Gauge Mediation in an Extra Dimension

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Talk at tuesday's "Werkstatt Seminar"

June 12, 2012

References

[1] P. Meade, N. Seiberg and D. Shih, "General Gauge Mediation," [arXiv:0801.3278].

[2] E. A. Mirabelli and M. E. Peskin, "Transmission of supersymmetry breaking from a 4- dimensional boundary," [arXiv:hep-th/9712214].

[3] McGarrie, Moritz, "Gauge Mediated Supersymmetry Breaking in Five Dimensions," [ArXiv:1109.6245].

[4] D. E. Kaplan, G. D. Kribs, and M. Schmaltz, "Supersymmetry breaking through transparent extra dimensions," [arXiv:hep-ph/9911293].

[5] Z. Chacko, M. A. Luty, A. E. Nelson, and E. Ponton, "Gaugino mediated supersymmetry breaking," ,[arXiv:hep-ph/9911323].

[6] R. Auzzi and A. Giveon, *Superpartner spectrum of minimal gaugino-gauge mediation*, [arXiv:1011.1664].

[7] Arkani-Hamed, Nima and Porrati, Massimo and Randall, Lisa, "Holography and phenomenology, [hep-th/0012148]

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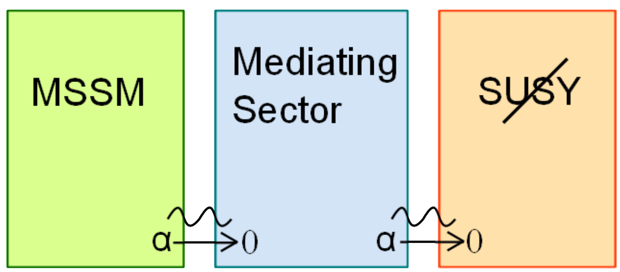
1 Motivation

- Gauge mediated supersymmetry breaking
- No FCNCs automatically
- A formalism for strong coupling
- Addresses the Hierarchy problem

Defined @ $M_{susy} \sim 10^4 - 10^{10} GeV$ low scale. $> 10^{10}$ GeV high scale.



We assume the SUSY breaking sector is SQCD-like which has as a global symmetry the standard model gauge groups. In particular, we wish to a explore strongly coupled, in α_{hidden}, SUSY breaking sector. We work perturbatively in α_{SM}. Our answers may NEED to be all orders in α_{hidden}. Additionally we may be able to apply a duality transformation of the hidden sector and obtain, for instance, an O'Raifeartaigh model which is perturbative in some dual coupling $\alpha_{hiden} \leftrightarrow \alpha_{dual}$.

Use current correlators. Integrate out a hidden sector and encode in a set of current correlators. susy breaking scale $\sqrt{F}$, hidden sector mass scale M.

$$\mathcal{L} \supset g_{SM} \int d^4\theta \mathcal{J} V = g(j^\mu A_\mu - j^\alpha \lambda_\alpha - \bar{j}_{\dot{\alpha}} \bar{\lambda}^{\dot{\alpha}} - JD) \tag{1}$$

For a weak description currents extracted from the kinetic terms

$$\int d^4\theta \mathcal{J}(1 + gV +) = \int d^4\theta (\varphi^\dagger \varphi - \tilde{\varphi}\tilde{\varphi}^\dagger)(1 + gV + (g^2)) \tag{2}$$

$$\mathcal{J}^{\mathcal{A}} = J^{\mathcal{A}} + i\theta j^{\mathcal{A}} - i\bar{\theta}\bar{j}^{\mathcal{A}} - \theta\sigma^{\mu}\bar{\theta}j_{\mu}^{\mathcal{A}} + \frac{1}{2}\theta^2\bar{\theta}\bar{\sigma}^{\mu}\partial_{\mu}j^{\mathcal{A}} - \frac{1}{2}\bar{\theta}^2\theta\sigma^{\mu}\partial_{\mu}\bar{j}^{\mathcal{A}} - \frac{1}{4}\theta^2\bar{\theta}^2\Box J^{\mathcal{A}} , \tag{3}$$

square and Wick contract to obtain an effective action at g_{SM}^2

$$\delta\mathcal{L}_{eff} = -g_5^2\tilde{C}_{1/2}(0)i\lambda\sigma^{\mu}\partial_{\mu}\bar{\lambda} - g_5^2\frac{1}{4}\tilde{C}_1(0)F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}g_5^2\tilde{C}_0(0)D^2 \tag{4}$$

$$- g_5^2\frac{1}{2}(M\tilde{B}_{1/2}(0)\lambda\lambda + M\tilde{B}_{1/2}(0)\bar{\lambda}\bar{\lambda})$$

These are Fourier Transforms of Wick contracted current correlators. In 5D we will need 5d $\mathcal{N} = 1SYM$, where $D = D_5\Sigma$.

