SU(3) Flavour Symmetries and CP Violation

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EPS HEP 2009
July 16th, 2009

Overview

- Why Flavour Symmetries in SUSY?
- Implementation of SU(3) in the MSSM
- LFV, K^0, B_s^0, eEDM, nEDM
- Conclusions

Flavour and CP Problems in SUSY

- SUSY Flavour Problem: Flavoured parameters cannot be generic!

$$m^2_{\tilde{d}^c_R} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} m_0^2$$

Flavour and CP Problems in SUSY

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$$m^2_{\tilde{d}^c_R} = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} m_0^2$$

- SUSY CP Problem: CP Violation cannot be flavour independent!

$$\arg\left(\delta^d_{LR}\right)_{11} = 90^{\circ}$$

Flavour and CP in the SM

- The SM is not generic!
- CPV is not flavour independent!

$$V_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

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We do not understand flavour textures.

(And maybe we don’t understand CPV either)

Our Guides

$$Y_u \propto \begin{pmatrix} 0 & \varepsilon^3 & \varepsilon^3 \\ \varepsilon^3 & \varepsilon^2 & \varepsilon^2 \\ \varepsilon^3 & \varepsilon^2 & 1 \end{pmatrix} \qquad Y_d \propto \begin{pmatrix} 0 & \bar{\varepsilon}^3 & \bar{\varepsilon}^3 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & 1 \end{pmatrix}$$

$$\varepsilon = 0.05 \qquad \bar{\varepsilon} = 0.15$$

R. G. Roberts, A. Romanino, G. G. Ross, L. Velasco-Sevilla (hep-ph/0104088)

SU(3) Flavour Model

Relevant Symmetries:

- MSSM: $SU(3)_C\ SU(2)_L\ U(1)_Y\ Z_R$
- SU(3) in flavour sector.
- Exact CP
- Additional U(1)s: avoid particular terms.

S. F. King, G. G. Ross (hep-ph/0307190)

G. G. Ross, L. Velasco-Sevilla, O. Vives (hep-ph/0401064)

SU(3) Flavour Model

Effective Superpotential:

$$W = H_d Q_\alpha d^c_\beta \left[\frac{\theta_3^\alpha \theta_3^\beta}{M_d^2} + \frac{\theta_{23}^\alpha \theta_{23}^\beta (\theta_3 \bar{\theta}_3)}{M_d^4} + \varepsilon^{\alpha\mu\nu} \frac{\bar{\theta}_{23\mu} \bar{\theta}_{3\nu} \theta_{23}^\beta (\theta_{23} \bar{\theta}_3)}{M_d^5} \right.$$

$$\left. + \varepsilon^{\alpha\beta\mu} \frac{\bar{\theta}_{23\mu} (\theta_{23} \bar{\theta}_3)^2}{M_d^5} + \varepsilon^{\alpha\beta\mu} \frac{\bar{\theta}_{3\mu} (\theta_{23} \bar{\theta}_3)(\theta_{23} \bar{\theta}_{23})}{M_d^5} + \ldots \right]$$

SU(3) Flavour Model

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$$\langle \theta_3 \rangle = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \otimes \begin{pmatrix} a_3^u & 0 \\ 0 & a_3^d e^{i\chi} \end{pmatrix} \qquad \langle \theta_{23} \rangle = \begin{pmatrix} 0 \\ b_{23} \\ b_{23} e^{i\beta_3} \end{pmatrix}$$

SU(3) Flavour Model

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$$W = H_d Q_\alpha d_\beta^c \left[\frac{\theta_3^\alpha \theta_3^\beta}{M_d^2} + \frac{\theta_{23}^\alpha \theta_{23}^\beta \left(\theta_3 \bar{\theta}_3\right)}{M_d^4} + \varepsilon^{\alpha\mu\nu} \frac{\bar{\theta}_{23\mu} \bar{\theta}_{3\nu} \theta_{23}^\beta \left(\theta_{23} \bar{\theta}_3\right)}{M_d^5} \right.$$

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$$\frac{a_3^u}{M_u} = y_t \qquad \frac{a_3^d}{M_d} = y_b \qquad \frac{b_{23}}{M_u} = \varepsilon \qquad \frac{b_{23}}{M_d} = \varepsilon$$

Flavour Models in SUSY

SUSY provides new flavour contributions to low-energy processes.

$$L_{Soft} = -\tilde{Q}^* m_Q^2 \tilde{Q} - \tilde{L}^* m_L^2 \tilde{L}$$

$$- \tilde{u}^{c^*} m_{u^c}^2 \tilde{u}^c - \tilde{d}^{c^*} m_{d^c}^2 \tilde{d}^c - \tilde{e}^{c^*} m_{e^c}^2 \tilde{e}^c$$

$$- \tilde{Q} A_u \tilde{u}^c H_u - \tilde{Q} A_d \tilde{d}^c H_d - \tilde{L} A_e \tilde{e}^c H_d$$

Flavour Models in SUSY

Soft Mass Matrices:

(Minimal SU(3))

$$K = \tilde{\psi}_{\alpha}^{+}\tilde{\psi}_{\beta}.\left\{\delta^{\alpha\beta} + \frac{1}{M_{\psi}^{2}}\left[\theta_{3}^{\alpha^{+}}\theta_{3}^{\beta} + \theta_{23}^{\alpha^{+}}\theta_{23}^{\beta}\right]\right.$$

$$\left. + \frac{1}{M_{\psi}^{4}}\left(\varepsilon^{\alpha\mu\nu}\overline{\theta}_{3\mu}\overline{\theta}_{23\nu}\right)^{+}\left(\varepsilon^{\alpha\rho\sigma}\overline{\theta}_{3\rho}\overline{\theta}_{23\sigma}\right) + \ldots\right\}$$

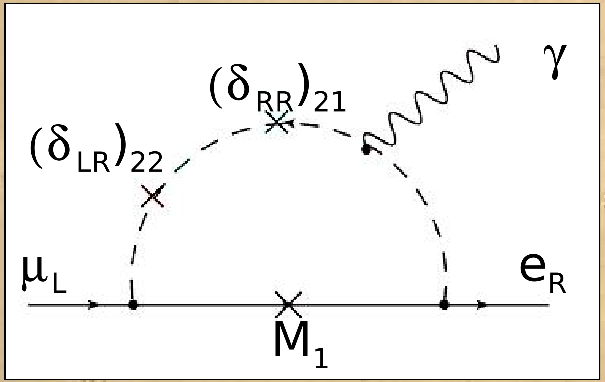
Flavour Models in SUSY

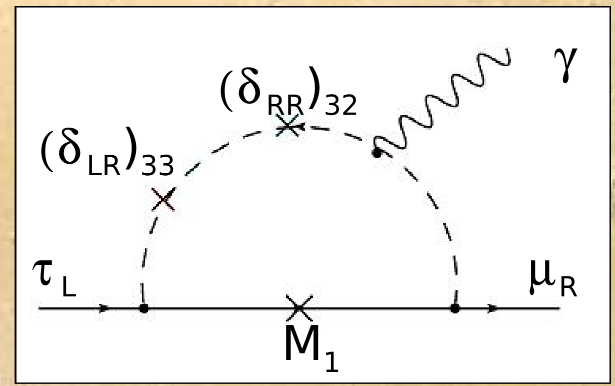
Soft Mass Matrices:

