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$\mathcal{N}=2$ AdS_4 IIA solutions

arXiv:1805.03661

with Daniël Prins and Alessandro Tomasiello

arXiv:1807.06031

with Ibrahima Bah and Peter Weck

motivation

AdS/CFT correspondence

Conformal Field Theories ⟷ Theories of Gravity on anti-de Sitter spacetime

AdS/CFT correspondence

space and properties of CFTs ⟵ space and properties of AdS solutions

AdS_4/CFT_3 correspondence

$\mathcal{N} = 2$ supersymmetry :

computational control $+$ variety of theories

M-theory

[Gabella,Martelli,AP,Sparks '12]

AdS_4/CFT_3 correspondence

M-theory

[Gabella,Martelli,AP,Sparks '12]

Type IIB

[AP,Solard,Tomasiello '17]

AdS_4/CFT_3 correspondence

M-theory

[Gabella,Martelli,AP,Sparks '12]

Type IIB

[AP,Solard,Tomasiello '17]

Type IIA

[AP,Prins,Tomasiello '18]

M2-branes on $\mathbb{C}^4$

$AdS_4 \times S^7$ / ABJM

M2-branes on CY_4

$AdS_4 \times SE_7$ / Chern-Simons-matter

Old Status

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- reductions of $AdS_4 \times SE_7$ solutions
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[Petrini, Zaffaroni ’09], [Lüst, Tsimpis ’09], [Tomasiello, Zaffaroni ’10]

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- reductions of $AdS_4 \times SE_7$ solutions
- solutions with non-zero Romans mass

[Petrini, Zaffaroni '09], [Lüst, Tsimpis '09], [Tomasiello, Zaffaroni '10]

[Guarino, Jafferis, Varela '15]

methodology

Background

$$\mathrm{d}s^2_{10} = e^{2A}\left(\mathrm{d}s^2_{\mathrm{AdS}_4} + \mathrm{d}s^2_{M_6}\right)$$

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$$+$$

$$\phi,\ H,\ F_{p_{\text{even}}}$$

preserving the symmetries of AdS_4

Supersymmetry

$$\exists\ \epsilon_{1,2}\ :\ \delta_{\epsilon_{1,2}}\psi = 0 = \delta_{\epsilon_{1,2}}\lambda$$

Supersymmetry

$$\epsilon_1 = \sum_{I=1}^{2} \chi_+^I \otimes \eta_{1+}^I + \sum_{J=1}^{2} \chi_-^J \otimes \eta_{1-}^J$$

$$\epsilon_2 = \sum_{I=1}^{2} \chi_+^I \otimes \eta_{2-}^I + \sum_{J=1}^{2} \chi_-^J \otimes \eta_{2+}^J$$

Supersymmetry

$$\epsilon_1 = \sum_{I=1}^{2} \chi_+^I \otimes \eta_{1+}^I + \sum_{J=1}^{2} \chi_-^J \otimes \eta_{1-}^J$$

$$\epsilon_2 = \sum_{I=1}^{2} \chi_+^I \otimes \eta_{2-}^I + \sum_{J=1}^{2} \chi_-^J \otimes \eta_{2+}^J$$

$$\nabla_\mu \chi_\pm^I = \frac{1}{2} \gamma_\mu \chi_\mp^I$$

Supersymmetry

$$\epsilon_1 = \sum_{I=1}^{2} \chi_+^I \otimes \eta_{1+}^I + \sum_{J=1}^{2} \chi_-^J \otimes \eta_{1-}^J$$

$$\epsilon_2 = \sum_{I=1}^{2} \chi_+^I \otimes \eta_{2-}^I + \sum_{J=1}^{2} \chi_-^J \otimes \eta_{2+}^J$$

Supersymmetry

$$\eta^{I}_{1+} \quad \eta^{J}_{2+}$$

$$so(2)_R \simeq u(1)_R$$

R-symmetry

G-structure

$$SO(6)$$

$$\Downarrow$$

$$G$$

stabilizer

G-structure

M_6 acquires a G-structure characterized by a set of tensors constructed as bilinears of $\{\eta^I_{1+},\ \eta^J_{2+}\}$

