Simple and direct communication of dynamical supersymmetry breaking

Andrea Romanino
SISSA

with Francesco Caracciolo arXiv:1207.5376

also based on earler work with Nardecchia, Ziegler, Monaco, Spinrath, Pierini

Supersymmetry

- Leads to
  - Gauge coupling unification
  - Plausible dark matter candidate (with R_P, independently motivated)
  - Calculable theory, can be extrapolated up to M_{Pl}
- Needs to be broken, hopefully spontaneously
  - Effective description in terms of O(100) parameters
  -

$$W = \lambda^U_{ij}\hat{u}^c_i\hat{q}_j\hat{h}_u + \lambda^D_{ij}\hat{d}^c_i\hat{q}_j\hat{h}_d + \lambda^E_{ij}\hat{e}^c_i\hat{l}_j\hat{h}_d + \mu\,\hat{h}_u\hat{h}_d$$

$$\begin{aligned}-\mathcal{L}_{\rm soft} = {} & A^U_{ij}\tilde{u}^c_i\tilde{q}_j h_u + A^D_{ij}\tilde{d}^c_i\tilde{q}_j h_d + A^E_{ij}\tilde{e}^c_i\tilde{l}_j h_d + m^2_{ud}h_u h_d + \text{h.c.} \\ & + (\tilde{m}^2_q)_{ij}\tilde{q}^\dagger_i\tilde{q}_j + (\tilde{m}^2_{u^c})_{ij}(\tilde{u}^c_i)^\dagger\tilde{u}^c_j + (\tilde{m}^2_{d^c})_{ij}(\tilde{d}^c_i)^\dagger\tilde{d}^c_j + (\tilde{m}^2_l)_{ij}\tilde{l}^\dagger_i\tilde{l}_j \\ & + (\tilde{m}^2_{e^c})_{ij}(\tilde{e}^c_i)^\dagger\tilde{e}^c_j + m^2_{h_u}h^\dagger_u h_u + m^2_{h_d}h^\dagger_d h_d \\ & + \frac{M_3}{2}\tilde{g}_A\tilde{g}_A + \frac{M_2}{2}\tilde{W}_a\tilde{W}_a + \frac{M_1}{2}\tilde{B}\tilde{B} + \text{h.c.}\end{aligned}$$

aking

- m_{sq} > 1.4 TeV (but $m_{1,2} \neq m_3$)
- $m_H \approx$ 125 GeV? (but NMSSM, λSUSY)

Origin of supersymmetry breaking

A wide class of models of supersymmetry breaking

[Polchinski Susskind,
Dine Fischler,
Dimopoulos Raby,
Barbieri Ferrara Nanopoulos]

?

SUSY breaking

?

