General Gaugino Mediation

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The spectrum of a class of gaugino mediation models with arbitrary hidden sector is considered. These models are defined by a diagonal breaking of the mediating gauge group, which places them outside the realm of General Gauge Mediation. While gauginos get masses as in ordinary gauge mediation, the scalar masses are screened.

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1. Introduction

In this short note, I evaluate the soft spectrum resulting from a broad class of gauge-mediated \[1-12\] supersymmetry (SUSY) breaking models that fall under the umbrella of gaugino mediation \[13,14\]. The class of models is not described by the standard formulas of general gauge mediation \[15\] because a non-standard mediating gauge structure is assumed. As we will discuss, the structure of the theories leads to a screening of scalar masses. This is particularly appealing in the context of gauge mediation where complete models tend to yield a hierarchy between scalars and gauginos \[16-19\].

The calculation is performed for four-dimensional models of the form described in \[20,21\]. Simple and explicit dynamical realizations of such constructions were recently found \[22\]. We will consider a general SUSY-breaking hidden sector, expressing the results in terms of current correlators. The result is shown to be expressible in terms of the elementary results for mediation via a massless \[15\] or massive \[23\] vector multiplet.

Note added: The results of an explicit two-loop calculation of the spectrum in the minimal scenario were recently reported \[24\].

2. The Basic Setup

Let’s begin by considering a toy theory with gauge group \(G = U(1)_1 \times U(1)_2\) and with the following matter content.

|     | \(U(1)_1\) | \(U(1)_2\) |
|-----|------------|------------|
| \(Q\) | 1          | 0          |
| \(\tilde{Q}\) | -1         | 0          |
| \(L\) | 1          | 1          |
| \(\tilde{L}\) | -1         | -1         |
| \(\Phi\) | 0          | 1          |
| \(\tilde{\Phi}\) | 0          | -1         |

Let the superpotential be given by

\[ W = S\tilde{\Phi}\Phi, \tag{2.1} \]

and let the fields have non-zero vevs as follows.

\[ \langle S \rangle = M + \theta^2 F, \quad \langle \tilde{L} \rangle = \langle L \rangle = v. \tag{2.2} \]
It is easy to generate these vevs from a complete theory, but those details are irrelevant for the present analysis.

This model is similar to minimal gauge mediation, where the $Q$ fields would belong to the visible sector and the $\Phi$ would be messengers. In minimal gauge mediation, these two sets of fields would interact through a common gauge group leading to two-loop visible-sector scalar masses. Before the Higgsing, however, the “selectron” fields only interact with the $U(1)_1$ gauge fields, which interact with the “link” fields $L$, which interact with the $U(1)_2$ gauge fields, which finally interact with the messengers yielding scalar masses at four loops.

After Higgsing the situation is quite different. The vevs of the link fields break one linear combination of the $U(1)$’s while preserving another. Since the selectron and messenger fields are both charged under these linear combinations, we essentially recover ordinary gauge mediation. The difference is that one now has contributions via a combination of massless and massive gauge fields. Note that one linear combination of gauginos is massive at tree level, while the other receives the ordinary one-loop mass $[15,25]$, so no new computation is needed here.

3. The Mass Calculation

To evaluate the scalar masses, it is convenient to employ some of the methods of general gauge mediation $[13]$. We begin by writing part of the Lagrangian in superspace,

$$\mathcal{L} \supset 2 \int d^4 \theta (g_1 J_1 V_1 + g_2 J_2 V_2).$$  (3.1)

We continue to consider the simple gauge group, $G = U(1)_1 \times U(1)_2$ where $V_{1,2}$ are the corresponding vector superfields and $g_{1,2}$ are the gauge coupling constants. It’s only an exercise in notation to generalize to realistic gauge groups. The hidden sector, however, is now unconstrained (up to obvious assumptions needed to preserve the breaking structure). In particular, we have

$$J_1 = Q^\dagger Q - \tilde{Q}^\dagger \tilde{Q} + L^\dagger L - \tilde{L}^\dagger \tilde{L}, \quad J_2 = J_h + L^\dagger L - \tilde{L}^\dagger \tilde{L}.$$  (3.2)

Under the shift to the stable vacuum, $L, \tilde{L} \to L, \tilde{L} + v$ ($v$ chosen positive without loss of generality), the Lagrangian picks up a term,

$$\mathcal{L} \supset 4v \int d^4 \theta (g_1 V_1 + g_2 V_2) \Sigma,$$  (3.3)
Figure 1. A term contributing to the mass of a visible sector scalar. The propagator connecting this scalar to the hidden sector is $\langle D_1 D_2 \rangle$.

where $\Sigma \sim \text{Re}(L - \tilde{L})$ is the scalar component of the massive vector multiplet.

