

Hunting for SUSY Breaking Vacua in Theories that S-Confine

John D. Mason
SUSY Breaking '11
May 19th 2011

Tongyan Lin, JM, Aqil Sajjad : to appear

Motivation

SUSY breaking is straightforward to arrange by hand:

$$W = X(A^2 - F) + mAY$$

Would like to understand:

- 1) Dynamical generation of all mass scales.
- 2) Why certain operators are absent (i.e. origin of the R-symmetry)

Let's see what types of OR models can emerge from simple strong gauge dynamics

Outline

- $N=1$ $SU(N)$ S-Confining Theories
- Theory 8
- Theory 7
- Conclusions

S-confinement

- 1) All degrees of freedom in the IR are gauge invariant composites
- 2) Admits a smooth effective theory in terms of gauge invariants everywhere (i.e. includes the origin)
- 3) A Dynamical Superpotential gets generated

S = “screening” or “smooth”

Csaki, Schmaltz, Skiba (1997)

$N=1$ $SU(N)$ S-confining Theories

Theory 1 :	$SU(N) \mid N + 1 \times (\square + \bar{\square})$	}	Seiberg (1994)
Theory 2 :	$SU(2N) \mid \begin{array}{ c } \hline \square \\ \hline \end{array} + 2N \bar{\square} + 4 \square$		
Theory 3 :	$SU(2N + 1) \mid \begin{array}{ c } \hline \square \\ \hline \end{array} + (2N + 1) \bar{\square} + 4 \square$	}	Murayama (1995) Poppitz, Trivedi (1996)
Theory 4 :	$SU(2N) \mid \begin{array}{ c } \hline \square \\ \hline \end{array} + \begin{array}{ c } \hline \bar{\square} \\ \hline \end{array} + 3(\square + \bar{\square})$		
Theory 5 :	$SU(2N + 1) \mid \begin{array}{ c } \hline \square \\ \hline \end{array} + \begin{array}{ c } \hline \bar{\square} \\ \hline \end{array} + 3(\square + \bar{\square})$	}	Pouliot (1996)
Theory 6 :	$SU(6) \mid \begin{array}{ c } \hline \square \\ \square \\ \hline \end{array} + 4(\square + \bar{\square})$		
Theory 7 :	$SU(5) \mid 3(\begin{array}{ c } \hline \square \\ \hline \end{array} + \bar{\square})$	}	Csaki, Schmaltz, Skiba (1997)
Theory 8 :	$SU(5) \mid 2\begin{array}{ c } \hline \square \\ \hline \end{array} + 4 \bar{\square} + 2 \square$		
Theory 9 :	$SU(6) \mid 2\begin{array}{ c } \hline \square \\ \hline \end{array} + 5 \bar{\square} + \square$	}	Veldhuis (1998)
Theory 10 :	$SU(7) \mid 2\begin{array}{ c } \hline \square \\ \hline \end{array} + 6 \bar{\square}$		



N=1 SU(N) S-confining Theories

Theory 1 : $SU(N) \mid N + 1 \times (\square + \bar{\square})$

Seiberg (1994)

Theory 2 : $SU(2N) \mid \begin{array}{|c|} \hline \square \\ \hline \end{array} + 2N \bar{\square} + 4 \square$

Murayama (1995)

Theory 3 : $SU(2N + 1) \mid \begin{array}{|c|} \hline \square \\ \hline \end{array} + (2N + 1) \bar{\square} + 4 \square$

Poppitz, Trivedi (1996)

Theory 4 : $SU(2N) \mid \begin{array}{|c|} \hline \square \\ \hline \end{array} + \begin{array}{|c|} \hline \bar{\square} \\ \hline \end{array} + 3(\square + \bar{\square})$

Pouliot (1996)

Theory 5 : $SU(2N + 1) \mid \begin{array}{|c|} \hline \square \\ \hline \end{array} + \begin{array}{|c|} \hline \bar{\square} \\ \hline \end{array} + 3(\square + \bar{\square})$

See Y. Shadmi's Talk

Theory 6 : $SU(6) \mid \begin{array}{|c|} \hline \square \\ \hline \square \\ \hline \end{array} + 4(\square + \bar{\square})$

Csaki, Schmaltz, Skiba (1997)

Theory 7 : $SU(5) \mid 3(\begin{array}{|c|} \hline \square \\ \hline \end{array} + \bar{\square})$

Theory 8 : $SU(5) \mid 2\begin{array}{|c|} \hline \square \\ \hline \end{array} + 4 \bar{\square} + 2 \square$

Veldhuis (1998)

Theory 9 : $SU(6) \mid 2\begin{array}{|c|} \hline \square \\ \hline \end{array} + 5 \bar{\square} + \square$

I'll discuss these two

Theory 10 : $SU(7) \mid 2\begin{array}{|c|} \hline \square \\ \hline \end{array} + 6 \bar{\square}$

Theory 8 (elementary)

$$SU(5) \mid 2\begin{array}{|c|} \hline \square \\ \hline \end{array} + 4\bar{\square} + 2\square \quad W = 0$$

