On extended GMSB models

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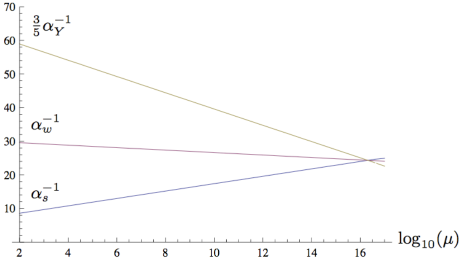
1. MSSM

Still the best candidate for BSM is softly broken MSSM:

- solves problem of quadratic corrections to m_{h^0}
- dark matter candidate $\rightarrow$ LSP
- better unification of gauge couplings at 10^{16} GeV$\rightarrow$ hint for GUT model



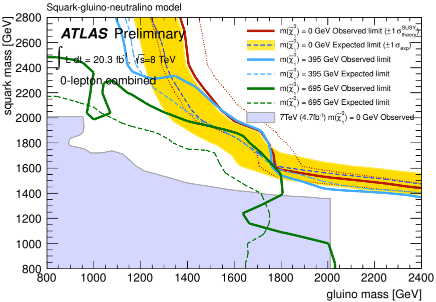
Problems:

- one needs additional sectors: SUSY breaking and mediation
- fine-tuning
- a lot of parameters (soft terms) $\rightarrow$ explain them using RGE and some simple set of initial conditions at high scale $\rightarrow$ GUT model

2. LHC vs. MSSM

What do the LHC searches tell us about MSSM?

- no SUSY signal so far
- relevant exclusions only for 1st and 2nd family
- still $\widetilde{Q}_3, \ldots$ can be as light as 500 GeV



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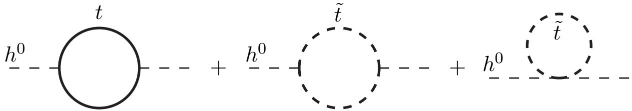
BUT important information comes from Higgs mass measurement:

- $m \sim 125$ GeV $\rightarrow$ need for large loop corrections

ASSUME other MSSM Higgses are much heavier and masses of $\widetilde{Q}_{1,2}$ and $\widetilde{g}$ are bigger than 1.8 TeV.

3. 1-loop corrections to m_{h^0}

- dominant contribution from top quarks and stops (due to $y_t \sim 1$):

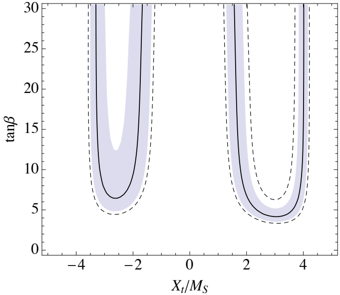
$\Delta(m^2_{h^0}) =$ 

$$m^2_{h^0} = m^2_Z \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2}\left[\ln\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right] \approx (125\,\mathrm{GeV})^2,$$

$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$
$$X_t = A_t - \mu\cot\beta$$

A-terms:

$$V_{\rm soft} \supset y_t A_t H_u \widetilde{Q}_3 \widetilde{U}^c_3 \longrightarrow y_t A_t h_0 \tilde{t}_1 \tilde{t}_2$$



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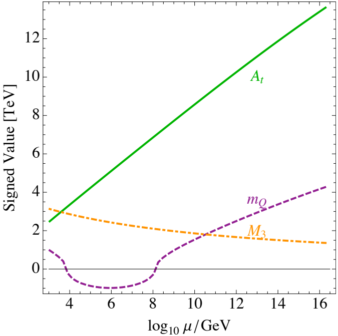
4. How to generate large A-terms?

- value of A-term gives initial condition for RGE evolution



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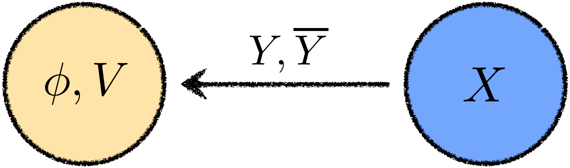
$$\mu \frac{dA_t}{d\mu} \sim y_t^2 A_t + g_3^2 M_3$$

- how to get A-terms in GUT model?

