More Seiberg duality

$SO(N)$ gauge theory

with F quarks in the vector representation

	$SO(N)$	$SU(F)$	$U(1)_R$
Q	$\square$	$\square$	$\frac{F+2-N}{F}$

discrete for $N > 3$, axial Z_{2F} symmetry

$$Q \to e^{2\pi i/2F} Q$$

for $N = 3$ there is a discrete axial Z_{4F} symmetry

one-loop β function coefficient, for $N > 4$ is

$$b = 3(N-2) - F$$

no dynamical spinors, static spinor sources cannot be screened
distinction between area-law confining and Higgs phases

$SO(N)$ group theory

adjoint of $SO(N)$ is two-index antisymmetric tensor

odd N, there is one spinor representation
even N there are two inequivalent spinors

for $N = 4k$ the spinors are self-conjugate
for $N = 4k + 2$ the two spinors are complex conjugates

$SO(N)$ group theory

$SO(2N+1)$		
Irrep $\mathbf{r}$	$d(\mathbf{r})$	$2T(\mathbf{r})$
$\Box$	$2N+1$	2
S	2^N	2^{N-2}
$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}$	$N(2N+1)$	$4N-2$
$\Box\Box$	$(N+1)(2N+1)-1$	$4N+6$

$SO(2N)$		
Irrep $\mathbf{r}$	$d(\mathbf{r})$	$2T(\mathbf{r})$
$\Box$	$2N$	2
$S, \overline{S}$	2^{N-1}	2^{N-3}
$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}$	$N(2N-1)$	$4N-4$
$\Box\Box$	$N(2N+1)-1$	$4N+4$

S denotes a spinor, and $\overline{S}$ denotes the conjugate spinor

The $SO(N)$ moduli space $F < N$

D-flatness conditions (up to flavor transformations):

$$\langle \Phi \rangle = \begin{pmatrix} v_1 & & \\ & \ddots & \\ & & v_F \\ 0 & \ldots & 0 \\ \vdots & & \vdots \\ 0 & \ldots & 0 \end{pmatrix}$$

generic point in the classical moduli space $SO(N) \rightarrow SO(N-F)$
$NF - N(N-1) + (N-F)(N-F-1)$ massless chiral supermultiplets

The $SO(N)$ moduli space $F \geq N$

$$\langle\Phi\rangle = \begin{pmatrix} v_1 & & & 0 & \dots & 0 \\ & \ddots & & \vdots & & \vdots \\ & & v_N & 0 & \dots & 0 \end{pmatrix}$$

generic point in the moduli space the $SO(N)$ broken completely
$NF - N(N-1)$ massless chiral supermultiplets.

describe light degrees of freedom by “meson” and (for $F \geq N$) “baryon” fields:

$$\begin{aligned} M_{ji} &= \Phi_j \Phi_i \\ B_{[i_1,\dots,i_N]} &= \Phi_{[i_1} \dots \Phi_{i_N]} \end{aligned}$$

The $SO(N)$ moduli space $F \geq N$

Up to flavor transformations:

$$\begin{aligned} \langle M \rangle &= \begin{pmatrix} v_1^2 & & & & & \\ & \ddots & & & & \\ & & v_N^2 & & & \\ & & & 0 & & \\ & & & & \ddots & \\ & & & & & 0 \end{pmatrix} \\ \langle B_{1,\ldots,N} \rangle &= v_1 \ldots v_N \end{aligned}$$

rank of M is at most N

If the rank of M is N, then $B = \pm\sqrt{\det' M}$

The $SO(N)$ $F < N - 2$

	$U(1)_A$	$U(1)_R$
W^a	0	1
Λ^b	$2F$	0
$\det M$	$2F$	$2(F+2-N)$

ADS superpotential:

$$W_{\rm dyn} = c_{N,F} \left(\frac{\Lambda^b}{\det M} \right)^{1/(N-2-F)}$$

Duality for $SO(N)$

$F \geq 3(N-2)$ lose asymptotic freedom

F just below $3(N-2)$ we have an IR fixed point

solution to the anomaly matching for $F > N-2$, is given by:

