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# Irreducible flavour & CP violation in SUGRA flavour models

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# Outline

- Flavour models, SUSY FV and CPV & SUGRA
- Flavon $F$-terms
- $F_X$ contra $F_\phi$
- Irreducible SUGRA flavour & CP violation in flavour models

# Models of flavour

Flavour symmetries provide a handle to the generic Yukawa sector of the Standard Model.
If matter is charged with respect to $\mathcal{F}$ some (or even all) of the couplings arrise at the effective level only after the proper breakdown of $\mathcal{F}$ by means of gauge-singlet $\mathcal{F}$-nonsinglet Higgs fiedls.

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Exampe: $U(1)$ flavour symmetry

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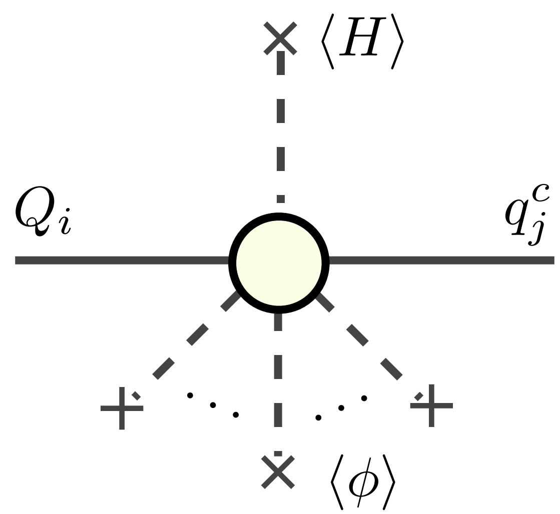


$$\varepsilon \equiv \frac{\langle \phi \rangle}{M_m}$$

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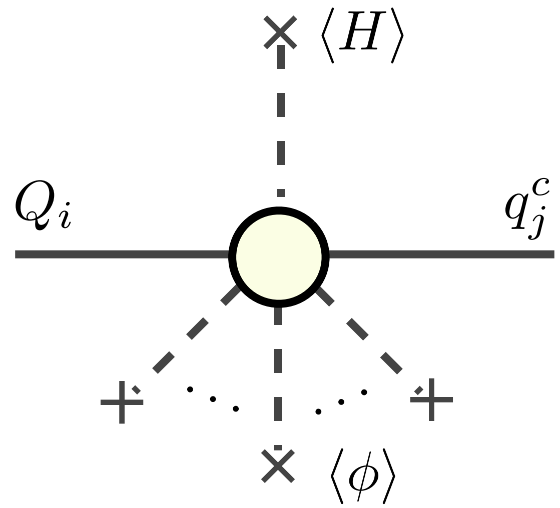


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In practice, the neutrinos tend to call for non-abelian symmetries (like for example $SU(3)_{\mathcal{F}}$) or their discrete subgroups. In such a case matter fields and flavons enter higher dimensional irreps of the flavour symmetry group and the Yukawa patterns arise as a consequence of flavour-nontrivial vacuum alignment of $\langle\phi\rangle$'s.

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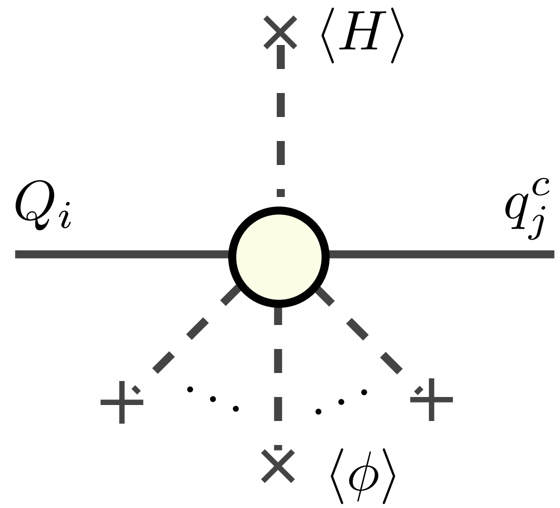


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Currently, there is a plenty of models like this... Extra input is badly needed to constrain them.
One such option is SUSY with the constraints coming from SUSY flavour and CP puzzles...

