

Non-Supersymmetric Seiberg duality Beyond the Planar Limit

Input from non-critical string theory

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A. Armoni, D.I., G. Moraitis and V. Niarchos, arXiv:0801.0762

Introduction

- IR dynamics of non-supersymmetric gauge and string theories are poorly understood as few constraints are left when susy is absent
 - In gauge theory, the prominent example is QCD for which non-lattice quantitative dynamics are mainly out of reach
 - ➔ study non-susy gauge theory having some connection with supersymmetric ones
 - In string theory one expects that only string theories with some degree of (asymptotic) spacetime supersymmetry are well-defined
 - ➔ what happens for deeply non-susy string theories ?
 - These two class of problems can be related using the general logic of holographic gauge/string correspondence
- ➔ A better understanding of non-susy gauge dynamics may be related to similar progress in string theory

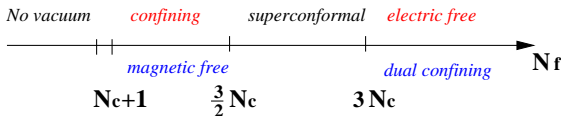
Outline

- 1 SQCD, Orientifold QCD and planar equivalence
- 2 Seiberg duality for OQCD at finite N : a conjecture
- 3 Non-critical type $0'$ strings
- 4 OQCD in non-critical strings and duality

Seiberg duality in SQCD

- Low energy phase structure of $\mathcal{N} = 1$ QCD is well understood using e.g. the strong constraints of holomorphy and R-symmetry *(Seiberg 94)*
- $SU(N_c)$ SQCD made of a vector multiplet (A_μ, λ) , N_f quarks chiral multiplets Q in \square and N_f quarks multiplets \tilde{Q} in $\bar{\square}$.
- Loses asymptotic freedom for $N_f \geq 3N_c \rightarrow$ free theory of quarks and gluons in the IR
- One-loop β -function vanishes at $N_f = 3N_c \rightarrow$ for $N_* < N_f < 3N_c$ expected to flow in the IR to an interacting fixed point
- SQCD has a **dual "magnetic" description** with gauge group $SU(N_f - N_c)$ and dual quarks multiplets q_i and \tilde{q}^i , with an extra meson singlet multiplet M and the superpotential $W_{\text{TREE}} = M_i^j q_i \tilde{q}^j$
- Loses asymptotic freedom, hence IR free, for $N_f < \frac{3}{2}N_c \rightarrow$ free magnetic phase
- One-loop magnetic β -function vanishes for $N_f = \frac{3}{2}N_c$

- One predicts then a *conformal window* $\frac{3}{2} N_c < N_f < 3 N_c$
- In the conformal window interacting IR fixed point from both electric and magnetic descriptions
- Close to lower bound, magnetic description weakly coupled while close to upper bound the electric description is more appropriate
- Numerous checks as 't Hooft anomaly matching, matching of moduli spaces, study of the chiral ring of the superconformal algebra, and same global symmetries



Planar equivalence

- One would like to extend this analysis to non-supersymmetric gauge theories \rightarrow in $SU(3)$ YM with N_f fundamental flavors, only the upper bound of the conformal window is known *(Banks, Zaks 82)*
- One can define non-supersymmetric theories modding out $\mathcal{N} = 1$ theories by a discrete symmetry $\Gamma \rightarrow$ (orient/orbi)fold field theories
- One can show that planar diagrams are in one-to-one correspondence leading to perturbative equivalence in their common sector
- "Daughter" theory non-perturbatively equivalent to the "mother" theory in their common sector of Γ -even states, in the $N \rightarrow \infty$ planar limit, only if Γ not spontaneously broken \rightarrow *planar equivalence*
(Kovtun Unsal Yaffe; Armoni Shifman Veneziano)
- In string theory embeddings, this condition means no coupling to a closed string tachyon *(Armoni 07)*
 \rightarrow rules out e.g. naive type 0B constructions or $AdS_5 \times S^5/\Gamma$ non-susy orbifolds (problem comes from twisted sector)
- Planar equivalence provides exact non-perturbative results for (a restricted class of) non-susy gauge theories

