Models of Flavor Symmetries

and the Stability of their Predictions

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Based on work done in collaboration

with Maximilian Fallbacher, Michael Ratz, Christian Staudt, arXiv:1208.2947 [hep-ph]

with K.T. Mahanthappa, Phys. Lett. B681 (2009) 444; Phys. Lett. B652 (2007) 34

BeNE 2012, Trieste, Italy, September 18, 2012

Where Do We Stand?

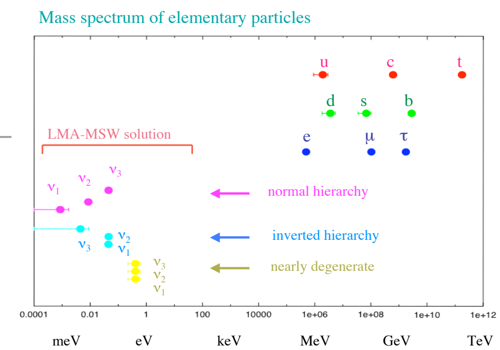
- Exciting Time in ν Physics: recent hints of large θ_{13} from T2K, MINOS, Double Chooz, and Daya Bay, RENO
- Latest 3 neutrino global analysis (including recent results from reactor experiments):

$$P(\nu_a \to \nu_b) = \left|\langle \nu_b | \nu,\ t \rangle\right|^2 \simeq \sin^2 2\theta\ \sin^2\left(\frac{\Delta m^2}{4E} L\right)$$

Fogli, Lisi, Marrone, Montanino, Palazzo, Rotunno, 2012

Parameter	Best fit	1σ range	2σ range	3σ range
$\delta m^2/10^{-5}$ eV^2 (NH or IH)	7.54	7.32 – 7.80	7.15 – 8.00	6.99 – 8.18
$\sin^2\theta_{12}/10^{-1}$ (NH or IH)	3.07	2.91 – 3.25	2.75 – 3.42	2.59 – 3.59
$\Delta m^2/10^{-3}$ eV^2 (NH)	2.43	2.33 – 2.49	2.27 – 2.55	2.19 – 2.62
$\Delta m^2/10^{-3}$ eV^2 (IH)	2.42	2.31 – 2.49	2.26 – 2.53	2.17 – 2.61
$\sin^2\theta_{13}/10^{-2}$ (NH)	2.41	2.16 – 2.66	1.93 – 2.90	1.69 – 3.13
$\sin^2\theta_{13}/10^{-2}$ (IH)	2.44	2.19 – 2.67	1.94 – 2.91	1.71 – 3.15
$\sin^2\theta_{23}/10^{-1}$ (NH)	3.86	3.65 – 4.10	3.48 – 4.48	3.31 – 6.37
$\sin^2\theta_{23}/10^{-1}$ (IH)	3.92	3.70 – 4.31	3.53 – 4.84 $\oplus$ 5.43 – 6.41	3.35 – 6.63
δ/π (NH)	1.08	0.77 – 1.36	—	—
δ/π (IH)	1.09	0.83 – 1.47	—	—

Origin of Mass Hierarchy and Mixing

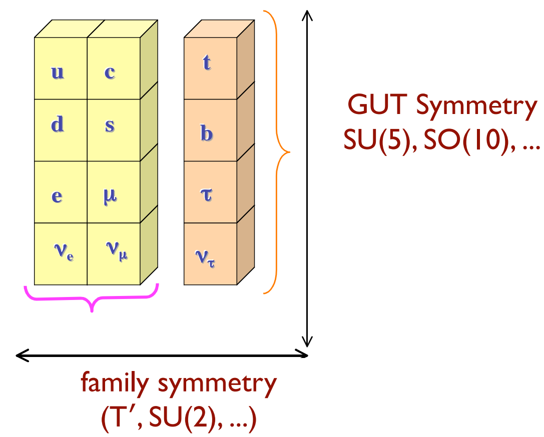


- In the SM: 22 physical quantities which seem unrelated
- Question arises whether these quantities can be related
- No fundamental reason can be found in the framework of SM
- less ambitious aim ⇒ reduce the # of parameters by imposing symmetries
  - SUSY Grand Unified Gauge Symmetry
    - GUT relates quarks and leptons: quarks & leptons in same GUT multiplets
      - one set of Yukawa coupling for a given GUT multiplet ⇒ intra-family relations
    - seesaw mechanism naturally implemented
  - Family Symmetry
    - relate Yukawa couplings of different families
      - inter-family relations ⇒ further reduce the number of parameters

⇒ Experimentally testable correlations among physical observables

Origin of Flavor Mixing and Mass Hierarchy

- Several models have been constructed based on
  - GUT Symmetry [SU(5), SO(10)] $\oplus$ Family Symmetry G_F
- Family Symmetries G_F based on continuous groups:
  - U(1)
  - SU(2)
  - SU(3)



- Recently, models based on discrete family symmetry groups have been constructed
  - A_4 (tetrahedron)
  - T´ (double tetrahedron)
  - S_3 (equilateral triangle)
  - S_4 (octahedron, cube)
  - A_5 (icosahedron, dodecahedron)
  - Δ_{27}
  - Q_4