	$SO(F-N+4)$	$SU(F)$	$U(1)_R$
q	$\square$	$\overline{\square}$	$\frac{N-2}{F}$
M	$\mathbf{1}$	$\square\square$	$\frac{2(F+2-N)}{F}$

For $F > N-1$, $N > 3$ unique superpotential

$$W = \frac{M_{ji}}{2\mu} \phi^j \phi^i$$

dual baryon operators:

$$\widetilde{B}^{[i_1,\ldots,i_{\widetilde{N}}]} = \phi^{[i_1} \ldots \phi^{i_{\widetilde{N}}]}$$

Hybrid "Baryon" Operators

since adjoint is an antisymmetric tensor. In $SO(N)$ we have:

$$\begin{aligned} h_{[i_1,\ldots,i_{N-4}]} &= W_\alpha^2 \Phi_{[i_1} \ldots \Phi_{i_{N-4}]} \\ H_{[i_1,\ldots,i_{N-2}]\alpha} &= W_\alpha \Phi_{[i_1} \ldots \Phi_{i_{N-4}]} \end{aligned}$$

While in the dual theory we have:

$$\begin{aligned} \widetilde{h}^{[i_1,\ldots,i_{\widetilde{N}-4}]} &= \widetilde{W}_\alpha^2 \phi^{[i_1} \ldots \phi^{i_{\widetilde{N}-4}]} \\ \widetilde{H}_\alpha^{[i_1,\ldots,i_{\widetilde{N}-2}]} &= \widetilde{W}_\alpha \phi^{[i_1} \ldots \phi^{i_{\widetilde{N}-4}]} \end{aligned}$$

The two theories thus have a mapping of mesons, baryons, and hybrids:

$$\begin{aligned} & M \leftrightarrow M \ , \\ & B_{i_1,\ldots,i_N} \leftrightarrow \epsilon_{i_1,\ldots,i_F} \widetilde{h}^{i_1,\ldots,i_{\widetilde{N}-4}} \\ & h_{i_1,\ldots,i_{N-4}} \leftrightarrow \epsilon_{i_1,\ldots,i_F} \widetilde{B}^{i_1,\ldots,i_{\widetilde{N}}} \\ & H_\alpha^{[i_1,\ldots,i_{N-2}]} \leftrightarrow \epsilon_{i_1,\ldots,i_F} \widetilde{H}_\alpha^{[i_1,\ldots,i_{\widetilde{N}-2}]} \end{aligned}$$

Dual one-loop β function

$$\beta(\widetilde{g}) \propto -\widetilde{g}^3(3(\widetilde{N}-2)-F) = -\widetilde{g}^3(2F-3(N-2))$$

lose asymptotic freedom when $F \leq 3(N-2)/2$

When

$$F = 3(\widetilde{N}-2) - \epsilon\widetilde{N}$$

perturbative IR fixed point in the dual theory

$SO(N)$ with F vectors has an interacting IR fixed point for $3(N-2)/2 < F < 3(N-2)$

$N-2 \leq F \leq 3(N-2)/2$ IR free massless composite gauge bosons, quarks, mesons, and their superpartners

Special case: $F \leq N - 5$

$SO(N) \to SO(N-F) \supset SO(5)$

gaugino condensation, dynamical superpotential:

$$W_{\rm dyn} \propto \langle \lambda\lambda \rangle \propto \left(\frac{16\Lambda^{3(N-2)-F}}{\det M} \right)^{1/(N-2-F)}$$

runaway vacua

Special case: $F = N - 4$

$SO(N) \to SO(4) \sim SU(2)_L \times SU(2)_R$
two gaugino condensates

$$W_{\mathrm{cond.}} = 2\langle\lambda\lambda\rangle_L + 2\langle\lambda\lambda\rangle_R = \frac{1}{2}(\epsilon_L + \epsilon_R)\left(\frac{16\Lambda^{2N-1}}{\det M}\right)^{1/2}$$

$$\epsilon_{L,R} = \pm 1$$

two physically distinct branches: $(\epsilon_L + \epsilon_R) = \pm 2$ and $(\epsilon_L + \epsilon_R) = 0$
first branch has runaway vacua, second has a quantum moduli space.
at $M = 0$, M satisfies the 't Hooft anomaly matching
confinement without chiral symmetry breaking, no baryons
Integrating out a flavor on first branch gives runaway $(F = N - 5)$
second branch no SUSY vacua

