Meta-Stable Dynamical Supersymmetry Breaking Near Points of Enhanced Symmetry

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UC Davis, Seminar
Monday, December 17th, 2007

based on:

(see also arxiv:0710.4311 [hep-th])
RE, Kuver Sinha, Gonzalo Torroba
Motivation

- If SUSY relevant for hierarchy problem, then

\[ M_{\text{SUSY}} \ll M_{\text{Planck}} \]

- How can we obtain this naturally?

\[ \Rightarrow \text{Dynamical Supersymmetry Breaking (DSB)} \]

- can dynamically generate a scale related to SUSY

scale that is hierarchically smaller than any

fundamental scale:

\[ \Lambda = M \ e^{-c/g(M)^2} \ll M \]

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Motivation (ctd.): DSB in \textit{stable} vacua is hard

Many non-trivial “requirements” for (stable) SUSY:

- chiral matter (some exceptions, e.g. with massless vector-like matter Intriligator, Thomas, 1996; Izawa, Yanagida, 1996)

- lifting of all non-compact flat directions and a spontaneously broken global symmetry Affleck, Dine, Seiberg, 1984

- $U(1)_R$ – symmetry or non-generic superpotential Nelson, Seiberg, 1993

$\Rightarrow$ DSB seems non-generic and hard to achieve
Motivation (ctd.): DSB in *metastable* vacua is generic

- No such requirements for DSB in *metastable* vacua!
- metastable DSB *generic*
- Intriligator, Seiberg, Shih 2006: metastable vacua in supersymmetric QCD (SQCD) with massive flavors

- **many papers:** Csaki, Shirman, Terning 2006; Murayama & Nomura; Dine, Feng & Silverstein; Franco & Kachru; Dine & Mason; Argurio, Bertolini; Kitano, Ooguri & Ookouchi; Brummer; Bai, Fan & Han; Dudas, Mourad & Nitti; Gomes-Reino & Scrucca; Amariti, Girardello & Mariotto; Ahn; Serone & Westphal; Cho & Park; Abel, Durnford, Jaeckel & Khoze; Tatar & Wetenhall; van den Broek; Ferretti; Pastras; Ooguri, Ookouchi & Park; Kawano, Ooguri & Ookouchi; Kachru, Kallosh, Linde & Trivedi; Choi, Falkowski, Nilles, Olechowski, Pokorski; Endo, Yamaguchi & Yoshioka; Choi, Jeong & Okumura; Falkowski, Lebedev & Mambrini; Kitano & Nomura; Lebedev, Nilles & Ratz; Lebedev, Loewen, Mambrini, Nilles & Ratz; Acharya, Bobkov, Kane, Kumar & Vaman (Shao); Randall & Sundrum; Giudice, Luty, Murayama & Rattazzi .........

- will discuss our model (RE, Sinha, Torroba) in this talk

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Motivation (ctd.): Why is our model interesting?

- Model Building Goals for a realistic/aesthetically pleasing theory of SUSY:
  - broken $U(1)_R$
    (here: spontaneous breaking gives non-zero gaugino masses
    + small explicit breaking gives non-zero R-axion mass)
  - No relevant parameters, all scales dynamically generated
  - Singlets coupled to DSB fields
  - Renormalizable model (calculability)
  - Large Global Symmetry (direct gauge mediated SUSY)

- Also: look for features that could be generic in the landscape of all possible SUSY gauge theories (and in the landscape of string vacua)

The model presented in this talk has all these desirable features

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Outline

A) Review of Intriligator, Seiberg & Shih (ISS) model:
   SUSY in SQCD with massive flavors

B) Our model:
   SUSY in two copies of SQCD which are coupled by a singlet
   Key features:
   - no relevant parameters (quark masses generated dynamically)
   - SUSY near enhanced symmetry points along a “pseudo-runaway”
     direction: a runaway ($V \rightarrow 0$) lifted by perturbative quantum corrections

C) i) Show metastable vacua are long-lived
   ii) Show R-symmetry is broken spontaneously and explicitly
   iii) Brief comments on direct gauge mediation, cosmology etc.

