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$SU(5)$ $\overline{\boxminus} + \boxminus$

$SU(5)$ $\boxminus + \overline{\boxminus} + 4(\square + \bar{\square})$

	$SU(5)$	$SU(4)$
$M \sim Q\bar{Q}$	$\bar{\square}$	$\square$
$H \sim A\bar{Q}^2$	$\boxminus$	1
$B_1 \sim A^2 Q$	1	$\square$
$B_3 \sim A Q^3$	1	$\bar{\square}$
$\bar{B} \sim \bar{Q}^5$	1	1

$$W = \frac{1}{\Lambda^4}\Big((A^2Q)\overbrace{(Q\bar{Q})^3(A\bar{Q}^2)} + (AQ^3)(Q\bar{Q})(A\bar{Q}^2)^2 + (\bar{Q}^5)(A^2Q)(AQ^3)$$

$$+ \underbrace{\sum_{i=1}^{4} m(Q_i\bar{Q}_i) + \sum_{i,j\le 4}\lambda_{ij}(A\bar{Q}_i\bar{Q}_j)}_{\text{lifts flat directions}}\Big)$$

(1) $\dfrac{\partial W}{\partial(\bar{Q}^5)} = (A^2Q)(AQ^3) = 0$

(2) $\dfrac{\partial W}{\partial(Q\bar{Q})_{ij}} = 3(Q\bar{Q})^2(A^2Q)(A\bar{Q}^2) + (AQ^3)(A\bar{Q}^2) + m = 0$

assume $(A^2Q)\neq 0 \Rightarrow (AQ^3) = 0$

mult. (2) by (A^2Q) antisymm. $\Rightarrow$ 1st term vanish

$$(AQ^3)(A\bar{Q}^2) + m = 0$$

no solution

assume $(AQ^3)\neq 0 \Rightarrow (A^2Q) = 0$
plug into (2)

multiply by (AQ^3) antisymm. $\Rightarrow 0 = -m$

no solution

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Intriligator - Thomas - Izawa - Yanagida

	$SU(2)$	$SU(4)$
Q	$\square$	$\square$
S	1	$\boxminus$

Vector-like theory

$\mathrm{Pf}M : \epsilon^{i_1 \dots i_{2F}} M_{i_1 i_2} \dots M_{i_{2F-1} i_{2F}}$

$Q \to \begin{pmatrix} q \\ \bar{q} \end{pmatrix}$ $\quad B = \epsilon^{ij} q_i q_j$

$\bar{B} = \epsilon^{ij} \bar{q}_i \bar{q}_j$

$M = \bar{q} q$

$\mathrm{Pf}(QQ) : \det M - B\bar{B} = \Lambda_2^4$

$$W = \lambda S^{ij} Q_i Q_j$$

constraint $\mathrm{Pf}(QQ) = \Lambda_2^4$

$$\frac{\partial W}{\partial S^{ij}} = \lambda Q_i Q_j = 0$$

SUSY is broken

$$W_{eff} = \lambda S M + X(\mathrm{Pf}M - \Lambda_2^4)$$

$\lambda << 1$ SUSY QCD $F = N$ mass $m_{ij} = \lambda \langle S_{ij} \rangle$

$$V = \sum_i \left| \frac{\partial W_{eff}}{\partial Q_i} \right| + \sum_{ij} \left| \frac{\partial W}{\partial S_{ij}} \right|^2$$

$$Q_i Q_j = \left(\mathrm{Pf}(\lambda S) \Lambda^{3N-F} \right)^{\frac{1}{N}} \left(\frac{1}{\lambda S} \right)_{ij}$$

$$V = \sum_{ij} \left| \frac{\partial W_{eff}}{\partial S_{ij}} \right| = |\lambda|^2 \sum_{ij} |Q_i Q_j|^2$$

$$= |\lambda|^2 |\mathrm{Pf} S \Lambda^4| \sum_{ij} \left| \left(\frac{1}{S_{ij}} \right) \right|^2$$

minimized at $S^{ij} = (\mathrm{Pf} S)^{1/2} \epsilon^{ij}$

$$V = |\lambda|^2 \Lambda^4$$

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agrees gaugino condesation

$$\Lambda_{eff}^3 = \Lambda^{3N-2} Pf(\lambda S)$$

$$W_{eff} \propto \Lambda_{eff}^3 = \Lambda^2 Pf(\lambda S)^{1/2}$$

$Pf(S)$ is a flat direction $\frac{\partial W}{\partial Pf(S)} \propto \lambda \Lambda^2$