# SUSY flavour and CP puzzle

MSSM:

$$
\begin{aligned}
W_Y &\sim \varepsilon_{\alpha\beta}\left[\hat{H}_u^\alpha \hat{Q}^{\beta i} Y_{ij}^u \hat{u}^{cj} + \hat{H}_d^\alpha \hat{Q}^{\beta i} Y_{ij}^d \hat{d}^{cj} + \hat{H}_u^\alpha \hat{L}^{\beta i} Y_{ij}^\nu \hat{N}^{cj} + \hat{H}_d^\alpha \hat{L}^{\beta i} Y_{ij}^e \hat{e}^{cj}\right] + \hat{N}^{ci}(M_R)_{ij}\hat{N}^{cj} \\
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Convenience - the 'super CKM' basis: Dugan, Grinstein, Hall, Nucl.Phys.B255(1985)

- basis in which the neutralino couplings to matter are flavour diagonal
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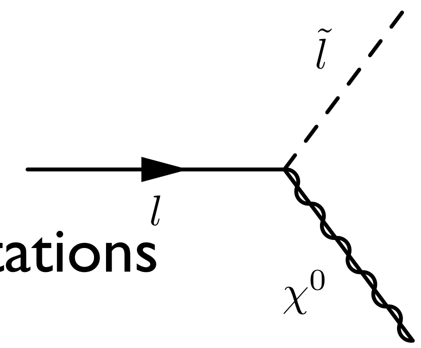

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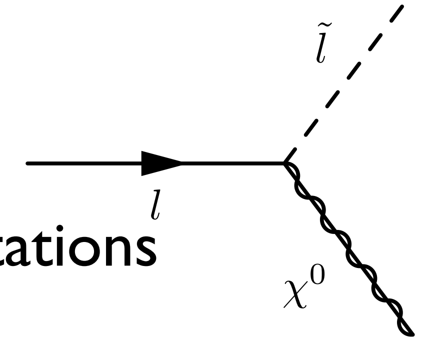


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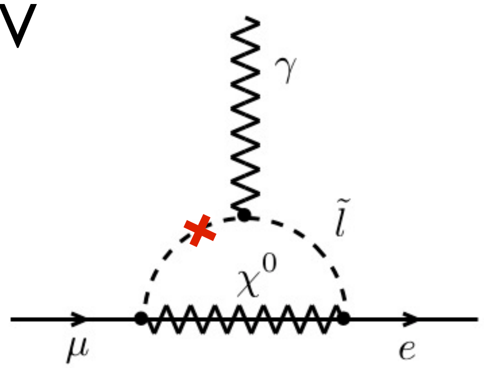

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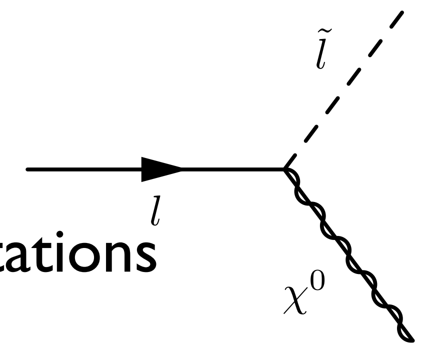


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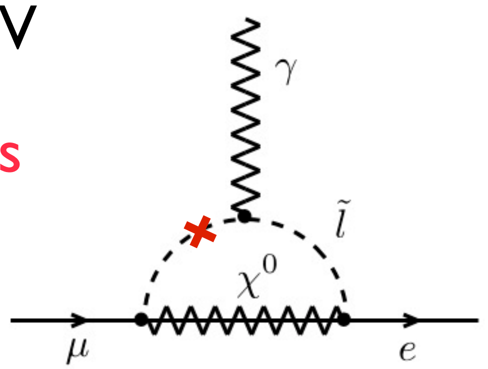

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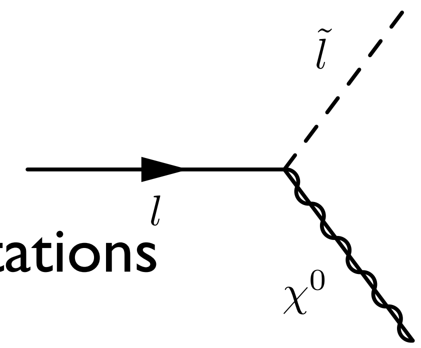


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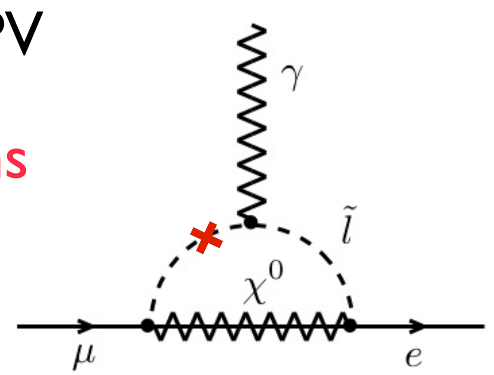


Minimal flavour violation: $m^2_{soft}\propto m_0^2\mathbb{1},\quad A^f\propto A_0Y^f$

# SUGRA 'solution' to SUSY flavour and CP puzzles

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m^2_{soft} &= m^2_{3/2}\tilde{K}_{\overline{a}b} - \sum_{S,S'} F_{\overline{S}'}\left[\partial_{\overline{S}'}\partial_S\tilde{K}_{\overline{a}b} - \partial_{\overline{S}'}\tilde{K}_{\overline{a}c}(\tilde{K}^{-1})_{c\overline{d}}\partial_S\tilde{K}_{\overline{d}b}\right]F_S \\
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**where** $K(\psi, X, \ldots) = \tilde{K}_{\overline{a}b}(X,\ldots)\psi^*_{\overline{a}}\psi_b + \ldots + K_{hid.}(X,\ldots)$ $\langle F_X\rangle \neq 0$

