

# ***Local SUSY-breaking minima in $N_f = N_c$ SQCD?***

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# Outline

1. ISS review and  $N_f = N_c$  conjecture
2. Another deformation, saddle point
3. Phenomenological consequences
4. Conclusions

Itriligator, Seiberg, Shih, 2006

- ⑥ framework  $SU(N_c)$  SQCD;  $N_c + 1 \leq N_f < \frac{3}{2}N_c$ ,  
 $W_{\text{tree}} = (m_Q)_{ij} \bar{Q}_i Q_j$  and  $\text{rank}[m_Q] > N_c$
- ⑥ SUSY-breaking local minimum near the origin
- ⑥ magnetic dual: SUSY is broken by rank condition
- ⑥ possesses SUSY vacuum

Demand  $m_Q \ll \Lambda$  to get

- ⑥ calculability
- ⑥ SUSY vacuum far from the origin  $\implies$  **metastability**

$$N_f = N_c \text{ *conjecture*}$$

## ISS approach:

- ⑥ take  $N_f = N_c + 1$ , local SUSY-breaking minimum exists
- ⑥ consider the limit  $(m_Q)_{N_f, N_f} \rightarrow \infty$
- ⑥ conjecture:  $N_f = N_c$  has a similar vacuum,

$$N_f = N_c \text{ **conjecture**}$$

## ISS approach:

- ⑥ take  $N_f = N_c + 1$ , local SUSY-breaking minimum exists
- ⑥ consider the limit  $(m_Q)_{N_f, N_f} \rightarrow \infty$
- ⑥ conjecture:  $N_f = N_c$  has a similar vacuum,

**but  $N_f = N_c$  is very different**

- ⑥  $N_f > N_c$ :  $\frac{m_Q}{\Lambda} \ll 1 \Rightarrow$  non-calculable terms (Kähler) are under control
- ⑥  $N_f = N_c$ :  $m_Q/\Lambda$  **small, but Kähler is not under control**

# Why is $N_f = N_c$ so different? Kähler potential

Kähler metric

$$g_{MM^\dagger}^{-1} \sim \frac{\text{Tr} M^\dagger M}{\Lambda^2} + \frac{\text{Tr} M \text{Tr} M^\dagger}{\Lambda^2} + \frac{(B_+ + B_+^\dagger)^2}{\Lambda^2} + \dots$$

Potential:

$$V = g_{MM^\dagger}^{-1} |F_M|^2$$

$$F_M = m_Q \Lambda.$$

$$V \sim m_Q^2 (\text{Tr} M M^\dagger + \text{Tr} M \text{Tr} M^\dagger + (B_+ + B_+^\dagger)^2)$$

Contribution stays finite at  $N_f = N_c$

# *Limit $N_f = N_c$ : calculable versus uncalculable*

Consider  $N_f = N_c + 1$  with one very heavy pair of quarks

- ⑥  $(m_Q)_{N_c+1}$  - the heaviest mass
- ⑥  $\hat{\Lambda}$  - confining scale of  $N_f = N_c + 1$

$(m_Q)_{N_c+1} \rightarrow \infty$  we approach  $N_f = N_c$  limit

- ⑥ calculable, tree  $m^2 \sim \frac{m_Q \hat{\Lambda}}{m_{N_c+1}} \rightarrow 0$
- ⑥ pseudo-moduli  $m^2 \sim \frac{1}{16\pi^2} \frac{m_Q \hat{\Lambda}}{m_{N_c+1}} \rightarrow 0$
- ⑥ uncalculable  $m_{\text{uncalc}}^2 \sim m_Q^2$  **finite**
- ⑥ **we do not even know the sign of  $m^2$**

## Another deformation - ITIY

*Itriligator, Thomas, 1996; Izawa, Yanagida, 1996*

Try another deformation

- ⑥ does the extremum survive?
- ⑥ is it still a minimum?
- ⑥ where is calculability lost?

