Prediction for Neutrino Masses, CP Violation and Neutrinoless Double Beta Decay from $\mathcal{T}_{13}$ Family Symmetry

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The Asymmetric Texture

The **minimal Yukawa texture** based on $SU(5)$ GUT that explains GUT-scale mass ratios and mixings of quarks and leptons:

$$Y^{(\frac{2}{3})} \sim \text{diag}\,(\lambda^8, \lambda^4, 1),$$

$$Y^{(-\frac{1}{3})} \sim \begin{pmatrix} bd\lambda^4 & a\lambda^3 & b\lambda^3 \\ a\lambda^3 & c\lambda^2 & g\lambda^2 \\ d\lambda & g\lambda^2 & 1 \end{pmatrix},$$

$$Y^{(-1)} \sim \begin{pmatrix} bd\lambda^4 & a\lambda^3 & d\lambda \\ a\lambda^3 & -3c\lambda^2 & g\lambda^2 \\ b\lambda^3 & g\lambda^2 & 1 \end{pmatrix},$$

$$\mathcal{U}_{Seesaw} = \text{diag}\,(1, 1, e^{i\delta})\,\mathcal{U}_{TBM},$$

where $a = c = \frac{1}{3}, g = A, b = A\sqrt{\rho^2+\eta^2}, d = \frac{2a}{g} = \frac{2}{3A}$ and $\cos\delta = 0.2$. The origin of the texture is traced back to an $SU(5)\times\mathcal{T}_{13}$ model.

Model Building Features

- diagonal $Y^{(\frac{2}{3})}$: should be explained from group theory
- asymmetry along $(13)-(31)$ of $Y^{(\frac{-1}{3})}$ and $Y^{(-1)}$: need a discrete subgroup of $SU(3)$ with at least two inequivalent triplet representations
- zero subdeterminant with respect to the (22) element: GUT-scale mass ratios suggest $\det Y^{(-\frac{1}{3})} = \det Y^{(-1)}$
- TBM seesaw mixing with a phase: should originate from breaking of family symmetry

The minimum order group that fits the bill is $\mathcal{T}_{13} = \mathcal{Z}_{13} \rtimes \mathcal{Z}_3$ at order 39.

Key Predictions

- Dirac CP violation: $\delta_{CP} = 1.32\pi$, $\mathcal{J}_{CP} = -0.028$
  PDG 2020 fit: $\delta_{CP} = 1.36 \pm 0.17\pi$ at 1σ
  5σ measurement by DUNE and Hyper-K in $\sim 5-10$ yrs
- Normal ordering of neutrino masses: $m_{\nu_1} = 27.6$ meV, $m_{\nu_2} = 28.9$ meV, $m_{\nu_3} = 57.8$ meV
  Normal ordering over inverted ordering is preferred over 3.6σ from T2K and NOνA
- Sum of neutrino masses: $\sum_i m_{\nu_i} = 114.3$ meV
  Planck 2018: $\sum_i m_{\nu_i} < 120$ meV, error bar less than 10 meV expected from combining Euclid, LSST data with DESI, WFIRST
- Majorana invariants: $\mathcal{I}_1 = -0.106$, $\mathcal{I}_1 = -0.011$
- Invariant mass parameter for $0\nu\beta\beta$: $|m_{\beta\beta}| = 13.02$ or 25.21 meV
  KamLAND-Zen: $|m_{\beta\beta}| < 61-165$ meV, prediction is sensitive to LEGEND ($11-28$ meV), nEXO ($8-22$ meV, CUPID ($6-17$ meV)
- Baryon asymmetry of the universe can be explained through leptogenesis with right handed neutrino masses $\sim 10^8 - 10^{12}$ GeV.

