Title: Gauge mediation of SUSY breaking

Date: Jun 05, 2008 12:25 PM

URL: http://pirsa.org/08060045

Abstract:

The LHC is around the corner

The LHC is around the corner

What will the LHC find?

What will the LHC find?

- My personal prejudice is that the LHC will discover something we have not yet thought of.

What will the LHC find?

- My personal prejudice is that the LHC will discover something we have not yet thought of.
- Among the known suggestion I view supersymmetry as the most conservative and most conventional possibility for LHC physics. It is also the most concrete one.

What will the LHC find?

- My personal prejudice is that the LHC will discover something we have not yet thought of.
- Among the known suggestion I view supersymmetry as the most conservative and most conventional possibility for LHC physics. It is also the most concrete one.
- We need to understand:
  - How is supersymmetry broken?
  - How is the information about supersymmetry breaking mediated to the MSSM?
  - Predict the soft breaking terms.

SUSY Breaking mediation

	Gravity mediation	Gauge mediation
Coupling to MSSM	Through Planck suppressed ops.	MSSM gauge interactions
FCNC	Challenging	Naturally suppressed
Dark matter	Simple	Challenging
$\mu / B\mu$ problem	Simple	Challenging

Minimal gauge mediation – models with simple messengers [Dine, Nelson, Nir, Shirman, ..

$$W = X\Phi^2 + ...$$
$$\langle X \rangle = M + \theta^2 F$$

X couples to the SUSY breaking sector. Its vev is the only source of SUSY breaking. It can be treated classically.

Φ are messengers in a real representation of the MSSM gauge group

The messengers' spectrum is not SUSY.
Their coupling to the MSSM gauge fields feeds SUSY breaking to the rest of the MSSM.

Properties of minimal gauge mediation

- Very simple – calculable (perturbative)
- Very predictive (too predictive?)
  - Gaugino masses arise at one loop

$$m_{\lambda_r} \sim \alpha_r \frac{F}{M}$$
$$r = 1, 2, 3$$

  - Sfermion mass squares arise at two loops (8 graphs).

$$m^2_{\tilde{f}} \sim \frac{F^2}{M^2} \sum_{r=1}^{3} \alpha_r^2 c_2^r$$

$$m_{\tilde{f}} \sim m_\lambda \sim \alpha \frac{F}{M}$$

$$m_{\tilde{f}} \sim m_\lambda \sim \alpha \frac{F}{M}$$

- Flavor universality – no FCNC
- Colored superpartners are heavier than non-colored ones
- Relations between gaugino masses and sfermion masses
- Small A-terms
- Hard to generate $\mu \sim B \sim m_\lambda$
- Gravitino LSP
- Bino or stau are NLSP
- …

Original gauge mediation models – direct mediation

[Dine, Fischler, Nappi, Ovrut, Alvarez-Gaume, Claudson, Wise…

- Start with the O'Raifeartaigh model

$$W = X(\Phi^2 - F) + MY\Phi$$

- Let Y, Φ be in a real representation of the MSSM gauge group. (Need to extend it to break its R-symmetry.)
- Similar to the previous case but:
  - The spontaneous SUSY breaking mechanism is manifest (explicit).
  - The messengers participate in SUSY breaking – more economical.

Direct mediation of dynamical supersymmetry breaking

Direct mediation of dynamical supersymmetry breaking

- Dynamical SUSY breaking is more natural [Witten].

Direct mediation of dynamical supersymmetry breaking

- Dynamical SUSY breaking is more natural [Witten].
- Combine DSB with direct mediation [Affleck, Dine, NS].

Direct mediation of dynamical supersymmetry breaking

- Dynamical SUSY breaking is more natural [Witten].
- Combine DSB with direct mediation [Affleck, Dine, NS].
- Messengers participate in SUSY breaking or might not even be well defined (strongly coupled messengers).

Direct mediation of dynamical supersymmetry breaking

- Dynamical SUSY breaking is more natural [Witten].
- Combine DSB with direct mediation [Affleck, Dine, NS].
- Messengers participate in SUSY breaking or might not even be well defined (strongly coupled messengers).
- More elegant, but:
  - Landau poles in MSSM
  - R-symmetry problem
  - Complicated models
  - Hard to compute

Direct mediation of dynamical supersymmetry breaking

- Dynamical SUSY breaking is more natural [Witten].
- Combine DSB with direct mediation [Affleck, Dine, NS].
- Messengers participate in SUSY breaking or might not even be well defined (strongly coupled messengers).
- More elegant, but:
  - Landau poles in MSSM
  - R-symmetry problem
  - Complicated models
  - Hard to compute
- These difficulties are made easier or even avoided using metastable DSB [… Intriligator, NS, Shih …].

