Retrofitting the ISS model

Felix Brümmer, Universität Heidelberg

based on arXiv:0705.2153[hep-ph], JHEP 07 (2007) 043,
"A natural renormalizable model of metastable SUSY breaking"

Motivation and overview

Why is M_{EW} so small?

- SUSY, with $M_{\not{\text{SUSY}}} \ll M_{\text{Planck/String/GUT}\ldots}$

Why is $M_{\not{\text{SUSY}}}$ so small?

- Dynamical SUSY breaking (→ Witten '81): Strong gauge dynamics in hidden sector can break SUSY
  Hierarchy generated from running gauge coupling:

$$\left(\frac{\Lambda}{\mu}\right)^{b_0} = \exp\left(-\frac{8\pi^2}{g^2(\mu)}\right)$$

How can we realize dynamical ~~SUSY~~ ?

- Realistic models used to be extremely complicated
- Much simpler models now possible with metastable dynamical ~~SUSY~~ (see → H. Murayama's talk).

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permit SUSY vacua but assume
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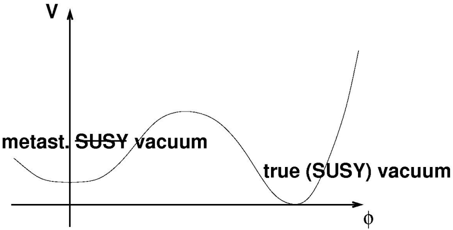
Simplest model is just SQCD.



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  - via higher-dimensional operators (→ Aharony/Seiberg ’06)
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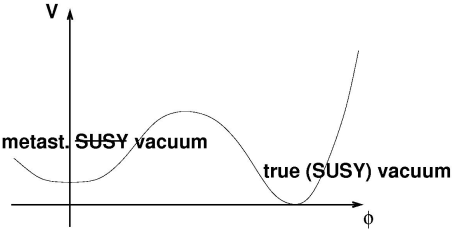

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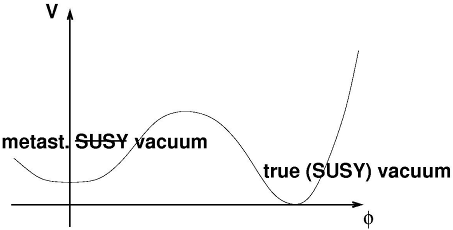

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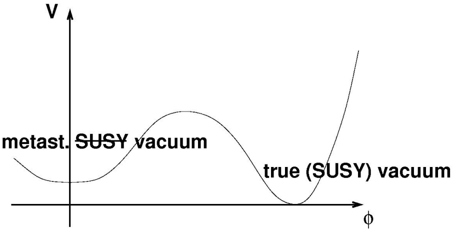

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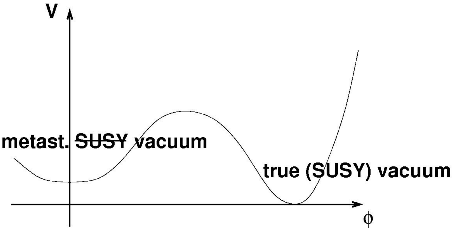

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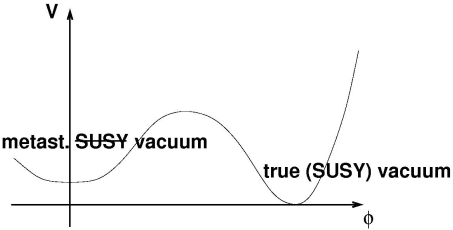

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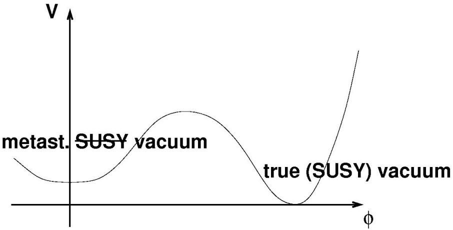

