Non-Universal MSSM and Effective Flavour Theories

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D. Das, M.L. López-Ibáñez, M.J. Perez and O.V., arXiv:1607.xxxx

Standard Model

All Observed *Flavour Changing Neutral Currents* can be accomodated in Yukawa couplings:

$$\mathcal{L}_Y = H\ \bar{Q}_i\ Y^d_{ij}\ d_j + H^*\ \bar{Q}_i\ Y^u_{ij}\ u_j$$

Only masses and CKM mixings, $V_{\rm CKM}$, observable...

But... $\Rightarrow$ a) what is the origin of the Yukawa structures??
b) why is there a CP-violating phase in CKM??

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New Physics

New flavour structures generically present $\Rightarrow$ measure of new observables provides new information on flavour origin...

SUSY Flavour (and CP) problems

Soft masses fixed by $m_{3/2}$. $O(m_{3/2})$ elements in soft matrices.

$\Rightarrow$ **Severe FCNC problem !!!**

CP broken, we can expect all complex paramaters have $O(1)$ phases. $\Rightarrow$ **Too large EDMs !!!**

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SM Flavour and CP

Fermion masses fixed by M_W. If $O(1)$ elements in Yukawa matrices and $O(1)$ phases

$\Rightarrow$ **Impossible reproduce masses, mixings and CP observables !!!**

Flavour symmetries in SUSY

- Very different elements in Yukawa matrices: $y_t \simeq 1$, $y_u \simeq 10^{-5}$
- Expect couplings in a "fundamental" theory $\mathcal{O}(1)$
- Small couplings generated as function of small vevs or loops.
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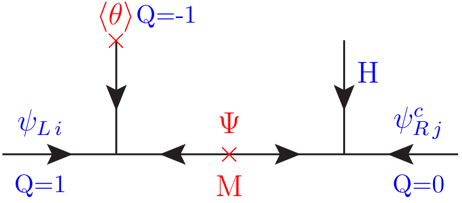

$$\Rightarrow Y_{ij} = \left(\frac{\langle\theta\rangle}{M}\right) \ll 1$$

- Flavour symmetry explains masses and mixings in Yukawas.
- Yukawa couplings forbidden by symmetry, generated only after Spontaneous Symmetry Breaking.

- Unbroken symmetry applies both to fermion and sfermions.
- Diagonal soft masses allowed by symmetry.
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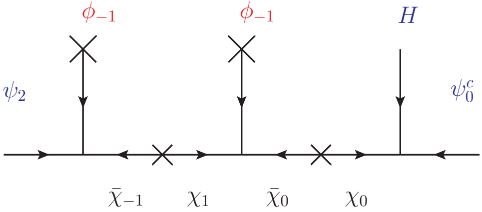
$$\Downarrow$$

We can relate the structure in Yukawa matrices to the nonuniversality in Soft Breaking masses !!!

Froggatt-Nielsen effective theory

- Yukawa couplings in $W_{\rm eff}$ after integration of heavy states.



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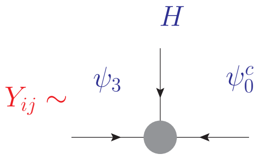

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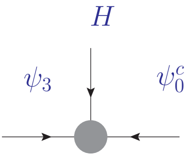

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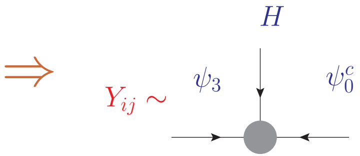

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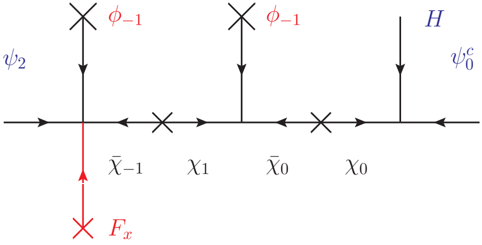

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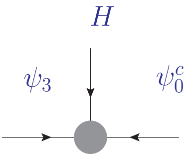

