Lepton mixing induced by flavour symmetry and Leptogenesis constraints

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Corfu 2010/09/03

Outline

The paper

Talk based on [0908.0907]

The authors

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Type I seesaw

$$m_\nu = m_D M_R^{-1} m_D^T$$

showing the diagonalising matrices:

$$\hat{m}_\nu = D\,(U_{TB}^T U_L)\,\hat{m}_D\,(U_R^\dagger\, V_R)\,\hat{M}_R^{-1}\,(V_R^T\, U_R^*)\,\hat{m}_D\,(U_L^T\, U_{TB})\,D$$

The notation

D diagonal (with the Majorana phases)
U_L, U_R diagonalize m_D
V_R diagonalizes M_R

A remark on leptogenesis

The asymmetry

$$\epsilon_{N_\alpha} \propto \frac{\sum_{\beta\neq\alpha} \mathbb{I}\text{m}\left[\left((m_D^{R\,\dagger}\, m_D^R)_{\beta\alpha}\right)^2\right]}{(m_D^{R\dagger} m_D^R)_{\alpha\alpha}}$$

$$m_D^R \equiv m_D V_R$$

Casas-Ibarra parametrisation

The R matrix

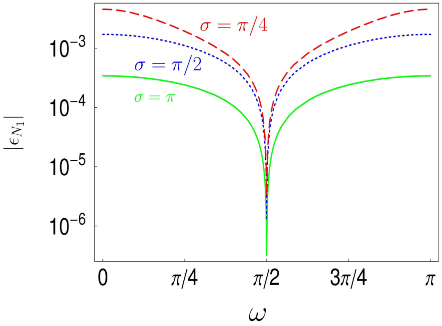
$$R^* = (\hat{m}_\nu)^{-1/2}\, U^T\, m_D^R\, (\hat{M}_R)^{-1/2}$$

The return of the asymmetry

$$\epsilon_{N_\alpha} \propto M_\alpha \frac{\mathbb{I}\mathrm{m}\left[\sum_j m_j^2 R_{j\alpha}^2\right]}{\sum_j m_j |R_{j\alpha}|^2}$$

Leptogenesis with exact mixing schemes

Possible to have TB (by chance) and leptogenesis



ω is an angle of the R matrix, has no connection with U_{TB}

Form-diagonalisability

$$\hat{m}_\nu = D\,(U_{TB}^T U_L)\,\hat{m}_D\,(U_R^\dagger\,V_R)\,\hat{M}_R^{-1}\,(V_R^T U_R^*)\,\hat{m}_D\,(U_L^T\,U_{TB})\,D$$

No fine-tuning conditions

$$U_{TB}^T U_L = P_L\,O_{D_i} \rightarrow U_L = U_{TB}\,P_L\,O_{D_i}$$

and

$$U_R^\dagger\,V_R = O_{D_i}^\dagger\,P_R\,O_{R_m}$$

P_L, P_R are diagonal phase matrices
O are orthogonal and interchange degenerate eigenvalues
$O = 1$ for simplicity (non-degenerate case)

Re-expressing

$$\hat{m}_\nu = D\,(U_{TB}^T U_L)\,\hat{m}_D\,(U_R^\dagger\,V_R)\,\hat{M}_R^{-1}\,(V_R^T U_R^*)\,\hat{m}_D\,(U_L^T\,U_{TB})\,D$$

$$\rightarrow \hat{m}_\nu = D\,U_{TB}^T U_{TB} P_L\,\hat{m}_D\,P_R\,\hat{M}_R^{-1}\,(V_R^T U_R^*)\,\hat{m}_D\,(U_L^T\,U_{TB})\,D$$

Going through a phase

$$P_L\,diag(v_1, v_2, v_3)\;P_R$$

absorb P_L,P_R and move through to the left to P)

$$\rightarrow P\hat{v}$$

where $\hat{v} = diag(|v_1|, |v_2|, |v_3|)$

Explicit reality

$$\begin{aligned}\hat{m}_\nu &= D\, U_{TB}^T (U_{TB}\, P\, \hat{v}\,) \hat{M}_R^{-1} (\hat{v}\, P\, U_{TB}^T) U_{TB}\, D \\ &= (\hat{v} \hat{M}_R^{-1/2} R^\dagger)(R^* \hat{M}_R^{-1/2} \hat{v})\end{aligned}$$

R Matrix Reloaded

$$\hat{m}_\nu^{-1/2}\, \hat{v}\, \hat{M}_R^{-1/2} R^\dagger = 1$$

$$\hat{m}_\nu^{-1/2}\, \hat{v}\, \hat{M}_R^{-1/2} = R^* = R$$

R is explicitly real and $\epsilon_{N_\alpha} = 0$

A_4 properties

A formal introduction

$$A_4 \equiv \Delta(12)$$

$$3 \times 3 = 3_a + 3_s + 1 + 1' + 1''$$

some invariants:

$$1' \times 1''$$

$$(3 \times 3)_1$$

$$3 \times 3 \times 3$$

The table

Based on [0903.0831] by Y. Lin

	L	e^c	μ^c	τ^c	N^c	H^u	H^d	φ_T	ξ'	φ_S	ξ	ζ
A_4	3	1	1	1	3	1	1	3	$1'$	3	1	1
Z_3	1	1	1	1	ω	1	1	1	1	ω	ω	ω^2
Z_4	1	$-i$	-1	1	1	1	$-i$	i	i	1	1	1

Don't Panic!
(there are towels by the swimming pool)

LO potential

Focus on neutrinos

$$\mathcal{W}_\nu = \frac{1}{\Lambda} y \left(L N^c\right) \zeta H^u + x_a \left(N^c N^c\right) \xi + x_b \left(N^c N^c \varphi_S\right)$$