5. SUSY breaking mediation



visible sector messengers hidden sector

SUSY breaking

- such structure is dictated by SUSY
- mediation = interactions between $Y, \overline{Y}$ and other fields
- singlet $\langle X \rangle = M + \theta^2 F \to$ spontaneous SUSY breaking
- X does not interact via superpotential with visible sector
- messengers have large masses e.g. $M \sim 10^{14}$ GeV

6. SUSY breaking mediation

- supergravity
  - no control over FCNC at all $\to$ arbitrary mixings between families
- gauge interactions
  - no FCNC effects at M scale (small mixing generated via RGE)
  - $A \approx 0$ at M scale
  - $m_{h^0} \sim 125$ GeV $\to M \gtrsim 10^{14}$ GeV (i.e. A needs long RGE evolution)
- Yukawa (and gauge) interactions $\to$ EXTENDED GMSB MODELS
  - FCNC effects controlled by Yukawa-type couplings of messengers
  - A-terms $\neq 0$ at M scale
  - easy to satisfy $m_{h^0} \sim 125$ GeV even for $M \sim 10^8$ GeV
  - rich phenomenology

7. Messenger couplings in EGMSB models

Focus on: $SU(5)$ unification model with messengers in $5+\overline{5}$ and $10+\overline{10}$

- matter Φ_i in $5, \overline{5}$ or 10 (in MSSM only $5\,10\,10$ and $\overline{5}\,\overline{5}\,10$)
- pair of messengers $\mathsf{Y} = (Y, \overline{Y})$

$$W_Y = \eta \mathsf{YYY} + h_I^i \Phi_i \mathsf{YY} + h_{II}^{ij} \Phi_i \Phi_j \mathsf{Y}$$

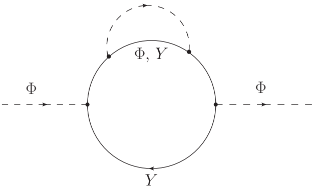
- allowed couplings: $5\,10\,10$, $\overline{5}\,\overline{5}\,10$, $\overline{5}\,\overline{10}\,\overline{10}$, $5\,5\,\overline{10}$
- $h_{I,II}$ quite well explored (Yukawa-Deflected Gauge Mediation)

  usually some hierarchy for $h_{I,II}$ is assumed
- couplings of three messengers $\eta \rightarrow$ additional effects!
  - relevant only if occur together with h_I or h_{II}
  - do not contribute to A-terms (nor to 1-loop masses)

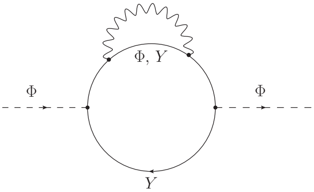
8. Soft terms

- 2-loop contributions to soft masses

$$W_Y = \eta \mathsf{YYY} + h_I^i \Phi_i \mathsf{YY} + h_{II}^{ij} \Phi_i \Phi_j \mathsf{Y}$$



$\sim h^4, h^3 y, h^2 y^2$

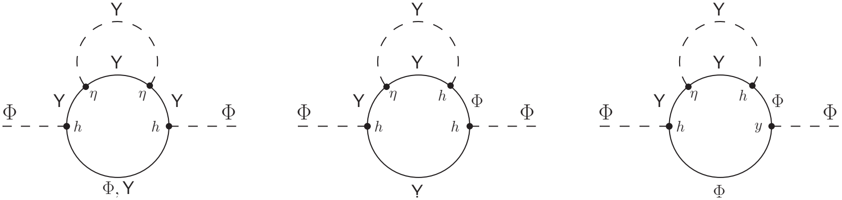


$\sim h^2 g^2$

$$m^2_{\widetilde{\Phi},h} \sim \frac{1}{(4\pi)^4}(h^4 + h^3 y + h^2 y^2 + h^2 g^2)\left(\frac{F}{M}\right)^2$$