Orientifold QCD

- ✓ Orientifold QCD is a variant of $U(N_c)$ SQCD with N_f flavors. The bosonic sector is the same but fermions transform as:
 - "gluinos" : $\text{Ad}(U(N_c)) \longrightarrow$ *symmetric* (OQCD-S) or *antisymmetric* (OQCD-AS) representation of $U(N_c)$
 - quarks : fundamental \longleftrightarrow anti-fundamental representations exchanged w.r.t. squarks (seen from the interactions at large N)
- ➔ anomaly-free global symmetry: $SU(N_f) \times SU(N_f) \times U(1)$
- ➔ OQCD-AS with $N_c=3$, $N_f = 0$: one flavor QCD!

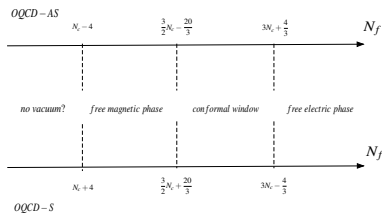
- ✓ Perturbative Coleman-Weinberg potential for the squark vev is non-vanishing at finite N
- ➔ moduli space is lifted. One is looking for duality at the origin of the pseudo-moduli space

Large N Seiberg duality

- ✓ one-loop β -function vanishes for $N_f = 3N_c \mp 4$
 - ➔ for more flavors, free electric phase
 - ➔ for $N_* < N_f < 3N_c \pm 4$ one may expect a conformal window
- ✓ Planar equivalence with SQCD proven *(Armoni, Shifman, Veneziano)*
 - Therefore an orientifold "magnetic" theory is naturally inherited from SQCD in the planar limit $N_c, N_f \rightarrow \infty, N_f/N_c$ fixed
 - Predicts a **non-supersymmetric Seiberg duality** in OQCDs in this large N limit, with a conformal window
- ✓ This magnetic theory has a singlet meson as magnetic SQCD, but "mesinos" transform in symmetric (OQCD-AS) or antisymmetric (OQCD-S) representation
 - ➔ what happens at finite N ?

Seiberg duality at finite N_c : a conjecture

- We propose that (N_c, N_f) OQCD-S/OQCD-AS is dual to a "magnetic theory" with $(N_f - N_c \mp 4, N_f)$ for any N_f and any $N_c > 5$ *(Armoni, DI, Moraitis, Niarchos 08)*
- Rank of magnetic gauge group fixed by 't Hooft anomaly matching assuming duality holds
 → however not enough to give strong evidence for the duality
- This duality if true predicts the following phase structure, with a **conformal window** $\frac{3}{2}N_c \pm \frac{20}{3} < N_f < 3N_c \mp \frac{4}{3}$:



→ more evidence comes from a string theory construction

String theories without fermions

- One expects a string theory realization of OQCD to be without space-time fermions (hadronic spectrum of OQCD purely bosonic)
➔ *do such string theories exist ?*
- No spontaneous breaking of Γ mapped to the *absence of closed string tachyons* (Armoni'07)
- *Kutasov-Seiberg theorem*, based on modular invariance, states that having no tachyons requires **asymptotic supersymmetry** at high energies
➔ Loophole : **unoriented strings** ! $\mathcal{Z} = \text{circle} + \text{figure-eight}$
- Sagnotti orientifold of type 0B (type 0'B) is tachyon-free but develops a RR tadpole ➔ adding D9-branes is needed, NSNS tadpole left hence strong wrapping of spacetime (Sagnotti 95)

$$\Omega' : |0\rangle_{NS} \rightarrow -|0\rangle_{NS} , \quad \psi_r^i \bar{\psi}_r^j |0\rangle_{NS} \rightarrow \psi_r^j \bar{\psi}_r^i |0\rangle_{NS}$$

- Only such string theories known with full tree-level consistency:
non-critical type 0' strings

Non-critical type 0'A theories

- Start e.g. with type 0A on $\mathbb{R}^{3,1} \times [\mathcal{N} = 2 \text{ Liouville}]$
 ➔ **non-chiral GSO projection**, contains a tachyon sector + doubling of the RR forms