Special case: $F = N - 3$

$SO(N) \to SO(4) \sim SU(2)_L \times SU(2)_R \to SU(2)_d \sim SO(3)$
instanton effects $(\Pi_3(G/H) = \Pi_3(SU(2)) = Z)$
and gaugino condensation

$$W_{\text{inst.+cond.}} = 4(1+\epsilon)\frac{\Lambda^{2N-3}}{\det M}$$

two phases of the gaugino condensate
two physically distinct branches: $\epsilon = 1$ and with $\epsilon = -1$
first has runaway vacua, while the second has a quantum moduli space
Integrating out a flavor, we would need to find two branches again
so $W \neq 0$ even on the second branch

Special case: $F = N - 3$

must have some other fields
anomaly matching given by:

	$SU(F)$	$U(1)_R$
q	$\overline{\square}$	$\frac{N-2}{F}$
M	$\square\square$	$\frac{2(F+2-N)}{F}$

most general superpotential

$$W = \frac{1}{2\mu} Mqq\ f\left(\frac{\det M\ Mqq}{\Lambda^{2N-2}}\right)$$

where $f(t)$ is an unknown function
adding a mass term gives

$$q_F = \pm iv$$

which gives correct number of ground states

$$q \leftrightarrow h = Q^{N-4} W_\alpha W^\alpha$$

confinement without chiral symmetry breaking with hybrids

Special case: $F = N - 1$

Starting with the $F = N$ dual which has an $SO(4)$ gauge group, and integrating out a flavor there will be instanton effects when we break to $SO(3)$
dual superpotential is modified in the case $F = N - 1$ to be:

$$W = \frac{M_{ji}}{2\mu}\phi^j\phi^i - \frac{1}{64\Lambda^{2N-5}}\det M$$

Special case: $F = N - 2$

both descriptions generically break to $SO(2) \sim U(1)$

monopoles

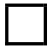
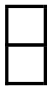
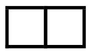
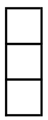
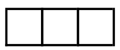
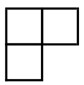
SUSY $Sp(2N)$

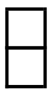
An $Sp(2N)$ gauge theorywith $2F$ quarks (F flavors) in the fundamental representation has a global $SU(2F) \times U(1)_R$ symmetry as follows:

	$Sp(2N)$	$SU(2F)$	$U(1)_R$
Q	$\square$	$\square$	$\frac{F-1-N}{F}$

adjoint of $Sp(2N)$ is the two-index symmetric tensor

$Sp(2N)$ Representations

	$Sp(2N)$	
Irrep $\mathbf{r}$	$d(\mathbf{r})$	$T(\mathbf{r})$
	$2N$	1
	$N(2N-1)-1$	$2N-2$
	$N(2N+1)$	$2N+2$
	$\frac{N(2N-1)(2N-2)}{3}-2N$	$\frac{(2N-3)(2N-2)}{2}-1$
	$\frac{N(2N+1)(2N+2)}{3}$	$\frac{(2N+2)(2N+3)}{2}$
	$\frac{2N(2N-1)(2N+1)}{3}-2N$	$(2N)^2-4$

dimension  smaller by -1 than naive expectation

invariant tensor of $Sp(2N)$ is ϵ_{ij}

representation formed with two antisymmetric indices is reducible

SUSY $Sp(2N)$

one-loop β function for $N > 4$ is

$$b = 3(2N + 2) - 2F$$

moduli space is parameterized by a "meson"

$$M_{ji} \quad = \quad \Phi_j \Phi_i$$

antisymmetric in the flavor indices i, j

holomorphic intrinsic scale considered as a spurion field

Pfaffian of a $2F \times 2F$ matrix M is given by

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

	$U(1)_A$	$U(1)_R$
$\Lambda^{b/2}$	$2F$	0
$\mathrm{Pf}M$	$2F$	$2(F-1-N)$

SUSY $Sp(2N)$

for $F < N+1$ possible to generate a dynamical superpotential

$$W_{\rm dyn} \propto \left(\frac{\Lambda^{\frac{b}{2}}}{{\rm Pf}M}\right)^{1/(N+1-F)}$$

