Unified model of fermion masses with a Universal Texture Zero

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Summary of data: quark mixing

Wolfenstein parametrisation

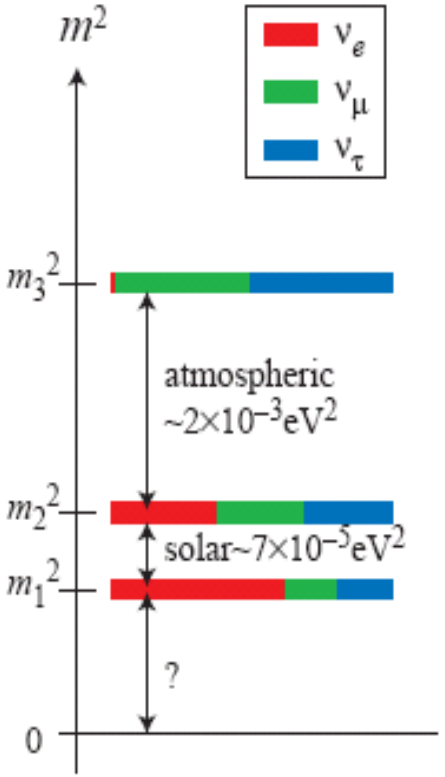
$$V_{CKM} \simeq \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ \lambda^3 & -\lambda^2 & 1 \end{pmatrix}$$

$\lambda \simeq 0.23$ (Sine of the Cabibbo angle)

Summary of data: lepton mixing

Tri-bi-maximal (TBM) mixing

$$V_{PMNS} \simeq \begin{pmatrix} -\sqrt{\frac{2}{3}} & \sqrt{\frac{1}{3}} & 0 \\ \sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & \sqrt{\frac{1}{2}} \\ \sqrt{\frac{1}{6}} & \sqrt{\frac{1}{3}} & -\sqrt{\frac{1}{2}} \end{pmatrix}$$



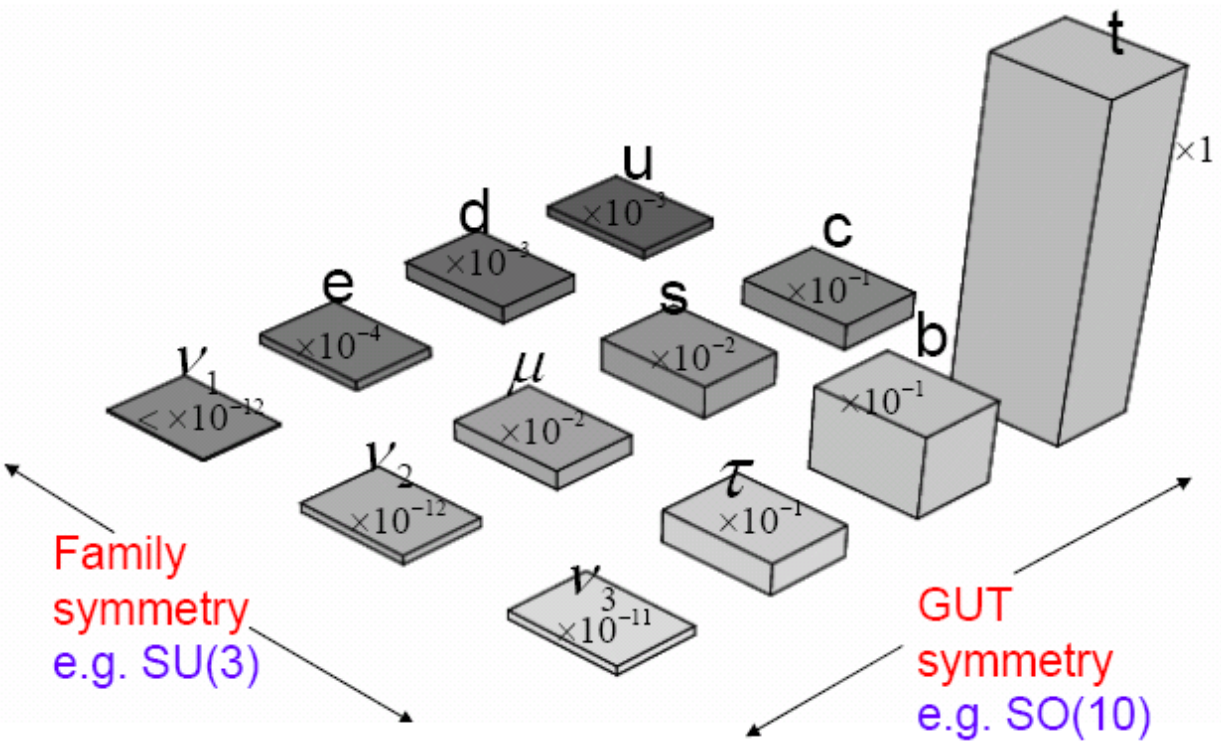
Beyond the Standard Model with family symmetries