D) Conclusions
A) Review of ISS model  

ISS = Intriligator, Seiberg, Shih 2006

- ISS model: $SU(N_c)SQCD$, with $N_f$ flavors, with masses $m_{ISS}$ much smaller than strong coupling scale $\Lambda$ ($\beta_{el} = 3N_c - N_f$)

- “electric” theory (asymptotically free for $N_f < 3N_c$):

$$W_{electric} = m_{ISS} \text{ tr } Q\bar{Q}$$  \hspace{1cm} \text{(tree-level)}

- when $m_{ISS} \ll \Lambda$ have calculable quantum corrections for

$$N_c + 1 \leq N_f < \frac{3}{2}N_c$$

$\Rightarrow$ dual “magnetic” theory, which has same IR behavior as electric theory (Seiberg dual, 1994);
dual theory is infrared free (theory is said to be in the “free magnetic range”)
Review of ISS model (ctd.): the Seiberg dual

- Seiberg dual: \( SU(\tilde{N}_c) \) SQCD, \( \tilde{N}_c = N_f - N_c \),
  \( N_f^2 \) singlets \( M_{ij} = Q_i \bar{Q}_j / \Lambda \),
  and \( N_f \) magnetic quarks \((q, \bar{q})\) (all weakly coupled)
  with superpotential:

\[
W_{\text{magnetic}} = m_{\text{ISS}} \Lambda \text{tr} \, M + h \text{tr} \, qM\bar{q} \quad \text{(tree-level)}
\]

\[ g^2(\mu) \]

**magnetic theory**

is IR free

Landau pole at

\[ \tilde{\Lambda} = \Lambda \]

**electric theory**

is UV free

Strong coupling scale at \( \Lambda \)

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Review of ISS model (ctd.): \textbf{SUSY} at tree-level

- Can study \textbf{SUSY} in dual model without including gauge dynamics (these will only dynamically restore \textbf{SUSY} far away from \textbf{SUSY} vacuum, see later)

- Dual theory breaks supersymmetry at tree-level:

\[
\frac{\partial W}{\partial M_{ij}} \equiv W_{M_{ij}} = m_{\text{ISS}} \Lambda \delta_{ij} + h q_i^c \tilde{q}_{jc} \neq 0
\]

\(\delta_{ij}\) has rank \(N_f\)

\(q_i \tilde{q}_j\) has rank \(\tilde{N}_c = N_f - N_c\)

\(c = 1, \ldots, N_f - N_c\)

\(i, j = 1, \ldots, N_f\)

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Review of ISS model (ctd.): vacua are metastable

- Classical moduli space of SUSY vacua:

\[
q = (q_0 \ 0), \quad \tilde{q} = \begin{pmatrix} \tilde{q}_0 \\ 0 \end{pmatrix}, \quad M = \begin{pmatrix} 0 & 0 \\ 0 & 0 + X \cdot I_{N_c \times N_c} \end{pmatrix} \quad h q_{0i} \tilde{q}_{0j} = -m_{\text{ISS}} \Lambda \delta_{ij} \\
\]

\[i, j = 1, \ldots, N_f - N_c\]

- Many massless fields

- Pseudo-moduli: Arbitrary \((N_f-N_c) \times (N_f-N_c)\) and \(N_c \times N_c\) fields

- These obtain a non-tachyonic mass from one-loop quantum corrections (Coleman-Weinberg potential):

\[
V^{(1)}_{\text{eff}} = \frac{1}{64\pi^2} \text{STr} \left( \mathcal{M}^4 \log \frac{\mathcal{M}^2}{M_{\text{cutoff}}^2} \right)
\]

\[\Rightarrow \text{Vacua (meta)stable!}\]

Vacua at \(X=0\), i.e. \(M=0\)
Review of ISS model (ctd.): SUSY vacua far away

- Elsewhere in field space, SUSY is dynamically restored.

