Hints on 5d Fixed Point Theories from Non-Abelian T-duality

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- 5d fixed point theories arise in the infinite bare coupling limit of N=1 SUSY gauge theories with very specific gauge groups and matter content (Seiberg'96; Intriligator, Morrison, Seiberg'97)

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- Search for AdS_6 backgrounds: Brandhuber and Oz's quite unique (Passias'12)

In this talk:

- New AdS_6 solution through non-Abelian T-duality

  (Y.L., O Colgain, Rodriguez-Gomez, Sfetsos, PRL (2013))

- Hints on the associated dual CFT

  (Y.L., O Colgain, Rodriguez-Gomez, arXiv:1311.4842)

Non-Abelian T-duality in AdS/CFT

- **In 4 dim:** (Sfetsos & Thompson'10)

$AdS_5 \times S^5$ $\xrightarrow{\text{NATD}}$ Uplift to 11 dim $AdS_5 \times H_2 \times M_4$ $(H_2 \to S^2)$

(Gaiotto & Maldacena geometries for N=2 SCFTs)

$AdS_5 \times T^{1,1}$ $\xrightarrow{\text{NATD}}$ Uplift to 11 dim $AdS_5 \times H_2 \times M_4$ $(H_2 \to S^2)$

(Sicilian quivers (N=1 SCFTs) (Benini, Tachikawa, Wecht))

Klebanov & Strassler $\xrightarrow{\text{NATD}}$ New geometries in massive IIA
Confining quarks, domain walls, Seiberg duality,...

(Itsios, Nuñez, Sfetsos & Thompson'13)
(Nuñez & colab'13,14)

- In 5 dim: (Y.L., O Colgain, Rodriguez-Gomez, Sfetsos'12; Y.L., O Colgain, Rodriguez-Gomez'13)

$$AdS_6 \times S^4 \xrightarrow{\text{NATD}}$$

New AdS_6 geometry in IIB
Dual CFT quiver with two nodes

Outline

1. 5d fixed point theories
2. The D4-D8 system
3. Non-Abelian T-duality back in the 90's
4. Non-Abelian T-duality as a solution generating technique
5. The non-Abelian T-dual of Brandhuber & Oz
6. Hints on the 5d dual CFT
7. Conclusions and open issues

1. 5d fixed point theories

5d gauge theories are non-renormalizable:

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- 5d SYM with minimal SUSY can be at fixed points for specific gauge groups and matter content, where they can exhibit interesting phenomena such as exceptional global symmetry groups (Seiberg'96; Intriligator, Morrison, Seiberg'97)

- 5d fixed point theories are intrinsically strongly coupled
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$\rightarrow$ Search for new realizations by scanning over the possible AdS_6 vacua in SUGRA

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Passias'12:
- Unique SUSY solution in massive IIA:
  Near horizon of the D-brane system giving rise to $Sp(N)$ with specific matter content
  (Brandhuber, Oz'99)*
- Non-existence of AdS_6 solutions in other SUGRAs not completely excluded, but strongly suggested

* And orbifolds thereof (Bergman, Rodríguez-Gómez'12)

2. The D4-D8 system

5d SUSY fixed points with E_{N_f+1} global symmetry can be obtained in the infinite bare coupling limit of N=1 SYM with gauge group Sp(N), one antisymmetric hypermultiplet and $N_f < 8$ fundamental hypermultiplets (Seiberg'96)

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From the D4-D4 sector:

Vector multiplet with Sp(N) gauge symmetry
Massless hyper in the antisym. of Sp(N)

From the D4-D8 sector:

Massless hypers in the fundamental of $SO(2N_f)$

A D4-brane probe in the D8-O8 background metric

(Brandhuber, Oz'99; Ferrara, Kehagias, Partouche, Zaffaroni'98)

$$ds^2 = H_8^{-1/2}(-dt^2 + dx_1^2 + \cdots + dx_8^2) + H_8^{1/2} dz^2$$

$$H_8(z) = c + 16\frac{z}{l_s} - \sum_{i=1}^{8} \frac{|z - z_i|}{l_s} - \sum_{i=1}^{8} \frac{|z + z_i|}{l_s}$$

(z_i : locations of the 16 D8-branes)

has a gauge coupling $\frac{1}{g^2} = \frac{H_8}{l_s}$

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In the field theory limit ($l_s \to 0$ + gauge coupling fixed):

$\phi = \frac{z}{l_s^2}$ must be constant $\Rightarrow$ Region near $z = 0$ (location of the $O8^-$ plane)

Then: $$\frac{1}{g^2} = \frac{c}{l_s} + 16\phi - \sum_{i=1}^{8} |\phi - m_i| - \sum_{i=1}^{8} |\phi + m_i|$$

with $\phi = \frac{z}{l_s^2}$, $m_i = \frac{z_i}{l_s^2}$.