Gaugino masses immediate.

$$m_{1/2} = g^2 MB_{1/2}(0) \tag{5}$$

Scalar masses a little more work.

$$m_{\phi}^2 \sim g^4 \int \frac{d^4p}{(2\pi)^4}\frac{1}{p^2}[\tilde{C}_0(p^2/M^2) + 3\tilde{C}_1(p^2/M^2) - 4\tilde{C}_{1/2}(p^2/M^2)] \tag{6}$$

4D In general scalar and sfermion masses depend on *different* correlators.

For a minimal model where the susy breaking sector is a spurion coupled to messengers a typical O'Raifeartaigh model. The superpotential is given by

$$W = X\varphi\tilde{\varphi} \tag{7}$$

with $X = M + \theta^2 F$.

$$m_{\lambda} = \frac{\alpha}{4\pi}\frac{F}{M} \qquad m_{\phi}^2 = (\frac{\alpha}{4\pi})^2|\frac{F}{M}|^2 \ \text{ RATIO is } \ m_{\lambda}^2/m_{\phi}^2 \sim 1 \tag{8}$$

off-shell: 1+3 bosonics dof, 4 fermion dof.

As an aside, one can in fact write the Gravitino mass as a current correlator

$$m_{3/2}\Psi_{\mu}^{\alpha}(\sigma^{\mu\mu})_{\alpha\beta}\Psi_{\nu}^{\beta} = \frac{1}{M_{Pl}^2}\Psi_{\mu}^{\alpha}\left\langle S_{\alpha}^{\mu}S_{\beta}^{\nu}\right\rangle_{F.T.}\Psi_{\nu}^{\beta}. \tag{9}$$

2 In 5D

Let us now imagine a similar 5d scenario. We are essentially adding a new scale 1/length. Technically we may start from $\mathcal{N}=1$ SYM in 5d with $R^{1,4}$ times an Orbifold of length ℓ. The fixed points are "branes". The Mirabelli & Peskin Model [2]. The presence of the fixed points breaks the 8 supercharges to just 4. We may also assign parity under $i\gamma_4$, whereby an $\mathcal{N}=1$ vector multiplet is even and couples to the branes and a chiral superfield that is odd and does not.

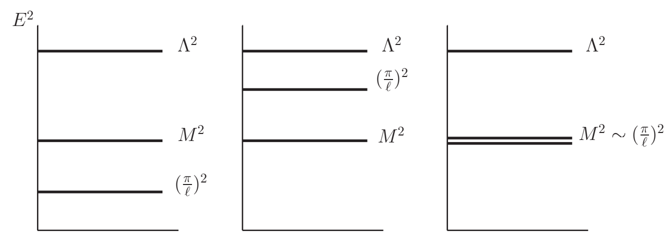


Figure 1: Relative mass scales for Gaugino Mediated, Gauge Mediated, Hybrid Mediation

The bulk matter content is a vector superfield

$$V = -\theta\sigma^\mu\bar{\theta}A_\mu - i\bar{\theta}^2\theta\lambda - i\theta^2\bar{\theta}\bar{\lambda} + \frac{1}{2}\theta^2\bar{\theta}^2(X^3 - D_5\Sigma) \tag{10}$$

and an Adjoint Chiral superfield, which does not couple to the boundaries

$$\Phi = \frac{1}{\sqrt{2}}(\Sigma + iA_5) + \sqrt{2}\theta\xi + \theta^2 F. \tag{11}$$

There is no $n=0$ state for this multiplet.

The main component we actually need is the propagator

$$\langle\phi(x,x_5)\phi(y,y_5)\rangle = \frac{1}{2\ell}\sum_n \int \frac{d^4p}{(2\pi)^4}\frac{i}{p^2+p_5^2}e^{-ix.p}(e^{ip_5(x_5-y_5)} + Pe^{ip_5(x_5+y_5)}) \tag{12}$$

The first diagram is

$$m_\phi^2 = g^4 \sum_{n,n'} \int \frac{d^4p}{(2\pi)^4}\frac{(-1)^{n+n'}}{p^2-p_5^2}\frac{p^2}{p^2-p_5^2}[\tilde{C}_0(\frac{p^2}{M^2}) + 3\tilde{C}_1(\frac{p^2}{M^2}) - 4\tilde{C}_{1/2}(\frac{p^2}{M^2})] \tag{13}$$