With VEV (alignment not discussed here)

$$\langle \varphi_S \rangle \propto (1, 1, 1)$$

LO masses

$$m_D \propto \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$$M_R = \begin{pmatrix} b+2d & -d & -d \\ -d & 2d & b-d \\ -d & b-d & 2d \end{pmatrix}$$

NLO potential

$Z_3 \times Z_4$ only admits NLO corrections to the Dirac terms

NLO contributions to LN^c

$$-\mathcal{W}_{\nu}^{NLO} = \frac{1}{\Lambda} y_1 \left(LN^c\right)' \left(\varphi_S \varphi_S\right)'' H^u$$

$$+\frac{1}{\Lambda} y_2 \left(LN^c\right)'' \left(\varphi_S \varphi_S\right)' H^u + \frac{1}{\Lambda} y_3 \left(\left(LN^c\right)_A \varphi_S\right) \xi H^u$$

NLO masses

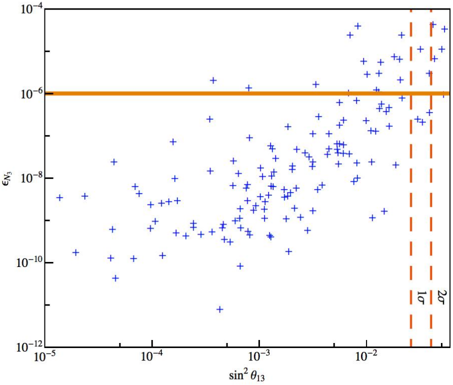
$m_D^{(1)}$

$$m_D^{(1)} = \begin{pmatrix} 0 & y_1 + y_3 & y_2 - y_3 \\ y_1 - y_3 & y_2 & y_3 \\ y_2 + y_3 & -y_3 & y_1 \end{pmatrix} v^u \frac{v_S^2}{\Lambda^2} \, ,$$

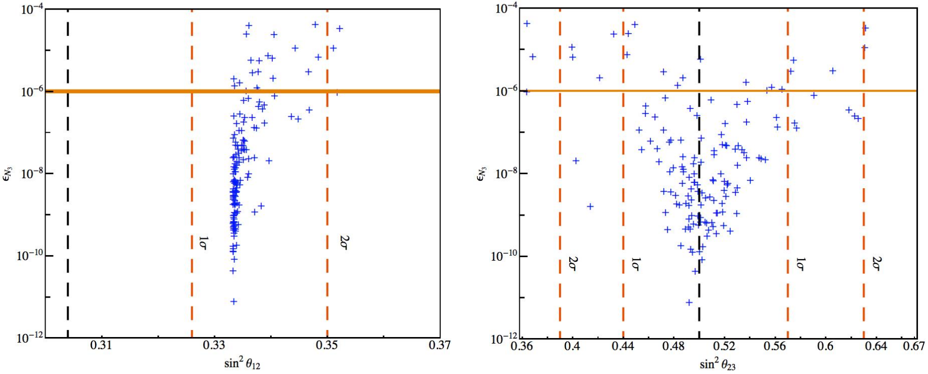
(tri-maximal type)

The Plots thicken...

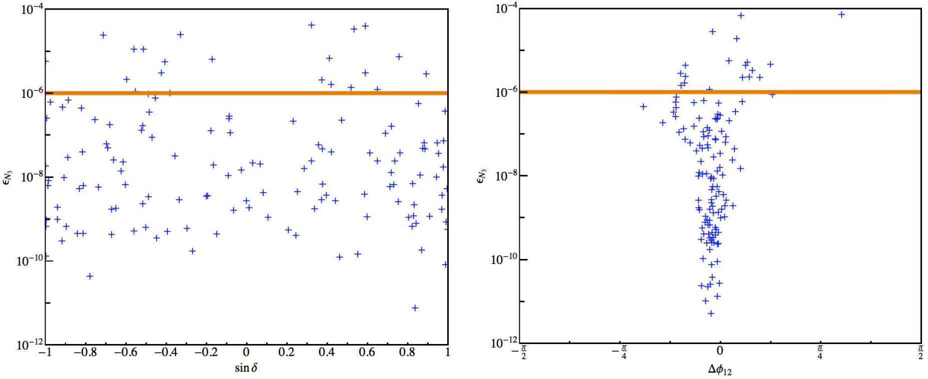
Leptogenesis constraints (mostly on 13 angle)



Too Graphic...


10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
ϵ_{N_3}
0.31
0.33
0.35
0.37
$\sin^2\theta_{12}$
1σ
2σ
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
ϵ_{N_3}
0.36
0.4
0.44
0.48
0.52
0.56
0.6
0.64
0.67
$\sin^2\theta_{23}$
2σ
1σ
1σ
2σ

It Figures...


10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
ϵ_{N_3}
−1 −0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1
$\sin\delta$
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
ϵ_{N_3}
$-\frac{\pi}{2}$ $-\frac{\pi}{4}$ 0 $\frac{\pi}{4}$ $\frac{\pi}{2}$
$\Delta\phi_{12}$

See...

Our paper [0908.0907]

- All the technical details

and also...

Other papers on Leptogenesis and flavour symmetries

- Bertuzzo, Di Bari, Feruglio, Nardi [0908.0161] (group theory)
- Hagedorn, Molinaro, Petcov [0908.0240] (a model with correlations)
- González Felipe, Serôdio [0908.2947] (matrix symmetry)
- Choubey,King, Mitra [1004.3756] (R matrix)

Summary

Conclusions

- In type I seesaw scenarios with exact mixing schemes (form-diagonal matrices) Leptogenesis is not possible.
- In models with deviations from mixing schemes (model dependent) requiring Leptogenesis constrains the parameter space.