Witten's loop-hole in the index argument

theory with $m_S S^2$ is different from $m_S \to 0$

in O'Raifeartaigh model with ~~susy~~

flat is only pseudo-flat

$$\lambda S \gg \Lambda$$

$$Z = 1 + \underset{\substack{\uparrow \\ \text{IR free}}}{c} \lambda \lambda^{\dagger} \ln\left(\frac{\mu^2}{S^2}\right)$$

$$V = \frac{|\lambda|^2 \Lambda^4}{|Z|} \simeq |\lambda|^2 \Lambda^4 \left(1 + c \lambda \lambda^{\dagger} \ln\left(\frac{S^2}{\mu^2}\right)\right)$$

tilts up

gauge part of $SU(4)$ to stabilize

otherwise calculate O'Raifeartaigh models

near $S \simeq 0$

$$SU(4) \sim SO(6)$$

S_a, M_a $\cdot a = 1, \dots 6$

↑ rescale to dim 1

$M_a M_a = \Lambda^2$ SO(6) breaks to SO(5)

$M_6 = (\Lambda^2 - M'^2)^{1/2}$ $\qquad M'_a = M_a \quad \cdot a = 1, \dots 5$

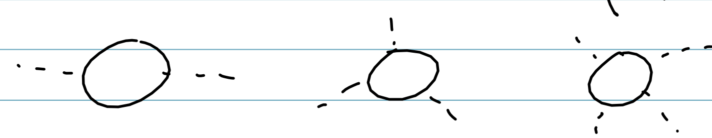
$$W = \lambda \Lambda S M$$
$$= \lambda \Lambda S_6 (\Lambda^2 - M'^2)^{1/2} + \lambda \Lambda S' M'$$

$$\left.\begin{aligned} \frac{\partial W}{\partial S_6} &= \lambda \Lambda (\Lambda^2 - M'^2)^{1/2} \\ \frac{\partial W}{\partial S'_a} &= \lambda \Lambda M'_a \end{aligned}\right\} \text{incompatable}$$

~~su4~~

S', M' mass matrix $\sim \begin{pmatrix} 0 & \lambda \Lambda \\ \lambda \Lambda & \lambda \langle S_6 \rangle \end{pmatrix} \ll \Lambda$

C.W.



$$V_{\text{one-loop}} \sim m^4 \sim \frac{|\lambda^4| \Lambda^2 |S_6|^2}{16\pi^2} + \mathcal{O}(S_6^4)$$

stable minimum $S_6 = 0$

$$\langle S \rangle \sim \mathcal{O}\left(\frac{\Lambda}{\lambda}\right) ??$$

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generically if DSB sector reduces to WZ-type model then
n fields ϕ

$$\frac{\delta W}{\delta \phi_i} = 0 \qquad n \text{ eq.}$$

SB R symmetry $\langle \phi_1 \rangle \neq 0$

$$\psi_i = \phi_i^{1/r_i} \big/ \phi_1^{1/r_1} \qquad i = 2, \ldots, n$$

$$W = \phi_1^{2/r_1} \tilde{W}(\psi)$$

$$\frac{\delta W}{\delta \phi_1} = \frac{2}{r_1} \phi_1^{\frac{2}{r_1}-1} \tilde{W}(\psi) = 0 \Rightarrow \tilde{W}(\psi) = 0$$

$$\frac{\delta W}{\delta \psi_i} = \phi_1^{2/r_1} \frac{\partial \tilde{W}}{\partial \psi_i} = 0 = \frac{\delta \tilde{W}}{\delta \psi_i} = 0$$

n eq. $\quad n-1$ variables

for a generic $\tilde{W}$, no solution

Baryon Runaway

	$SU(2N-1)$	$Sp(2N)$	$SU(2N-1)$
Q	$\Box$	$\Box$	1
L	1	$\Box$	$\Box$
$\bar{u}$	$\bar{\Box}$	1	$\bar{\Box}$
$\bar{D}$	$\bar{\Box}$	1	1

