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Gravity duals of 6d (1,0) SCFTs on punctured Riemann surfaces

arXiv:1704.07389 I.Bah, AP, A.Tomasiello

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“Geometry, Gravity and Supersymmetry”

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Introduction: AdS_5 solutions in String/M-theory

Type IIB supergravity

- Freund–Rubin backgrounds: $AdS_5 \times S^5$, $AdS_5 \times SE_5$ ($T^{1,1}$, $Y^{p,q}$, $L^{a,b,c}$)
- [Pilch, Warner '00], T-duals [Macpherson, Núñez, Pando Zayas, Rodgers, Whiting '14]
- analysis of general $\mathcal{N} = 1$ AdS_5 backgrounds [Gauntlett, Martelli, Sparks, Waldram '05]

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11D supergravity

- general $\mathcal{N} = 1$ AdS_5 backgrounds [Gauntlett, Martelli, Sparks, Waldram '04]
- general $\mathcal{N} = 2$ AdS_5 backgrounds [Lin, Lunin, Maldacena '04]

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An interesting class arises from wrapping M5-branes on Riemann surfaces

[Maldacena, Núñez '00] [Gaiotto, Maldacena '09] [Bah, Beem, Bobev, Wecht '12] [Bah '13,'15]

$$\mathrm{AdS}_7 \times S^4 \qquad \cdots\cdots \qquad \mathrm{AdS}_5 \times \Sigma \times \tilde{S}^4$$

Introduction: AdS_5 solutions in String/M-theory

Type IIA supergravity accessible from 11D, but what about adding Romans mass?

Introduction: AdS_5 solutions in String/M-theory

Massive Type IIA supergravity

$\mathrm{AdS}_6 \times S^4$ [Brandhuber, Oz '99]

	x_0	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
D4	×	×	×	×	×	–	–	–	–	–
O8–D8	×	×	×	×	×	×	×	×	×	–

Introduction: AdS_5 solutions in String/M-theory

Massive Type IIA supergravity

$AdS_7 \times M_3$ [Apruzzi, Fazzi, Rosa, Tomasiello '13]

	x_0	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
NS5	×	×	×	×	×	×	–	–	–	–
D6	×	×	×	×	×	×	×	–	–	–
D8	×	×	×	×	×	×	–	×	×	×

AdS_5 solutions in massive IIA supergravity

[Apruzzi, Fazzi, AP, Tomasiello '15] analysis of supersymmetric $\mathrm{AdS}_5 \times M_5$ solutions

$$ds^2_{10} = e^{2W} ds^2_{\mathrm{AdS}_5} + ds^2_{M_5}$$

+ all p-form fields preserving the $SO(2,4)$ symmetry

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. supersymmetry

$\exists$ $Spin(1,9)$ Majorana spinor ϵ such that the gravitino and dilatino supersymmetry variations

$$\delta_\epsilon \psi = \delta_\epsilon \lambda = 0$$

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$$SO(5) \to G$$

G is the stabilizer group of the supersymmetry parameters: two Dirac spinors η_1, η_2

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$$\delta_\epsilon \psi = \delta_\epsilon \lambda = 0 \rightsquigarrow \text{differential constraints on the G-structure}$$

AdS_5 solutions in massive IIA supergravity

$$G = \begin{cases} SU(2) \\ \\ Id \end{cases}$$

only $G = Id$ is allowed – in contrast to type IIB

AdS_5 solutions in massive IIA supergravity

$$G = \begin{cases} SU(2) \\ \\ Id \end{cases}$$

only $G = Id$ is allowed – in contrast to type IIB

| an identity structure is characterized by a local frame

- the p-form fields are expressed in terms of the identity structure
- the equations of motion are implied by

  supersymmetry equations

  + Bianchi identities $dH = 0, \;\; dF_2 - F_0 H = 0, \;\; dF_4 - F_2 \wedge H = 0$

