Family Symmetry

Lam; Luhn,SFK…

Consider the TB Neutrino Mass Matrix

$$M^{\nu}_{TB} = U_{TB}\begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix} U^T_{TB}$$

$$M^E = \begin{pmatrix} m_e & 0 & 0 \\ 0 & m_\mu & 0 \\ 0 & 0 & m_\tau \end{pmatrix} = T M^E T^\dagger$$

$$M^{\nu}_{TB} = m_1\Phi_1\Phi_1^T + m_2\Phi_2\Phi_2^T + m_3\Phi_3\Phi_3^T$$

$$\Phi_1 = \frac{1}{\sqrt{6}}\begin{pmatrix} -2 \\ 1 \\ 1 \end{pmatrix}, \quad \Phi_2 = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}, \quad \Phi_3 = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ 1 \\ -1 \end{pmatrix}$$

$$T = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \omega^2 & 0 \\ 0 & 0 & \omega \end{pmatrix} \qquad \omega = e^{2\pi i/3}$$

TB Neutrino Mass Matrix is invariant under a discrete $Z_2^S \times Z_2^U$ group generated by S,U

$$M^{\nu}_{TB} = S\, M^{\nu}_{TB} S^T$$

$$M^{\nu}_{TB} = U\, M^{\nu}_{TB} U^T$$

Family Symmetry G_{Fam}

$$S, T, U \rightarrow S_4$$

$$S, T \rightarrow A_4$$

$$S = \frac{1}{3}\begin{pmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{pmatrix}, \qquad U = -\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

Two Approaches with family symmetry

Ma, Altarelli, Feruglio, ….

Direct Models

G_{Fam}

S, U broken but T preserved by flavon VEV ϕ_T

T broken but S,U preserved by flavons ϕ_S, ϕ_U

Charged Lepton Sector

U_{TB}

Neutrino Sector

$\mathcal{L}^{Yuk} \sim \psi(\phi_T + \phi_I)\psi^c H$ $\quad \mathcal{L}^{Maj} \sim \psi(\phi_S + \phi_U + \phi_I)\psi H H$

Indirect Models

SFK, Ross, ….

G_{Fam}

G_{Fam} broken by flavon VEVs

$$\langle\phi_1\rangle = v_1\Phi_1, \quad \langle\phi_2\rangle = v_2\Phi_2, \quad \langle\phi_3\rangle = v_3\Phi_3$$

$$\Phi_1 = \frac{1}{\sqrt{6}}\begin{pmatrix}-2\\1\\1\end{pmatrix}, \quad \Phi_2 = \frac{1}{\sqrt{3}}\begin{pmatrix}1\\1\\1\end{pmatrix}, \quad \Phi_3 = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\1\\-1\end{pmatrix}$$

Accidental $Z_2^S \times Z_2^U$ symmetry emerges

$$\mathcal{L}^{Maj} \sim \psi(\phi_1\phi_1^T + \phi_2\phi_2^T + \phi_3\phi_3^T)\psi H H$$

$$M^{\nu}_{TB} = m_1\Phi_1\Phi_1^T + m_2\Phi_2\Phi_2^T + m_3\Phi_3\Phi_3^T$$

e.g. type I see-saw mechanism with $m_1 \rightarrow 0$ from constrained sequential dominance

Vacuum alignment of flavons with discrete family symmetry and SUSY

F-term (direct models)

Altarelli, Feruglio

$$M(\varphi_T \varphi_0^T) + g(\varphi_0^T \varphi_T \varphi_T) + g_1(\varphi_0^S \varphi_S \varphi_S)$$

$$\phi_S \sim \begin{pmatrix}1\\1\\1\end{pmatrix} \quad \phi_T \sim \begin{pmatrix}1\\0\\0\end{pmatrix}$$

D-term (indirect models)

SFK, Ross, Varzielas

$$\Delta V = \kappa \sum \phi^{i\dagger}\phi^{i}\phi^{i\dagger}\phi^{i} + \lambda|\phi_2^{\dagger}.\phi_3|^2$$

$$\phi_2 \sim \begin{pmatrix}1\\1\\1\end{pmatrix} \quad \phi_3 \sim \begin{pmatrix}0\\1\\-1\end{pmatrix}$$

8d Orbifold (direct models)