Motivation: Tri-bimaximal (TBM) neutrino mixing

For anomaly constraints: see talk by Michael Ratz this afternoon

Tri-bimaximal Neutrino Mixing

- Neutrino Oscillation Parameters

$$P(\nu_a \to \nu_b) = \left|\langle \nu_b | \nu,\ t\rangle\right|^2 \simeq \sin^2 2\theta\ \sin^2\left(\frac{\Delta m^2}{4E} L\right)$$

$$U_{MNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- Latest Global Fit (3σ)

Fogli, Lisi, Marrone, Montanino, Palazzo, Rotunno, 2012

$$\sin^2\theta_{atm} = 0.386\ (0.331 - 0.637) \qquad \sin^2\theta_{\odot} = 0.307\ (0.259 - 0.359)$$

$$\sin^2\theta_{13} = 0.0241\ (0.0169 - 0.0313)$$

- Tri-bimaximal Mixing Pattern

Harrison, Perkins, Scott (1999)

$$U_{TBM} = \begin{pmatrix} \sqrt{2/3} & \sqrt{1/3} & 0 \\ -\sqrt{1/6} & \sqrt{1/3} & -\sqrt{1/2} \\ -\sqrt{1/6} & \sqrt{1/3} & \sqrt{1/2} \end{pmatrix}$$

$$\sin^2\theta_{\text{atm, TBM}} = 1/2 \qquad \sin^2\theta_{\odot,\text{TBM}} = 1/3$$

$$\sin\theta_{13,\text{TBM}} = 0.$$

- Generally: TBM (from symmetry) + holomorphic Corrections/contributions

Tri-bimaximal Neutrino Mixing

	θ_{12}	θ_{13}	θ_{23}
TBM prediction:	$\arctan\left(\sqrt{0.5}\right) \approx 35.3^\circ$	0	45°
Best fit values ($\pm 1\sigma$):	$\left(33.6^{+1.1}_{-1.0}\right)^\circ$	$\left(8.93^{+0.46}_{-0.48}\right)^\circ$	$\left(38.4^{+1.4}_{-1.2}\right)^\circ$

Fogli, Lisi, Marrone, Montanino, Palazzo, Rotunno, 2012

An Example: Non-Abelian Finite Family Symmetry A_4

- TBM mixing matrix: can be realized with finite group family symmetry based on A_4

Ma, Rajasekaran (2001); Babu, Ma, Valle (2003); Altarelli, Feruglio (2005)

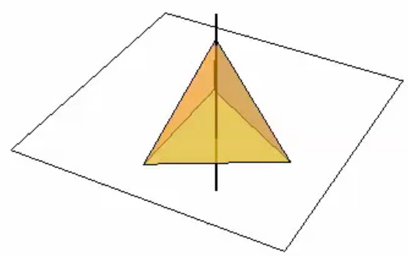
- A_4: even permutations of 4 objects

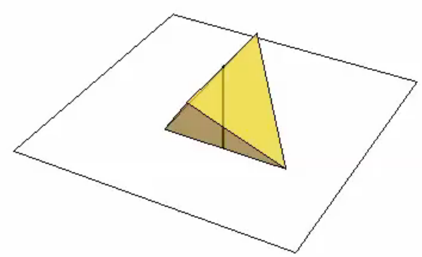
  S: (1234) → (4321)

  T: (1234) → (2314)

- a group of order 12

- Invariant group of tetrahedron





[Animation Credit: Michael Ratz]

Tri-bimaximal Neutrino Mixing from A_4

Altarelli, Feruglio (2005)

- fermion charge assignments:

$$L = \begin{pmatrix} \ell_1 \\ \ell_2 \\ \ell_3 \end{pmatrix} \sim 3, \quad e_R \sim 1, \quad \mu_R \sim 1'', \quad \tau_R \sim 1'$$

- SM Higgs ~ singlet under A_4
- operators for neutrino masses: $\frac{HHLL}{M}\left(\frac{\langle\xi\rangle}{\Lambda} + \frac{\langle\eta\rangle}{\Lambda}\right)$
- two scalar (flavon) fields for neutrino sector: $\xi \sim 3, \quad \eta \sim 1$

$$A_4 \to G_{TST^2}: \quad \langle\xi\rangle = \xi_0 \Lambda \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \qquad A_4 - \text{invariant:} \quad \langle\eta\rangle = u\Lambda$$

- product rules:

$$\mathbf{3} \otimes \mathbf{3} = \mathbf{1} \oplus \mathbf{1}' \oplus \mathbf{1}'' \oplus \mathbf{3}_{\mathrm{s}} \oplus \mathbf{3}_{\mathrm{a}}$$

