General Semi Direct Gauge Mediation

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Based on works with R. Argurio, M. Bertolini and G. Ferretti
arXiv:0906.0727, arXiv:0912.0743, arXiv:1006.5465

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Bonn

SUPERSYMMETRY AND ITS BREAKING

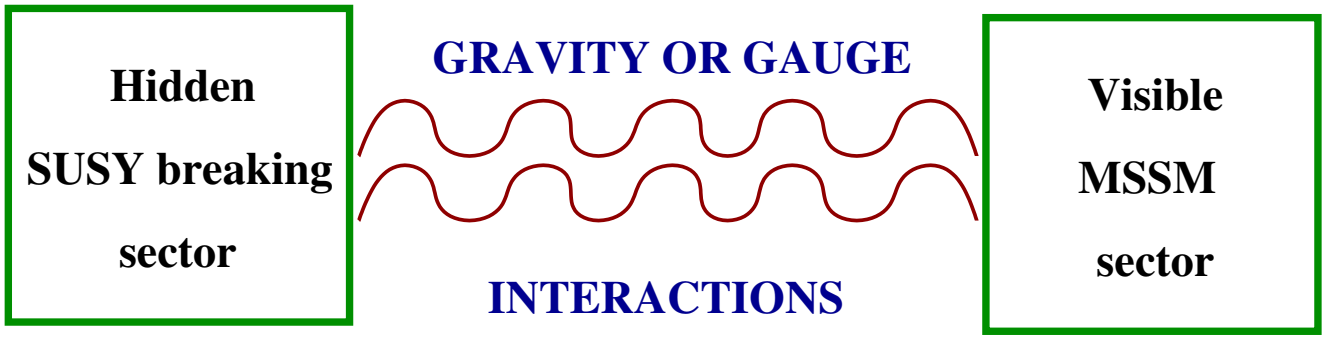
- Supersymmetry is one of the best candidate of BSM physics
- Supersymmetric extension of the SM, the MSSM
  - No quadratic divergencies
  - $\Rightarrow$ Address the hierarchy problem
  - Shows GUT unification
  - Dark Matter Candidate
  - Expected from String Theory

- Susy not realized at the weak scale

SUSY MUST BE BROKEN!!!

- It should be broken at low energy to solve the hierarchy problem
- $\Rightarrow$ hence Dynamical Supersymmetry Breaking
- Standard paradigm: Mediation of susy breaking
  - Susy is broken in a hidden sector
  - Some kind of interaction between Hidden sector and MSSM
  - $\Rightarrow$ Susy breaking is communicated to the MSSM

MEDIATION OF SUPERSYMMETRY BREAKING



- Gravity Mediation
  - Effective Lagrangian description, Plank suppressed operators
  - Problem: Flavour violation $\Rightarrow$ FCNC
- Gauge Mediation
  - No FCNC
  - No gravity
  - Predictive for the soft terms
  - Problem: Landau Pole, μ, $B\mu$ ...
- Mediation mechanism can give pheno signatures independently from hidden sector model

General Gauge Mediation P. Meade, N. Seiberg and D. Shih: arXiv:0801.3278

- Parametrize susy breaking sector in a model independent way
- Gauge mediation definition

$$\lim g_v \to 0 \qquad \text{No susy breaking in visible sector}$$

- Complete Lagrangian, perturbative in g_v

$$\mathcal{L} = \mathcal{L}_{MSSM} + 2g_v \int d^4\theta V_{MSSM} \mathcal{J}^{SUSYBR}$$

