NEAR ADS_2 SPECTROSCOPY

Strings, Fields and Holograms Conference

Ascona, October 2021

Design and control on the statistical description of black hole.

$$S_{BH} = \frac{A_H}{4G_N} + \cdots$$

$$S_{BH} = \ln d_{micro}$$

In the context of a holographic description,

- what are universal aspects of the dual theory?
- what are aspects that depend on the background ?
- what are aspects that depend on the surrounding?

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- what are aspects that depend on the surrounding? Theory that contains BH

Do we need a periodic table? Black Hole Chemistry

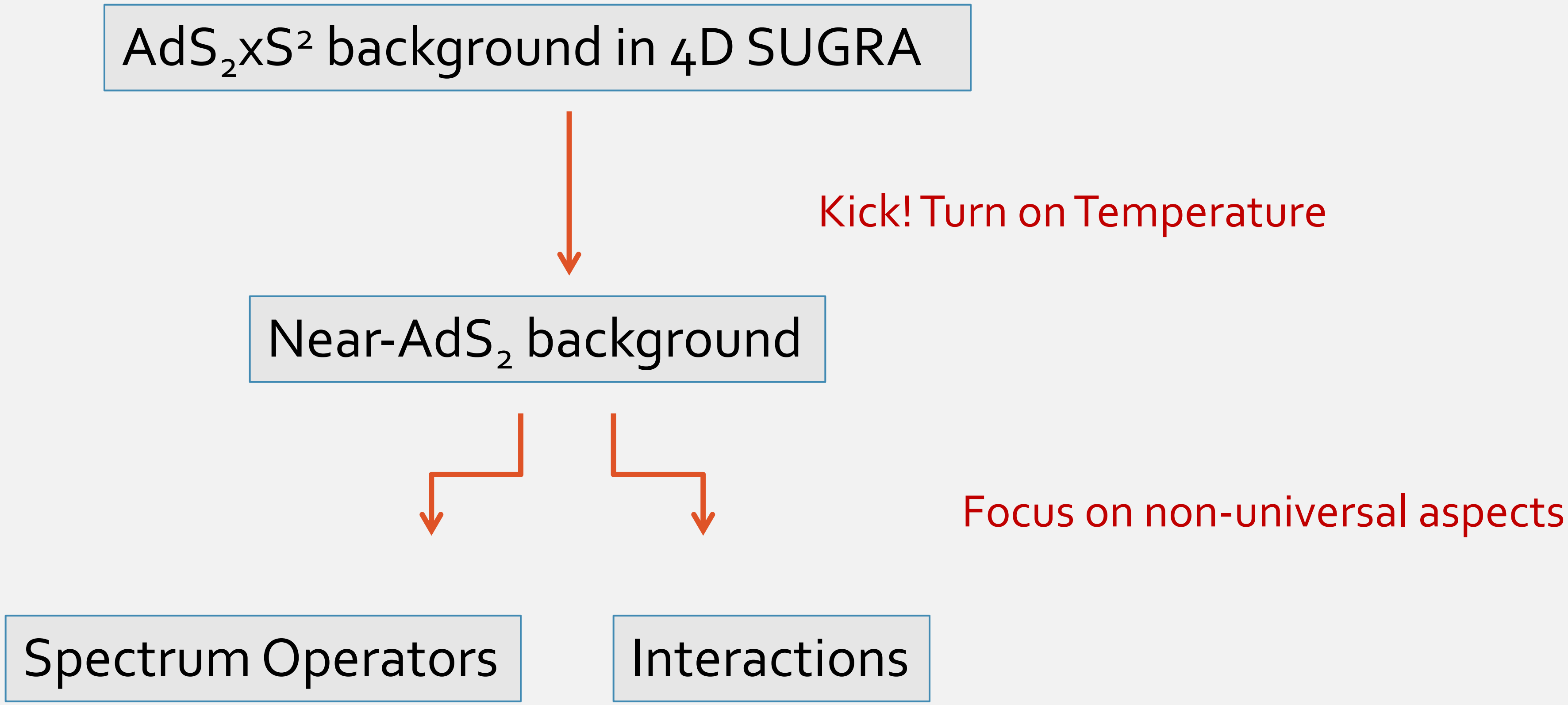
STRATEGY

$AdS_2 x S^2$ background in 4D SUGRA

↓ Kick! Turn on Temperature

Near-AdS_2 background

STRATEGY


AdS$_2$xS^2 background in 4D SUGRA
Kick! Turn on Temperature
Near-AdS$_2$ background
Focus on non-universal aspects
Spectrum Operators
Interactions

BASED ON

Work with Evita Verheijden [2110.04208]

Related work that incorporates rotation:

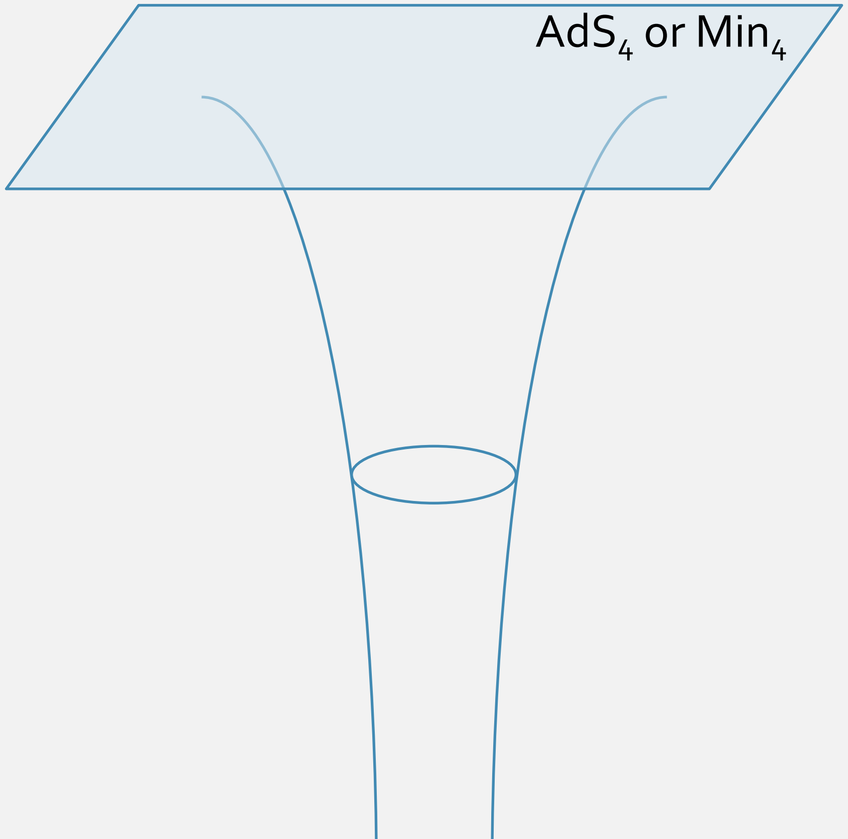
w Juan Pedraza, Chiara Toldo, Evita Verheijden [2106.00649]
w Victor Godet, Joan Simon, Wei Song, Boyang Yu [2102.08060]
w Finn Larsen, Ioannis Papadimitriou [1807.06988]