AdS_5 solutions in massive IIA supergravity

. local geometry – no assumptions

$$ds^2_{10} = e^{2W}\left[ds^2_{AdS_5} + e^{2A}\left(dx_1^2 + dx_2^2\right) + \tfrac{1}{3}e^{-6\lambda}ds^2_3\right]$$

$$ds^2_3 = -\frac{4}{\partial_s D_s}\eta_\psi^2 - \partial_s \widetilde{D}_s\, ds^2 - 2\partial_u D_s\, du ds - \partial_u D_u\, du^2\,, \qquad \eta_\psi = d\psi - \tfrac{1}{2}\star_2 d_2 D_s$$

⋆ ∂_ψ generates the U(1) R-symmetry

| The solution is determined by two functions (D_u, D_s)

AdS_5 solutions in massive IIA supergravity

. local geometry – no assumptions

$$ds^2_{10} = e^{2W}\left[ds^2_{AdS_5} + e^{2A}\left(dx_1^2 + dx_2^2\right) + \tfrac{1}{3}e^{-6\lambda}ds_3^2\right]$$
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$\star$ ∂_ψ generates the U(1) R-symmetry

| The solution is determined by two functions (D_u, D_s) subject to three PDEs:

$$\Delta_2 D_s = 3\partial_s e^{6\lambda+2A} + \frac{F_0}{24\sqrt{2s}}\partial_s e^{D_s}$$
$$\Delta_2\left(\partial_u D_u\right) = 3\partial_u^2 e^{6\lambda+2A} + \frac{2F_0}{3\sqrt{2s}} s\partial_s e^{2A}$$
$$\frac{F_0}{36\sqrt{2s}} = \frac{\partial_u\left(\partial_s D_u - \partial_u D_s\right)}{\partial_s D_s}$$

AdS_5 solutions in massive IIA supergravity

. assumptions

$$e^{2A}(dx_1^2 + dx_2^2) = ds^2_{\Sigma_g}$$

+ separability in (s, u) & (x_1, x_2).

| For zero Romans mass we recover known solutions:

[Maldacena, Núñez '00] [Bah, Beem, Bobev, Wecht '12] [Itsios, Núñez, Sfetsos, Thompson '13]

| For non-zero Romans mass we find

a family of $AdS_5 \times \Sigma_{g>1} \times M_3$ solutions with an AdS_7 origin

$$M_3 = S^2 \times I$$

AdS_5 solutions in massive IIA supergravity

. assumptions

$$e^{2A}(dx_1^2 + dx_2^2) = f(s,u)ds^2_{\Sigma_g}$$

++ . . .

$\mathrm{AdS}_5 \times \Sigma_g$ solutions for every genus g

$+$

brane sources as punctures

AdS_5 solutions with punctures

. local geometry

$$ds^2_{10} = e^{2W}\left[ds^2_{AdS_5} - \frac{p'}{9z^2}ds^2_5\right], \qquad e^{4W} = \frac{z}{k}\frac{3p - zp'(1-k^3)}{-p'}$$

$$ds^2_5 = ds^2(\Sigma_g) + \frac{3z dz^2}{p} + \frac{9z^3}{3p - zp'}\left[\frac{k dk^2}{1-k^3} + \frac{4}{3}\frac{(1-k^3)p}{3p - zp'(1-k^3)}\eta^2_\psi\right]$$

$$p = (z - z_0)\left[\kappa(z^2 + z_0 z + z_0^2) - 3\ell z_1^2\right]$$

parameters: $z_0 \in \mathbb{R}$, $(z_1 \in \mathbb{R},\ z_1 \geqslant 0)$, $\ell \in \{-1, 1\}$, $\kappa \in \{-1, 0, 1\}$

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. reflection symmetry

$$z \to -z, \qquad z_0 \to -z_0$$

AdS_5 solutions with punctures

. local geometry

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. scaling "symmetry"

$$z \to L^2 z\,, \qquad z_0 \to L^2 z_0\,, \qquad z_1 \to L^2 z_1$$

AdS_5 solutions with punctures

. local geometry

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. positivity constraints

$$zp \geqslant 0\,, \qquad -p' \geqslant 0\,, \qquad 0 \leqslant k \leqslant 1$$

AdS_5 solutions with punctures

. local geometry

$$ds_{10}^2 = e^{2W}\left[ds^2_{AdS_5} - \frac{p'}{9z^2}ds_5^2\right]\,, \qquad e^{4W} = \frac{z}{k}\frac{3p - zp'(1-k^3)}{-p'}$$

