# Supersymmetry and Little Higgs

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# Outline

Motivations

sLittle Higgs: a model

Summary

# SUSY and Little Hierarchy Problem

Radiative EWSB in generic SUSY model is fine-tuned

$$M_Z^2 \sim \frac{3y_t^2}{2\pi^2} m_{\tilde{t}}^2 \ln \frac{f}{m_{\tilde{t}}}$$

$f$ is a scale where EWSB is generated $m_h^2(f) = 0$. $M_Z$ is generically large compared to measure value.
Avoid fine-tuning:

$$m_{\tilde{t}} \lesssim \text{few hundred GeV} \quad f \lesssim \text{few TeV}$$

Cutoff $f$ determined dynamically as a function of many parameters:$g_3, \lambda_t, M_{1/2}/m_{\text{soft}}$.

$m_H \sim 100$ GeV requires fine-tuning.

# Little Higgs

- Higgs as a pseudo-Goldstone boson
  $V = 0 \cdot |h|^2 + 0 \cdot |h|^4 \quad \rightarrow \quad V = \frac{\mathcal{O}(g^2,\lambda^2)}{16\pi^2} cos(h/f)$
- Generically – small mass and small quartic
- Collective symmetry breaking: two different interactions are required to break global symmetry
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- Tree level quartic, but loop suppressed mass

Ideally $\quad h \sim \frac{y_t}{4\pi} f \ll f$

In practice $\quad h < f$

Precision tests imply scale of symmetry breaking $f \geq$ few TeV

Higgs tends to be heavy – models fine-tuned

# sLittle-Higgs

Marriage proposal:

$$m^2 \sim \frac{\mathcal{O}(g^2, \lambda_t^2)}{(4\pi^2)} m_{\tilde{t}}^2 \ln \frac{f}{m_{\tilde{t}}}$$

- No quartic from the superpotential for MSSM matter content
- D-terms break global symmetry at tree level

$$m^2 \sim (|H_u|^2 - |H_d|^2)(|H_{u'}|^2 - |H_{d'}|^2)$$

# The Model

Csáki, Marandella, Y.S., Strumia

Embed $H'_u$ and $H'_d$ into real rep of global symmetry

$$SU(3)_{H,\bar{H}} \times SU(3)_\Sigma, \quad H'_u, H'_d \subset \Sigma \quad \text{(adjoint of } SU(3)\text{)}$$

Gauge group:

$$SU(3)_c \times SU(2)_W \times U(1)_Y \subset SU(3)_c \times SU(3)_W \times U(1)_X \subset SU(6)$$

Higgs content: $H(1,3,1/3), \quad \bar{H}(1,\bar{3},-1/3), \quad \Sigma(1,8,0)$

$$H = \begin{pmatrix} 0 \\ 0 \\ f/\sqrt{2} \end{pmatrix} \quad \bar{H} = \begin{pmatrix} 0 \\ 0 \\ f/\sqrt{2} \end{pmatrix} \quad \Sigma = \begin{pmatrix} w/2 & 0 & 0 \\ 0 & w/2 & 0 \\ 0 & 0 & -w \end{pmatrix}$$

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$$s = \sin(3w/fF) \quad c = \cos(f/3wF) \quad F^2 = f^2 + 9w^2$$

# Matter sector

Matter in complete $SU(6)$ reps:

$15, \bar{6}, \bar{6} \quad \leftarrow \quad$ 3 chiral generations
$20 \quad \leftarrow \quad$ needed for top Yukawa and little Higgs mechanism

Decomposition

$$
\begin{array}{lll}
15 & \supset & Q(3,3,0), \quad E(1,\bar{3},2/3), \quad \overline{U}(\bar{3},1,-2/3) \\
2\times\bar{6} & \supset & 2\times\ \overline{D}(\bar{3},1,1/3), \quad 2\times\ L(1,\bar{3},-1/3) \\
20 & \supset & Q'(\bar{3},3,-1/3), \quad \bar{Q}'(3,\bar{3},1/3), \quad N(0,0,1), \quad \bar{N}(0,0,-1)
\end{array}
$$

Exotic matter – quark/antiquark pair, 2 lepton doublets and 2 sterile neutrinos from chiral fields.
20 contains vector-like fields: doublet and singlet quarks and $U(1)_X$ fields

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# Top sector

Superpotential

$$W = 20\Sigma 20 + 20H15 + 15\bar{H}\bar{6}$$

Top mass

$$W_{\text{top}} = \lambda_1 \bar{Q}'\Sigma Q' + \lambda_2 \bar{Q}' H \overline{U} + \lambda_3 Q H Q'$$