Tri-bimaximal Neutrino Mixing from A_4

- Neutrino Masses: triplet flavon contribution

Altarelli, Feruglio (2005)

$$3_S = \frac{1}{3}\begin{pmatrix} 2\alpha_1\beta_1 - \alpha_2\beta_3 - \alpha_3\beta_2 \\ 2\alpha_3\beta_3 - \alpha_1\beta_2 - \alpha_2\beta_1 \\ 2\alpha_2\beta_2 - \alpha_1\beta_3 - \alpha_3\beta_1 \end{pmatrix} \qquad 1 \;\; = \alpha_1\beta_1 + \alpha_2\beta_3 + \alpha_3\beta_2$$

- Neutrino Masses: singlet flavon contribution

$$1 \;\; = \alpha_1\beta_1 + \alpha_2\beta_3 + \alpha_3\beta_2$$

- resulting mass matrix:

$$M_\nu = \frac{\lambda v^2}{M_x}\begin{pmatrix} 2\xi_0 + u & -\xi_0 & -\xi_0 \\ -\xi_0 & 2\xi_0 & u - \xi_0 \\ -\xi_0 & u - \xi_0 & 2\xi_0 \end{pmatrix} \qquad U_{\rm TBM} = \begin{pmatrix} \sqrt{2/3} & 1/\sqrt{3} & 0 \\ -\sqrt{1/6} & 1/\sqrt{3} & -1/\sqrt{2} \\ -\sqrt{1/6} & 1/\sqrt{3} & 1/\sqrt{2} \end{pmatrix}$$

$$V_\nu^{\rm T} M_\nu V_\nu = {\rm diag}(u + 3\xi_0,\, u,\, -u + 3\xi_0)\frac{v_u^2}{M_x}$$

Form diagonalizable:
-- no adjustable parameters
-- neutrino mixing from CG coefficients!

Tri-bimaximal Neutrino Mixing from A_4

Altarelli, Feruglio (2005)

- charged lepton sector -- without quarks
  - operators for charged fermion masses

$$(\ell\phi)_1 e_R(1) + (\ell\phi)_{1'}\mu_R(1'') + (\ell\phi)_{1''}\tau_R(1')$$

  - scalar sector: flavon triplet for charged lepton masses

$$\begin{aligned} 1 &= \alpha_1\beta_1 + \alpha_2\beta_3 + \alpha_3\beta_2 \\ 1' &= \alpha_3\beta_3 + \alpha_1\beta_2 + \alpha_2\beta_1 \\ 1'' &= \alpha_2\beta_2 + \alpha_1\beta_3 + \alpha_3\beta_1 \end{aligned}$$

$$A_4 \to G_T : \qquad \langle\phi\rangle = \phi_0\Lambda \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

- resulting charged lepton mass matrix = diagonal
- leptonic mixing matrix = tri-bimaximal

$$V_{MNS} = V_{e,L}^{\dagger} V_{\nu} = \mathcal{I} \cdot U_{TBM} = U_{TBM}$$

An Example: Non-Abelian Finite Family Symmetry A_4

- TBM mixing matrix: can be realized with finite group family symmetry based on A_4

- Deficiencies:
  - does NOT give quark mixing
  - does NOT explain mass hierarchy
  - all CG coefficients real

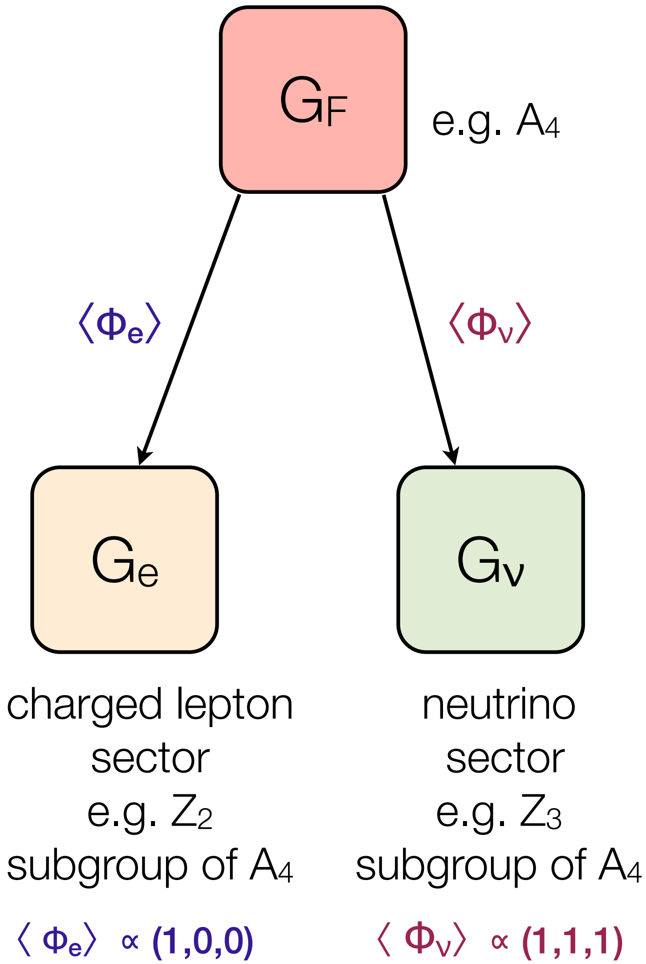
- SU(5) GUT compatible ⇒ T′ Symmetry (double covering of A_4)

  see talk by K.T. Mahanthappa on Thursday

  - large θ_{13} possible
  - complex CG coefficients of T′ ⇒ novel origin of CP violation