G-structure

$$G = \begin{cases} \mathrm{SU}(2) \\ \\ \text{identity} \end{cases}$$

SU(2)-structure

$$\{w,\ j,\ \omega\}$$

$$\iota_w j = 0 = \iota_w \omega \qquad j \wedge \omega = 0 \qquad j \wedge j = \frac{1}{2}\omega \wedge \overline{\omega}$$

Supersymmetry Equations

$$\Phi_{\pm}^{IJ} = \eta_{1+}^{I}\overline{\eta^{J}}_{2\pm}$$

Supersymmetry Equations

$$\Phi_{\pm}^{IJ} \equiv \eta_{1+}^{I}\overline{\eta^{J}}_{2\pm}$$

$$+$$

$$\Phi_{\pm}^{IJ} \propto \sum_{p} \overline{\eta^{J}}_{2\pm}\gamma_{m_1\ldots m_p}\eta_{1+}^{I}\gamma^{m_1\ldots m_p}$$

Supersymmetry Equations

$$\Phi_{\pm}^{IJ} \equiv \eta_{1+}^{I}\overline{\eta^{J}}_{2\pm}$$

$$+$$

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$$+$$

$$\gamma^{m_1\ldots m_k} \to dx^{m_1} \wedge \cdots \wedge dx^{m_k}$$

Supersymmetry Equations

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$$\gamma^{m_1\ldots m_k} \to dx^{m_1}\wedge\cdots\wedge dx^{m_k}$$

$$\Downarrow$$

polyforms

$$\Phi_{\pm}^{IJ}(w,\, j,\, \omega)$$

Supersymmetry Equations

$$\delta_{\epsilon_{1,2}}\psi = 0 = \delta_{\epsilon_{1,2}}\lambda$$

$$\rightsquigarrow$$

constraints on $\{\eta^I_{1+}, \eta^J_{2+}\}$

$$\rightsquigarrow$$

constraints on $\Phi^{IJ}_{\pm}(w, j, \omega)$

$$\rightsquigarrow$$

constraints on SU(2)-structure $\{w, j, \omega\}$

geometry

Generic Geometry

$$ds^2_{M_6} = \overline{w}w(y,\psi) + \underbrace{ds^2_{M_4}(x^i)}_{\text{Base}}$$

Generic Geometry

$$ds^2_{M_6} = \frac{1}{e^{4A} - y^2} dy^2 + \frac{1}{4}(1 - e^{-4A} y^2)(d\psi + \rho)^2 + \underbrace{ds^2_{M_4}}_{\text{Base}}$$

Generic Geometry

$$ds^2_{M_6} = \frac{1}{e^{4A} - y^2} dy^2 + \frac{1}{4}(1 - e^{-4A} y^2)(d\psi + \rho)^2 + \underbrace{ds^2_{M_4}}_{\text{Base}}$$

- ∂_ψ generates $U(1)_R$
-

Generic Geometry

$$ds^2_{M_6} = \frac{1}{e^{4A} - y^2} dy^2 + \frac{1}{4}(1 - e^{-4A} y^2)(d\psi + \rho)^2 + g_{ij}(y, x^i) dx^i dx^j$$

- ∂_ψ generates $U(1)_R$
- g_{ij} conformally Kähler

family of solutions #1

Complex M_6

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$$g(y, x^i) = \begin{cases} \end{cases}$$

Complex M_6

$$g(y, x^i) = \begin{cases} f(y)\, g_{KE_4}(x^i) \\ \\ \end{cases}$$

Complex M_6

$$g(y, x^i) = \begin{cases} f(y)\, g_{KE_4}(x^i) \\ \\ f_1(y)\, g_{\Sigma_1}(x^i) + f_2(y)\, g_{\Sigma_2}(x^i) \end{cases}$$

