Low-Scale GMSB from Radiative *R* Symmetry Breaking

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JLE, Sudano, Yanagida Phys.Lett.B696:348-351,2011.
JLE, Ibe, Sudano, Yanagida arXiv:1103.4549

Outline

1. Minimal Gauge Mediation
   - Minimal Gauge Mediation
   - Gravitino of GMSB
2. An Effective Solution
   - Generating a Spurion
3. A UV Complete Model
   - Generating Cascade Mediation at One Loop

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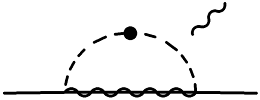
The SUSY Flavor Problem

- Softly broken MSSM has many parameters(105 Martin)

$$m^2_{\tilde{f}}, M_i, A_{ij}, B_{ij}$$

- Generic Soft Masses and A terms give FV



- Phenomenology requires

$$m^2_{\tilde{f}_{ij}} \simeq M_{f_i} \delta_{ij} \ \text{etc.}$$

- Need a well motivated model with no FV

Minimal Gauge Mediated SUSY Breaking

- Messenger sector: a SM singlet, a 5, and a $\bar{5}$

$$W_m = \lambda S \bar{\psi} \psi$$

- Effective theory of SUSY breaking

$$S = M_S + \theta^2 F_S$$

- SUSY breaking communicated to the visible sector via gauge interactions.
  - Mass Matrices diagonal: no flavor problems
  - Scalar Masses arise at two loops and gaugino masses at one loop

$$M_{\tilde{f}}^2 \sim \left(\frac{\alpha}{4\pi}\right)^2 \left(\frac{F}{M}\right)^2 \qquad M_{\tilde{\chi}} \sim \frac{\alpha}{4\pi} \left(\frac{F}{M}\right)$$

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The Gravitino of Gauge Mediation

- Gravitino of low scale gauge mediation very light

$$m_{3/2} \simeq \frac{\Lambda^2}{\sqrt{3}M_P}$$

- Cosmology severely constrain the mass range of $m_{3/2}$

$$m_{3/2} \lesssim 16\mathrm{ev} \quad m_{3/2} \sim 100\mathrm{GeV} \quad m_{3/2} > 100\mathrm{TeV}$$

  - $16\mathrm{eV} - 100\mathrm{GeV}$ need very low reheat temperature
  - $100\mathrm{GeV} - 100\mathrm{TeV}$ can decay and interferes with BBN

- Low scale gauge mediation

$$\Lambda \lesssim 260\mathrm{TeV}$$

Almost Low-Scale Gauge Mediation

- Tree level SUSY breaking

$$W = \mu^2 S + (m_{ij} + \lambda_{ij} S)\bar{\psi}_i \psi_j$$

  - Leading order **gaugino mass suppressed**

$$m_{gau} = \frac{\alpha}{4\pi} \frac{F_S}{M} \left| \frac{F_S}{M} \right|^2$$

  - **Destabilizing vacuum** $\rightarrow$ larger gaugino mass
  - Difficult to meet Tevatron constraints on m_{χ^0}, m_{χ^+}
- Direct Gauge mediation
  - Large flavor symmetries are needed
  - DSB scale pushed up to avoid **Landau pole**
- Semi Direct gauge mediation
  - Gauginos leading order contribution again vanishes

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Cascade Mediation GMSB

- SUSY breaking communicated via Kahler potential

$$K = |Z|^2 + |S|^2 + \frac{c}{\Lambda^2}|Z|^2|S|^2 + \cdots ,$$
$$W = \mu^2 Z + \lambda S\bar{\psi}\psi + \frac{h}{3}S^3 ,$$

- SUSY is clearly broken $F_Z = \mu^2$
- These types of models can natural suppress CP violation
  - Including $m_{3/2}$ in Superpotential$\rightarrow$ phase suppressions
- Communicating SUSY breaking to the messenger sector

$$m_S^2 = -c\frac{|F_Z|^2}{\Lambda^2}$$

- SUSY breaking communicated to visible sector via m_S^2.

Cascade Mediation: Continued

- Cascade mediation models
  - Strong dynamics (Ibe, Shirman, Yanagida)
  - Three Loop model (Nomura, Tobe, Yanagida)
  - New One Loop model (Evans, Ibe, Sudano, Yanagida)
- Global minimum from $-|m_S|^2$

$$V_{eff} = -|m_S|^2|S|^2 + |h|^2|S|^4 \quad \Rightarrow \quad |S|^2 = \frac{|m_S|^2}{2|h|^2}$$

- Global minimum provides precisely the spurion of mGMSB

$$\langle S \rangle = e^{i\delta_S}\frac{|m_S|}{\sqrt{2}h} \qquad F_S = -h\langle S^* \rangle^2 = -h|\langle S^* \rangle|^2 e^{-2i\delta_S}$$

