\dagger$$

Generators

$$G_i = g_2 \mathbb{I} + (g_1 - g_2) v_i v_i^\dagger$$

where $|g_i| = 1$.

Symmetry Group

$$\mathbf{U(1) \times U(1) \times U(1)}$$

- **Symmetric Matrices:**

$$G^T M G = M\,, \quad M = U^* d U^\dagger$$

Generators

$$G_i = g_2 \mathbb{I} + (g_1 - g_2) v_i v_i^\dagger$$

where $g_i^2 = 1$.

Symmetry Group

$$\mathbf{Z_2 \times Z_2 \times Z_2}$$

Pure mathematical result!

Symmetry of mass as residual symmetry

R. González Felipe, HS, PRD (2010)

Type-I: $-\mathcal{L}_{High} = \overline{\nu_L} m_D \nu_R + \frac{1}{2}\overline{\nu_R^c} M_R \nu_R \longrightarrow \mathcal{L}_{Low} = \frac{1}{2}\overline{\nu_L} m_\nu \nu_L^c$

We always have

$$G_L^\dagger m_\nu G_L^* = m_\nu \quad \text{and} \quad G_R^T M_R G_R = M_R$$

What are the consequences if:

$$\nu_L \to G_L \nu_L \,, \quad \nu_R \to G_R \nu_R$$

is a residual symmetry?

We get the constraint

$$G_L^\dagger m_D G_R = m_D$$

Symmetry of mass as residual symmetry

In the physical basis for Leptogenesis

$$G_R'^T d_R G_R' = d_R \quad \text{and} \quad G_R'^\dagger H G_R' = H$$

- **non-degenerate M_i**: G_R is diagonal with ± 1. H diagonal
- **degenerate M_i**: $G_R'^T G_R' = 1 \longrightarrow G_R''^\dagger V_H^T V_H G_R'' = V_H^T V_H$, where V_H diagonalizes H. $V_H^T V_H$ has to be diagonal.

  Parametrize: $V_H = O_1 K O_2$.

  Two conditions:

  1) $O_2 = d\mathcal{P}\,, \quad d = diag(\pm 1, \pm 1, \pm 1)$
  2) $K^2 = e^{i\alpha}$

  $H_{ij} \in \mathbb{R}$, the freedom $\nu_R \to O\nu_R$ leads to H diagonal

$$G_L^\dagger m_D G_R = m_D \Leftrightarrow U_L^D = U_\nu \mathcal{P} K\,,\ U_R^D = U_R \mathcal{P}' K$$ **No leptogenesis!**

see also: E.Bertuzzo, P.Di Bari, F.Feruglio, E.Nardi, JHEP (2009)

Mass-independent textures

The diagonalization independent of the mass parameters (eigenvalues).

Rewriting the see-saw: $d_\nu = A\, d_R^{-1} A^T$ with $A = U_\nu^\dagger U_L^D\, d_D\, U_R^{D\dagger} U_R$

$$\sum_k M_k^{-1} A_{ik}^2 = m_i\,, \quad \sum_k M_k^{-1} A_{ik} A_{jk} = 0$$

A is real, at least 6 A_{ij} vanish. ν_R degen. $U_R \to U_R O$.

Two distinct solutions:

- $\mathbf{det(m_\nu) \neq 0}$: $A = \mathcal{P} K\, d_D\, K^* \mathcal{P}'$

$$U_L^D = U_\nu \mathcal{P} K\,, \quad U_R^D = U_R \mathcal{P}' K$$

$$G_L^\dagger m_D G_R = m_D$$

- $\mathbf{det(m_\nu) = 0}$: $m_D = U_\nu A$

$$H = A^T A \text{ (real)}$$

$$m^*_{D,\alpha i} m_{D,\alpha j} = \sum_{k,k'} U^*_{\alpha k} U_{\alpha k'} A_{ki} A_{k'j}$$

Again **No leptogenesis!**

see also:
D. Aristizabal Sierra, F. Bazzocchi, I. de Medeiros Varzielas, L. Merlo, S. Morisi, NPB (2010)
S.Choubey, S.F. King, M.Mitra, PRD(2010)

TB mixing from A_4 and Resonant Leptogenesis

G.C.Branco, R. González Felipe, N.M.Rebelo, HS, PRD (2009)

Resonant flavoured Leptogenesis:

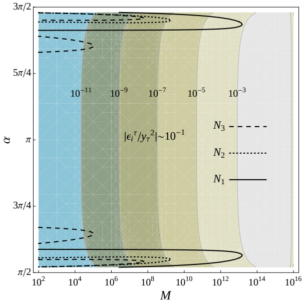
$$\epsilon_i^\alpha \propto \sum_{j\neq i} \frac{\delta_{ij}^N}{\left(\delta_{ij}^N\right)^2 + \left(\frac{H_{jj}}{16\pi}\right)^2} \frac{\mathcal{I}m\left[H_{ij} Y_{\alpha i}^* Y_{\alpha j}\right]}{H_{ii}}$$

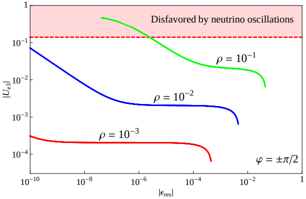
using RGE $(t = \ln(\Lambda/M)/16\pi^2)$

$$\delta_{ij}^N = 2\left(H_{ii} - H_{jj}\right) t\,, \quad H_{ij} \simeq 3 y_\tau^2 Y_{3i}^* Y_{3j} t$$

using soft breaking $\delta M \overline{\nu_{3R}^c} \nu_{3R}$

$$M_R^{-1} = \frac{1}{M} \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1+\rho e^{i\varphi} \end{pmatrix}$$





T2K latest results: Normal(Inverted) $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$

Leptogenesis in Type-II

I. de Medeiros Varzielas, R. González Felipe, HS, PRD (2011)

Type-II

- unflavoured
  $\epsilon_a \propto \text{Im}\left[\mu_a^* \mu_b \text{Tr}\left(Y^b Y^{\dagger a}\right)\right]$
  product C and P is traceless.
  Zero unless D is present
  or $Y \sim C + P$
- flavoured
  $\epsilon_a^{\alpha\beta} \propto \text{Im}\left[\mu_a^* \mu_b Y^b_{\alpha\beta} Y^{*a}_{\alpha\beta}\right]$
  $\propto \text{Im}\left[\text{Tr}\left(Y^b Y^{\dagger a}\right) Y^b_{\alpha\beta} Y^{*a}_{\alpha\beta}\right]$
  not restricted in general

TB mixing (de Medeiros's Talk)

$$m_{TB} = x' C + y' P + z' D,$$

$$C = \frac{1}{3}\begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix}$$

$$P = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \quad D = \frac{1}{3}\begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

mass-independent mixing (X)

$$m_\nu = K_X m_{TB} K_X^T \,, \; U_X = K_X U_{TB}$$

Conclusions

- Type-I see-saw flavour models that predict a mass-independent mixing $\longrightarrow$ No leptogenesis in leading order
- In these models the symmetry of mass matrices is the residual symmetry of the Lagrangian, i.e. $\nu_L \to G_L \nu_L$ and $\nu_R \to G_R \nu_R$.
- Type-II see-saw is not so restrictive in flavour models, and in the simplest implementation can be related to the inverted neutrino mass spectrum.