UNIVERSAL ASPECTS

Shared features among black holes

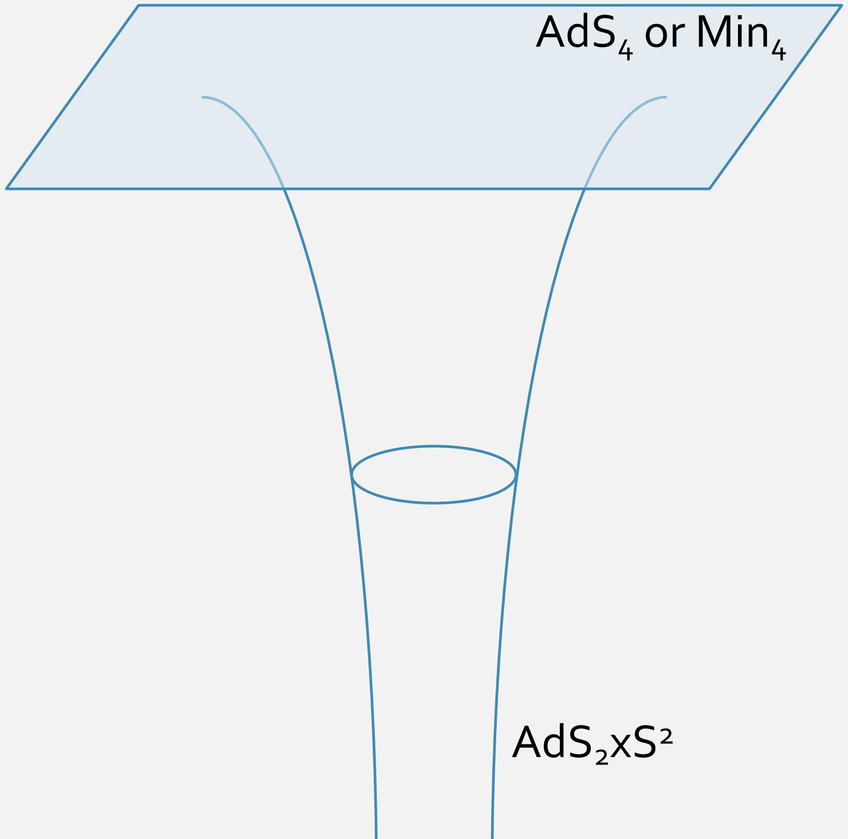
BLACK HOLES IN 4D

- Backgrounds in N=2 D=4 $U(1)^4$ SUGRA
  - Gauged theory ($g \neq 0$) truncation of SO(8)
  - Ungauged theory ($g = 0$) STU theory



BLACK HOLES IN 4D

- Backgrounds in N=2 D=4 $U(1)^4$ SUGRA
  - Gauged theory $(g \neq 0)$ truncation of SO(8)
  - Ungauged theory $(g = 0)$ STU theory
- Supported by four gauge fields F^I: dyonic solutions
- Moduli: three scalars φ_i, three axions χ_i
- Extremal limit $(T = 0)$:
  - Near Horizon Region: $AdS_2 x S^2$
  - Attractor Mechanism for moduli



HOW DO BLACK HOLES HEAT UP?

AdS_2 is fragile, but we have control if we kick the black hole away from extremality.
This defines near-AdS_2.