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Taking N_f massless hypermultiplets:

$$\frac{1}{g^2} = \frac{1}{g_{cl}^2} + 16\phi - \sum_{i=1}^{N_f} |\phi - m_i| - \sum_{i=1}^{N_f} |\phi + m_i|$$

one gets:

$$\frac{1}{g^2} = \frac{1}{g_{\rm cl}^2} + (16 - 2N_f)\phi$$

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The field theory calculation can be generalized to other gauge groups and matter content (Intriligator, Morrison, Seiberg'97) , which lack however an AdS/CFT description

The near horizon geometry of the D4-D8 system is a fibration of AdS_6 over half-S^4 with an S^3 boundary at the position of the O8-plane, preserving 16 SUSYs

$$ds^2 = \frac{W^2\, L^2}{4} \left[9\, ds^2(AdS_6) + 4\, ds^2(S^4)\right] \qquad \theta \in [0, \frac{\pi}{2}]$$

$$F_4 = 5\, L^4\, W^{-2}\, \sin^3\theta\, d\theta \wedge \text{Vol}(S^3)$$

$$e^{-\phi} = \frac{3\, L}{2\, W^5}\,, \qquad W = (m\, \cos\theta)^{-\frac{1}{6}} \qquad m = \frac{8 - N_f}{2\pi l_s}$$

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- $SO(5)$ symmetry broken to $SO(4) \sim SU(2) \times SU(2)$:

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- $SO(2,5) \leftrightarrow$ Conformal symmetry

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We will see: New AdS_6 solution in Type IIB through non-Abelian T-duality*

* Also through Abelian T-duality, describing the same fixed point theory

3. Non-Abelian T-duality back in the 90's

Rocek and Verlinde's formulation of Abelian T-duality for ST in a curved background (Buscher'88) :

$$S = \frac{1}{4\pi\alpha'} \int \Big(g_{\mu\nu}\, dX^\mu \wedge *dX^\nu + B_{\mu\nu}\, dX^\mu \wedge dX^\nu \Big) + \frac{1}{4\pi} \int R^{(2)} \phi$$

In the presence of an Abelian isometry: $\delta X^\mu = \epsilon\, k^\mu$ /

$$\mathcal{L}_k g = 0\,,\ \mathcal{L}_k B = d\omega\,,\ i_k d\phi = 0$$

i) Go to adapted coordinates: $X^\mu = \{\theta, X^\alpha\}$ such that

$\theta \to \theta + \epsilon$ and $\partial_\theta(\text{backgrounds}) = 0$

ii) Gauge the isometry: $d\theta \to D\theta = d\theta + A$

A non-dynamical gauge field / $\delta A = -d\epsilon$

iii) Add a Lagrange multiplier term: $\tilde{\theta}\, dA$, such that

$$\int \mathcal{D}\tilde{\theta} \;\to\; dA = 0 \;\Rightarrow\; A$$ exact

(in a topologically trivial worldsheet)

+ fix the gauge: $A = 0 \;\to$ Original theory

iv) Integrate the gauge field

+ fix the gauge: $\theta = 0 \;\to$ Dual sigma model:

$\{\theta, X^\alpha\} \to \{\tilde{\theta}, X^\alpha\}$ and

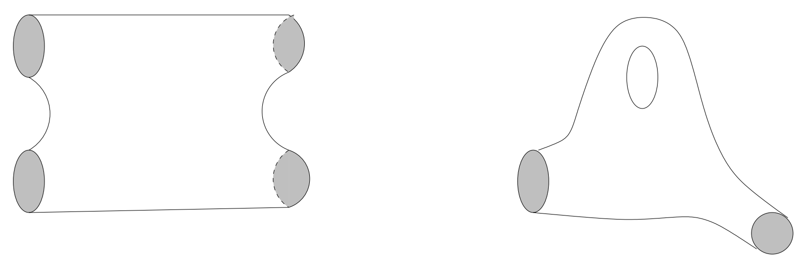
$$\tilde{g}_{00} = \frac{1}{g_{00}}; \quad \tilde{g}_{0\alpha} = \frac{B_{0\alpha}}{g_{00}}; \quad \tilde{g}_{\alpha\beta} = g_{\alpha\beta} - \frac{g_{0\alpha}g_{0\beta} - B_{0\alpha}B_{0\beta}}{g_{00}}$$

$$\tilde{B}_{0\alpha} = \frac{g_{0\alpha}}{g_{00}}; \quad \tilde{B}_{\alpha\beta} = B_{\alpha\beta} - \frac{g_{0\alpha}B_{0\beta} - g_{0\beta}B_{0\alpha}}{g_{00}}$$

$$\tilde{\phi} = \phi - \log g_{00}$$

Buscher's formulae

- Conformally invariant
- Involutive transformation: $\tilde{S} \xrightarrow[\tilde{\theta} \to \tilde{\theta} + \epsilon]{} S$
- Arbitrary worldsheets? (symmetry of string perturbation theory):