where

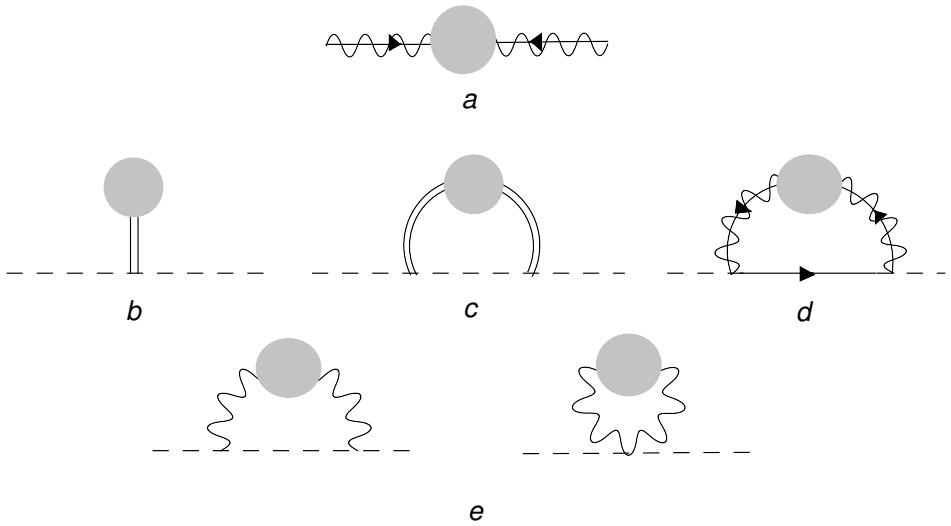
$$2g_v \int d^4\theta V_{MSSM} \mathcal{J}^{SUSYBR} = g_v(J^{SB} D - \lambda j^{SB} - \bar{\lambda}\bar{j}^{SB} - j^{SB}_{\mu} A^{\mu})$$

- $\mathcal{J}^{SUSYBR}$ supercurrent of the susy breaking sector with respect to G_{MSSM}
- Supersymmetry breaking encoded in two point functions of current

$$\begin{aligned}
\langle J^{SB}(p) J^{SB}(-p)\rangle &= C_0^{SB}(p^2/M^2)\,, \\
\langle j^{SB}_{\alpha}(p) \bar{j}^{SB}_{\dot{\alpha}}(-p)\rangle &= p_{\mu}\sigma^{\mu}_{\alpha\dot{\alpha}} C_{1/2}^{SB}(p^2/M^2)\,, \\
\langle j^{SB}_{\alpha}(p) j^{SB}_{\beta}(-p)\rangle &= \epsilon_{\alpha\beta} M B^{SB}(p^2/M^2)\,, \\
\langle j^{SB}_{\mu}(p) j^{SB}_{\nu}(-p)\rangle &= (p_{\mu}p_{\nu} - p^2\eta_{\mu\nu}) C_1^{SB}(p^2/M^2)\,,
\end{aligned}$$

- M set the susy breaking scale

SOFT MASSES IN GGM



- Soft masses

$$m_\lambda = g_v^2\, M\, B_{1/2}^{SB}(0)$$

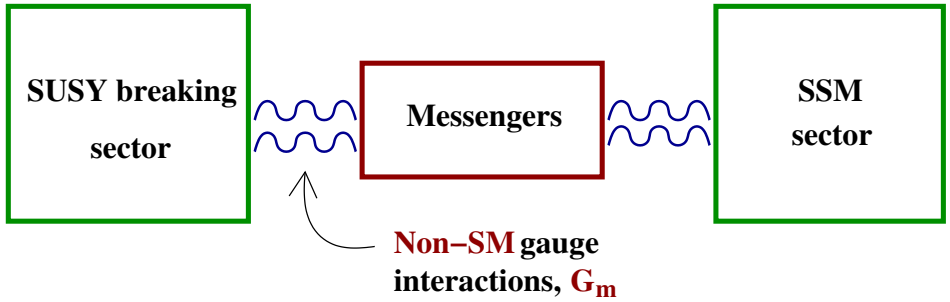
$$m_{sf}^2 = -g_v^4 \int \frac{d^4p}{(2\pi)^4 p^2}\left(C_0^{SB}(p^2/M^2) - 4C_{1/2}^{SB}(p^2/M^2) + 3C_1^{SB}(p^2/M^2)\right)$$

- Susy limit

$$B_{1/2}^{SB}(0) = 0, \qquad C_0^{SB} - 4C_{1/2}^{SB} + 3C_1^{SB} = 0$$

- D term $\Leftrightarrow \langle J^{SB}\rangle \neq 0$, can lead to negative squared mass for sfermions
- Sum rules for sfermion masses: $\mathrm{Tr}Ym^2 - \frac{5}{4}\mathrm{Tr}(B-L)m^2 = 0$