MSSM

Hidden sector $\longleftrightarrow$ **Observable sector**

Z chiral superfield

$\langle Z \rangle = F\theta^2$

$F \gg (M_Z)^2$

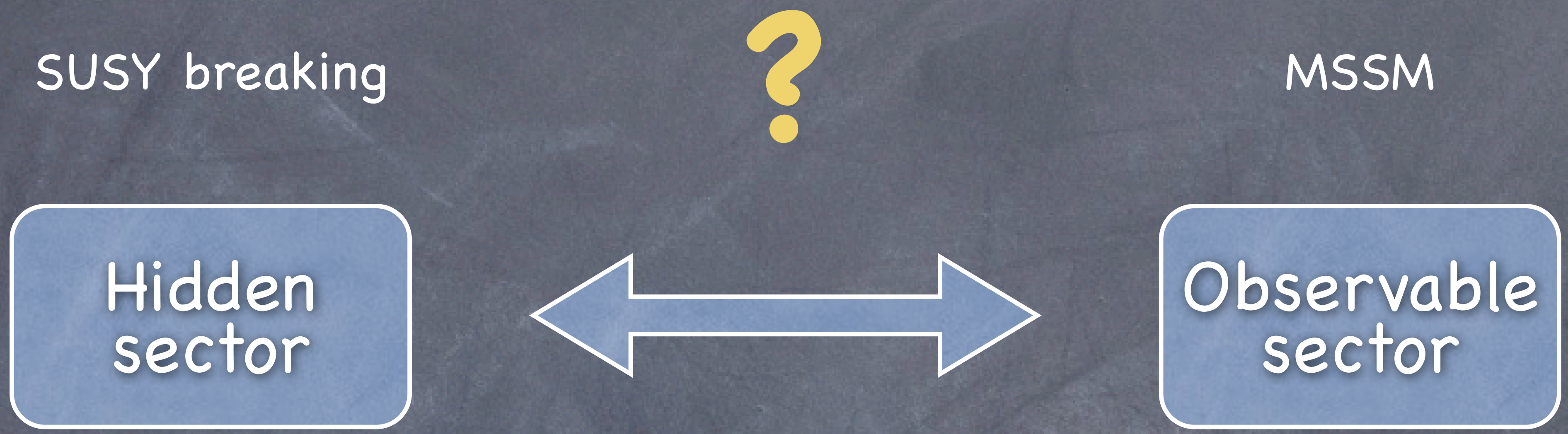
SM singlet

M

Q chiral superfield

$$\int d^4\theta \, \frac{Z^\dagger Z \, Q^\dagger Q}{M^2} \quad \to m^2 \tilde{Q}^\dagger \tilde{Q}, \quad m = \frac{F}{M}$$

A wide class of models of supersymmetry breaking



A useful guideline: the supertrace constraint

- Str $M^2 \equiv \Sigma_{\text{bosons}}\, m^2 - \Sigma_{\text{fermions}}\, m^2$ (weighted by # of dofs)
- Ren. Kähler + tree level + $\mathrm{Tr}(T_a) = 0$: $\boxed{\mathrm{Str}\, \mathcal{M}^2 = 0}$
- Holds separately for each set of conserved quantum numbers
- MSSM: incompatible with $\boxed{(\mathrm{Str}\, M^2)_{f,\mathrm{MSSM}} = \Sigma_{\text{sfermions}}\, m^2 - \Sigma_{\text{fermions}}\, m^2 > 0}$
- $G = G_{SM}$: incompatible with $\boxed{\tilde{m}^2_{\text{lightest } d\text{-sfermion}} \leq m_d^2 - \frac{1}{3} g' D_Y}$

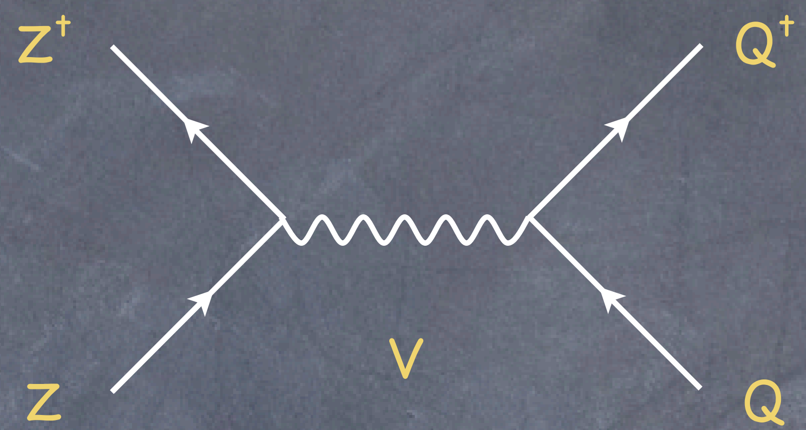
  (if $D_Y < 0$, consider up sfermions)

Addressing the supertrace constraint

- Ren. Kähler + tree level + $\mathrm{Tr}(T_a) = 0 \;\rightarrow\; \mathrm{Str}\, M^2 = 0$
- Supergravity: non-renormalizable Kähler: $\mathrm{Str} \neq 0$ FCNC ?
- "Loop" gauge-mediation: loop-induced: $\mathrm{Str} \neq 0$ FCNC OK
- Anomalous U(1)'s: $\mathrm{Tr}(T_a) \neq 0$: $\mathrm{Str} \neq 0$ FCNC OK
- Tree-level gauge mediation: $\mathrm{Str} = 0$ FCNC OK

Tree-level gauge mediation

$$\int d^4\theta\, \frac{Z^\dagger Z\, Q^\dagger Q}{M^2}$$



↑

massive vector of a
spontaneously broken U(1)
$G \supset G_{SM} \times U(1)$

⇒ Z, Q charged under U(1)

