Supersymmetry Breaking Triggered by Monopoles

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Motivation

- **Always looking for new ways to break SUSY.**

  $\rightarrow$ The unique characteristics of dynamical monopoles makes them worthy of investigation in this context.

  - Seiberg-Witten methods allow us to find theories with massless monopoles and/or dyons, and include them in model building.

- Light monopoles *might* play a role in electroweak symmetry breaking (Csaki, Shirman, Terning 2010)

  $\longrightarrow$ Problems with calculablity. Toy Models?

(Very) Brief Review:

Seiberg-Witten Analysis

of

$\mathcal{N} = 2$ $SU(2)$ SYM

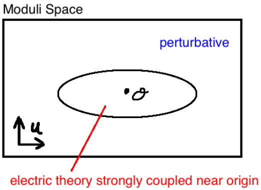
$\mathcal{N} = 2$ $SU(2)$ SYM (Seiberg, Witten 1994)

A^a

λ^a ψ^a

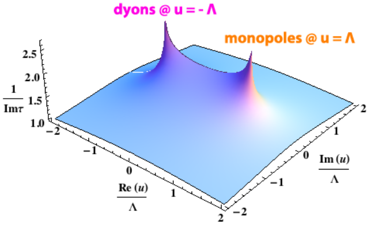
ϕ^a

D-flat: $[\phi^\dagger, \phi] = 0 \implies$ Moduli Space parameterized by $u = \frac{1}{2}\mathrm{Tr}\phi^2$. $SU(2) \to U(1)$



Seiberg-Witten Analysis

Some topological objects become massless, elementary and weakly coupled:



Near monopole singularity: $U(1)_{mag}$ with $W_{eff} \approx (u - \Lambda) M\tilde{M}$.

Upshot

- Can exactly solve for low-energy theory of $\mathcal{N} = 2$ $SU(2)$ SYM.
  - $\rightarrow$ generalizes to $SU(N)$ with fundamental flavors ($\square$, $\bar{\square}$ hypers)
  - $\rightarrow$ cool stuff at higher rank: $SU(3)$ SYM can have simultaneously massless electric & magnetic charges! (Argyres-Douglas Point)
- Can softly break to $\mathcal{N} = 1$ to learn about nontrivial $\mathcal{N} = 1$ physics, e.g. gaugino condensation as magnetic Meissner effect.
- These methods can give us some information even in $\mathcal{N} = 1$ theories.

Application of SW Methods to $\mathcal{N} = 1$ Theories

$$\downarrow$$

The $SU(2)^3$ Model

Application to $\mathcal{N} = 1$ SUSY (Intriligator, Seiberg '94)

Apply SW methods to $\mathcal{N} = 1$ theories in the Coulomb phase.

- Can calculate the following as a function of the moduli:
  - holomorphic low-energy $U(1)$ gauge coupling τ_{eff}. If singular, we know there are light monopoles or dyons!
  - effective superpotential near the singularity.
- Cannot calculate
  - explicit masses for monopoles/dyons.
  - Kähler potential

This allows us to identify $\mathcal{N} = 1$ theories with light monopoles and dyons, and learn something about their low-energy behavior.

$SU(2)^3$ Model

(Csaki, Erlich, Freedman, Skiba '02)

	$SU(2)_1$	$SU(2)_2$	$SU(2)_3$
Q_1	$\square$	$\square$	
Q_2		$\square$	$\square$
Q_3	$\square$		$\square$

4 moduli space coordinates:

$M_i = Q_i Q_i$

$T = Q_1 Q_2 Q_3$

Similar to $N = 2$ SU(2) SYM: When

$$\Lambda_1^4 M_2 + \Lambda_2^4 M_3 + \Lambda_3^4 M_1 - M_1 M_2 M_3 + T^2 \longrightarrow \pm 2\Lambda_1^4 \Lambda_2^4 \Lambda_3^4$$

magnetic or dyonic charges become massless, elementary and weakly coupled.

Near monopole singularity, the effective superpotential is

$$W_{eff} = \left[-M_1 - M_2 - M_3 + \frac{M_1 M_2 M_3}{\Lambda^2} - \frac{T^2}{\Lambda} + 2\Lambda \right] E_+ \tilde{E}_+$$

(Rescaled moduli, and set $\Lambda_i = \Lambda$ for simplicity.)