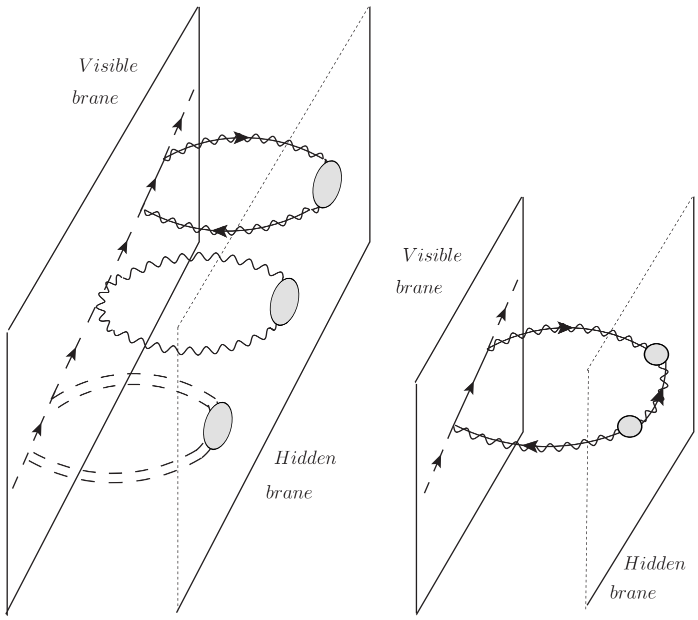


Figure 2: The leading (α^2) and subleading (α^3) scalar soft mass diagrams.

The subleading diagram is

$$m_\phi^2 = g^6 \sum_{n,n',''} \int \frac{d^4p}{(2\pi)^4} \frac{(-1)^{n+n'}}{p^2 - p_5^2} \frac{p^2}{p^2 - p_5'^2} \frac{|MB_{1/2}(\frac{p^2}{M^2})|^2}{p^2 - p_5''^2} \tag{14}$$

In the limit the extra dimension is small with respect to M we just get the 4d answers. When ℓ is big we get

$$m_\phi^2 = (\frac{\alpha}{4\pi})^2 |\frac{F}{M}|^2 (\frac{1}{M\ell})^2 + (\frac{\alpha}{4\pi})^3 |\frac{F}{M}|^2 \tag{15}$$

This large ℓ limit in which only the subleading diagrams contribute may be dubbed Gaugino Mediated [4, 5]. In this limit there is only one correlator that sets all the soft masses.

3 Deconstruction

Even completely 4d models show similar features. Many features are analogous to low energy QCD. In fact this model has been shown to arise in the

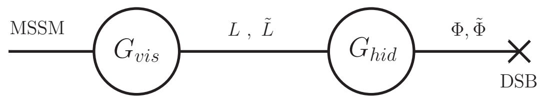


Figure 3: A two site quiver model of Gauge Mediation

magnetic description (using Seiberg Duality) of SQCD and is metastable. The relevant part of the model is shown only. This type of model is more similar to a circle, S^1, than an interval.

In the interaction basis The Linking fields are bifundamentals with superpotential

$$W = K(L\tilde{L} - v^2) \to \frac{\partial W}{\partial K} = L\tilde{L} - v^2 = 0 \tag{16}$$

The kinetic terms give

$$D_\mu L D^\mu L = (\partial_\mu - ig_1 A^1_\mu + ig_2 A^2_\nu)(v + \delta L)(\partial^\mu - ig_1 A^{1\mu} + ig_2 A^{2\nu})(v + \delta L) \tag{17}$$

Generating a mass matrix which once diagonalised give in the mass basis

$$\tilde{A}_{\mu k} = \frac{1}{\sqrt{N}} \sum_{j=1}^{N} e^{i(\frac{2\pi jk}{N})} A_{\mu j} \quad \text{with masses} \quad m_k^2 = 8g^2 v^2 \sin^2(\frac{k\pi}{N}). \tag{18}$$