Without $y_f H \bar{F} f$, $\mathcal{L}_{\nu SM}$ has accidental symmetry $U(3)^6$

FS: upgrade subgroup of $U(3)^6$ to actual symmetry of $\mathcal{L}$

1. Generations charged differently under FS
2. Yukawa couplings no longer invariant
3. FS must be broken somehow...

$SO(10) \times SU(3)$?



Unification with family symmetry

All fermions can have the same Dirac mass structure!

P. Ramond, R.G. Roberts, G. G. Ross
https://arxiv.org/abs/hep-ph/9303320
G. G. Ross, M. Serna
https://arxiv.org/abs/0704.1248

$$\frac{M^{Dirac}}{m_3} = \begin{pmatrix} 0 & \varepsilon^3 & -\varepsilon^3 \\ \varepsilon^3 & a\varepsilon^2 + \varepsilon^3 & -a\varepsilon^2 + \varepsilon^3 \\ -\varepsilon^3 & -a\varepsilon^2 + \varepsilon^3 & 1 \end{pmatrix}$$

$$\varepsilon_d = 0.15, \quad a^d = -2/3$$
$$\varepsilon_l = 0.15, \quad a^e = -3$$
$$\varepsilon_u = 0.05, \quad a^u = 4/3$$
$$\varepsilon_\nu = 0.05, \quad a^\nu = 0$$

Seesaw and Georgi-Jarlskog (GJ) factors distinguish quarks and leptons

Texture Zero for quarks

$$M_{11}^{LR} = 0 \tag{1}$$

Texture Zero for up and down quarks gives the Gatto-Sartori-Tonin (GST) relation:

$$\sin\theta_c = \left| \sqrt{\frac{m_d}{m_s}} - e^{i\delta} \sqrt{\frac{m_u}{m_c}} \right| \tag{2}$$

But how to get $M_{11}^{LR} = 0$... And what about the leptons?

Mass matrices from aligned VEVs

In this talk:

Directions $\langle \bar{\phi}_{\text{sol}} \rangle = (1, 1, 1)$ and $\langle \bar{\phi}_{\text{atm}} \rangle = (0, 1, -1)$

FS invariants $(\bar{\phi}^i_{\text{sol}} F_i)$, $(\bar{\phi}^i_{\text{atm}} F_i)$

Mass matrices example

Term sol L / atm R

$$+y_{\odot}(\bar{\phi}^{i}_{\mathrm{sol}}F_{i})(\bar{\phi}^{j}_{\mathrm{atm}}f_{Rj})H$$

Respective mass matrix

$$+y_{\odot}\begin{pmatrix} 0 & \epsilon^{3} & -\epsilon^{3} \\ 0 & \epsilon^{3} & -\epsilon^{3} \\ 0 & \epsilon^{3} & -\epsilon^{3} \end{pmatrix}$$

Mass matrices example

Term atm L / sol R

$$+y_{@}(\bar{\phi}^{i}_{\text{atm}}F_{i})(\bar{\phi}^{j}_{\text{sol}}f_{Rj})H$$

Respective mass matrix

$$+y_{@}\begin{pmatrix} 0 & 0 & 0 \\ \epsilon^3 & \epsilon^3 & \epsilon^3 \\ -\epsilon^3 & -\epsilon^3 & -\epsilon^3 \end{pmatrix}$$

$SO(10) \times SU(3)$ with (near) TBM

IdMV, G.G. Ross

https://arxiv.org/abs/hep-ph/0507176

Strategy to pass the mixing to low energy after seesaw:

$$\begin{array}{c} \\ (\bar{\phi}_{\rm atm} F) \\ (\bar{\phi}_{\rm sol} F) \\ (\bar{\phi}_{\rm atm} N^c) \\ (\bar{\phi}_{\rm sol} N^c) \end{array} \begin{array}{c} \begin{array}{cccc} (\bar{\phi}_{\rm atm} F) & (\bar{\phi}_{\rm sol} F) & (\bar{\phi}_{\rm atm} N^c) & (\bar{\phi}_{\rm sol} N^c) \end{array} \\ \begin{pmatrix} 0 & 0 & 0 & \kappa^\nu \\ 0 & 0 & \kappa^\nu & 0 \\ 0 & \kappa^\nu & \kappa_1^M & 0 \\ \kappa^\nu & 0 & 0 & \kappa_2^M \end{pmatrix} \end{array} \tag{3}$$