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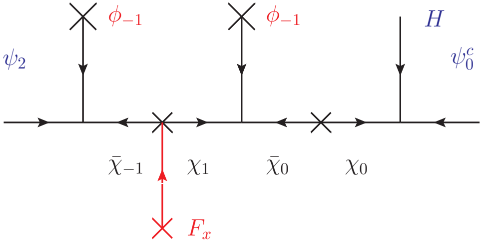

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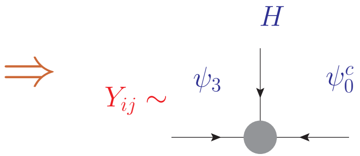

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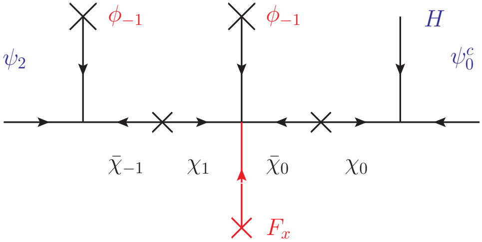

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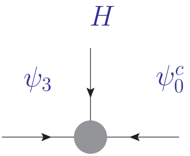
$\Rightarrow$ $Y_{ij} \sim$ 

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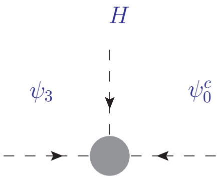
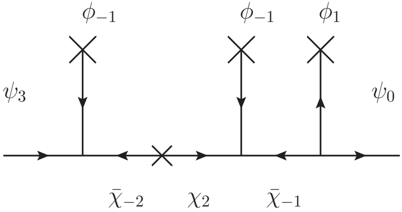
$Y_{ij}^A \sim$  $= 5\ m_0\ Y_{ij}$

- Similar with corrections to kinetic terms and soft masses.



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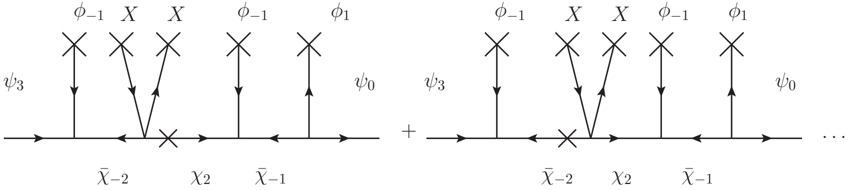

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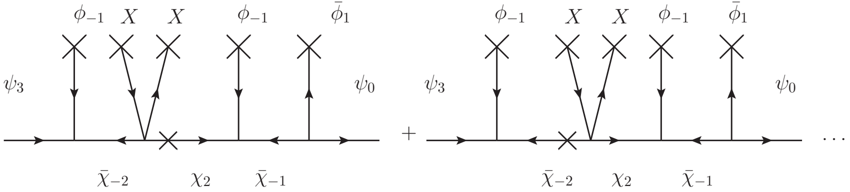

$$\Downarrow$$

$$\left(m^2_{\tilde{\psi}}\right)_{ij} = n\ m_0^2 \times \left(\frac{\theta_i \theta_j^\dagger}{M^2}\right)$$

Abelian Flavour symmetry

- "Simple" Abelian model with charges

$$Q_1 \sim 3, \quad Q_2 \sim 2, \quad Q_3 \sim 0, \quad d_1^c \sim 1, \quad d_2^c \sim 0, \quad d_3^c \sim 0,$$
$$u_1^c \sim 3, \quad u_2^c \sim 2, \; u_3^c \sim 0, \; \phi_1 \sim -1 \text{ with } \frac{\langle\phi_1\rangle}{M} = \lambda_c$$

- Yukawa couplings proportional to: $Y_{ij} = (\langle\phi_1\rangle/M)^{(q_1^i+q_1^j)}$

$$M^d = \langle H_1\rangle \begin{pmatrix} \lambda^4 & \lambda^3 & \lambda^3 \\ \lambda^3 & \lambda^2 & \lambda^2 \\ \lambda & 1 & 1 \end{pmatrix}, \quad M^u = \langle H_2\rangle \begin{pmatrix} \lambda^6 & \lambda^5 & \lambda^3 \\ \lambda^5 & \lambda^4 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}.$$

