Non-Supersymmetric Seiberg Duality in orientifold QCD and Non-Critical Strings

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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

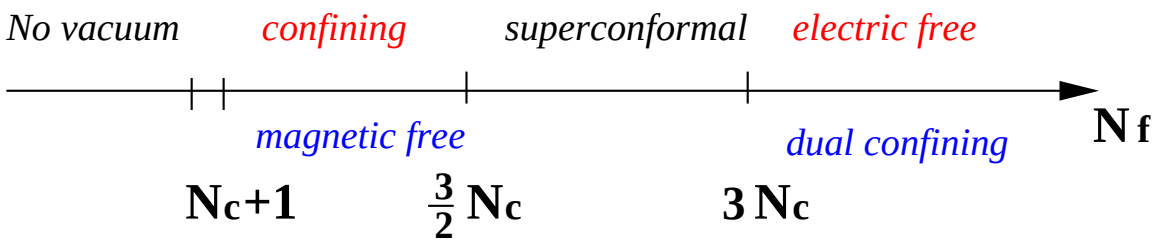
Outline

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 $\bar{\square}$.
- Looses asymptotic freedom for $N_f \geqslant 3N_c$ ➥ free theory of quarks and gluons in the IR
- One-loop β-function vanishes at $N_f = 3N_c$ ➥ for $N_\star < N_f < 3N_c$ 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 $\tilde{q}^{\tilde{\imath}}$, with an extra meson singlet multiplet M and the superpotential $W_{\text{TREE}} = M^i_{\tilde{\imath}} q_i \tilde{q}^{\tilde{\imath}}$
- Looses asymptotic freedom, hence IR free, for $N_f < \frac{3}{2} N_c$ ➥ free magnetic phase
- One-loop magnetic β-function vanishes for $N_f = \frac{3}{2} N_c$

- One predicts then a *conformal window* $\frac{3}{2}N_c < N_f < 3N_c$
- 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 ➥ 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 Γ ➥ (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 $N \longrightarrow \infty$ planar limit, only if Γ not spontaneously broken ➥ *planar equivalence*

(Kovtun Unsal Yaffe; Armoni Shifman Veneziano)

- In string theory embeddings, this condition means no coupling to a closed string tachyon *(Armoni 07)*
  ➥ 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 $U(\mathrm{N}_c)$ SQCD with N_f flavors. The bosonic sector is the same but fermions transform as:

- "gluinos" : $\mathrm{Ad}(U(\mathrm{N}_c)) \longrightarrow$ *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)

➥ relevant symmetry Γ for the projection : charge conjugation
➥ global symmetry: $SU(N_f) \times SU(N_f) \times U(1)$
➥ OQCD-AS with N_c=3, $\mathrm{N}_f = 0$: 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 $N_\star < N_f < 3N_c \pm 4$ one may expect a conformal window

✔ Planar equivalence with SQCD proven *(Armoni, Shifman, Veneziano)*

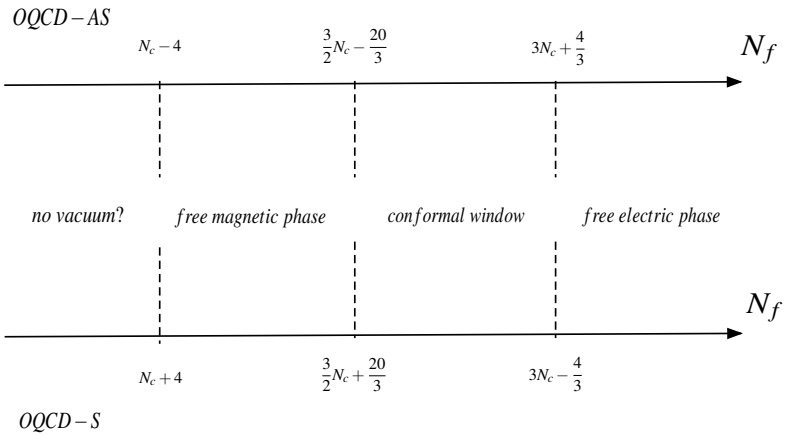
- Therefore an orientifold "magnetic" theory is naturally inherited from SQCD in the planar limit $\mathrm{N_c}, \mathrm{N_f} \to \infty$, $\mathrm{N_f}/\mathrm{N_c}$ fixed
- Predicts a non-supersymmetric Seiberg duality in OQCDs in this large N limit, with a conformal window

✔ 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: a conjecture

- We propose that $(\mathrm{N}_c, \mathrm{N}_f)$ OQCD-S/OQCD-AS is dual to a "magnetic theory" with $(\mathrm{N}_f - \mathrm{N}_c \mp 4, \mathrm{N}_f)$ for any N_f and any $\mathrm{N}_c > 5$ *(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 $\frac{3}{2}\mathrm{N}_c \pm \frac{20}{3} < \mathrm{N}_f < 3\mathrm{N}_c \mp \frac{4}{3}$:



➥ 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 ! $\mathcal{Z} =$ 
- 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)*

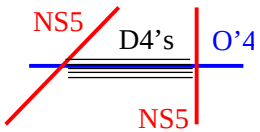
$$\Omega' \ : |0\rangle_{\rm NS} \to -|0\rangle_{\rm NS} \ , \quad \psi_r^i \bar{\psi}_r^j |0\rangle_{\rm NS} \to \psi_r^j \bar{\psi}_r^i |0\rangle_{\rm NS}$$

- Only such string theories known with full tree-level consistency: *non-critical type 0' strings* *(DI, Niarchos)*

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 :
$$m^2 = p_\mu p^\mu + p_\phi^2 + \frac{1}{4} + \frac{1}{2}(n+w)^2 + \cdots - \frac{1}{2}$$
($\mathcal{N} = 2$ 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:
$$\text{Tr}_{\text{OPEN},|B\rangle}\left(\mathcal{P} e^{-\pi t H_o}\right) = \sum_{\text{closed}} \langle B | \mathcal{P} e^{-\frac{H_c}{4\pi t}} | \mathcal{C}_\mathcal{P} \rangle$$
- 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 ➥ 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 ➥ 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 ➥ leading order backreaction (holographic β-function) suggests that the gauge theory has a quartic coupling, also for SQCD model: $\int \mathrm{d}^2\theta\, Q\tilde{Q}Q\tilde{Q}$.

Gauge duality in non-critical strings

- $\mathcal{N} = 2$ Liouville has a potential $\mu \int \mathrm{d}^2\theta \, e^{\Phi/\sqrt{2}}$ with $\mu \in \mathbb{C}$
- μ is the NS5-branes relative position in the HW picture
  ➥ Seiberg duality for SQCD obtained through the transformation $\mu \to -\mu$ *(Elitzur et al. 97)*
- Reproduced in the non-critical string context using *brane and crosscap monodromies* under $\mu \to -\mu$ *(Murthy Troost 06)*

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

- 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