AdS$_4$/CFT$_3$ holography from massive IIA

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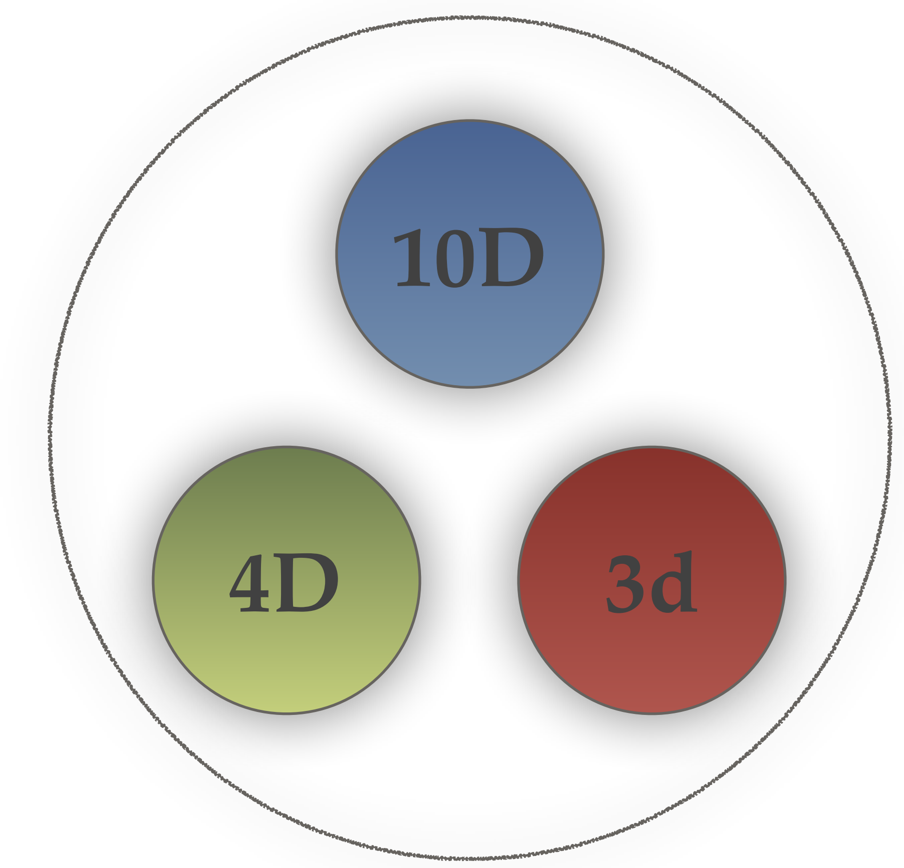

Geometry, Duality and Strings 2018
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With D. Jafferis , J. Tarrío and O. Varela :

arXiv:1504.08009 , arXiv:1508.04432 , arXiv:1509.02526
arXiv:1605.09254 , arXiv:1703.10833 , arXiv:1706.01823
arXiv:1712.09549

Outlook

- Electric-magnetic duality in N=8 supergravity
- Massive IIA on S^6 / SYM-CS duality
- Holographic RG flows: domain-walls & black holes

Electric-magnetic duality in N=8 supergravity

N=8 supergravity in 4D

- SUGRA : metric + 8 gravitini + 28 vectors + 56 dilatini + 70 scalars
  (s = 2) (s = 3/2) (s = 1) (s = 1/2) (s = 0)

Ungauged (abelian) supergravity: Reduction of M-theory on a *torus* T^7 down to 4D produces $N = 8$ supergravity with $G = U(1)^{28}$ [Cremmer, Julia '79]

Gauged (non-abelian) supergravity:

- Reduction of M-theory on a *sphere* S^7 down to 4D produces $N = 8$ supergravity with $G = SO(8)$ [de Wit, Nicolai '82]
- Reduction of M-theory on S^1 (Type IIA) and subsequently on S^6 down to 4D produces $N = 8$ supergravity with $G = ISO(7) = SO(7) \ltimes \mathbb{R}^7$ [Hull '84]

✱ These gauged supergravities believed to be unique for 30 years…

Electric-magnetic deformations

• Uniqueness historically inherited from the connection with NH geometries of branes and SCFT's

Type IIB : $AdS_5 \times S^5$ (D3-brane ~ N = 4 SYM in 4d) [Maldacena '97]

M-theory : $AdS_4 \times S^7$ (M2-brane ~ ABJM theory in 3d)

[Aharony, Bergman, Jafferis, Maldacena '08]

• N=8 supergravity in 4D admits a deformation parameter c yielding inequivalent theories. It is an electric/magnetic deformation

$$D = \partial - g\,(A^{\text{elec}} - c\,\tilde{A}_{\text{mag}})$$

g = 4D gauge coupling
c = deformation param.

[Dall'Agata, Inverso, Trigiante '12]

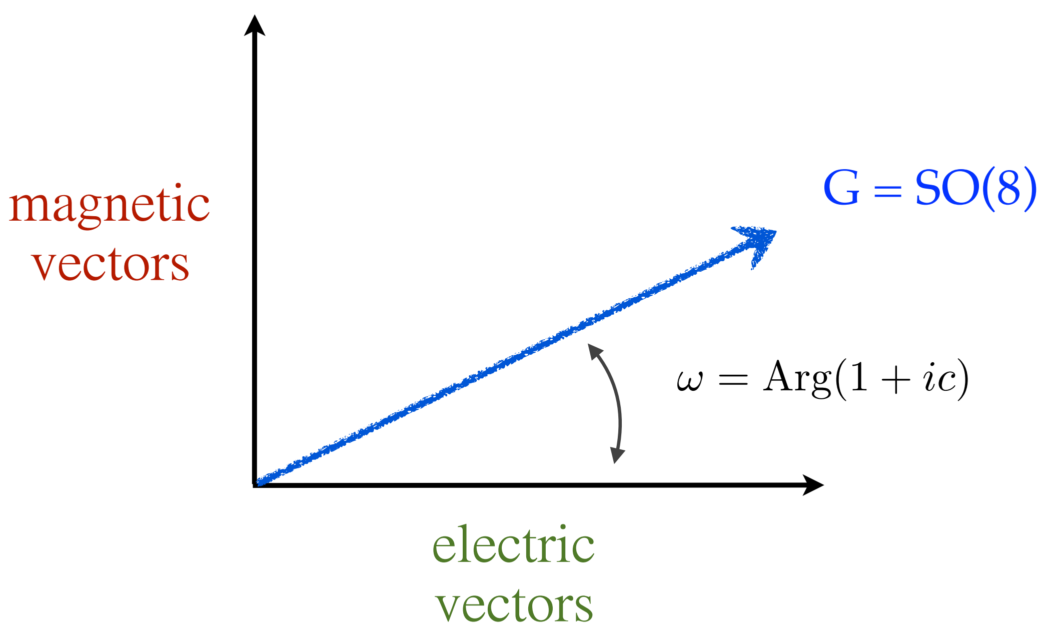
• There are two generic situations :

