Holographic RG flows from massive IIA on S^6

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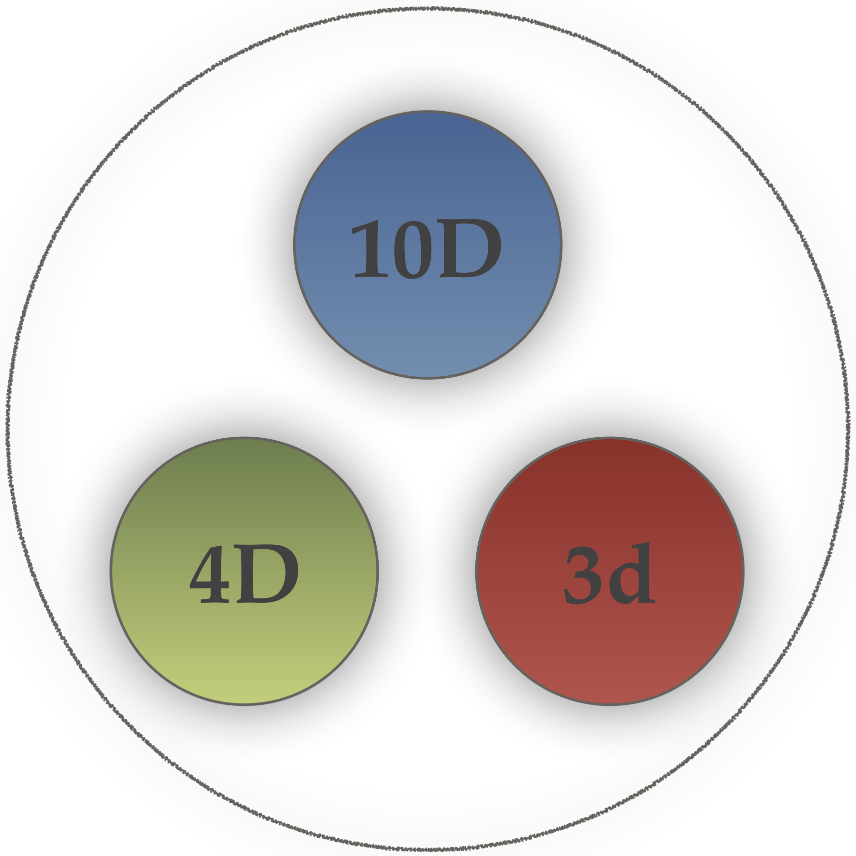
August 8th , C.E.R.N.



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

Outlook

- Motivation
- Deformed SO(8)-gauged supergravity
- Deformed ISO(7)-gauged supergravity
- Massive IIA on S^6 / SYM-CS duality
- Holographic RG flows: domain-walls and black holes

Motivation

electric-magnetic deformations

• The uniqueness of the maximal (N=8) supergravities is historically inherited from their connection to sphere reductions [Cvetic, Lu, Pope '00]

$AdS_5 \times S^5$ (D3-brane) , $AdS_4 \times S^7$ (M2-brane) , $AdS_7 \times S^4$ (M5-brane)

• 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.

• 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]
[Dall'Agata, Inverso, Trigiante '12]

The questions arise:

- Does such an electric/magnetic deformation of 4D maximal supergravity enjoy a string/M-theory origin, or is it just a 4D feature ?

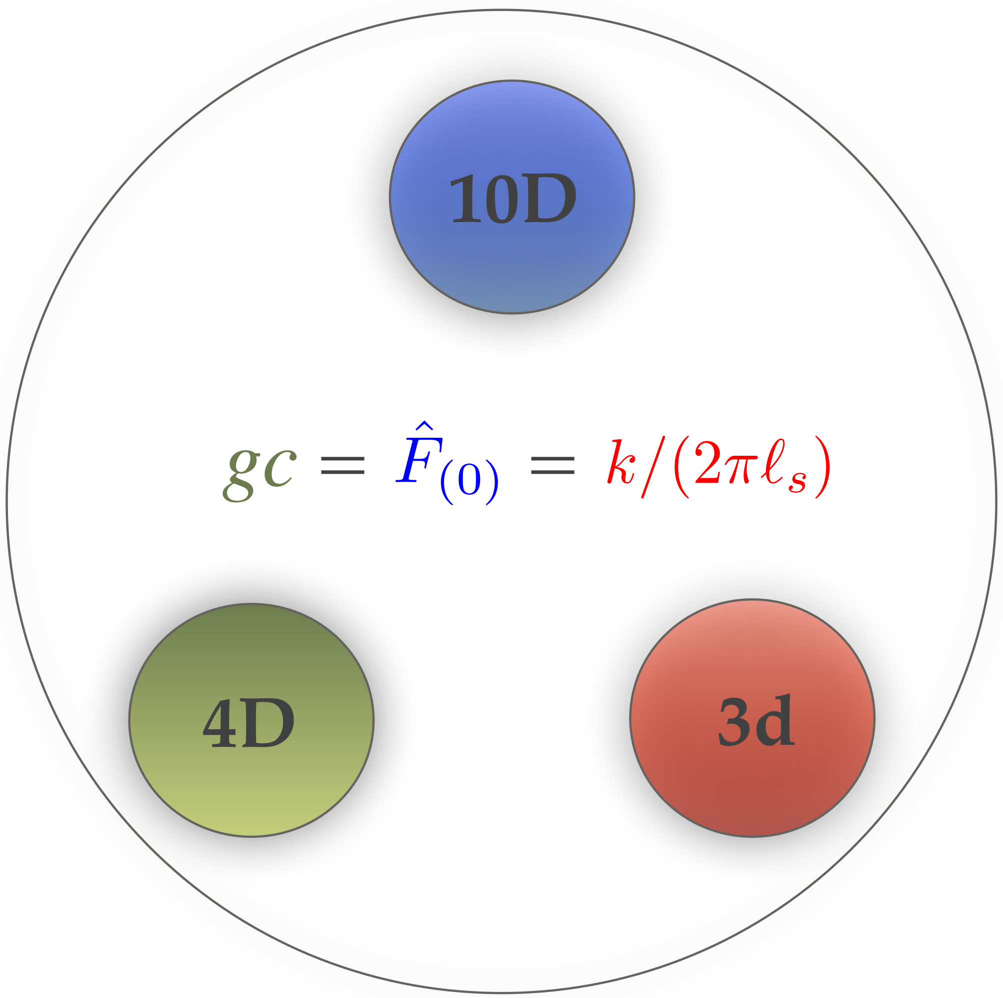
Obstruction for $SO(8)_c$, *cf*. [Lee, Strickland-Constable, Waldram '15]

