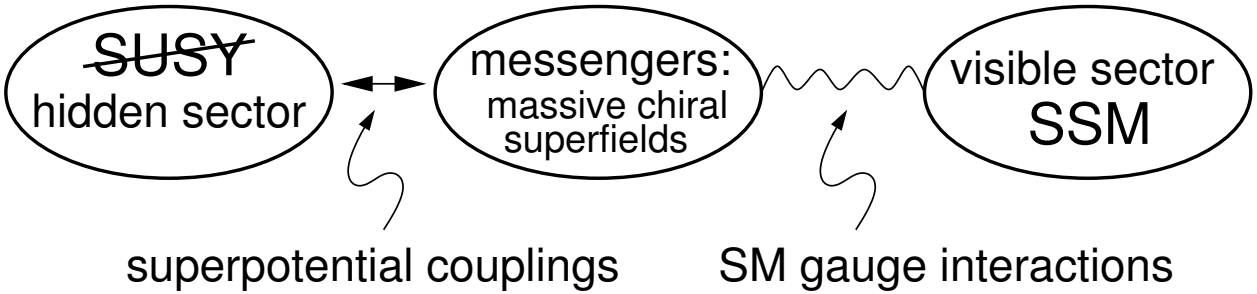
Flavour gauge messengers

Felix Brümmer

with M. McGarrie, A. Weiler

Messenger gauge mediation recap



Features:

- soft term spectrum calculable, few parameters
- flavour universality
  $\Rightarrow$ no FCNC problem

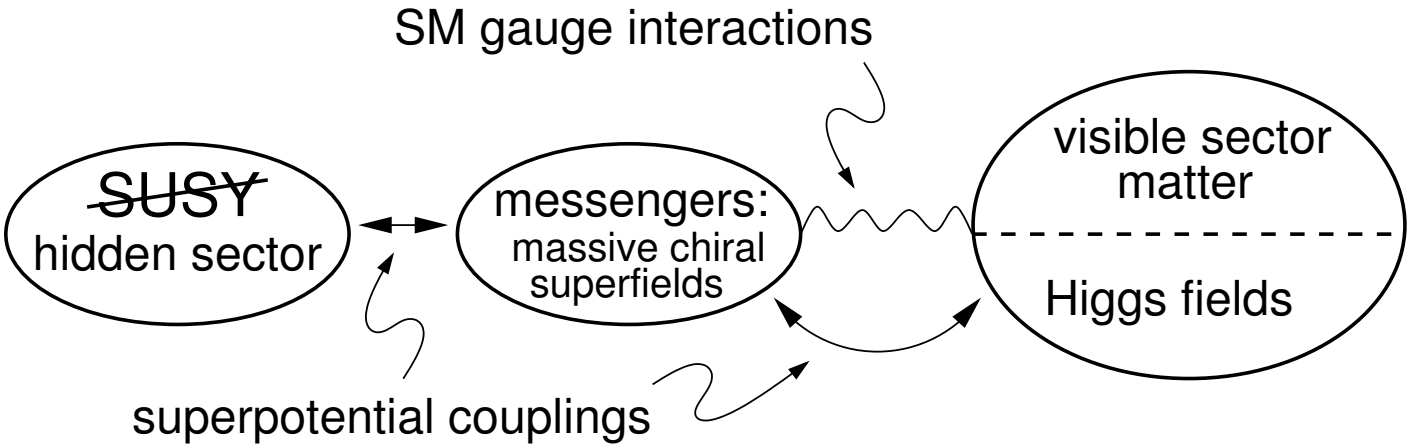
Bugs:

- $\mu/B\mu$ problem
- trilinear A-terms?
- flavour universality + LHC bounds on 1st gen. squarks
  $\Rightarrow$ all squarks heavy

Messenger gauge-Higgs mediation

Allow for superpotential couplings between messenger and Higgs fields

see e.g. → Craig/Knapen/Shih '13; Shih's talk



- μ, $B\mu$ ✓
- trilinears ✓
- flavour ✓ ×

Flavoured gauge mediation, higgsed gauge mediation

Non-universal squark masses in gauge mediation:

- Introduce also matter-messenger couplings in W:
  generically large flavour violation
  (can be averted with extra flavour symmetries)
  "Flavoured gauge mediation / Yukawa deflected GM" → Shadmi/Szabo '11, Kang et al. '12, Albaid/Babu '12, Abdullah et al. '12, Galon/Perez/Shadmi '13, talks by Jelinski, Galon
- Introduce chiral messengers charged under gauged horizontal symmetry:
  Non-universal squark masses from partial higgsing at different scales
  "Higgsed gauge mediation" → Craig/McCullough/Thaler '12