Complex M_6

$$g(y, x^i) = \begin{cases} f(y)\, g_{KE_4}(x^i) \\ \\ f_1(y)\, g_{\Sigma_1}(x^i) + f_2(y)\, g_{\Sigma_2}(x^i) \end{cases}$$

solution determined by $A(y)$ subject to a Riccati ODE

$M_4 = KE_4$

$$ds^2_{M_6} = -\frac{1}{4}\frac{q'}{xq}dx^2 - \frac{q}{xq' - 4q}(d\psi + \rho)^2 + \frac{\kappa q'}{3q' - xq''}ds^2_{KE_4} ,$$

$$e^{2A} = \sqrt{\frac{x^2 q' - 4xq}{q'}} \qquad e^{2\phi} = \frac{xq'}{(3q' - xq'')^2}\left(\frac{x^2 q' - 4xq}{q'}\right)^{3/2}$$

$$q^{\beta,\gamma}(x) = x^6 + 3(2\gamma^2 - \beta)x^4 + 8\gamma x^3 + 3x^2 - \beta$$

$M_4 = \mathrm{KE}_4$

positivity restricts x to lie in an interval

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- positivity restricts x to lie in an interval
- compactness: the ψ-circle shrinks at the endpoints

$M_4 = \mathrm{KE}_4$

- positivity restricts x to lie in an interval
- q has zeros at the endpoints

x_0	$q(x_0)$	$q'(x_0)$	$q''(x_0)$	interpretation
	0			regular

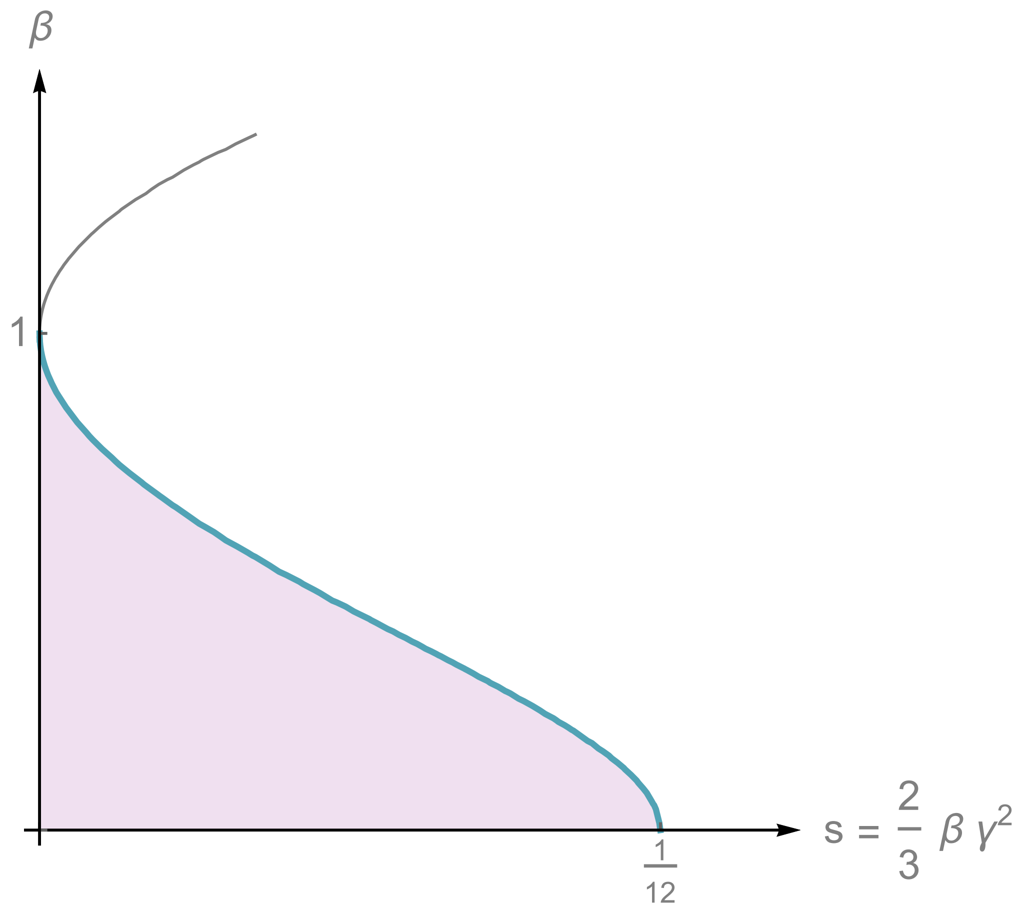
$$ds^2_{M_6} \sim \underbrace{dr^2 + r^2(d\psi + \rho)^2}_{\mathbb{R}^2 \text{ for } \psi \in [0,2\pi]} + ds^2_{KE_4}$$