Kobayashi, Omura, Yoshioka; Burrows, SFK

$$\varphi_S(-z_1) = P_2 \varphi_S(z_1)$$
$$\varphi_T(\omega z_2) = P_3 \varphi_T(z_2)$$

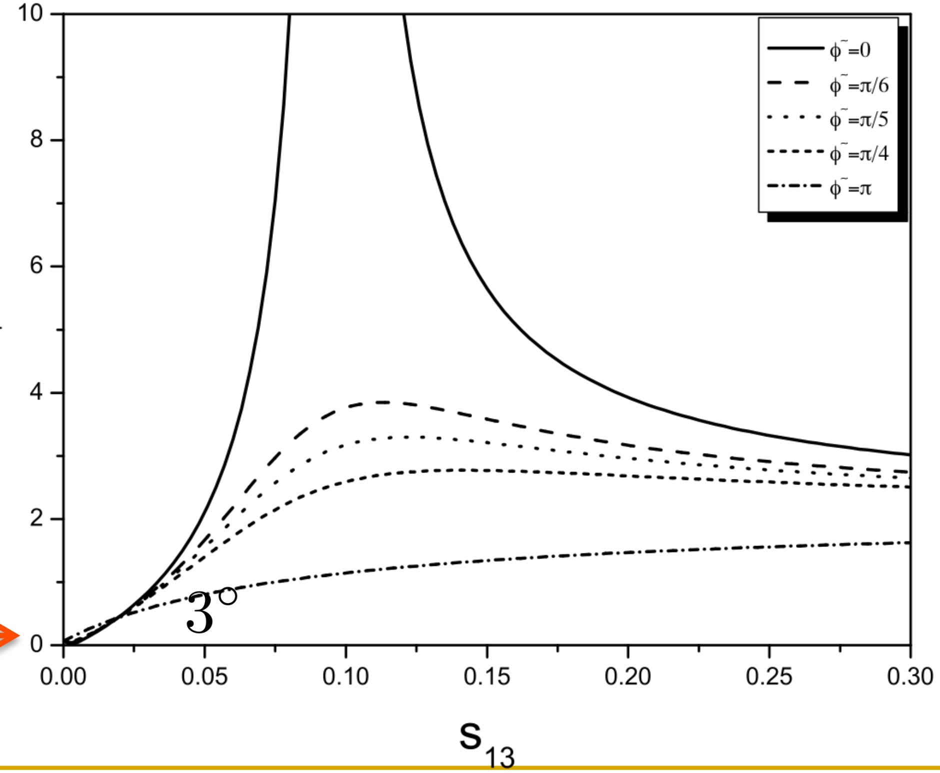
$$\phi_S \sim \begin{pmatrix}1\\1\\1\end{pmatrix} \quad \phi_T \sim \begin{pmatrix}1\\0\\0\end{pmatrix}$$

Is TBM accidental?

Abbas and Smirnov: M_ν can differ greatly from M_ν^{TB} (within current errors on the mixing angles) therefore present data on the mixing angles does not suggest that TBM results from a symmetry (since any symmetry constrains M_ν not the mixing angles)

$$\Delta_e \equiv \frac{m_{e\mu} - m_{e\tau}}{m_{e\mu}}$$

TBM



Tri-bimaximal-reactor mixing **0903.3199**

Alternative vacuum alignment in indirect models giving an alternative to TBM:

$$\langle\phi_{123}\rangle = \frac{b}{\sqrt{3}}\begin{pmatrix}1\\1\\-1\end{pmatrix}, \quad \langle\phi_{23}\rangle = \frac{c}{\sqrt{2}}\begin{pmatrix}\varepsilon\\1\\1\end{pmatrix}$$

$$\lambda_1|\phi_1^\dagger.\phi_{23}|^2 + \lambda_{23}|\tilde{\phi}_{23}^\dagger.\phi_{23}|^2$$

$$U_{TBR} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & U_{e3} \\ -\frac{1}{\sqrt{6}}(1+\sqrt{2}U_{e3}^*) & \frac{1}{\sqrt{3}}(1-\frac{1}{\sqrt{2}}U_{e3}^*) & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}}(1-\sqrt{2}U_{e3}^*) & -\frac{1}{\sqrt{3}}(1+\frac{1}{\sqrt{2}}U_{e3}^*) & \frac{1}{\sqrt{2}} \end{pmatrix}$$