

Minimal flavour seesaw models

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M. B. Gavela, T. Hambye, P. Hernández, D.H., 0906.1461

THE STANDARD MODEL

$$\mathcal{L}_{SM} = \sum_i \mathcal{L}_{kin}^i + V(\phi)$$

Possesses a Flavour symmetry for $Y_e, Y_u, Y_d \simeq 0$

$$G = SU(3)_{Q_L} \times SU(3)_u \times SU(3)_d \times SU(3)_L \times SU(3)_e$$

What is Minimal Flavour Violation

Turning on Y_u and Y_d

$$\mathcal{L} = \dots - Y_u^{\alpha\beta} \bar{Q}_L^\alpha \phi u_R^\beta - Y_d^{\alpha\beta} \bar{Q}_L^\alpha \tilde{\phi} d_R^\beta$$

Breaks flavour symmetry (G). Transform Yukawas to recover!

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MINIMAL FLAVOUR VIOLATION

In the effective Lagrangian we have

$$\mathcal{L}_{\text{eff}} = \sum_i c_{d=5}^i \mathcal{O}_{d=5}^i + c_{d=6}^i \mathcal{O}_{d=6}^i + \dots$$

$$c_{d=5} \equiv c_{d=5}(Y_u, Y_d), \quad c_{d=6} \equiv c_{d=6}(Y_u, Y_d)$$

MFV Hypothesis \equiv The Yukawas are the only sources (*irreducible*) of flavour violation.

R. S. Chivukula and H. Georgi, Phys. Lett. B 188, 99 (1987).



In the case of leptons

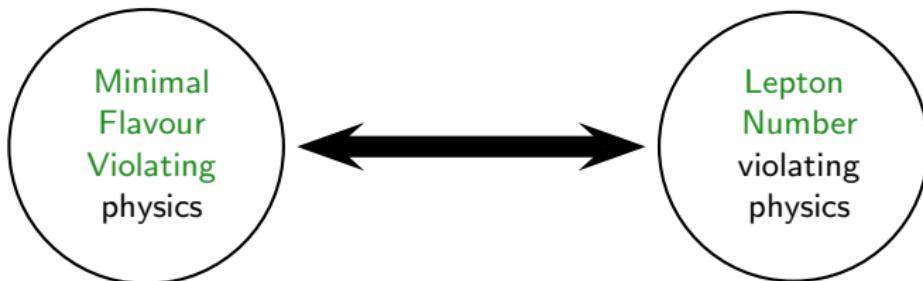
In the lepton sector

$$\mathcal{L}_{SM} = \cdots + Y_e \bar{L} \phi e_R + (?) + \dots$$

Need mass for the neutrinos! (Model dependent, Majorana)

$$\mathcal{L}_{\text{eff}} = \sum_i c_{d=5}^i \mathcal{O}_{d=5}^i + c_{d=6}^i \mathcal{O}_{d=6}^i + \dots$$

$$c_{d=5} \equiv c_{d=5}(Y_e, ?), \quad c_{d=6} \equiv c_{d=6}(Y_e, ?)$$



Requirements for a model of MFV

- Tiny neutrino masses should be deducible. Λ_{LN} Big.
- Rare flavour processes should be measurable. $\Lambda_{fl} \ll \Lambda_{LN}$
- Predictivity. The flavour structure of the coefficients of the $d = 6$ operator should be fixed by that of the $d = 5$ one.

Ex:

$$c_{d=6}^{\alpha\beta} \propto c_{d=5}^{\alpha\beta}, \quad c_{d=6}^{\alpha\beta} \propto (c_{d=5}^\dagger)^{\alpha\sigma} c_{d=5}^{\sigma\beta}, \quad \text{any other possibility?}$$

An unsuccessful model

Standard Seesaw (Type I) doesn't work

$$\mathcal{L} = \cdots - Y_N \bar{N} \phi^\dagger L_L - \Lambda_{LN} \bar{N}^c N \dots$$

- **Neutrino masses:** Ok. $M_\nu \propto Y_N^T \frac{1}{\Lambda_{LN}} Y_N$
- **Measurable flavour:** NOT OK!. $\Lambda_{fl} \equiv \Lambda_{LN}$
- **Predictivity:** More or less Ok. $c_{d=5} \propto c_{d=6}$ if no CP

Scalar mediated seesaw

$$\begin{aligned}\mathcal{L}_\Delta = & \cdots + (D_\mu \Delta)^\dagger (D^\mu \Delta) - m_\Delta^2 \Delta^\dagger \Delta + + \\ & + Y_{\Delta}^{\alpha\beta} \overline{\ell_L} (\tau \cdot \Delta) \ell_L + \mu_\Delta \tilde{\phi}^\dagger (\tau \cdot \Delta)^\dagger \phi + \dots\end{aligned}$$