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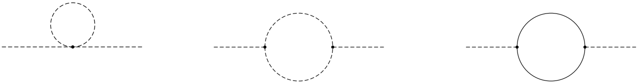
How to Generate a Tachyonic Mass at One Loop

- Three types of one loop mass diagrams (renormalizable)



(1) (2) (3)

  - Two contribute negatively(2,3) and and one positively(1)
  - In the SUSY limit the sum mass vanish
  - SUSY breaking only splits scalar masses(2,3)
  - Diagram (2) further suppressed by additional propagator
- Tachyonic mass requires (2)> (3)
  - (1) has no mass split fields
  - (2) has an IR singularity

Global SUSY Breaking Minimum

- O'Raifeartaigh model with global SUSY breaking

$$W = Z(\mu^2 + g_{ij}B_iB_j) + M_{ij}B_iC_j$$

  - One flat direction in Z and $B_i = C_j = 0$.

- Problem of Additional trilinear terms

$$W = Z(\mu^2 + g_{ij}B_iB_j) + M_{ij}B_iC_j + \lambda SC_jB_k$$

  - Trilinear mixes $F = 0$ conditions
  - Z and S can indirectly be used to get $F_S, F_Z = 0$

- Trilinear with SUSY breaking

$$W = Z(\mu^2 + g_{ij}B_iB_j) + M_{ij}B_iC_j + M'_{ij}B_iD_j + \lambda SD_jE_k$$

Generating $m_S^2 < 0$ in Cascade Mediation

- Simplest model with SUSY breaking vacuum and $m_S^2 < 0$

$$W = Z(\mu^2 + gB^2) + mB(C + D) + \lambda SDE$$

  - S interact with B only through $\lambda SEm^* B^* \to m_S^2 < 0$
  - C enforces SUSY breaking
- Symmetric under $S \Longleftrightarrow E$
  - Additional fields are needed to stabilize E
- Stabilize E and $\sqrt{F_S}, S \neq 0$

$$W = Z(\mu^2 + gB^2) + mB(C + D) + \lambda SDE + m'(EF + GD)$$

  - Generic under $U(1)_R \times U(1)_m \times Z_2$.

D-term One loop $m_S^2 < 0$

- Simplest model for D term breaking

$$W = mq\bar{q} + \lambda S q\bar{q}$$
$$D = -k - \frac{e}{2}(|q|^2 - |\bar{q}|^2)$$

- D term cascade mediation relies on IR singularity
- Trilinear terms provide a singular propagator

$$\mathcal{L}_{tri} = \lambda S\bar{q}m^*\bar{q}^* \rightarrow \frac{1}{(p^2 - m^2 + ek)^2}$$

- Similar results with R symmetry

$$W = m(q\bar{q}_1 + q_1\bar{q}) + \lambda S q\bar{q}$$
$$D = -k - \frac{e}{2}(|q|^2 - |\bar{q}|^2)$$

Acceptably Light Gravitino

- Constraints on B mass

$$g\mu^2 \lesssim 0.5m^2$$

- $|m_S|$ bounded from above for given μ

$$|m_S| \simeq \left(\frac{g^2\lambda^2}{16\pi^2}\frac{\mu^4}{m^2}|g(x,y)|\right)^{1/2} \lesssim \frac{g^{1/2}\lambda}{8\pi}\mu\ ,$$

- Gluino mass bound

$$m_{\rm gluino} \lesssim 50\,{\rm GeV} \times N_{\rm mess} g^{1/2}\lambda\left(\frac{\mu}{260\,{\rm TeV}}\right)\ ,$$

- Perturbativity to the GUT scale requires $g^{1/2}\lambda \lesssim 1$
- ATLAS constrains $m_{gluino} \gtrsim 700$ GeV

UV Completion

- IYIT model of DSB ($SU(2)$ gauge symetry) $i = 1..4$

$$\begin{aligned} W &= g_{ij}^{kl} Z_{ij} Q_k Q_l \;, \; (i < j) \;, \\ &= g_0 Z_0 (QQ)_0 + g' Z_a (QQ)_a \;, (a = 1 \cdots 5) \;, \end{aligned}$$

  - Largest possible global symmetry $SU(4) \simeq SO(6)$
  - Assume $SO(5)$ global symmetry
  - $a = 1..5$ correspond to fundamentals under $SO(5)$
- Quantum modified constraints ($M_A \sim (Q_A Q_A)$)

$$\mathrm{Pf}(Q_i Q_j) = \Lambda_{\rm dyn}^2 \rightarrow M_A M_A = \Lambda_{\rm dyn}^2$$

- Enforcing the quantum modified constraint

$$W_{\rm eff} \simeq g_0 \Lambda_{\rm dyn}^2 Z_0 - \frac{g_0}{2} Z_0 M_a M_a + g' \Lambda_{\rm dyn} Z_a M_a + O(M_a^4) \;.$$

