Split supersymmetry from SUGRA

General analysis of soft terms from supergravity

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Outline:

- Supergravity soft terms with only $F$-breaking

- Supergravity soft terms with $D$ and $F$-breaking (general expressions; parameterisations)

- Models/scenarios
  - $D$-dominated split SUSY
Soft terms from SUGRA (F-breaking)

Scalar potential:

\[ V = e^G (G_i G_i - 3) \]

\[ G_i = K + \ln |W|^2 \]

Kähler

Superpotential

Hidden sector

\[ k = k_1 (h_m, h_m) + k_2 (h_m, h_m) \phi_i \phi_j^+ \]

\[ + (k_3 (h_m, h_m) \phi_i \phi_j + H.C.) + \ldots \]

Visible sector

\[ w = w_1 (h_m, h_m) + y_{ijk} (h_m, h_m) \phi_i \phi_j \phi_k \]

\[ + m_{ij} (h_m, h_m) \phi_i \phi_j + m_i^2 \phi_i + \ldots \]

F-terms:

\[ G_i = \frac{\partial G}{\partial \bar{z}^i} \]

\[ z^i \in \{ h_m, \phi_i \} \]
At minimum, at least one $\langle G_{hm} \rangle \neq 0$ breaking SUSY spontaneously.

Global limit

$m_{3/2} \rightarrow 0$

MSSM + soft terms

(representative of a renormalisable theory)

\[
K = h_m h_m^+ + \phi_i \phi_i^+ + (Z H_1 H_2 + H.c)
\]

Giudice, Masiero '88

Barbieri, Ferrara, Savoy '81

Amendola, Chamie, Nappi '81

Hall, Lyskken, Weinberg '83

\[
W = W(h_m, h_m^+) + W_{MSSM}
\]

but things can be more general...
One can express soft terms in terms of 'G' to enable us to study other possibilities for example, string based supergravities

cancellation of cosmological constant + minimum constraints:

(i) \( \langle e^{G_i G_j - 3} \rangle = 0 \)

(ii) \( \langle G_k + G_I \nabla_k G_I \rangle = 0 \)

SOFT TERMS:

\[ m_{ij}^2 = M_{3/2}^2 (G_{ij} - R_{ij} \frac{1}{\sqrt{2}} G^\alpha G^\beta) \] scalar masses

\[ m_{ij}^2 = M_{3/2}^2 (2 \nabla_i G_j + G^\alpha \nabla_i \nabla_j G_\alpha) \] B term

\[ A_{ijk} = M_{3/2}^2 (3 \nabla_i \nabla_j G_k + G^\alpha \nabla_i \nabla_j \nabla_k G_\alpha) \] A term

\[ \mu = M_{3/2}^2 (\nabla_i G_j + \frac{1}{3} G_i G_j) \] \( \mu \) term

\[ \mu_Y = 1/2 M_{3/2} \sum a_\alpha G_\alpha \] gaugino masses

No large hierarchies within soft spectrum.
<table>
<thead>
<tr>
<th>MSSM</th>
<th>SPLIT MSSM</th>
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<tr>
<td>&quot;plus&quot; Gauge hierarchy problem</td>
<td>&quot;minus&quot;</td>
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<tr>
<td>&quot;plus&quot; Dark Matter</td>
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<tr>
<td>&quot;plus&quot; Gauge coupling unification</td>
<td>&quot;plus&quot;</td>
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<td>&quot;plus&quot; Direct searches at LHC/Tevatron</td>
<td>&quot;plus&quot;/&quot;minus&quot;</td>
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<td>&quot;plus&quot; Indirect searches</td>
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**Split Susy Requirements on soft spectra:**