For the two site model this is easy to see

3.1 The mass spectrum

We may define the gauge boson states

$$\tilde{A}^1_\mu = \frac{g_1 A^1_\mu + g_2 A^2_\mu}{\sqrt{g_1^2 + g_2^2}} \quad , \quad \tilde{A}^2_\mu = \frac{g_1 A^1_\mu - g_2 A^2_\mu}{\sqrt{g_1^2 + g_2^2}}, \tag{19}$$

with masses

$$m_0 = 0 \quad \text{and} \quad m_1 = m_v. \tag{20}$$

The gaugino fields

$$\tilde{\lambda}^1 = i\frac{g_1 \lambda^1 + g_2 \lambda^2}{\sqrt{g_1^2 + g_2^2}} \quad , \quad \tilde{\lambda}^2 = i\frac{g_1 \lambda^1 - g_2 \lambda^2}{\sqrt{g_1^2 + g_2^2}} \quad , \quad \eta = \frac{\psi_L - \psi_{\tilde{L}}}{\sqrt{2}}. \tag{21}$$

$\tilde{\lambda}^1$ is massless at tree level. The second two states combine into a Dirac fermion mith mass m_v.

Computing the scalar mass spectrum we find

$$2v^2|\delta K|^2 + v^2|\delta L + \delta\tilde{L}|^2 + \frac{m_v^2}{8}(\delta L + \delta L^* - \delta\tilde{L} - \delta\tilde{L}^*)^2 \tag{22}$$

where $m_v = 2v\sqrt{g_1^2 + g_2^2}$. The real part $\mathrm{Re}[\frac{1}{\sqrt{2}}(\delta L - \delta\tilde{L})]$ gets a mass m_v, the $\mathrm{Im}[\frac{1}{\sqrt{2}}(\delta L - \delta\tilde{L})]$ of the scalar is eaten by the Higgs mechanism. These correspond to the $(\Sigma^1 + iA_5^1)$ the n=1 modes of the supergauge connection Φ. The component $\mathrm{Re}[\frac{1}{\sqrt{2}}(\delta L + \delta\tilde{L})]$ and $\mathrm{Im}[\frac{1}{\sqrt{2}}(\delta L + \delta\tilde{L})]$ both get masses $m_\Theta^2 = 2v^2$ and corresponds to $(\Sigma^0 + iA_5^0)$. $\mathrm{Re}[K]$ and $\mathrm{Im}[K]$ are additional degrees of freedom that are unrelated to the Wilson line, however they get mass squareds $m_\Theta^2 = 2v^2$. The fermionic sector is interesting as

$$v(\psi_K\psi_L + \psi_K\psi_{\tilde{L}}) \tag{23}$$

lead to masses $m_\Theta = \sqrt{2}v$ which is of Dirac type, mixing ψ_k with $\tilde{\eta} = \frac{1}{\sqrt{2}}(\psi_L + \psi_{\tilde{L}})$.

The propagator for an N-site quiver is then found to be

$$\langle p^2; k, q\rangle = \frac{1}{N}\sum_j e^{-i(\frac{2\pi jk}{N})}e^{i(\frac{2\pi jq}{N})}\frac{i}{p^2 + m_j^2} \tag{24}$$

For the two site model we obtain

$$m_\phi^2 = g^4\int\frac{d^4p}{(2\pi)^4}\frac{1}{p^2}[\frac{m_v^2}{p^2 + m_v^2}]^2[\tilde{C}_0(\frac{p^2}{M^2}) + 3\tilde{C}_1(\frac{p^2}{M^2}) - 4\tilde{C}_{1/2}(\frac{p^2}{M^2})] \tag{25}$$

These two loop diagrams may be evaluated analytically exactly. The answer is complicated but essentially

$$m_\phi^2 \sim (\frac{\alpha}{4\pi})^2|\frac{F}{M}|^2(\frac{m_v}{M})^\rho \quad \text{with} \quad \rho \in [0, 2] \tag{26}$$

Where the gaugino mass stays the same but now both gaugino kk modes get a soft mass.

Here is an example of a typical spectrum for such a simple model

4 Warped Models

Use the AdS/CFT correspondence to have a weak description of the SUSY breaking sector. An approximate $SU(N_c)_{CFT}$ with global symmetry $SU(5)_{SM}$. Make both branes dynamical: a natural interpretation in terms of the Holographic correspondence. The IR brane acts as a regulator [7]. It breaks conformal invariance in the IR and gives a discrete spectra with an S-matrix.

We will use the metric

$$ds^2 = e^{-ky}\eta^{\mu\nu}dx_\mu dx_\mu + dy^2 \tag{27}$$

Now we have the AdS warp factor $1/k$ and as well as ℓ. There is a technique called "theta-warping" to keep track of the warp factors $\theta \to e^{-\frac{1}{2}\sigma}\theta$.