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- Trilinear couplings::

$$Y_d^A = \begin{pmatrix} 9\lambda^4 & 7\lambda^3 & 7\lambda^3 \\ 7\lambda^3 & 5\lambda^2 & 5\lambda^2 \\ 3\lambda & 1 & 1 \end{pmatrix}, \quad Y_u^A = \begin{pmatrix} 13\lambda^6 & 11\lambda^5 & 7\lambda^3 \\ 11\lambda^5 & 9\lambda^4 & 5\lambda^2 \\ 7\lambda^3 & 5\lambda^2 & 1 \end{pmatrix}.$$

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$\Longrightarrow$ **In SCKM basis trilinear couplings not diagonalized, preserve the structure of Yukawas in flavour basis!!!**

- Soft mass coupling $\phi_i^\dagger \phi_i$ invariant under all symmetries
  $\Longrightarrow$ flavour diagonal soft masses allowed by flavour symmetry

- Diagonal masses equal with single F_x as required by phenomenology

- After symmetry breaking offdiagonal entries proportional to flavon vevs, $M_{ij}^2 = m_0^2 \, (\langle\phi_1\rangle/M)^{|q_1^i - q_1^j|}$

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Flavour Observables

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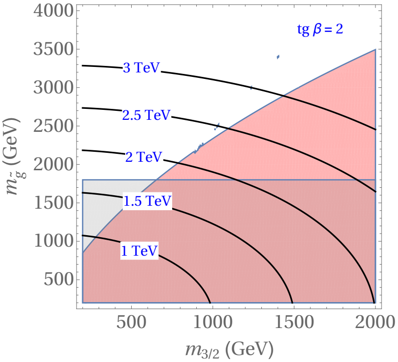

Red area excuded by K–$\overline{K}$, gray rectangle LHC direct searches, black lines average squark masses.

Conclusions

- Flavour symmetries solve the CP and flavour problems both in New Physics (SUSY) and in the SM.
- New flavour structures will provide valuable information on the origin of flavour
- In SUSY, non-universality always present in soft-breaking terms.
- Flavour structures of soft masses and trilinears remember structures in flavour basis.
- Large reach of flavour observables in realistic flavour models, beyond LHC.
- Sizeable contribution in Kaon and B sector naturally expected.

Backup 1

Mediator Superpotential

$$W \supset g \sum_{q_i} \left(\psi_{q_i} \bar{\chi}_{-q_i+1} \phi \;+\; \chi_{q_i} \bar{\chi}_{-q_i+1} \phi \;+\; \chi_{q_i-1} \bar{\chi}_{-q_i} \bar{\phi} \;+\; \bar{\chi}_{-q_i} \psi^c_{r,q_i} H \right)$$
$$\quad + \; M \sum_{q_i} \chi_{q_i} \bar{\chi}_{-q_i} \;+\; M \phi \bar{\phi} \;+\; \ldots$$

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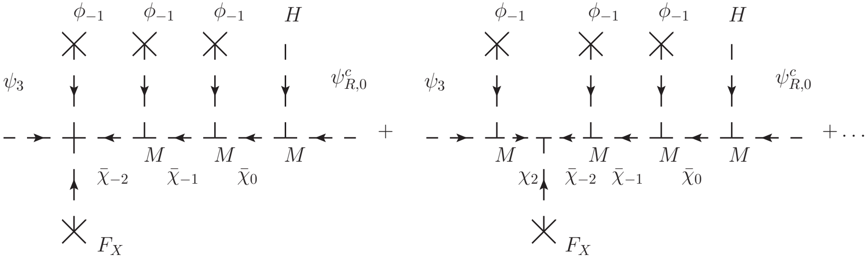
Diagrams in components



Backup 2

$\Delta q = 1$ mixing