1) Family of $SO(8)_c$ theories : $c = [0, \sqrt{2} - 1]$ is a continuous param [similar for $SO(p,q)_c$]

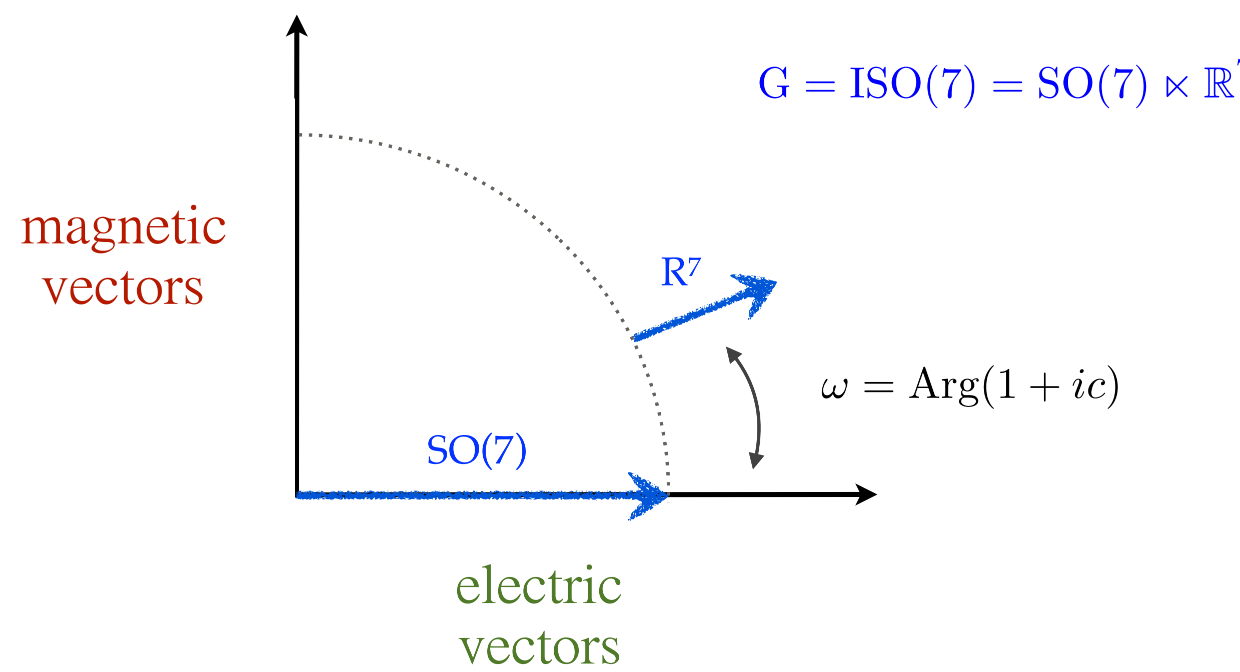
2) Family of $ISO(7)_c$ theories : $c = 0$ *or* 1 is an (on/off) param [same for $ISO(p,q)_c$]

[Dall'Agata, Inverso, Marrani '14]

$SO(8)_c$ *vs* $ISO(7)_c$



$$D = \partial - g\,(A^{\rm elec} - c\,\tilde{A}_{\rm mag})$$



$$D = \partial - g\,A^{\rm elec}_{SO(7)} - g\,(A^{\rm elec}_{\mathbb{R}^7} - c\,\tilde{A}_{\mathbb{R}^7\,{\rm mag}})$$

Higher-dimensional origin?

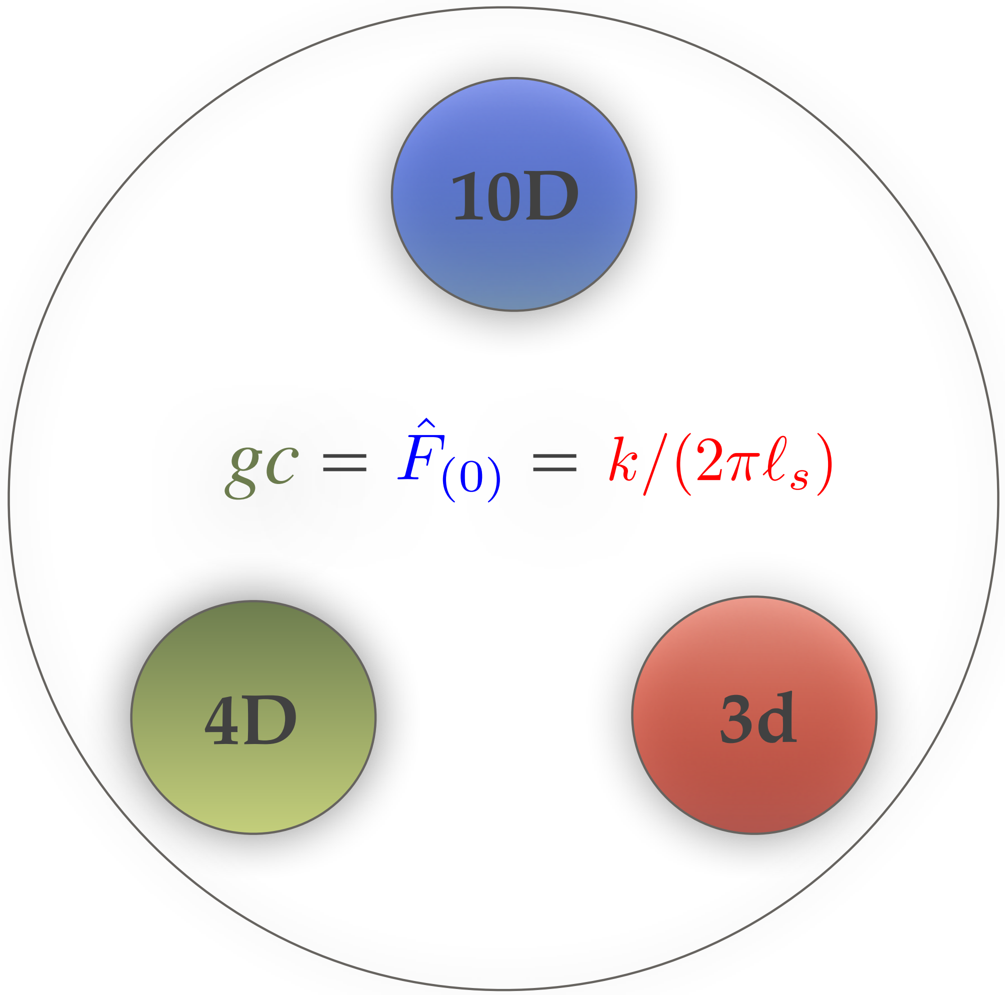
Obstruction for $SO(8)_c$, *cf.* [de Wit, Nicolai '13]