$$ds^2 = g_{ab}dx^a dx^b + \Phi(x)^2\, d\Omega_2^2$$

$$ds^2 = g_{ab}^0 dx^a dx^b + (\Phi_0^2 + Y(x))\, d\Omega_2^2$$

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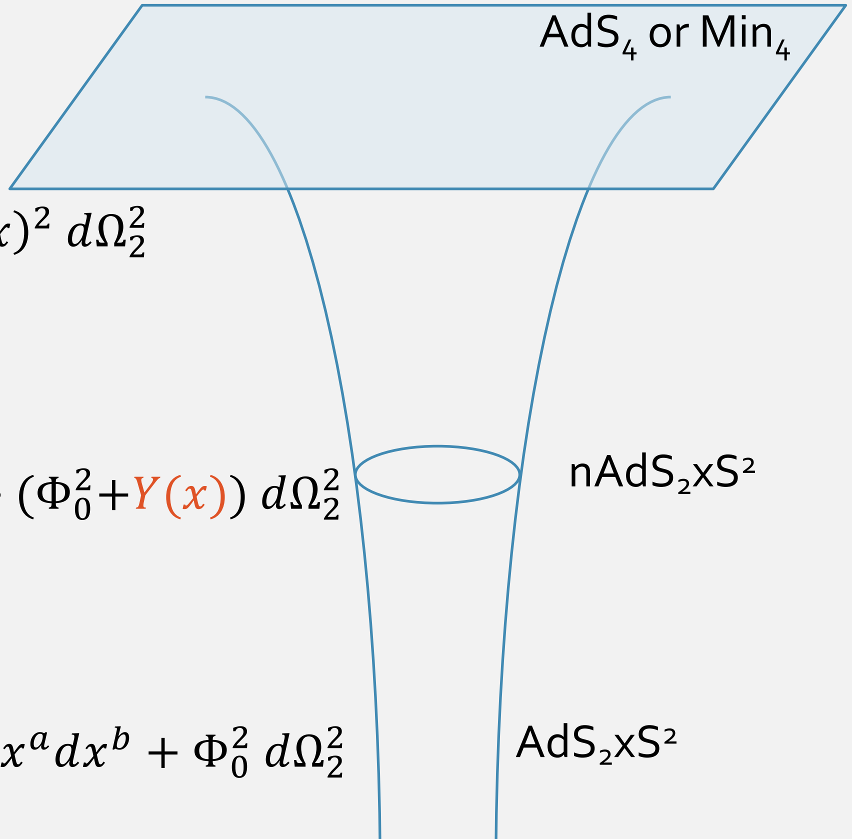

[Almheiri & Polchinski; Maldacena, Stanford & Yang]

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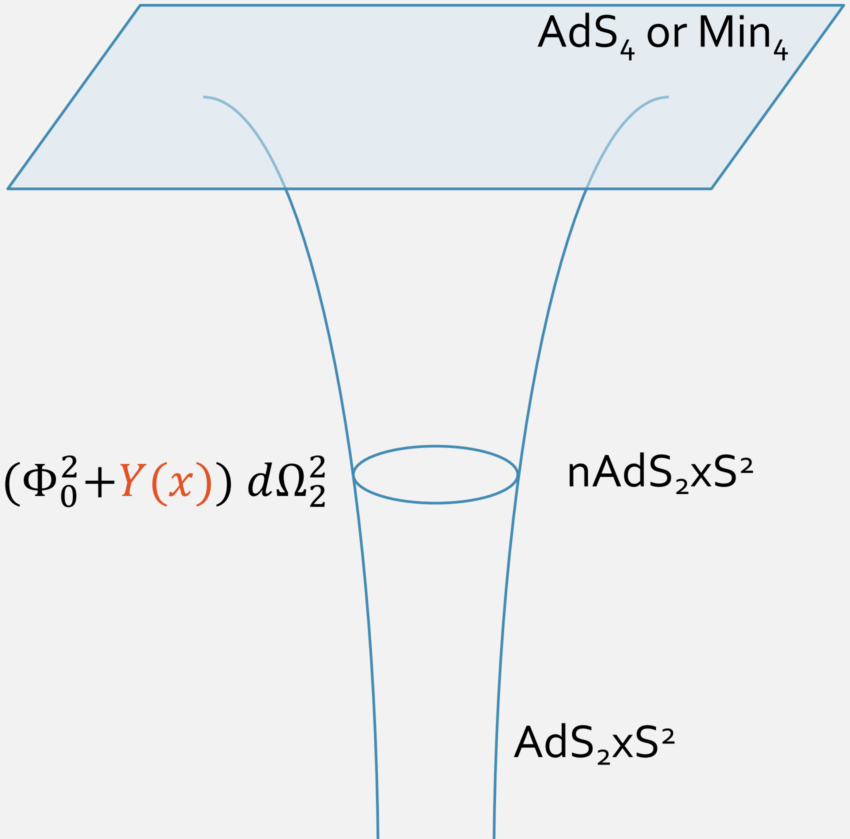

[Almheiri & Polchinski; Maldacena, Stanford & Yang]

HOW DO BLACK HOLES HEAT UP?

