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A light neutralino in hybrid models of Supersymmetry Breaking

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Outline

• Gravity and gauge mediation: advantages/problems

- Hybrid models

• Models with GUT induced doublet-triplet messenger splitting

• SUSY breaking sector

• Low-energy phenomenology

• Prospects

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1. Gravity and gauge mediation : advantages/problems

- Gravity mediation

SUSY broken in a "hidden" sector which communicates with our sector via (super)gravitational interactions

MSSM $\leftrightarrow$ Hidden Sector

nonren.int. $T_i, \langle F_i \rangle \neq 0$

Define $F^2 = \sum_i |F_i|^2$, then

$$M_{SUGRA} \sim m_{3/2} \quad , \quad m_{3/2} = \frac{F}{\sqrt{3} M_P}$$

Ex : $(G = K + \ln |W|^2,\ F^\alpha = m_{3/2} G^\alpha)$

$$m^2_{i\bar{j}} = m^2_{3/2} \, (G_{i\bar{j}} - R_{i\bar{j}\alpha\bar{\beta}} G^\alpha G^{\bar{\beta}} \,)$$

Advantages:

• Natural solution for the μ-problem via Giudice-Masiero mechanism

$$\mu \ \sim \ m_{3/2} \quad , \quad B\mu \ \sim \ m_{3/2}^2$$

where

$$L_{MSSM} = (\int d^2\theta \ \mu H_1 H_2) + B\mu h_1 h_2 + c.c. + \cdots$$

• Easy to construct explicit models, natural in string theory (moduli fields)

Problems

• FCNC effects are generically problematic in SUGRA theories (GIM not enough)

Solutions for FCNC problem :

i) flavor universality : $(m_0^2)_{ij} = (m_0^2)\delta_{ij}$

ii) alignement : $(m_0^2)_{ij}$ are aligned to Yuk. Y_{ij}

(diagonalized in the same basis)

If not squark, slepton masses $>$ 50 TeV or so !

• Universality/alignment are not generic in gravity mediation.

- **Gauge mediation**

Transmission of SUSY breaking through SM gauge loops

= gauge mediation

SUSY breaking sector	$\leftrightarrow$	Messenger sector	$\leftrightarrow$	MSSM
$X = \langle X \rangle + \theta^2 F_X$	$\rightarrow$	$X \Phi \tilde{\Phi}$	$\rightarrow$	soft terms

Messengers are typically :

- vector-like, charged under SM gauge group.
- If $SU(5)$ complete multiplets (say N pairs $5 + \bar{5}$), they preserve MSSM gauge coupling unification.

• MSSM soft terms, minimal gauge mediation:

- gaugino masses $\rightarrow$ 1-loop

$$M_{1/2} \sim N_m \frac{g^2}{16\pi^2} \left(\frac{F_X}{\langle X \rangle}\right) \sim N_m M_{GMSB}$$

- scalar (squarks,sleptons) masses : two-loops

$$m_0^2 \sim N_m \left(\frac{g^2}{16\pi^2}\right)^2 \left(\frac{F_X}{\langle X \rangle}\right)^2 \sim N_m M_{GMSB}^2$$

Typically $M_{GMSB} \gg m_{3/2}$, gravitino very light (LSP)

Minimal gauge mediation has

- $StrM^2 = 0$ in the messenger sector.

- $SU(5)$ symmetric messenger masses.

Advantages :

- Gauge mediation solves the flavor problem
- In its minimum version, highly predictive spectrum.

Problems :

- Very difficult to generate μ, $B\mu$ of correct size.
- Complicated explicit models (vacuum metastability) .

- Hybrid models

Couplings of messengers to SUSY breaking sector:

$$W_m = \Phi(\lambda_X X \ + \mathcal{M})\tilde{\Phi}$$

Gauge / SUGRA contributions to MSSM soft terms

$$\frac{M_{GMSB}}{m_{3/2}} \ \sim \ N_m \frac{g^2}{16\pi^2} \lambda_X \frac{M_P}{\mathcal{M}}$$

In recent works messengers are taken to be very heavy

$$\mathcal{M} \ \sim \ 10^{13} - 10^{16} \ GeV$$

Then $m_{3/2} \sim M_{GMSB}$ is possible.