SEMI DIRECT GAUGE MEDIATION



Simple further assumptions

- Additional weakly coupled gauge group G_m
- Messengers couple to the susy breaking sector only via gauge interactions G_m

$$\Phi_{a,i} \quad , \quad \tilde{\Phi}_{j,b} \qquad a,b \in G_m \qquad i,j \in G_{MSSM}$$

- Messengers do not partecipate to the susy breaking
- Tree level mass term for the messengers

$$W_{mess} = m_{mess}\Phi\tilde{\Phi}$$

- No Landau Pole problem (G_m can be a $U(1)$)
- Observe: $\lim g_m \to 0$ No susy breaking in the visible sector

SEMI DIRECT GAUGE MEDIATION: PROPERTIES

REALIZED IN LOCAL MODEL OF D-BRANES AT SINGULARITY

- Quiver gauge theories natural set up
- Naturalness of parameters (messengers mass)
  - Dynamical mechanism can generate small messenger mass
  - Associated to geometry parameters
- Step in view of using gauge/gravity duality

arXiv.0906.0727

??? General phenomenology ???
??? Pheno signatures in a model independent way ???

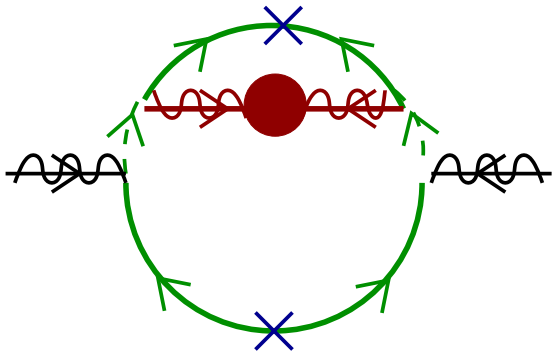
General semidirect gauge mediation arXiv.0912.0743

- Model independent parametrization for SDGM???
- Note: Decoupling of susybr sector is in SDGM as in GGM with $g_v \leftrightarrow g_m$
- $\Rightarrow$ Use again supercurrent formalism!
- Complete Lagrangian, perturbative in g_m

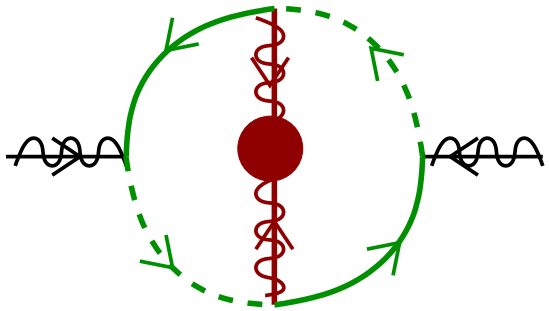
$$\begin{aligned}\mathcal{L} &= \mathcal{L}_{\rm MSSM} + \int d^4\theta \left(\Phi^\dagger e^{g_v V_v + g_m V_m}\Phi + \tilde{\Phi} e^{-g_v V_v - g_m V_m}\tilde{\Phi}^\dagger\right) \\ &+ \int d^2\theta\, m_{mess}\Phi\tilde{\Phi} + \int d^2\theta\, {\rm tr}\mathcal{W}_m^2 + h.c. + 2g_m \int d^4\theta\, V_m \mathcal{J}^{SB}\end{aligned}$$

- Visible soft terms via many loops in g_m and g_v
- We could think of messengers as MSSM matter in GGM, but, technical important differences with GGM:
  - Messengers have also susy mass m_{mess}
  - G_m can be Higgsed

GAUGINO MASS



m_λ^a



m_λ^b

- Contribution at three loop level, two graphs

$$m_\lambda = m_\lambda^a + m_\lambda^b = 8\, g_v^2\, g_m^4\, \frac{M}{m^2} \int \frac{d^4k}{(2\pi)^4} \frac{1}{k^2} \left(L^a(k^2/m^2) + L^b(k^2/m^2)\right) B_{1/2}^{SB}(k^2/M^2)$$

- Visible gaugino mass determined only by the function $B_{1/2}^{SB}$
- They sum to 0 !!!!

$$L^a(x) + L^b(x) = 0$$

- Next contribution at 5 loops, $O(g_v^6 g_m^4)$
- Completely model independent feature!!!