Jackiw-Teitelboim (JT) Gravity

$$I_{2D} = \int d^2x \ Y(x)(\ R + 2) + \cdots$$

$$\nabla_a \nabla_b Y - g_{ab} \nabla^2 Y + \frac{1}{\ell^2} g_{ab} Y = 0$$

$$\boxed{\Delta_Y = 2}$$

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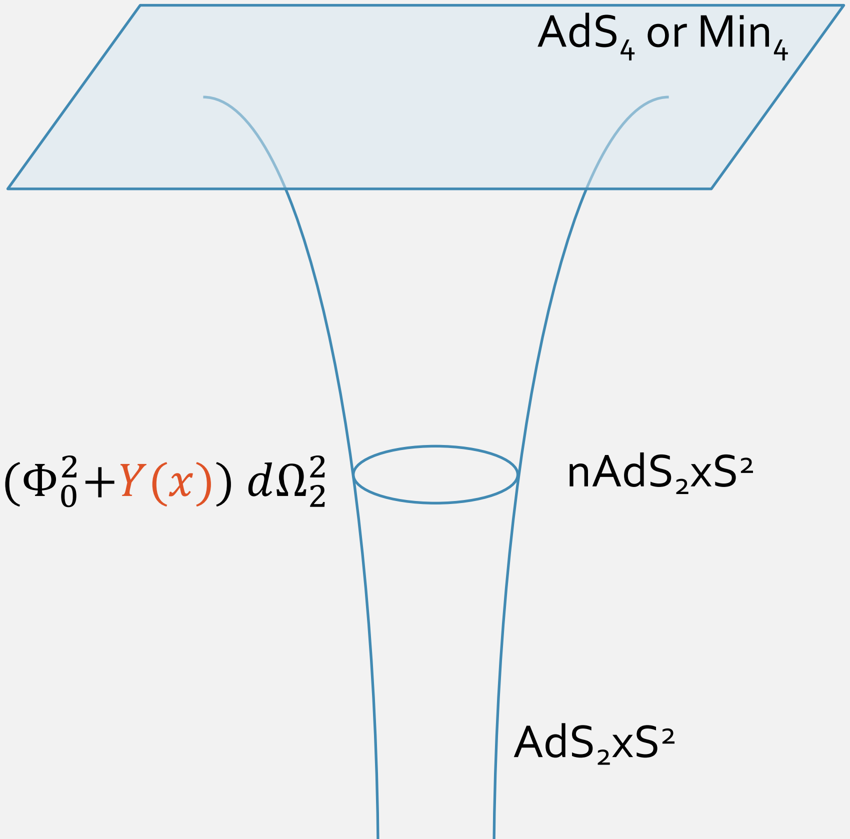