Not the only possibilities

Aim of this talk

Construct a gauge-mediated model with

1. light 3rd generation, heavy and degenerate 1st and 2nd
2. FCNCs under control

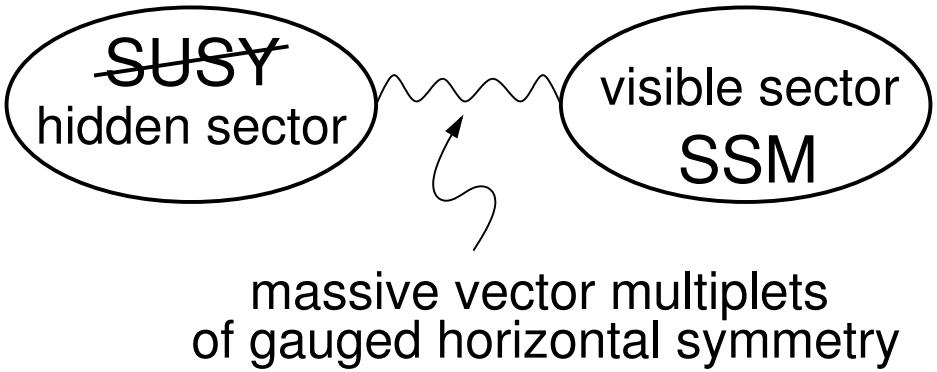
Crucial ingredients:

$SU(3)_C \times SU(2)_L \times U(1)_Y \times SU(3)_F$ gauge group

Both chiral + gauge messengers

Flavour gauge messengers

Central idea: Messengers = massive ~~chiral~~ vector superfields



Needs:

- Extra gauge group G under which hidden and visible sector are charged, e.g. $G = \mathrm{SU}(3)_F$
- break G non-supersymmetrically by F-term VEVs

  $\Rightarrow$ tree-level G-gaugino masses, loop-level visible-sector soft terms

Brief history of gauge messengers

- Invented in 1980s GUT model building
  → Witten's inverted hierarchy '81, Dimopoulos/Raby '83, Kaplunovsky '83,...
- More detailed studies in late '90s (product gauge groups broken to SM)
  → Dimopoulos et al. '97, Murayama '97, Giudice/Rattazzi '97,...
- Briefly resurrected in 2000s → Dermisek/Kim/Kim '06
- Again of interest in GGM context → Buican/Komargodski '09,Intriligator/Sudano '10

Never very popular for (GUT-)model building (we'll see why)

This talk: Idea works well if G is gauged flavour symmetry

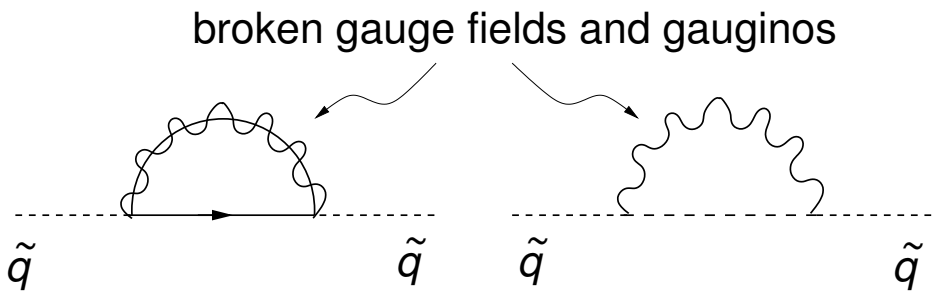
Effects of flavour gauge messengers

SSM Quark superfields $Q, U, D = \mathbf{3}$ under $\mathrm{SU}(3)_F$

Hidden sector superfields $T, X = \mathbf{3}$ and $\widetilde{T}, \widetilde{X} = \bar{\mathbf{3}}$

Break $\mathrm{SU}(3)_F \rightarrow \mathrm{SU}(2)_F$ by
$\langle \widetilde{T} \rangle^\dagger = \langle T \rangle = (0,\, 0,\, v)$ and $\langle \widetilde{X} \rangle^\dagger = \langle X \rangle = (0,\, 0,\, F_X \theta^2)$

- higher-dimensional operators $\Rightarrow$ top Yukawa coupling: $\widetilde{T}\widetilde{T}QUH_u$
- SUSY-breaking X VEV: SUSY-breaking mass splittings between broken gauge fields and gauginos
- Dominant effect: Tachyonic one-loop squark mass^2 $\rightarrow$ Intriligator/Sudano '10