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Outline

The ISS model

- Start with SU(N_c) SQCD with N_f flavours of massive quarks . . .
- . . . where $3N_c/2 > N_f > N_c$, and quark masses much smaller than strong-coupling scale, $m \ll \Lambda$
- IR description at scales $\ll \Lambda$ in terms of weakly coupled "magnetic variables" (Seiberg duality, → Seiberg '94): SU($N_f - N_c$) SQCD with N_f dual quarks and antiquarks $\varphi, \tilde{\varphi}$ and N_f^2 mesons Φ

- Electric theory asymptotically free
- Magnetic theory IR free

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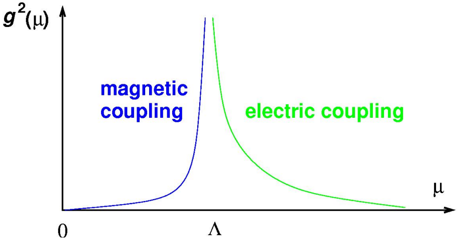

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The ISS model

- IR superpotential

$$W = \mathrm{tr}\,\tilde{\varphi}\Phi\varphi - m\Lambda\,\mathrm{tr}\,\Phi + \left(\frac{\det\Phi}{\Lambda^{3N_c-2N_f}}\right)^{1/(N_f-N_c)}$$

gives Meson F-terms

$$F_{\Phi_j^i} = \tilde{\varphi}_i^c\varphi_c^j - m\Lambda\delta_i^j$$

which cannot all vanish because $\mathrm{rank}(\tilde{\varphi}_i^c\varphi_c^j) = N_f - N_c$, $\mathrm{rank}(\delta_i^j) = N_f$:

SUSY broken

- Local ~~SUSY~~ minimum (“ISS vacuum”) at

$$\Phi = 0, \qquad (\tilde{\varphi}_i^c) = (\varphi_c^j)^T = \begin{pmatrix} m\mathbb{1}_{N_f-N_c} \\ 0 \end{pmatrix}$$

- Tree-level flat directions stabilized by Coleman-Weinberg potential

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- IR superpotential for small Φ

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The ISS model

- Global SUSY minima (proper vacua) found when incorporating $\det \Phi$-term in W — but far away in field space from ISS vacuum
- Analysis requires $m \ll \Lambda$: Small parameter m put in by hand
- Lifetime of metastable vacuum (see also talks by → N. Craig, A. Westphal)

$$\Gamma \sim e^{-S_{\text{bounce}}}, \qquad \text{where} \quad S_{\text{bounce}} \approx \left(\frac{\Lambda}{m}\right)^{\frac{6N_c-4N_f}{N_c}}$$

  Lifetime large if m/Λ small

To make ISS model natural, should generate small m dynamically:

"Retrofitting"

(in more general context see → Dine et al. '06)

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Retrofitting with higher-dimensional operators

Simple retrofitted ISS model (→ Aharony/Seiberg '06):

- Introduce additional SYM sector: Field strength W'_α, scale Λ'
- Assume dimension 6-coupling to ISS quarks $q, \tilde{q}$, suppressed by UV-completion scale M:

$$\mathcal{L} \supset \int d^2\theta \, \frac{\operatorname{tr} q\tilde{q}}{M^2} \operatorname{tr} W'_\alpha W'^\alpha + \text{h.c.}$$

- Gaugino condensation in auxiliary sector: $\langle \lambda'_\alpha \lambda'^\alpha \rangle = \Lambda'^3$
  $\rightarrow$ mass term for ISS quarks, $m = \Lambda'^3 / M^2$
- $m \ll \Lambda$ easily achievable
- Drawback: dependence on physics at UV-completion scale (what generates this higher-dimensional coupling? Why are other ones absent or negligible?)