[Lee, Strickland-Constable, Waldram '15]

Holographic dual?

A new 10D/4D/3d correspondence

massive IIA on S^6 « ISO(7)$_c$-gauged sugra » SU(N)$_k$ SYM-CS theory



gc = elec/mag deformation in 4D

$\hat{F}_{(0)}$ = Romans mass in 10D

k = Chern-Simons level in 3d

[AG, Jafferis, Varela ’15]
[AG, Varela ’15]

Well-established and independent dualities :

Type IIB on S^5/ N=4 SYM — M-theory on S^7/ ABJM — **mIIA on S^6/SYM-CS**

Massive IIA on S^6 / SYM-CS duality

4D : ISO(7)$_c$ Lagrangian

$\mathbb{M} = 1, \dots, 56$
$\Lambda = 1, \dots, 28$
$I = 1, \dots, 7$

$$\mathcal{L}_{\text{bos}} = (R - V)\,\text{vol}_4 - \tfrac{1}{48} D\mathcal{M}_{\mathbb{M}\mathbb{N}} \wedge * D\mathcal{M}^{\mathbb{M}\mathbb{N}} + \tfrac{1}{2} \mathcal{I}_{\Lambda\Sigma}\, \mathcal{H}^{\Lambda}_{(2)} \wedge * \mathcal{H}^{\Sigma}_{(2)} - \tfrac{1}{2} \mathcal{R}_{\Lambda\Sigma}\, \mathcal{H}^{\Lambda}_{(2)} \wedge \mathcal{H}^{\Sigma}_{(2)}$$
$$+ g\, c \left[\mathcal{B}^I \wedge \big(\tilde{\mathcal{H}}_{(2)I} - \tfrac{g}{2} \delta_{IJ} \mathcal{B}^J\big) - \tfrac{1}{4} \tilde{\mathcal{A}}_I \wedge \tilde{\mathcal{A}}_J \wedge \big(d\mathcal{A}^{IJ} + \tfrac{g}{2}\, \delta_{KL}\, \mathcal{A}^{IK} \wedge \mathcal{A}^{JL}\big) \right]$$

✦ Setting $c = 0$, all the magnetic pieces in the Lagrangian disappear.

∗ *Ingredients :*

- Electric vectors (21 + 7) : $\mathcal{A}^{IJ} = \mathcal{A}^{[IJ]}$ [SO(7)] and $\mathcal{A}^I$ [$\mathbb{R}^7$] with $\mathcal{H}^{\Lambda}_{(2)} = (\mathcal{H}^{IJ}_{(2)}, \mathcal{H}^{I}_{(2)})$
- Auxiliary magnetic vectors (7) : $\tilde{\mathcal{A}}_I$ [$\mathbb{R}^7$] with $\tilde{\mathcal{H}}_{(2)I}$ field strength
- $E_7/SU(8)$ scalars : $\mathcal{M}_{\mathbb{M}\mathbb{N}}$
- Auxiliary two-forms (7) : $\mathcal{B}^I$ [$\mathbb{R}^7$]
- Topological term : $g\, c$ […]
- Scalar potential : $V(\mathcal{M}) = \dfrac{g^2}{672} X_{\mathbb{M}\mathbb{N}}{}^{\mathbb{R}} X_{\mathbb{P}\mathbb{Q}}{}^{\mathbb{S}} \mathcal{M}^{\mathbb{M}\mathbb{P}} \big(\mathcal{M}^{\mathbb{N}\mathbb{Q}} \mathcal{M}_{\mathbb{R}\mathbb{S}} + 7\, \delta^{\mathbb{Q}}_{\mathbb{R}}\, \delta^{\mathbb{N}}_{\mathbb{S}}\big)$

AdS_4 solutions

[AG, Varela '15]