M.-C.C, Mahanthappa, Phys. Lett. B681, 444 (2009)

Flavor Model Structure: A_4 Example



- interplay between the symmetry breaking patterns in two sectors lead to lepton mixing (BM, TBM, ...)
- symmetry breaking achieved through flavon VEVs
- each sector preserves different residual symmetry
- full Lagrangian does not have these residual symmetries
- general approach: include high order terms in holomorphic superpotential
- possible to construct models where higher order holomorphic superpotential terms vanish to ALL orders
- quantum correction?

  ⇒ uncertainty due to Kähler corrections

Leurer, Nir, Seiberg (1993); Dudas, Pokorski, Savoy (1995);
Dreiner, Thormeier (2003);
King, Peddie (2003); King, Peddie, Ross, Velaso-Sevilla, Vives (2004)

Kähler Corrections

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Superpotential: holomorphic

$$\mathscr{W}_{\text{leading}} = \frac{1}{\Lambda}(\Phi_e)_{gf}\, L^g\, R^f\, H_d + \frac{1}{\Lambda\,\Lambda_\nu}(\Phi_\nu)_{gf}\, L^g\, H_u\, L^f\, H_u$$

$$\longrightarrow \mathscr{W}_{\text{eff}} = (Y_e)_{gf}\, L^g\, R^f\, H_d + \frac{1}{4}\kappa_{gf}\, L^g\, H_u\, L^f\, H_u$$

order parameter
<flavon vev> / Λ ~ θc

- Kähler potential: non-holomorphic

$$K = K_{\text{canonical}} + \Delta K$$

- Canonical Kähler potential

$$K_{\text{canonical}} \supset \left(L^f\right)^\dagger \delta_{fg}\, L^g + \left(R^f\right)^\dagger \delta_{fg}\, R^g$$

- Correction

$$\Delta K = \left(L^f\right)^\dagger (\Delta K_L)_{fg}\, L^g + \left(R^f\right)^\dagger (\Delta K_R)_{fg}\, R^g$$

- can be induced by flavon VEVs
- important for order parameter ~ θc
- can lead to non-trivial mixing

Kähler Corrections

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Consider infinitesimal change, x :

$$K \;=\; K_{\text{canonical}} + \Delta K \;=\; L^\dagger\,(1 - 2x\,P)\,L$$

- rotate to canonically normalized L':

$$L \;\rightarrow\; L' \;=\; (1 - x\,P)\,L$$

⇒ corrections to neutrino mass matrix

$$\begin{aligned}
\mathcal{W}_\nu &= \frac{1}{2}(L\cdot H_u)^T\kappa_\nu(L\cdot H_u)\\
&\simeq \frac{1}{2}[(\mathbb{1}+xP)L'\cdot H_u]^T\kappa_\nu[(\mathbb{1}+xP)L'\cdot H_u]\\
&\simeq \frac{1}{2}(L'\cdot H_u)^T\kappa_\nu L'\cdot H_u + x(L'\cdot H_u)^T(P^T\kappa_\nu+\kappa_\nu P)L'\cdot H_u
\end{aligned}$$

with $\kappa\cdot v_u^2 \;=\; 2m_\nu$

Kähler Corrections

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Consider infinitesimal change, x :

$$K \;=\; K_{\mathrm{canonical}} + \Delta K \;=\; L^\dagger \, (1 - 2x\, P)\, L$$

- rotate to canonically normalized L′:

$$L \;\to\; L' \;=\; (1 - x\, P)\, L$$

⇒ corrections to neutrino mass matrix

$$m_\nu(x) \;\simeq\; m_\nu + x\, P^T\, m_\nu + x\, m_\nu\, P$$

⇒ differential equation

$$\frac{\mathrm{d}m_\nu}{\mathrm{d}x} \;=\; P^T\, m_\nu + m_\nu\, P$$

- same structure as the RG evolutions for neutrino mass operator
- analytic understanding of evolution of mixing parameters

S. Antusch, J. Kersten, M. Lindner, M. Ratz (2003)

- size of Kähler corrections can be substantially larger (no loop suppression)

Back to A_4 Example

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Kähler corrections due to flavon field:
  - linear in flavon:

$$\Delta K_{\text{linear}} \;=\; \sum_{i\,\in\{\text{a,s}\}} \left(\frac{\kappa^{(i)}_{\Phi_\nu}}{\Lambda}\, \Delta K^{(i)}_{L^\dagger\,(L\otimes\Phi_\nu)_{\mathbf{3}_i}} + \frac{\kappa^{(i)}_{\Phi_e}}{\Lambda}\, \Delta K^{(i)}_{L^\dagger\,(L\otimes\Phi_e)_{\mathbf{3}_i}} \right) + \frac{\kappa_\xi}{\Lambda}\, \Delta K_{\xi L^\dagger L} + \text{h.c.}$$

