Semi-Direct Gauge Mediation

Brian Wecht

Institute for Advanced Study, Princeton

based on
Nathan Seiberg, Tomer Volansky, BW (0809.4437)
Henriette Elvang, BW (0904.4431)
Outline

1 Motivation
   - Methods of Gauge Mediation

2 Semi-Direct Gauge Mediation
   - Basic Features
   - Phenomenology

3 Outlook
Outline

1. **Motivation**
   - Methods of Gauge Mediation

2. **Semi-Direct Gauge Mediation**
   - Basic Features
   - Phenomenology

3. **Outlook**
There are many known methods of breaking SUSY:

- Gauge Mediation
- Gravity Mediation
- Anomaly Mediation
- ...

No framework is completely satisfactory, and each has its distinct advantages. Because gauge mediation naturally suppresses flavor-violating effects and relies only on QFT (and not Planck-scale physics), I regard it as the most promising avenue.
The two main frameworks for gauge mediation are Direct Mediation (DM) and Minimal Gauge Mediation (MGM). Let’s review.

**Direct Mediation**
- \( SU(5) \subset \) flavor symmetry of hidden sector.
- No messenger sector.
- Simple idea; aesthetically pleasing.

But it has its problems...
- Landau poles.
- R-symmetry breaking (ISS).
Motivation

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Outlook

Methods of Gauge Mediation

Direct vs. Minimal

Minimal Gauge Mediation

- Hidden sector has a singlet $\langle X \rangle = M + \theta^2 F$.
- Messengers $L + \bar{L}$ in $5 + \bar{5}$.
- SSM feels SUSY breaking by $W = \int d^2 \theta XL\bar{L}$.

The messengers have a mass matrix

$$
\begin{pmatrix}
L & \bar{L}^\dagger
\end{pmatrix}
\begin{pmatrix}
|M|^2 + D & F \\
F^\dagger & |M|^2 - D
\end{pmatrix}
\begin{pmatrix}
L^\dagger \\
\bar{L}
\end{pmatrix}.
$$

(1)

We will refer to the terms with $LL^\dagger$ as **diagonal** masses and $L\bar{L}$ as **off-diagonal** masses.
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MGM also has problems:

- SUSY CP
- $\mu - B_\mu$
- $m_f^2 < 0$

Can we find a framework that helps with some (or all) of these?
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**Semi-Direct Gauge Mediation.**

SDGM = SSM + massive messengers $\ell$ + SUSY-breaking sector.

- $\ell$’s couple to SSM and SUSY-breaking sector **only** via gauge interactions.
- $\ell$’s play **no role** in breaking SUSY in the hidden sector.
- Mass $m$ inserted by hand but could be dynamically generated (Argurio, Bertolini, Ferretti, Mariotti ’09).
- SSM sits inside (weakly gauged) messenger flavor symmetry.

We call this framework “Semi-Direct" because it in some sense fits **in between** DM and MGM models.
There are many choices one can make here. Two that have been done so far are

- Hidden Sector = $SU(3) \times SU(2)$ DSB model of Affleck-Dine-Seiberg.
- $\ell = 2N_f$ $SU(2)$ doublets, $W_{mess} = m\ell^2$.
- SSM $\subset Sp(N_f)$
  
  (N. Seiberg, T. Volansky, BW ’08)

- Hidden Sector = $SU(4) \times U(1)$ DSB model of Dine-Nelson-Nir-Shirman; Poppitz-Trivedi.
- $\ell, \bar{\ell} = N_f$ fields charged under $U(1)$, $W_{mess} = m\ell\bar{\ell}$.
- SSM $\subset SU(N_f)$
  
  (H. Elvang, BW ’09)
The slogan for this talk is

**D-terms from F-terms**

A rather generic feature of Semi-Direct models is that the F-terms from the hidden sector generate D-terms for the hidden sector vectors.

Since the messengers couple to the hidden sector gauge group, we find messenger masses

\[
\begin{pmatrix}
\ell & \ell^\dagger
\end{pmatrix}
\begin{pmatrix}
m^2 + \text{tree} & 1 - \text{loop} \\
1 - \text{loop} & m^2 - \text{tree}
\end{pmatrix}
\begin{pmatrix}
\ell^\dagger \\
\ell
\end{pmatrix},
\]

where “tree” is induced by F-terms. In MGM models, such diagonal masses are generated by FI-terms!
We do not have enough time to go through the calculation, but there is a simple way to see the non-zero D-terms.

If the hidden sector gauge group is Higgsed, we should integrate out the massive vectors to get the appropriate low-energy theory.

\[
K = \Phi^\dagger e^{V_I T^I} \Phi \\
= \Phi^\dagger (1 + V_I T^I + \frac{1}{4} V_I V_J \{ T^I, T^J \} + ...) \Phi
\]

Solving the EOM \( \partial \mathcal{L}/\partial V^I = 0 \), we get

\[
V^I \sim \Phi^\dagger T^I \Phi
\]
\[ V^I \sim \Phi^\dagger T^I \Phi. \] (6)

We can now see that if \( \langle \Phi \rangle = v + \theta^2 F \), the vector will have a non-zero \( \theta^2 \bar{\theta}^2 \) D-component

\[ D \sim |F|^2. \] (7)

It’s worth noting that this actually doesn’t take us off the moduli space, since the bottom component of the massive vector superfield also becomes nonzero, and compensates for the nonzero D-component.
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Phenomenology

To embed the SSM, we need to pick a large enough number of flavors. In the case of the 3-2 model, we need $N_f \geq 5$ so that $SU(5) \subset Sp(N_f)$.

The phenomenology of these models has good and bad points:

- Easy to remove Landau poles, since messengers can be charged under small groups like $SU(2)$ or $U(1)$.
- Both 4-1 and 3-2 models preserve CP, so this may help with SUSY CP.
- Messenger parity.
- Gaugino masses vanish to leading order (uh oh).
- $Str_{mess}m^2 < 0$, may help positive sfermion masses.
Semi-Direct models are a new framework for gauge mediation.

Interesting that D-terms are generated via F-terms.

Still lots of models one could explore.

Unclear if there’s reasonable phenomenology or not.

Thanks!