- For $\langle M \rangle \neq 0$, magnetic quarks are massive; integrate them out; left with pure supersymmetric Yang-Mills $\Rightarrow$ gaugino condensation generates nonperturbative superpotential

$$W_{dyn} \sim (\det M)^{1/(N_f-N_c)}$$

leads to $N_c$ SUSY vacua:

$$\langle M \rangle \sim \left( m_{ISS}^{N_f-N_c} \Lambda^{2N_c-N_f} \right)^{1/N_c}$$

- Metastable vacua long-lived for $m_{ISS} \ll \Lambda$

Going beyond ISS

- ISS contains explicit quark masses, i.e. a relevant parameter. Can $m_{\text{ISS}}$ be generated dynamically using only renormalizable operators? (not “retrofitting”, which uses non-renormalizable operators. Dine, Feng, Silverstein 2006; Aharony, Seiberg 2006.)

Simply replacing $m_{\text{ISS}}$ by $\lambda \Phi$, where $\Phi$ is a singlet, does not lead to SUSY, and gives $\Phi = 0$

$\implies$ need something more....

- Note: $W_{\text{magnetic}} = m_{\text{ISS}} \Lambda \text{tr} \ M + h \text{tr} \ qM\tilde{q}$

has a $U(1)_R$ -symmetry with charges $R[M]=2$, $R[q]=0$, $R[\tilde{q}]=0$

Since metastable state in ISS has $M=0$, the $R$-symmetry is not spontaneously broken
Going beyond ISS (ctd.)

- In ISS have small explicit R-symmetry breaking, coming from non-perturbative term (recall: R[M]=2)

\[ W_{np} \sim (\det M)^{1/(N_f-N_c)} \sim M^{N_f/(N_f-N_c)} \]

- R-symmetry breaking mass terms contributing to gaugino masses are then given by

\[ \frac{\partial^2 W_{np}}{\partial M^2} \sim M^{(2N_c-N_f)/(N_f-N_c)} \]

- But M=0 in SUSY minimum, so these contributions vanish (in free magnetic range) and thus the explicit R-symmetry breaking also does not give rise to non-zero gaugino masses
Outline

A) Review of Intriligator, Seiberg & Shih (ISS) model:

- $\text{SUSY}$ in SQCD with massive flavors

B) Our model:

- $\text{SUSY}$ in two copies of SQCD which are coupled by a singlet

  Key features:
  - no relevant parameters (quark masses generated dynamically)
  - $\text{SUSY}$ near enhanced symmetry points along a “pseudo-runaway” direction: a runaway ($V \rightarrow 0$) lifted by perturbative quantum corrections

C) i) Show metastable vacua are long-lived
   ii) Show R-symmetry is broken spontaneously and explicitly
   iii) Brief comments on direct gauge mediation, cosmology etc.

D) Conclusions
B) A Model with Moduli Dependent Masses

Consider two SUSY QCD sectors with \((N_c, N_f, \Lambda)\) & \((N'_c, N'_f, \Lambda')\) coupled by a singlet \(\Phi\)

\[
SU(N_c) \quad SU(N'_c)
\]

\[
\begin{array}{c|c|c}
Q_i & \Box & 1 \\
\overline{Q}_i & \Box & 1 \\
P_{i'} & 1 & \Box \\
\overline{P}_{i'} & 1 & \Box \\
\Phi & 1 & 1 \\
\end{array}
\]

with tree-level superpotential

\[
W = (\lambda \Phi + \xi) \text{tr}(Q \overline{Q}) + (\lambda' \Phi' + \xi') \text{tr}(P \overline{P})
\]

explicit quark mass

Note: large global symmetry \(SU(N_f)_V \times SU(N'_f)_V\)
A Model with Moduli Dependent Masses (ctd.)