1. $$m^2_{H_u} \sim m^2_{H_d} \sim B_{\mu} \gg M^2_w \sim \mathcal{O}(10^9 - M_{GUT})$$
2. $$\mu, M^2_{H_d} \sim \mathcal{O}(500 \text{ GeV} - 1 \text{ TeV})$$
3. $$m^2_{\tilde{\phi}} \sim m^2_{\tilde{G}} \sim m^2_{\tilde{D}} \sim m^2_{\tilde{E}} \sim m^2_{\tilde{\nu}} \gg M^2_w \sim \mathcal{O}(10^9 - M_{GUT})$$
General analysis including D-terms:

\[ V = e^G (G^i G_i - 3) + \frac{1}{2} g_A^2 D_A^2 \]

earlier analysis was within limits:

\[ 0 \leq D_A \leq m^{3/2}_{3/2} \]

no effect on the soft spectra

but, other part of the limit:

\[ m^{3/2}_{3/2} \leq D_A \leq \Lambda_{\text{Planck}} m^{3/2}_{3/2} \]

consistent with cancellation of cosmological constant

two constraints while deriving soft terms:

(i) \[ \langle e^G (G^i G_i - 3) + \frac{1}{2} g_A^2 D_A^2 \rangle = 0 \]

(ii) \[ \langle e^G (G^M \nabla_k G_m + G_k) + g_A^2 D_A (\nabla_k D_A - \frac{1}{2} G_k D_A) \rangle = 0 \]

existence of a minima
General Soft Spectrum with D-terms:

\[ m^2_{ij} = m^2_{3/2} \left( G^i_j - R^i_j a^p G^\alpha \bar{G}^p \right) - \frac{1}{2} g_A^2 D_A^i D_A^j \]

Scalar masses

\[ + g_A^2 D_A^i d_i d_j D_A \]

D-term

\[ + g_A^2 D_A^i d_i d_j D_A \]

\[ A_{ijk} = m^2_{3/2} \left( 3 \nabla_i \nabla_j \nabla_K + g^\alpha \nabla_i \nabla_j \nabla_K G_\alpha \right) - \frac{1}{2} g_A^2 D_A^i \nabla_i \nabla_j \nabla_K D_A \]

A-term

\[ + g_A^2 D_A^i d_i d_j d_K D_A \]

\[ \mu = m^2_{3/2} \left( \nabla_i G_j + \frac{1}{3} G_i G_j \right) \]

M-term

\[ M_{1/2} = m^2_{3/2} \left( \frac{1}{2} \left( \text{Re} f_A \right)^{-1} f_{AM} G^M \right) \]

Gaugino Masses.

D-terms start dominating the scalar spectrum in the limit \( m^2_{3/2} \leq D_A \leq m^2_{3/2} M_P \).

"Natural" split SUSY

* dilaton + D-terms
* Moduli + D-terms

Parameterizations
Model: D- dominated Split SUSY

- No F-breaking terms present.
- The magnitude of D-type SUSY term is fixed by the requirement of cancellation of cosmological constant.
- The W has a VEV giving rise to gravitino mass.

Assume a single anomalous $U(1)_X$:

(i) Scalars attain masses through D-terms:

$$m_{ij}^2 = 8 \delta_{ij} m_{3/2} \left( \sqrt{2} g_a g_X m_{\text{pl}} - 2 m_{3/2} \right) + \frac{\sqrt{6}}{2} g x g_i \tilde{g}^a x m_{3/2}$$

$$m_{\text{pl}} \left| q_a - q_b \right| \equiv l_{q_a - q_b}$$

Illy for $B_i$ and $A_{ijk}$

(ii) Gauginos attain masses through Anomaly Mediation:

$$M_A = -\frac{b c}{16 \pi^2} m_{3/2}$$

"new phenomenological scenario" under study

(i) $B_i$ through GM mechanism.

(ii) $A_{ijk}$ through GM mechanism.
Conclusions

1). We have generalised expressions for soft terms in supergravity to accommodate split SUSY like soft spectra.

2). We have done this in a consistent manner by adding D-terms to the scalar potential.

3). We find a "predictive" split SUSY scenario where F-type SUSY breaking terms are completely absent.