[de Wit, Nicolai '13]

- For deformed 4D supergravities with supersymmetric AdS_4 vacua, are these AdS_4/CFT_3-dual to any identifiable 3d CFT ?

A new 10D/4D/3d correspondence

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

Deformed SO(8)-gauged supergravity

$N = 8$ supergravities 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]

✱ SO(8)-gauged supergravity believed to be unique for 30 years…

… but … is this true?

Framework to study N = 8 supergravities in 4D

[de Wit, Samtleben, Trigiante '03 , '07]

Gauging procedure : Part of the global E_7 symmetry group is promoted to a local symmetry group G (gauging)

$[\,\alpha = 1, \ldots, 133\,]$

Embedding tensor : It is a "selector" specifying which generators of E_7 (there are 133!!) become the gauge symmetry G and, therefore, have associated gauge fields.

Formulation in terms of 56 vectors A_μ^M , though… $M = 1 , \ldots , 56 = 28$ (elec) + 28 (mag)

Sp(56) *Elec/Mag group*

$$A_\mu = A_\mu^M \, \Theta_M{}^\alpha \, t_\alpha$$

Redundancy!!

$$X_M = \Theta_M{}^\alpha \, t_\alpha \quad \Rightarrow \quad [\, X_M \, , \, X_N \,] = X_{MN}{}^P \, X_P \quad \text{with} \quad X_{MN}{}^P = \Theta_M{}^\alpha \, [t_\alpha]_N{}^P$$

✱ Closure of the gauge algebra : $\Omega^{MN} \, \Theta_M{}^\alpha \, \Theta_N{}^\beta = 0$

Only 28 physical l.c. of vectors!!

A family of $G = SO(8)$ supergravities in 4D

- Choose $G = SO(8)$

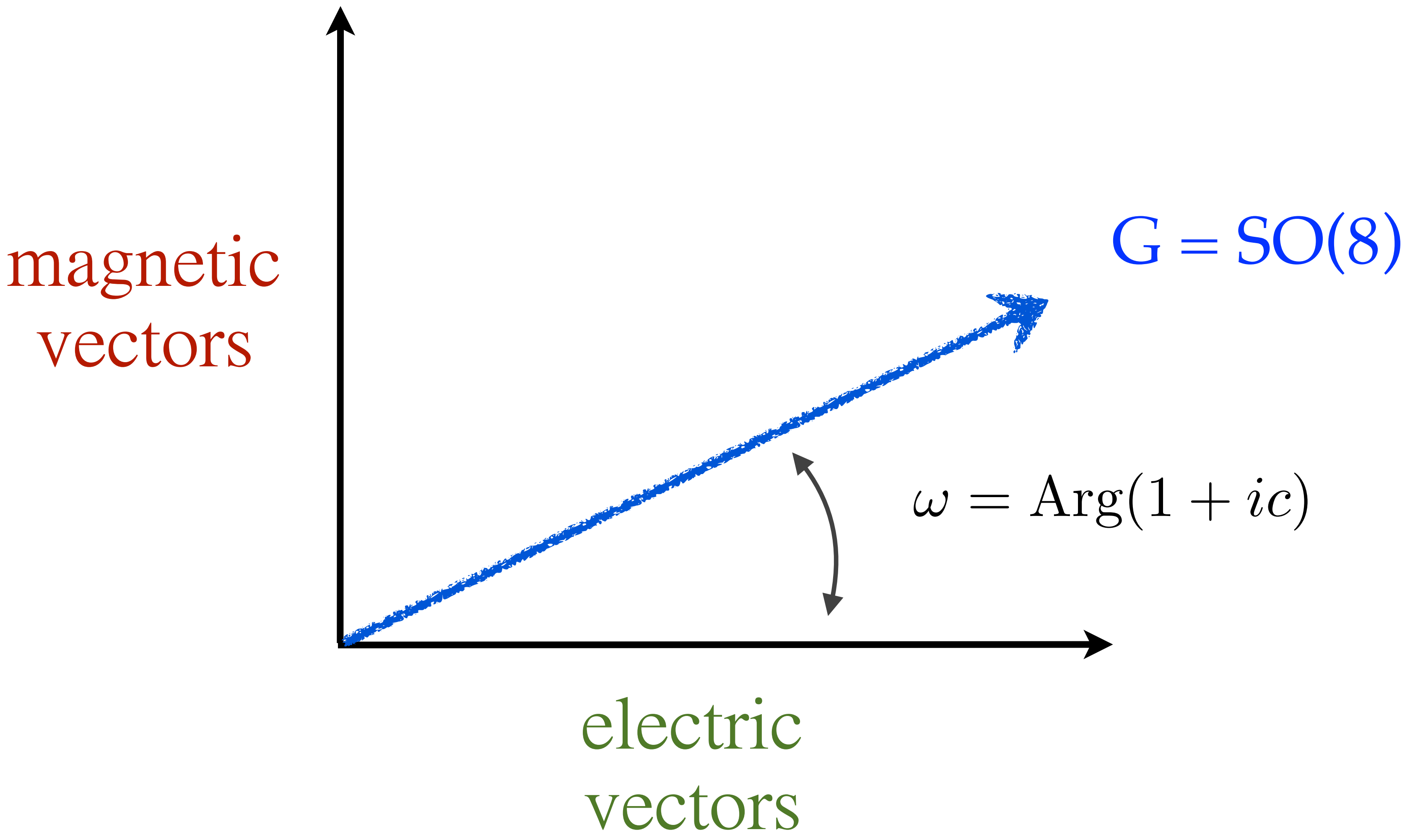
- Solve $\Omega^{MN} \, \Theta_M{}^{\alpha} \, \Theta_N{}^{\beta} = 0$ ⇒ One-parameter (c) family of $SO(8)_c$ theories !!