$\mathcal{N}$	G_0	$c^{-1/3}\,\chi$	$c^{-1/3}\,e^{-\varphi}$	$c^{-1/3}\,\rho$	$c^{-1/3}\,e^{-\phi}$	$\frac{1}{4}\,g^{-2}\,c^{1/3}\,V_0$	M^2L^2
$\mathcal{N}=1$	G_2	$-\frac{1}{2^{7/3}}$	$\frac{5^{1/2}\,3^{1/2}}{2^{7/3}}$	$-\frac{1}{2^{7/3}}$	$\frac{5^{1/2}\,3^{1/2}}{2^{7/3}}$	$-\frac{2^{22/3}\,3^{1/2}}{5^{5/2}}$	$4\pm\sqrt{6}\,,\ -\frac{1}{6}(11\pm\sqrt{6})$
$\mathcal{N}=2$	$U(3)$	$-\frac{1}{2}$	$\frac{3^{1/2}}{2}$	0	$\frac{1}{2^{1/2}}$	$-3^{3/2}$	$3\pm\sqrt{17}\,,\ 2\,,\ 2$
$\mathcal{N}=1$	$SU(3)$	$\frac{1}{2^2}$	$\frac{3^{1/2}\,5^{1/2}}{2^2}$	$-\frac{3^{1/2}}{2^2}$	$\frac{5^{1/2}}{2^2}$	$-\frac{2^6\,3^{3/2}}{5^{5/2}}$	$4\pm\sqrt{6}\,,\ 4\pm\sqrt{6}$
$\mathcal{N}=0$	$SO(6)_+$	0	$2^{1/6}$	0	$\frac{1}{2^{5/6}}$	$-3\,2^{5/6}$	$6\,,\ 6\,,\ -\frac{3}{4}\,,\ 0$
$\mathcal{N}=0$	$SO(7)_+$	0	$\frac{1}{5^{1/6}}$	0	$\frac{1}{5^{1/6}}$	$-\frac{3\,5^{7/6}}{2^2}$	$6\,,\ -\frac{12}{5}\,,\ -\frac{6}{5}\,,\ -\frac{6}{5}$
$\mathcal{N}=0$	G_2	$\frac{1}{2^{4/3}}$	$\frac{3^{1/2}}{2^{4/3}}$	$\frac{1}{2^{4/3}}$	$\frac{3^{1/2}}{2^{4/3}}$	$-\frac{2^{10/3}}{3^{1/2}}$	$6\,,\ 6\,,\ -1\,,\ -1$
$\mathcal{N}=0$	$SU(3)$	0.455	0.838	0.335	0.601	-5.864	$6.214\,,\ 5.925\,,\ 1.145\,,\ -1.284$
$\mathcal{N}=0$	$SU(3)$	0.270	0.733	0.491	0.662	-5.853	$6.230\,,\ 5.905\,,\ 1.130\,,\ -1.264$

✦ N = 2 solution will play a central role in holography !!

10D : ISO(7)$_c$ into type IIA supergravity

[AG, Varela '15]

$$d\hat{s}^2_{10} = \Delta^{-1}\, ds^2_4 + g_{mn}\, Dy^m\, Dy^n \; ,$$

$$\begin{aligned} \hat{A}_{(3)} &= \mu_I \mu_J \left(\mathcal{C}^{IJ} + \mathcal{A}^I \wedge \mathcal{B}^J + \tfrac{1}{6} \mathcal{A}^{IK} \wedge \mathcal{A}^{JL} \wedge \tilde{\mathcal{A}}_{KL} + \tfrac{1}{6} \mathcal{A}^I \wedge \mathcal{A}^{JK} \wedge \tilde{\mathcal{A}}_K \right) \\ &\quad + g^{-1} \left(\mathcal{B}_J{}^I + \tfrac{1}{2} \mathcal{A}^{IK} \wedge \tilde{\mathcal{A}}_{KJ} + \tfrac{1}{2} \mathcal{A}^I \wedge \tilde{\mathcal{A}}_J \right) \wedge \mu_I D\mu^J + \tfrac{1}{2} g^{-2}\, \tilde{\mathcal{A}}_{IJ} \wedge D\mu^I \wedge D\mu^J \\ &\quad - \tfrac{1}{2}\, \mu_I\, B_{mn}\, \mathcal{A}^I \wedge Dy^m \wedge Dy^n + \tfrac{1}{6} A_{mnp}\, Dy^m \wedge Dy^n \wedge Dy^p \; , \end{aligned}$$

$$\hat{B}_{(2)} = -\mu_I \left(\mathcal{B}^I + \tfrac{1}{2} \mathcal{A}^{IJ} \wedge \tilde{\mathcal{A}}_J \right) - g^{-1}\, \tilde{\mathcal{A}}_I \wedge D\mu^I + \tfrac{1}{2} B_{mn}\, Dy^m \wedge Dy^n \; ,$$

$$\hat{A}_{(1)} = -\mu_I\, \mathcal{A}^I + A_m\, Dy^m \; .$$

where we have defined : $Dy^m \equiv dy^m + \frac{1}{2}\, g\, K^m_{IJ}\, \mathcal{A}^{IJ}$, $D\mu^I \equiv d\mu^I - g\, \mathcal{A}^{IJ} \mu_J$

The scalars are embedded as

$$\begin{aligned} g^{mn} &= \tfrac{1}{4}\, g^2\, \Delta\, \mathcal{M}^{IJ\,KL}\, K^m_{IJ}\, K^n_{KL} \quad , \quad & B_{mn} &= -\tfrac{1}{2}\, \Delta\, g_{mp}\, K^p_{IJ}\, \partial_n \mu^K\, \mathcal{M}^{IJ}{}_{K8} \; , \\ A_m &= \tfrac{1}{2}\, g\, \Delta\, g_{mn}\, K^n_{IJ}\, \mu_K\, \mathcal{M}^{IJ\,K8} \quad , \quad & A_{mnp} &= \tfrac{1}{8}\, g\, \Delta\, g_{mq}\, K^q_{IJ}\, K^{KL}_{np}\, \mathcal{M}^{IJ}{}_{KL} + A_m B_{np} \; . \end{aligned}$$

N=2 solution of massive type IIA

- N=2 & U(3) AdS_4 point of the $ISO(7)_c$ theory

$$d\hat{s}^2_{10} = L^2 \frac{\big(3+\cos 2\alpha\big)^{\frac{1}{2}}}{\big(5+\cos 2\alpha\big)^{-\frac{1}{8}}} \left[ds^2(\mathrm{AdS}_4) + \frac{3}{2}\, d\alpha^2 + \frac{6\sin^2\alpha}{3+\cos 2\alpha}\, ds^2(\mathbb{CP}^2) + \frac{9\sin^2\alpha}{5+\cos 2\alpha}\, \boldsymbol{\eta}^2 \right] ,$$

$$e^{\hat{\phi}} = e^{\phi_0}\, \frac{\big(5+\cos 2\alpha\big)^{3/4}}{3+\cos 2\alpha} \quad , \qquad \hat{H}_{(3)} = 24\sqrt{2}\, L^2\, e^{\frac{1}{2}\phi_0}\, \frac{\sin^3\alpha}{\big(3+\cos 2\alpha\big)^2}\, \boldsymbol{J}\wedge d\alpha \ ,$$

$$L^{-1}\, e^{\frac{3}{4}\phi_0}\, \hat{F}_{(2)} = -4\sqrt{6}\, \frac{\sin^2\alpha\cos\alpha}{\big(3+\cos 2\alpha\big)\big(5+\cos 2\alpha\big)}\, \boldsymbol{J} - 3\sqrt{6}\, \frac{\big(3-\cos 2\alpha\big)}{\big(5+\cos 2\alpha\big)^2}\, \sin\alpha\ d\alpha\wedge\boldsymbol{\eta} \ ,$$

