# Viable and simplified semi-direct gauge mediation

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# Motivations

- Theory: perturbative non-renormalization theorem

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Supersymmetry can be broken by tiny non-perturbative effects if it is classically preserved

- Theoretically appealing
- Calculable models

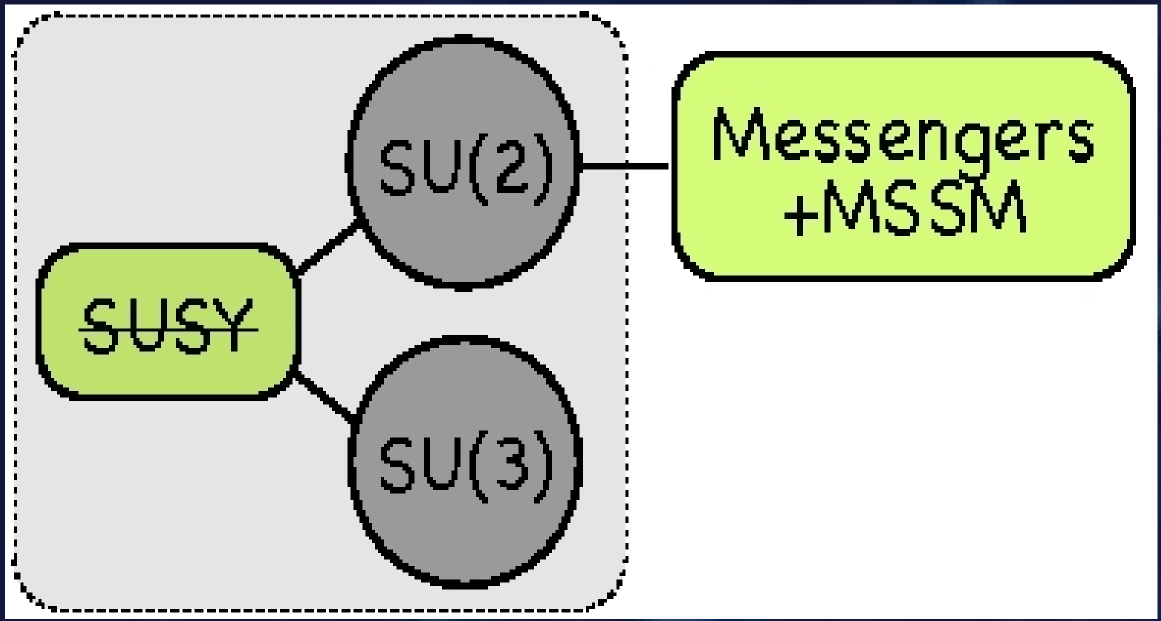
- Phenomenology: it is hard to obtain models with dynamically broken supersymmetry in which gaugino and sfermion masses are comparable, as required by the naturalness criterion

- R-symmetry — Nelson, Seiberg (1994)
- Komargodski-Shih theorem — Komargodski, Shih (2009)
- Semi-direct gauge mediation — Seiberg, Volansky, Wecht (2008)

- In this talk, I want to show a *simple*, *calculable* and *phenomenologically viable* model with *dynamically* broken supersymmetry

- Messengers *and* MSSM fields are coupled to the hidden sector without taking part to the supersymmetry breaking mechanism
- Gaugino and sfermion masses are of the same order of magnitude
- Communication of supersymmetry breaking is achieved via non-SM gauge interactions
- Dynamical realization of tree-level gauge mediation — Nardecchia, Romanino, Ziegler (2009 - 2010); Monaco, Nardecchia, Romanino, Ziegler (2011)

# Scheme of the mechanism




The MSSM scalar fields acquire a soft mass term through *renormalizable non-SM gauge interactions*

Messengers give mass to gauginos at one-loop, but the hierarchy between sfermions and gauginos is reduced by various factors

# 3 - 2 Model (a brief review)

Affleck, Dine, Seiberg (1985)

| | SU(3) | SU(2) |
|---|---|---|
| $Q$ | 3 | 2 |
| $U^c$ | $\bar{3}$ | 1 |
| $D^c$ | $\bar{3}$ | 1 |
| $L$ | 1 | $\bar{2}$ |

$$W_{32} = h\, Q^{aA} D^c_a L_A + \frac{\Lambda_S^7}{Q^{rA} Q^{sB} D^c_r U^c_s \varepsilon_{AB}}$$

$$\langle \phi \rangle \sim M + F\theta^2 \qquad g^2 \langle D \rangle \sim \frac{F^2}{M^2}$$

$$M \equiv \frac{\Lambda_S}{h^{1/7}} \qquad F \equiv h^{5/7} \Lambda_S^2$$

- $\langle L_1 \rangle = 0.28\, M + 1.35\, F\theta^2 \qquad \langle L_2 \rangle = 0$
- $g_2^2 \langle D_3^{SU(2)} \rangle = -2.96 \dfrac{F^2}{M^2} = -2 g_3^2 \langle D_3^{SU(3)} \rangle$
- Assumption: $g_3 \gg g_2 \gg h \qquad h \ll 1$