x_0	$q(x_0)$	$q'(x_0)$	$q''(x_0)$	interpretation
	0			regular
	0	0	0	conical CY

$$ds^2_{M_6} \sim dr^2 + r^2 \underbrace{\left(\frac{1}{9}(d\psi + \rho)^2 + \frac{1}{6} ds^2_{KE_4}\right)}_{SE_5}$$

x_0	$q(x_0)$	$q'(x_0)$	$q''(x_0)$	interpretation
	0			regular
	0	0	0	conical CY

$$ds^2_{M_6} \sim dr^2 + r^2 \underbrace{\left(\frac{1}{9}(d\psi + \rho)^2 + \frac{1}{6} ds^2_{\mathbb{CP}^2}\right)}_{S^5 \text{ for } \psi \in [0, 6\pi]}$$



β
1
1/12
s = 2/3 β γ²

$M_4 = \Sigma_1 \times \Sigma_2$

$$ds^2_{M_6} = -\frac{1}{4}\frac{q'}{xq}dx^2 - \frac{q}{xq' - 4q}(d\psi + \rho)^2 + \frac{\kappa_1 q'}{xu_1}ds^2_{\Sigma_1} + \frac{\kappa_2 q'}{xu_2}ds^2_{\Sigma_2}$$

$$e^{2A} = \sqrt{\frac{x^2 q' - 4xq}{q'}} \qquad e^{2\phi} = \frac{q'}{xu_1u_2}\left(\frac{x^2q' - 4xq}{q'}\right)^{3/2} .$$

$$q = q^{\beta,\gamma_1,\gamma_2}(x), \qquad u_1 = u_1^{\gamma_1}(x), \qquad u_2 = u_2^{\gamma_2}(x)$$

$M_4 = \Sigma_1 \times \Sigma_2$

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$$q^{\beta,\gamma_1,\gamma_2}(x) = x^6 + 3(2\gamma_1\gamma_2 - \beta)x^4 + 4(\gamma_1 + \gamma_2)x^3 + 3x^2$$

