Effective textures from a $[SU(3)]^3$ flavored scalar sector

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Outline

Motivation and context

- Any extension of the SM must incorporate a mechanism to suppress FCNC. A simple approach is introduce constraints that obey Minimal Flavor Violation (MFV) or similar protection.
- When Yukawa sector is absent the SM model lagrangian obey a global symmetry

$$G = [U(1)]^3 \times SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$$

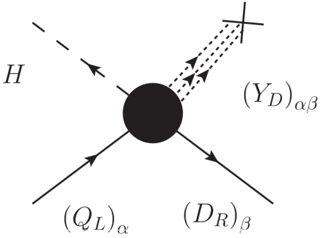
- There are more options. In this model we dynamically generate leptonic Yukawa textures from spontaneous breaking of an extended flavor symmetry

$$G_F = SU(3)_L \times SU(3)_R \times SU(3)_F$$

  in the leptonic sector.
- We look for the minimal new extra scalar degrees of freedom that connects flavon VEV hierarchies to neutrino mass ordering and CP phase constraints;

Minimal Flavor Violation

Minimal Flavor Violation (MFV): Core Idea



- **Flavor problem:** Generic TeV-scale NP induces large FCNCs, CPV $\Rightarrow$ tension with ε_K, $\Delta m_{B_{d,s}}$, $b \to s\gamma$, etc.
- **MFV principle:** All sources of flavor and CP violation $\equiv$ SM Yukawas.

- Quark flavor symmetry (no Yukawas):

$$\mathcal{G}_q = U(3)_{Q_L} \times U(3)_{U_R} \times U(3)_{D_R}.$$

- Yukawas as spurions:

$$Y_u \sim (3, \bar{3}, 1), \quad Y_d \sim (3, 1, \bar{3}).$$

- Any NP operator must be invariant under $\mathcal{G}_q$ with $Y_{u,d}$ spurions.

MFV in Quark Sector: Operator Structure

$\Delta F = 2$ example

$$\mathcal{L}^{\rm MFV}_{\Delta F=2} = \frac{c}{\Lambda^2}\left(\bar{Q}_L\gamma^\mu(Y_u Y_u^\dagger)Q_L\right)^2.$$

In down basis: $(Y_u Y_u^\dagger)_{ij} \simeq y_t^2 V_{3i}^* V_{3j}$.

Dipole operators $(b \to s\gamma)$

$$\mathcal{O}_7^{ij} \sim \frac{e}{\Lambda^2}\,\bar{Q}_L^i\sigma^{\mu\nu}(Y_u Y_u^\dagger Y_d)_{ij} D_R^j F_{\mu\nu}.$$

$\Rightarrow$ CKM + Yukawa suppressions aligned with SM.

- NP inherits CKM hierarchies and chirality/Yukawa suppressions.
- Correlated effects in K, B_d, B_s systems; no new CPV phases (minimal case).

Minimal Lepton Flavor Violation (MLFV)

- Lepton flavor symmetry (no Yukawas):

$$\mathcal{G}_\ell = U(3)_L \times U(3)_E.$$

- Spurions:

$$Y_e \sim (3, \bar{3}), \quad \kappa \text{ (Weinberg op.)} \quad \text{or} \quad Y_\nu \text{ (seesaw)}.$$

- Example operator (CLFV dipole, seesaw):

$$\mathcal{O}_D^{ij} \sim \frac{e}{\Lambda^2} \bar{L}^i \sigma^{\mu\nu} (Y_\nu Y_\nu^\dagger Y_e)_{ij} E_R^j F_{\mu\nu}.$$

- Predictions:
  - CLFV rates $\propto (Y_\nu Y_\nu^\dagger)_{ij}$ or $(\kappa\kappa^\dagger)_{ij}$.
  - Correlated with PMNS mixing + neutrino masses.
  - Suppressed in minimal EFT, potentially larger in seesaw MLFV.