M ≈ M_V scale of U(1) breaking

$$\tilde{m}_Q^2 = q_Q q_Z \frac{F^2}{M_V^2/g^2}$$

Need of extra heavy (through U(1) breaking) fields

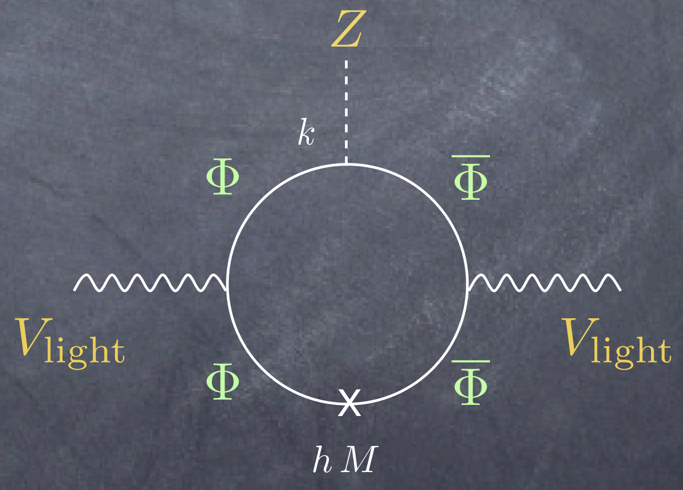
- SU(5)xU(1) $\subseteq$ G, flavour universal charges, $q_Z > 0$ for definitess
- $(l, d^c) = \bar{5}$: $q_5 > 0$ $(m^2_5 > 0$, tree level)
  $(q, u^c, e^c) = 10$: $q_{10} > 0$ $(m^2_{10} > 0$, tree level)
- $SU(5)^2 xU(1)$ anomaly cancellation: $0 = 3(\underbrace{q_5 + 3q_{10}}_{>0}) + \underbrace{\text{extra}}_{<0}$
  (guaranteed if SU(5)xU(1) is embedded in SO(10))
  $\Downarrow$
  M from U(1) breaking
- Masses^2 (before EWSB)

	$\bar{5} + 10$	extra = $\Phi + \bar{\Phi}$
fermions	0	M^2
scalars	$0 + m^2$	$M^2 - m^2$