(a) (b)

$\Rightarrow$ Non-trivial topologies + compact isometry orbits

Large gauge transformations: $\oint_\gamma d\epsilon = 2\pi n\,;\ n \in \mathbb{Z}$

To fix them:

Multivalued Lagrange multiplier: $\oint_\gamma d\tilde{\theta} = 2\pi m\,;\ m \in \mathbb{Z}$
such that

$$\int [\text{exact}] \rightarrow dA = 0 \qquad \textbf{+} \qquad \int [\text{harmonic}] \Rightarrow A \text{ exact}$$

$\Rightarrow$ The gauging procedure works for all genera

(Rocek, Verlinde'91)

Non-Abelian T-duality

(De la Ossa, Quevedo'93)

Non-Abelian continuous isometry: $X^m \to g^m_n X^n \,, g \in G$

i) Gauge it: $dX^m \to DX^m = dX^m + A^m_n X^n$

$A \in$ Lie algebra of G $\quad A \to g(A+d)g^{-1}$

ii) Add a Lagrange multiplier term: $\mathrm{Tr}(\chi F)$

$F = dA - A \wedge A$

$\chi \in$ Lie Algebra of G, $\chi \to g\chi g^{-1}$, such that

$\int \mathcal{D}\chi \;\to\; F = 0 \;\Rightarrow\; A$ exact
(in a topologically trivial worldsheet)

+ fix the gauge: $A = 0 \Rightarrow$ Original theory

iii) Integrate the gauge field + fix the gauge $\rightarrow$ Dual theory

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Example: Principal chiral model with group SU(2):

Geometrically: S^3

$$L = Tr(g^{-1}dg \wedge *g^{-1}dg)\,;\; g \in SU(2)$$

Invariant under:

$$g \rightarrow h_1\, g\, h_2\,;\; h_1, h_2 \in SU(2)$$

Choose: $g \rightarrow hg\,;\; h \in SU(2)$

$$\tilde{L} = \frac{1}{1+\chi^2}\Big(\delta_{ij} - \epsilon_{ijk}\chi^k + \chi_i\chi_j\Big) d\chi^i \wedge *d\chi^j$$

Invariant under $\chi \rightarrow h\chi h^{-1}\,;\; h \in SU(2)$

- Non-involutive
- Higher genus generalization? Set to zero $W_\gamma = P\, e^{\oint_\gamma A}$
- Global properties?

  $\chi \in \mathbb{R}^3$: Global completion of $\mathbb{R}^3$?

- Conformal invariance not proved in general

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True symmetry in String Theory?

Still, interesting as a solution generating technique

(Sfetsos, Thompson'10)

4. Non-Abelian T-duality as a solution generating technique:

Need to know how the RR fields transform

In the Abelian case: Reduce to a unique N=2, d=9 SUGRA

(Bergshoeff, Hull, Ortín'95)

Hassan'99: Implement the relative twist between left and right movers in the bispinor formed by the RR fields:

$$\hat{P} = P\Omega^{-1} \qquad P = \frac{e^{\phi}}{2}\sum_k \frac{1}{k!} F_{\mu_1\dots\mu_k}\Gamma^{\mu_1\dots\mu_k}$$

with $\Omega = \sqrt{g_{00}^{-1}}\Gamma_{11}\Gamma^0$

Same thing in the non-Abelian case (Sfetsos, Thompson'10)

Interesting new solutions have been found with CFT duals

But what if NATD is not a symmetry of ST?

Some of the properties of the CFT may no longer hold after adding corrections on the inverse ‘t Hooft coupling or 1/N

5. The non-Abelian T-dual of Brandhuber and Oz

- Take the $AdS_6 \times S^4$ background

$$ds^2 = \frac{W^2 L^2}{4}\left[9ds^2(AdS_6) + 4\left(d\theta^2 + \sin^2\theta ds^2(S^3)\right)\right]$$