- Alignment of X and T VEVs: largest effect for 3rd generation squarks

1-loop squark mass from flavour gauge messengers

$$K_{\text{eff}}^{(1\text{-loop})} = \frac{1}{16\pi^2}\,\text{tr}\left(M_V^2 \log\frac{M_V^2}{\Lambda^2}\right)$$
$$= \frac{g^2}{16\pi^2}\left(Q_i^\dagger \mathbf{T}^{ab}_{ij} Q_j + U_i^\dagger \mathbf{T}^{ab}_{ij} U_j + D_i^\dagger \mathbf{T}^{ab}_{ij} D_j\right) \times$$
$$\times \log\left(\frac{T_i^\dagger \mathbf{T}_{ij} T_j + X_i^\dagger \mathbf{T}_{ij} X_j + \widetilde{T}_i \mathbf{T}_{ij} \widetilde{T}_j^\dagger + \widetilde{X}_i \mathbf{T}_{ij} \widetilde{X}_j^\dagger}{\Lambda^2}\right)^{ab} + \ldots$$

where $\mathbf{T}^{ab} = \{\mathrm{t}^a, \mathrm{t}^b\}$ (fundamental generators)
and $\langle\widetilde{T}\rangle^\dagger = \langle T\rangle = (0,\, 0,\, v)$; $\quad \langle\widetilde{X}\rangle^\dagger = \langle X\rangle = (0,\, 0,\, F_X\theta^2)$

$$\Rightarrow \qquad m_Q^2 = m_U^2 = m_D^2 = -\frac{g^2}{16\pi^2}\frac{|F_X|^2}{v^2}\begin{pmatrix} \frac{7}{6} & 0 & 0 \\ 0 & \frac{7}{6} & 0 \\ 0 & 0 & \frac{8}{3} \end{pmatrix}$$

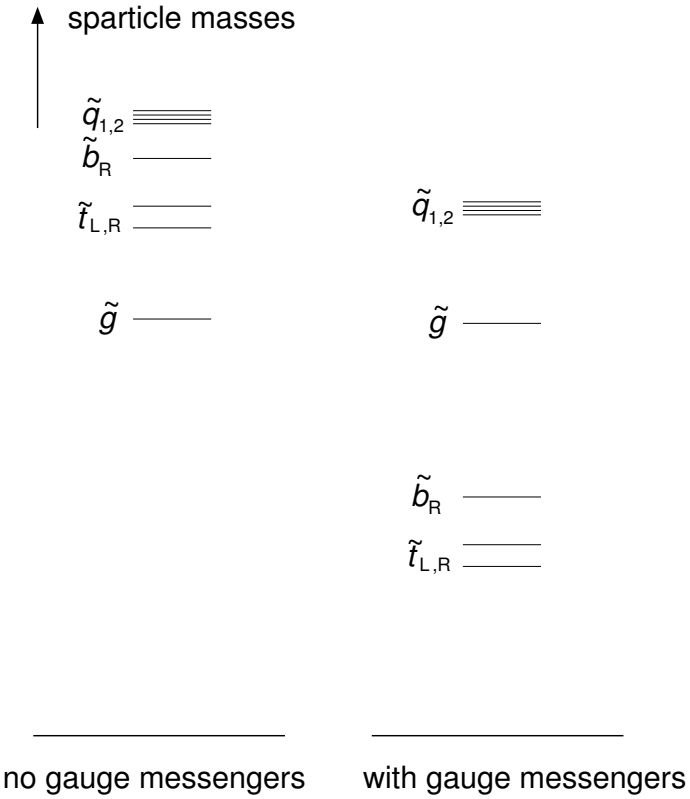
(More general: $m^2 = -\frac{g^2}{16\pi^2}\Delta c_2\, \Lambda^2$ → Intriligator/Sudano '10)

Effect on the superpartner spectrum

Tachyonic contribution to squark masses from flavour gauge messengers:

$$\delta m^2_{Q,U,D} = -\frac{g_F^2}{16\pi^2} \begin{pmatrix} \frac{7}{6} & 0 & 0 \\ 0 & \frac{7}{6} & 0 \\ 0 & 0 & \frac{8}{3} \end{pmatrix} \frac{F^2}{M^2}$$

- largest for stops and sbottoms
- if one-loop $SU(3)_F$ effects comparable with two-loop $SU(3)_C \times SU(2)_L \times U(1)_Y$ effects:
  - stop and sbottom masses lowered
  - first- and second-generation squark masses slightly lowered
  - rest of spectrum hardly affected



Effect on the superpartner spectrum

- 3rd generation squarks tachyonic at mediation scale,
  runs positive due to gluino loops

  (cf. also → Dermisek/Kim '06, Dermisek/Kim/Kim '06, Draper et al. '11)
- Can get sub-TeV stops and sbottoms
  with first-generation squarks above LHC limits
- Can get maximal stop mixing contributions to m_{h^0} in MSSM
  with moderate or zero A_t at mediation scale