$M_4 = \Sigma_1 \times \Sigma_2$

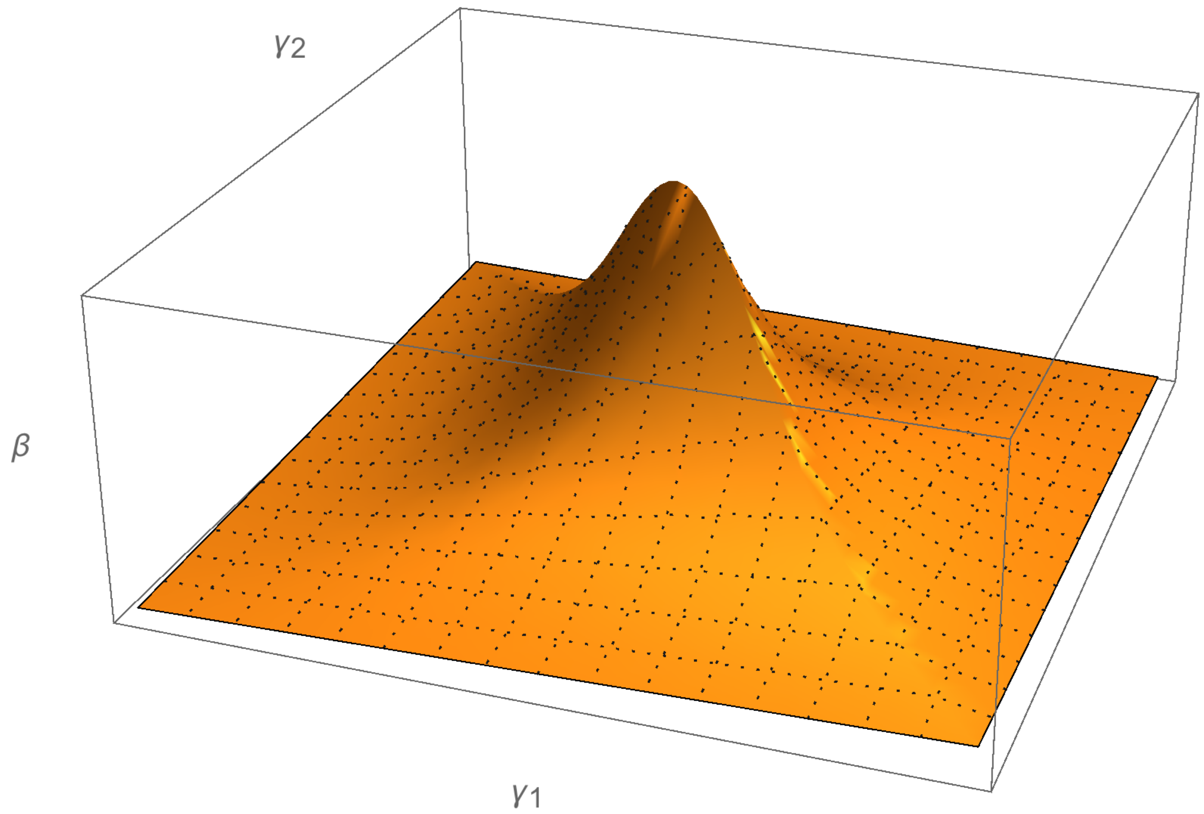
$$ds^2_{M_6} = -\frac{1}{4}\frac{q'}{xq}dx^2 - \frac{q}{xq' - 4q}(d\psi + \rho)^2 + \frac{\kappa_1 q'}{xu_1}ds^2_{\Sigma_1} + \frac{\kappa_2 q'}{xu_2}ds^2_{\Sigma_2}$$

$$e^{2A} = \sqrt{\frac{x^2q' - 4xq}{q'}} \qquad e^{2\phi} = \frac{q'}{xu_1u_2}\left(\frac{x^2q' - 4xq}{q'}\right)^{3/2} .$$

$$u_1^{\gamma_1}(x) = 12(1 + 2\gamma_1 x - x^4), \qquad u_2^{\gamma_2}(x) = 12(1 + 2\gamma_2 x - x^4)$$

x_0	$q(x_0)$	$q'(x_0)$	$q''(x_0)$	$u_1(x_0)$	$u_2(x_0)$	interpretation
	0	0		0		$\mathbb{R}^4/\mathbb{Z}_2$

$$ds^2_{M_6} \sim dr^2 + \frac{1}{4}r^2 \left((d\psi + \rho)^2 + ds^2_{S^2} \right) + ds^2_{\Sigma_2}$$



γ2
β
γ1

family of solutions #2

Compactifying Higher Dimensional Field Theories

- large classes of theories in lower dimensions
- their properties admit a description in terms of the geometry and topology of the compact manifold

(2,0) theory on a Riemann surface

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

Class $\mathcal{S}$ SCFTs in four dimensions

(2,0) theory on a Riemann surface

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

$$\mathrm{AdS}_5 \times_w \mathrm{M}_6$$

(2,0) theory on a Riemann surface

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

$$\begin{array}{ccc} S^4 & \longrightarrow & M_6 \\ & & \downarrow \\ & & \Sigma_g \end{array}$$

(2,0) theory on a Riemann surface

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

part of a domain wall geometry which at large distances asymptotes to $\mathrm{AdS}_7 \times S^4$