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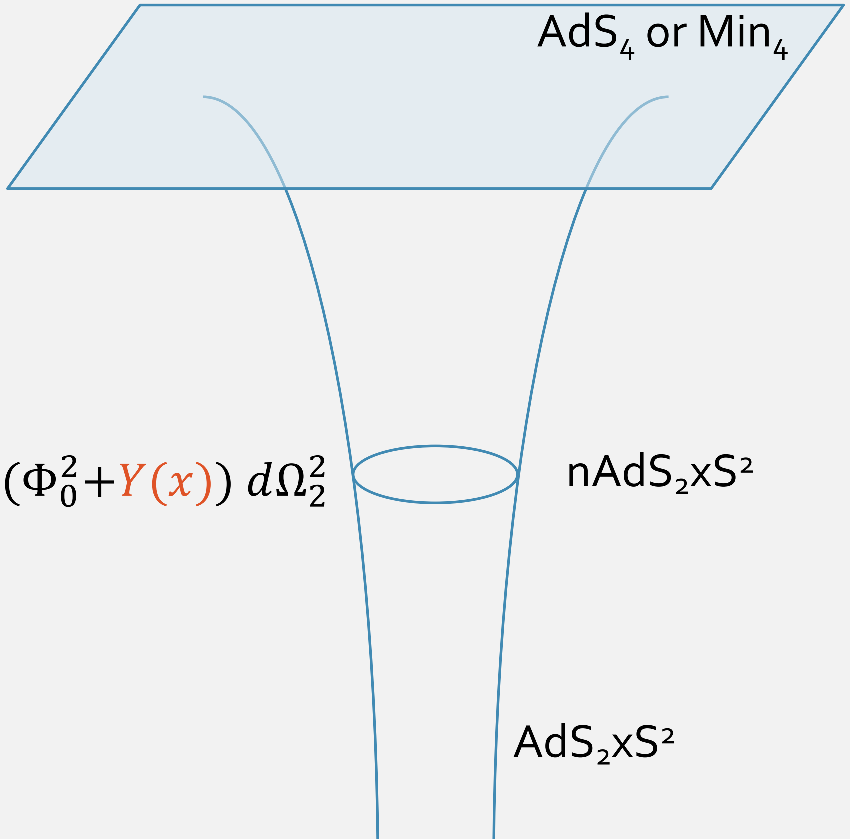
Universality in this deformation:

- Goldstone modes described by a Schwarzian effective action.
- Heat capacity near extremality (Mass gap).
- Dual theory: SYK model captures many aspects.

$$ds^2 = g^0_{ab} dx^a dx^b + (\Phi_0^2 + Y(x))\, d\Omega_2^2$$



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Initial work Reissner-Nordström black hole:
Einstein-Maxwell theory

[Almheiri & Kang; Nayak, Shukla, Soni, Trivedi & Vishal]

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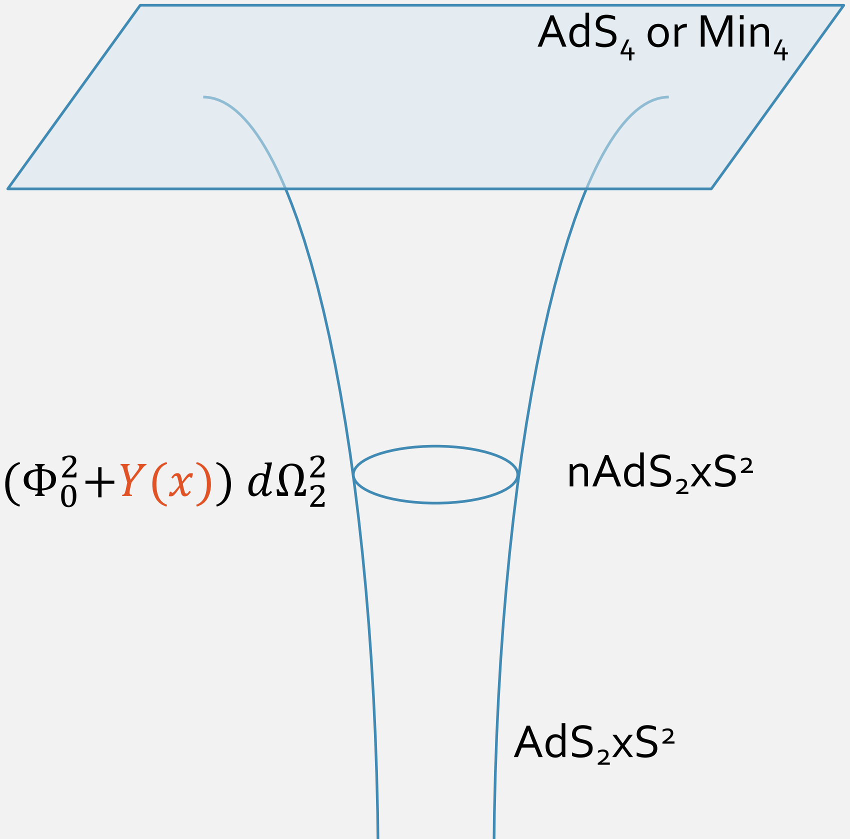

NON-UNIVERSAL ASPECTS

Spectrum and Interactions in the near-AdS_2 region

DO ALL BLACK HOLES REACT EQUALLY?