For \( \xi = \xi' \) can absorb masses into \( \Phi \)

\[
W = \lambda \Phi \text{ tr}(Q\overline{Q}) + \lambda' \Phi \text{ tr}(P\overline{P}) \tag{tree-level}
\]

**Note:**
- \( W \) contains no relevant parameters, only marginal couplings
- The point at which the quarks of both sectors become massless (\( \Phi = 0 \)) coincides for both gauge groups
  (we refer to this as an enhanced symmetry point, or ESP)
- Gauging a non-anomalous discrete symmetry can make it technically natural for the ESPs of both gauge groups to coincide
- Can add \( \kappa \Phi^3 \) to \( W \) and stabilise \( \Phi \) supersymmetrically
  (Brügger 2007); we’ll find metastable vacua without this term
There are supersymmetric vacua

\[ W = \lambda \Phi \; \text{tr}(Q\overline{Q}) + \lambda' \Phi \; \text{tr}(P\overline{P}) \]  

tree-level

For \( \Phi \) very large, can integrate out Q’s and P’s to obtain two copies of pure SYM; get gaugino condensation in both sectors:  

\[ W = N_c \left[ (\lambda \Phi)^{N_f} \Lambda^{3N_c-N_f} \right]^{1/N_c} + N'_c \left[ (\lambda' \Phi)^{N'_f} \Lambda'^{3N'_c-N'_f} \right]^{1/N'_c} \]

non-perturbative

Can solve \( \partial W / \partial \Phi = 0 \)

for \( \Phi \) to find SUSY vacua

Not important for rest of the discussion

How do we choose \((N_c, N_f, \Lambda)\) and \((N'_c, N'_f, \Lambda')\)?

Primed sector:

choose \(N'_f < N'_c\) and consider energies \(E \gg \Lambda'\)

\(SU(N'_c)\) weakly coupled

Full superpotential for primed sector is

\[
\lambda' \Phi \text{ tr } P \bar{P} + (N'_c - N'_f) \left( \frac{\Lambda' 3 N'_c - N'_f}{\det P \bar{P}} \right)^{1/(N'_c - N'_f)}
\]

\(\lambda' \Phi \text{ tr } P \bar{P}\) tree-level

non-perturbative (gaugino condensation)

Affleck-Dine-Seiberg superpotential

after eliminating P’s:

\[
V \sim |\partial W / \partial \Phi|^2 \sim \Phi^{2(N'_f - N'_c)/N'_c}
\]

Key point: \(\Phi\) pushed away from 0!

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How do we choose \((N_c, N_f, \Lambda)\) and \((N_c', N_f', \Lambda')\)?

**Unprimed sector:**

Choose \(N_c + 1 \leq N_f < \frac{3}{2} N_c\) and consider energies \(E \ll \Lambda\). 

\(SU(N_c)\) strongly coupled; go to IR free weakly coupled Seiberg dual, \(SU(\tilde{N}_c), \tilde{N}_c = N_f - N_c\) (as in ISS)

**Full superpotential for unprimed sector in magnetic dual is**

\[
\begin{align*}
    m \Phi \text{ tr } M + h \text{ tr } q M \tilde{q} + (N_f - N_c) \left( \frac{\det M}{\Lambda^{3N_c - 2N_f}} \right)^{1/(N_f - N_c)} \\
    m = \lambda \Lambda \\
    M_{ij} = Q_i \bar{Q}_j / \Lambda \\
    \Lambda = \text{Landau pole in Seiberg dual}
\end{align*}
\]
The full superpotential for $\Lambda' \ll E \ll \Lambda$:

Full superpotential in this range is then:

$$W = m\Phi \text{ tr } M + h \text{ tr } qM\tilde{q} + \lambda' \Phi \text{ tr } P\bar{P} + (N'_c - N'_f) \left( \frac{\Lambda'^{3N'_c-2N_f}}{\det P\bar{P}} \right)^{1/(N'_c-N'_f)}$$

$$+ (N_f - N_c) \left( \frac{\det M}{\Lambda^{3N_c-2N_f}} \right)^{1/(N_f-N_c)}$$

negligible for $\Lambda \rightarrow \infty$

Take limit $\Lambda \rightarrow \infty$: can neglect unprimed gauge dynamics (gives dynamical SUSY restoration)
Check: No SUSY if neglect gauge dynamics of primed sector

- Neglect gauge dynamics of primed sector by taking $\Lambda' \to 0$

- Superpotential reduces to

$$W_{cl} = m\Phi \, \text{tr} \, M + h \, \text{tr} \, qM\tilde{q} + \lambda'\Phi \, \text{tr} \, P\bar{P}$$

= ISS (if $\Phi =$ constant) + additional tree-level term

No SUSY!