Now instead: small m from renormalizable operators

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Renormalizable retrofitting: The auxiliary sector

Consider SU(N_c') SQCD with N_f' massless quarks and antiquarks Q, $\tilde{Q}$ with $N_c' > N_f'$. Couple to singlet S, classical superpotential:

$$W_{\text{tree}} = S \operatorname{tr} Q\tilde{Q} - S^3$$

Only cubic terms $\Rightarrow$ only dimensionless couplings (can be enforced by imposing a discrete $\mathbb{Z}_3$)

Quantum theory: ADS superpotential generated nonperturbatively,

$$W_{\text{np}} \sim \left(\frac{\Lambda'^{3N_c' - N_f'}}{\det Q\tilde{Q}} \right)^{1/(N_c' - N_f')}$$

Full quantum superpotential: $W = W_{\text{tree}} + W_{\text{np}}$ by symmetry & holomorphy

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Only cubic terms $\Rightarrow$ only dimensionless couplings (can be enforced by imposing a discrete $\mathbb{Z}_3$)
Quantum theory: ADS superpotential generated nonperturbatively,

$$W_{\text{np}} \sim \left(\frac{\Lambda'^{3N_c' - N_f'}}{\det Q\tilde{Q}} \right)^{1/(N_c' - N_f')}$$

Full quantum superpotential: $W = W_{\text{tree}} + W_{\text{np}}$ by symmetry & holomorphy

Renormalizable retrofitting: The auxiliary sector

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In IR: use gauge invariant composites as variables, $M^i_j = \frac{1}{\Lambda'} Q^i \tilde{Q}_j$.
Low-energy effective superpotential

$$W_{\text{eff}} = \Lambda' S \,\text{tr}\, M - S^3 + \left(\frac{\Lambda'^{3N'_c - 2N'_f}}{\det M} \right)^{1/(N'_c - N'_f)}$$

This gives SUSY vacua at

$$S \sim \Lambda', \qquad M \sim \Lambda' \, \mathbb{1}_{N_f}$$

(up to phases & $\mathcal{O}(1)$ prefactors).
Idea: S obtains a vev which can be naturally small

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Renormalizable retrofitting: The full model

ISS sector:

- SU(N_c) gauge group
- N_f flavours $q, \tilde{q}$
- $N_c < N_f$
- scale Λ

Auxiliary sector:

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Both sectors coupled by singlet S, full tree-level superpotential:

$$W = -\lambda S \,\mathrm{tr}\, q\tilde{q} + S \,\mathrm{tr}\, Q\tilde{Q} - S^3$$

Require $\lambda \ll 1$ such that $\lambda\Lambda \ll \Lambda'$ and $\lambda\Lambda' \ll \Lambda$. This is mild tuning ($\lambda = 10^{-2}$ will do). Necessary to ensure that ISS dynamics does not destabilize S vev. Hierarchy still mainly generated dynamically.

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- In the UV start with

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Renormalizable retrofitting: Numerical example

$N_c = 5$, $N_f = 6$, $N_c' = 4$, $N_f' = 3$, gauge couplings at Planck scale $M_P = 10^{19}$ GeV:

$$\frac{g^2(M_P)}{4\pi} = \frac{1}{42}, \qquad \frac{g'^2(M_P)}{4\pi} = \frac{1}{45}$$

Gives $\Lambda \approx 1.8 \cdot 10^6$ GeV and $\Lambda' \approx 2.3 \cdot 10^5$ GeV. Choose $\lambda = 10^{-2}$ to get $\lambda\Lambda/\Lambda' \approx 8 \cdot 10^{-2}$ and $m/\Lambda = \lambda\Lambda'/\Lambda \approx 10^{-3} \Rightarrow$ both small. Lifetime of the vacuum with the bounce action

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Need only $S_{\text{min}} \approx 400$ for universe to survive for 10^{10} yrs $\Rightarrow$ vacuum is sufficiently long-lived.

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Summary

- ISS model $+$ auxiliary sector $\rightarrow$ fully natural model of metastable dynamical SUSY breaking
- With renormalizable retrofitting, all scales generated dynamically from dimensional transmutation — No dimensionful parameters
- Still relatively simple model (just two copies of SQCD + singlet)

Outlook

- Can add messenger sector for gauge mediation? ($\rightarrow$ Murayama/Nomura '06)
- Can use this mechanism for models of direct gauge mediation? ($\rightarrow$ Kitano/Ooguri/Ookouchi, Csáki/Shirman/Terning '06, ...)
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