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!!!!

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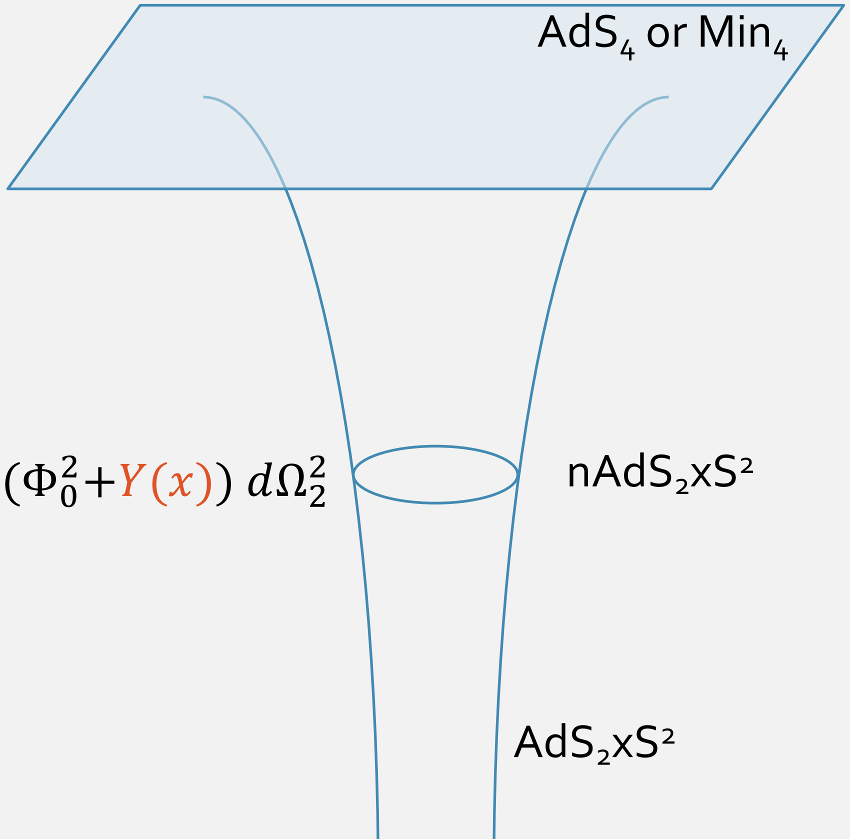