The coupling (3.3) is all we need. Consider the $D$-mediated contribution to the scalar component of $Q$ shown in Figure 1. Since $Q$ only couples to $D_1$ and $J_h$ only couples to $D_2$, the only relevant propagator is $\langle D_1(p)D_2(-p) \rangle$, which is determined by inverting a simple $3 \times 3$ matrix:

$$L \supset D^T \Delta^{-1} D,$$

$$\Delta^{-1} = \begin{pmatrix} 1 & 0 & 2g_1 v \\ 0 & 1 & 2g_2 v \\ 2g_1 v & 2g_2 v & -p^2 \end{pmatrix} \Rightarrow \langle D_1(p)D_2(-p) \rangle = \frac{4g_1 g_2 v^2}{p^2 + m_V^2}, \quad (3.4)$$

where $m_V^2 \equiv 4(g_1^2 + g_2^2)v^2$ is the squared mass of the vector multiplet. The diagram is then trivially evaluated in terms of the correlator function coefficient $\tilde{C}_0(p^2)$ \[16\], and supersymmetry dictates the other contributions\[17\]. Restoring group theory factors and defining $1/g^2 \equiv 1/g_1^2 + 1/g_2^2$, the result is

$$m_r^2 = -g^4 c_2(r) m_V^4 \int \frac{d^4p}{(2\pi)^4} \frac{1}{p^2(p^2 + m_V^2)^2} \left( \tilde{C}_0(p^2) - 4\tilde{C}_1/2(p^2) + 3\tilde{C}_1(p^2) \right). \quad (3.5)$$

For a scalar transforming in the representation $r$ of the group, $c_2(r)$ is the quadratic Casimir in that group and for that representation. The “diagonal” nature of the breaking is such that the Casimir is the same before and after breaking. For a product gauge group,

\[1\] It is also straightforward to evaluate the full effective potential as in \[23\]. In that case one needs a diagonal entry, $V(|Q|^2) = g_2^2 \text{Tr} \int \frac{d^4p}{(2\pi)^4} \langle D_2(p)D_2(-p) \rangle \left( \tilde{C}_0(p^2) - 4\tilde{C}_1/2(p^2) + 3\tilde{C}_1(p^2) \right)$, evaluated with the visible-sector field given a background value. The quartic and higher terms are generally irrelevant for collider physics, but they may be important for cosmology \[26\].

\[2\] The assumption here is that the gauge multiplet masses are independent of SUSY breaking. When the gaugino and gauge boson masses are split, we do not get a simple linear combination of the correlator coefficients \[27,28\].
one simply needs to sum over the factors with each having the above form. Note that a different \( m_V \) and and a different set of \( \tilde{C} \)’s may appear for each group. The above formula is a special case of one obtained in [23], which is the deconstructed [30,31] version of [32].

The hidden sector piece is familiar from ordinary gauge mediation, but the rest of the integrand is not. One can relate this expression to more familiar results, however. For example, one can use the following identity

\[
\frac{m_V^4}{{p^2(p^2 + m_V^2)}^2} = f(0) + f(m_V^2) - \frac{2}{m_V^2} \int_0^{m_V^2} dx \ f(x), \quad f(x) = \frac{p^2}{(p^2 + x)^2}. \tag{3.7}
\]

This is useful because \( f(m_V^2) \) is the factor in the integrand for the standard Higgsed case [23], and \( f(0) \) is that in the massless mediator case [15]. So for minimal gauge mediation (2.1), one can in principle use the known results for standard gauge mediation [33,25] and Higgsed gauge mediation [34]. The decomposition in (3.7) is not coincidental. If one computes in the mass eigenbasis for the vector multiplets, there are three contributing diagrams corresponding to the three terms above; the first has two massless mediating fields, the second has two massive ones, and the third is from a mixed diagram.

The fact that the masses computed above are smaller than those that would result from a conventional mediation is readily demonstrated by considering the difference,

\[
\frac{1}{p^2} - \frac{m_V^4}{{p^2(p^2 + m_V^2)}^2} = \frac{p^2 + 2m_V^2}{(p^2 + m_V^2)^2} > 0. \tag{3.8}
\]

For a given hidden sector, we see that the integrand (and therefore the mass) from mediation via a massless vector field [15] is always greater than that which we have computed.

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