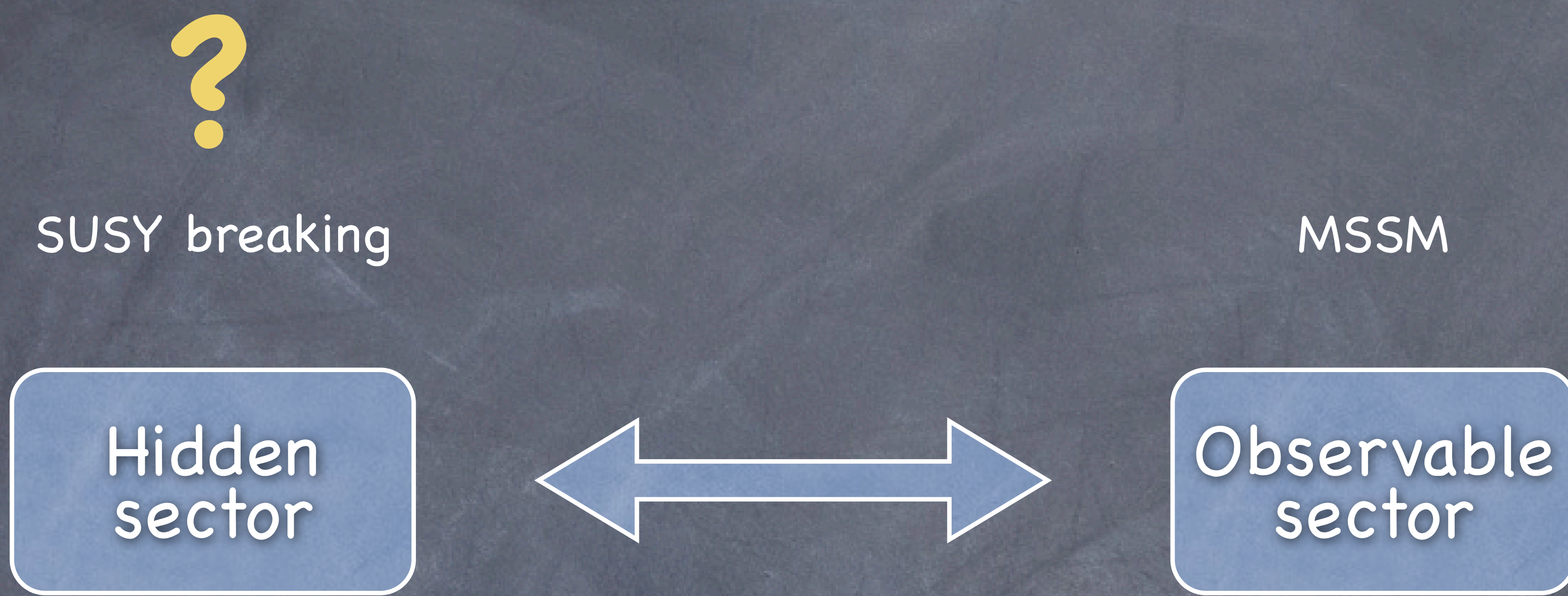
STr = 0

The extra heavy fields as chiral messengers

- U(1) breaking: $\langle Y \rangle = M$
- SUSY breaking: $\langle Z \rangle = F\theta^2$
- In concrete models: $q_Z = q_Y$
- $h\, Y\, \bar{\Phi}\, \Phi \quad \rightarrow M_\Phi = hM$
- $k\, Z\, \bar{\Phi}\, \Phi \quad \rightarrow \boxed{M_g \sim \frac{\alpha}{4\pi}\frac{k}{h}\frac{F}{M}}$



A wide class of models of supersymmetry breaking



- Phenomenologically viable supersymmetric models not always are theoretically complete

- Theoretically complete models of susy breaking not always are phenomenologically viable

- Phenomenologically viable and theoretically complete models not always are extremely simple

Reminder

- Non-renormalization: $W_{cl} = W_{\text{all orders in PT}}$

- $\boxed{W = W_{cl} + W_{NP}}$

“Classical” breaking

“Dynamical” breaking

$$M_{SUSY} \approx M_0 \, e^{-(2\pi/\alpha\, b)}$$

The (problematic) role of the R-symmetry

- An exact R-symmetry prevents (Majorana) gaugino masses
- Nelson-Seiberg: R-symmetry needed in a susy-breaking model where
  - i) the susy-breaking minimum is stable and
  - ii) the superpotential is generic
- Non vanishing gaugino masses then require
  - non generic superpotential (R-breaking) or
  - metastable susy-breaking minima or
  - spontaneous R-breaking or
  - Dirac gaugino masses

as if it that were not enough..

- Spontaneous R-breaking in generalized O'R models needs $R \neq 0,2$ (e.g. ISS flows to $R = 0,2$)

Shih, hep-th/0703196
Curtin Komargodski Shih Tsai, 1202.5331

- Even if $R \neq 0,2$: the stability (everywhere) of the pseudoflat direction along which the R-symmetry is spontaneously broken forces $M_g = 0$ at 1-loop

Komargodski Shih, 0902.0030

- More gaugino screening takes place (semi-direct)

Arkani-Hamed Giudice Luty Rattazzi, hep-ph/9803290
Argurio Bertolini Ferretti Mariotti, 0912.0743

A simple, viable, dynamical model:
3-2 + messenger/observable fields

[N=1 global, canonical K, no FI]

Reminder: 3-2 model

[Affleck Dine Seiberg]

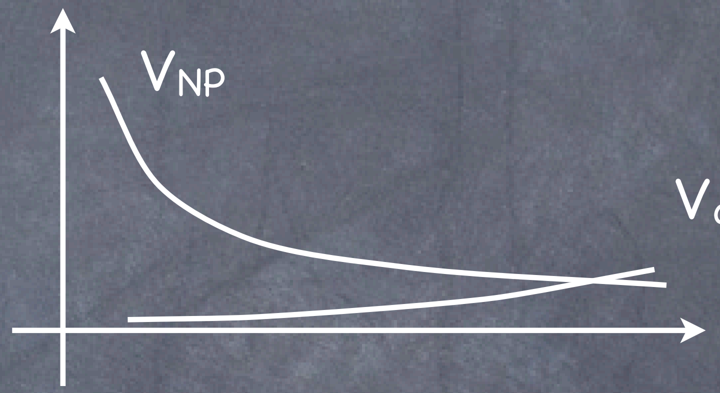
- SU(3) strong at Λ_3 where SU(2) weak

	SU(3)	SU(2)	$G \supseteq G_{\rm SM}$
Q	3	2	1
U^c	$\overline{3}$	1	1
D^c	$\overline{3}$	1	1
L	1	2	1

$$W_{\rm cl} = h\, Q D^c L$$

$$W_{\rm NP} = \frac{\Lambda_3^7}{\det Q\tilde{Q}}$$

$$\tilde{Q} = \begin{pmatrix} D^c \\ U^c \end{pmatrix}$$



- h « 1: calculability

- SU(3) x SU(2) broken at M = $\Lambda_3/h^{1/7}$ » Λ_3

- SUSY broken at F = h M^2 « M^2

- $\langle L_2 \rangle = 0.3\ M + 1.3\ F\theta^2$ $\qquad \langle L_1 \rangle = 0$

