When AMSB is UV Sensitive

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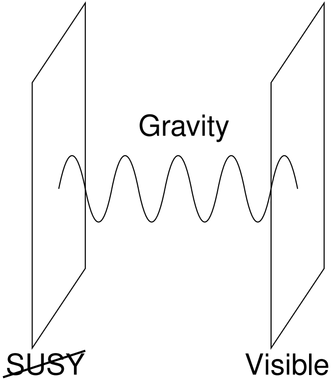
The Punchline

When is Anomaly Mediated SUSY Breaking (AMSB) UV Sensitive?

- More often than literature implies
- Under broader conditions than literature implies
  - AMSB potentially sensitive to large thresholds
  - Naively expect these thresholds are UV insensitive

AMSB Idea



- SUSY Broken in hidden sector
- Auxiliary scalar of SUGRA multiplet, $\phi = (1, 0, F_\phi)$, transmits breaking
- ϕ coupling to visible fields (and thus SUSY breaking) dictated by superconformal invariance

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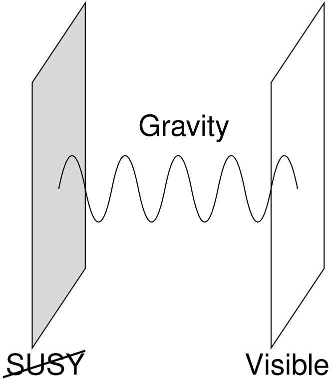

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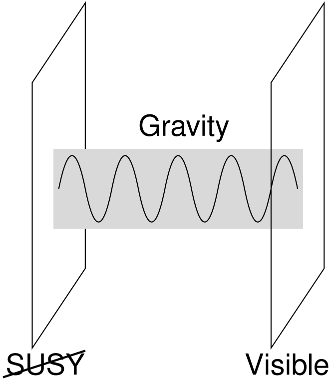

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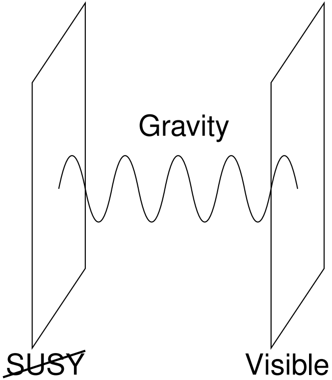

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AMSB Implications

- SUSY breaking form completely dictated
  - Conformal invariance implies mass scales paired with ϕ
- In theories with no explicit mass scales at tree level, Quantum Mechanics induces one
  - Renormalization introduces a running scale μ
  - SUSY breaking only introduced through renormalization
  - SUSY breaking expressions are ‘evaluated’ at variable scale μ so UV insensitive
- Only one new parameter in the theory, $F_\phi \gtrsim$ 20 TeV

AMSB Issues

However. . .

- Problem: Tachyonic sleptons in MSSM+AMSB
    - Using AMSB expressions for scalar masses, slepton mass$^2 < 0$
- Solutions:
    - Add a constant (mAMSB)
    - Introduce new Yukawa couplings to sleptons
    - Disrupt or Deflect from AMSB form at some scale M_{int}
      [Pomarol and Rattazzi **JHEP 9905 (1999) 013** arXiv:hep-ph/9903448]

Threshold Decoupling

- Consider threshold $M_{\rm int}$
  - Superfields Q have mass much less than $M_{\rm int}$
  - Superfields Δ have mass of $M_{\rm int}$
- General lagrangian above $M_{\rm int}$:

$$\mathcal{L}^+ = \mathcal{L}_Q^+ + \mathcal{L}_{Q\Delta} + \mathcal{L}_\Delta$$

- Schematic lagrangian below $M_{\rm int}$:

$$\mathcal{L}^- = \mathcal{L}_Q^- + M_{\rm int}^4 + \left[\left[\frac{Q^4}{M_{\rm int}\phi} + \cdots\right]_F + \text{h.c.}\right] + \left[\frac{\left(Q^\dagger Q\right)^2}{M_{\rm int}^2\phi^\dagger\phi} + \cdots\right]_D$$

Additional SUSY Breaking?

- Assume no change in renormalizable portion of light fields' lagrangian $(\mathcal{L}_Q^+ = \mathcal{L}_Q^-)$: no new SUSY breaking from $\mathcal{L}_Q$
- Form of $\mathcal{L}^-$ gives new SUSY breaking due to M_{int}:

$$\frac{F_\phi}{M_{\text{int}}}$$

$$\frac{\langle F_Q \rangle}{M_{\text{int}}}$$

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$$\frac{\langle F_Q \rangle}{M_{\rm int}} \longrightarrow \begin{cases} \ll F_\phi & \text{if } \langle F_Q \rangle \ll M_{\rm int} F_\phi \\ \sim F_\phi & \text{if } \langle F_Q \rangle \sim M_{\rm int} F_\phi \end{cases}$$

No Deflection

$$\mathcal{L}_Q^- = \mathcal{L}_Q^+$$

No change in renormalizable lagrangian of light fields

$$\langle F_Q \rangle \ll M_{\text{int}} F_\phi$$

All F-term VEVs of light fields are "small"

- No new SUSY breaking from threshold
- Threshold decouples
- Threshold in superspace is $M_{\text{int}}\phi$
  (to retain superconformal invariance)
  - If M_{int} due to VEV, superfield obeys $\langle \Delta \rangle = M_{\text{int}}\phi$

Pomarol and Rattazzi

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Are "large" F-term VEVs for light fields possible?