UV Completion and Gravitino

- Transcribe the model

$$\begin{array}{rcl} Z_0 & \to & Z\,, \quad M_a \to B_a\,, \quad Z_a \to D_a\,, \\ g_0\Lambda_{\rm dyn}^2 & \to & \mu^2 \quad g'\Lambda_{\rm dyn} \to m\,, \quad g_0 \to 2g\,. \end{array}$$

- Add additional fundamental fields of $SO(5)$

$$\begin{aligned} W_{\rm eff} &\simeq Z\left(\mu^2 - gB_a^2\right) + mB_a(D_a + C_a) + \tilde{m}F_a(E_a + G_a) \\ &\quad + \lambda S D_a E_a + \frac{h}{3}S^3 + kS\bar{\psi}\psi\,, \end{aligned}$$

- With UV complete model

$$\begin{aligned} W_{\rm tree} &\simeq g_0 Z_0 (QQ)_0 + g' D_a (QQ)_a + g' C_a (QQ)_a + \tilde{m}F_a(E_a + G_a) \\ &\quad + \lambda S D_a E_a + \frac{h}{3}S^3 + kS\bar{\psi}\psi\,, \end{aligned}$$

- The gluino mass constraint in these models

$$m_{\rm gluino} \lesssim 2\,{\rm TeV} \times \lambda \left(\frac{N_{\rm mess}}{5}\right)\left(\frac{g}{4\pi}\right)^{1/2}\left(\frac{\mu}{260\,{\rm TeV}}\right)\,.$$

R-axion

- R axion mass arise from one loop Kahler potential

$$K \simeq -\frac{1}{16\pi^2}\left(5N_{\rm mess}k^2|S|^2 \ln\frac{k^2|S|^2}{\mu_R^2}\right) \; ,$$

$$V_{\text{R-breaking}} \simeq -\frac{1}{16\pi^2}\left(5k^2 N_{\rm mess}\right) m_{3/2} F_S^* S + h.c.$$

- One loop R axion mass

$$m_R \lesssim 40\,{\rm MeV} \times k^{1/2}\left(\frac{N_{\rm mess}}{5}\right)^{1/2}\left(\frac{g}{4\pi}\right)^{1/4}\left(\frac{m_{3/2}}{16\,{\rm eV}}\right)^{3/4} \; ,$$

Conclusions

- A viable model of low-scale gauge mediation is difficult to realize
- Cascade gauge mediation provides a frame work for addressing all of gauge mediations difficulties
- One loop spontaneous R symmetry breaking works well in conjunction with gauge mediation
- By UV completing, spontaneous R symmetry breaking provides a viable model of low scale gauge mediation

μ/B_μ in Cascade Mediation

- Gaugino masses and μ/B_μ generated by Kahler Potential

$$K = |Z|^2 + |S|^2 + |S'|^2 + \frac{c}{\Lambda^2}|Z|^2|S|^2 + \frac{c'}{\Lambda^2}|Z|^2|S'|^2 + \cdots ,$$
$$W_0 = \mu^2 Z + \lambda S\psi\bar{\psi} + \lambda' S' H\bar{H} + \frac{h}{3}S^3 + \frac{h'}{3}S'^3 + m_{3/2}M_P^2$$

- Charge S, S' under separate Z_3's prevents direct mixing
- Potential separates into two separate sectors

$$V = -m_S^2|S|^2 + |h|^2|S|^4 - m_{S'}^2|S'|^2 + |h'|^2|S'|^4 + \mathcal{O}(\frac{|S|^2}{\Lambda^2}, \frac{|S'|^2}{\Lambda^2})$$

- If $|m_S|^2 \gg |m_{S'}|^2$ μ/B_μ problem sloved

$$\sqrt{F_S} \sim \langle S\rangle \sim |m_S| \sim 100\mathrm{TeV} \qquad \sqrt{F_{S'}} \sim \langle S'\rangle \sim |m_{S'}| \sim 1\mathrm{TeV}$$

μ/B_μ in Cascade Mediation: Continued

- Another CP phase from the additional spurion
- Vanishing CC again suppresses CP violation

$$V = e^{K/M_P^2}\left(g^{\bar{S}'S'}\left|W_{S'} + \frac{K_{S'}W}{M_P^2}\right|^2 - 3\frac{|W|^2}{M_P^2}\right) + V_{soft}.$$

$$K = |S'|^2 - \frac{s'}{\Lambda^2}|S'|^4 + \ldots, \qquad g_{i\bar{j}} = \partial_i\partial_{\bar{j}}K, \qquad W = W_0 + m_{3/2}M_P^2$$

- Important Plank suppressed contributions to potential

$$V \supset -m_{S'}^2|S'|^2 + |\lambda'|^2|S'|^4 + 4\lambda m_{3/2}\frac{s'}{\Lambda^2}|S'|^5\cos 3\delta_{S'}.$$

- This minimization gives a vanishing phase for the B_μ

$$Arg(B_\mu) = Arg(F_{S'}M_{S'}^*) = -3\delta_{S'} = 0 \quad Mod(2\pi)$$