Effective Theory

- **To analyze SUSY-breaking, we need to parameterize our ignorance of the Kahler potential.**
- To restrict Kahler using global symmetries, expand around particular point in moduli space:

$$M_1 = 2\Lambda + \delta M_1, \qquad M_2 = \delta M_2, \quad M_3 = \delta M_3, \quad T = \delta T.$$

- A global $\mathbb{Z}_4$ symmetry (M_i, T charge 1, 2) is broken to $\mathbb{Z}_2$. This forbids $\delta M_i \delta T$ Kahler mixing at quadratic order.
- It is possible to define (approximately) canonical fluctuations $\tilde{M}_i$ around $M_1 = 2\Lambda$. The effective superpotential becomes

$$W_{eff} = \left[a\tilde{M}_1 + b\tilde{M}_2 + c\tilde{M}_3 - d\frac{T^2}{\Lambda} + \text{H.O.T.} \right] E_+ \tilde{E}_+.$$

- **Can this theory be modified to break SUSY?**

Shih model of SUSY breaking

Shih's O'Raifeartaigh model (2008)

- We will deform the $SU(2)^3$ theory to become this model in a low-energy limit.
- generalized O'Raifeartaigh model with R-charges other than $0, 2$, which can break R-symmetry without tuning.
- $W = X(f + \lambda\phi_1\phi_2) + m_1\phi_1\phi_3 + \frac{1}{2}m_2\phi_2^2$
  - This is generic for $R_X = 2, R_{\phi_1} = -1, R_{\phi_2} = 1, R_{\phi_3} = 3$.
  - Two dimensionless parameters control whether SUSY and R-symmetry can be spontaneously broken in a metastable vacuum:

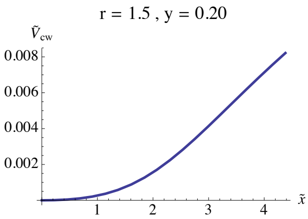
$$y = \frac{\lambda f}{m_1 m_2} \quad , \qquad r = \frac{m_2}{m_1},$$

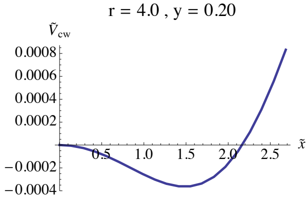
Minimizing the scalar potential

- For $y < 1$, there exists a stable SUSY-breaking pseudomoduli space

$$\phi_i = 0 \ , \qquad X = \text{undetermined at tree-level} \quad \text{with } |X| < X_{max}$$

- 1-loop quantum corrections generate $V_{\text{CW}}(|X|)$:

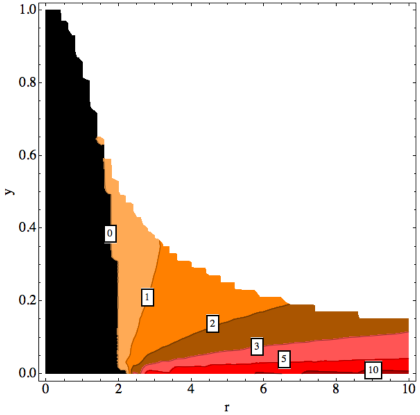




- There is also a SUSY-runaway → metastable ~~SUSY~~.

SUSY and R

For $y < 1$, the Shih-model can exhibit SUSY. For $r \gtrsim 2$, also have R.



$\langle X \rangle$ in units of $\sqrt{f/\lambda}$

Scaling Behavior of V_{CW}

- The deformed $SU(2)^3$ model will resemble the Shih-model up to uncalculable corrections.
- To ensure that the false vacuum is not destabilized we have to understand how the 1-loop potential scales. Numerically we find
  - $y < y_{max} \approx 2/r$ for ~~SUSY~~
  - $\langle X \rangle \approx (1 - y^2) \frac{m_2}{4\lambda}$
  - $m_X \sim \frac{1}{3} \frac{\sqrt{\lambda^5 f^3}}{m_1 m_2}$
  - $\left[\frac{\Delta V}{\Delta |X|}\right]_{max} \sim \frac{1}{8\pi^2} \frac{\lambda^3 f^2}{m_2}$

  ↑ This indicates how robustly the pseudomodulus X is stabilized.

SUSY-Breaking triggered by Monopole Condensation

Deforming the $SU(2)^3$ model

- We will deform the $SU(2)^3$ model to get an effective Shih model of metastable ~~SUSY~~.

→ We would like the ~~SUSY~~ to vanish in the absence of a monopole condensate.