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In spherical coordinates adapted to the remaining $SU(2)$:

$$ds^2 = \frac{W^2 L^2}{4}\left[9\, ds^2(AdS_6) + 4\, d\theta^2\right] + e^{-2A}\, dr^2 + \frac{r^2 e^{2A}}{r^2 + e^{4A}}\, ds^2(S^2)$$

$$B_2 = \frac{r^3}{r^2 + e^{4A}}\, \mathrm{Vol}(S^2) \qquad e^{-\phi} = \frac{3L}{2W^5}\, e^{A} \sqrt{r^2 + e^{4A}}$$

$$F_1 = -G_1 - m\, r\, dr \qquad F_3 = \frac{r^2}{r^2 + e^{4A}}\left[-r\, G_1 + m\, e^{4A}\, dr\right] \wedge \mathrm{Vol}(S^2)$$

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- Boundary at $\theta = \frac{\pi}{2}$ inherited.
- What about r ?
  - Background perfectly smooth for all r
  - No global properties inferred from the non-Abelian transf.
  - Assume $r \in [0, R]$ (to avoid a continuous spectrum of fluctuations), and try to infer global properties by demanding consistency to the dual background

6. Hints on the 5d dual CFT

i) Quantization of charges:

D4 → D5 (N_5^θ)

D4 → D7 (N_7^θ)

D8 → D7 (N_7^r)

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N_5^θ and N_5^r depend on the large gauge transf. of B_2:

$$B_2 = \left(\frac{r^3}{r^2+e^{4A}} - n\pi\right)\mathrm{Vol}(S^2) \quad / \quad b = \frac{1}{4\pi^2}\int_{S^2} B_2 \in [0,1]$$

(which seems, on the other hand, to undergo something reminiscent of the cascade in KS), in such a way that they cannot be integers for all (r,θ) unless $n=0$

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This fixes the maximum value of r to $r=\pi$

ii) Probe the Coulomb branch:

2 directions $\leftrightarrow$ BPS D5 and D7 branes

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Fluctuations of these branes:

D5: $S_{DBI} = \int \frac{1}{g_{D5}^2} F_{\mu\nu}^2$, $\frac{1}{g_{D5}^2} = \frac{9\, L^2\, m^{-1/3}\, N_7^r}{128\, \pi^3}\, \rho$

$$S_{5d\,CS} = \frac{(2\pi)^3}{6} T_5 \int F_1 \int A \wedge F \wedge F = -\frac{N_7^r}{24\, \pi^2} \int A \wedge F \wedge F$$

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D7: Same with $N_7^r \leftrightarrow N_5^r$, D1 $\leftrightarrow$ D3 wrapped on S^2

ii) Baryon-like operators:

Dual to branes wrapped on the internal geometry with a tadpole proportional to the rank of the gauge group

In the D4-D8 background: D4-brane with N charge, projected out by the orbifold

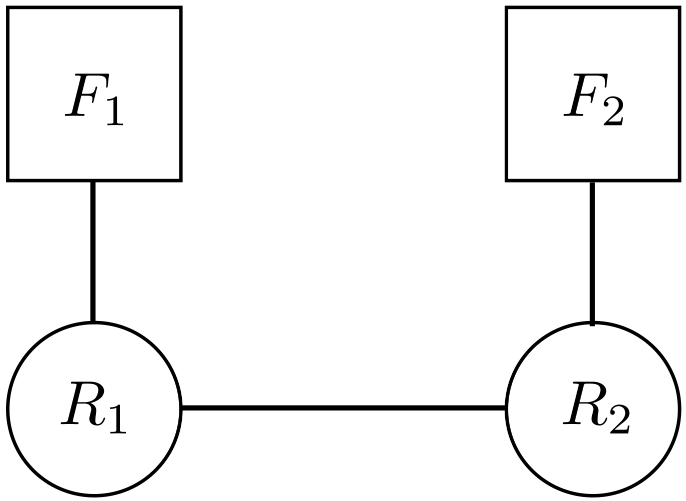
In the non-Abelian dual: D1-brane with N_7^θ charge plus D3-brane (wrapped on S^2) with N_5^θ charge

Projected out by the dual orbifold

In any case they inform about the ranks of the dual gauge groups

iv) Putting it all together:

We seem to have two gauge groups with ranks $N_7^\theta\,,N_5^\theta$ and flavor symmetries $N_5^r\,,N_7^r$



N_5^θ actually zero, such that the background is globally well defined

Manifestation in the CFT of a perfectly regular background terminating at a point?

7. Conclusions and open issues

- Could a clear prescription for global properties lead to a regular background for arbitrary large gauge transformations, with non depleted gauge groups in the dual CFT?

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Non-Abelian T-dual as an effective description? (Sfetsos'13)

- Nature of the dual gauge groups: What is the orientifold projection in the dual theory?

$$O8^- \to O5^-$$
$$O8^- \to O7^-$$

$I_\theta \Omega \to I_\theta I_\chi \Omega$:

Dual Op^- located at $\theta = \frac{\pi}{2}, r = 0$

D5-D7 system?

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Thanks!