Building the Yukawas

- $Y^{(-\frac{1}{3})} \leftarrow FTH_{\bar{5}}\varphi^{(-\frac{1}{3})}$:

$$\begin{pmatrix} F_1 \\ F_2 \\ F_3 \end{pmatrix}_{\mathbf{3}_1} \otimes \begin{pmatrix} T_1 \\ T_3 \\ T_2 \end{pmatrix}_{\mathbf{3}_2} = \begin{pmatrix} F_3T_2 \\ F_1T_1 \\ F_2T_3 \end{pmatrix}_{\mathbf{3}_1} \oplus \begin{pmatrix} F_3T_1 \\ F_1T_3 \\ F_2T_2 \end{pmatrix}_{\bar{\mathbf{3}}_2} \oplus \begin{pmatrix} F_3T_3 \\ F_1T_2 \\ F_2T_1 \end{pmatrix}_{\mathbf{3}_2}$$

$\mathcal{T}_{13}$ can dial *individual* matrix elements!

- $Y^{(\frac{2}{3})} \leftarrow TT\bar{H}_5\varphi^{(\frac{2}{3})}$:

$$\begin{pmatrix} T_1 \\ T_3 \\ T_2 \end{pmatrix}_{\mathbf{3}_2} \otimes \begin{pmatrix} T_1 \\ T_3 \\ T_2 \end{pmatrix}_{\mathbf{3}_2} = \begin{pmatrix} T_3T_3 \\ T_2T_2 \\ T_1T_1 \end{pmatrix}_{\bar{\mathbf{3}}_1} \oplus \begin{pmatrix} T_3T_2 \\ T_2T_1 \\ T_1T_3 \end{pmatrix}_{\bar{\mathbf{3}}_2} \oplus \begin{pmatrix} T_2T_3 \\ T_1T_2 \\ T_3T_1 \end{pmatrix}_{\bar{\mathbf{3}}_2}$$

Diagonals are distinguished from off-diagonals!

Zero Subdeterminant

$$\begin{pmatrix} bd\lambda^4 & \times & b\lambda^3 \\ \times & \times & \times \\ d\lambda & \times & 1 \end{pmatrix} = \begin{pmatrix} b\lambda^3\cdot d\lambda & \times & b\lambda^3\cdot 1 \\ \times & \times & \times \\ d\lambda & \times & 1 \end{pmatrix}$$

(33) term $\rightarrow FTH_{\bar{5}}\varphi^{(1)}$
(31) term $\rightarrow FTH_{\bar{5}}\varphi^{(2)}$
(13) term $\rightarrow FTH_{\bar{5}}\varphi^{(1)}\varphi^{(3)}$
(11) term $\rightarrow FTH_{\bar{5}}\varphi^{(2)}\varphi^{(3)}$

Higgs $H_{\bar{5}}$ is a family singlet and the familons $\varphi^{(i)}$ are gauge singlets and family (anti)triplets.

Seesaw Sector

- Introduce four right handed neutrinos $\bar{N} \sim (\mathbf{1}, \mathbf{3}_2)$ and $\bar{N}_4 \sim (\mathbf{1}, \mathbf{1})$
- Dirac Yukawa matrix, $Y^{(0)}$: $F\bar{N}\bar{H}_{\mathbf{5}}\varphi_{\mathcal{A}}$
- Majorana matrix, $\mathcal{M}$: $\bar{N}\bar{N}\varphi_{\mathcal{B}}$ and $\bar{N}\bar{N}_4\varphi_z$
- Seesaw matrix, $\mathcal{S} = Y^{(0)}\,\mathcal{M}^{-1}\,Y^{(0)^T}$ is diagonalized by the complex TBM matrix: $\mathcal{S} \propto \mathcal{U}_{TBM}(\delta)\text{diag}\,(m_{\nu_1}, m_{\nu_3}/2, m_{\nu_3})\,\mathcal{U}^T_{TBM}(\delta)$.
- Neutrino masses are determined from $m_{\nu_2} = \frac{1}{2}m_{\nu_3}$ using oscillation data
- TBM phase $\delta = \cos^{-1} 0.2$ yields the Dirac and Majorana CP phases and $|m_{\beta\beta}|$
- Successful leptogenesis can occur for right handed neutrino masses $\sim 10^8 - 10^{12}$ GeV

References

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