  ↑

  naive prediction of gauge mediation

(may not hold if $\mu/B\mu$ generated by Higgs-messenger couplings → Shih's talk)

- Can also lift m_{h^0} by extra d.o.f. or non-decoupling effects...
  flavour gauge messengers really just affect the flavour sector

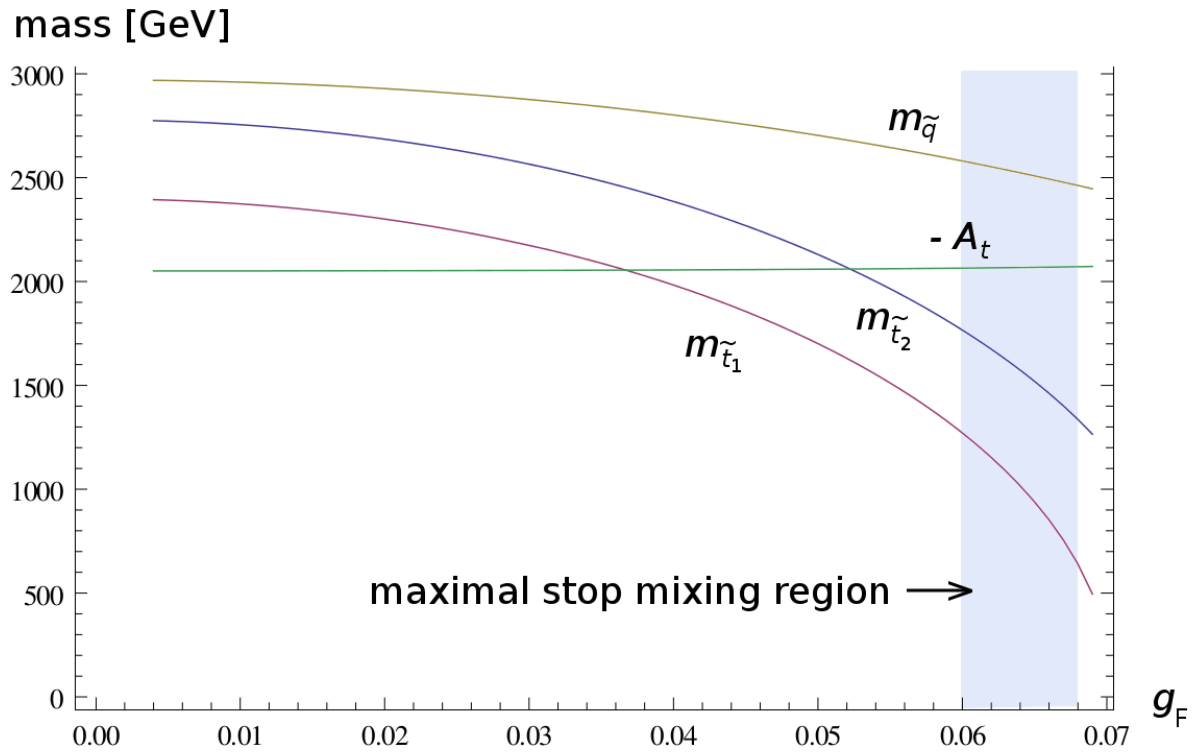
Light stops and lightest Higgs mass in MSSM

Gaugino and matter soft terms: minimal GMSB + flavour gauge messengers

Higgs soft terms: free parameters (gauge-Higgs mediation)

RG evolution: SOFTSUSY → Allanach '01

Effect of switching on $SU(3)_F$ gauge coupling:



$\Lambda_{\mathrm{MGM}} = 3 \cdot 10^5$ GeV, $M = 10^7$ GeV, $N_5 = 1$, $A_0 = -2$ TeV, $m^2_{H_u} = m^2_{H_d} = 10^5\ (\mathrm{GeV})^2$, $\tan\beta = 10$

Light stops and lightest Higgs mass in MSSM

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Higgs mass: `FeynHiggs` → Heinemeyer/Hollik/Weiglein et al. '98−, ±3 GeV th. unc.