Gives effective LL Majorana mass terms

$$-\frac{(\kappa^\nu)^2}{\kappa_2^M}(\bar{\phi}_{\rm atm} F)(\bar{\phi}_{\rm atm} F) - \frac{(\kappa^\nu)^2}{\kappa_1^M}(\bar{\phi}_{\rm sol} F)(\bar{\phi}_{\rm sol} F) \tag{4}$$

$SO(10) \times \Delta(27)$

Directions $\langle \bar{\phi}_{\rm sol} \rangle = (1,1,1)$ and $\langle \bar{\phi}_{\rm atm} \rangle = (0,1,-1)$
Easy to align in $\Delta(27)$ (discrete) family symmetry
IdMV, S. F. King, G. G. Ross
https://arxiv.org/abs/hep-ph/0607045

Effective Majorana mass terms

$$-\frac{(\kappa^{\nu})^2}{\kappa_2^M}(\bar{\phi}_{\rm atm} F)(\bar{\phi}_{\rm atm} F) - \frac{(\kappa^{\nu})^2}{\kappa_1^M}(\bar{\phi}_{\rm sol} F)(\bar{\phi}_{\rm sol} F) \tag{5}$$

Democratic contribution fills all entries

$$M_{11}^{LR} = 0; M_{11}^{RR} \neq 0; M_{11}^{LL} \neq 0 \tag{6}$$

TBM in neutrino sector, modified slightly by charged lepton matrix which is not diagonal in this basis: θ_{13} too small!

Universal Texture Zero

IdMV, G. G. Ross, J. Talbert

https://arxiv.org/abs/1710.01741

Preserve the M_{11} texture zero in the Majorana mass matrix and into the effective neutrino mass matrix after seesaw:

$$M_{11}^{LR} = M_{11}^{RR} = M_{11}^{LL} = 0 \tag{7}$$

Predictive limit of tri-maximal (TM) scenario!

$SO(10) \times \Delta(27)$ with UTZ

$$
\begin{array}{c} \\ (\bar{\phi}_{\rm sol} F) \\ (\bar{\phi}_{\rm atm} F) \\ (\bar{\phi}_{\rm sol} N^c) \\ (\bar{\phi}_{\rm atm} N^c) \end{array}
\begin{array}{c}
\begin{array}{cccc} (\bar{\phi}_{\rm sol} F) & (\bar{\phi}_{\rm atm} F) & (\bar{\phi}_{\rm sol} N^c) & (\bar{\phi}_{\rm atm} N^c) \end{array} \\
\begin{pmatrix} 0 & 0 & 0 & \kappa_2^\nu \\ 0 & 0 & \kappa_2^\nu & \kappa_1^\nu \\ 0 & \kappa_2^\nu & 0 & \kappa_2^M \\ \kappa_2^\nu & \kappa_1^\nu & \kappa_2^M & \kappa_1^M \end{pmatrix}
\end{array}
\tag{8}
$$

Seesaw into effective Majorana mass terms

$$
\begin{array}{c} \\ (\bar{\phi}_{\rm sol} F) \\ (\bar{\phi}_{\rm atm} F) \end{array}
\begin{array}{c}
\begin{array}{cc} (\bar{\phi}_{\rm sol} F) & (\bar{\phi}_{\rm atm} F) \end{array} \\
\begin{pmatrix} 0 & \frac{(\kappa_2^\nu)^2}{\kappa_2^M} \\ \frac{(\kappa_2^\nu)^2}{\kappa_2^M} & f\left(\kappa_{1,2}^{\nu,M}\right) \end{pmatrix}.
\end{array}
\tag{9}
$$

Results

DETAILS ABOUT THE MODEL

Results (summarised)

At L.O., with 9 (low energy) parameters we fit
all SM fermion mass and mixing
(with tension only in CKM elements 13 and 31)
At H.O. this gets fixed by 2 additional parameters

Universal Texture Zero works very well!

Predictive family symmetry GUT model with UTZ
Important postdictions:
Cabibbo angle (GST),
charged lepton masses (GJ),
reactor angle (TM)

Conclusions

- Elegant $SO(10)$ inspired model, $\Delta(27) \times Z_N$ with UTZ
- Universal fermion structure is viable (supporting FS GUTs)