[Dall' Agata, Inverso, Trigiante '12]

- Immediate questions :

1) What?	(Yes, surprising but true)
2) Are these c-theories equivalent?	(No)
3) Are there new AdS_4 solutions?	(Yes)
4) Higher-dimensional origin?	(Good question…)
5) AdS_4/CFT_3 dual?	(Good question too… ABJ?)

Physical meaning in 4D : electric / magnetic deformation



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

Physical meaning in 11D …

?

Holographic AdS_4/CFT_3 meaning …

?

[Hull '84 (electric)]

In this talk we are going to investigate the electric/magnetic deformation of a different N=8 supergravity closely related to the $G = SO(8)$ theory …

… the $G = ISO(7) = SO(7) \ltimes \mathbb{R}^7$ supergravity !!

electric/magnetic deformation	higher-dimensional origin	Holographic AdS_4/CFT_3 dual ?
✓	✓	✓

Deformed ISO(7)-gauged supergravity

A family of G = ISO(7) supergravities in 4D

- Choose G = ISO(7)

- Solve $\Omega^{MN}\,\Theta_M{}^{\alpha}\,\Theta_N{}^{\beta} = 0$ ⇒ One-parameter (c) family of $\text{ISO}(7)_c$ theories !!

[Hull '84 (electric)]

[Dall'Agata, Inverso, Marrani '14]

- Immediate questions :

1) What? (Yes, and still surprising)

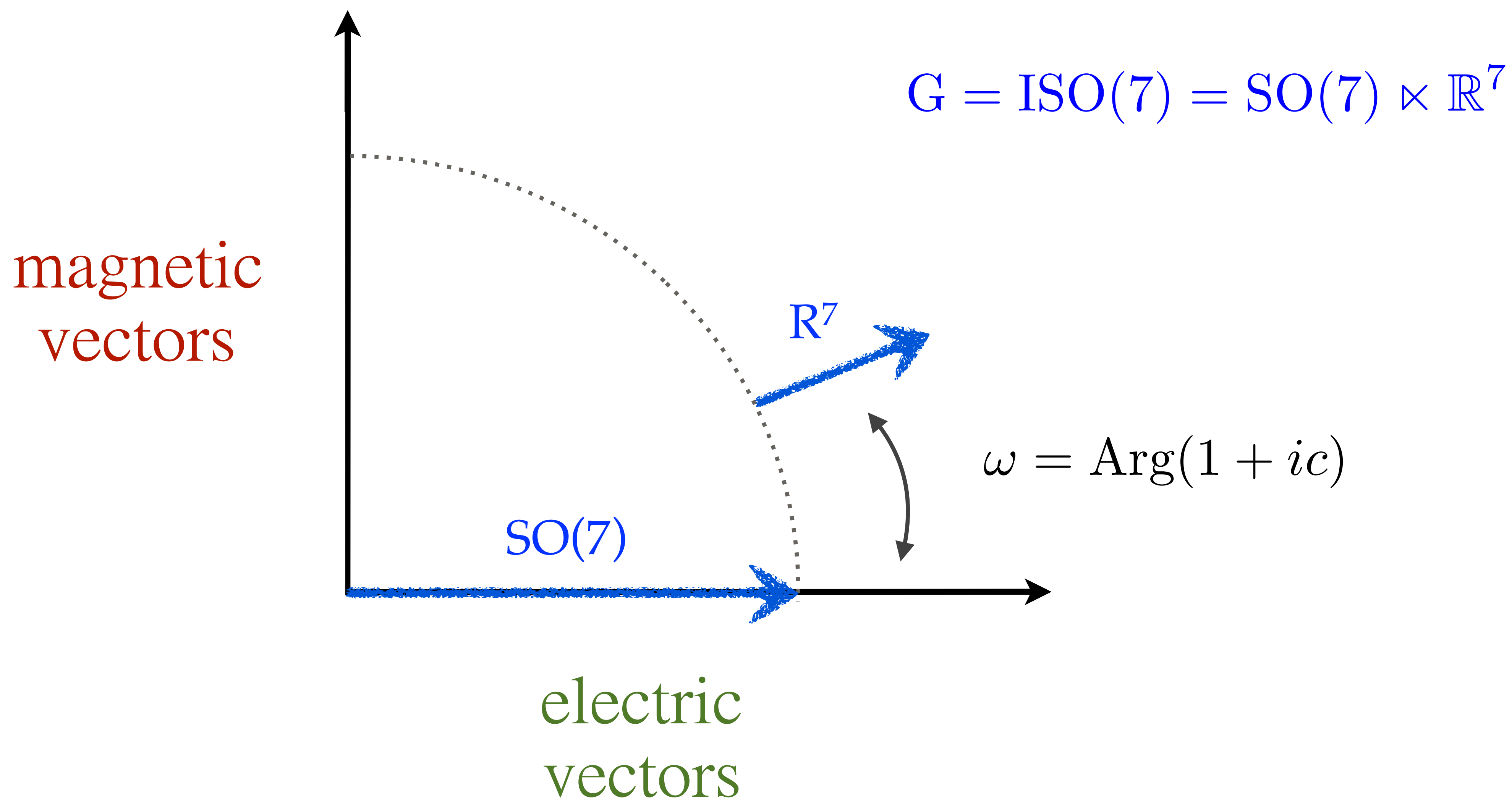
2) Are these c-theories equivalent? (No)