Goals

- Understand how to couple a strongly coupled "hidden sector" to the MSSM (early work by Luty).

Goals

- Understand how to couple a strongly coupled "hidden sector" to the MSSM (early work by Luty).
- Find a formalism which simultaneously deals with all gauge mediation models.

Goals

- Understand how to couple a strongly coupled "hidden sector" to the MSSM (early work by Luty).
- Find a formalism which simultaneously deals with all gauge mediation models.
- Find general predictions of gauge mediation.

Goals

- Understand how to couple a strongly coupled "hidden sector" to the MSSM (early work by Luty).
- Find a formalism which simultaneously deals with all gauge mediation models.
- Find general predictions of gauge mediation.

Based on Meade, NS and Shih arXiv:0801.3278

Definition: gauge mediation

- In the limit $\alpha_r \to 0$ the theory decouples to two sectors.

- The hidden sector includes
  - the SUSY breaking sector
  - messengers if they exist
  - other particles outside the MSSM
- For small α_r the gauge fields of the MSSM couple to the hidden sector and communicate SUSY breaking.

The hidden sector

The hidden sector

- It is characterized by a scale M.

The hidden sector

- It is characterized by a scale M.
- It is supersymmetric at short distance but breaks SUSY at long distance, of order $1/M$.

The hidden sector

- It is characterized by a scale $M.$
- It is supersymmetric at short distance but breaks SUSY at long distance, of order $1/M.$
- It has a global symmetry $G.$

The hidden sector

- It is characterized by a scale M.
- It is supersymmetric at short distance but breaks SUSY at long distance, of order $1/M$.

- It has a global symmetry G.
- A subgroup of it $H \subseteq G$ includes (part of) the MSSM gauge symmetry

$$H \subseteq SU(3) \times SU(2) \times U(1)$$

Example: $G = H = SU(3) \times SU(2) \times U(1)$

The hidden sector

- It is characterized by a scale M.
- It is supersymmetric at short distance but breaks SUSY at long distance, of order $1/M$.

- It has a global symmetry G.
- A subgroup of it $H \subseteq G$ includes (part of) the MSSM gauge symmetry

$$H \subseteq SU(3) \times SU(2) \times U(1)$$

Example: $G = H = SU(3) \times SU(2) \times U(1)$

- When $\alpha_r \neq 0$, the two sectors are coupled via these gauge fields.

The currents

- All the hidden sector information we'll need is captured by the global symmetry currents and their correlation functions.

- Assume for simplicity that the global symmetry is $U(1)$.
- The conserved current is in real a supermultiplet $\mathcal{J}(x,\theta,\bar{\theta}$ satisfying the conservation equation

$$D^2\mathcal{J}=0.$$

- In components

$$\mathcal{J}=J+i\theta j-i\bar{\theta}\bar{j}-\theta\sigma^{\mu}\bar{\theta}j_{\mu}+...$$

The ellipses represent terms which are determined by the lower components, and

$$\partial_{\mu}j^{\mu}=0.$$

Current correlation functions

$$\mathcal{J} = J + i\theta j - i\bar{\theta}\bar{j} - \theta\sigma^{\mu}\bar{\theta}j_{\mu} + \ldots$$

Lorentz invariance and current conservation determine the nonzero two point functions:

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

Couple to the MSSM gauge fields

- Expanding to second order in g we need the exact current two point functions in the hidden sector theory.

- $C_a(p^2)$ correct the kinetic terms of the gauge multiplets:

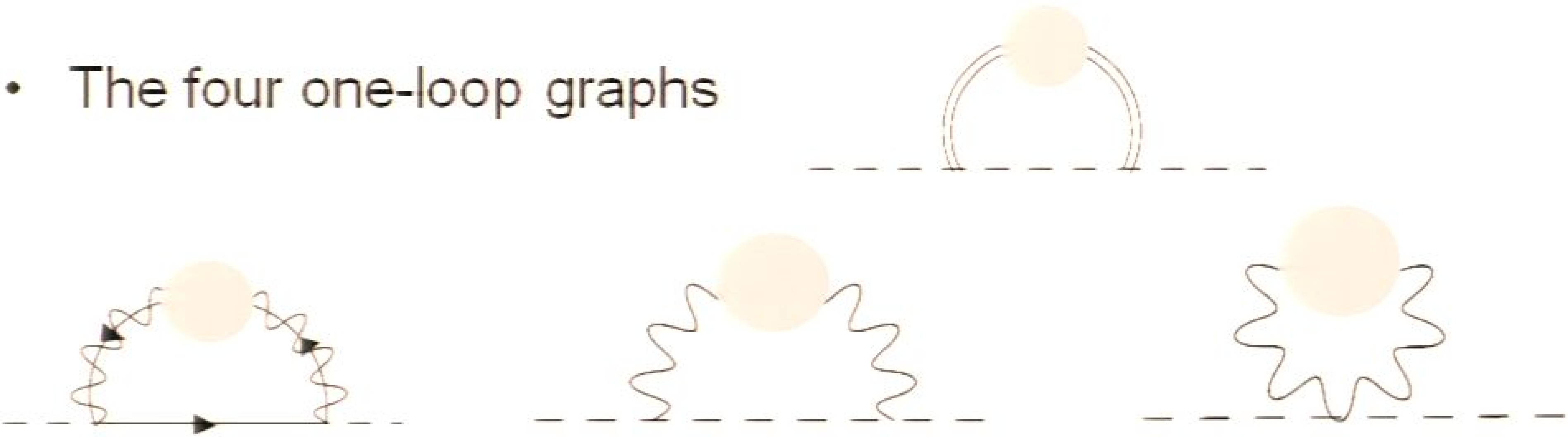
$$\frac{1}{2}g^2\left[C_0(p^2)D^2 - C_{\frac{1}{2}}(p^2)i\lambda\sigma^\mu\partial_\mu\bar{\lambda} - \frac{1}{4}C_1(p^2)F_{\mu\nu}^2\right].$$