Textures

Yukawa Textures in SM Extensions

- **Motivation:** SM Yukawas $\Rightarrow$ arbitrary 3×3 complex matrices. $\rightarrow$ Too many free parameters, no explanation for hierarchies and mixing.
- **Textures:** Ansatz for Yukawa matrices with zero entries or symmetry-imposed structures.
  - Reduce parameter space.
  - Correlate quark/lepton masses and CKM/PMNS mixing.
  - May arise from discrete symmetries (Z_n, S_3, A_4, etc.).
- Famous examples: Fritzsch textures, nearest-neighbour interaction (NNI).
- Goal: understand flavour hierarchies and suppress FCNCs in extensions.

2 zero texture matrices

Usual classification of 2 zero textures has the four classes generated by

$$M_i^{(\beta)} = P_i^T M_0^{(\beta)} P_i$$

for $\beta = \text{I,II,III,IV}$ and $P_i \in S_3$:

$$M_0^{(\text{I})} = \begin{pmatrix} 0 & A & 0 \\ A^* & e & C \\ 0 & C^* & f \end{pmatrix} ; M_0^{(\text{II})} = \begin{pmatrix} 0 & A & B \\ A^* & e & 0 \\ B^* & 0 & f \end{pmatrix} ;$$
$$M_0^{(\text{III})} = \begin{pmatrix} 0 & A & B \\ A^* & 0 & C \\ B^* & C^* & f \end{pmatrix} ; M_0^{(\text{IV})} = \begin{pmatrix} d & 0 & 0 \\ 0 & e & C \\ 0 & C^* & f \end{pmatrix} .$$

The physics BSM is contained in the parameters of the texture

Two-Higgs-Doublet Model (2HDM): Yukawas

- Lagrangian:

$$\mathcal{L}_Y = \bar{Q}_L(Y_1^u \tilde{\Phi}_1 + Y_2^u \tilde{\Phi}_2)U_R + \bar{Q}_L(Y_1^d \Phi_1 + Y_2^d \Phi_2)D_R + \text{h.c.}$$

- Generic case: both Higgs doublets couple to each fermion type. $\rightarrow$ After EWSB: two Yukawa matrices per sector ($M_f \propto v_1 Y_1^f + v_2 Y_2^f$).
- Problem: Tree-level FCNCs from non-diagonal neutral couplings.
- **Solution strategies:**
  1. Discrete symmetry (Z_2): each fermion type couples to only one Higgs (2HDM type I/II/X/Y).
  2. **Textures:** choose $Y_{1,2}^f$ with specific zero patterns or alignments $\rightarrow$ controlled FCNCs.

2HDM with Yukawa Textures

- Example: **Cheng–Sher Ansatz** for FCNC control:

$$(Y_{ij}^f) \sim \frac{\sqrt{m_i m_j}}{v}\,\chi_{ij},$$

  with $\chi_{ij} \sim \mathcal{O}(1)$ parameters. $\rightarrow$ Suppresses off-diagonal couplings naturally.
- Texture zeros (Fritzsch, NNI) can be implemented in Y_1^f, Y_2^f to reproduce CKM while suppressing FCNC.
- **Phenomenology:**
  - Higgs-mediated FCNC $\propto$ texture pattern.
  - Predictive correlations in B mixing, $b \to s\ell^+\ell^-$, $\mu \to e\gamma$.
  - Testable in LHC Higgs flavour observables.
- Textures in 2HDM = intermediate path: richer than Z_2-models, but still predictive vs. full generic case.