$\Lambda_{SU} \to 0$

Sp

$N \geq 6$ IR FP

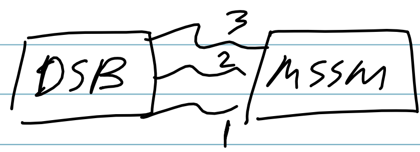
$N = 4,5$ IR free

$N = 3$ s. conf.

$N = 2$ def. moduli

$$W = \lambda Q L \bar{u}$$

Direct Mediation



$\Lambda_{Sp} \to 0$

SU s. conf

classical moduli space

$$\frac{\partial W}{\partial Q_{\alpha m}} = \lambda \epsilon^{\alpha\beta} L_{\beta i} \bar{u}^{mi} = 0$$

		$SU(2N-1)$
M	$= L_i L_j$	$\boxminus$
B	$= \bar{u}^{2N-2} \bar{D}$	$\Box$
b	$= \bar{u}^{2N-1}$	1

$$M_{ij} B_k \epsilon^{ijk l_1 \ldots l_{2N-3}} = 0$$

$$M_{ij} b = 0$$

two branches $\quad M = 0 \quad B, b \neq 0 \quad \leftarrow$

$\quad M \neq 0 \quad B, b = 0$

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$M = 0 \qquad \bar{U} \neq 0 \qquad \bar{D} \neq 0$

$SU(2N-1)$ gauge group broken

$W = \lambda Q L \bar{U}$ gives masses to Q, L

$\mu << \lambda v$

pure $Sp(2N)$ gaugino condensation

$$\Lambda_{eff}^{3(2N+2)} = \Lambda_{Sp}^{3(2N+2)-2(2N-1)} (\lambda \bar{U})^{2(2N-1)}$$

$$W_{eff} = \Lambda_{eff}^3 \approx \Lambda_{Sp}^3 \left(\frac{\lambda \bar{U}}{\Lambda_{Sp}} \right)^{\frac{2N-1}{N+1}}$$

$N > 2 \qquad \bar{U} \to 0$

(05)

$v \ll \Lambda_{SU}$ $\Lambda_{Sp} \ll \Lambda_{SU}$

$SU(2N-1)$ s-confines

	$Sp(2N)$	$SU(2N-1)$	
L	$\square$	$\square$	$\times$
$(Q\bar{u})$	$\square$	$\bar{\square}$	$\times$
$(Q\bar{D})$	$\square$	$\cancel{1}$	
(Q^{2N-1})	$\square$	1	
B	1	$\square$	
b	1	1	

$$W = \lambda (Q\bar{u}) L + \frac{1}{\Lambda_{SU}^{4N-3}} \left((Q^{2N-1})(Q\bar{u}) B + (Q^{2N-1})(Q\bar{D}) b - \det \bar{Q}Q \right)$$

$(Q\bar{u})$, L massive $(Q\bar{u}) = 0$

$$W_{eff} = \frac{1}{\Lambda_{SU}^{4N-3}} (Q^{2N-1})(Q\bar{D}) b$$

$\langle b \rangle \sim \langle \bar{u}^{2N-1} \rangle$ gives mass to (Q^{2N-1}) and $(Q\bar{D})$

pure $Sp(2N)$

$$\Lambda_{eff}^{3(2N+2)} = \Lambda_{Sp}^{3(2N+2)-2(2N-1)} (\lambda \Lambda_{SU})^{2(2N-1)} \left(\frac{b}{\Lambda_{SU}}\right)^2$$

$$W_{eff} = \Lambda_{eff}^3 = b^{\frac{1}{N+1}} \left(\Lambda_{Sp}^{N+4} \lambda^{(2N-1)} \Lambda_{SU}^{(2N-2)} \right)^{\frac{1}{N+1}}$$