Details

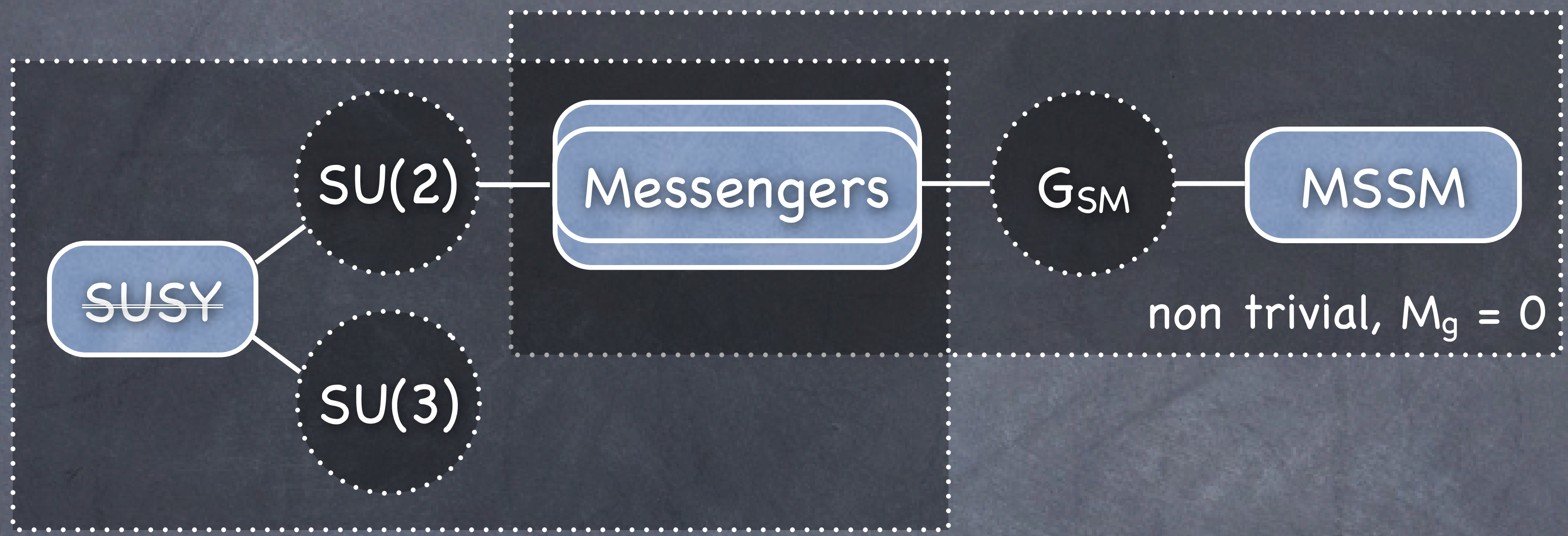
$$Q = \tilde{Q} = \begin{pmatrix} a & 0 \\ 0 & b \\ 0 & 0 \end{pmatrix} M \qquad L = \begin{pmatrix} 0 & \sqrt{a^2 - b^2} \end{pmatrix} M$$

a ≈ 1.164
b ≈ 1.131

$$F_Q = F_{\tilde{Q}} = \begin{pmatrix} a\sqrt{a^2 - b^2} - 1/(a^3 b^2) & 0 \\ 0 & -1/(a^2 b^3) \\ 0 & 0 \end{pmatrix} F \qquad F_L = \begin{pmatrix} 0 & a^2 \end{pmatrix} F$$