3) Are there new AdS_4 solutions? (Yes)

4) Higher-dimensional origin? (Yes)

5) AdS_4/CFT_3 dual? (Yes)

Physical meaning in 4D = electric / magnetic deformation



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

Deformed ISO(7)$_c$ Lagrangian $(m = gc)$

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

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

✦ Setting $m = 0$, 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 : $\mathcal{M}_{\mathbb{MN}}$
- Auxiliary two-forms (7) : $\mathcal{B}^I$ [$\mathbb{R}^7$]
- Topological term : $m\,[\; \ldots \;]$
- Scalar potential : $V(\mathcal{M}) = \dfrac{g^2}{672} X_{\mathbb{MN}}{}^{\mathbb{R}} X_{\mathbb{PQ}}{}^{\mathbb{S}} \mathcal{M}^{\mathbb{MP}} (\mathcal{M}^{\mathbb{NQ}} \mathcal{M}_{\mathbb{RS}} + 7\,\delta^{\mathbb{Q}}_{\mathbb{R}}\,\delta^{\mathbb{N}}_{\mathbb{S}})$

A truncation : $G_0 = SU(3)$ invariant subsector

[Warner '83]

- Truncation : Retaining the fields and couplings which are invariant (singlets) under the action of a subgroup $G_0 \subset \mathrm{ISO}(7)$

- SU(8) R-symmetry branching : gravitini $\mathbf{8} \rightarrow \mathbf{1} + \mathbf{1} + \mathbf{3} + \bar{\mathbf{3}}$ ➡ N = 2 SUSY

- Scalars fields : $\mathbf{70} \rightarrow \mathbf{1}\ (\times 6) + \text{non-singlets}$ ➡ 6 real scalars $(\varphi\,,\,\chi\,;\,\phi\,,\,a\,,\,\zeta\,,\,\tilde{\zeta}\,)$

- Vector fields : $\mathbf{56} \rightarrow \mathbf{1}\,(\times 4) + \text{non-singlets}$ ➡ vectors $(\,A^0, A^1\,;\,\tilde{A}_0, \tilde{A}_1\,)$

- N = 2 gauged supergravity with $\mathrm{G} = \mathrm{U}(1) \times \mathbb{R}_c$ coupled to 1 vector & 1 hypermultiplet

$$\mathcal{M}_{\text{scalar}} = \frac{\mathrm{SU}(1,1)}{\mathrm{U}(1)} \times \frac{\mathrm{SU}(2,1)}{\mathrm{U}(2)}$$

The truncated Lagrangian

- The Lagrangian contains a non-dynamical tensor field B^0 :

$\Lambda = 0, 1$

$$
\begin{aligned}
\mathcal{L} &= (R - V)\,\text{vol}_4 + \tfrac{3}{2}\left[d\varphi \wedge *d\varphi + e^{2\varphi}\, d\chi \wedge *d\chi\right] \\
&+ 2\, d\phi \wedge *d\phi + \tfrac{1}{2}\, e^{2\phi}\,[D\zeta \wedge *D\zeta + D\tilde{\zeta} \wedge *D\tilde{\zeta}] \\
&+ \tfrac{1}{2}\, e^{4\phi}\,[Da + \tfrac{1}{2}(\zeta D\tilde{\zeta} - \tilde{\zeta} D\zeta)] \wedge *[Da + \tfrac{1}{2}(\zeta D\tilde{\zeta} - \tilde{\zeta} D\zeta)] \\
&+ \tfrac{1}{2}\,\mathcal{I}_{\Lambda\Sigma}\, H^{\Lambda}_{(2)} \wedge *H^{\Sigma}_{(2)} - \tfrac{1}{2}\,\mathcal{R}_{\Lambda\Sigma}\, H^{\Lambda}_{(2)} \wedge H^{\Sigma}_{(2)} + m\, B^0 \wedge d\tilde{A}_0 \;+\; \tfrac{1}{2}\, g\, m\, B^0 \wedge B^0
\end{aligned}
$$

with field strengths $H^1_{(2)} = dA^1$ and $H^0_{(2)} = dA^0 + m\, B^0$.