The Model

Field content and symmetry

- Under the flavor group: $G_F = SU(3)_L \times SU(3)_R \times SU(3)_F$ the Yukawa behaves as spurions with:

$$Y_\nu \sim (1,1,8) \quad (1)$$
$$Y_\ell \sim (1,1,8) \quad (2)$$

- It is introduce new scalar flavons, SM singlets:

	$SU_L(2)$	$SU_L(3)$	$SU_R(3)$	$SU_F(3)$
ξ_L	1	3	1	3
ξ_R	1	1	$\bar{3}$	3
$\tilde{\phi}$	1	3	$\bar{3}$	1
H	2	1	1	1
f_L	2	1	1	3
ℓ_R	1	1	1	$\bar{3}$
ν_R	1	1	1	3

- Effective Yukawa sector up to dim-7 is given by:

$$-\mathcal{L}_{Y_l} = \bar{f_{Li}} \left[D_{ij} + \frac{(\xi^{\dagger a}_{Li} \xi^{a}_{Lj} + i\xi^{\dagger \tilde{a}}_{Ri} \xi^{\tilde{a}}_{Rj})}{\Lambda^2} + \frac{\xi^{a}_{Li} \tilde{\phi}^{\dagger a \tilde{b}} \xi^{\tilde{b}}_{Rj}}{\Lambda^3} \right] f_{Rj} H,$$

Effective Yukawa and VEV's

After SSB the Yukawa is given by

$$Y = D + \frac{1}{\Lambda^2}(\Delta_L + \Delta_R) + \frac{1}{\Lambda^3}\Gamma',$$

with

$$\begin{aligned}(\Delta_L)_{ij} &= \xi^{a\dagger}_{Li}\xi^{a}_{Lj},\\ (\Delta_R)_{ij} &= \xi^{\tilde{a}\dagger}_{Ri}\xi^{\tilde{a}}_{Rj},\\ (\Gamma')_{ij} &= \xi^{a}_{Li}\tilde{\phi}^{\dagger a\tilde{a}}\xi^{\tilde{a}}_{Rj},\end{aligned}$$

Cayley–Hamilton invariants to build the potential

$$\begin{aligned}A_{L(R)} &= \mathrm{Tr}(\Delta_{L(R)}),\\ A_{\phi} &= \mathrm{Tr}(\tilde{\phi}^{\dagger}\tilde{\phi}),\\ B_{\Gamma} &= \mathrm{Tr}(\Gamma')\\ C_{LL(RR)} &= \mathrm{Tr}(\Delta^{\dagger}_{L(R)}\Delta_{L(R)}),\end{aligned}$$

$$\begin{aligned}C_{LR} &= \mathrm{Tr}(\Delta_L\Delta_R).\\ D_{L(R)} &= \mathrm{Det}(\Delta_{L(R)}),\\ E_{\Gamma} &= \mathrm{Det}(\Gamma'),\end{aligned}$$

Flavon invariants and potential

- Potential truncated to dim-7 terms (sufficient to generate three nonzero masses):

$$
\begin{aligned}
V_F = {} & \sum_{i=L,R,\phi} \mu_i^2 A_i + \gamma B_\Gamma + \sum_{i,j=L,R,\phi} \tilde{g}_{ij} A_i A_j + \sum_{J=LL,RR,LR} g_J C_J \\
& + \sum_{i,j=L,R,\phi} \lambda_i A_i B_\Gamma + \sum_{i,j,k=L,R,\phi} \tilde{\lambda}_{ijk} A_i A_j A_k + \sum_{\substack{i=L,R,\phi \\ J=LL,RR,LR}} \lambda'_{iJ} A_i C_J \\
& + \sum_{k=L,R} \lambda''_k D_k + \tilde{\gamma} B_\Gamma^2 + \sum_{i,j=L,R,\phi} \sigma_{ij} A_i A_j B_\Gamma + \sum_{J=LL,RR,LR} \tilde{\sigma}_J C_J B_\Gamma .
\end{aligned}
$$

- Complex phases in invariants imply new CP sources; (work in progress)