  - possible to forbid these terms with additional symmetries

Back to A4 Example

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Kähler corrections due to flavon field:
  - quadratic in flavon

$$\Delta K^{\text{quadratic}}_{\phi^{(\prime)}} \supset \frac{1}{\Lambda^2} \sum_{X}^{6} \kappa^{X}_{\phi^{(\prime)},\text{quadratic}} \left(L\phi^{(\prime)}\right)^{\dagger}_{X} \left(L\phi^{(\prime)}\right)_{X} + \text{h.c.}$$

$$(L\Phi_\nu)^\dagger (L\Phi_\nu) \quad \text{and} \quad (L\Phi_e)^\dagger (L\Phi_e)$$

  - such terms cannot be forbidden by any (conventional) symmetry
  - Kähler corrections once flavon fields attain VEVs
  - additional parameters $\kappa^{X}_{\phi^{(\prime)}}$ diminish predictivity of the scheme
  - possible to forbid all contributions from RH sector as well as $(L\Phi_\nu)^\dagger (L\Phi_e)$ with additional symmetries in the particular A4 model

Back to A4 Example

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Kähler corrections due to flavon field χ : $$\Delta K \supset \sum_{i=1}^{6} \kappa^{(i)}\, \Delta K^{(i)}_{(L\chi)^\dagger_{\boldsymbol{X}}(L\chi)_{\boldsymbol{X}}} + \text{h.c.}$$
  - six possible contractions:

$$\begin{aligned}
\Delta K^{(1)}_{(L\chi)^\dagger_{\mathbf{1}}(L\chi)_{\mathbf{1}}} &= (L_1^\dagger\,\chi_1^\dagger + L_2^\dagger\,\chi_3^\dagger + L_3^\dagger\,\chi_2^\dagger)(L_1\,\chi_1 + L_2\,\chi_3 + L_3\,\chi_2)\;, \\
\Delta K^{(2)}_{(L\chi)^\dagger_{\mathbf{1}'}(L\chi)_{\mathbf{1}'}} &= (L_3^\dagger\,\chi_3^\dagger + L_1^\dagger\,\chi_2^\dagger + L_2^\dagger\,\chi_1^\dagger)(L_3\,\chi_3 + L_1\,\chi_2 + L_2\,\chi_1)\;, \\
\Delta K^{(3)}_{(L\chi)^\dagger_{\mathbf{1}''}(L\chi)_{\mathbf{1}''}} &= (L_2^\dagger\,\chi_2^\dagger + L_1^\dagger\,\chi_3^\dagger + L_3^\dagger\,\chi_1^\dagger)(L_2\,\chi_2 + L_1\,\chi_3 + L_3\,\chi_1)\;, \\
\Delta K^{(4)}_{(L\chi)^\dagger_{\mathbf{3}_1}(L\chi)_{\mathbf{3}_1}} &= (L_1^\dagger\,\chi_1^\dagger + \omega^2\,L_2^\dagger\,\chi_3^\dagger + \omega\,L_3^\dagger\,\chi_2^\dagger)(L_1\,\chi_1 + \omega\,L_2\,\chi_3 + \omega^2\,L_3\,\chi_2) \\
&+ (L_3^\dagger\,\chi_3^\dagger + \omega^2\,L_1^\dagger\,\chi_2^\dagger + \omega\,L_2^\dagger\,\chi_1^\dagger)(L_3\,\chi_3 + \omega\,L_1\,\chi_2 + \omega^2\,L_2\,\chi_1) \\
&+ (L_2^\dagger\,\chi_2^\dagger + \omega^2\,L_1^\dagger\,\chi_3^\dagger + \omega\,L_3^\dagger\,\chi_1^\dagger)(L_2\,\chi_2 + \omega\,L_1\,\chi_3 + \omega^2\,L_3\,\chi_1) \\
\Delta K^{(5)}_{(L\chi)^\dagger_{\mathbf{3}_2}(L\chi)_{\mathbf{3}_2}} &= (L_1^\dagger\,\chi_1^\dagger + \omega\,L_2^\dagger\,\chi_3^\dagger + \omega^2\,L_3^\dagger\,\chi_2^\dagger)(L_1\,\chi_1 + \omega^2\,L_2\,\chi_3 + \omega\,L_3\,\chi_2) \\
&+ (L_3^\dagger\,\chi_3^\dagger + \omega\,L_1^\dagger\,\chi_2^\dagger + \omega^2\,L_2^\dagger\,\chi_1^\dagger)(L_3\,\chi_3 + \omega^2\,L_1\,\chi_2 + \omega\,L_2\,\chi_1) \\
&+ (L_2^\dagger\,\chi_2^\dagger + \omega\,L_1^\dagger\,\chi_3^\dagger + \omega^2\,L_3^\dagger\,\chi_1^\dagger)(L_2\,\chi_2 + \omega^2\,L_1\,\chi_3 + \omega\,L_3\,\chi_1) \\
\Delta K^{(6)}_{(L\chi)^\dagger_{\mathbf{3}_1}(L\chi)_{\mathbf{3}_2}} &= (L_1^\dagger\,\chi_1^\dagger + \omega^2\,L_2^\dagger\,\chi_3^\dagger + \omega\,L_3^\dagger\,\chi_2^\dagger)(L_1\,\chi_1 + \omega^2\,L_2\,\chi_3 + \omega\,L_3\,\chi_2) \\
&+ (L_3^\dagger\,\chi_3^\dagger + \omega^2\,L_1^\dagger\,\chi_2^\dagger + \omega\,L_2^\dagger\,\chi_1^\dagger)(L_3\,\chi_3 + \omega^2\,L_1\,\chi_2 + \omega\,L_2\,\chi_1) \\
&+ (L_2^\dagger\,\chi_2^\dagger + \omega^2\,L_1^\dagger\,\chi_3^\dagger + \omega\,L_3^\dagger\,\chi_1^\dagger)(L_2\,\chi_2 + \omega^2\,L_1\,\chi_3 + \omega\,L_3\,\chi_1)
\end{aligned}$$