SFERMION MASSES

- Contributions at 4 loops
- Lots of graphs
- They depends only on C_i^{SB} functions (not on $B_{1/2}^{SB}$)
- By direct computation we find

$$m_{sf}^2 = \frac{g_v^4 g_m^4}{(4\pi)^4} \int \frac{d^4k}{(2\pi)^4 k^2} K(k^2/m^2)\left(C_0^{SB}(k^2/M^2) - 4C_{1/2}^{SB}(k^2/M^2) + 3C_1^{SB}(k^2/M^2)\right)$$

- Supersymmetric limit $C_0^{SB} - 4C_{1/2}^{SB} + 3C_1^{SB} \to 0$, $m_{sf}^2 \to 0$
- Kernel $K(k^2/m^2)$ encodes semi direct gauge mediation
- Kernel K is positive and soft behavior at large momenta

$$K(x) = \frac{5}{18}x^2 - \frac{137}{1350}x^3 + \frac{5437}{176400}x^4 + \mathcal{O}(x^5) \quad \text{for } x \to 0$$
$$K(x) \sim \gamma \log x \quad \text{for } x \to \infty$$

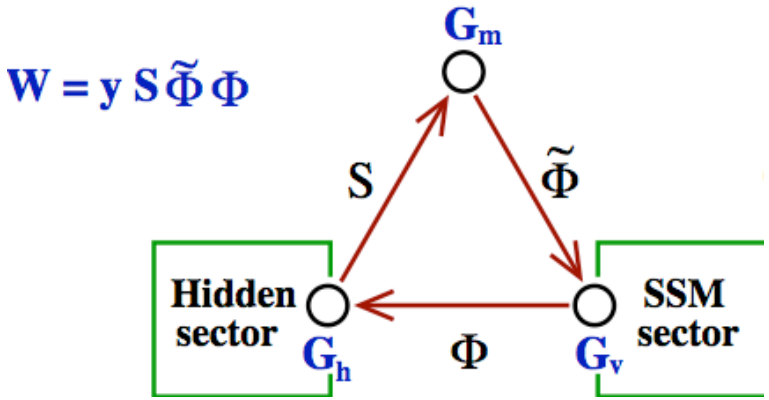
- Sfermion masses have opposite sign compared to GGM
- $K(x) \sim o(x^2) \Rightarrow D$ terms for G_m give vanishing contribution to m_{sf}^2

UNSCREENING GAUGINO MASS arXiv:1006.5465

- Chiral Messengers $\Rightarrow$ No mass term for messengers
- Messengers couple to different gauginos

$$\tilde{\Phi} \leftrightarrow \lambda_m \text{ (SUSY)} \qquad , \qquad \Phi \leftrightarrow \lambda_h \text{ (SUSYBR)}$$

- $\Rightarrow$ No cancellation anymore
- Messengers get mass via higgsing below hidden sector scale M
- We provided explicit example of this mechanism



- $y\langle S\rangle = m$ sets the messenger mass scale and Higgses $G_h \times G_m \to G_{diag}$
- Visible Gaugino Mass given by energy scale difference between M and m_{λ_h},

$$m_{\lambda_v} \sim g^2 g_v^2 \, m_{\lambda_h} \log \frac{M^2}{m_{\lambda_h}^2} \qquad \text{(in the approx } m_{\lambda_h} > y\langle S\rangle\text{)}$$

Conclusion

- Semi Direct gauge mediation is a large class of gauge mediation models
- It can be naturally embedded in string theory
- We provided a model independet (current based) description
  - We computed the resulting superpartner mass spectrum
  - Generically gaugino mass is screened
  - SDGM reverse sfermion squared mass sign with respect to same susy breaking sector in gauge mediation
  - Can be used in combination with other mechanisms (AM or DGM)
- Gaugino can be unscreened via a chiral messenger sector

- More quantitative analysis of combination with other mechanism
- Other soft terms: A-terms
- Further inspection of brane embedding and gauge/gravity description