- Due to linear dilaton ϕ , positive mass shift :

$$m^2 = p_\mu p^\mu + p_\phi^2 + \frac{1}{4} + \frac{1}{2}(n + w)^2 + \dots - \frac{1}{2}$$

($\mathcal{N} = 2$ Liouville contains an S^1 at radius $R = \sqrt{2}$ with momentum n and winding number w)

➔ not enough to lift the tachyon

- With the A-type parity $P = \Omega \mathcal{I}_x (-)^{n+w+F}$ of $\mathcal{N} = 2$ Liouville, one gets a non-critical analogue of type 0'B orientifold
- Crosscap wavefunction can be determined by **open/closed channel duality** from the Möbius amplitude:

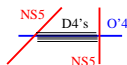
$$\text{Tr}_{\text{OPEN}, |B\rangle} (P e^{-\pi t H_0}) = \sum_{\text{closed}} \langle B | P e^{-\frac{H_C}{4\pi t}} | C \rangle$$

- Closed string tachyon is projected out, while no tadpole is generated (RR tadpole is massive) ➔ **perturbatively stable**

OQCD in non-critical strings: framework

- Adding D-branes one can engineer OQCD in type 0'A NCS
- Not a coincidence, as the non-critical type 0'A represents a configuration of two orthogonal NS5-branes with an O'4-plane, in a suitable decoupling limit

➔ OQCD realized as some sort of "near-horizon" Hanany-Witten (HW) construction



- Note that the usual HW approach is not under control here – as the "bulk" away from the O'4 plane is tachyonic ➔ these tachyonic modes are removed in the near-horizon limit !
- RR charge jump of the orientifold across the NS5-branes accounted for by the crosscap state found ➔ extended orientifold (FZZ-like) contains a localized piece (ZZ-like) with opposite RR-charge

Color and flavor branes for OQCD

- D-branes boundary states same as the NSNS part of their type IIA analogues \rightarrow the latter realize $\mathcal{N} = 1$ SQCD
(Fotopoulos Niarchos Prezas; Ashok Murthy Troost 05)
- **Localized** D4-branes near the Liouville wall (ZZ-like): **color** degrees of freedom \rightarrow with the Möbius amplitude contributing to the open RR sector, symmetric or antisymmetric fermions
- **Extended** D4-branes (FZZT-like): no 4d degrees of freedom on their worldvolume. Open strings between localized and extended branes realize **flavor** degrees of freedom
- Realize "electric" OQCD-S/OQCD-AS \rightarrow leading order backreaction (holographic β -function) suggests that the gauge theory has a quartic coupling, also for SQCD model: $\int d^2\theta Q\tilde{Q}Q\tilde{Q}$.

Gauge duality in non-critical strings

- $\mathcal{N} = 2$ Liouville has a potential $\mu \int d^2\theta e^{\Phi/\sqrt{2}}$ with $\mu \in \mathbb{C}$
- μ is the NS5-branes relative position in the HW picture
 ➔ Seiberg duality for SQCD obtained through the transformation

$$\mu \rightarrow -\mu$$

(Elitzur et al. 97)

- Reproduced in the non-critical string context using *brane and crosscap monodromies* under $\mu \rightarrow -\mu$

(Murthy Troost 06)

★ In OQCD, we found that duality gives a magnetic theory of the same type, with $N_c \rightarrow N_f - N_c \mp 4$

- No massless meson because of the quartic coupling ➔ monodromies consistent with backreaction
- Due the orientifold, only $\mu \in \mathbb{R}$ allowed ➔ one goes through strong coupling $\mu = 0$, creating ± 4 extra color branes
 ➔ however no extra stringy dynamics at $\mu = 0$ is expected to affect the gauge theory IR dynamics

Conclusions

- String theories with only bosonic degrees of freedom and full tree-level stability (tachyon- and tadpole- free) are very rare
- On the gauge theory side, few non-susy models inherit properties of susy theories through planar equivalence
- Not surprisingly one can engineer such gauge theories (orientifold QCD) in such string theories (non-critical 0'A)
- The string theory picture strongly supports a Seiberg duality in OQCD at finite N , and predicts an exact conformal window
- A genuine holographic duality pair could be constructed if one knew how to include D-brane and orientifold backreaction properly