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Example: 'Sequestered' shape of a Kähler potential makes the soft masses universal !
(after canonical normalization of $\overline{\psi}_{\overline{a}}\tilde{K}_{\overline{a}b}D_\mu\gamma^\mu\psi_b$)

If, moreover, the Yukawas do not feel $X$ (or do in a flavour-blind way), the $A$-terms are aligned to $Y$'s and CP and FV is essentially O.K.

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Flavour symmetries can still control the Kähler so that one does not get far from universality. However, in flavour models, there are always fields with nonzero $F$-terms felt by the Yukawas !

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THE FLAVONS...

# Induced flavon F-terms & irreducible flavour violation in SUGRA flavour models

The generic SUGRA $F$-term:

$$F_I = -e^{K/2M_{Pl}^2}(K^{-1})_{I\bar{J}}\left(\frac{1}{M_{Pl}^2}W^* K_{\bar{J}} + W^*_{\bar{J}}\right) = -(K^{-1})_{I\bar{J}}\left(m_{3/2}K_{\bar{J}} - e^{K/2M_{Pl}^2}W^*_{\bar{J}}\right)$$

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Ross, Vives, Phys.Rev.D67 (2003)

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This means that the following pieces are always present in the soft masses and trilinears:

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and give an irreducible contribution to flavour violation...

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$$\begin{aligned} m^2_{soft} &= m^2_{3/2}\tilde{K}_{\overline{a}b} - \sum_{\phi,\phi'} F_{\overline{\phi}'}\left[\partial_{\overline{\phi}'}\partial_\phi \tilde{K}_{\overline{a}b} - \partial_{\overline{\phi}'}\tilde{K}_{\overline{a}c}(\tilde{K}^{-1})_{c\overline{d}}\partial_\phi \tilde{K}_{\overline{d}b}\right] F_\phi \\ \mathcal{A}_{abc}Y_{abc} &= k\left\{\frac{F_X}{M_{Pl}^2}(\partial_X K_{hid.})Y_{abc} + \sum_\phi F_\phi \partial_\phi Y_{abc} - \sum_\phi F_\phi\left[(\tilde{K}^{-1})_{d\overline{e}}\partial_\phi \tilde{K}_{\overline{e}a}Y_{dbc} + cycl.\right]\right\} \end{aligned}$$

and give an irreducible contribution to flavour violation... How about the magnitude ?

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If flavour symmetry is broken well below the Planck scale, we get $F_\phi \ll F_X$.
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A (non)trivial example: generic Kähler with both $X$ and $\phi$ mixed together

$$\tilde{K}_{\overline{a}b} \sim \delta_{\overline{a}b}\left(c_0 + d_0 \frac{X^\dagger X}{M_{Pl}^2}\right) + \left(c_2 + d_2 \frac{X^\dagger X}{M_{Pl}^2}\right)\frac{1}{M^2}(\phi\phi^*)_{\overline{a}b} + \ldots$$

$$\Delta m^2_{soft} = F_{\overline{X}}\left(\partial_{\overline{X}}\partial_X \tilde{K}_{\overline{a}b}\right) F_X - F_{\overline{\phi}}\left(\partial_{\overline{\phi}}\partial_\phi \tilde{K}_{\overline{a}b}\right) F_\phi + \ldots$$

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$$F_{\overline{\phi}}\left(\partial_{\overline{\phi}}\partial_\phi \tilde{K}_{\overline{a}b}\right) F_\phi \sim m^2_{3/2}\langle\phi^*\rangle\left(c_2 + d_2\frac{X^\dagger X}{M_{Pl}^2}\right)\frac{1}{M^2}\langle\phi\rangle \sim m^2_{3/2}\mathcal{O}\left(\frac{|\langle\phi\rangle|^2}{M^2}\right)$$

$$F_{\overline{X}}\left(\partial_{\overline{X}}\partial_X \tilde{K}_{\overline{a}b}\right) F_X \sim m^2_{3/2}\langle X^\dagger\rangle\left(\frac{d_0}{M_{Pl}^2} + \frac{d_2}{M_{Pl}^2}\frac{1}{M^2}\phi\phi^*\right)\langle X\rangle \sim m^2_{3/2}\left[\mathcal{O}(1) + \mathcal{O}\left(\frac{|\langle\phi\rangle|^2}{M^2}\right)\right]$$

Once the catastrophic leading order terms are tamed the the irreducible part is competitive !

# Conclusions

- SUSY flavour and CP puzzles challenge the flavour models
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**Thanks for your kind attention !**