# Coupling to the MSSM

| | $SU(3)$ | $SU(2)$ | $G_{SM}$ |
|---|---|---|---|
| $Q$ | $3$ | $2$ | $1$ |
| $U^c$ | $\bar{3}$ | $1$ | $1$ |
| $D^c$ | $\bar{3}$ | $1$ | $1$ |
| $L$ | $1$ | $\bar{2}$ | $1$ |
| $\Phi$ | $1$ | $2$ | $\rho_{SM+\nu^c}$ |
| $\bar{\varphi}$ | $1$ | $1$ | $\bar{\rho}_{SM+\nu^c}$ |

$$\Phi = \begin{pmatrix} \varphi \\ f \end{pmatrix}$$

$$W = W_{32} + y L_1 \varphi \bar{\varphi} + y L_2 f \bar{\varphi}$$

$$V_{soft} \supset g_2^2 \langle D_3^{SU(2)} \rangle \Phi^\dagger \frac{\sigma_3}{2} \Phi =$$

$$= -1.48 \frac{F^2}{M^2} \varphi^\dagger \varphi + 1.48 \frac{F^2}{M^2} f^\dagger f$$

- $f$'s are the MSSM superfields, with sfermion mass $\tilde{m} = 1.21 \frac{F}{M}$
- $\varphi$ and $\bar{\varphi}$ are the messenger superfields
- Gaugino masses arise at the one-loop level: $\tilde{M}_i^g = 12 \frac{\alpha_i}{4\pi} \frac{F_L}{M_L}$
- Net effect of the enhancing factors: $\tilde{M}_3^g \approx 0.35\, \tilde{m}$

# Recovering the MSSM superpotential...

- The Higgs sector is model dependent: in this slide I show the simplest realization which leads to a viable low-energy theory

| | $SU(3)$ | $SU(2)$ | $G_{SM}$ |
|---|---|---|---|
| $Q$ | $3$ | $2$ | $1$ |
| $U^c$ | $\bar{3}$ | $1$ | $1$ |
| $D^c$ | $\bar{3}$ | $1$ | $1$ |
| $L$ | $1$ | $\bar{2}$ | $1$ |
| $\Phi$ | $1$ | $2$ | $\rho_{SM+\nu^c}$ |
| $\bar{\varphi}$ | $1$ | $1$ | $\bar{\rho}_{SM+\nu^c}$ |
| $h_u$ | $1$ | $3$ | $(1,2,1/2)$ |
| $h_d$ | $1$ | $3$ | $(1,2,-1/2)$ |

$$\lambda_1 h_u \Phi^2 + \lambda_2 h_d \Phi^2 \supset$$

$$\lambda_u h_u^+ q\, u^c + \lambda_d h_d^+ q\, d^c + \lambda_n h_u^+ l\, \nu^c + \lambda_e h_d^+ l\, e^c$$

# Loop effects (I)

- Two-loop minimal gauge mediation contributions to sfermion masses cannot be larger than $\mathrm{O}(1\%)$ with respect to $\tilde{m}$
- $$W \supset y_{\alpha\beta} L_2 f_\alpha \overline{\varphi_\beta} + h_u^0 \lambda_{U\alpha\beta}\left(\frac{f_\alpha \varphi_\beta + \varphi_\alpha f_\beta}{\sqrt{2}}\right) + h_d^0 \lambda_{D\alpha\beta}\left(\frac{f_\alpha \varphi_\beta + \varphi_\alpha f_\beta}{\sqrt{2}}\right)$$

$$V \supset A_{ij}^U \tilde{u}_i^c \tilde{q}_j h_u^+ + A_{ij}^D \tilde{d}_i^c \tilde{q}_j h_d^+$$

$$A^U = \lambda_U A_q + A_{u^c}^T \lambda_U \qquad A^D = \lambda_D A_q + A_{d^c}^T \lambda_D$$

$$A_q = -\frac{1}{32\pi^2}\frac{F_L}{M_L}\left(2 y_q^* y_q^T + \lambda_U^\dagger \lambda_U + \lambda_D^\dagger \lambda_D\right)$$

$$A_{u^c} = -\frac{1}{32\pi^2}\frac{F_L}{M_L}\left(2 y_{u^c}^* y_{u^c}^T + 2\lambda_U^\dagger \lambda_U\right)$$

$$A_{d^c} = -\frac{1}{32\pi^2}\frac{F_L}{M_L}\left(2 y_{d^c}^* y_{d^c}^t + 2\lambda_D^\dagger \lambda_D\right)$$

Potentially large *A*-terms

# Loop effects (II)

- Messenger-matter couplings do not induce relevant one-loop contributions to soft scalar masses, while they do at the two-loop level

$$\delta \tilde{m}_f^2 = \frac{y_f^* y_f^T}{8\pi^2}\left(\frac{T}{32\pi^2} - c_f^r \frac{g_r^2}{8\pi^2} + \frac{y_f^* y_f^T}{16\pi^2}\right)$$

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

- Constraints from flavor physics can be easily satisfied

# Conclusions

- I have shown a simple, phenomenologically viable and theoretically motivated model of supersymmetry breaking
- Sfermion masses are degenerate, providing a rationale for CMSSM
- Sizeable loop effects to *A*-terms and soft sfermion masses
- The hidden sector structure is far from unique; in particular, it is possible to identify the $U(1)$ factor of the 4-1 model as the mediator of supersymmetry breaking