Coupling to observable fields: semi-direct GM

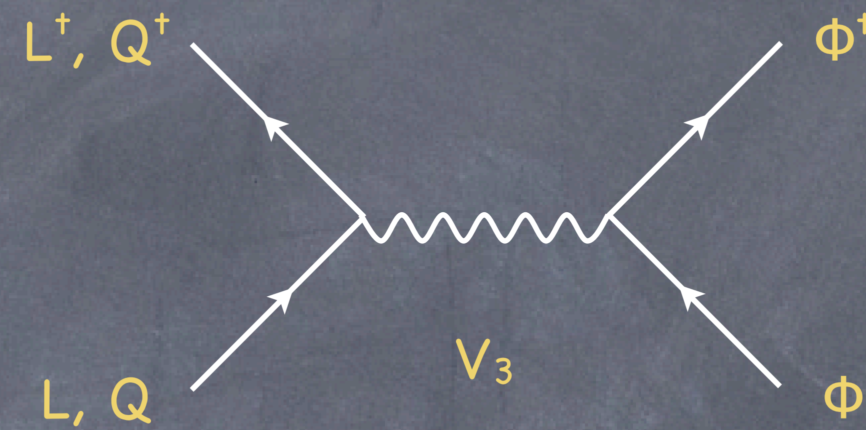
[Seiberg, Volansky, Wecht]



Our model

[Caracciolo, R]

	SU(3)	SU(2)	$G \supseteq G_{\rm SM}$
Q	3	2	1
U^c	$\overline{3}$	1	1
D^c	$\overline{3}$	1	1
L	1	2	1
Φ_i	1	2	$R_{\rm SM}$
$\overline{\phi}_i$	1	1	$\overline{R}_{\rm SM}$



$$\tilde{m}^2_{\Phi} = -g^2\, T_3 \frac{F^2}{M_V^2} = \mp \tilde{m}^2 \qquad \tilde{m}^2_{\overline{\phi}} = 0$$

$$\Phi_i = \begin{pmatrix} \phi_i \\ f_i \end{pmatrix}, \quad \overline{\phi}_i$$

$$W = L\,\Phi_i\,\overline{\phi}_i$$ [no explicit mass term]

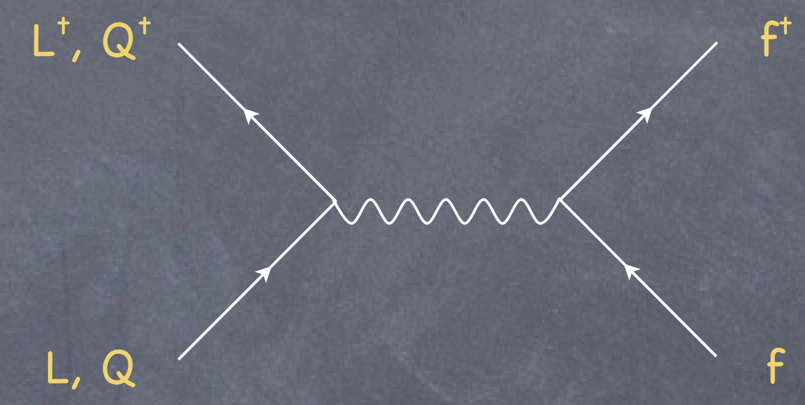
$f =$ MSSM fields $\qquad M_f = 0 \qquad M^2_{\tilde{f}} = +\tilde{m}^2$

$\phi_i, \overline{\phi}_i =$ messengers of MGM $\qquad M_{\phi,\overline{\phi}} = M \qquad M^2_{\tilde{\phi}_\pm} = M^2 \pm F^2 - \frac{\tilde{m}^2}{2}$

gaugino masses

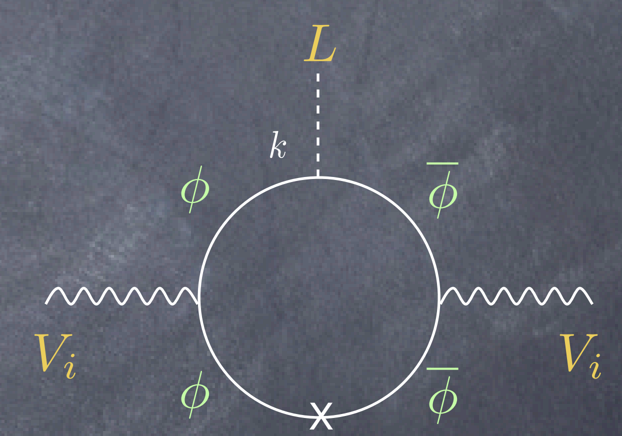
More details

$$\tilde{m}^2 = c\frac{F^2}{M^2} \qquad c = \frac{2a^8b^8 + 2a^2 + 4a^4b^4\sqrt{a^2-b^2} - 2b^2}{3a^8b^6 - a^6b^8} \approx 1.48$$



