New AdS/CFT duals through non-Abelian T-duality

Yolanda Lozano (U. Oviedo)

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- Non-Abelian T-duality (NATD) very useful in generating new supergravity backgrounds with CFT duals
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In this talk we will use NATD to generate new AdS_6 and AdS_4 backgrounds

We will analyze the dual CFTs and provide an interpretation for the running of the non-compact direction

AdS_6 : AdS_6 backgrounds are quite unique ("no-go" theorem) (Passias'12; Apruzzi, Fazzi, Passias, Ross, Tomasiello'14)

Dual to 5d CFT's (fixed point theories with interesting properties)

(Seiberg'96; Intriligator, Morrison, Seiberg'97)

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AdS_4 : Dual to 3d CFT

AdS_4 IIB background with N=2 SUSY not in Lüst, Tsimpis'09

Interesting realization in the CFT of the running of the non-compact direction generated by NATD: Spectral flow (Y.L., Macpherson, arXiv:1408.0912)

1. Non-Abelian T-duality in AdS/CFT

- In 4 dim:

Sfetsos & Thompson'10:

$AdS_5 \times S^5$ $\xrightarrow[\text{Uplift to 11 dim}]{\text{NATD}}$ Gaiotto & Maldacena geometries (dual to Gaiotto's N=2 SCFTs)

Itsios, Nuñez, Sfetsos & Thompson'13:

$AdS_5 \times T^{1,1}$ $\xrightarrow[\text{Uplift to 11 dim}]{\text{NATD}}$ Bah, Beem, Bobev, Wecht sols. (dual to N=1 SCFTs (Sicilian quivers (Benini, Tachikawa, Wecht) ..)

Non-conformal (MN, KT, KS) $\xrightarrow{\text{NATD}}$ New geometries in massive IIA Confining quarks, domain walls, Seiberg duality,...

(Nuñez, Gaillard, Macpherson, Sfetsos, Thompson, Cáceres, Barranco (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

- **In 3 dim:** Y.L., Macpherson'14

$AdS_4 \times CP^3$ $\xrightarrow{\text{NATD}}$ New AdS_4 geometry in IIB
Dual CFT quiver with four nodes and a spectral flow

2. 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:

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

$$\int \mathcal{D}\tilde{\theta} \;\rightarrow\; dA = 0 \;\Rightarrow\; A \text{ exact} \quad \text{(trivial worldsheets)}$$

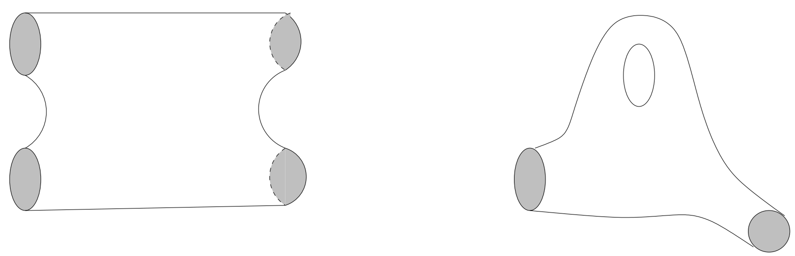
+ fix the gauge: $A = 0 \;\rightarrow$ Original theory

iv) Integrate the gauge field

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

$\{\theta, X^\alpha\} \rightarrow \{\tilde{\theta}, X^\alpha\}$ and $(\tilde{g}, \tilde{B}_2, \tilde{\phi})$ given by Buscher's formulae

- 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

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

$\Rightarrow$ The gauging procedure works for all genera

(Rocek, Verlinde'91)

- Conformally invariant

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

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

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

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

However,

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

NATD as a solution generating technique

(Sfetsos, Thompson'10)

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

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Given that NATD is not guaranteed to be a symmetry of ST:

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- In fact, possibly new CFTs!

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Explore 5d and 3d examples

3. Non-Abelian T-duality and 5d fixed point theories

5d gauge theories are non-renormalizable:

$[g^2] = M^{-1} \quad \rightarrow \quad g^2 E \quad \rightarrow$ UV completion

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- The string theory realization is however only known in very specific cases

- In particular, $Sp(N)$ (with specific matter content) can be realized in a D4/D8/O8 system. (Seiberg'96)

  An AdS_6 background arises as the near horizon geometry (Brandhuber, Oz'99)

3a. The D4/D8/O8 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)

The theory can be engineered in Type I' ST on a stack of N D4-branes probing a $O8^-$ plane with N_f D8-branes

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 $SO(2N_f)$

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

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

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

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

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

  $SU(2) \leftrightarrow SU(2)_R$ R-symmetry of the field theory

  $SU(2) \leftrightarrow$ global symmetry massless antisym. hyper

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

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New fixed point theory?

3b. The non-Abelian T-dual of Brandhuber and Oz

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

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

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

- Dualize it w.r.t. one of the $SU(2)$ symmetries

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

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

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

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

- It solves the IIB equations of motion
- SUSY preserved! First example of a non-Abelian T-dual geometry with supersymmetry fully preserved

  This is because the internal symmetry is really $SU(2) \times SU(2)_R$ and we dualize on the $SU(2)$ global symmetry *

- Boundary at $\theta = \frac{\pi}{2}$ inherited.
- What about r ?
  - Background perfectly smooth for all $r \in \mathbb{R}^+$
  - No global properties inferred from the non-Abelian transf.
  - Puzzle to the dual CFT (!)

