Supersoft Supersymmetry Breaking.

a G.E.M. of an idea

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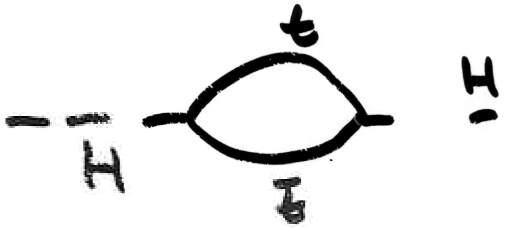
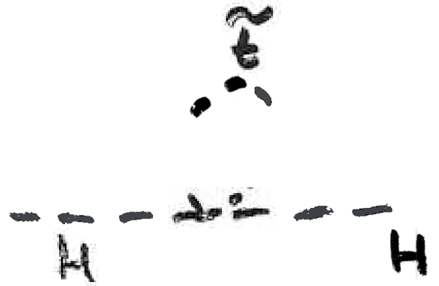
Hierarchy problem



$$\Rightarrow \Delta m_H^2 \sim \Lambda^2 + m_t^2 \log\left(\frac{\Lambda}{m_t}\right) + \ldots$$

SUSY solves hierarchy problem



$$\Rightarrow \Delta m_H^2 \sim m_t^2 \log\left(\frac{\Lambda}{m_t}\right)$$

$$m_t^2 \log\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

Soft ~~SUSY~~ introduces log dependence on cutoff

Supersoft breaks SUSY w/o introducing log divergence, scalar masses finite

Some SUST

is good.

More SUST

is better!?

Gauge Extended Models

Extend SUSY $N=2$ Gauge sector
N Matter sector

5D bulk
gauge fields

Introduce $N=2$ partners of gauge superfields – A_i ($G_i = U(1), SU(2), SU(3)$)

Extended Super Partners – ESPs

$N=2$	$N=1$
(V_i, A_i)	Q U D L E
(H_u, H_d) or	H_u, H_d

Spur analysis

F-term breaking: ~~SUSY~~ parametrized by $\langle X \rangle = \theta^2 F$.

Scalar masses: $\int d^4\theta \; X^+ X \; Q^+ Q$

Gaugino masses: $\int d^2\theta \; \frac{X}{M}$

Generica, not flavour universal.

→ Gauge mediation, gaugino mediation
anomaly mediation

D-term breaking: $\langle W_\alpha' \rangle = \theta_\alpha D$

Scalar masses: $\int d^4\theta \; \frac{(W'^\alpha W'_\alpha)^\dagger (W'^\alpha W'_\alpha)}{M^6} Q^+ Q$

With GEMs introduce a hidden sector $U(1)'$ acquires D component vev

Supersoft op $\int d^2\theta \, \sqrt{2} \, \frac{W'^{\alpha} W_{\alpha}^{j} A^{j}}{M}$

$\hookrightarrow \mathcal{L} \supset m_D \lambda_i \tilde{a}_i \quad m_D^2 (a_i + a_i^*)^2$

$m_D (a_i + a_i^*) \sum_j g \, q_j^* t_i q_j$

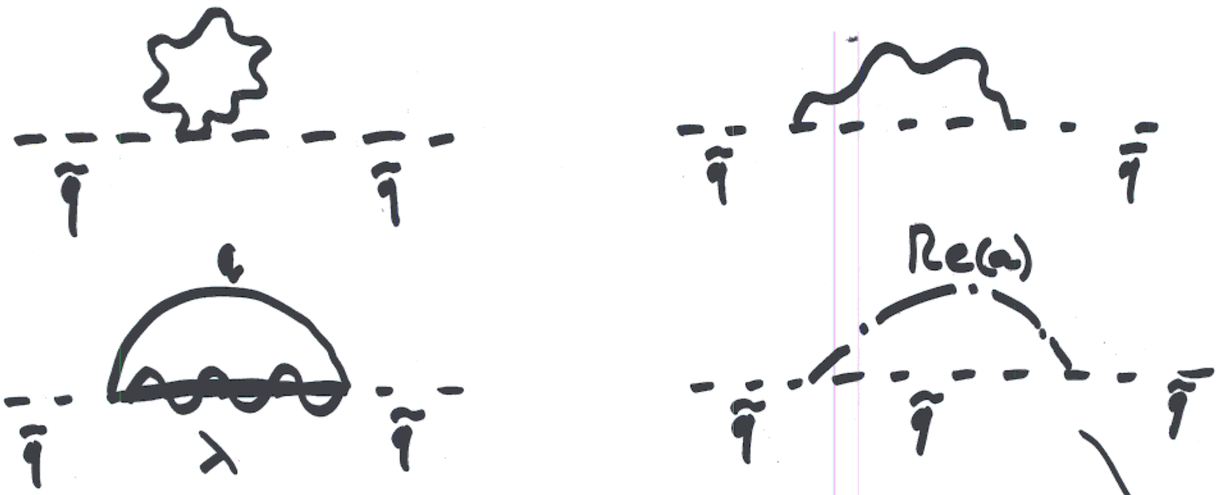
$m_D = \frac{D'}{M}$

Dirac gaugino mass gaugino marries ESP

Mass for real part of ESP scalar

New scalar trilinear, no analogue in MSSM

Implications



One loop contributions,

$$4 g_i^2 C_i \int \frac{d^4k}{(2\pi)^4}\left[\frac{1}{k^2} - \frac{1}{k^2-m_i^2} + \frac{m_i^2}{k^2(k^2-\delta_i^2)}\right]$$

m_i = gaugino mass , δ_i = ~~SUSY~~ mass of Re(a)

$$m^2 = \frac{C_i \alpha_i m_i^2}{\pi} \log\left(\frac{\delta_i^2}{m_i^2}\right)$$

Finite!