$$L^{-3}\, e^{\frac{1}{4}\phi_0}\, \hat{F}_{(4)} = 6\,\mathrm{vol}_4 + 12\sqrt{3}\, \frac{7+3\cos 2\alpha}{\big(3+\cos 2\alpha\big)^2}\, \sin^4\alpha\ \mathrm{vol}_{\mathbb{CP}^2} + 18\sqrt{3}\, \frac{\big(9+\cos 2\alpha\big)\sin^3\alpha\cos\alpha}{\big(3+\cos 2\alpha\big)\big(5+\cos 2\alpha\big)}\, \boldsymbol{J}\wedge d\alpha\wedge\boldsymbol{\eta} \ ,$$

where we have introduced the quantities $L^2 \equiv 2^{-\frac{5}{8}}\, 3^{-1}\, g^{-2}\, c^{\frac{1}{12}}$ and $e^{\phi_0} \equiv 2^{\frac{1}{4}}\, c^{-\frac{5}{6}}$

✦ The angle $0\leq\alpha\leq\pi$ locally foliates S_6 with S_5 regarded as Hopf fibrations over $\mathbb{CP}^2$

3D : CFT$_3$ dual & matching of free energies

[Schwarz '04]
[Gaiotto, Tomassiello '09]

- 3d SYM + (N=2) Chern-Simons with simple group SU(N) , level k , three adjoint matter and a cubic superpotential W = Tr(X[Y,Z])

- The 3d free energy F = -Log(Z), where Z is the partition function of the CFT on a Euclidean S$_3$, can be computed via localisation over supersymmetric configurations $N \gg k$

$$F = \frac{3^{13/6}\pi}{40}\left(\frac{32}{27}\right)^{2/3} k^{1/3} N^{5/3}$$

[Pestun '07] [Kapustin, Willett, Yaakov '09]
[Jafferis '10] [Jafferis, Klebanov, Pufu, Safdi '11]
[Closset, Dumitrescu, Festuccia, Komargodski '12 '13]

- The gravitational free energy can be computed from the warp factor in the N=2 massive IIA solution. Using the charge quantisation condition $N = -(2\pi\ell_s)^{-5} \int_{S^6} e^{\frac{1}{2}\phi} \hat{*}\hat{F}_{(4)} + \hat{B}_{(2)} \wedge d\hat{A}_{(3)} + \frac{1}{6}\hat{F}_{(0)}\hat{B}_{(2)}^3$ for the D2-brane, one finds

$$F = \frac{16\pi^3}{(2\pi\ell_s)^8}\int_{S^6} e^{8A}\text{vol}_6 = \frac{\pi}{5} 2^{1/3}\, 3^{1/6}\, k^{1/3}\, N^{5/3}$$

provided

$$g\, c \;=\; \hat{F}_{(0)} \;=\; k/(2\pi\ell_s)$$

[Emparan, Johnson, Myers '99]

Holographic RG flows: domain-walls & black holes

Holographic description of RG flows

[Boonstra, Skenderis, Townsend ’98]

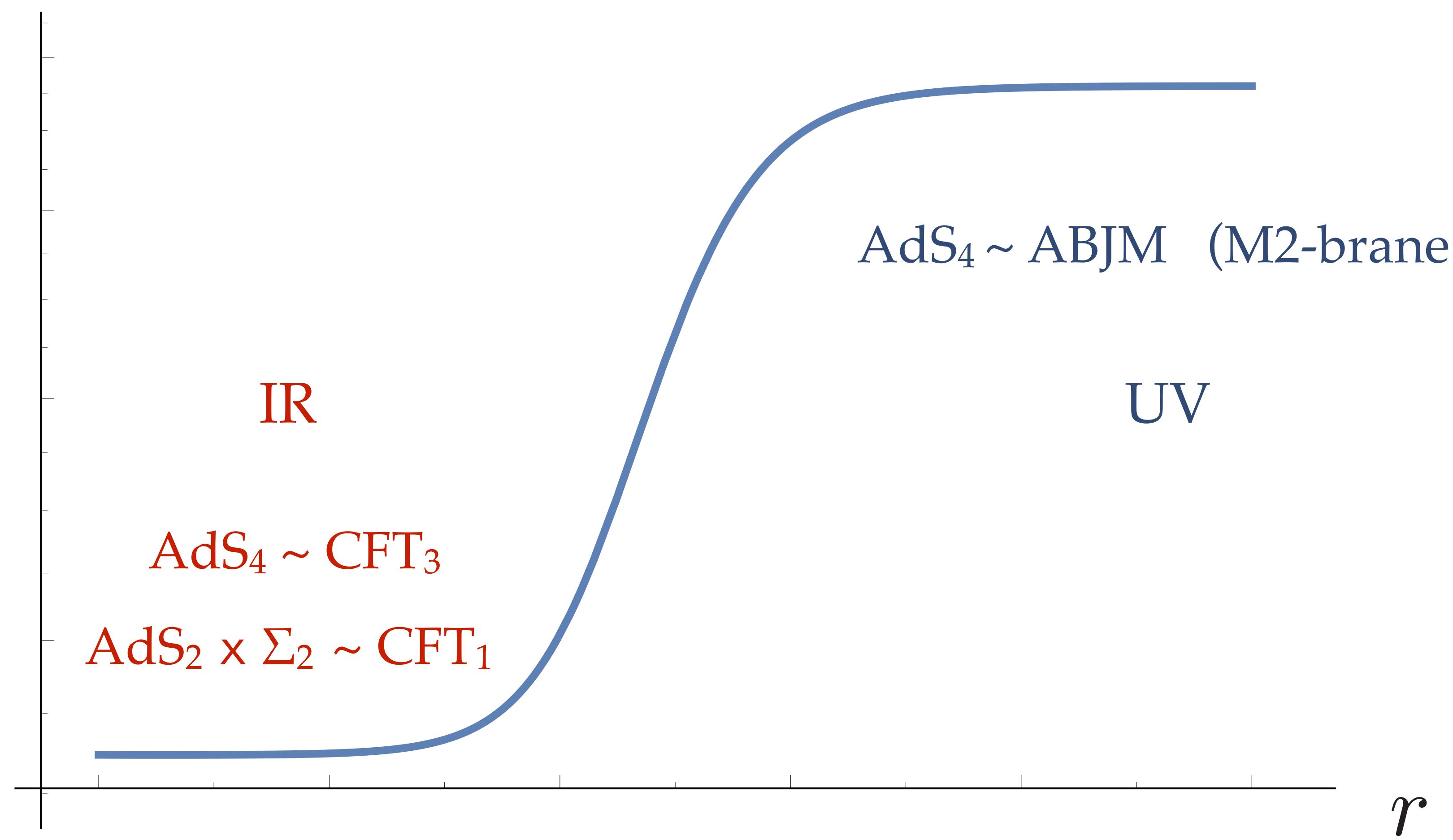
- RG flows are described holographically as non-AdS_4 solutions in gravity