$$M_i = 12\,\frac{a^2}{\sqrt{a^2-b^2}}\,\frac{\alpha_i}{4\pi}\,\frac{F}{M}$$

$$\boxed{M_3(\mathrm{TeV}) \approx 0.35\,\tilde{m}}$$

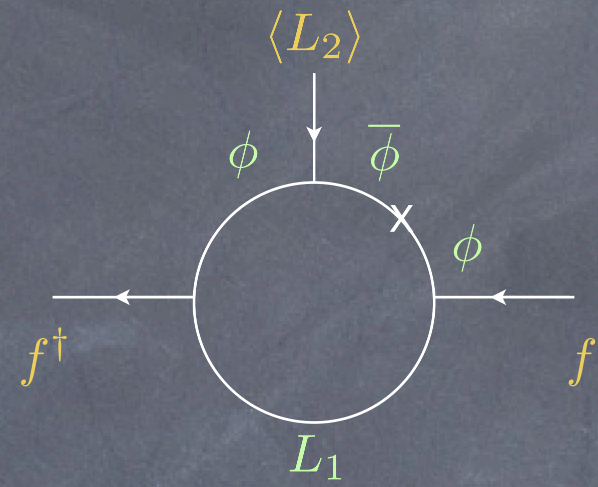


M > 10^{11} GeV

Yukawa interactions and Higgs

- Yukawa interactions
  - SM fermions have $T_3 = -1/2 \rightarrow$ Higgs doublets have $T_3 = 1$ (triplets)
  - $W_Y = \lambda^u_{ij}\ \Phi_i\ \Phi_j\ H_u + \lambda^d_{ij}\ \Phi_i\ \Phi_j\ H_d$
- The Higgs sector
  - Is model dependent
  - Two additional Higgs pairs not coupled to the SM fermions
  - The Higgs pair interacting with fermions has negative soft masses