- $B(p^2)$ generates $-\frac{1}{2}g^2 M B(p^2)\lambda\lambda.$

- It leads to gaugino masses

$$m_\lambda = g^2 M B(p=0).$$

- The four one-loop graphs



lead to sfermion masses

$$m^2_{\tilde{f}} = -\alpha^2 \int dp^2 \left[C_0(p^2) - 4C_{\frac{1}{2}}(p^2) + 3C_1(p^2) \right]$$

The typical momentum in the integral is of order $M.$ Therefore this effect cannot be computed in the low energy theory with $p \ll M.$

More generally, for the MSSM gauge group

- We have independent functions labeled by $r = 1, 2, 3$ for the three factors of

$$SU(3) \times SU(2) \times U(1).$$

- The gaugino masses

$$m_{\lambda_r} = g^2 M B^r(p = 0)$$

are in general unrelated to each other. This fact is independent of preserving unification. (Is there a CP problem?)

- The sfermion masses

$$m_{\tilde{f}}^2 = \sum_{r=1}^{3} \alpha_r^2 c_2^r(f) A_r$$

$$A_r = -\int dp^2 \left[C_0^r(p^2) - 4C_{\frac{1}{2}}^r(p^2) + 3C_1^r(p^2) \right]$$

depend on the Casimirs of the representation of f under the factor labeled by r, and on the gauge coupling α_r.

- The sfermion masses are in general unrelated to the gaugino masses.

$$m_{\tilde{f}}^2 = \sum_{r=1}^{3} \alpha_r^2 c_2^r(f) A_r$$

$$m_{\tilde{f}}^2 = \sum_{r=1}^{3} \alpha_r^2 c_2^r(f) A_r$$

- All the dependence on the hidden sector is through the three real numbers A_r.

$$m_{\tilde{f}}^2 = \sum_{r=1}^{3} \alpha_r^2 c_2^r(f) A_r$$

- All the dependence on the hidden sector is through the three real numbers A_r.
- 5 sfermion masses are expressed in terms of 3 constants. Hence there must be two linear relations between them – sum rules:

$$\mathrm{Tr}\ (B-L) m_{\tilde{f}}^2 = 0$$

$$\mathrm{Tr}\ Y m_{\tilde{f}}^2 = 0.$$

These are valid at the scale M and should be renormalized down.

Parameters

Parameters

- The general model has 3 complex parameters (gaugino masses) and 3 real parameters (determining the sfermion masses).
- There exist models with weakly coupled messengers leading to this number of parameters. Hence, generically there cannot be additional relations [Carpenter, Dine, Festuccia and Mason].
- Additional couplings and parameters are needed to explain $\mu/B\mu$.

Conclusions

Conclusions

- Formalism for dealing with dynamical direct mediation models

Conclusions

- Formalism for dealing with dynamical direct mediation models
- Generic predictions of gauge mediation
  - Sfermion degeneracy (no FCNC)
  - Two mass relations
  - Small A-terms
  - $\mu/B\mu$ are challenging
  - Gravitino LSP

Conclusions

- Formalism for dealing with dynamical direct mediation models
- Generic predictions of gauge mediation
  - Sfermion degeneracy (no FCNC)
  - Two mass relations
  - Small A-terms
  - $\mu / B\mu$ are challenging
  - Gravitino LSP
- Specific to simple models with messengers
  - Relations between gaugino masses
  - Relations between gaugino and sfermion masses
  - Large hierarchies between different sfermion masses
  - Bino or stau NLSP