- RG flows on M2-brane : SO(8)-gauged sugra from M-theory on S^7

[Ahn, Paeng ’00] [Ahn, Itoh ’01]
[Bobev, Halmagyi, Pilch, Warner ’09]

[Cacciatori, Klemm ’09]
[Halmagyi, Petrini, Zaffaroni ’13]
[Chimento, Klemm, Petri ’15]
[Benini, Hristov, Zaffaroni ’15 ’16]

AdS_4 in IR : domain-wall
$AdS_2 \times \Sigma_2$ in IR : black hole



- RG flows on D3-brane : SO(6)-gauged sugra from type IIB on S^5 and N=4 SYM in 4D

[Freedman, Gubser, Pilch, Warner ’99]
[Pilch, Warner ’00] [Benini, Bobev ’12,’13]

Holographic RG flows on the D2-brane

- D2-brane :

$$d\hat{s}_{10}^2 = e^{\frac{3}{4}\phi}\left(-e^{2U}dt^2 + e^{-2U}dr^2 + e^{2(\psi-U)}ds_{\Sigma_2}^2\right) + g^{-2}e^{-\frac{1}{4}\phi}ds_{S^6}^2$$

$$e^{\hat{\Phi}} = e^{\frac{5}{2}\phi}$$

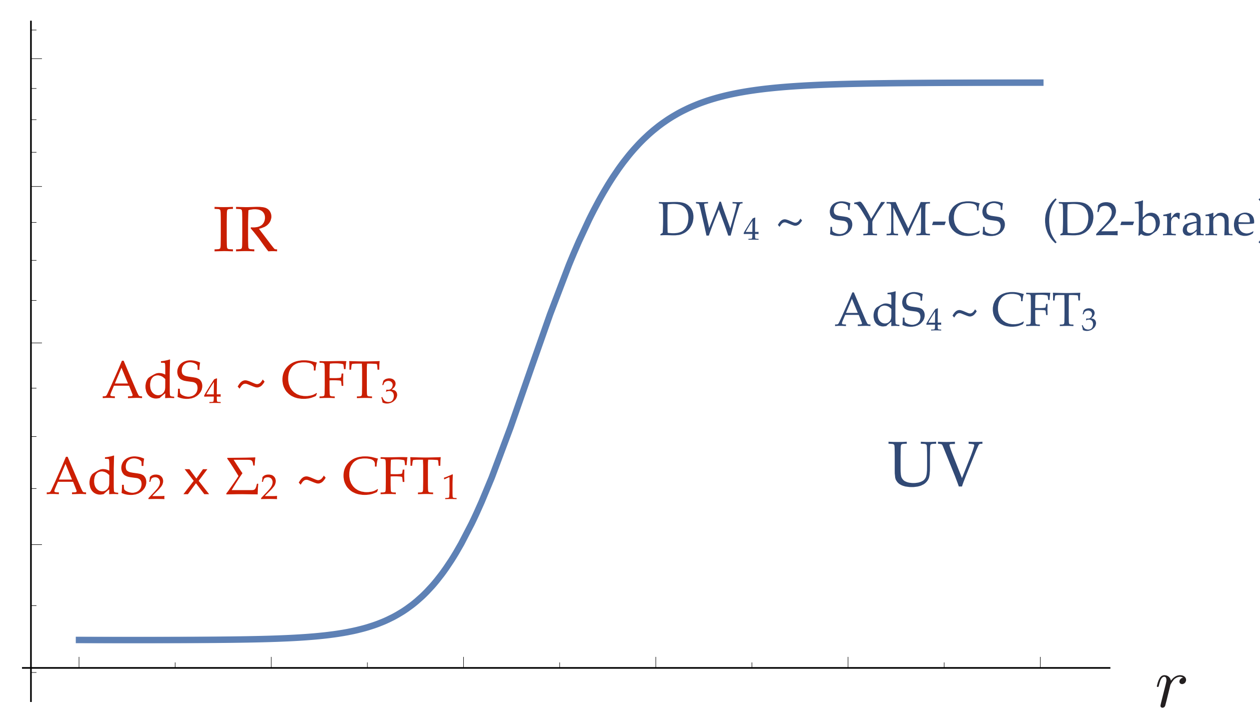
$$\hat{F}_{(4)} = 5\,g\,e^{\phi}\,e^{2(\psi-U)}\,dt\wedge dr\wedge d\Sigma_2$$

with $e^{2U}\sim r^{\frac{7}{4}}$, $e^{2(\psi-U)}\sim r^{\frac{7}{4}}$ and $e^{\phi}\sim r^{-\frac{1}{4}}$ ⇒ DW_4 domain-wall (SYM-CS)