$$m^2_{\tilde{d}^c} = \begin{pmatrix} 1+\bar{\varepsilon}^2 y_b & \bar{\varepsilon}^3 & \bar{\varepsilon}^3 \\ \bar{\varepsilon}^3 & 1+\bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & 1+y_b \end{pmatrix} m_0^2$$

$$m^2_{\tilde{Q}} = \begin{pmatrix} 1+\varepsilon^2 y_t & \varepsilon^2\bar{\varepsilon} & \bar{\varepsilon}^3 \\ \varepsilon^2\bar{\varepsilon} & 1+\varepsilon^2 & \bar{\varepsilon}^2 \\ \bar{\varepsilon}^3 & \bar{\varepsilon}^2 & 1+y_t \end{pmatrix} m_0^2$$

Lepton Flavour Violation





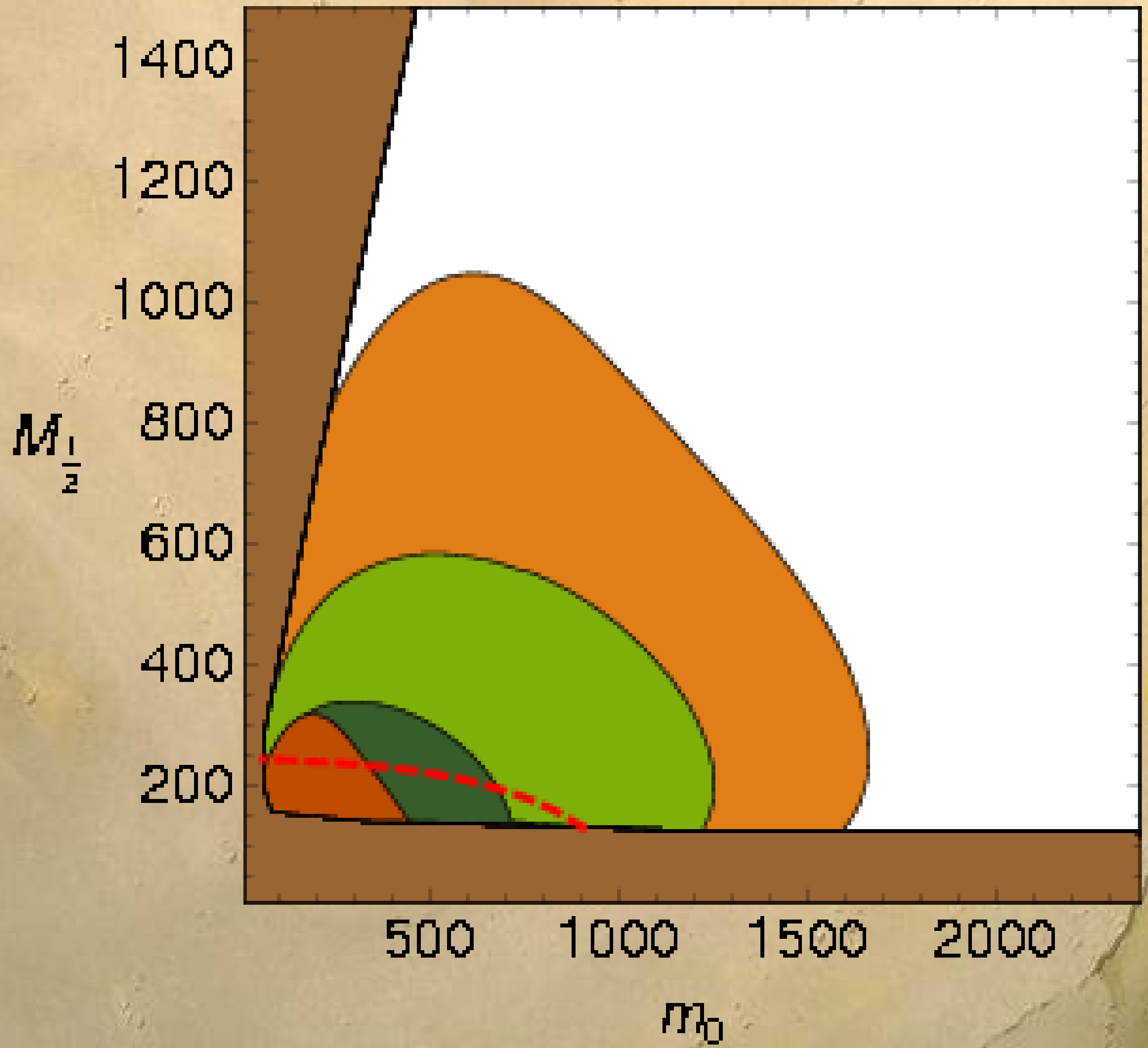
MEGA: BR = 1.2 x 10^{-11}

MEG: BR = 1 x 10^{-13}

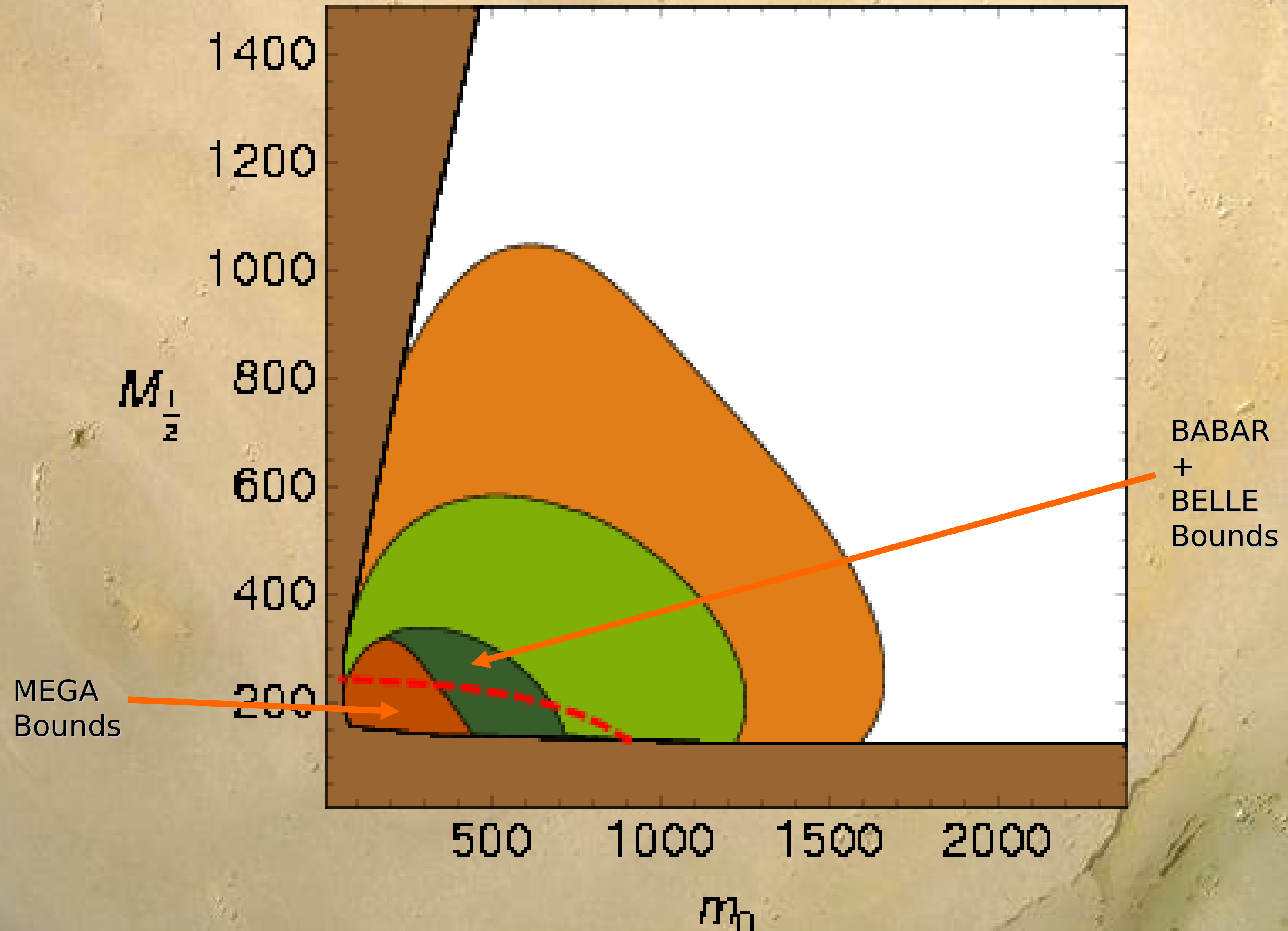
Babar+Belle: BR = 4.5 x 10^{-8}

SuperFlavour: BR = 1 x 10^{-9}

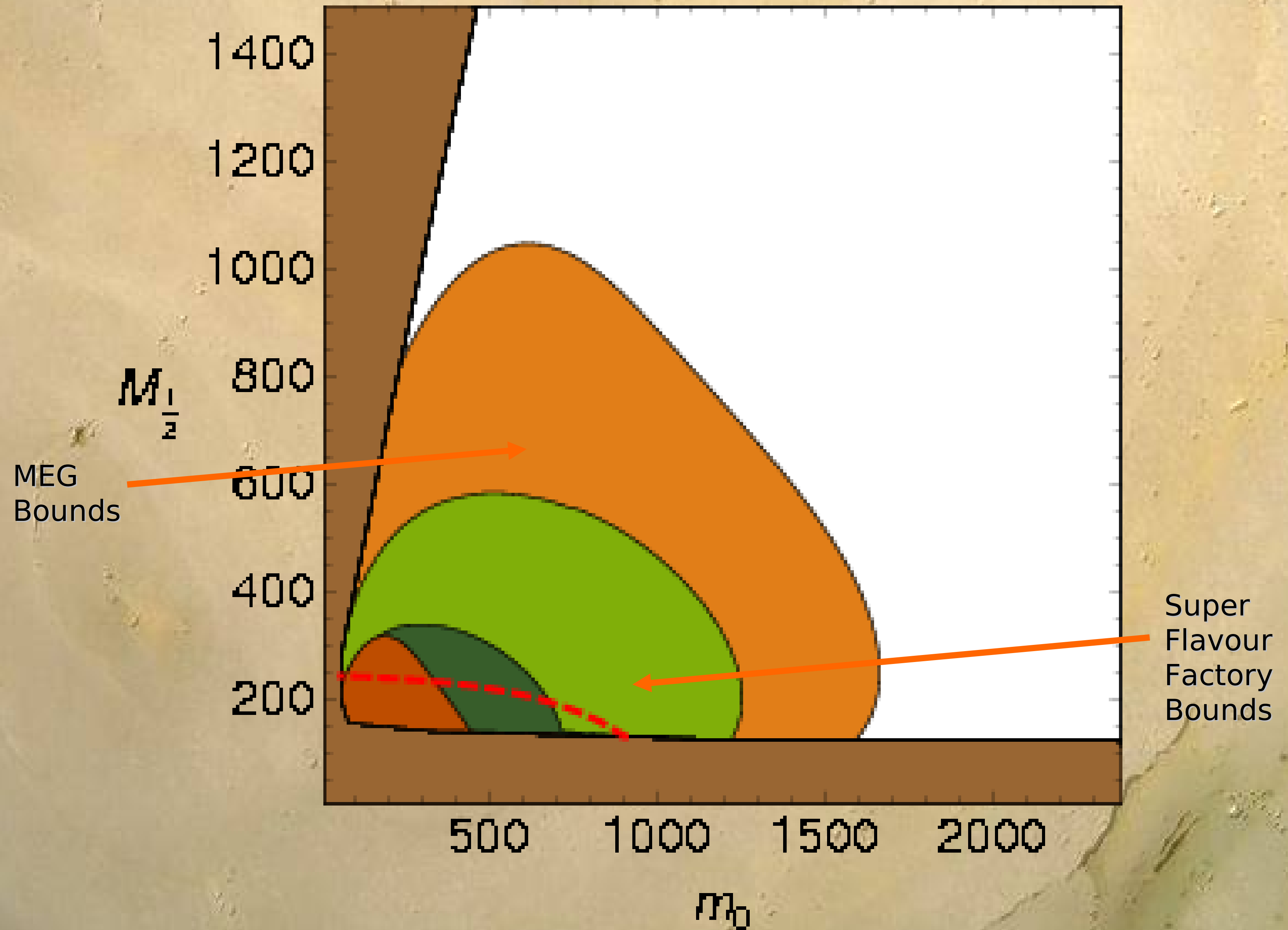
LFV ($\tan\beta=10$, $A_0=0$)