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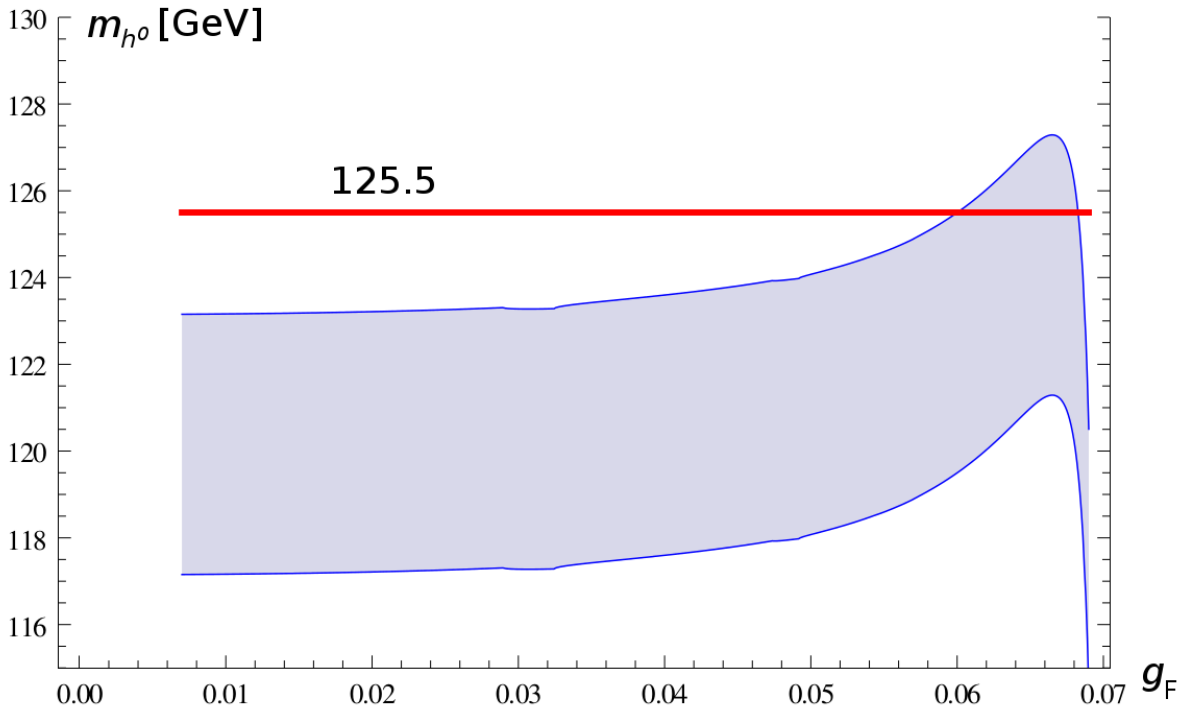

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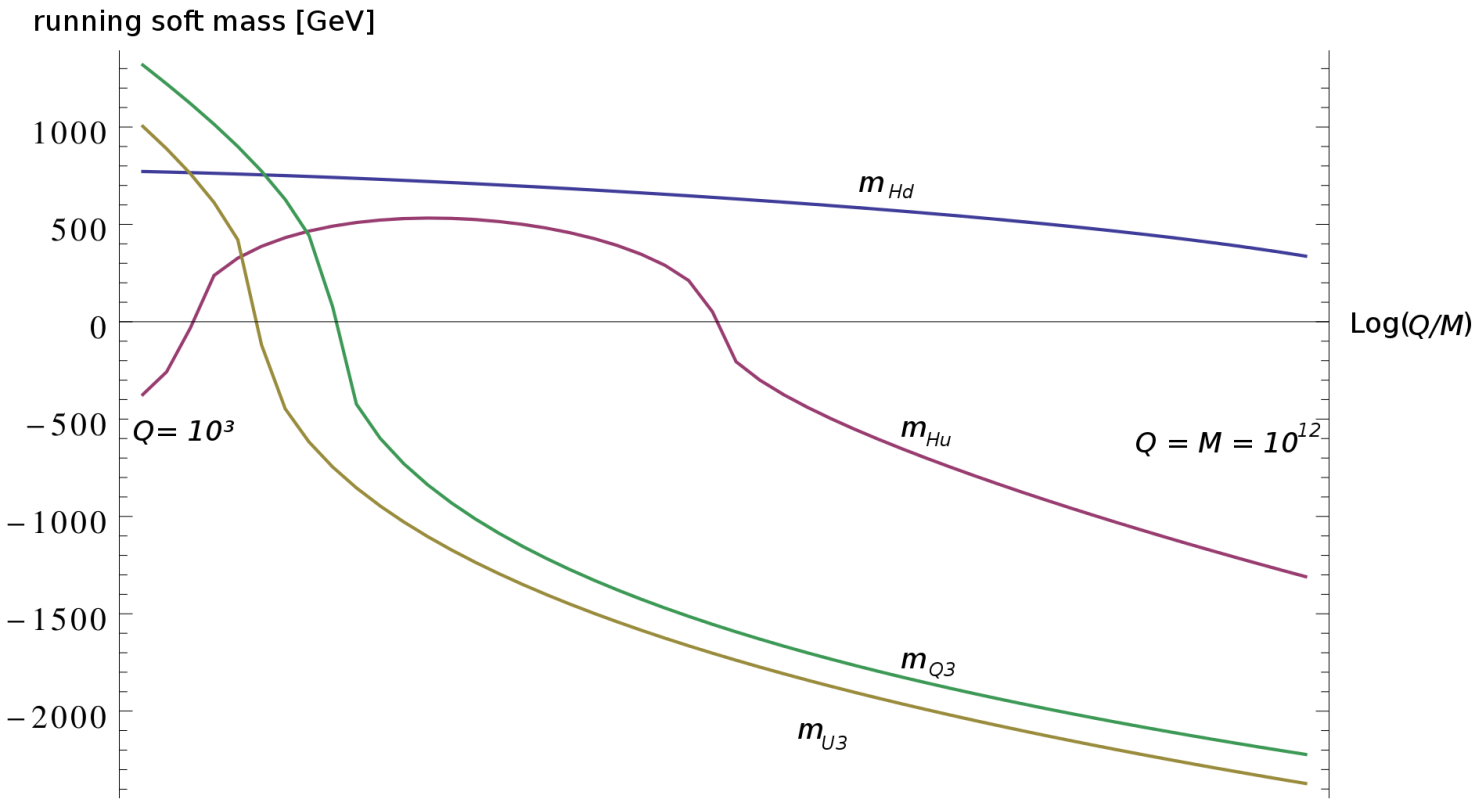
Radiative maximal stop mixing