Back to A_4 Example

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- Contributions from Flavon VEVs (1,0,0) and (1,1,1)
  - five independent “basis” matrices

$$P_{\mathrm{I}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad P_{\mathrm{II}} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}, \quad P_{\mathrm{III}} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$P_{\mathrm{IV}} = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix}, \quad P_{\mathrm{V}} = \begin{pmatrix} 0 & \mathrm{i} & -\mathrm{i} \\ -\mathrm{i} & 0 & \mathrm{i} \\ \mathrm{i} & -\mathrm{i} & 0 \end{pmatrix}$$

- RG correction: essentially along P_{III} = diag(0,0,1) direction due to y_τ dominance
- Kähler corrections can be along different directions than RG

Enhanced θ_{13}

M.-C.C., Fallbacher, Ratz, Staudt (2012)

- consider change due to correction along P_V direction
- Kähler metric:

$$\mathcal{K}_L = 1 - 2xP \qquad \text{with} \qquad P_{\mathrm{V}} = \begin{pmatrix} 0 & \mathrm{i} & -\mathrm{i} \\ -\mathrm{i} & 0 & \mathrm{i} \\ \mathrm{i} & -\mathrm{i} & 0 \end{pmatrix}$$

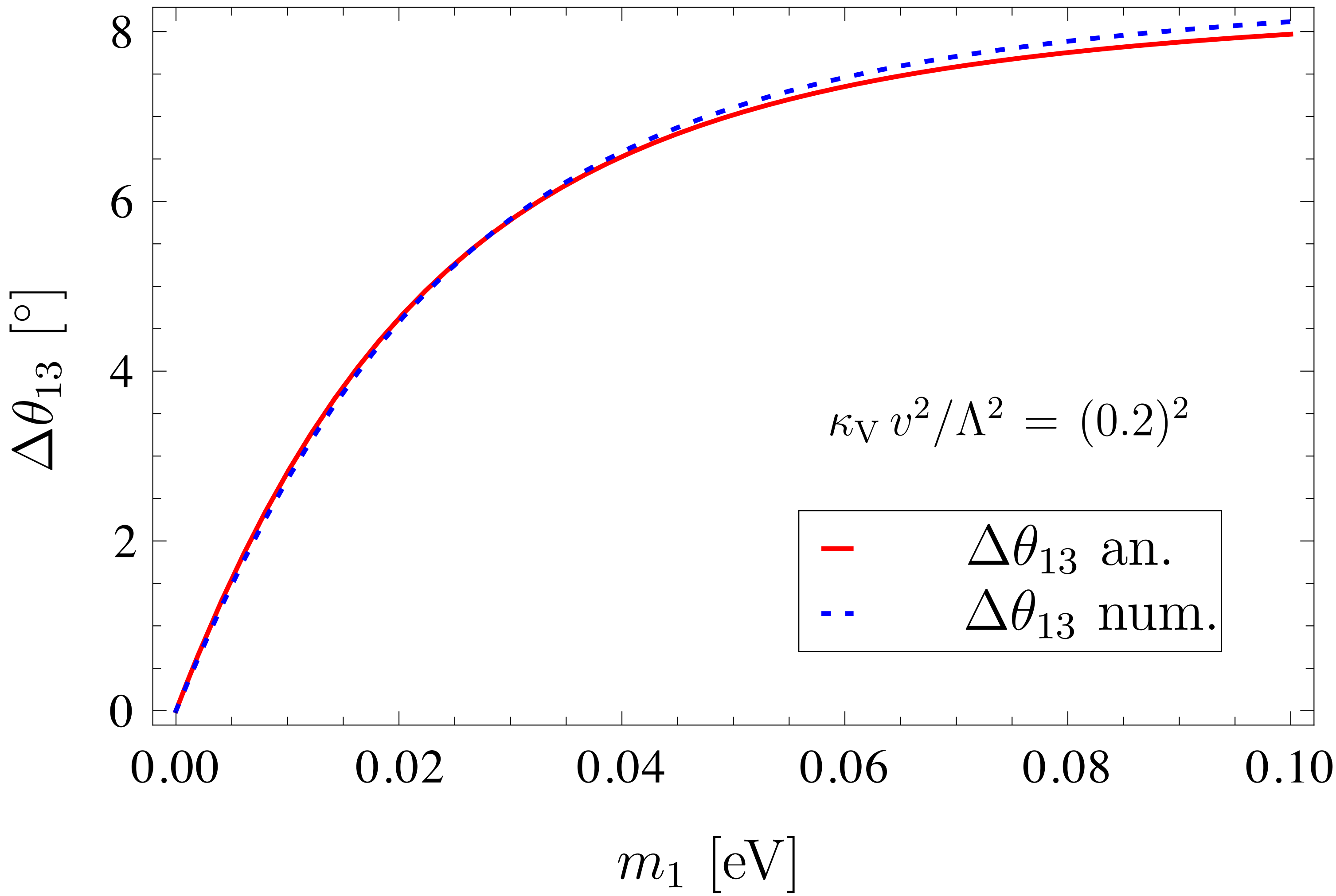
- Contributions of flavon VEV: $\langle \Phi \rangle = (1, 1, 1)\, v$
- Corrections to the leading order TBM prediction ($m_e \ll m_\mu \ll m_\tau$)