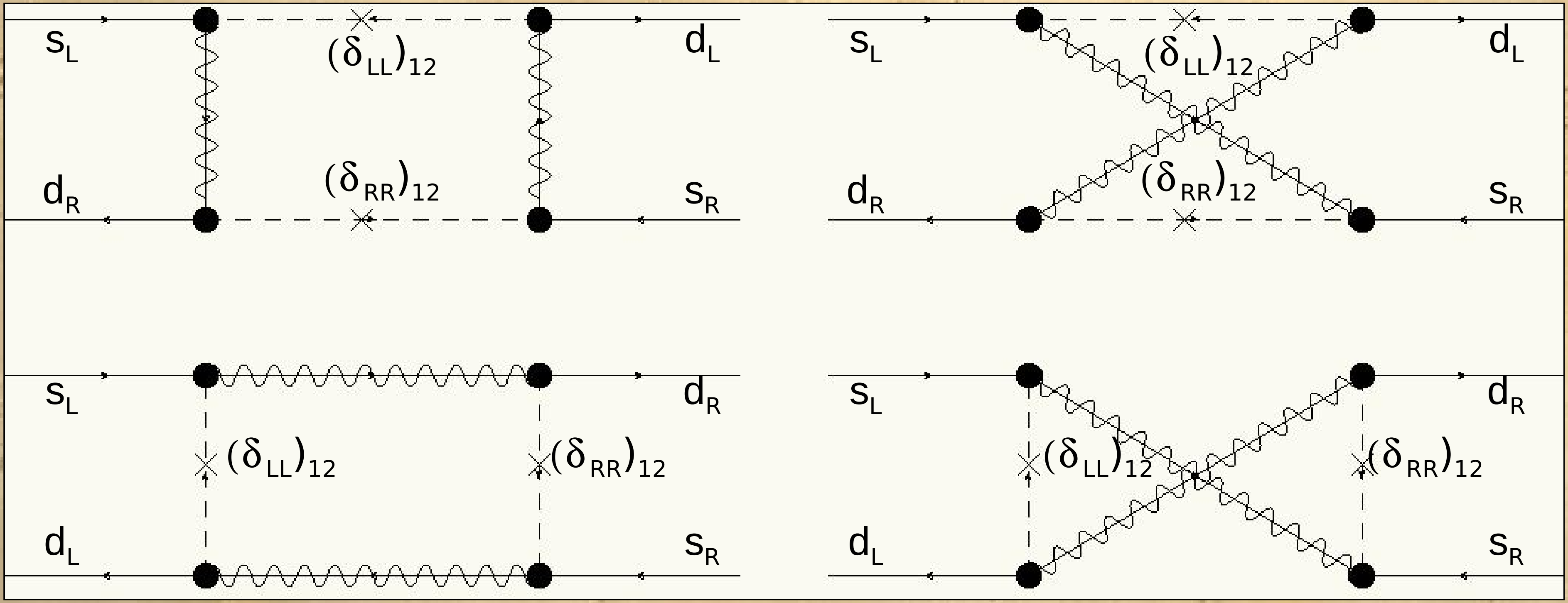
LFV ($\tan\beta=10$, $A_0=0$)



LFV ($\tan\beta$=10, A_0=0)



Meson Mixing



ε_K Tension: $(1.78 \pm 0.25) \times 10^{-3}$

“Central Value Problem”

Buras and Guadagnoli

(Phys.Rev.D78:033005,2008)

ϕ_{Bs} Discrepancy: $(1.2 \pm 0.12) \cup (0.33 \pm 0.14)$ rad

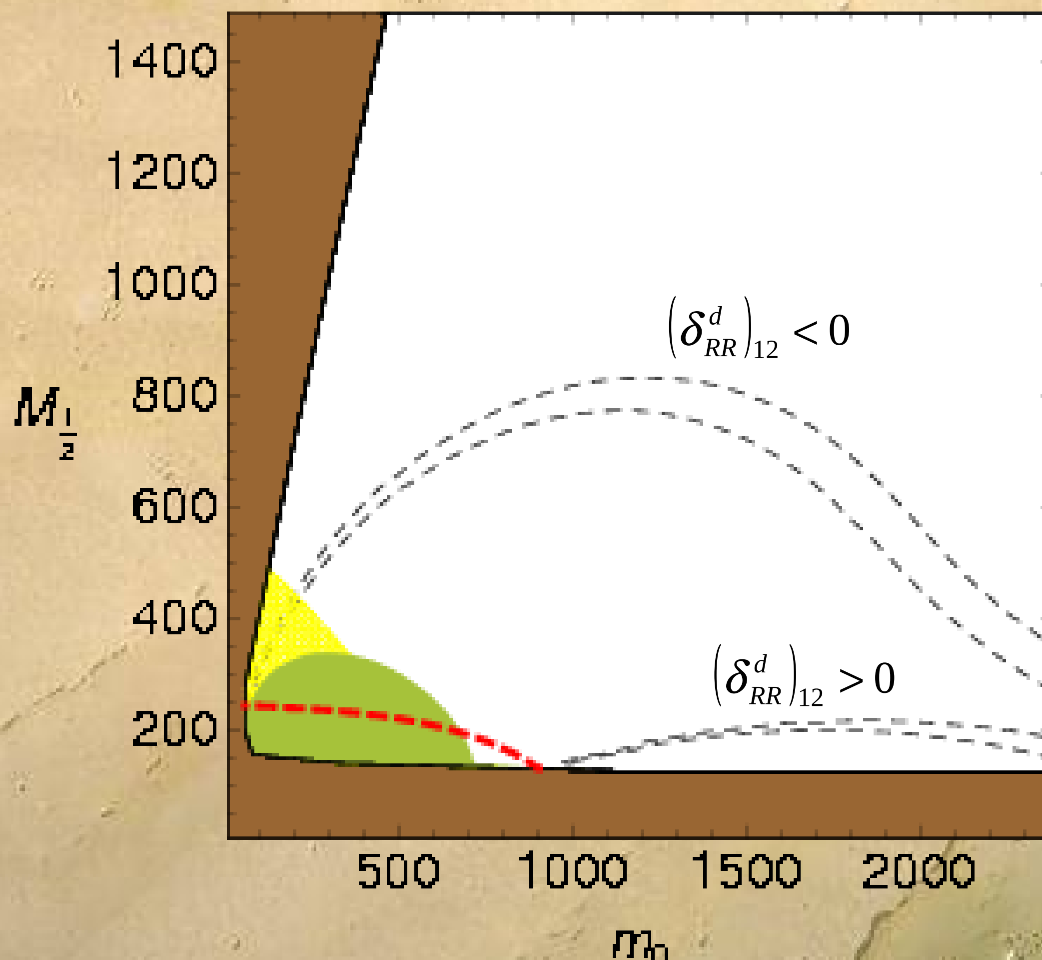
2 σ Problem

UTFit Collaboration
(0803.0659 [hep-ph])

ε_K

SUSY contributions are of the required order of magnitude.