A-terms

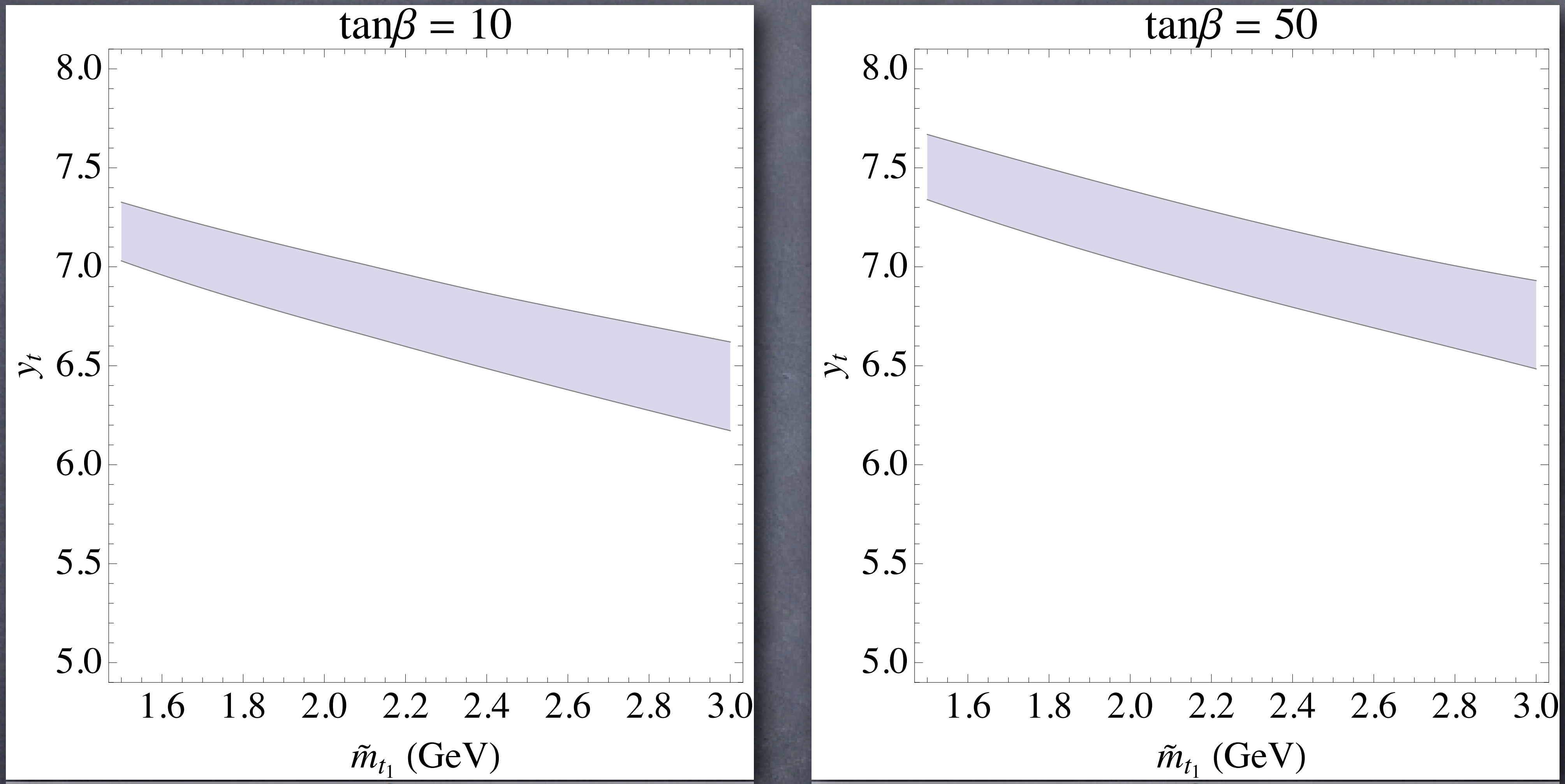
- Do arise from δK = 

$$W = y\, L\Phi\, \overline{\phi} = y L_2 \phi \overline{\phi} + y L_1 f \overline{\phi}$$

- Because of the embedding of the messenger U(1) in a larger group (SU(2), SO(10))

- Numerically: $A_t \approx -\dfrac{\alpha_y}{6\alpha_3} M_3$ (no A-m^2 problem)

In order to get a 125 GeV Higgs



2-loop corrections to sfermion masses

"Minimal" gauge mediation:	O(1%)	flavour-blind
Matter-messenger couplings:	O(3%)	flavour-safe

More details

$$\delta\tilde{m}_f^2 = 2\frac{y_f^* y_f^T}{(4\pi)^2}\left(\frac{T}{2(4\pi)^2} - 2c_f^r\frac{g_r^2}{(4\pi)^2} + \frac{y_f^* y_f^T}{(4\pi)^2}\right)\left(\frac{F_L}{M_L}\right)^2$$

$$T = \mathrm{Tr}\left(6y_q y_q^\dagger + 3y_{u^c} y_{u^c}^\dagger + 3y_{d^c} y_{d^c}^\dagger + 2y_l\, y_l^\dagger + y_{n^c} y_{n^c}^\dagger + y_{e^c} y_{e^c}^\dagger\right)$$

$$\left[y^* y^T \left(8\,\mathrm{Tr}(y^* y^T) + y^* y^T\right)\right]_{12}^D < 1.5$$

$$\left[y^* y^T \left(8\,\mathrm{Tr}(y^* y^T) + y^* y^T\right)\right]_{13}^D < 0.5 \cdot 10^2$$

$$\left[y^* y^T \left(8\,\mathrm{Tr}(y^* y^T) + y^* y^T\right)\right]_{23}^D < 1.5 \cdot 10^2$$

$$\left[y^* y^T \left(8\,\mathrm{Tr}(y^* y^T) + y^* y^T\right)\right]_{12}^U < 6.$$

Summary

- Supersymmetry breaking remains the key of phenomenologically and theoretically successful supersymmetry models
- Phenomenological issues/guidelines: FCNC, fine-tuning
- Theoretical issues/guidelines: Str, R-symmetry
- A simple, theoretically complete, and phenomenologically viable option
- Susy breaking is communicated by extra, SB gauge interactions
- Messenger and observable fields are charged under the hidden sector gauge group
- Positive sfermion masses arise at the tree level, in a dynamical realization of TGM, but are not hierarchically larger than gaugino's
- A-terms are generated, and are possibly sizeable