- RG flows on D2-brane : ISO(7)$_c$-gauged sugra from mIIA on S^6

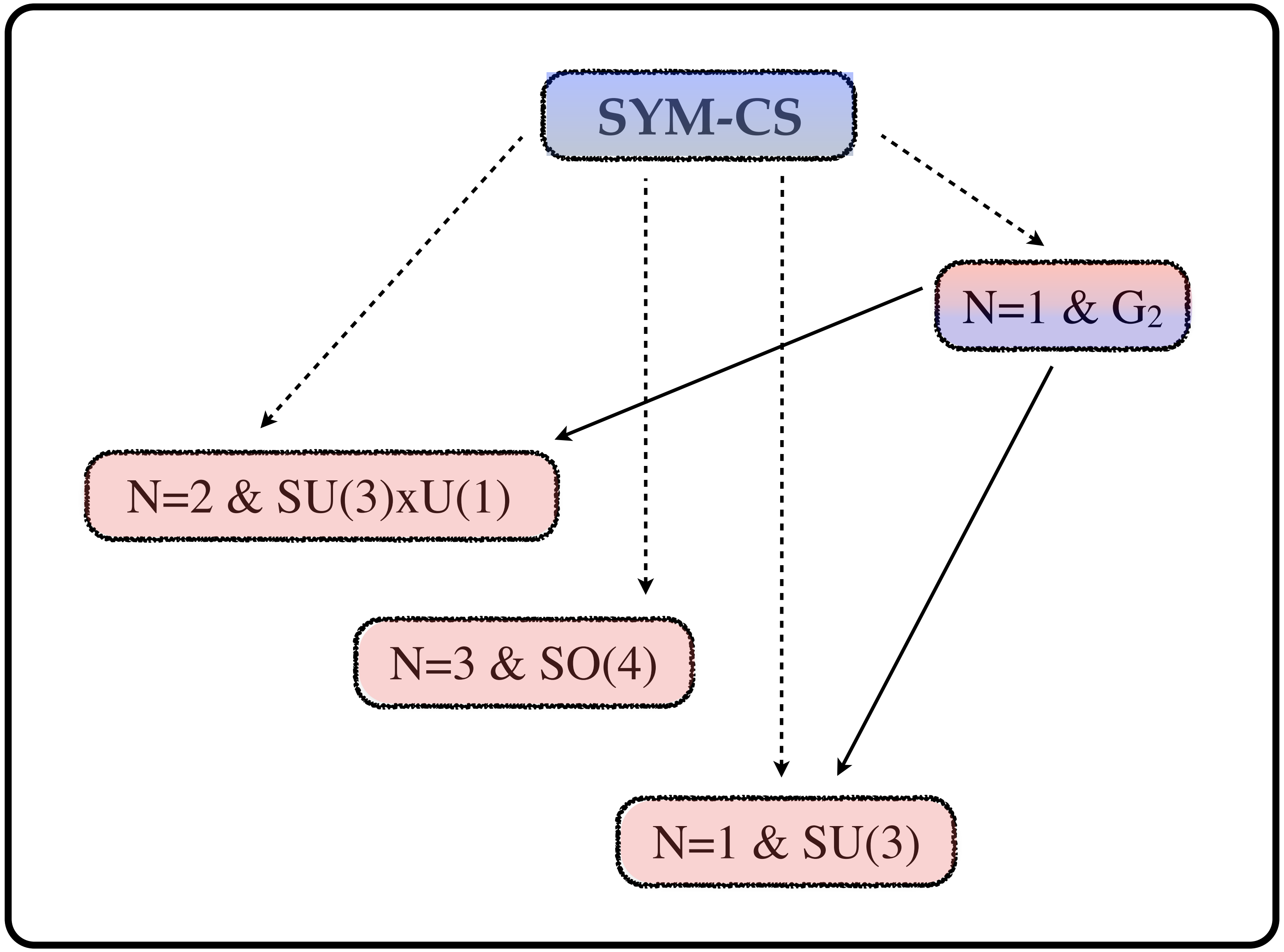
AdS_4 in IR : domain-wall

$AdS_2 \times \Sigma_2$ in IR : black hole



Domain-walls

[AG, Tarrío, Varela '16]



- RG flows from SYM-CS (dotted lines) and between CFT's (solid lines) dual to BPS domain-wall solutions of the dyonic ISO(7)-gauged supergravity

Black holes (I)

$\Lambda = 0, 1$

- N=2 model with 1 vector + 1 hyper (universal)

- Black hole Anstaz :

$$ds^2 = -e^{2U(r)} dt^2 + e^{-2U(r)} dr^2 + e^{2(\psi(r)-U(r))} \left(d\theta^2 + \left(\frac{\sin\sqrt{\kappa}\,\theta}{\sqrt{\kappa}} \right)^2 d\phi^2 \right)$$

$$\mathcal{A}^\Lambda = \mathcal{A}_t{}^\Lambda(r)\, dt - p^\Lambda \frac{\cos\sqrt{\kappa}\,\theta}{\kappa} d\phi$$

$$\tilde{\mathcal{A}}_\Lambda = \tilde{\mathcal{A}}_{t\,\Lambda}(r) dt - e_\Lambda \frac{\cos\sqrt{\kappa}\,\theta}{\kappa} d\phi$$

$$\mathcal{B}^0 = b_0(r) \frac{\sin\sqrt{\kappa}\,\theta}{\sqrt{\kappa}} d\theta \wedge d\phi$$

- Attractor equations :

$$\mathcal{Q} = \kappa\, L^2_{\Sigma_2}\, \Omega\, \mathcal{M}\, \mathcal{Q}^x\, \mathcal{P}^x - 4\,\mathrm{Im}(\bar{\mathcal{Z}}\, \mathcal{V}) \ ,$$

$$\frac{L^2_{\Sigma_2}}{L_{\mathrm{AdS}_2}} = -2\, \mathcal{Z}\, e^{-i\beta} \ ,$$

$$\langle \mathcal{K}^u, \mathcal{V} \rangle = 0 \ ,$$

[Dall'Agata, Gnecchi '10]
[Klemm, Petri, Rabbiosi '16]

- Unique $AdS_2 \times H^2$:

(N=2 & U(3) AdS_4 vev's)

[AG, Tarrío '17]

$$e^{\varphi_h} = \frac{2}{\sqrt{3}} \left(\frac{g}{m} \right)^{\frac{1}{3}} , \quad \chi_h = -\frac{1}{2} \left(\frac{g}{m} \right)^{-\frac{1}{3}} , \quad e^{\phi_h} = \sqrt{2} \left(\frac{g}{m} \right)^{\frac{1}{3}} , \quad a_h = \zeta_h = \tilde{\zeta}_h = 0 \ ,$$

$$p^0 + \frac{1}{2}\, m\, b_0^h = \pm \frac{1}{6}\, m^{\frac{2}{3}}\, g^{-\frac{5}{3}} , \quad e_0 + \frac{1}{2}\, g\, b_0^h = \pm \frac{1}{6}\, m^{-\frac{1}{3}}\, g^{-\frac{2}{3}} \ ,$$