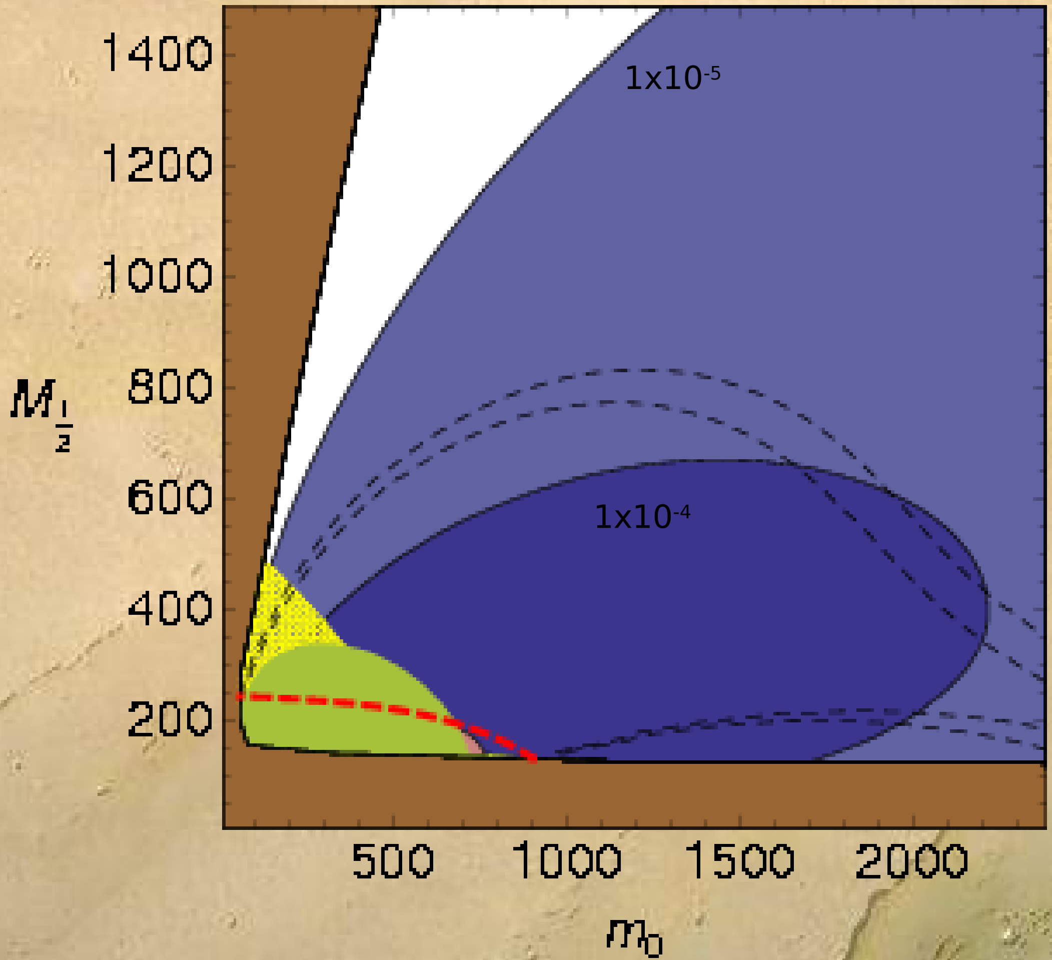
Sign of (δ_{RR}) is important, and $(g\text{-}2)_\mu$ favours a negative sign.



ϕ_{Bs}

This particular model cannot reproduce observation of ϕ_{Bs}.

Variations of this model have larger values of ϕ_{Bs}, but are not compatible with ε_K and $(g-2)_\mu$.