For $F = N+1$ one finds confinement with chiral symmetry breaking

$${\rm Pf}M = \Lambda^{2(N+1)}$$

For $F = N+2$ one finds s-confinement with a superpotential:

$$W = {\rm Pf}M$$

Duality for $Sp(2N)$

solution to the anomaly matching for $F > N - 2$:

	$Sp(2(F-N-2))$	$SU(2F)$	$U(1)_R$
q	$\Box$	$\overline{\Box}$	$\frac{N+1}{F}$
M	$\mathbf{1}$	$\begin{array}{c}\Box\\[-3pt]\Box\end{array}$	$\frac{2(F-1-N)}{F}$

a unique superpotential:

$$W = \frac{M_{ji}}{\mu}\phi^j\phi^i$$

For $3(N+1)/2 < F < 3(N+1)$ we have an IR fixed point
For $N+3 \leq F \leq 3(N+1)/2$ the dual is IR free

Why chiral gauge theories are interesting

vector-like theory we can give masses to all the matter fields
$\rightarrow$ pure YM, gaugino condensation but no SUSY breaking

Witten's index argument: number of bosonic minus fermionic vacua does not change

If taking the mass to zero does not move some vacua in from or out to infinity, then the massless theory has unbroken SUSY

first example of a chiral gauge theory

	$SU(N)$	$SU(N+4)$
$\overline{Q}$	$\overline{\square}$	$\square$
T	$\square\!\square$	$\mathbf{1}$

dual to

	$SO(8)$	$SU(N+4)$
q	$\square$	$\overline{\square}$
p	$\mathbf{S}$	$\mathbf{1}$
$U \sim \det T$	$\mathbf{1}$	$\mathbf{1}$
$M \sim \overline{Q}T\overline{Q}$	$\mathbf{1}$	$\square\!\square$

with a superpotential

$$W = Mqq + Upp$$

This dual theory is vector-like!

chiral dual of vector theory

The dual β function coefficient is:

$$b = 3(8 - 2) - (N + 4) - 1 = 13 - N$$

So the dual is IR free for $N > 13$

Csaki, Schmaltz, Skiba

S-Confinement

$SU(N)$ with $N+1$ flavors.

$$W = \frac{1}{\Lambda^{2N-1}} \left(\det M - BM\overline{B} \right)$$

meson–baryon description was valid over the whole moduli space
smooth description with no phase transitions
theory has complementarity, static source screened by squarks

To generalize:
need fields that are fundamentals of SU or Sp and spinors of SO
only consider theories with superpotential in the confined description
Theories that satisfy these conditions are called s-confining

S-Confinement

single gauge group G, choose $U(1)_R$ such that

	G	$U(1)_R$
ϕ_i	$\mathbf{r_i}$	q
$\phi_{j\neq i}$	$\mathbf{r_j}$	0

q is determined by anomaly cancellation:

$$\begin{aligned} 0 &= (q-1)T(\mathbf{r_i}) + T(Ad) - \textstyle\sum_{j\neq i} T(\mathbf{r_j}) \\ &= q\,T(\mathbf{r_i}) + T(Ad) - \textstyle\sum_j T(\mathbf{r_j}) \end{aligned}$$

can do this for any field, and for each choice the superpotential has R-charge 2, we have

$$W \propto \Lambda^3 \left[\Pi_i \left(\frac{\phi_i}{\Lambda}\right)^{T(\mathbf{r_i})} \right]^{2/(\sum_j T(\mathbf{r_j}) - T(Ad))}$$

in general, a sum of terms with different contractions of gauge indices

S-Confinement

Requiring superpotential be holomorphic at the origin $\Rightarrow$ integer powers of the composites $\Rightarrow$ integer powers of the fundamental fields

Unless all the $T(r_i)$ have a common divisor must have

$$\begin{aligned} \sum_j T(r_j) - T(Ad) &= 1 \text{ or } 2, \text{ for } SO \text{ or } Sp \\ 2\left(\sum_j T(r_j) - T(Ad)\right) &= 1 \text{ or } 2, \text{ for } SU \end{aligned}$$

cases from different conventions for normalizing generators, for SO and Sp $T(\Box) = 1$, while for SU $T(\Box) = 1/2$