- Covariant derivatives :

$$
Da = da + g\, A^0 - m\, \tilde{A}_0 \quad , \quad D\zeta = d\zeta - 3\, g\, A^1\, \tilde{\zeta} \quad , \quad D\tilde{\zeta} = d\tilde{\zeta} + 3\, g\, A^1\, \zeta
$$

- Scalar potential :

$$
\begin{aligned}
V &= \tfrac{1}{2}\, g^2 \left[e^{4\phi - 3\varphi}(1 + e^{2\varphi}\chi^2)^3 - 12\, e^{2\phi-\varphi}(1 + e^{2\varphi}\chi^2) - 12\, e^{2\phi+\varphi}\rho^2(1 - 3\, e^{2\varphi}\chi^2)\right. \\
&- \left. 24\, e^{\varphi} + 12\, e^{4\phi+\varphi}\, \chi^2\, \rho^2\, (1 + e^{2\varphi}\chi^2) + 12\, e^{4\phi+\varphi}\rho^4\, (1 + 3\, e^{2\varphi}\chi^2)\right] \\
&- \tfrac{1}{2}\, g m\, \chi\, e^{4\phi+3\varphi}\, (12\, \rho^2 + 2\chi^2) + \tfrac{1}{2}\, m^2\, e^{4\phi+3\varphi} \;,
\end{aligned}
$$

note : $\rho^2 \equiv \frac{1}{4}\,(\zeta^2 + \tilde{\zeta}^2)$

AdS critical points !!

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 !!

Massive IIA on S^6 / SYM-CS duality

Collecting clues

- The deformed $\mathrm{ISO}(7)_c$ gauging has its SO(7) piece untouched by the deformation. This points towards an undeformed S^6 description in higher dimension.

- If the higher-dim geometry is not affected, it should then be the higher-dim theory the one changing. The massive IIA theory by Romans proves a natural candidate.

[Romans '86]

- The Romans mass parameter $\hat{F}_{(0)}$ is a discrete (on/off) deformation, exactly as the parameter c in the deformed $\mathrm{ISO}(7)_c$ theory.

Embedding of ISO(7)$_c$ into massive IIA supergravity

[AG, Varela '15]

$$d\hat{s}_{10}^2 = \Delta^{-1}\, ds_4^2 \, + g_{mn}\, Dy^m\, Dy^n \ ,$$

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

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

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

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

The scalars are embedded as

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

A new N=2 solution of massive type IIA

- Using the uplifting formulae, it is a straightforward exercise to obtain the 10D embedding of a 4D critical point. An example is the N=2&U(3) AdS_4 point of the $ISO(7)_c$ theory

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

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

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

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

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 $\mathbb{CP}^2$

CFT$_3$ candidate and matching of free energies

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

- We propose and N=2 Chern-Simons-matter theory with simple gauge group SU(N), level k , three adjoint matter and cubic superpotential, as the CFT dual of the N=2 massive IIA solution.

- 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

$$Z = \int \prod_{i=1}^{N} \frac{d\lambda_i}{2\pi} \prod_{i<j=1}^{N} \left(2\sinh^2(\frac{\lambda_i-\lambda_j}{2})\right) \times \prod_{i,j=1}^{N} \left(\exp(\ell(\frac{1}{3}+\frac{i}{2\pi}(\lambda_i-\lambda_j)))\right)^3 e^{\frac{ik}{4\pi}\sum\lambda_i^2}$$

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

where λ_i are the Coulomb branch parameters. In the $N \gg k$ limit, the result is given by

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

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

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

provided

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

[Emparan, Johnson, Myers '99]

Holographic RG flows: domain-walls and black holes

Holographic description of RG flows

[Boonstra, Skenderis, Townsend ’98]