9. New contributions to soft masses

$$W_Y = \eta \mathsf{YYY} + h_I^i \Phi_i \mathsf{YY} + h_{II}^{ij} \Phi_i \Phi_j \mathsf{Y}$$



$$m^2_{\widetilde{\Phi},\eta} \sim \frac{1}{(4\pi)^4}\left(\eta^2 h^2 + \eta h^3 + \eta h^2 y\right)\left(\frac{F}{M}\right)^2$$

10. Phenomenological constraints

Assumptions:

- no rapid proton decay via

$$\phi_{\overline{5}}\phi_{\overline{5}}\phi_{10}, \quad \frac{1}{M}\phi_{\overline{5}}\phi_{10}\phi_{10}\phi_{10} \quad \frac{1}{M^2}(\phi_{10}^{\dagger}\phi_{10})^2$$

- absence of μ/B_μ problem
- no $\mu H_u H_d$ term in the superpotential; but Higgs mass via

$$\frac{1}{M_{GUT}}X^{\dagger}H_u H_d$$

One needs addtional selection rules → e.g. global $U(1)$ symmetry

Examples?

- $U(1)$ charges

H_5	$H_{\overline{5}}$	$\phi_{\overline{5}}$	ϕ_{10}	Y_5	$Y_{\overline{5}}$	Y_{10}	$Y_{\overline{10}}$	X
$-8q$	$-7q$	$3q$	$4q$	$17q$	$-2q$	$14q$	q	$-15q$

- Yukawa-type couplings of messengers

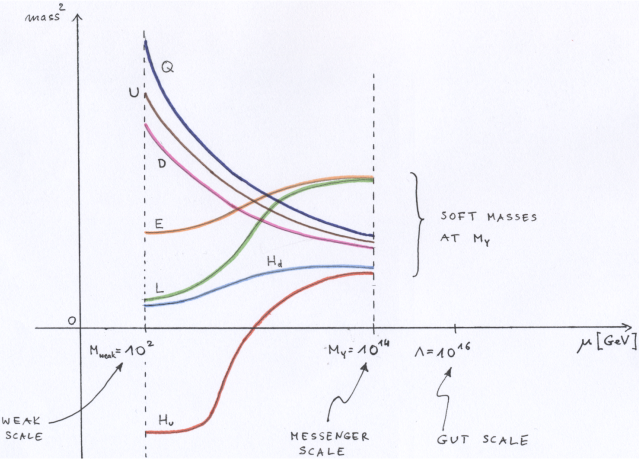
$$W_{\mathsf{Y}} = \frac{1}{2} h_{14} \phi_{10} Y_{\overline{5}} Y_{\overline{5}} + \frac{1}{2} \eta_2 Y_{\overline{5}} Y_{\overline{10}} Y_{\overline{10}}.$$

- soft terms

$$m^2_{\widetilde{Q},\eta} = 6\alpha_{h_{14}} \alpha_{\eta_2} \frac{\xi^2}{16\pi^2}, \quad m^2_{\widetilde{Q},h} = \alpha_{h_{14}} \left(6\alpha_{h_{14}} - \frac{7}{15}\alpha_1 - 3\alpha_2 - 6\alpha_3 \right) \frac{\xi^2}{16\pi^2}$$

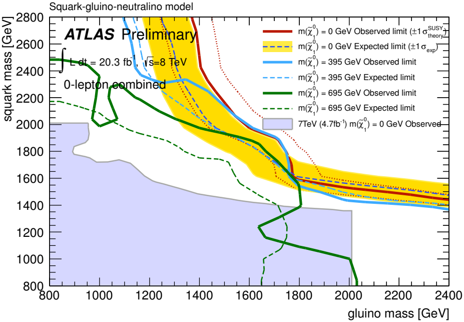
$$A_t = A_b = -\alpha_{h_{14}} \frac{\xi}{4\pi}$$

Reverse the initial problem and evolve parameters from M to EWSB scale:



Find spectrum and check if phenomenology is correct i.e.