$\rightarrow$ SUGRA and GMSB contributions are comparable.

$$m_0^2 \sim m_{3/2}^2 + N_m M_{GMSB}^2 \ ,$$
$$M_{1/2} \sim m_{3/2} + N_m M_{GMSB}$$

Most models are metastable (lower vacuum with messenger vev's); lifetime of our vacuum

$$\tau \ \sim \ e^{\frac{1}{\lambda_X^2}}$$

- Stability prefers gravity mediation.
- Hybrid models combine advantages of both transmissions if

$$M_{GMSB} \ \sim TeV \sim \ 30 - 100 \ m_{3/2} \qquad (1)$$

2. Hybrid models with GUT induced doublet-triplet messenger splitting

Messengers are naturally very heavy if they couple to $SU(5)$ GUT adjoint. Denote $(\phi_i, \tilde{\phi}_i)$ the component messenger fields belonging to definite SM gauge representations and by Y_i their hypercharge, one has

$$\mathrm{Tr}\,(\Phi\langle\Sigma\rangle\tilde{\Phi}) \;=\; 6v\sum_i Y_i\,\phi_i\tilde{\phi}_i \;,$$

yielding a mass $M_i = 6\lambda_\Sigma v Y_i$ for $(\phi_i, \tilde{\phi}_i)$. For $(\bar{5}, 5)$ and $(10, \overline{10})$ messengers, the component fields and masses are

$$\Phi(\bar{5}) = \left\{\phi_{\bar{3},1,1/3}\,,\,\phi_{1,2,-1/2}\right\}, \quad M = \{2\lambda_\Sigma v\,,\,-3\lambda_\Sigma v\}\,,$$

$$\Phi(10) = \left\{\phi_{3,2,1/6}\,,\,\phi_{\bar{3},1,-2/3}\,,\,\phi_{1,1,1}\right\}, \; M = \{\lambda_\Sigma v\,,\,-4\lambda_\Sigma v\,,\,6\lambda_\Sigma v\}$$

$\langle\Sigma\rangle \sim vY \ \rightarrow$ peculiar spectrum at high energy.

Main outcome : GMSB contribution to the bino mass

$$M_1 \sim Tr(Y^2/M) \ \sim \ TrY \ = 0$$

vanishes at one-loop. If $M_1 = m_{3/2} \ll M_{GMSB}$, neutralino is the LSP, even if mediation is mostly gauge.

Neutralino much lighter than the other superpartners.

Other models with neutralino LSP in gauge mediation : conformal sequestering (Craig-Green: Yanagida et al.)

Generically

$$\tilde{m}_{ij}^2 \;=\; \tilde{m}^2 \delta_{ij} \;+\; \lambda_{ij} m_{3/2}^2$$

FCNC gravity contributions are :

- suppressed in the squark sector (further suppression is needed for CP violating phases).

- not enough suppressed in the slepton sector (right-handed sleptons are light) $\rightarrow$ need additional flavor symmetries in the leptons sector.

Some typical numbers :

$$m_{3/2} \;=\; 80\ GeV \;,\; \tilde{m}_q \;\sim\; 1\ TeV \;,\; \tilde{m}_{E_i^c} \;\sim\; 100\ GeV$$

3. SUSY breaking sector

We use ISS (Intriligator-Seiberg-Shih) model as sector that breaks SUSY (other DSB models similar results).

$$W = W_{ISS} + W_m + W_\mu + W_{MSSM}$$
$$W_{ISS} = hqX\tilde{q} - hf^2 TrX$$
$$W_\mu = (\lambda_1 \frac{q\tilde{q}}{M_P} + \lambda_2 \frac{X^2}{M_P})\ H_1 H_2$$

where $f^2 = m\Lambda \sim (10^{10} GeV)^2$.

ISS SUSY breaking vacuum is

$$\langle q^i_a \rangle = \langle \tilde{q}^a_i \rangle = f\ \delta^a_i\ ,\ \langle X \rangle = 0 \tag{3}$$

- $\lambda_X \sim \Lambda / M_P \ll 1 \rightarrow$ large lifetime.

At tree-level there are pseudo-moduli in X: X_0=flat direction.

$$X = \begin{pmatrix} Y_0 + \delta\tilde{Y} & \delta Z^\dagger \\ \delta\tilde{Z} & X_0 + \delta\tilde{X} \end{pmatrix}$$

Y_0 have a tree-level potential.