Add singlets. Under  $SU(N_f)_L \times SU(N_f)_R$ :

- ⑥  $S_{ij} \quad (\bar{\mathbf{N}}, \mathbf{N})$
- ⑥  $T \quad (\mathbf{1}, \mathbf{1}), \quad \bar{T} \quad (\mathbf{1}, \mathbf{1})$



# Low-energy Superpotential

$$W = \mathcal{A}(\det M - B\bar{B} - \Lambda^{2N}) +$$

$$\lambda \text{Tr}(SM) + \kappa(TB + \bar{T}\bar{B}) +$$

$$m_Q \text{Tr} M + \frac{m_S}{2} S^2 + \frac{m_T}{2} (T^2 + \bar{T}^2)$$

moduli space  
deformation

ISS  
mass-term

ITIIY  
coupling

singlet masses -  $m_Q$  has no effect w/o them

## **ISS $N_f = N_c$ limit**

Decoupling limit:

$$\frac{\lambda^2}{m_S} \rightarrow 0; \quad \frac{\kappa^2}{m_T} \rightarrow 0$$

SUSY-breaking solution should:

- ⑥  $M \rightarrow 0, B_+ \rightarrow 0, B_- \rightarrow \Lambda$  at the decoupling limit
- ⑥  $F_M \propto m_Q$

SUSY solution:

- ⑥ decoupling limit - finite distance from the origin
- ⑥ sufficiently far from SUSY-breaking solution

# Non-SUSY solution and decoupling limit

- look for solution along *baryonic* branch
- take  $(m_Q)_{ij} \propto \delta_{ij}$

Non-SUSY solution near the origin:

$$M \sim \left( \frac{\lambda^2}{m_S} \frac{m_T}{\kappa^2} \right)^{\frac{1}{N-2}}$$

Decoupling:

$$M \rightarrow 0 \quad \implies \quad \frac{\lambda^2/m_S}{\kappa^2/m_T} \rightarrow 0$$

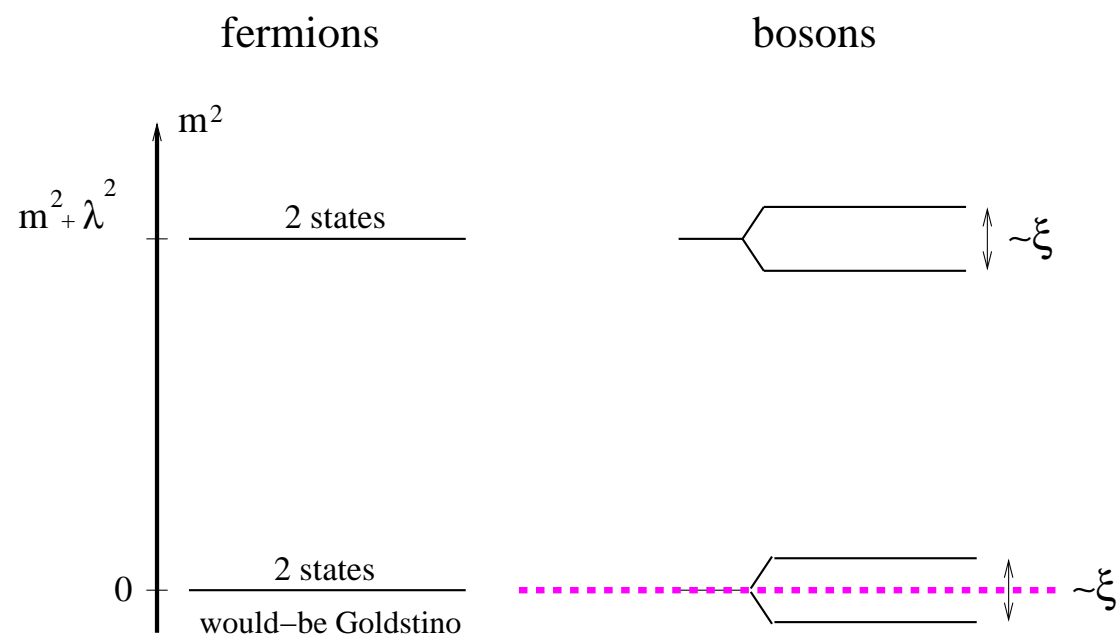
$S_{ij}$  decouples faster than  $T, \bar{T}$

# ***Spectrum at SUSY-breaking point***

- ⑥ spectrum for  $B$  and  $T$  - supersymmetric
- ⑥ ISS: mesino is Goldstino
- ⑥ expect: Goldstino reduces to mesino in decoupling limit
- ⑥ before: admixture of  $M$  and  $S$
- ⑥ one SUSY-breaking parameter:  $\xi$

$$\xi \propto \frac{\lambda^2}{m_S} m_Q^*$$

# Saddle point



Always one state below zero - instability.