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$$p = (z - z_0)\left[\kappa(z^2 + z_0 z + z_0^2) - 3\ell z_1^2\right]$$

parameters: $z_0 \in \mathbb{R}$, $(z_1 \in \mathbb{R},\, z_1 \geqslant 0)$, $\ell \in \{-1, 1\}$, $\kappa \in \{-1, 0, 1\}$

. regularity of shrinking S^1

$$\psi \in [0, 2\pi]$$

AdS_5 solutions with punctures

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. singularities

$$k = 0\,, \qquad (z, k) = (z_r, 1)\,, \qquad z = 0\,, \qquad p' = 0$$

interpretation as brane sources

Brane sources

. O8-plane–D8-branes

$k = 0$ region

$$ds^2_{10} \sim r^{-1/2} ds^2_9(z) + r^{1/2} dr^2 \,, \qquad e^{\phi} \sim \frac{1}{F_0} r^{-5/4} \,.$$

. . . .

$$ds^2_{10} = H_8^{-1/2} ds^2_{||} + H_8^{1/2} dx_9^2 \,, \qquad e^{\phi} = g_s H_8^{-5/4} \,,$$

$$H_8 = c + g_s F_0 x_9 \,, \qquad F_0 = \frac{8 - n_8}{2\pi \ell_s} \mathrm{sign}(x^9) \,.$$

Brane sources

. D6-branes

$(z, k) = (z_r, 1)$ region

$$\frac{1}{3z_r} ds^2_{10} \sim r^{1/2} \left[ds^2_{AdS_5} - \frac{p'(z_r)}{9z_r^2} ds^2_{\Sigma_g} \right] + r^{-1/2} \left[dr^2 + r^2 ds^2_{S^2} \right] , \qquad e^{\phi} \sim \frac{1}{F_0} \frac{3^{3/2}}{z_r^{1/2}} r^{3/4} .$$

. . . .

$$ds^2_{10} = H_6^{-1/2} ds^2_{\parallel} + H_6^{1/2} ds^2_{\perp} , \qquad e^{\phi} = g_s H_6^{-3/4} ,$$

$$H_6 = 1 + \frac{L_6}{r}, \qquad L_6 = \frac{1}{2} M \ell_s g_s .$$

Brane sources

. D6-branes

| flux quantization

$$\frac{1}{2\pi\ell_s}\int dC_1 = M = \frac{2}{3}\frac{z_r F_0}{\ell_s}\,, \qquad \frac{1}{(2\pi\ell_s)^3}\int dC_3 = m = \frac{V_g F_0}{18\pi^2\ell_s^3}\left(\kappa z_r^2 + \ell z_1^2\right)\,.$$

$$dC_1 = F_2 - F_0 B\,, \qquad dC_3 = F_4 - B\wedge F_2 + \frac{1}{2}F_0 B\wedge B\,.$$

Brane sources

. D4-branes

$z = 0$ region

$$ds^2_{10} \sim \left(\tfrac{3}{2} r \cos(\theta)\right)^{-1/3} \left[Q^{-1/2} r^{2/3} ds^2_{\mathrm{AdS}_5} + Q^{1/2} r^{-2/3} ds^2_5\right] , \qquad e^{\phi} \sim \tfrac{1}{F_0} Q^{-1/4} r^{1/3} \left(\tfrac{3}{2} r \cos(\theta)\right)^{-5/6}$$

$$ds^2_5 = \tfrac{1}{3} p(0) ds^2_{\Sigma_g} + dr^2 + r^2 ds^2_{S^2} , \qquad Q \equiv \left(\tfrac{3}{2}\right)^{-4/3} \ell z_1^2 / p(0) .$$

D4-branes $\subset$ D8-branes, smeared on the Riemann surface

| flux quantization

$$\frac{1}{(2\pi \ell_s)^3} \int dC_3 = n = \frac{V_g F_0}{18 \pi^2 \ell_s^3} \ell z_1^2$$

