# Supersymmetric Musings on the Predictivity of Flavor Symmetries

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Based on work being done in collaboration with
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# Nothing but Problems with Flavor

**Standard Model**

- $m_e = 511\,\text{keV} \ll m_t = 173\,\text{GeV}$
- Values of mixing angles not understood

**SUSY**

- New source of flavor violation in soft SUSY-breaking parameters
- No suppression of flavor-changing neutral currents expected
- Observations require suppression

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- Vector-like messengers $\chi$, mass $M > \langle\overline{\phi}\rangle$
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$$Y_{ij} \sim \left(\frac{\langle\overline{\phi}\rangle}{M}\right)^{n_{ij}} \sim 0.1^{n_{ij}}$$

- Power $n_{ij}$ of suppression depends on $i, j$ $\rightsquigarrow$ mass hierarchy

# Towards a Cure II

- Non-Abelian symmetry, matter fields in 3D representation

$$\psi, \psi^c \sim \mathbf{3}$$

- Gravity-mediated SUSY breaking
  $\Rightarrow$ ~~SUSY~~ terms generated at $M_{\text{Pl}} \gg \langle \overline{\phi} \rangle$
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  - $\Rightarrow$ Invariant under flavor symmetry
- Allowed scalar mass term:

$$\widetilde{\psi}_i^* \, \delta_{ij} \, m_0^2 \, \widetilde{\psi}_j \quad \Rightarrow \quad \text{Soft mass matrices } \widetilde{m}^2 = m_0^2 \, \mathbb{1}$$

- Trilinear couplings a=0

$\leadsto$ SUSY flavor problem solved

# Added Bonus

Flavor symmetry breaking

- ⇝ Off-diagonal scalar masses

$$\widetilde{m}^2_{ij} \sim m_0^2 \left( \frac{\langle \overline{\phi} \rangle}{M} \right)^n$$

- ⇝ Non-zero trilinears

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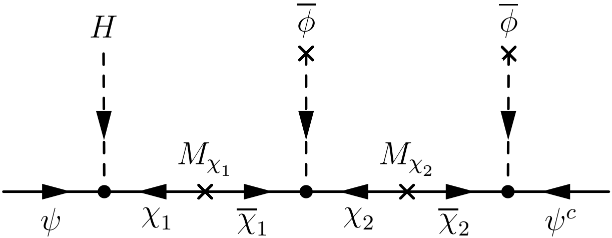
New terms

- Suppressed ⇝ flavor and CP violation still under control
- Predicted ⇝ additional experimental test

Abel, Antusch, Calibbi, Feruglio, Hagedorn, Ishimori, Jones-Perez, Khalil, King, Kobayashi, Lebedev, Lin, Malinský, Merlo, Nomura, Ohki, Olive, Omura, Ross, Stolarski, Takahashi, Tanimoto, Velasco Sevilla, Vives,
hep-ph/0112260, hep-ph/0211279, hep-ph/0401064, 0708.1282, 0801.0428, 0803.0796, 0804.4620, 0807.3160, 0807.4625, 0807.5047, 0808.1380

# Example: SU(3)




de Medeiros Varzielas, Ross, hep-ph/0507176

- Matter fields $\psi, \psi^c \sim \mathbf{3}$
- Flavon $\overline{\phi} \sim \overline{\mathbf{3}}$
- $Y \sim \dfrac{\langle\overline{\phi}\rangle^2}{M_{\chi_1} M_{\chi_2}}$ $\rightsquigarrow$ only product of messenger masses determined

# Consequences for Soft Parameters

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2. Integrate out messengers $\rightsquigarrow$ effective super- and Kähler potential
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  Antusch, King, Malinský, 0712.3759

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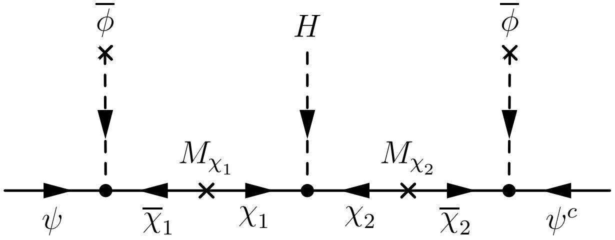
- Trilinears: same conclusion