For a Bulk field

$$\langle\phi(x, x_5)\phi(y, y_5)\rangle = \frac{1}{2\ell}\sum_n \int \frac{d^4p}{(2\pi)^4}\frac{ie^{-ip.x}}{p^2 + m_n^2}(f(x_5)f(y_5)) \tag{28}$$

Where

$$V = \frac{1}{\sqrt{2}}\sum_n V_n(x)f_n(y) \tag{29}$$

The functions $f_n(y)$ are related to modified Bessel functions. The mass poles are

$$m_n \simeq (n - 1/4)\pi k e^{-k\ell}. \tag{30}$$

It turns out that in the $k > M$ limit we obtain simply

$$m_\lambda = \frac{\alpha}{4\pi}\frac{F}{M}e^{-k\ell} \quad m_\phi^2 = (\frac{\alpha}{4\pi})^2|\frac{F}{M}|^2 e^{-2k\ell} \text{ RATIO is } m_\lambda^2/m_\phi^2 \sim 1 \tag{31}$$

In other words the spectrum will look four dimensional. Clearly the Hierarchy problem is solved by the taking $k\ell \gg 1$. Additionally, in the $k < M$ limit

$$m_\lambda = \frac{\alpha}{4\pi}\frac{F}{M}e^{-k\ell} \quad m_\phi^2 = (\frac{\alpha}{4\pi})^2|\frac{F}{M}|^2(\frac{k^2\ell}{M})^2 e^{-3k\ell} \text{ RATIO is } m_\lambda^2/m_\phi^2 \sim e^{k\ell} \tag{32}$$

$N_{\text{mess}} = 1$	$M = 2.4 \times 10^5$	$M = 10^8$	$M = 10^{15}$
$\tan\beta = 20$	$\Lambda = 0.99M$	$\Lambda = 2.1 \times 10^5$	$\Lambda = 1.5 \times 10^5$
$\alpha_{g_2}^{-1} = 10$	$v = 9.6 \times 10^4$	$v = 3.9 \times 10^7$	$v = 3.7 \times 10^{14}$
(y_1, y_2, y_3)	$(1, 1.10, 1.66)$	$(1, 1.10, 1.39)$	$(1, 1.03, 1.05)$
$(s(1), s(2), s(3))$	$(0.02, 0.03, 0.09)$	$(0.10, 0.12, 0.16)$	$(0.10, 0.11, 0.11)$
(M_1, M_2, M_3)	$(497, 862, 1808)$	$(372, 589, 999)$	$(430, 472, 497)$
(m_Q, m_u, m_d)	$(665, 652, 651)$	$(707, 668, 663)$	$(332, 289, 275)$
(m_L, m_e)	$(140, 59)$	$(257, 131)$	$(205, 152)$
$(\mu, B\mu)$	$(534, 736^2)$	$(661, 598^2)$	$(610, -176^2)$
$m_{\tilde g}$	2131	1475	1089
$m_{\tilde\chi_0}$	$(425, 526, 528, 845)$	$(281, 520, 637, 666)$	$(198, 375, 606, 618)$
$m_{\tilde\chi_\pm}$	$(516, 845)$	$(520, 665)$	$(375, 618)$
$(m_{\tilde u_L}, m_{\tilde d_L})$	$(1405, 1407)$	$(1298, 1300)$	$(1027, 1030)$
$(m_{\tilde u_R}, m_{\tilde d_R})$	$(1380, 1380)$	$(1258, 1256)$	$(981, 975)$
$(m_{\tilde t_1}, m_{\tilde t_2})$	$(1280, 1383)$	$(1102, 1251)$	$(781, 978)$
$(m_{\tilde b_1}, m_{\tilde b_2})$	$(1354, 1377)$	$(1218, 1249)$	$(929, 965)$
$(m_{\tilde e_R}, m_{\tilde e_L}, m_{\tilde\nu_e})$	$(129, 302, 292)$	$(174, 363, 354)$	$(223, 368, 359)$
$(m_{\tilde\tau_1}, m_{\tilde\tau_2}, m_{\tilde\nu_\tau})$	$(106, 309, 291)$	$(150, 368, 352)$	$(197, 371, 355)$
m_{h_0}	116	116	116
$(m_{H_0}, m_{A_0}, m_{H_\pm})$	$(566, 566, 572)$	$(689, 689, 694)$	$(660, 660, 666)$
$(\mu, B\mu)$	$(519, 641^2)$	$(631, 735^2)$	$(600, 687^2)$

TABLE II: Sparticle masses in some numerical examples with $\mu > 0$ and $\tan\beta = 20$.

Figure 4: Table taken from [6] Λ is F/M