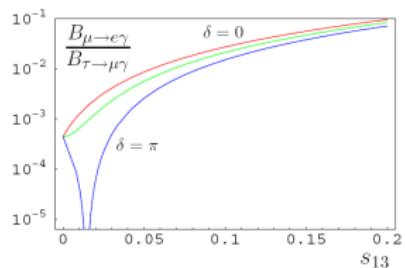
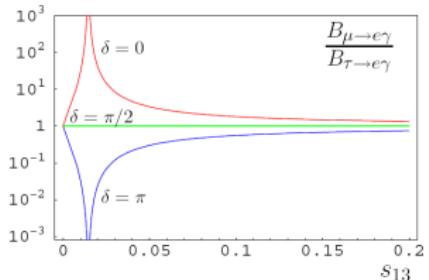
Yields the *effective coefficients*

$$c_{d=5}^{\alpha\beta} \propto Y_{\Delta\alpha\beta} \frac{\mu_\Delta}{M_\Delta^2},$$

$$c_{d=6}^{\alpha\beta\gamma\delta} \propto \frac{1}{M_\Delta^2} Y_{\Delta\alpha\beta}^\dagger Y_{\Delta\delta\gamma}.$$

Hence

$$c_{d=6}^{\alpha\beta\gamma\delta} \propto (c_{d=5}^\dagger)^{\alpha\beta} c_{d=5}^{\gamma\delta}$$



Leptonic Seesaws I

$$\mathcal{L}_{M_\nu} = \begin{pmatrix} \bar{L}_i & \bar{N}^c & \bar{N}'^c \\ 0 & Y_N^T v & \epsilon Y_N'^T v \\ Y_N v & 0 & \Lambda^T \\ \epsilon Y_N' v & \Lambda & 0 \end{pmatrix} \begin{pmatrix} L_i^c \\ N \\ N' \end{pmatrix}$$

Lepton number violation driven by ϵ

$$c_{\alpha\beta}^{d=5} \equiv \epsilon \left(Y_N'^T \frac{1}{\Lambda} Y_N + Y_N^T \frac{1}{\Lambda} Y_N' \right)_{\alpha\beta}, \quad c_{\alpha\beta}^{d=6} \equiv \frac{1}{\Lambda^2} \left(Y_N^\dagger Y_N \right)_{\alpha\beta} + o(\epsilon)$$

Leptonic Seesaws I

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FUNDAMENTAL

	moduli	phases
Y_N	3	3
Y_N'	3	3
Λ	1	1

vs

LOW ENERGY

	moduli	phases
	3 angles +	$3 \in L_i,$
	2 masses +	$1 \in N,$
	2 overall factors	$1 \in N'$

- A normalization factor apart, Yukawas are determined from the U_{PMNS} and neutrino masses!

Leptonic Seesaw II

For both hierarchies

$$Y_N = \frac{y}{\sqrt{2}} \left[f_1 \left(\frac{\Delta m_{sol}^2}{\Delta m_{atm}^2} \right) U_{i3}^* + f_2 \left(\frac{\Delta m_{sol}^2}{\Delta m_{atm}^2} \right) U_{i2}^* \right]$$

- Yukawas are a linear combination of the rows of the PMNS matrix.
- Spectrum determined (modulo normal/inverted hierarchy)

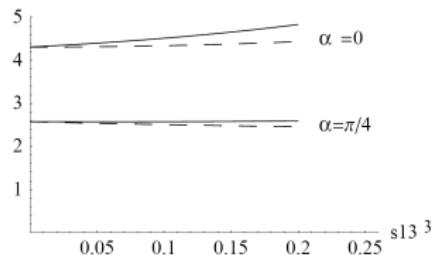
Hence, measuring the neutrino mass matrix ($c_{d=5}$) determines
EVERYTHING!!

Ex:

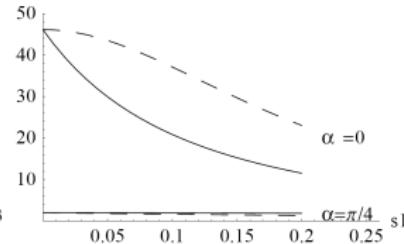
$$B_{\mu \rightarrow e\gamma} \propto |Y_{N_e} Y_{N_\mu}|^2, \quad |m_{ee}|_{IH} \simeq |s_{12}^2 e^{-2i\alpha} - c_{12}^2 e^{2i\alpha}|$$

Leptonic Seesaw III

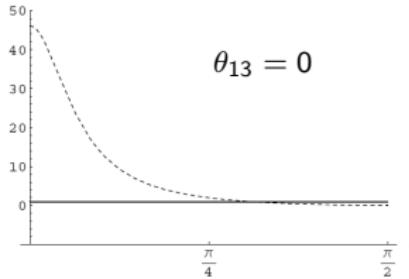
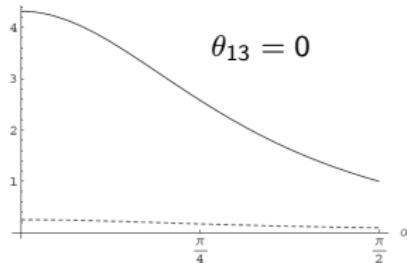
$$\frac{B_{e\mu}}{B_{e\tau}}$$



$$\frac{B_{e\mu}}{B_{e\tau}}$$



Strong dependence on the Majorana phase!



Conclusions

- Simple seesaw models with at least two separate scales are realizations of the MFV hypothesis in the lepton sector. Ex: Type II Seesaw, Inverse Seesaws, etc.
- Furthermore, what might be the simplest model of realistic neutrino mass generation has been presented. It implements as well several attracting features that include,
 - A separation of the typical scales of flavour and lepton number breaking processes.
 - A full determination of the Yukawa vectors up to overall factors.
 - Only three parameters undetermined by present data, a CP phase, a Majorana phase and θ_{13}