Brane sources

. D4–branes inside D8–branes

[Youm '99]

$$ds_{10}^2 = (H_8 H_4)^{-\frac{1}{2}}(-dx_0^2 + \cdots + dx_4^2) + H_4^{\frac{1}{2}} H_8^{-\frac{1}{2}}(dx_5^2 + \cdots + dx_8^2) + (H_4 H_8)^{\frac{1}{2}} dx_9^2 \,.$$

$$\partial_{x_9}^2 H_4 + H_8 \sum_{i=5}^{8} \partial_{x_i}^2 H_4 = 0 \,, \qquad \partial_{x_9}^2 H_8 = 0 \,.$$

Brane sources

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$$\partial_{x_9}^2 H_4 + H_8(\partial_{x_7}^2 + \partial_{x_8}^2) H_4 = 0\,, \qquad \partial_{x_9}^2 H_8 = 0\,.$$

Brane sources

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$$H_8 = Q_8 |x_9| \,, \qquad H_4 = 1 + Q_4 \left(\sigma^2 + \frac{4}{9} Q_8 |x_9|^3\right)^{-2/3} \,, \qquad \sigma^2 = x_7^2 + x_8^2 \,.$$

Brane sources

. D4–branes inside D8–branes

after a coordinate transformation

$$|x_9| = \left(\frac{4}{9}Q_8\right)^{-1/3} \lambda^{2/3}\,, \qquad \lambda = \sigma\cos(\theta), \qquad \sigma = r\sin(\theta)$$

near the core $H_4 \simeq Q_4(r\cos(\theta))^{-4/3}$:

$$ds^2_{10} = \left(\frac{3}{2}Q_8 r\cos(\theta)\right)^{-1/3} [Q_4^{-1/2} r^{2/3} ds^2_{\parallel} + Q_4^{1/2} r^{-2/3} ds^2_{\perp}]\,,$$

$$ds^2_{\parallel} = -dx_0^2 + \cdots + x_4^2\,, \qquad ds^2_{\perp} = dx_5^2 + dx_6^2 + dr^2 + r^2\left(d\theta^2 + \sin^2(\theta) d\psi^2\right).$$

Brane sources

. D4–branes

$p' = 0$ region : $\{z = z_1,\ \kappa = \ell\}$

$$ds^2_{10} \sim (\cos(\theta))^{-1/3}\left[(\tilde{Q}r)^{-1/2}ds^2_{AdS_5} + (\tilde{Q}r)^{1/2}ds^2_5\right]\,, \qquad e^{\phi} \sim \frac{1}{F_0}\frac{1}{z_1}(\tilde{Q}r)^{-1/4}(\cos(\theta))^{-5/6}$$

$$ds^2_5 = \tfrac{4}{9}\tilde{Q}^{-1}ds^2_{\Sigma_g} + \frac{4}{9}z_1^2\left(dr^2 + d\theta^2 + \sin^2(\theta)\eta^2_{\psi}\right)\,, \qquad \tilde{Q} \equiv \tfrac{4}{3}z_1/p(z_1)\,.$$

D4–branes smeared on Σ_g and on $S^2(\theta,\psi)$ — delocalized from the D8–branes

| flux quantization

$$\frac{1}{(2\pi\ell_s)^3}\int dC_3 = n = \frac{V_g F_0}{18\pi^2\ell_s^3}\ell z_1^2$$

Three classes of solutions

regularity and positivity constraints allow for

- $z \in [0, z_0]$

  $\ell = +1, \quad \kappa = -1, \quad (\kappa = 0, z_1 > 0), \quad (\kappa = +1, z_0 \leqslant z_1)$

  $\mathrm{k} = 0$: O8–D8, $\quad z = 0$: D4–O8–D8, $\quad (z, \mathrm{k}) = (z_0, 1)$: D6.

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  $\ell = +1, \quad \kappa = +1, \quad z_0 < -2z_1$

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Three classes of solutions

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- $z \in [z_1, z_0]$

  $\ell = -1, \quad \kappa = -1$

  $k = 0$: O8–D8, $\quad z = z_1$: D4, $\quad (z, k) = (z_0, 1)$: D6.