$$\Delta\theta_{13} \simeq \kappa_{\mathrm{V}} \cdot \frac{v^2}{\Lambda^2} \cdot 3\sqrt{6}\, \frac{m_1}{m_1 + m_3}$$

- Complex matrix P $\Rightarrow$ CP violation induced
- for the example considered: $\delta \approx \pi/2$

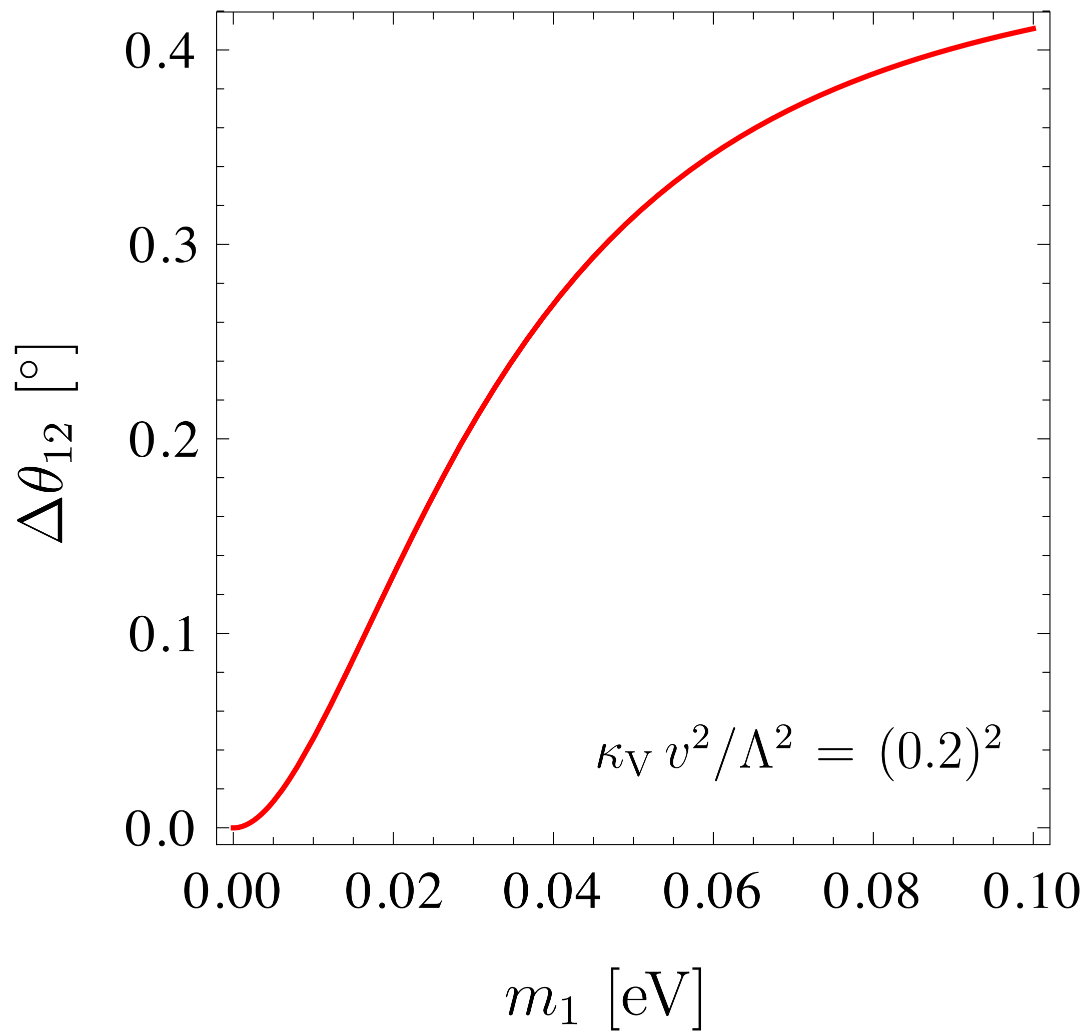
An Example: Enhanced θ$_{13}$

M.-C.C., Fallbacher, Ratz, Staudt (2012)