# Approaches for Improving Predictivity

- Extend model
  - Explicit theory of messenger sector
    Cf. King, Malinský, hep-ph/0608021 for SO(3)
    (already $M_\chi > \langle\overline{\phi}\rangle$ for *all* messengers and flavons could help)
  - Fix ratios of flavon vevs
  - Large $Y_{33}$ possibly helpful
- Change messenger sector

# More Predictive Messenger Sector




- $Y \sim \dfrac{\langle\overline{\phi}\rangle^2}{M_{\chi_1} M_{\chi_2}}$
- All messengers SU(3) singlets

# Soft Masses Again

- $$\widetilde{m}^2_{\psi^c} \sim m_0^2 \left(1 + \underbrace{\frac{\langle\overline{\phi}\rangle^2}{M^2_{\chi_2}}}_{\widetilde{\epsilon}^2_{u,d,e}}\right) \quad , \quad \widetilde{m}^2_{\psi} \sim m_0^2 \left(1 + \underbrace{\frac{\langle\overline{\phi}\rangle^2}{M^2_{\chi_1}}}_{\widetilde{\epsilon}^2_{Q,L}}\right)$$

# Soft Masses Again

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- Recall $Y \sim \dfrac{\langle\overline{\phi}\rangle^2}{M_{\chi_1} M_{\chi_2}} =: \epsilon^2_{u,d}$
- Off-diagonal elements in all soft mass matrices
- All messenger masses appear
- Relations between expansion parameters

$$\widetilde{\epsilon}_Q \, \widetilde{\epsilon}_u = \epsilon_u^2 \quad , \quad \widetilde{\epsilon}_Q \, \widetilde{\epsilon}_d = \epsilon_d^2 \quad , \quad \widetilde{\epsilon}_L \, \widetilde{\epsilon}_e = \epsilon_d^2$$

- None of them can be arbitrarily small: $\widetilde{\epsilon} \gtrsim 0.01$

# Experiment vs. Model Predictions

Simple example:

$$\widetilde{\epsilon}_Q = \widetilde{\epsilon}_d = \widetilde{\epsilon}_L = \widetilde{\epsilon}_e = \epsilon_d \approx 0.15 \quad , \quad \widetilde{\epsilon}_u = \frac{\epsilon_u^2}{\epsilon_d} \approx 0.02$$

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| | Our example | Bound |
|---|---|---|
| $(\delta^d_{RR})_{12}$ | $\frac{\widetilde{\epsilon}_d^2 \, \epsilon_d}{30} \sim 10^{-4}$ | $9 \cdot 10^{-3}$ |
| $(\delta^d_{LL})_{12}$ | $\frac{\widetilde{\epsilon}_Q^2 \, \epsilon_d}{30} \sim 10^{-4}$ | $1 \cdot 10^{-2}$ |
| $(\delta^d_{LR})_{12}$ | $\frac{\propto \epsilon_d^3}{30} \sim 3 \cdot 10^{-5}$ | $1 \cdot 10^{-5}$ |
| $(\delta^d_{LL})_{23}$ | $\frac{\widetilde{\epsilon}_Q^2}{30} \sim 8 \cdot 10^{-4}$ | $2 \cdot 10^{-1}$ |
| $(\delta^e_{LL})_{12}$ | $\frac{\widetilde{\epsilon}_L^2 \, \epsilon_d}{4} \sim 8 \cdot 10^{-4}$ | $6 \cdot 10^{-4}$ |

- Experimental bounds from $\Delta m_K$, $b \to s\gamma$, $\mu \to e\gamma$ etc.
  Ciuchini, Masiero, Paradisi, Silvestrini, Vempati, Vives, hep-ph/0702144
- Some tension in 12 sector
  See also Antusch, King, Malinský, 0708.1282
- Only weak constraints on $\delta^u$ and $\delta^e_{RR}$ $\rightsquigarrow$ easily satisfied

# Conclusions

- Non-Abelian flavor symmetries can solve flavor problems
- Predictions for SUSY-breaking parameters
- Predictivity depends on messenger sector
- Stay tuned for Kadota, JK, Velasco-Sevilla, 1006.xxxx