Instead find moduli space of SUSY vacua with $\Phi = 0$
and parametrised by $\partial W / \partial \Phi = m \, \text{tr} M + \lambda' \, \text{tr} P\bar{P} = 0$
Include gauge dynamics of primed sector:

- Take $\Lambda'$ finite, but $\lambda' \Phi \gg \Lambda'$

- $(P, \overline{P})$ are massive, and may be integrated out; again get gaugino condensation; $W$ reduces to

$$W = m\Phi \text{tr} \, M + h \text{tr} \, qM\tilde{q} + N_c' \left[ \lambda'^N_f \Lambda'^3 N_c \Lambda' - N_f' \Phi \right]^{1/N_c'}$$

- Still find no stable vacuum and SUSY not broken!

- Instead have a runaway $(V \to 0)$ towards $M \to \infty$, $\Phi \to 0$

But note: perturbative quantum corrections not yet included
Global view of potential:

Runaway ($V \to 0$) towards

$$M \to \infty, \Phi \to 0$$

Plot made with the help of K. van den Broek’s
“Vscape V1.1.0: An interactive tool for metastable vacua”
0705.2019 [hep-ph]

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Now include perturbative quantum corrections

- First expand around $M = 0$ (ESP) and let $\phi = \langle \Phi \rangle$

$$q = \begin{pmatrix} q_0 & 0 \end{pmatrix}, \quad \tilde{q} = \begin{pmatrix} \tilde{q}_0 \\ 0 \end{pmatrix}, \quad M = \begin{pmatrix} 0 & 0 \\ 0 & 0 + X \cdot I_{N_c} \end{pmatrix}$$

- $q_0$ and $\tilde{q}_0$ are $\tilde{N}_c \times \tilde{N}_c$ matrices, satisfying

$$hq_{0i} \tilde{q}_{0j} = -m_\phi \delta_{ij}, \quad i, j = 1, \ldots, N_f - N_c$$

- at $X = 0$

- at $\phi = \phi_0$

$m = \lambda \Lambda$

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Including perturbative quantum corrections (ctd.)

- Include perturbative quantum corrections (Coleman-Weinberg potential) at one-loop, from integrating out dominant massive fluctuations around (*):
  - corrections are logarithmic far from ESP and thus too small to stop the runaway
  - corrections are quadratic near ESP at $X = 0$ and can thus be important for potential:

$$V_{CW} = N_c b h^3 m |\phi||X|^2 + \ldots$$

$$m_{CW}^2 = b = (\log 4 - 1)/8\pi^2 \tilde{N}_c$$

(cf. ISS)

Other corrections not qualitatively important
Perturbative quantum corrections give metastable vacuum

- Find *metastable vacuum*!
- Need to choose $m = \lambda \Lambda$ much smaller than $m_{CW}$ - i.e.

$$
\epsilon \equiv \frac{m^2}{m_{CW}^2} = \frac{m}{N_c b h^3 \phi} \ll 1
$$

$\implies$ choose coupling $\lambda$ small enough

**CW potential overwhelms curvature (but not height) of the classical potential**

$$
|X_0| \sim \frac{m}{bh^3}
$$

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Potential near metastable vacuum:

Plot made with the help of “Vscape” (van den Broek)

**Pseudo-Runaway**: runaway lifted by *perturbative* quantum corrections

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  Key features:
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C) i) Show metastable vacua are long-lived
   ii) Show R-symmetry is broken spontaneously and explicitly
   iii) Brief comments on direct gauge mediation, cosmology etc.