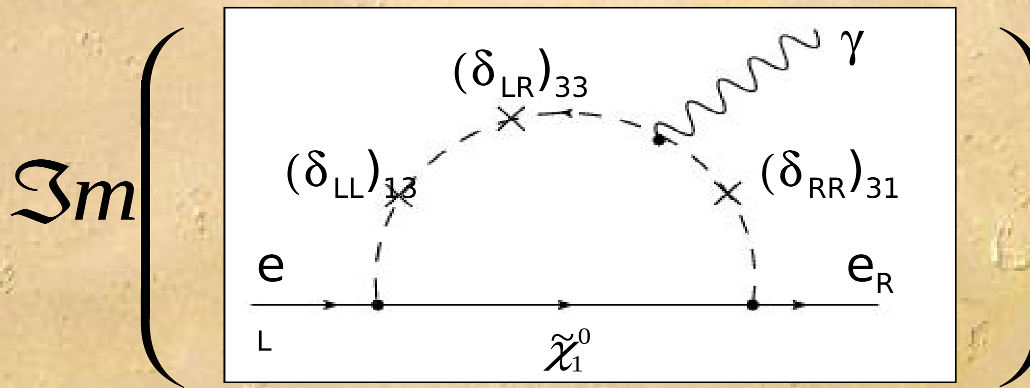


Electric Dipole Moments

eEDM

Current: $d_e < 1.4 \times 10^{-27}$ e cm

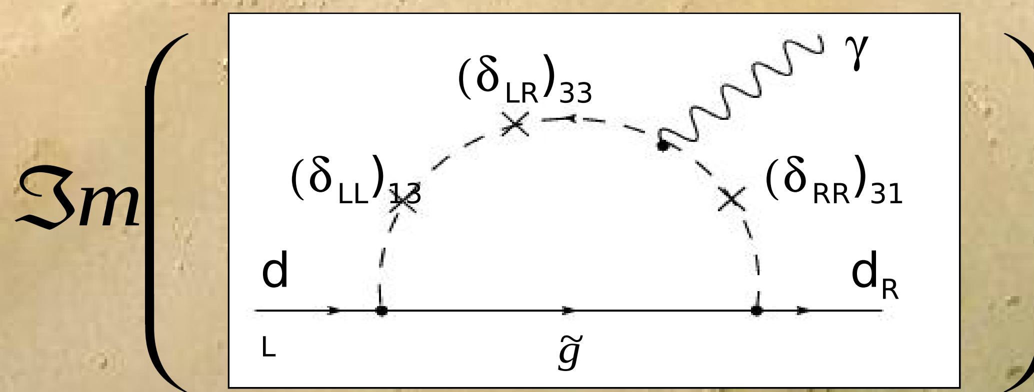
Future: $d_e < 1 \times 10^{-30}$ e cm



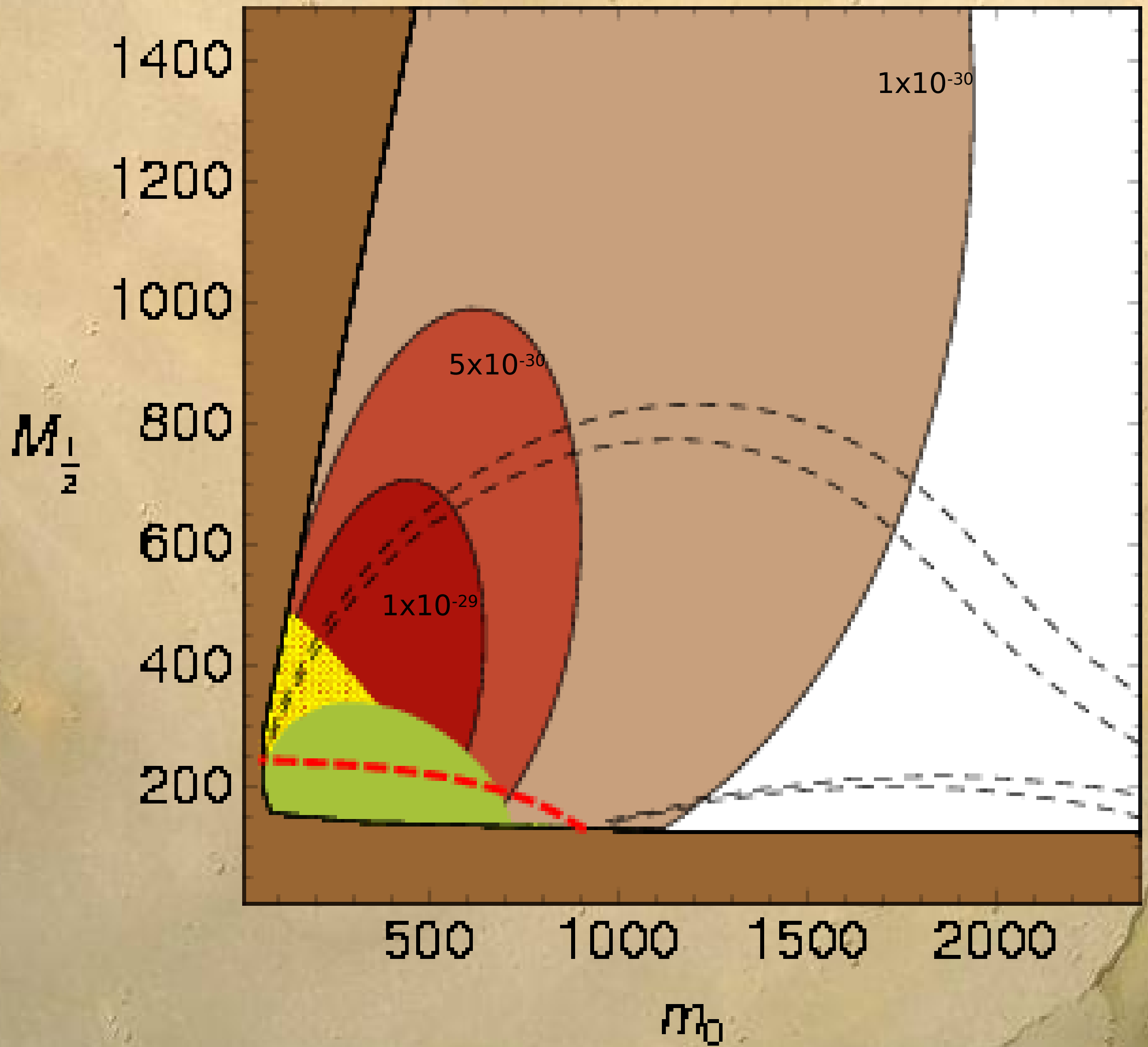
nEDM

Current: $d_n < 1 \times 10^{-26}$ e cm

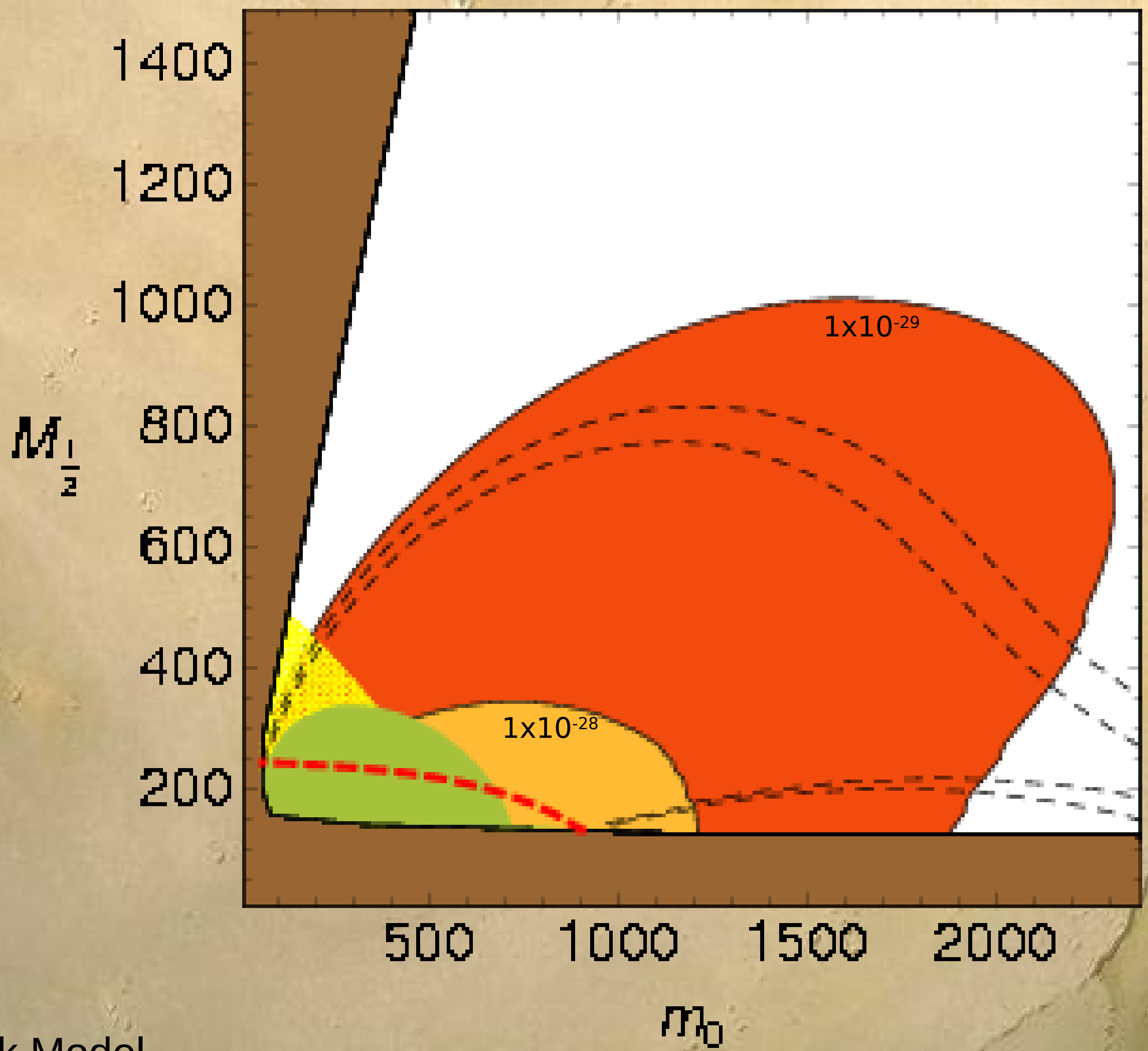
Future: $d_n < 1 \times 10^{-28}$ e cm



eEDM ($\tan\beta=10$, $A_0=0$)



nEDM ($\tan\beta=10$, $A_0=0$)