General form for F-term VEV is

$$\langle F_Q \rangle = L_Q + M_Q \langle \underline{Q} \rangle + \frac{1}{2!} Y_Q \langle \underline{Q} \rangle^2 + \cdots$$

$$M_Q \ll M_{\text{int}}$$

$$\langle \underline{Q} \rangle \sim M_Q \ll M_{\text{int}}$$

So if linear term is around $M_{\text{int}} F_\phi$,
threshold can introduce SUSY breaking comparable to F_ϕ

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At least one F-term VEV of a light field is "large"

- [Pomarol and Rattazzi **JHEP 9905 (1999) 013** arXiv:hep-ph/9903448]
- Field must be a singlet to allow linear term
- This singlet has zero VEV by assumption
- Equations of motion imply no SUSY mass term
  - Singlet acquires mass from SUSY breaking
  - Singlet's mass is at most $F_\phi \ll M_{\text{int}}$
- Expectation: Deflection accompanied by Light Singlet.

Deflection without Light Singlets

Consider

$$\mathcal{L} = \left[X^\dagger X + S^\dagger S\right]_D + \left[\left(\lambda X^2 - M_{\text{int}}^2\phi^2\right) S\right]_F$$

Solve for auxiliary fields

$$-F_S^* = \lambda \underline{X}^2 - M_{\text{int}}^2$$

$$-F_X^* = 2\lambda \underline{X}\,\underline{S}$$

Take SUSY limit

$$\langle \underline{X} \rangle = \frac{M_{\text{int}}}{\sqrt{\lambda}}$$

$$\langle \underline{S} \rangle = 0$$

Deflection without Light Singlets

- After VEV, both fields heavy:

$$\mathcal{L} \supset \left[2\sqrt{\lambda}M_{\rm int}XS\right]_F$$

- No light singlet, so no Pomarol and Rattazzi deflection
- Threshold decouples and retention of conformal invariance gives

$$\langle X\rangle = \frac{M_{\rm int}\phi}{\lambda}$$

- Permitting $F_\phi \neq 0$ implies

$$\langle X\rangle = \frac{M_{\rm int}}{\sqrt{\lambda}}(1, 0, F_\phi) \qquad \text{or} \qquad \frac{\langle F_X\rangle}{\langle \underline{X}\rangle} = F_\phi$$

Deflection without Light Singlets

- With SUSY breaking turned on, S superfield acquires a VEV
- Important question is ratio of $\langle F_S \rangle$ to $\langle \underline{S} \rangle$:

$$\frac{\delta V}{\delta \underline{X}} = -2\lambda F_{\overline{X}} \underline{S} - 2\lambda \underline{X} F_S = 0$$

Which implies

$$\frac{\langle F_S \rangle}{\langle \underline{S} \rangle} = -\frac{\langle F_X \rangle}{\langle \underline{X} \rangle} = -F_\phi$$

- Notice that the ratio is not F_ϕ, so that

$$\langle S \rangle = \frac{\langle \underline{S} \rangle}{\phi}$$

and the superconformal form is broken

Deflection without Light Singlets

- But so what?
  - Both X and S are heavy and integrated out at M_{int}
  - Deflection from $\langle S \rangle$ is thus lost
- However
  - Add messengers to communicate deflection

$$\mathcal{L}_{\text{Mess}} = \left[\lambda_Y S Y \overline{Y} \right]_F$$

  - Now at M_{int}, superconformal violating term induced for Y's

$$\mathcal{L}_{\text{Mess}} \supset \left[\frac{\lambda_Y \langle \underline{S} \rangle}{\phi} Y \overline{Y} \right]_F$$

The Messenger Mass

$$\left[\frac{\lambda_Y \langle \underline{S} \rangle}{\phi} Y\overline{Y}\right]_F = \left[\frac{\mu_Y}{\phi} Y\overline{Y}\right]_F \qquad \mu_Y = \frac{\lambda_Y}{\lambda} F_\phi^\dagger$$

- For $\mu_Y \sim F_\phi^\dagger$ looks like Extended Anomaly Mediation
  [Nelson and Weiner arXiv:hep-ph/0210288]
- But μ_Y not restricted to near F_ϕ
  - μ_Y depends on λ_Y/λ
  - For $\lambda \ll 1$, $\mu_Y \gg F_\phi$ (without violating perturbativity)
- Thus, at a general, large threshold μ_Y can get deflection, without light singlet

Conclusion

- AMSB is more UV sensitive than previously thought
- Deflection possible at any threshold without a remnant light singlet