Three heavy tops

$$M_{T_1}^2 = \lambda_1^2 w^2 + \frac{1}{2}\lambda_2^2 v^2 \qquad M_{T_{2,3}}^2 = \frac{1}{4}(\lambda_1^2 w^2 + 2\lambda_3^2 v^2)$$

SM top remains massless with Yukawa

$$y_t \simeq \begin{cases} \lambda_1/2 & \text{if } w \to 0 \\ 3f\lambda_2\lambda_3/(2w\lambda_1) & \text{if } f \to 0 \end{cases}$$

## Top loops generate potential for Goldstone

$$V(G) = -m^2|G|^2 + \lambda|G|^4$$

$\lambda \quad \leftarrow$ only MSSM physics

$m^2 \quad \leftarrow$ only physics up to $\mathcal{O}(M_T)$

In SUSY limit ***sGoldstone*** also massless.
If sGoldstone participates in EWSB Higgs mass not protected.
Goldstone direction: $H_u = H_d$, $\tan\beta = 1$ and quartic too small

- Quartic from sliding singlet mechanism:

$$W = \frac{1}{\Lambda}(SH + S'\frac{\Sigma H}{\Lambda'})(\bar{S}\bar{H} + \Sigma\bar{H})$$

- Can also obtain quartic from MSSM D-terms but LEP bound on Higgs mass restricts allowed parameters $\longleftarrow$ Berezhiani, Chankowski Falkowski, Pokorski

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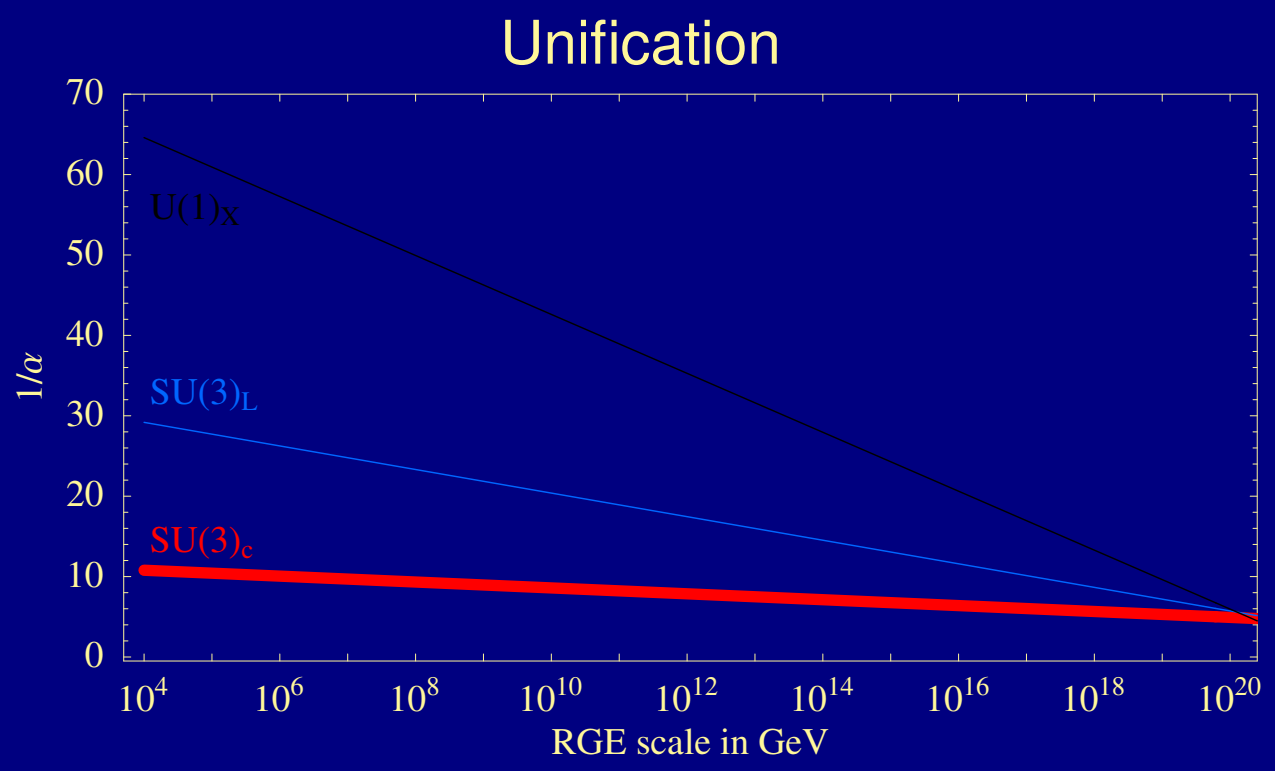
# Phenomenology