D) Conclusions
Metastable vacua are parametrically long-lived

Field tunnels in X-direction, with fixed $|\phi| = |\phi_0|$

Model potential in X-direction by a triangular barrier  

\[
|X_0| \sim \frac{m}{bh^3}
\]

\[
|X_{\text{peak}}| \sim \sqrt{m|\phi_0|}
\]

\[
|\tilde{X}| \sim b h^3 |\phi_0|
\]

\[
|X_{W\phi = 0}| \sim |\phi_0|
\]

\[
|X_{W\phi = 0}| \sim 1
\]

Plot made with the help of "Vscape", 0705.2019

Duncan, Jensen 1992

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Metastable vacua are parametrically long-lived (ctd.)

Thus: \[ |X_0| \ll |X_{\text{peak}}| \ll |\tilde{X}| \quad \text{as} \quad \epsilon \to 0 \]

Lifetime: \[ \sim e^B \]

Bounce Action: \[ B \sim \frac{\tilde{X}^4}{V(X_{\text{peak}}) - V(X_0)} \sim b h^3 \frac{1}{\epsilon^2} \]
\[ \to \infty \quad \text{as} \quad \epsilon \to 0 \]

Meta-stable vacua are parametrically long-lived for

\[ \epsilon \equiv \frac{m^2}{m_{CW}^2} = \frac{m}{N_c b h^3 \phi} \ll 1 \quad (m = \lambda \Lambda) \]
Approximate R-symmetry implies long-lived metastable vacua

- Problem with stable DSB (i.e. no SUSY vacua):
  generically require superpotential with $U(1)_R$ - symmetry
  BUT: to allow non-zero gaugino masses, R-symmetry
  should be broken explicitly and/or spontaneously

- Spontaneous breaking gives a massless R-axion

- Need explicit breaking to give R-axion a non-zero mass
  $\Rightarrow$ reintroduces SUSY vacua
  $\Rightarrow$ metastable DSB vacuum

- a small explicit breaking allows for an approximate
  R-symmetry, and a long-lived metastable state

Nelson, Seiberg 1993
Bagger, Poppitz, Randall 1994
Intriligator, Seiberg, Shih 2007
How can one break R-symmetry?

- Can add gauge interactions
  - Witten 1981; Dine, Mason 2006;
  - Csaki, Shirman, Terning 2006;
  - Intriligator, Seiberg, Shih 2007

- Consider more exotic ‘O Raifeartaigh models, containing a field with R-charge different from 0 or 2
  - Shih 2007
  - such models usually have runaway directions and thus vacua are only metastable - Ferretti 2007
  (Note: effective theory for many metastable DSB models can be described by an O’Raifeartaigh-type model)

- Add operators which explicitly break R-symmetry by small amount
  - Nomura, Murayama 2006, 2007; Aharony, Seiberg 2006;

- Our model shows another way R-symmetry may be broken

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Our model breaks R-symmetry \textit{spontaneously}

For our model:

Recall: Low energy superpotential (for $\Lambda \to \infty$)

$$W = m \Phi \text{tr} M + h \text{tr} q M \tilde{q} + N'_c \left[ \lambda'^N_f \Lambda'^{3N'_c - N'_f} \Phi^{N'_f} \right]^{1/N'_c}$$

It has an exact R-symmetry:

$$R_\phi = 2 \frac{N'_c}{N'_f}, \quad R_X = 2 \frac{N'_f - N'_c}{N'_f}, \quad R_q = R_{\tilde{q}} = \frac{N'_c}{N'_f}$$

\textbf{BUT:} these fields all have non-zero VEVs

$$\implies U(1)_R \text{- symmetry is \textit{spontaneously} broken!}$$

Pseudo-Runaways can break R-symmetry \textit{spontaneously}
Our model also breaks R-symmetry \textit{explicitly}

Including gauge dynamics of unprimed sector (finite $\Lambda$), R-symmetry is anomalous and \textit{explicitly} broken by small amount (as in ISS)

$\Rightarrow$ R-axion obtains mass

Therefore: - Gauginos can obtain a mass
  - R-axion has a mass

$\Rightarrow$ Good!
Another example with spontaneous R-symmetry breaking along a pseudo-runaway