D4–D8/O8 brane configuration

[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	×	×	×	×	×	×	×	×	×	–

$\mathcal{N} = 1$ SUSY $USp(2N)$ gauge theory

coupled to

- 1 hyper in the antisymmetric representation (H_a)
- N_f hypers in the fundamental (H_f)

vector multiplet scalar parametrizes x_9 fluctuations

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- 4 H_a scalars parametrize x_5–x_8 fluctuations

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- 4 H_a scalars parametrize x_5–x_8 fluctuations
- H_f from D4–D8 open strings

Global Symmetries

$$SU(2)_R \times SU(2) \times SO(2N_f) \times U(1)_I$$

Global Symmetries

$$\mathrm{SU}(2)_R \times \mathrm{SU}(2)$$

x^5–x^8 rotations

Global Symmetries

$SU(2)_R$

R−symmetry

Global Symmetries

$$\mathrm{SU}(2)$$
$$H_a$$

Global Symmetries

$$SO(2N_f)$$
$$H_f$$

Global Symmetries

$U(1)_I$

$j = *\mathrm{Tr}(F \wedge F)$

fixed point at strong coupling [Seiberg '96]

- fixed point at strong coupling [Seiberg ’96]
- degrees of freedom scale as $N^{5/2}$ at large N [Jafferis, Pufu ’12]

$\mathrm{AdS}_6 \times_w S^4$

[Brandhuber, Oz '99]

$$ds^2_{10} = \ell_s^2 \Omega \left[ds^2_{\mathrm{AdS}_6} + \tfrac{4}{9} d\alpha^2 + \cos^2(\alpha) ds^2_{S^3} \right], \qquad \Omega = \frac{18\pi^2 N}{n_0 \sin^{2/3}(\alpha)}$$

$$e^{-4\phi} = \frac{9 N n_0^3 \sin^{10/3}(\alpha)}{8\pi^2}, \qquad F_4 = \frac{80}{9} \ell_s^3 \pi N \cos^3(\alpha) \sin^{1/3}(\alpha) \mathrm{vol}_{S^3}$$

$\mathrm{AdS}_6 \times_w S^4$

[Brandhuber, Oz '99]

$$ds_{10}^2 = \ell_s^2 \Omega \left[ds^2_{\mathrm{AdS}_6} + \frac{4}{9} \underset{[-\frac{\pi}{2}, \frac{\pi}{2}]}{d\alpha^2} + \cos^2(\alpha) ds^2_{S^3} \right], \qquad \Omega = \frac{18\pi^2 N}{n_0 \sin^{2/3}(\alpha)}$$

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$\mathrm{AdS}_6 \times_w S^4$

[Brandhuber, Oz '99]

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$\mathrm{AdS}_6 \times_w S^4$

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$$SO(5) \to SO(4) \equiv SU(2)_R \times SU(2)$$

are there 3D SCFTs produced by
the 5D SCFT on a Riemann surface?

look for AdS_4 solutions

SUSY on $\mathbb{R}^{1,4}$

$$d\epsilon = 0$$

SUSY on $\mathbb{R}^{1,2} \times \Sigma$

$$\left(d + \frac{1}{4}\omega^{ab}\gamma_{ab}\right)\epsilon = 0$$

SUSY on $\mathbb{R}^{1,2} \times \Sigma$

$$\Big(\mathrm{d} + \underbrace{\tfrac{1}{4}\omega^{ab}\gamma_{ab} + A_R}_{=0}\Big)\epsilon = 0$$

SUSY on $\mathbb{R}^{1,2} \times \Sigma$

$$U(1)_{\text{holonomy}} \equiv U(1)_R \subset SU(2)_R$$

$$J_h = J_R$$

SUSY on $\mathbb{R}^{1,2} \times \Sigma$

$$\mathrm{U(1)_{holonomy}} \equiv \mathrm{U(1)_R,\ U(1) \subset SU(2)_R,\ SU(2)}$$

$$J_h = J_R + zJ$$

$AdS_4 \times \mathcal{M}_6$

$\mathrm{AdS}_4 \times M_6$

$$\begin{array}{ccc} S^4_{U(1)_R \times U(1)} & \longrightarrow & M_6 \\ & & \downarrow \\ & & \Sigma_g \end{array}$$