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

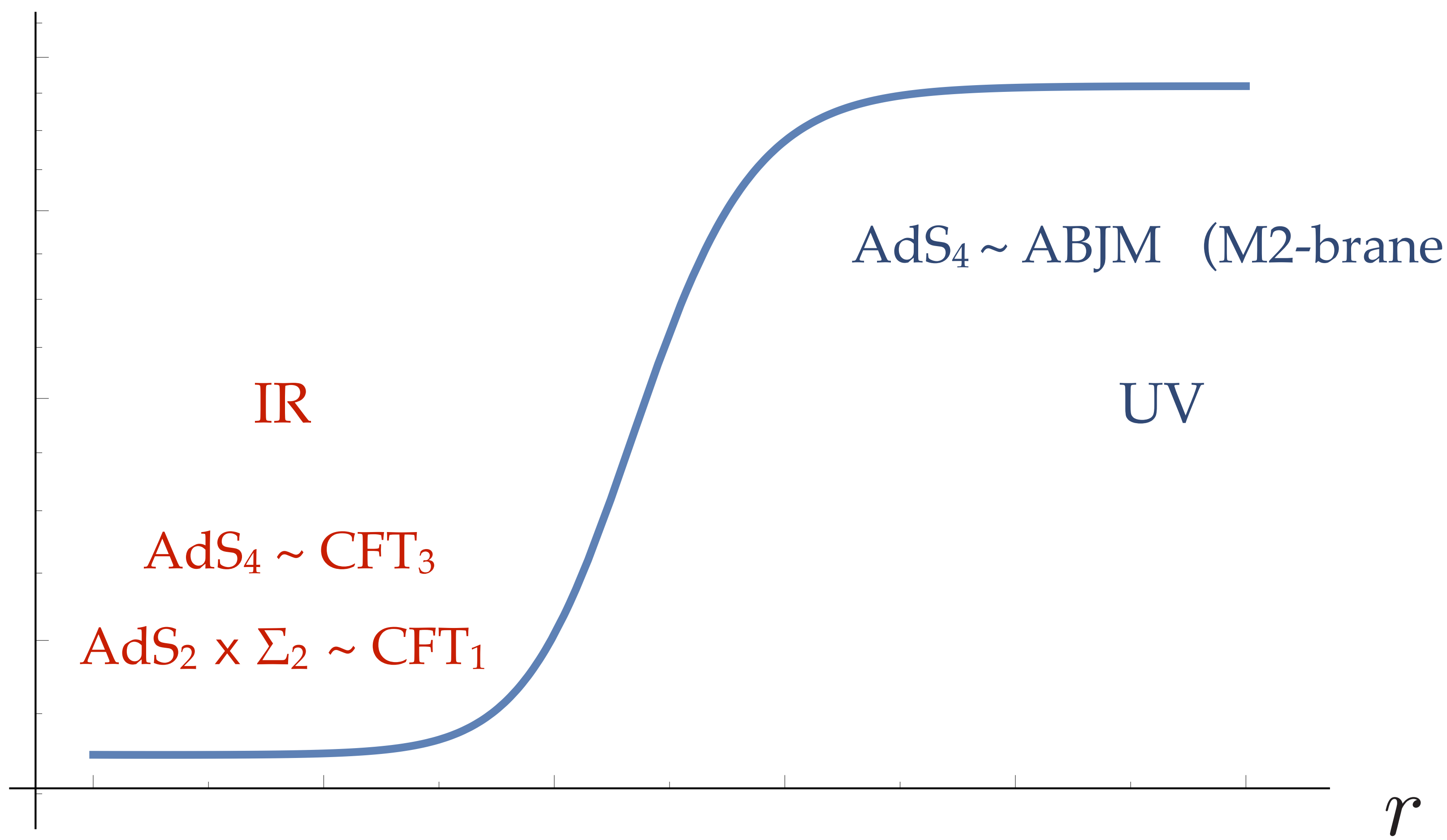
- RG flows on M2-brane :   SO(8)-gauged sugra from M-theory on S^7

[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 of massive IIA

- D2-brane :

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

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

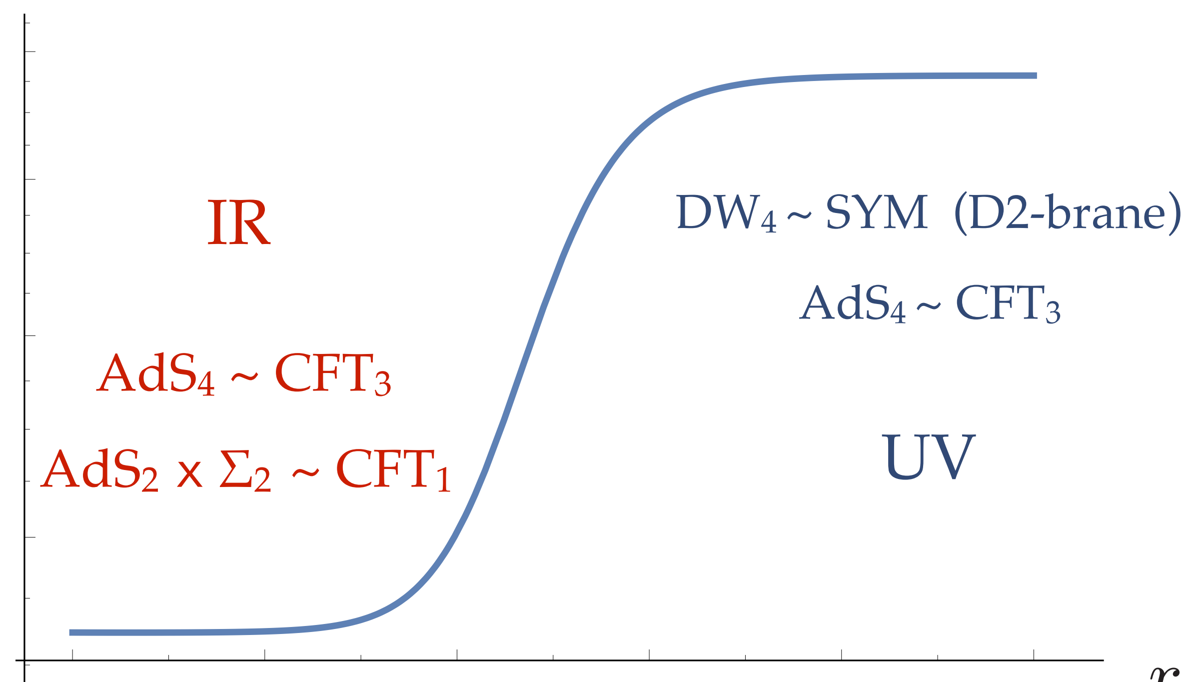
$$\hat{F}_{(4)} = 5\,g\,e^{\phi}\,e^{2(\psi-U)}\,\sinh\theta\,dt\wedge dr\wedge d\theta\wedge d\phi$$