Chiral-Quark Model

Conclusions

- Flavour Symmetries can reproduce fermion masses and mixing.
- Extended into SUSY, they provide a way of generating textures in flavoured matrices.
- SU(3) is a starting point that describes the minimum effects achievable by all of its subgroups (i.e. $\Delta(27)$)

Conclusions

- Observation of LFV is very likely in the near future.
- ε_K tension can be accomodated.
- ϕ_{Bs} is hard to reproduce, but is always incompatible with $(g-2)_\mu$.
- Electron EDM could be observed soon.
- Neutron EDM is somewhat smaller than the future bound.

Backups

SM Masses

At mZ (GeV):

I. Dorsner, P. Fileviez Perez, G. Rodrigo (hep-ph/0607208)

Family	1 ($\times 10^{-3}$)	2	3
m_u	1.4 ±0.5	0.63 ±0.08	170 ±2
m_d	3.0 ±1.2	0.056 ±0.016	2.89 ±0.11

SU(3)

Family	1 ($\times 10^{-3}$)	2	3
m_u	2.9	0.57	172
m_d	4.1	0.071	2.85

CKM Matrix

	λ	A	ρ	η
PDG	0.2257 ±0.001	0.814 ±0.022	0.135 ±0.031	0.349 ±0.017
SU(3)	0.2250	0.805	0.156	0.327

Renormalizable Superpotential

$$W_1 = u^c U_1 \theta_3 + \overline{U}_1 U_2 \theta_3 + \overline{U}_2 Q H_u$$

$$+ d^c D_1 \theta_3 + \overline{D}_1 D_2 \theta_3 + \overline{D}_2 Q H_d$$

$$+ M_u \left(U_1 \overline{U}_1 + U_2 \overline{U}_2 \right)$$

$$+ M_d \left(D_1 \overline{D}_1 + D_2 \overline{D}_2 \right)$$

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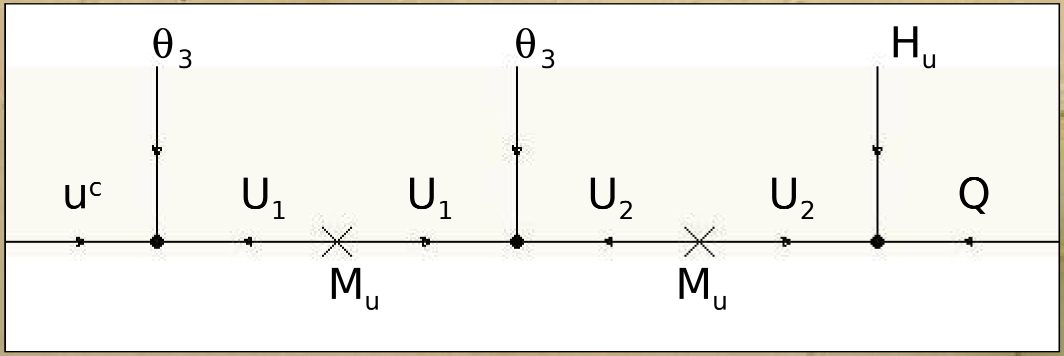


Renormalizable Superpotential

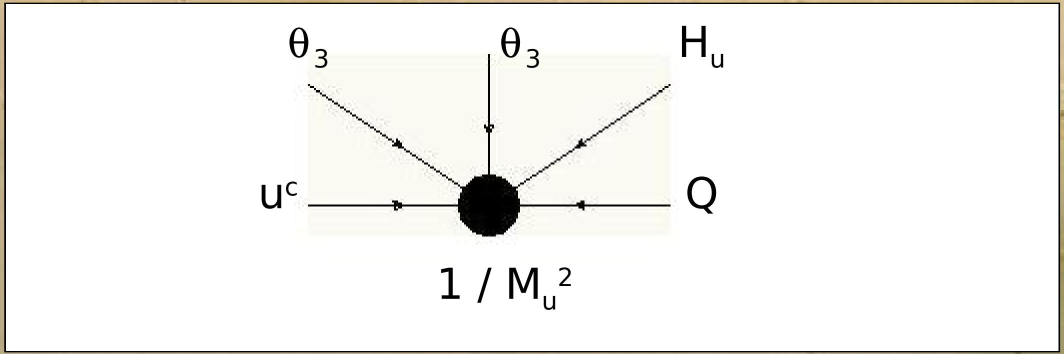
$$W_1 = u^c U_1 \theta_3 + \overline{U}_1 U_2 \theta_3 + \overline{U}_2 Q H_u$$

$$+ d^c D_1 \theta_3 + \overline{D}_1 D_2 \theta_3 + \overline{D}_2 Q H_d$$

$$+ M_u \left(U_1 \overline{U}_1 + U_2 \overline{U}_2 \right)$$

$$+ M_d \left(D_1 \overline{D}_1 + D_2 \overline{D}_2 \right)$$

$$H_u Q u^c \frac{\theta_3 \theta_3}{M_u^2}$$



Vacuum Alignment

$$W = P\left(\theta_3\bar{\theta}_3 + T\right) + U\left(\theta_{23}\bar{\theta}_{23} + S^2\right) + V\left(\left(\theta_3\bar{\theta}_3\right)^4 + S\bar{S}\right)$$

$$+ Y\left(\theta_3\bar{\theta}_2\right) + Z\left(\left(\theta_{23}\bar{\theta}_3\right)\left(\theta_{23}\bar{\theta}_2\right) + \bar{S}^2\right)$$

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$$\left\langle \theta_3\bar{\theta}_3 \right\rangle = -\left\langle T \right\rangle$$

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$$\left\langle \left(\theta_{23}\bar{\theta}_{23}\right) \right\rangle = -\left\langle S^2 \right\rangle$$

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$$\left\langle\left(\theta_{23}\bar{\theta}_{23}\right)\right\rangle = -\left\langle S^2\right\rangle$$

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$$\left\langle\bar{\theta}_2\right\rangle = \begin{pmatrix}0\\1\\0\end{pmatrix} \otimes \begin{pmatrix}a_2^u & 0\\ 0 & a_2^d\end{pmatrix}$$