Anomaly cancellation for SU and Sp require that the left-hand side be even.

condition is necessary for s-confinement, but not sufficient

S-Confinement

check explicitly (by exploring the moduli space) that for SO none of the candidate theories where the sum is 2 turn out to be s-confining

$$\sum_j T(r_j) - T(Ad) \quad = \quad \begin{cases} 1, \text{ for } SU \text{ or } SO \\ 2, \text{ for } Sp \end{cases}$$

gives finite list of candidate s-confining theories

check candidate theories by going out in moduli space
generically break to theories with smaller gauge groups
if the sub-group theory not s-confining the original theory not s-confining

S-Confinement

For SU one finds that the following theories are s-confinings:

$$
\begin{array}{l|l}
SU(N) & (N+1)(\Box + \overline{\Box})\ ;\ \begin{smallmatrix}\Box\\\Box\end{smallmatrix} + N\overline{\Box} + 4\Box;\ \begin{smallmatrix}\Box\\\Box\end{smallmatrix} + \overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}} + 3(\Box + \overline{\Box}) \\
SU(5) & 3\left(\begin{smallmatrix}\Box\\\Box\end{smallmatrix} + \overline{\Box}\right)\ ;\ 2\begin{smallmatrix}\Box\\\Box\end{smallmatrix} + 2\Box + 4\overline{\Box} \\
SU(6) & 2\begin{smallmatrix}\Box\\\Box\end{smallmatrix} + 5\overline{\Box} + \Box;\ \begin{smallmatrix}\Box\\\Box\\\Box\end{smallmatrix} + 4(\Box + \overline{\Box}) \\
SU(7) & 2\left(\begin{smallmatrix}\Box\\\Box\end{smallmatrix} + 3\overline{\Box}\right)
\end{array}
$$

$SU(N)$ with $\begin{smallmatrix}\square\\\square\end{smallmatrix}$, $F=4$

	$SU(2N+1)$	$SU(4)$	$SU(2N+1)$	$U(1)_1$	$U(1)_2$	$U(1)_R$
A	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	1	1	0	$2N+5$	0
$\overline{Q}$	$\overline{\square}$	1	$\square$	4	$-2N+1$	0
Q	$\square$	$\square$	1	$-2N-1$	$-2N+1$	$\frac{1}{2}$

confined description:

	$SU(4)$	$SU(2N+1)$	$U(1)_1$	$U(1)_2$	$U(1)_R$
$(Q\overline{Q})$	$\square$	$\square$	$3-2N$	$-4N+2$	$\frac{1}{2}$
$(A\overline{Q}^2)$	1	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	8	$-2N+7$	0
(A^NQ)	$\square$	1	$-2N-1$	$2N^2+3N+1$	$\frac{1}{2}$
$(A^{N-1}Q^3)$	$\overline{\square}$	1	$-6N-3$	$2N^2-3N-2$	$\frac{3}{2}$
$(\overline{Q}^{2N+1})$	1	1	$4(2N+1)$	$-4N^2+1$	0

$SU(N)$ with $\boxminus$, $F = 4$

s-confinement superpotential:

$$
\begin{aligned}
W \quad &= \quad \frac{1}{\Lambda^{2N}}\Big[(A^N Q)(Q\overline{Q})^3(A\overline{Q}^2)^{N-1} + (A^{N-1}Q^3)(Q\overline{Q})(A\overline{Q}^2)^N \\
&\qquad + (\overline{Q}^{2N+1})(A^N Q)(A^{N-1}Q^3)\Big]
\end{aligned}
$$

equations of motion reproduce classical constraints
integrating out a flavor gives confinement with chiral symmetry breaking

Deconfinement

Consider $SU(N)$ with $\begin{smallmatrix}\Box\\ \Box\end{smallmatrix}$ for odd N with $F \geq 5$ ($\overline{F} \equiv N + F - 4$):