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

- RG flows on D2-brane : ISO(7)-gauged sugra from type IIA on S^6

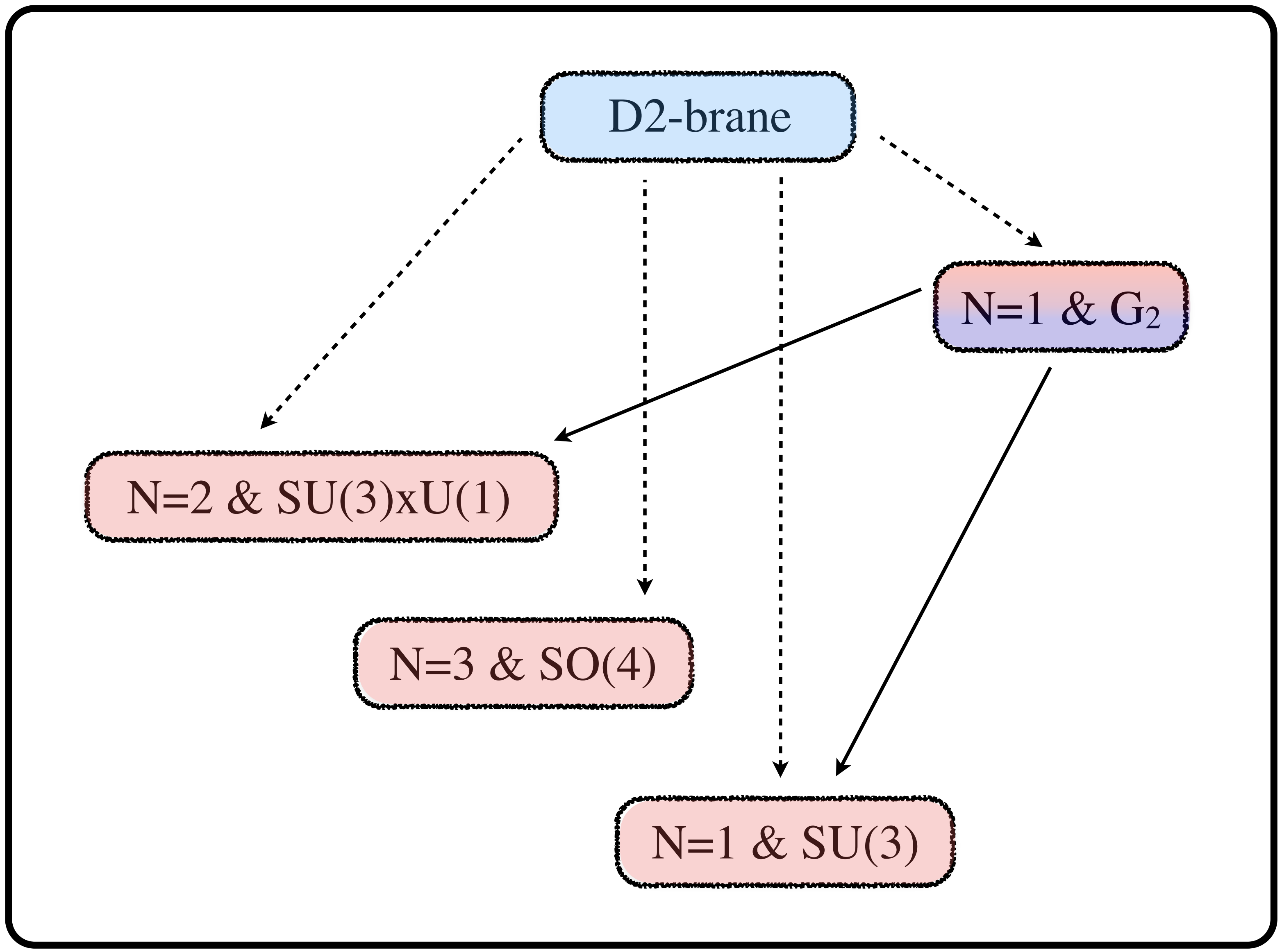
AdS_4 in IR : domain-wall

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



Holographic RG flows: domain-walls

[AG, Tarrío, Varela '16]



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

Holographic RG flows: black hole solutions (I)

$\Lambda = 0, 1$

- 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 $\mathrm{AdS}_2 \times \mathrm{H}^2$:

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

[AG, Tarrío '17]