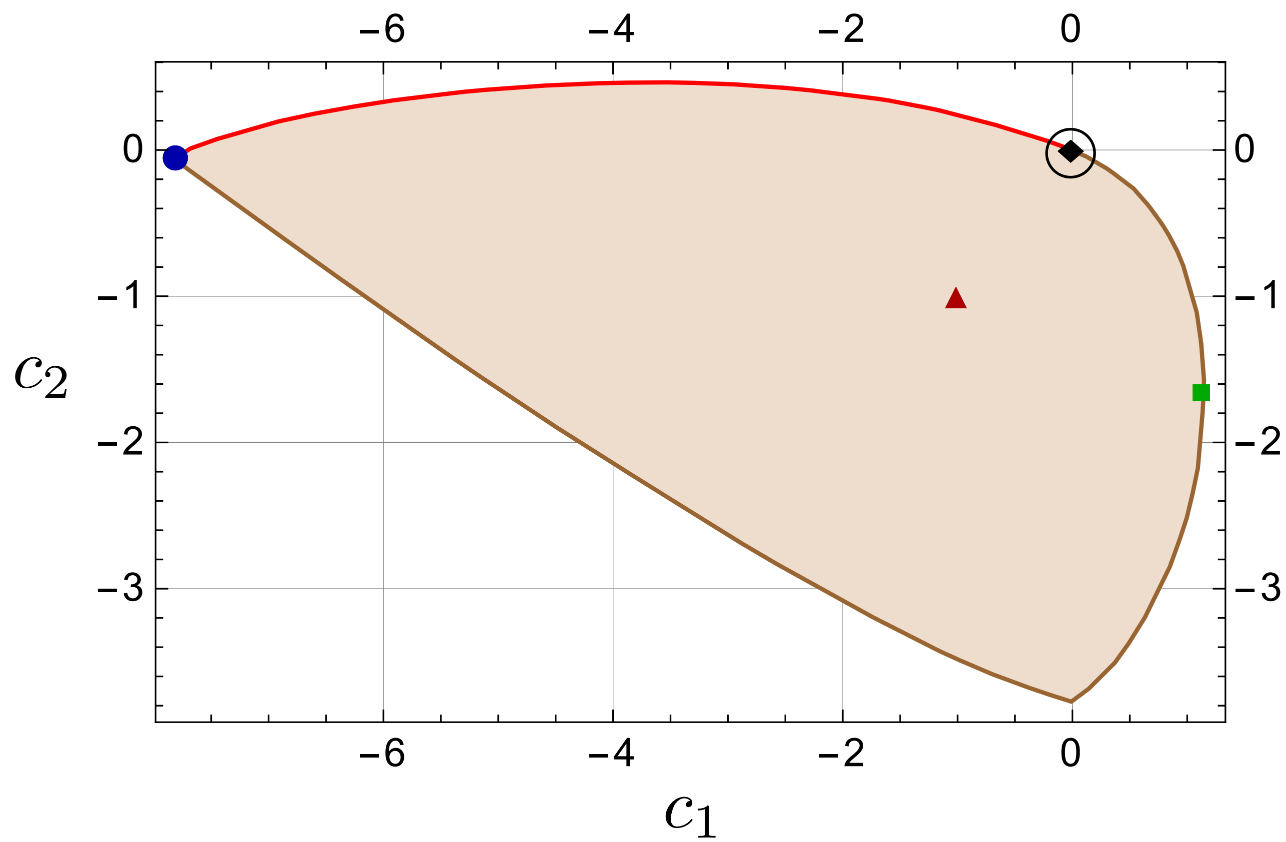
$$p^1 = \mp \frac{1}{3}\, g^{-1} , \quad e_1 = \pm \frac{1}{2}\, m^{\frac{1}{3}}\, g^{-\frac{4}{3}} \ ,$$

$$L^2_{\mathrm{AdS}_2} = \frac{1}{4\sqrt{3}}\, m^{\frac{1}{3}}\, g^{-\frac{7}{3}} , \quad L^2_{\mathrm{H}^2} = \frac{1}{2\sqrt{3}}\, m^{\frac{1}{3}}\, g^{-\frac{7}{3}} \ .$$

Black holes (II)

[Dall'Agata, Gnecchi '10]
[Klemm, Petri, Rabbiosi '16]

- Two irrelevant modes (c_1, c_2) when perturbing around the AdS_2 x H^2 solution in the IR



- ▲ : AdS_2 x H^2 to DW_4
- ◆ : AdS_2 x H^2 to AdS_4
- ● : AdS_2 x H^2 to Lifshitz (z=2)
- ■ : AdS_2 x H^2 to conf-Lifshitz

[AG, Tarrío '17]

- RG flows across dimension from SYM-CS **or** CFT_3 **or** non-relativistic to CFT_1
- Universal (constant scalars) RG flow (◆) CFT_3 to CFT_1 [Caldarelli, Klemm '98]

- AdS_2 x Σ_g horizons for mIIA on $H^{(p,q)}$: STU-models with 3 vectors + 1 hyper

[AG '17]

Summary

- Dyonic N = 8 supergravity with $ISO(7)_c$ gauging connected to massive IIA reductions on S^6.

- Any 4D configuration (AdS, DW, BH) is embedded into 10D via the uplifting formulas.
  Example : $AdS_4 \times S^6$ solution of massive IIA based on an N = 2 & U(3) AdS_4 vacuum.

- CFT_3 dual for the N = 2 $AdS_4 \times S^6$ solution of mIIA based on the D2-brane field theory (SYM-CS).

- Holographic study of RG flows on D2-brane : DW solutions (CFT_3 / CFT_3 & SYM-CS / CFT_3)
  BH solutions (CFT_3 / CFT_1 & SYM-CS / CFT_1)

- Generalisation & further tests/conjectures on the duality (semiclassical observables, level-rank duality, …)

  [Fluder, Sparks '15] [Passias, Prins, Tomasiello '18]
  [Araujo, Nastase '16] [Araujo, Itsios, Nastase, Ó Colgáin '17]

- Recent progress in the holographic counting of BH microstates

  [Benini, Hristov, Zaffaroni '16]
  [Azzurli, Bobev, Crichigno, Min, Zaffaroni '17]
  [Hosseini, Hristov, Passias '17] [Benini, Khachatryan, Milan '17]

- $SO(8)_c$ theories? [work in progress…]

¡ Muchas gracias !