Chiral matter only, $H, \bar{H}$ completed into $SU(6)$ rep
No top Yukawa coupling possible
$SU(6)$ partners of $\Sigma$ missing

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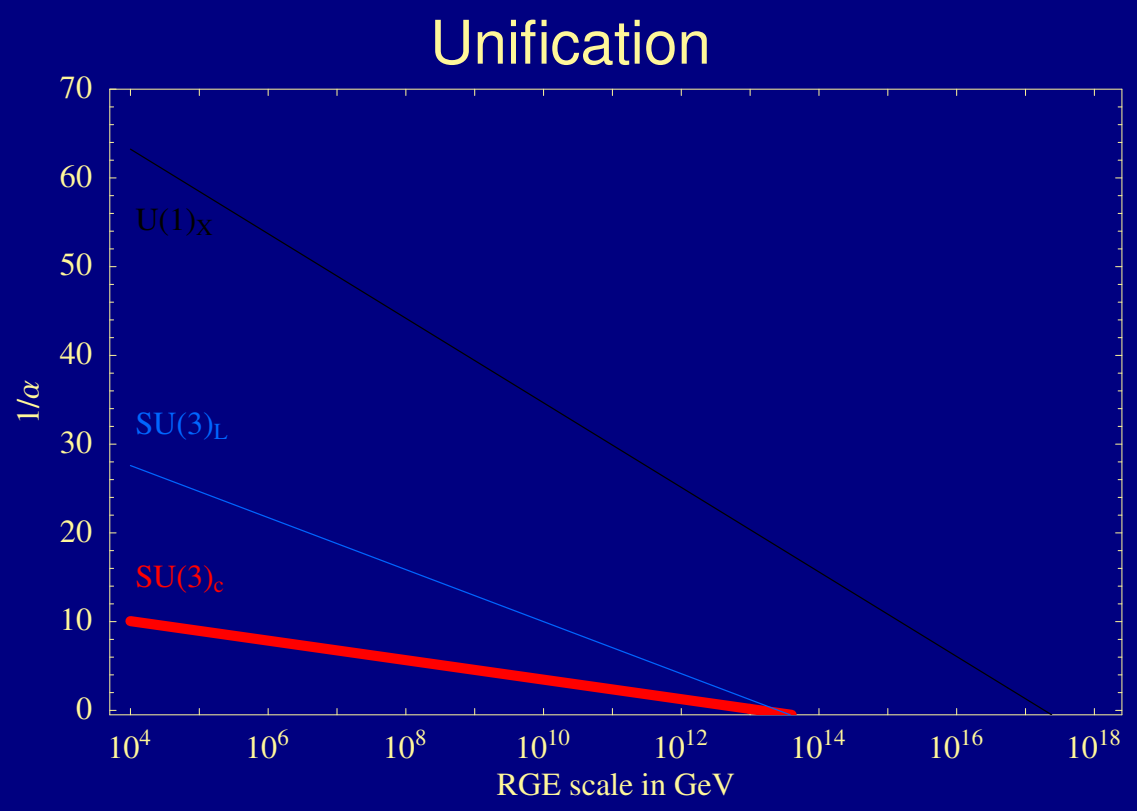


Full model content (including fields needed for top Yukawa coupling)

Removed colored Higgs triplets

Unification in string theory through duality cascade is possible

# Phenomenology

- Higgs triplet and $Z'$ affect precision data
  Need $f > 3\text{TeV}$ and $w > 0.5\text{TeV}$.
- New particles observable at LHC
- Extra heavy fermions decaying into ordinary fermions.
- Light sterile neutrinos can be produced at the accelerators through $SU(3)_W$ interactions
- In cosmology sterile neutrinos provide $\Delta N_\nu \sim 1.5$ dofs. Acceptable and testable by CMB and BBN experiments
- Steriles and active neutrinos mixing with singlets may provide “sterile” interpretation of LSND anomaly

# Summary

- Supersymmetric little Higgs models offer a promising possibility of simultaneous solutions to gauge and little hierarchy problems
- Realistic models can be constructed
- Mechanisms to generate Higgs quartic coupling not fully satisfactory
- Need to find more economical models
- Intriguing possibility of Planck scale unification