- Another example with a pseudo-runaway direction was found afterwards by Abel, Durnford, Jaeckel, Khoze 2007

- They deformed the ISS model by adding a baryon term

\[ W = \tilde{q}_{i\alpha} M_{ij} q_j^\alpha + \mu^2 M_{ii} + m \epsilon^{rs} \epsilon^{\alpha\beta} q_{r\alpha} q_{s\beta} \]

(has relevant couplings) (has field with R-charge $\neq 0,2$):

- Pseudo-runaway to a non-supersymmetric metastable minimum of ISS type

- R-symmetry also broken spontaneously
Metastability for non-coincident ESPs is fine-tuned

Recall, general superpotential is

\[ W = (\lambda \Phi + \xi)\text{tr}(Q\overline{Q}) + (\lambda' \Phi + \xi')\text{tr}(P\overline{P}) \]

- now assume \( \xi \neq \xi' \); can redefine \( \Phi \) and absorb \( \xi \);
- Have ESPs at: \( \Phi = 0 \) for unprimed sector
  \( \Phi \sim -\xi' \) for primed sector
- Low-energy superpotential becomes:

\[ W = m\Phi \text{tr} \ M + h \text{tr} \ qM\tilde{q} + N'_c \left[ \lambda''N'_f \Lambda'^3N'_{c''}e^{-N'_f} \ (\Phi + \xi)N'_f \right]^{1/N'_c} \]

- Generically \( \xi' \) is of order the UV cutoff, i.e. very large
Metastability for non-coincident ESPs is fine-tuned (ctd.)

Again find metastable minimum, but condition

\[ m \ll m_{CW} \]

leads to:

\[ m^3 \ll \frac{b \hbar^3 \left( \frac{N_c^f \lambda^{N_f^f/N_c^f} \Lambda^{(3N_c^f-N_f^f)/N_c^f}}{\xi^{3-2N_f^f/N_c^f}} \right)^2}{\xi^{3-2N_f^f/N_c^f}} \]

Large fine-tuning on m!

Thus, non-coincident ESPs lead to metastable vacua but these are not generic and require fine-tuning

No fine-tuning for coincident ESPs, so our setup is generic
Our model allows for Direct Gauge Mediation

- Subgroup of large global symmetry in SQCD can be identified with SM gauge group and weakly gauged

  e.g. Csaki, Shirman, Terning 2006; Murayama, Nomura 2006; Dine, Mason 2006; Ibe, Kitano 2006; Ibe, Kitano 2007; Aharony, Seiberg 2006; Amariti, Girardello, Mariotti 2006, 2007; Kitano 2006; Kitano, Ooguri, Ookouchi 2006;

- Very large global symmetry in our model:

  \[ SU(N_f) \times SU(N'_f) \]

- Also: have singlet field in model
Cosmology favors DSB vacua

- Early universe favors DSB vacua over SUSY vacua:
  - continuous (moduli) space of DSB vacua versus small number of discrete SUSY vacua
  - thermal effective potential favors DSB vacua since they are closer to origin of moduli space and have more light fields

Also:
- Gentle slope of potential could be useful for inflation

Craig, Fox, Wacker, 2006;
Fischler, Kaplunovsky, Krishnan, Mannelli, Torres, 2006;
Abel, Chu, Jaeckel, Khoze, 2006;
Abel, Jaeckel, Khoze, 2006;
L Anguelova, R Ricci, S Thomas, 2007;
Conclusions

Our SUSY model has the following desirable features:
- Renormalizability
- Large Global Symmetry
- No relevant parameters, all scales dynamically generated
- spontaneous and explicit breaking of $\text{U}(1)_R$ – symmetry
- parametrically long-lived metastable vacua

Interesting feature: “pseudo-runaways”- runaway directions lifted by perturbative quantum corrections

Metastable SUSY seems rather generic near certain Enhanced Symmetry Points on Moduli Spaces

⇒ May have important implications for the landscape

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