Example with a high messenger scale ($M = 10^{12}$ GeV), radiatively induced A_t, $m_{h^0} = 124 \pm 3$ GeV:

similar to → Draper/Meade/Reece/Shih '11



Drawback: uncomfortably large gluino mass ≈ 3 TeV

$\Lambda_{\text{MGM}} = 1.5 \cdot 10^5$ GeV, $M = 10^{12}$ GeV, $N_5 = 3$, $A_0 = 0$, $m^2_{H_u} = -1.8 \cdot 10^6\ (\text{GeV})^2$, $m^2_{H_d} = 10^5\ (\text{GeV})^2$, $g_F = 0.15$, $\tan\beta = 10$

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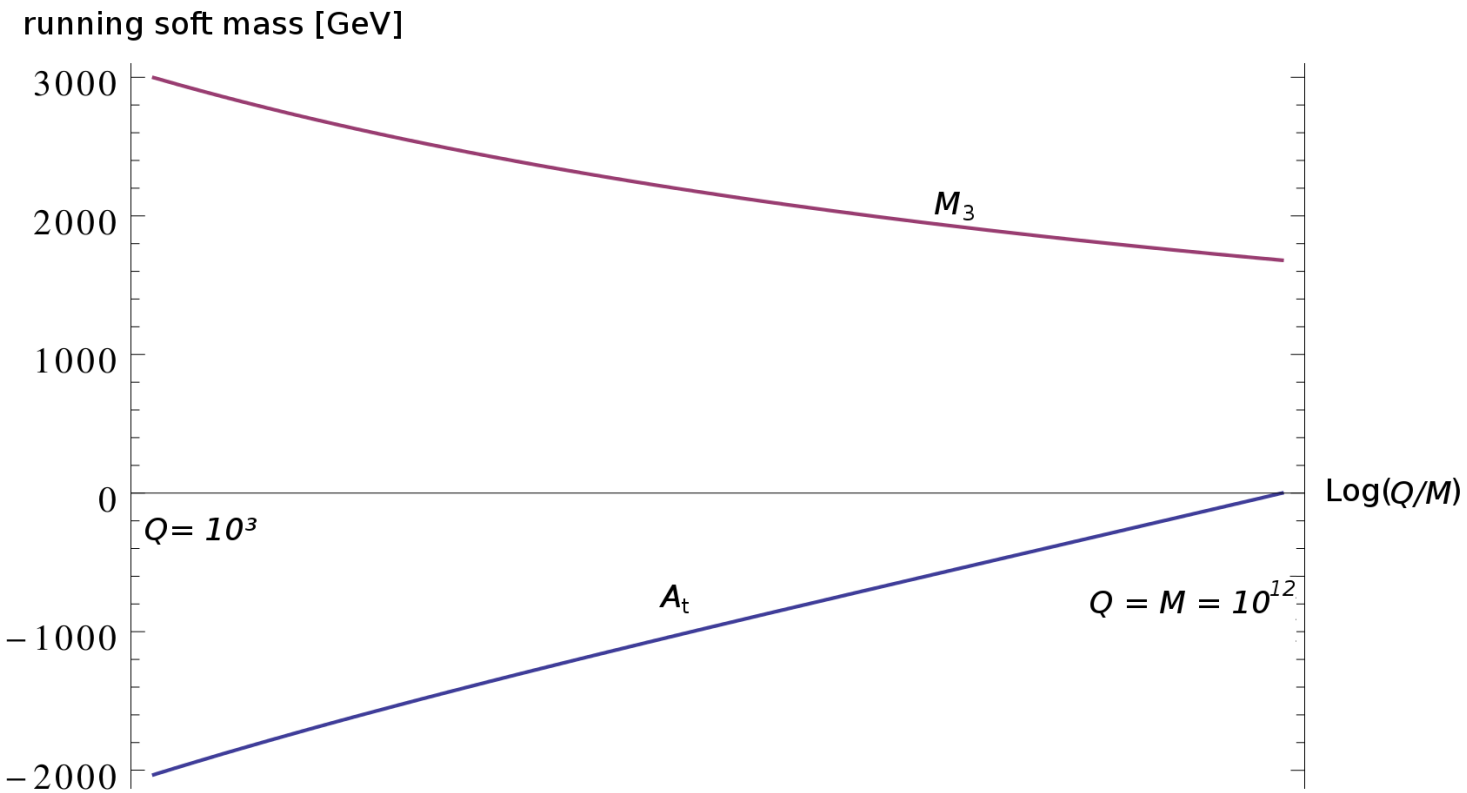