	$SU(5)$	$SU(2)$	$SU(4)$	$SU(2)$	$U(1)_1$	$U(1)_2$	$U(1)_R$
A	$\begin{array}{ c } \hline \square \\ \hline \end{array}$	\square	1	1	0	-1	0
\bar{Q}	\square	1	\square	1	1	1	$\frac{1}{3}$
Q	\square	1	1	\square	-2	1	$\frac{1}{3}$

Possesses a considerable amount of global symmetry.
 Superpotential is not modified, even non-perturbatively

Theory 8 (S-Confining)

$$P_1, P_2, X, Y, Z$$

$$W^{(dyn)} = \frac{1}{\Lambda^9} \left[XYZ + Y^2 P_1^2 + Y P_2 X P_1 + P_2^2 Y^2 \right]$$

	$SU(5)$	$SU(2)$	$SU(4)$	$SU(2)$	$U(1)_1$	$U(1)_2$	$U(1)_R$
$P_1 = QQ\bar{Q}$		1	□	□	-1	2	2
$X = A\bar{Q}^2$		□	□	1	2	1	2
$P_2 = A^2Q$		□□	1	□	-2	-1	3
$Y = A^3\bar{Q}$		□	□	1	1	-2	3
$Z = A^2Q^2\bar{Q}$		1	□	1	-3	1	1

Global anomalies match!

Theory 8 (perturbed)

$$\delta W = \lambda_{\bar{\alpha}\bar{\beta}}^i A^i \bar{Q}^\alpha \bar{Q}^\beta$$

$$\lambda_{\bar{\alpha}\bar{\beta}}^i = \lambda \left[\begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix} \right] \quad \begin{array}{l} i : SU(2) \\ \alpha, \beta : SU(4) \end{array}$$

	$SU(5)$	#	$Sp(4)$	$SU(2)$	$U(1)$	$U(1)_R$
A	$\begin{array}{ c } \hline \square \\ \hline \end{array}$	2	1	1	2	0
\bar{Q}	$\begin{array}{ c } \hline \square \\ \hline \end{array}$	1	\square	1	-1	1
Q	$\begin{array}{ c } \hline \square \\ \hline \end{array}$	1	1	\square	-4	-1

Some symmetry is explicitly broken

Theory 8 (perturbed and confined)

$$\delta W = \lambda_{\bar{\alpha}\bar{\beta}}^i A^i \bar{Q}^\alpha \bar{Q}^\beta \quad \rightarrow \quad \delta W = F_{\bar{\alpha}\bar{\beta}}^i X_i^{\alpha\beta}$$

$$W = XYZ + \frac{Y^2 P_1^2}{\Lambda^5} + \frac{Y P_2 X P_1}{\Lambda^5} + \frac{P_2^2 Y^2}{\Lambda^5}$$

$$\lambda \ll 1 \rightarrow F \sim \lambda \Lambda^2 \ll \Lambda^2$$

Theory 8 (perturbed and confined)

$$\delta W = \lambda_{\bar{\alpha}\bar{\beta}}^i A^i \bar{Q}^\alpha \bar{Q}^\beta$$



$$\delta W = F_{\bar{\alpha}\bar{\beta}}^i X_i^{\alpha\beta}$$

$$W = XYZ + \frac{Y^2 P_1^2}{\Lambda^5} + \frac{Y P_2 X P_1}{\Lambda^5} + \frac{P_2^2 Y^2}{\Lambda^5}$$

Irrelevant
couplings

$$W = hXYZ + FX$$

$$F = \lambda\Lambda^2$$

More specifically ...

	$SU(5)$	#	$Sp(4)$	$SU(2)$	$U(1)$	$U(1)_R$
P_1		1	\square	\square	-5	0
X		2	$\begin{matrix} \square \\ \square \end{matrix}$	1	0	2
P_2		3	1	\square	0	-1
Y		2	\square	1	5	1
Z		1	\square	1	-5	-1

$$W = \lambda_{\bar{\alpha}\bar{\beta}}^{\bar{i}} X_i^{\alpha\beta} + \epsilon_{\alpha\beta\delta\gamma} \epsilon^{ij} X_i^{\alpha\beta} Y_j^\delta Z^\gamma \quad \Rightarrow \quad F_{\bar{\alpha}\bar{\beta}}^{\bar{i}} - (Y^{\bar{i}} Z)_{\bar{\alpha}\bar{\beta}} = 0$$

These F-term equations have no solution. It is essentially a rank breaking condition, but is not solved because of a 2x4x4 tensor rank.

Theory 8 (pick a vacuum)

$$X = 0$$

$$Y_{\alpha}^{(1)} = \left(0, 0, 0, \frac{1}{2^{1/4}}\right) \sqrt{F}$$

$$Y_{\alpha}^{(2)} = \left(0, 0, 0, -\frac{1}{2^{1/4}}\right) \sqrt{F}$$

$$Z_{\alpha} = \left(0, 0, 0, 2^{1/4}\right) \sqrt{F}$$

$$Sp(4) \times U(1) \rightarrow SU(2) \times U(1)$$



7 Goldstone Bosons

Theory 8 (calculate masses)

At Tree level there are 20 dof in X, Y and Z that are massless
At one-loop level only 7 remain massless.
These are the goldstones. All others have mass.