- $m_{h^0} \approx 125\,\mathrm{GeV}$
- no tachyons
- scalar potential bounded from below, no CCB
- a_μ, $b \to s\gamma$
- ATLAS bounds on gluino and squarks of 1. and 2. generation



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14. The simplest model

$$W_{\mathsf{Y}} = \frac{1}{2}\eta_2 Y_{\overline{5}} Y_{\overline{10}} Y_{\overline{10}} + \frac{1}{2} h_{14}\phi_{10} Y_{\overline{5}} Y_{\overline{5}}$$

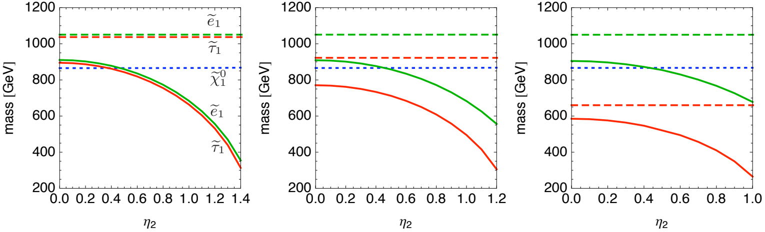
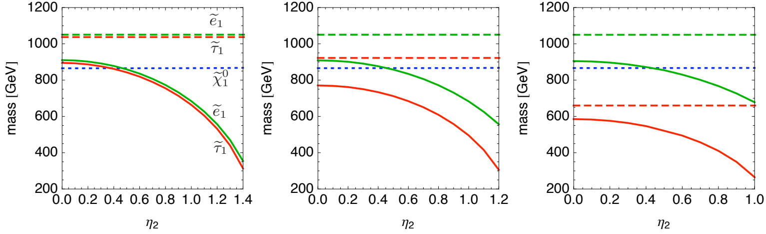


Figure : Plot of the particles masses vs. η_2 coupling for $\tan\beta = 10$ (left plot), $\tan\beta = 30$ (middle plot) and $\tan\beta = 50$ (right plot). h_{14} is set to 1.2, while $\xi = F/M$ scale is 1.6×10^5 GeV. Dashed lines show masses of the particles when $h_{14} = \eta_2 = 0$, which corresponds to the standard GMSB case. $\widetilde{\tau}_1$ and $\widetilde{e}_1$ are mostly right-handed.

15. The simplest model

$$W_{\mathsf{Y}} = \frac{1}{2}\eta_2 Y_{\overline{5}} Y_{\overline{10}} Y_{\overline{10}} + \frac{1}{2} h_{14}\phi_{10} Y_{\overline{5}} Y_{\overline{5}}$$



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$$m^2_{\tilde{Q},\eta} = 6\alpha_{h_{14}}\alpha_{\eta_2}\frac{\xi^2}{16\pi^2}, \quad m^2_{\tilde{Q},h} = \alpha_{h_{14}}\left(6\alpha_{h_{14}} - \frac{7}{15}\alpha_1 - 3\alpha_2 - 6\alpha_3\right)\frac{\xi^2}{16\pi^2}$$

$$\boxed{\mu\frac{d}{d\mu}m^2_{\tilde{E}_3} = \ldots + \frac{6}{10}g_1^2 m^2_{\tilde{Q},\eta}}$$

16. Conclusions

- Extended GMSB models naturally accommodate for left-right top squarks mixing
- in some cases superpotential couplings of three messengers are relevant to mass spectrum
- additional selection rules (e.g. global $U(1)$) are necessary to satisfy phenomenological constraints