Neutrino mass matrix restrictions up to dim-7

- Restrictions from the eigenvalues of M_D (at least one neutrino mass is strongly suppressed)

$$\mathrm{Det}(\tilde{M}_D) \simeq \alpha^3 + \frac{\alpha^2}{\Lambda^2}\left(\mathrm{Tr}(\Delta) - \Delta_{11}\right) + \frac{\alpha}{\Lambda^3}\left(\mathrm{Tr}(\Gamma) - \Gamma_{11}\right),$$

$$\frac{1}{2}\left[\mathrm{Tr}^2(\tilde{M}_D) - \mathrm{Tr}(\tilde{M}_D^2)\right] \simeq -3\alpha^2 + 2\alpha\,\mathrm{Tr}(\tilde{M}_D),$$

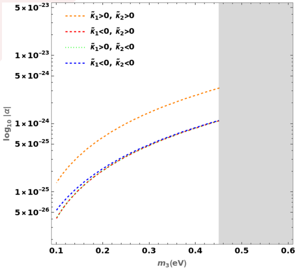
- Restriction from mixing angles

$$\left\{U^\dagger \mathrm{diag}\left[m_{\nu_1}(\Delta m^2_{lm}, m_{\nu_3}), m_{\nu_2}(\Delta m^2_{lm}, m_{\nu_3}), m_{\nu_3}\right] U - v\alpha 1\right\}_{ij} = \frac{v}{\Lambda^2}\left(\Delta + \frac{\Gamma}{\Lambda}\right)_{ij}.$$

- Possible restrictions from textures zeros:

$$\Delta_{ij} = \left(\frac{1}{\Lambda} - \frac{\Lambda^2 D_{ij}}{\Gamma_{ij}}\right)\Gamma_{ij}.$$

$$\Delta_{ij} \simeq \Gamma_{ij}/\Lambda$$



Texture zeros and VEV alignment (2-zero textures)

- We analyze Fritzsch-like 2-zero Hermitian textures (classes I–III), using weak-basis transformations (S_3) to enumerate equivalent textures. Appendix and tables in the paper list restrictions.
- Texture-zero conditions impose linear relations among VEV components, which translate into alignment surfaces in VEV space.
- As results some diagonal-zero textures are excluded for large NP scales ($\Lambda \gtrsim 10^3$ TeV) by CP-phase constraints (see the paper's figure and discussion).

Texture	Restrictions	Texture	Restrictions
$\begin{pmatrix} 0 & * & 0 \\ * & * & * \\ 0 & * & * \end{pmatrix}$	$\Lambda\Delta_{11} = \Gamma_{11} - \Lambda^3\alpha,$ $\Lambda\Delta_{13} = \Gamma_{13}.$	$\begin{pmatrix} * & * & * \\ * & 0 & 0 \\ * & 0 & * \end{pmatrix}$	$\Lambda\Delta_{22} = \Gamma_{22} - \Lambda^3\alpha,$ $\Lambda\Delta_{23} = \Gamma_{23}.$
$\begin{pmatrix} 0 & 0 & * \\ 0 & * & * \\ * & * & * \end{pmatrix}$	$\Lambda\Delta_{11} = \Gamma_{11} - \Lambda^3\alpha,$ $\Lambda\Delta_{12} = \Gamma_{12}.$	$\begin{pmatrix} * & * & 0 \\ * & * & * \\ 0 & * & 0 \end{pmatrix}$	$\Lambda\Delta_{33} = \Gamma_{33} - \Lambda^3\alpha,$ $\Lambda\Delta_{13} = \Gamma_{13}.$
$\begin{pmatrix} * & 0 & * \\ 0 & 0 & * \\ * & * & * \end{pmatrix}$	$\Lambda\Delta_{22} = \Gamma_{22} - \Lambda^3\alpha,$ $\Lambda\Delta_{12} = \Gamma_{12}.$	$\begin{pmatrix} * & * & * \\ * & * & 0 \\ * & 0 & 0 \end{pmatrix}$	$\Lambda\Delta_{33} = \Gamma_{33} - \Lambda^3\alpha,$ $\Lambda\Delta_{23} = \Gamma_{23}.$