- Consider $SU(2)^3$ model around $M_1 = 2\Lambda$:

$$W_{eff} \approx \left[a\tilde{M}_1 + b\tilde{M}_2 + c\tilde{M}_3 - d\frac{\tilde{T}^2}{\Lambda} \right] E_+ \tilde{E}_+ .$$

Add some tree-level terms and extra $SU(2)^3$ singlet fields:

$$\delta W = -\mu^2 \tilde{M}_1 + \lambda \tilde{M}_2 \phi_1 \phi_2 + \frac{1}{2} m_2 \phi_2^2 + m_1 \phi_1 \phi_3 + m_Z Z T + m_Y \tilde{M}_3 Y$$

S̶U̶S̶Y̶ Mechanism

$$W_{eff} \approx \left[a\tilde{M}_1 + b\tilde{M}_2 + c\tilde{M}_3 - d\frac{T^2}{\Lambda}\right] E_+\tilde{E}_+ - \mu^2\tilde{M}_1 + \lambda\tilde{M}_2\phi_1\phi_2 + \frac{1}{2}m_2\phi_2^2 + m_1\phi_1\phi_3 + m_Z ZT + m_Y\tilde{M}_3 Y$$

$F_{\tilde{M}_1} \to \langle E_+\tilde{E}_+\rangle \sim \mu^2 \Rightarrow \tilde{M}_2$ gets a tadpole $\sim \langle E_+\tilde{E}_+\rangle \sim \mu^2$.

(spectator moduli are stabilized by giving them a mass with singlets)

$\Rightarrow$ effective Shih-model with $X \to \tilde{M}_2$, $f \to \sim \langle E_+\tilde{E}_+\rangle$

Metastable SUSY-breaking triggered by monopole condensation!

Electric Theory

	$SU(2)_1$	$SU(2)_2$	$SU(2)_3$
Q_1	$\square$	$\square$	
Q_2		$\square$	$\square$
Q_3	$\square$		$\square$

$SU(2)$'s become strong below scale Λ

$$W_{\rm tree} = \tilde{m}(QQ)_A + \frac{\tilde{\lambda}}{\Lambda_{UV}}(QQ)_B\phi_1\phi_2 + \frac{1}{2}m_2\phi_2^2 + m_1\phi_1\phi_3 + \frac{a_Z}{\Lambda_{UV}}Q_1Q_2Q_3Z + a_y(QQ)_C Y, \qquad (\Lambda_{UV} \gg \Lambda)$$

- To ensure vacuum stability,
  - $(QQ)_{A,B,C}$ are linear combinations of Q_1^2, Q_2^2, Q_3^2 and Λ^2 that become canonical $\tilde{M}_i$ in the IR. Have to be lined up to a precision of $\sim 10^{-2} - 10^{-3}$,
  - Stability against Kähler corrections requires $m \ll m_{1,2} \ll \Lambda \ll \Lambda_{UV}$
- $\Lambda \to 0$ restores SUSY.

Other Deformations

It is instructive to embed the Shih model differently into $SU(2)^3$.

$$W_{eff} \approx \left[a\tilde{M}_1 + b\tilde{M}_2 + c\tilde{M}_3 - d\frac{T^2}{\Lambda} \right] E_+ \tilde{E}_+$$

- Composite ϕ_2 instead of pseudomodulus X:

$$\delta W \;=\; -f\tilde{M}_1 + X(\lambda T\phi_1 - \mu^2) + m_1\phi_1\phi_3 + m_Z Z\tilde{M}_2 + m_Y\tilde{M}_3 Y$$

  No Good: Not dynamical ~~SUSY~~.

- Composite ϕ_2 and pseudomodulus X:

$$\delta W \;=\; -f\tilde{M}_1 + \lambda\tilde{M}_2 T\phi_1 + m_1\phi_1\phi_3 + m_Y\tilde{M}_3 Y$$

  No Good: Cannot guarantee stability of vacuum.

Nevertheless, this method of constructing monopole models that break $\mathcal{N} = 1$ SUSY should be fairly general.

Conclusion

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- Seiberg-Witten methods give us a handle on topological monopoles and open up new model-building possibilities.
- We show that metastable SUSY-breaking can be triggered by monopole condensation.
- These strategies should make it possible to induce SUSY-breaking in a variety of models in the Coulomb phase by obtaining different low-energy ~~SUSY~~ models.
  - $\rightarrow$ Lots of things one could try!
- It would be very interesting to try and break SUSY in theories with light electric *and* magnetic charges.