In fact, scalar masses are finite to all orders.

Only ~~SUSY~~ is D-term, parametrized by spurion, $\frac{W_\alpha'}{M} = \theta_\alpha m_D$

Suppose this ~~SUSY~~ introduces div. corr. to scalar mass. Write down a supersymmetric, gauge inv. counterterm involving spurion

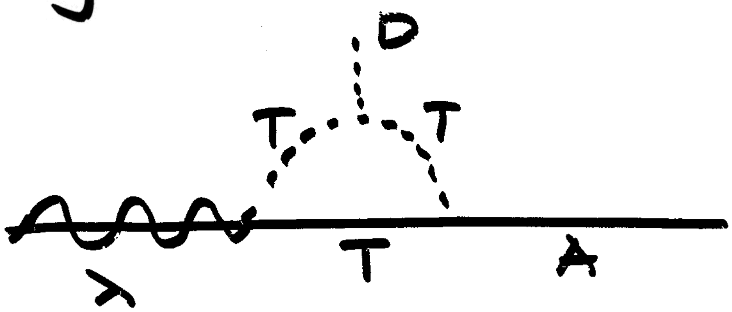
$$\int d^4\theta \; \frac{\theta^2 \bar{\theta}^2 m_D^4}{\Lambda^2} \, Q^\dagger Q$$

$\Lambda \to \infty$ c.t. vanishes $\therefore$ soft masses finite.

Origin of supersoft operator

- Generated in string theory, $M \sim M_s$
- Heavy messengers, $T, \bar{T}$, charged under $U(1)'$

$$\int d^2\theta \; M_T \bar{T}_i T^i + \lambda T_i A^i_j \bar{T}^j$$



$M \sim M_T$ If $M_T \ll M_{pl}$ LSP can be gravitino.

D term arises from F.I term.

SUGRA ? Hidden sector generating $D \gg F$?

GEMs and GUTs

ESPs spoil coupling const unification

Introduce GUT partners of A_i B_i

A_i B_i fill out GUT multiplet

A_i's fermion marries gaugino

B_i's fermion have no one to marry.

These "bachelor" fields provide a window to unification

2 possiblities – $SU(3)^3$, $SU(5)$

$SU(3)^3$

A, B in a 24

$24 \to \underbrace{8+3+1}_{\text{many gauginos}} + \underbrace{(2, \pm\tfrac{1}{2}) + 2\times(1,1,\pm) + 4\times(1,1,0)}_{\text{bachelors.}}$

Neutral bachelors dark matter?

$m^2_{\tilde{e}}$	$(100\ \text{GeV})^2$
$m^2_{\tilde{l}}$	$(312\ \text{GeV})^2$
$m^2_{\bar{q},\bar{u},\bar{d}}$	$(1740\ \text{GeV})^2$
m_1	450 GeV
m_2	3000 GeV
m_3	8250 GeV

SU(5)

$$24 = \underbrace{8 + 3 + 1}_{\text{many gauginos}} + \underbrace{(3,2)_{-5/6} + (\bar{3},2)_{5/6}}_{\text{bachelors}}$$

If gravitino is LSP then long-lived coloured bachelors → heavy hadrons, charge 2, long lived.

$m^2_{\tilde{e}}$	$(100\,\text{GeV})^2$
$m^2_{\tilde{l}}$	$(415\,\text{GeV})^2$
$m^2_{\tilde{q},\tilde{u},\tilde{d}}$	$(3450\,\text{GeV})^2$
m_1	1540 GeV
m_2	3960 GeV
m_3	15560 GeV

EWSB

Different from MSSM.

D-flatness ⇒ no D term quartic couplings present. $\frac{g^2+g'^2}{8} \to 0$, at tree level

(S)top loops give dominant correction.

For $m_{\tilde{t}} \sim 3\,\text{TeV}$ 1-loop correction sufficient to evade LEP bounds.

$m_{\tilde{t}} \sim 1\,\text{TeV}$ must introduce $\int d^2\theta \; M_A A_i A^i$

$M_A \sim m_D$.

N=2 violating or Higgs in N=2 sector alters physics.

Conclusions

Extending gauge sector → new SUSY

Positive, finite, UV insensitive scalar masses

- No SUSY CP problem
- No FCNC problems
- simple, relatively few SUSY params.
- new and different phenomenology.
- Dirac gaugino masses
- heavy squarks
- bachelors provide window to unification or dark matter