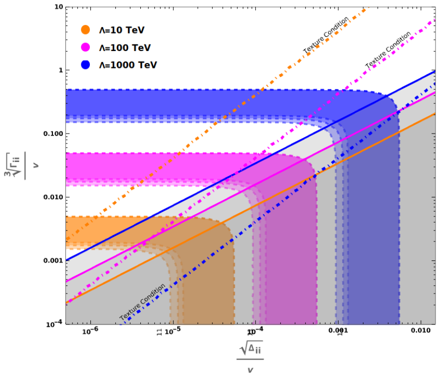
Allowed VEV parameter space (figures)

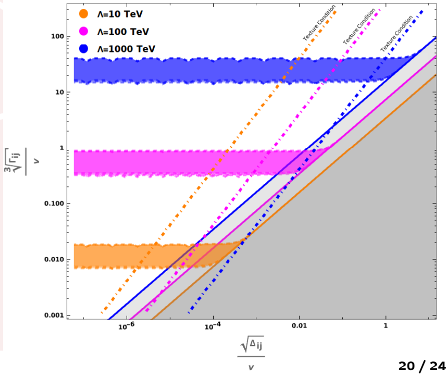
If it is defined $\Delta_{ij} = |\Delta_{ij}| e^{i\delta_{ij}}$ and $\Gamma_{ij} = |\Gamma_{ij}| e^{i\gamma_{ij}}$ thus

$$\frac{v^2}{\Lambda^4}\left[|\Delta_{ij}|^2 + \left(\frac{|\Gamma_{ij}|}{\Lambda}\right)^2 + 2\frac{|\Delta_{ij}||\Gamma_{ij}|}{\Lambda}\cos(\delta_{ij} - \gamma_{ij}) \right] \simeq \left| \sum_{k=1}^{3} U_{ki}^* U_{kj} m_{\nu_k}(\Delta m_{31}^2, \Delta m_{21}^2, m_{\nu_3}) \right|^2 ,$$

and

$$\tan \varepsilon_{ij} \simeq \frac{|\Delta_{ij}| \sin \delta_{ij} + \frac{|\Gamma_{ij}|}{\Lambda} \sin \gamma_{ij}}{|\Delta_{ij}| \cos \delta_{ij} + \frac{|\Gamma_{ij}|}{\Lambda} \cos \gamma_{ij}} ,$$





Phenomenological summary

1. Two flavon sets: $\xi_{L,R}$ (controls Yukawa suppression) and $\tilde{\Phi}$ (controls neutrino mass hierarchy). Typical hierarchy: $\langle \xi \rangle \ll \langle \tilde{\Phi} \rangle$ (around two orders of magnitude).
2. Predicts at least one nearly vanishing neutrino mass — consistent with normal ordering and KATRIN limits.
3. Texture zeros provide strong alignment constraints and may exclude certain textures depending on Λ and δ_{CP}.
4. Opens further studies: LFV predictions (suppressed here), possible embedding into gauged flavor symmetry or GUTs, leptogenesis implications.

Conclusions

- A flavon sector under $[SU(3)]^3$ can dynamically generate viable leptonic Yukawa textures with MFV-like protection.
- Neutrino data produce nontrivial bounds in flavon VEV space; at least one neutrino mass is naturally strongly suppressed in this framework.
- Texture-zero analysis reduces free parameters and produces testable alignment constraints — some textures excluded for high NP scale.
- Next steps: compute explicit LFV amplitudes, study UV completion (gauged flavour / anomaly cancellation), explore leptogenesis viability.

Thank you

References and further reading

- Carrillo-Monteverde A., Escorcia Ramírez R., Gómez-Ávila S., López-Lozano L., Int. J. Mod. Phys. A (2025) — main article used here.
- R. Alonso et al., JHEP 2011 (MFV scalar analyses).
- NuFIT global fits for oscillation inputs used in the analysis.