Dual SCFTs

- holographic central charge

$$a = \frac{\pi R^3_{\mathrm{AdS}_5}}{8G_5} = \int e^{3W-2\phi}\mathrm{vol}_5$$

Dual SCFTs

| holographic central charge

$$a = \frac{\pi R_{\mathrm{AdS}_5}^3}{8G_5} = \int e^{3W-2\phi}\mathrm{vol}_5$$

$[0, z_0]$

$$a = \frac{27}{32}\left(\frac{1}{5}(g-1)N^3M^2 + \frac{1}{3}nN^2M\right), \qquad N = \frac{1}{4\pi^2\ell_s^2}\int H, \quad g = 0 : n \geqslant MN$$

higher dimensional origin : AdS_7 / 6D (1,0) SCFT

Dual SCFTs

holographic central charge

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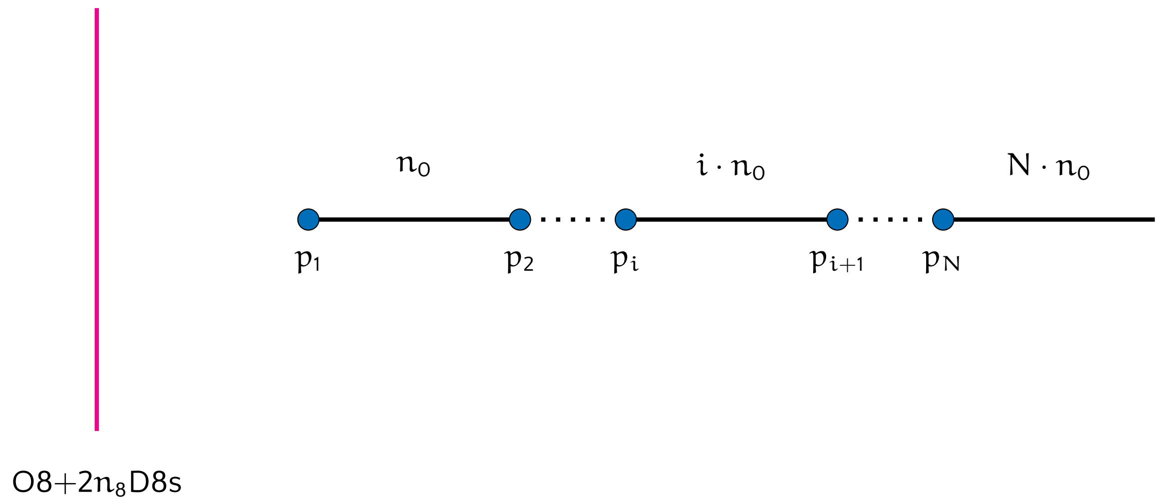

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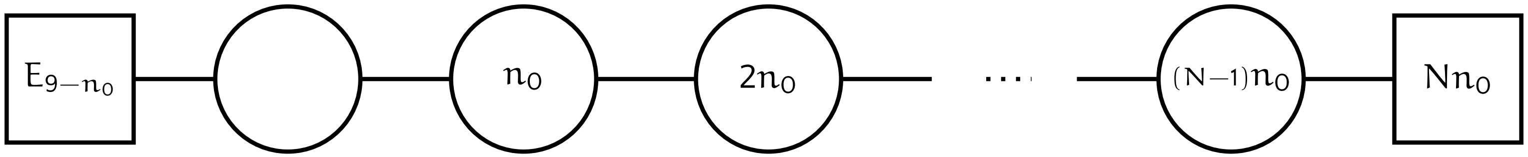

Dual SCFTs

| holographic central charge

$$a = \frac{\pi R^3_{\mathrm{AdS}_5}}{8G_5} = \int e^{3W-2\phi}\mathrm{vol}_5$$

$[0, z_1]$

$$a = \frac{9}{5\cdot 16}\frac{n^{5/2}}{n_0^{1/2}}, \qquad n_0 = 2\pi\ell_s F_0$$

same scaling as the AdS_6 solution

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$[z_1, z_0]$

$$a = \frac{27}{32}\left(\frac{1}{5}N^3M^2(1-g) + \frac{1}{3}nN^2M + \frac{2}{15}\frac{n^{5/2}}{n_0^{1/2}(1-g)^{3/2}}\right)$$

“hybrid”

the end. Thank you!