	$SU(N)$	$SU(F)$	$SU(\overline{F})$	$U(1)_1$	$U(1)_2$	$U(1)_R$
A	$\begin{smallmatrix}\Box\\ \Box\end{smallmatrix}$	$\mathbf{1}$	$\mathbf{1}$	0	$-2F$	$\frac{-12}{N}$
Q	$\Box$	$\Box$	$\mathbf{1}$	1	$N - F$	$2 - \frac{6}{N}$
$\overline{Q}$	$\overline{\Box}$	$\mathbf{1}$	$\Box$	$\frac{-F}{N+F-4}$	F	$\frac{6}{N}$

take A to be a composite meson of a s-confining Sp theory

	$SU(N)$	$Sp(N-3)$	$SU(F)$	$SU(N+F-4)$	$U(1)_1$	$U(1)_2$	$U(1)_R$
Y	$\Box$	$\Box$	$\mathbf{1}$	$\mathbf{1}$	0	$-F$	$\frac{-6}{N}$
Z	$\mathbf{1}$	$\Box$	$\mathbf{1}$	$\mathbf{1}$	0	FN	8
$\overline{P}$	$\overline{\Box}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	0	$F - FN$	$6 - \frac{6}{N}$
Q	$\Box$	$\mathbf{1}$	$\Box$	$\mathbf{1}$	1	$N - F$	$2 - \frac{6}{N}$
$\overline{Q}$	$\overline{\Box}$	$\mathbf{1}$	$\mathbf{1}$	$\Box$	$\frac{-F}{N+F-4}$	F	$\frac{6}{N}$

Deconfinement

superpotential

$$W = YZ\overline{P}$$

eqm for P sets the meson $(YZ) = 0$, also sets Pf $M = 0$ in dynamical superpotential to zero
$SU(N)$ gauge group of this new description has $N + F - 3$ flavors, use SUSY QCD duality to find another dual

Deconfinement

	$SU(F-3)$	$Sp(N-3)$	$SU(F)$	$SU(\overline{F})$
y	$\square$	$\square$	$\mathbf{1}$	$\mathbf{1}$
$\overline{p}$	$\overline{\square}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
q	$\square$	$\mathbf{1}$	$\overline{\square}$	$\mathbf{1}$
$\overline{q}$	$\overline{\square}$	$\mathbf{1}$	$\mathbf{1}$	$\overline{\square}$
M	$\mathbf{1}$	$\mathbf{1}$	$\square$	$\square$
L	$\mathbf{1}$	$\square$	$\mathbf{1}$	$\square$
B_1	$\mathbf{1}$	$\mathbf{1}$	$\square$	$\mathbf{1}$

with a superpotential

$$W = Mq\overline{q} + B_1 q\overline{p} + Ly\overline{q}$$

$Sp(N-3)$ with $N+2F-7$ fundamentals has an $Sp(2F-8)$ dual

Deconfinement

	$SU(F-3)$	$Sp(2F-8)$	$SU(F)$	$SU(\overline{F})$
$\widetilde{y}$	$\overline{\square}$	$\square$	$\mathbf{1}$	$\mathbf{1}$
$\overline{p}$	$\overline{\square}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
q	$\square$	$\mathbf{1}$	$\overline{\square}$	$\mathbf{1}$
$\overline{q}$	$\overline{\square}$	$\mathbf{1}$	$\mathbf{1}$	$\overline{\square}$
M	$\mathbf{1}$	$\mathbf{1}$	$\square$	$\square$
l	$\mathbf{1}$	$\square$	$\mathbf{1}$	$\overline{\square}$
B_1	$\mathbf{1}$	$\mathbf{1}$	$\square$	$\mathbf{1}$
a	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
H	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$
(Ly)	$\square$	$\mathbf{1}$	$\mathbf{1}$	$\square$

with

$$W = a\widetilde{y}\widetilde{y} + Hll + (Ly)l\widetilde{y} + Mq\overline{q} + B_1 q\overline{p} + (Ly)\overline{q}$$

Deconfinement

after integrating out (Ly) and $\overline{q}$ becomes

$$W = a\widetilde{y}\widetilde{y} + Hll + Mql\widetilde{y} + B_1 q\overline{p}$$

With $F = 5$ we have a gauge group $SU(2) \times SU(2)$ and one can show (using D[scalar]$\geq$ 1) that for $N > 11$ this theory has an IR fixed point also show that some of the fields (eg. H and l) are IR-free

integrating out one flavor completely breaks the gauge group
light degrees of freedom are just the composites of the s-confinment for $F = 4$