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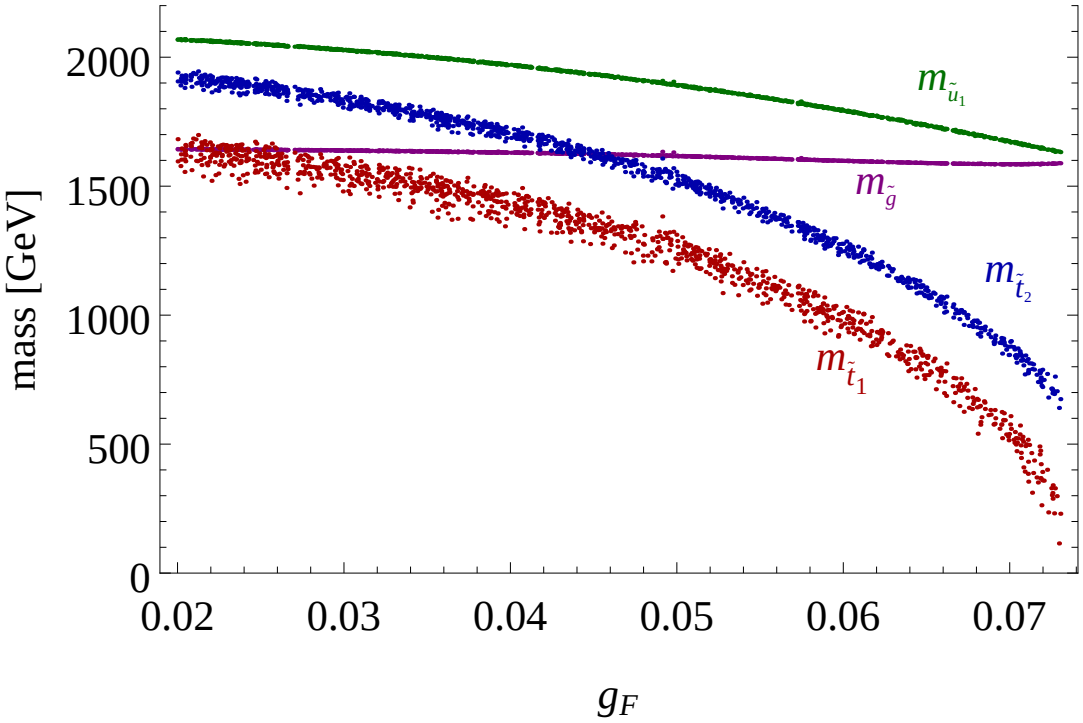
Gauge messengers in NMSSM

Similar picture:



(using `SPheno` → Porod '03)

- scan over Higgs sector parameters, requiring $m_{h^0} = 125.5 \pm 3$ GeV
- gauge mediation parameters held fixed

Model building: SUSY breaking

Simple O'Raifeartaigh model to illustrate alignment of VEVs:

$$W = \kappa Y \left(T\widetilde{T} - f^2 \right) + m\widetilde{X}T + mX\widetilde{T}$$

where $X, T = \mathbf{3}$, $\widetilde{X}, \widetilde{T} = \bar{\mathbf{3}}$, $Y =$ singlet

For $\kappa f > m$: Vacuum at $T = (0, 0, v)$, $F_X = m\,T$, $v^2 = f^2 - m^2/\kappa^2$

- SUSY breaking aligned with $\mathrm{SU}(3)_\mathrm{F} \to \mathrm{SU}(2)_\mathrm{F}$ breaking by e.o.m.
- "Small SUSY breaking limit", $F_X < v^2$
- For full flavour structure need to break also $\mathrm{SU}(2)_\mathrm{F}$ at lower scale (independently)
- On the wishlist: fully dynamical model