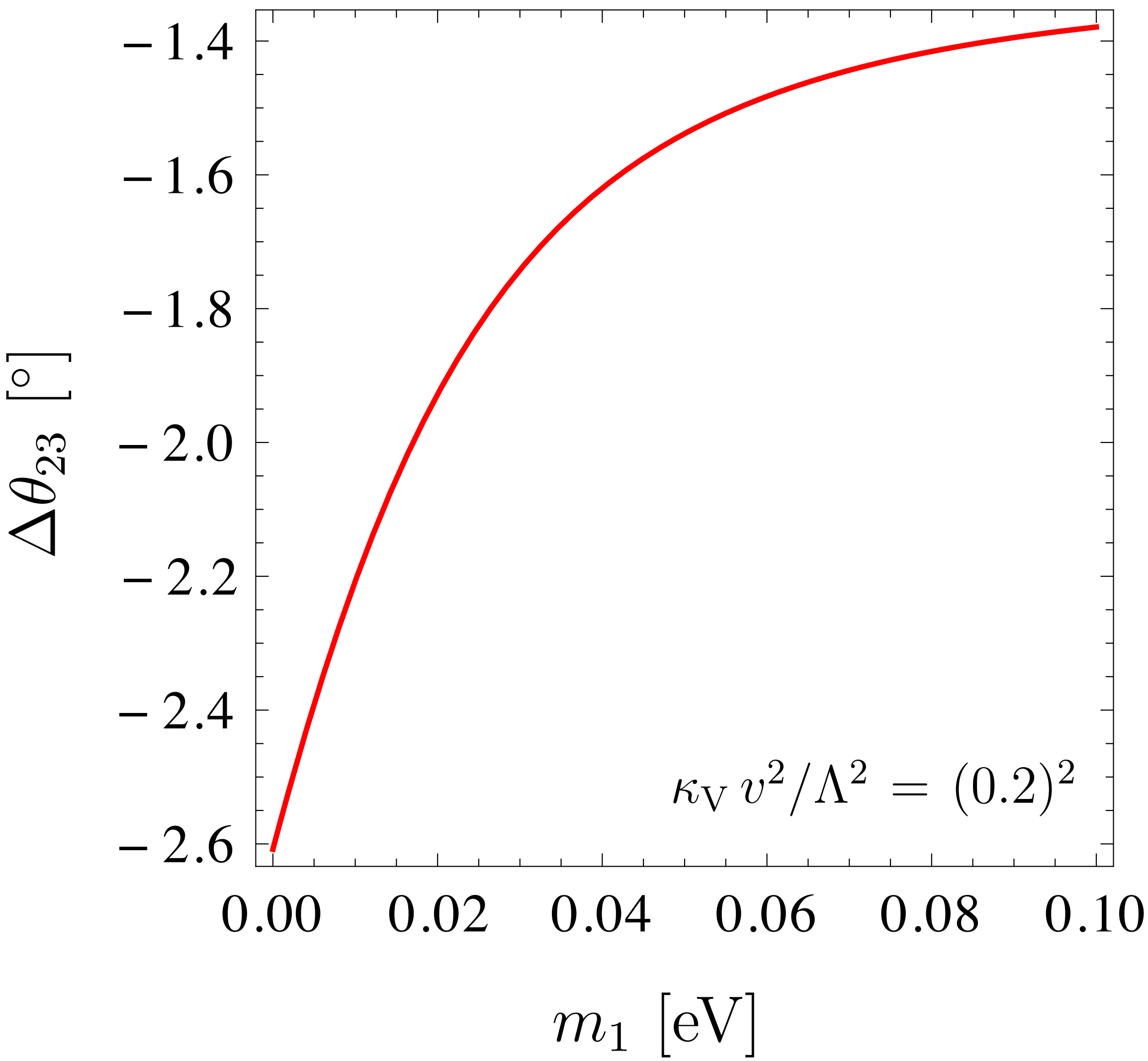
Corresponding Change in θ$_{12}$

M.-C.C., Fallbacher, Ratz, Staudt (2012)



Corresponding Change in θ_{23}

M.-C.C., Fallbacher, Ratz, Staudt (2012)



Conclusion

- Kähler corrections induced (and determined) by flavon VEVs (with order parameter ~ θ_c)
  - while similar in structure to RG corrections, can be along different directions than RG
  - size of Kähler corrections generically dominate RG corrections (no loop suppression, contributions from copies heavy states)
  - non-zero CP phases can be induced
  - additional parameters (Kähler coefficients) introduced
- robustness of model predictions diminished given the presence of these potentially sizable corrections and new parameters
- theoretical understanding of Kähler corrections crucial for achieving precision compatible with experimental accuracy