## Range of validity

⑥ wanted: calculable contributions  $\gg$  uncalculable

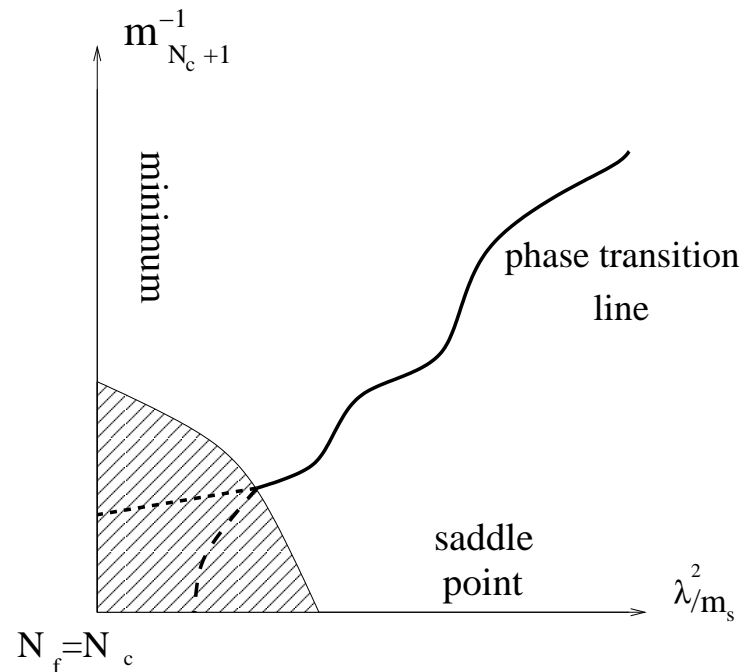
⑥ the lowest state  $m^2 \sim \pm|\xi|$

⑥ demand  $\frac{(\lambda\Lambda)^2 m_Q}{m_S} \gg m_Q^2$

calculable                      uncalculable

⑥ one can choose e.g.  $m_Q \ll (\lambda\Lambda) \ll m_S \lesssim \Lambda$

# $N_f = N_c$ conjecture overview



- ⑥ ISS points undergo phase transition
- ⑥ shaded region: ISS point is governed by non-calculable contributions from Kähler

# Phenomenological consequences - Pentagon

Banks, 2006, “Pentagon” model

- ⑥  $N_f = N_c = 5$  with diagonal ISS mass  $\Delta W = m_Q \text{Tr} M$
- ⑥ use ISS-conjectured minimum
- ⑥ flavor symmetry  $SU(5)_{\text{diag}}$
- ⑥ embed the SM into the flavor symmetry
- ⑥  $\mu$ -problem: need the singlet  $S$ :  $\Delta W = S H_u H_d$
- ⑥  $SU(3) \times SU(2) \times U(1)$  unbroken -  $S$  couples to the quarks through  $Y_{ij}$
- ⑥  $\Delta W_{SM} = \lambda S \text{Tr}(Y M)$
- ⑥ messengers - off diagonal components of  $M$



# *Spectrum of Pentagon*

Metastability  $m_Q \ll \Lambda_5$

Consider first  $\lambda \ll 1$  to avoid destabilization

ISS minimum? Answer in  $\Delta K$

*let's believe* ISS conjecture

Statement: weakly coupled messengers -  $\text{STr}[\text{mess}] > 0$


*Poppitz and Trivedi, 1997:*

large **negative** contributions to squarks  $m^2$

# Wrong-sign contributions to squark masses

⑥ small  $\lambda$  - tachyonic squarks,  $SU(3)_C$  is broken

⑥  $m^2[\text{squark}] \propto \log(\Lambda_5 / m_F)$


$$\sim \lambda^\# \sqrt{m_Q \Lambda_5}$$

⑥  $\lambda$  large - back to ITIY-like, no stable minimum

⑥ minimum may exist in intermediate range - not ISS-conjectured minimum!

$\lambda$  is large or small - Pentagon is ruled out. Intermediate  $\lambda$  - we do not know. **Unlikely to have viable minimum.**

# Conclusions

- ⑥ there is no clear indication that the meta-stable SUSY-breaking vacuum exists in  $N_f = N_c$  SQCD
- ⑥ no information can be gained by deforming the theory
- ⑥ minimum of one deformation - saddle point in another
- ⑥ coupled singlets - the instability may be generic
- ⑥ Pentagon - the coupling to singlet can not be too large or too small
- ⑥ if the conjectured minimum of Pentagon exists:
  - △ it's uncalculable
  - △ it's not ISS minimum