Model building: Flavour symmetry breaking

Non-universal gauge messenger contribution to squark masses is diagonal only in one particular flavour basis

Rotating to SCKM basis $\Rightarrow$ off-diagonal squark masses $\Rightarrow$ FCNCs

Model dependent

Simple example: Break $SU(2)_F \rightarrow 0$ with extra VEVs

$\langle S \rangle = (0, u, w), \qquad \langle \widetilde{S} \rangle^\dagger = e^{i\phi} \langle S \rangle$

Treat all fields as spurions; impose discrete symmetry; take $|w| \sim |u| \ll |v|$

$$W = \frac{\widetilde{T}_i \widetilde{T}_j}{\Lambda^2} Q_i U_j H_u + \frac{\widetilde{S}_i \widetilde{S}_j}{\Lambda^2} Q_i U_j H_u + \ldots + \frac{S_i \widetilde{T}_i S_j \widetilde{T}_j T_k S_l T_n S_q}{\Lambda^8} \epsilon_{klm} \epsilon_{npq} Q_m U_q H_u$$

induces realistic up-type Yukawa matrix if $|w|/|v| \sim |u|/|v| = \epsilon \approx 0.1$

Non-abelian Froggatt-Nielsen model

Down-type Yukawas similar

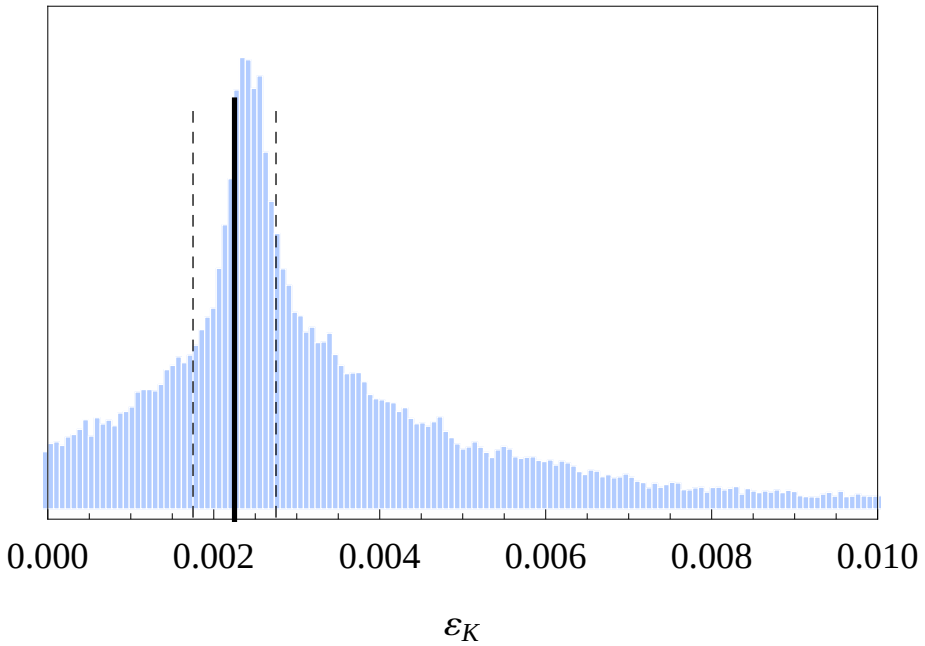
Model building: Flavour symmetry breaking

Mass and CKM hierarchies roughly reproduced, e.g.

$$V_{\text{CKM}} \sim \begin{pmatrix} 1 & \epsilon & \epsilon^2 \\ \epsilon & 1 & \epsilon \\ \epsilon^2 & \epsilon & 1 \end{pmatrix}$$

although V_{us}, V_{cb} a bit too small

Flavour constraints: mostly from $\Delta F = 2$ observables, especially ϵ_K
Using MCMC scan to sample flavour model parameter space:



On the wishlist: nicer flavour models

Conclusions

- Gauge messengers for a gauged flavour symmetry: interesting model-building ingredient
- For $SU(3)_F$ with SUSY breaking aligned with $SU(3)_F \rightarrow SU(2)_F$ breaking in flavour space:
  - large negative contributions to 3rd gen. masses $\Rightarrow$ stops and sbottoms light
  - smaller -ve contributions to 1st/2nd gen. masses $\Rightarrow$ other squarks heavy
- Allows for maximal stop mixing without extremely large A-terms $\Rightarrow$ 125 GeV Higgs in MSSM
- Alignment of VEVs can be realized dynamically
- Large contributions to ϵ_K possible. Model dependent, can be estimated in a given flavour model