One-loop :

- contribution of the ISS sector to the potential:

$$V_{ISS}^{(1)} = \frac{1}{64\pi^2}\, 8\, h^4 f^2 (\ln 4 - 1) N(N_f - N)|X_0|^2 \ ,$$

- messenger loop corrections

$$V_{\phi,\tilde{\phi}}^{(1)} = \frac{N_m |\mathrm{Tr}'\lambda|^2 h^2 f^4}{64\pi^2}\left[-\frac{35}{18\lambda_\Sigma^2 v^2}(\lambda_X X)^2 + \frac{10}{3\lambda_\Sigma v}\lambda_X X + \mathrm{h.c.}\right] \ .$$

Minimization generates vev's

$$X_0 \sim f^2/\lambda_\Sigma v \quad , \quad Y_0 \sim f^2/(16\pi^2 \lambda_\Sigma v)$$

In the end we find

$$m_{3/2} \sim \frac{F_X}{M_P} \sim \frac{f^2}{M_P}$$

$$\mu \sim \frac{\lambda_1}{h} m_{3/2} \quad , \quad B \sim \frac{\lambda_2 h}{\lambda_1} X_0$$

Easy to find $B, \mu \sim TeV \gg m_{3/2}$.

2. Low-energy phenomenology

• Squarks, sleptons, charginos, gluinos and three neutralinos get masses from gauge mediation.

• Lightest neutralino is mostly bino, mass $\leq m_{3/2}$.

• B, μ also gravitational origin, but enhanced w.r.t. $m_{3/2}$.

Spectrum at messenger scale :

i) $(5, \bar{5})$ **messenger pairs:** gluino and $SU(2)_L$ gaugino masses are

$$M_3 \; = \; \frac{1}{2} N_m \frac{\alpha_3}{4\pi} \frac{\lambda_X F_X}{\lambda_\Sigma v} \; , \qquad M_2 \; = \; -\frac{1}{3} N_m \frac{\alpha_2}{4\pi} \frac{\lambda_X F_X}{\lambda_\Sigma v} \; ,$$

where N_m is the number of messenger pairs, leading to the ratio $|M_3/M_2| = 3\alpha_3/2\alpha_2$ (≈ 4 at $\mu = 1$ TeV).

Scalar masses at a messenger scale of 10^{13} GeV :

$$m_Q^2 : m_{U^c}^2 : m_{D^c}^2 : m_L^2 : m_{E^c}^2 \approx 0.79 : 0.70 : 0.68 : 0.14 : 0.08 ,$$

in units of $N_m M_{GM}^2$, with $M_{GM} \equiv (\alpha_3/4\pi)(\lambda_X F_X/\lambda_\Sigma v)$.

ii) $(10, \overline{10})$ **messenger pairs:** gluino and $SU(2)_L$ gaugino masses are

$$M_3 \;=\; \frac{7}{4} N_m \frac{\alpha_3}{4\pi} \frac{\lambda_X F_X}{\lambda_\Sigma v} \;, \qquad M_2 \;=\; 3\, N_m \frac{\alpha_2}{4\pi} \frac{\lambda_X F_X}{\lambda_\Sigma v} \;,$$

leading to the ratio $M_3/M_2 = 7\alpha_3/12\alpha_2$ (≈ 1.5 at $\mu = 1$

TeV). Scalar masses at 10^{13} GeV messenger scale :

$$m_Q^2 : m_{U^c}^2 : m_{D^c}^2 : m_L^2 : m_{E^c}^2 \approx 8.8 : 5.6 : 5.5 : 3.3 : 0.17 \,,$$

• Notice the lightness of $m_{E^c}^2$. This is important for the relic density of dark matter, if LSP neutralino mass below 50 GeV.

• Bino gets GMSB mass only from $\lambda'_\Sigma \rightarrow$ bino and the gravitinos are the lightest.

• The other superpartner masses are 300 GeV - 1 TeV.

Prospects

• LHC will (re)start in 2009 the hunt for physics BSM and particularly low-energy SUSY.

• There are generically three possibilities :

- generic SUGRA mediation $\rightarrow$ all soft terms of the same order $m_{soft} \sim m_{3/2}$, but numerically different.

- gauge mediation $\rightarrow$ flavor universality and some correlation between the different soft terms. Very likely that this will be a metastable vacuum, in which case "There are reasons of anxiety" (Coleman, 1977).

- hybrid models : they can combine advantages and eliminate problems of gauge / gravity mediations

- For GUT induced doublet-triplet messenger splitting $\mathcal{M} \sim Y$, predictive spectrum :

- LSP is the lightest neutralino, which is much lighter than the other superpartners.

- peculiar mass ratios at high-energy: gaugino non-universality, light right-handed sleptons,etc.

- Dark matter properties are different.

- More general cases of SUSY breaking/mediation scenarios deserve attention from LHC perspective !