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

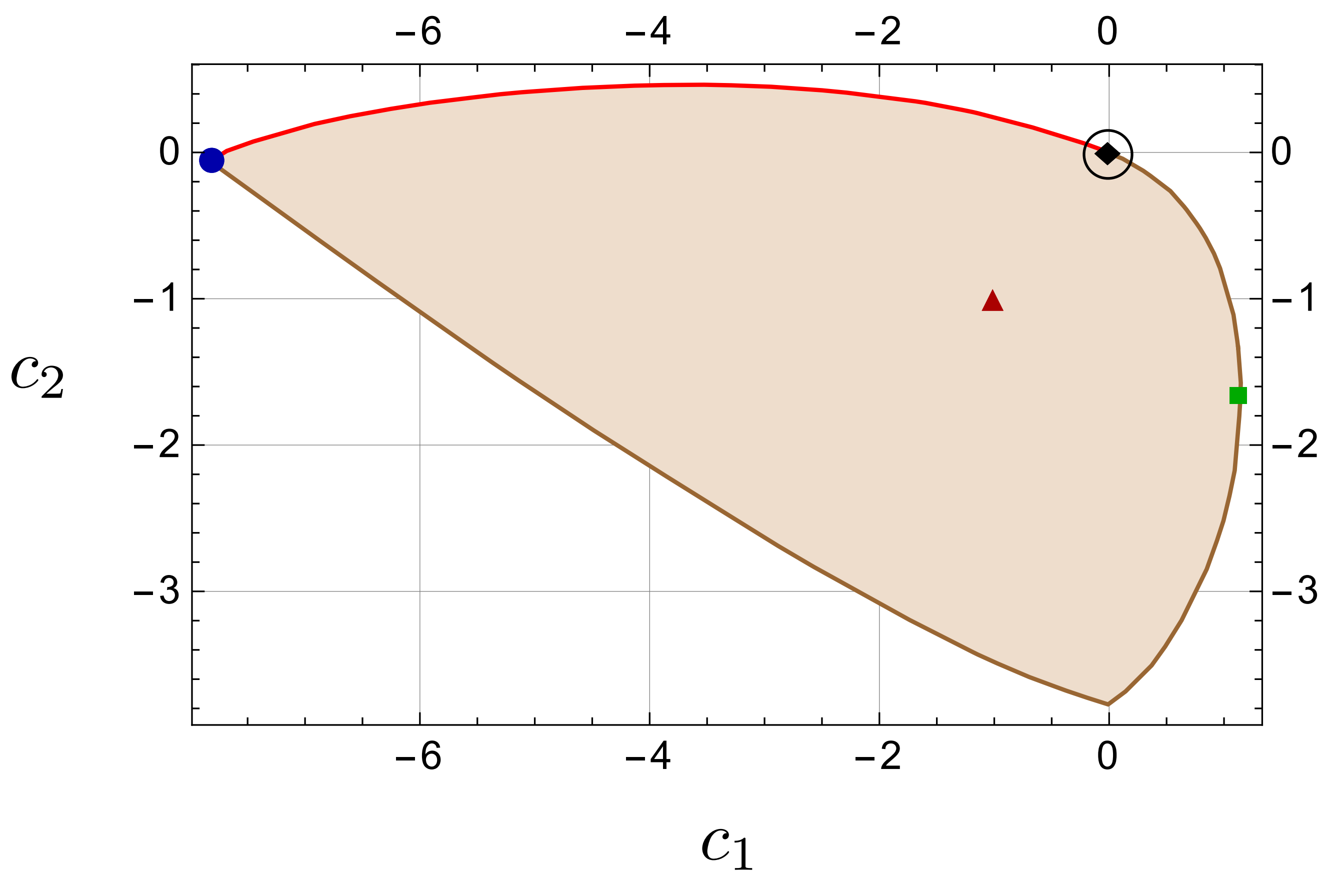
$$p^0 + \frac{1}{2}\,m\,b_0^h = \pm\frac{1}{6}\,m^{\frac{2}{3}}\,g^{-\frac{5}{3}}\ ,\quad e_0 + \frac{1}{2}\,g\,b_0^h = \pm\frac{1}{6}\,m^{-\frac{1}{3}}\,g^{-\frac{2}{3}}\ ,$$

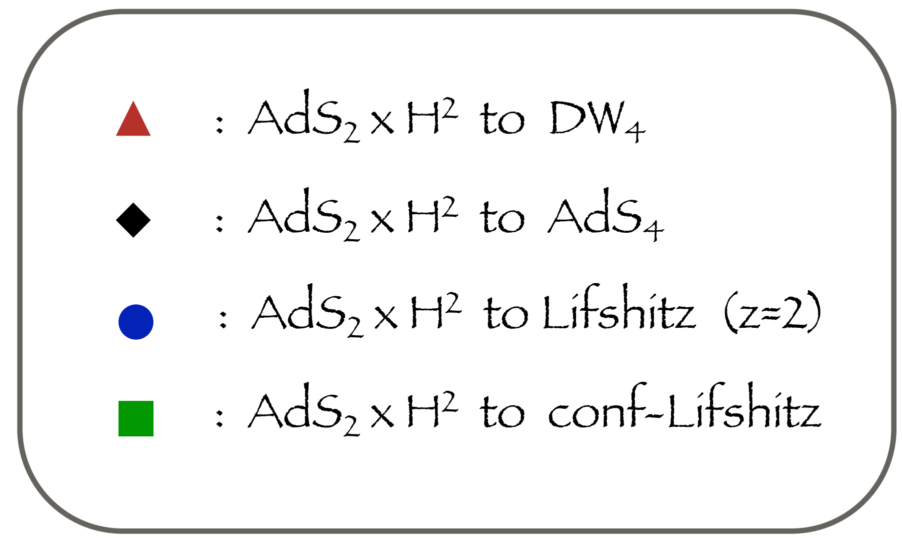
$$p^1 = \mp\frac{1}{3}\,g^{-1}\ ,\quad e_1 = \pm\frac{1}{2}\,m^{\frac{1}{3}}\,g^{-\frac{4}{3}}\ ,$$

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

Holographic RG flows: black hole solutions (II)

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





[AG, Tarrío '17]

- RG flows across dimension from SYM **or** CFT_3 **or** non-relativistic to CFT_1
- Universal RG flow (◆) CFT_3 to CFT_1 [Azzurli, Bobev, Crichigno, Min, Zaffaroni '17]

- $AdS_2 \times \Sigma_g$ horizon classification in the mIIA STU-model : 3 vector + 1 hyper [AG '17]

Summary

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

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

- We proposed a CFT_3 dual for the N = 2 $AdS_4 \times S^6$ solution of massive IIA based on the D2-brane field theory (SYM-CS). The gravitational and field theory free energies perfectly match!

- Holographic study of RG flows on D2-brane : DW solutions (CFT_3-CFT_3 & SYM_3-CFT_3)
  BH solutions (CFT_3-CFT_1 & SYM_3-CFT_1)

- 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]

- New holographic perspective on the one-parameter family of SO(8) theories?

Thanks !!