Vacuum Alignment

$$W = P\left(\theta_3\bar{\theta}_3 + T\right) + U\left(\theta_{23}\bar{\theta}_{23} + S^2\right) + V\left(\left(\theta_3\bar{\theta}_3\right)^4 + S\bar{S}\right)$$

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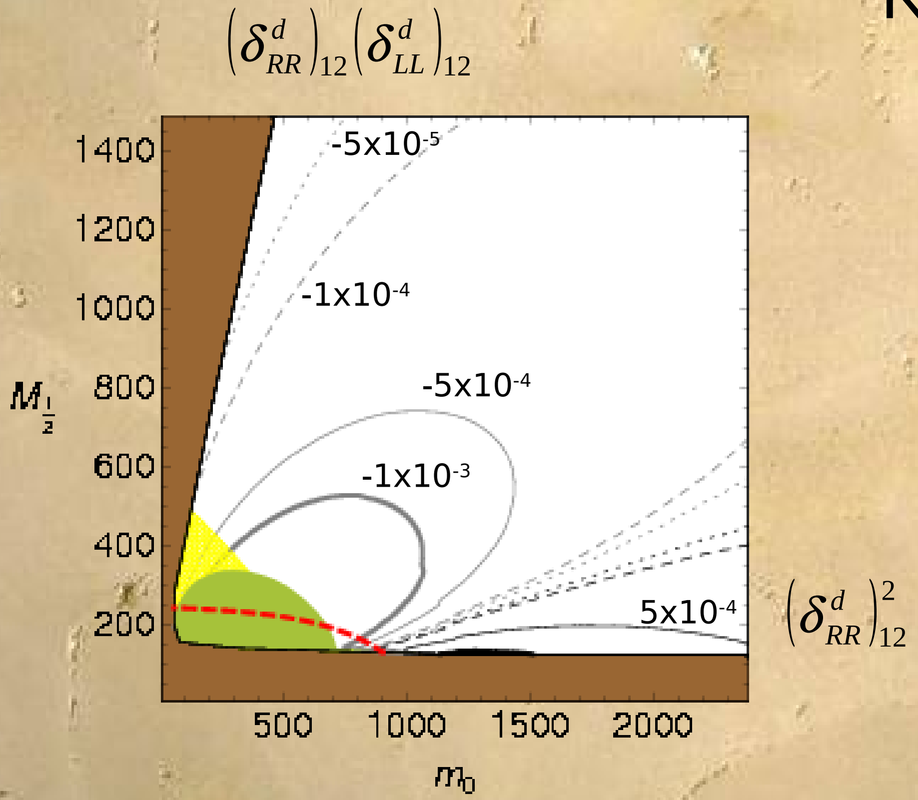
$$\langle\theta_{23}\rangle = \langle\bar{\theta}_{23}\rangle = \begin{pmatrix} 0 \\ b_{23} \\ b_{23} \end{pmatrix} \qquad \langle\bar{\theta}_2\rangle = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \otimes \begin{pmatrix} a_2^u & 0 \\ 0 & a_2^d \end{pmatrix}$$

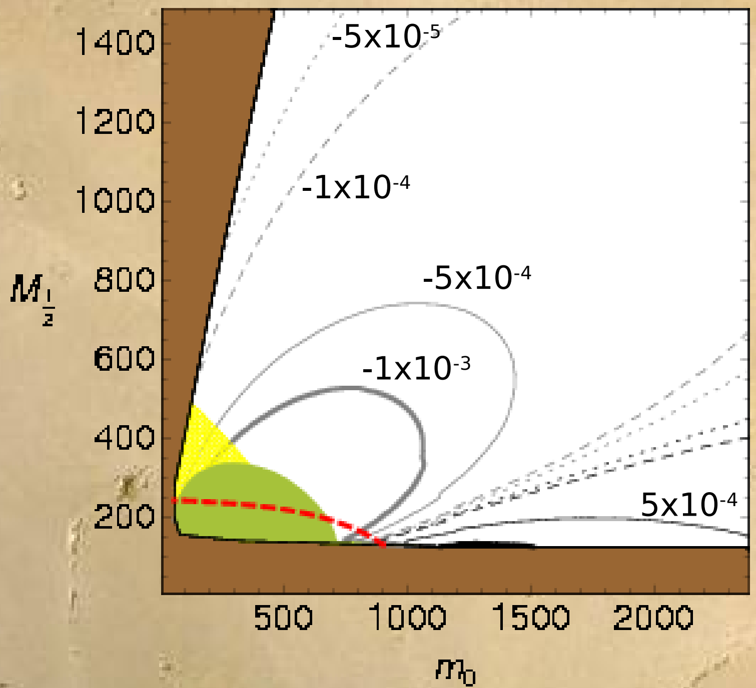
ε_K



Most of the parameter space has incorrect sign!

ε_K

$(\delta^d_{RR})_{12}(\delta^d_{LL})_{12}$

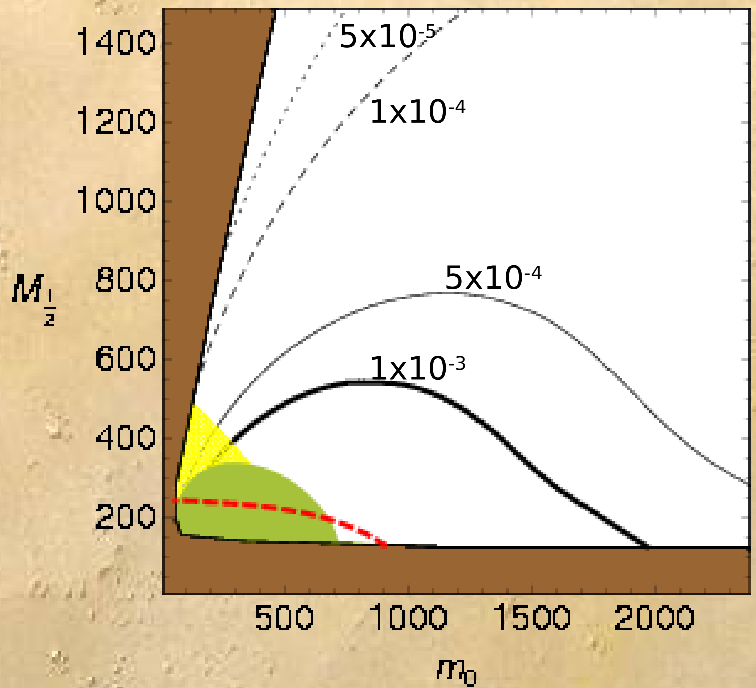


$(\delta^d_{RR})^2_{12}$

Most of the parameter space has incorrect sign!

$$(\delta^d_{RR})_{12} > 0$$

$(\delta^d_{RR})_{12}(\delta^d_{LL})_{12}$



$(\delta^d_{RR})^2_{12}$

All of the parameter space has correct sign!

$$(\delta^d_{RR})_{12} < 0$$