$P_1, P_2 \rightarrow$ “Higgsing pseudo-moduli” Intriligator, Shih,
Sudano (2009)

Gauging a combination of any of 4 anomaly free U(1)s
will stabilize these at 2-loop w/ positive masses.

$$m_{P_1, P_2}^2 \sim \frac{g^2 h^4}{(16\pi^2)^2} |F|$$

Theory 8 (recap)

$$SU(5) \mid 2 \square + 4 \bar{\square} + 2 \square \quad \delta W = \lambda_{\bar{\alpha}\bar{\beta}}^i A^i \bar{Q}^{\alpha} \bar{Q}^{\beta}$$

SUSY is broken by tree-level perturbation and s-confining dynamics. Vacuum is stable and calculable after a U(1) is gauged. All mass scales are dynamically generated and are the same order of magnitude: $|F|$.

Theory 7 (elementary)

$$SU(5) \mid 3 \left(\square + \bar{\square} \right) \quad W = 0$$

	$SU(5)$	$SU(3)$	$SU(3)$	$U(1)$	$U(1)_R$
A	\square	\square	1	1	0
\bar{Q}	$\bar{\square}$	1	\square	-3	$\frac{2}{3}$

This is just the Grand Unified Supersymmetric Standard Model without Higgs doublets. $W = 0$ is exact, even non-perturbatively.

Theory 7 (confined)

X, Y, Z

	$SU(5)$	$SU(3)$	$SU(3)$	$U(1)$	$U(1)_R$
$X = AQ^2$		\square	$\bar{\square}$	-5	$\frac{4}{3}$
$Y = A^3\bar{Q}$		$\begin{array}{ c } \hline \square \\ \hline \square \\ \hline \end{array}$	\square	0	$\frac{2}{3}$
$Z = A^5$		$\begin{array}{ c c } \hline \square & \square \\ \hline \end{array}$	1	5	0

$$W = XYZ + Y^3$$

Note that there no terms higher than cubic order.

Theory 7 (perturbed)

$$\delta W = \lambda A \bar{Q}^2 + \frac{A^3 \bar{Q}}{M_p} + \frac{A^5}{M_p^2}$$



$$W = XYZ + Y^3 + \lambda \Lambda^2 X + \left(\frac{\Lambda}{M_p}\right) \Lambda^2 Y + \left(\frac{\Lambda}{M_p}\right)^2 \Lambda^2 Z$$

$$\epsilon = \frac{\Lambda}{M_p} \quad F = \lambda \Lambda^2 \quad \epsilon \ll \lambda \ll 1$$

Only keep leading term for now.

$$W = XYZ + Y^3 + FX$$

Theory 7 (more specifically)

$$\delta W = \lambda_{i\bar{\alpha}} \epsilon^{\alpha\beta\gamma} A^i \bar{Q}_\alpha \bar{Q}_\beta \quad \lambda_{i\bar{\alpha}} = \lambda \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$W = X^{i\bar{\alpha}} Y^{a\alpha} T_{j\bar{k}}^a Z^{kl} \epsilon_{ijl} + \epsilon_{\alpha\beta\gamma} f^{abc} Y^{a\alpha} Y^{b\beta} Y^{c\gamma} + F_{i\alpha} X^{i\bar{\alpha}}$$

This theory has a runaway direction:

$$X = 0, \quad Y \rightarrow 0, \quad Z \rightarrow \infty$$

At large Z VEVs the gauge group is Higgsed and we can use the higgsed description.

Theory 7 (at large VEVs)

$$\delta W = \lambda A \bar{Q}^2 + \frac{A^3 \bar{Q}}{M_p} + \frac{A^5}{M_p^2}$$

If all flat directions can be lifted then:

- 1) Near the origin the confined description indicates that the potential slopes away from the origin.
- 2) Far from the origin the elementary dof description yields a rising potential.
- 3) The theory must stabilize in-between. SUSY and R-symmetry are broken but not calculable.

Theory 7 (recap)

$$SU(5) \mid 3 \left(\square + \bar{\square} \right)$$

$$\delta W = \lambda A \bar{Q}^2 + \frac{A^3 \bar{Q}}{M_p} + \frac{A^5}{M_p^2}$$

- 1) SUSY Breaking
- 2) R-symmetry Breaking
- 3) Not Calculable

Conclusions

S-Confining Theories have rich gauge dynamics that can be used to generate O'R models from the balance of a tree-level interaction and the confining superpotential.

All mass scales can be dynamically generated.

Theory 8 has a vacuum near the origin with SUSY Breaking and no R-symmetry Breaking.

Theory 7 has a vacuum in the incalculable regime with SUSY Breaking and R-symmetry Breaking.

Thank you!