Ansatz for M_4

$$ds^2_{M_4} = \underbrace{e^{2W}(dx_1^2 + dx_2^2)}_{\Sigma_g} + e^{2Z}[(d\tau + V_1)^2 + e^{2C}(d\varphi + V_2)^2]$$

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- ∂_φ Killing vector generating second U(1)
-

Ansatz for M_4

$$ds^2_{M_4} = \underbrace{e^{2W}(dx_1^2 + dx_2^2)}_{\Sigma_g} + e^{2Z}[(d\tau + V_1)^2 + e^{2C}(d\varphi + V_2)^2]$$

- ∂_φ Killing vector generating second U(1)
- keep F_0, F_4, ϕ

General System

$$ds^2_{10} = e^{2A}[ds^2_{AdS_4} + \frac{1}{4}H[(e^{2W}(dx_1^2 + dx_2^2) + 4h^{ij}\eta_i\eta_j + g_{ij}t^it^j)]$$

$$i, j = \pm, \qquad \eta_\pm = d\phi_\pm + \frac{1}{2} *_2 d_2 \partial_\pm D_0, \qquad (\partial^2_{x_1} + \partial^2_{x_2})D_0 = e^{2W}$$

Constant Curvature

$$ds^2_{10} = \frac{H^{-1/2}}{\frac{3}{2}^{1/6}\mu_0^{1/3}F_0^{2/3}}\left(ds^2(AdS_4) + e^{2\nu}ds^2(\Sigma_g) + ds^2(M_4)\right)$$

$$H = \frac{2}{3\mu_0^2 + 4(1-\mu_0^2)q(\theta)} \qquad q(\theta) = a_+\cos^2\theta + a_-\sin^2\theta$$

Constant Curvature

$$ds^2(M_4) = \frac{1}{3}\frac{1}{q(\theta)}\frac{d\mu_0^2}{1-\mu_0^2} + \frac{(1-\mu_0^2)}{2a_+a_-}H ds^2(M_3)$$

$$ds^2(M_3) = q(\theta)\left(d\theta - (a_+ + a_-)\frac{\sin(2\theta)}{2q(\theta)}\frac{\mu_0 d\mu_0}{1-\mu_0^2}\right)^2 + a_-\cos^2(\theta)\eta_+^2 + a_+\sin^2(\theta)\eta_-^2$$

$$\eta_\pm = d\phi_\pm - 2(\kappa \pm z)V, \qquad \theta \in [0, \pi/2], \qquad \mu_0 \in [0, 1]$$

Free Energy

$$\mathcal{F} = \frac{\pi L^2_{\mathrm{AdS}_4}}{2G_4} = \frac{16\pi^3}{(2\pi\ell_s)^8}\int e^{8A-2\phi}\mathrm{vol}(M_6)$$

Free Energy

$$\mathcal{F}_{g\neq 1} = \frac{8\pi}{5}\frac{2(1-g)N^{5/2}}{\kappa n_0^{1/2}} F_z(z,\kappa)$$

$$F_z(z,\kappa) = \frac{(|z^2-\kappa^2|)^{3/2}(\sqrt{\kappa^2+8z^2}-\kappa)}{(14z^2-\kappa^2+\kappa\sqrt{\kappa^2+8z^2})^{3/2}}$$

Free Energy

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Reproduced by

[Crichigno, Jain, Willett '18] and [Hosseini, Yaakov, Zaffaroni '18]

summary

Summary

$\mathcal{N} = 2$ AdS$_4$ SU(2)–structure classification

Family #1

Family #2

Summary

Family #1

$$\begin{array}{ccc} S^2 & \longrightarrow & M_6 \\ & & \downarrow \\ & & M_4 \end{array}$$

Chern–Simons–matter SCFTs

Summary

Family #2

$$\begin{array}{ccc} S^4 & \longrightarrow & M_6 \\ & & \downarrow \\ & & \Sigma_g \end{array}$$

5D SCFTs on Riemann surface

The End