* NATD and SUSY: Kelekci, Y.L., Macpherson, O Colgain, to appear

4. Non-Abelian T-duality in ABJM

Take the $AdS_4 \times CP^3$ IIA dual +

parameterize the CP^3 as a foliation in $T^{1,1} = S^2 \times S^3$ +

T-dualize w.r.t. the $SU(2)$ symmetry of the S^3

$\longrightarrow$ IIB AdS_4 solution:

- Metric + B_2 + dilaton + F_1, F_3, F_5
- $U(1) \times U(1)$ symmetric
- N=2 supersymmetric
- What about r ?
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5. Some hints on the dual CFTs

After an $SU(2)$ NATD:

$$F_q \to F_{q+1} \quad (M_1)$$

$$F_q \to F_{q+3} \quad (M_1 \times S^2)$$

$$F_q \to F_{q-1}$$

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In AdS_4:

$$F_2 \nearrow F_3$$
$$F_2 \searrow F_5$$

$$F_6 \nearrow \hat{F}_5 = -\hat{F}_3 \wedge n\pi \mathrm{Vol}(S^2)$$
$$F_6 \searrow \hat{F}_3$$

$\rightarrow$ Two ranks and two levels in the dual CFT

Large gauge transformations:

Singularity at $\zeta = 0$. Close to it the geometry is conformal to a singular cone with S^2 boundary

There $B_2 = -r\,\mathrm{Vol}(S^2)$

Large gauge transformations must be defined such that

$$\frac{1}{4\pi^2}\left|\int B_2\right| \in [0,1)$$

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For $r \in [n\pi, (n+1)\pi)$ $B_2 = (-r + n\pi)\,\mathrm{Vol}(S^2)$

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The division of $\mathbb{R}^+$ in $[n\pi, (n+1)\pi)$ intervals restricts non-trivially the global properties of the dual background

Color branes:

D3 on $\mathbb{R}_{1,2} \times M_1 \quad \longleftrightarrow \quad N_3 = n\, N_5 \quad , \quad g^2_{D3} \sim \frac{1}{k_5}$

D5 on $\mathbb{R}_{1,2} \times M_1 \times S^2 \quad \longleftrightarrow \quad N_5 \quad , \quad g^2_{D5} \sim \frac{1}{k_3}$

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Moving from an r interval to the previous one:

$N_3 \rightarrow N_3 - N_5$: Seiberg duality in N=1 $\leftrightarrow$ Large gauge transformations as geometric version of Seiberg duality in KT, KS..

(Benini, Canoura, Cremonesi, Nuñez, Ramallo'07)

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This, together with the analysis of particle-like configurations, giant gravitons, free energy, etc suggests a dual CFT:

$$U(N_3+N_5)_{k_3} \times U(N_3)_{k_5} \times U(N_3+N_5)_{-k_3} \times U(N_3)_{-k_5}$$

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In particular, all CFT should be equivalent to the one dual to the solution for $r \in [0, \pi)$: $U(N_5)_{k_3} \times U(N_5)_{-k_3}$ (N=2)

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N=2 3d CFT from M5-branes wrapped on a 3d manifold?

Speculate with a possible brane realization:

$$\begin{array}{lc|cccccccccc}
5_2^2: & \times & \times & \times & \times & \times & \times & & - & z_1 & z_2 & - \\
N_5\, D5: & \times & \times & \times & - & - & - & & \times & \times & \times & - \\
(5_2^2, k_3\,\mathrm{D3}): & \times & \times & \times & - & - & \cos\theta & & - & - & - & \sin\theta
\end{array}$$

6. Conclusions and open issues

- NATD useful as a solution generating technique:

Only known AdS_6 solution in IIB (+ Abelian T-dual)
(Only two explicit solutions to the PDEs in IIB recently derived in Apruzzi, Fazzi, Passias, Ross, Tomasiello'04)

New AdS_4/CFT_3 in IIB

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- First steps towards a systematic study of the dual CFTs

Realization in the CFT of the running of the non-compact direction: Spectral flow very similar to the cascade, but on the internal, not on the holographic, direction

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Also working in other NATD backgrounds?

The same idea works in 5d: $Sp(N_7^\theta)$ gauge theory with N_5^r flavors

$$\updownarrow$$

New fixed points associated with product gauge groups ruled out in the classification of Intriligator, Morrison, Seiberg

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- CFT dual to the new IIB AdS_4 background:

N=2: Low energy effective theory on the w.v. of 5-branes wrapping $\mathbb{R}_{1,2} \times M_3$ (3d-3d correspondence)?

Some of these theories: $U(1)^2$ isometry (Bah, Gabella, Halmagyi'14)

But free energy goes as $N^{3/2}$.. (Gabella, Martelli, Passias, Sparks'12)

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