$\langle b \rangle \to \infty$

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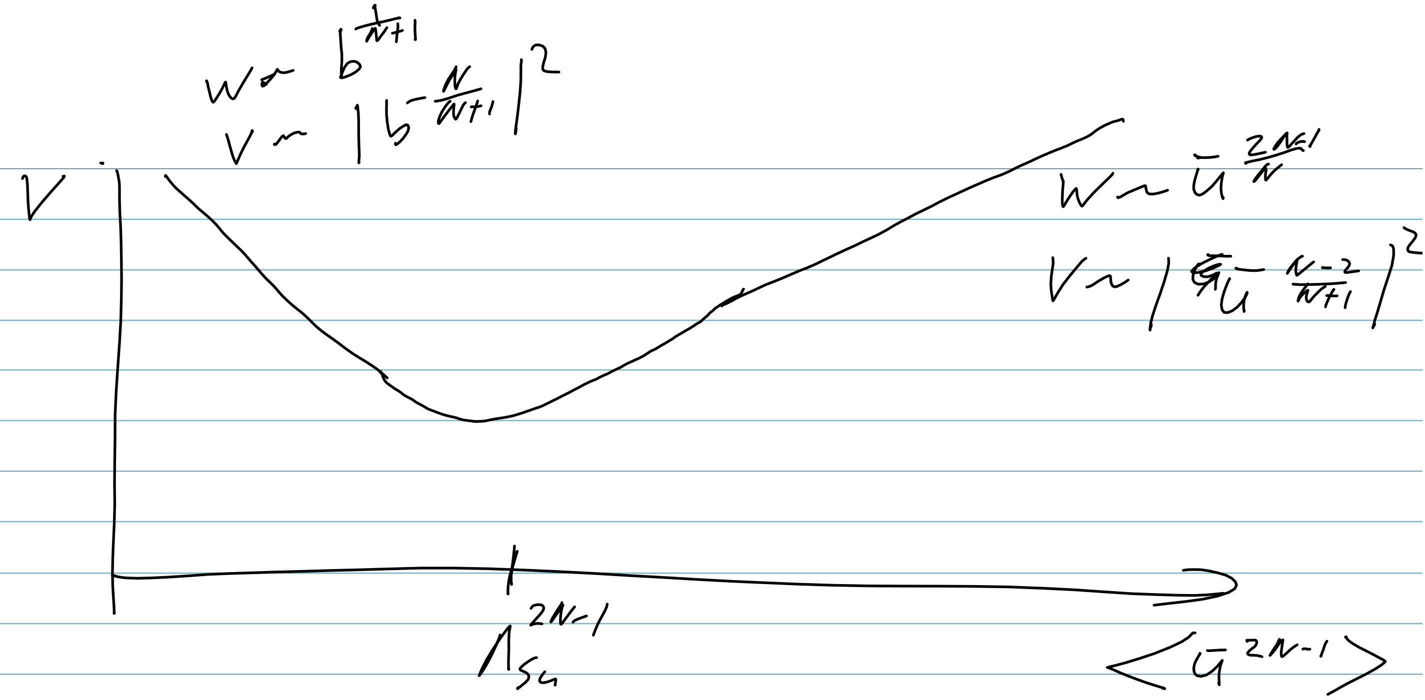

can also show for $\Lambda_{Sp} \gg \Lambda_{SU}$

Interesting case $N=3$
$Sp(6)$ s-confining

	$SU(5)$	$SU(5)$
(LL)	1	$\boxminus$
(QQ)	$\boxminus$	1
(QL)	$\square$	$\square$
$\bar{u}$	$\overline{\square}$	$\overline{\square}$
$\bar{D}$	$\overline{\square}$	1

$$W = \lambda (QL)\bar{u} + \underbrace{Q^{2N-1} L^{2N-1}}_{Pf}$$

integrate out

	$SU(5)$	$SU(5)$
(QQ)	$\boxminus$	1
$\bar{D}$	$\overline{\square}$	1

$W = 0$ + singlets