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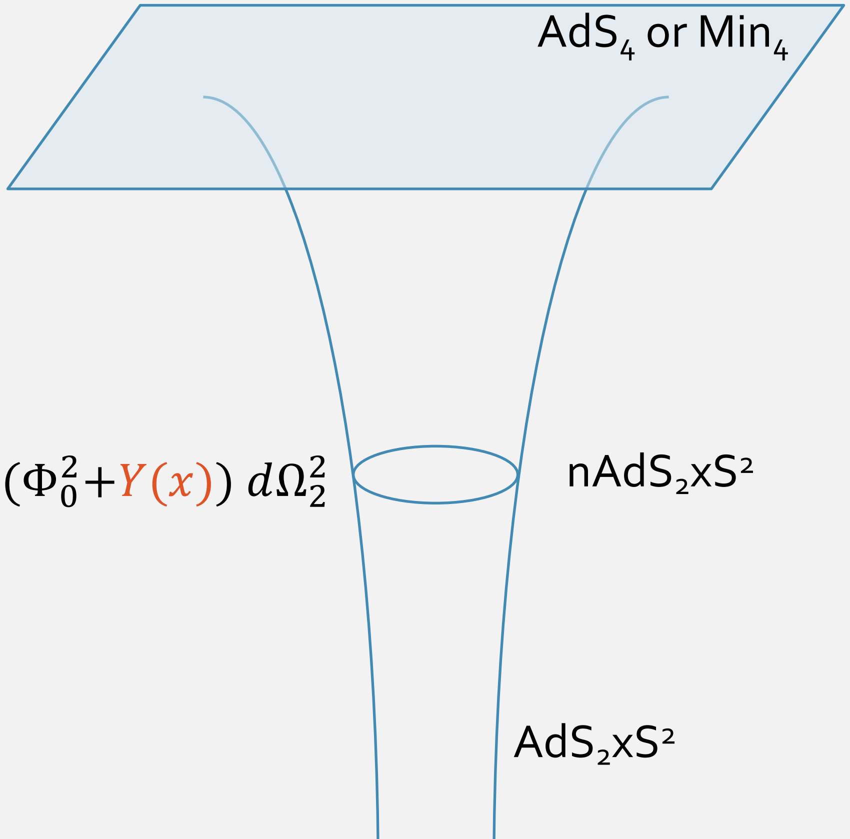


SPECTRUM

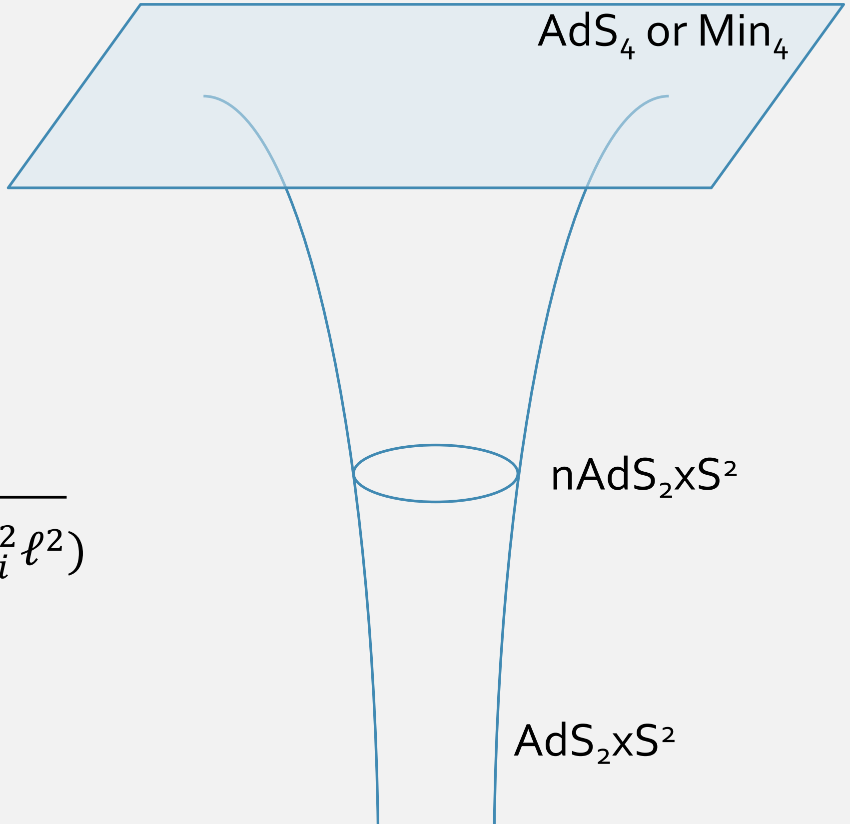
$$ds^2 = (g^0_{ab}+h_{ab})dx^a dx^b + (\Phi_0^2+Y(x))\, d\Omega_2^2$$

$$\varphi_i = \varphi_i^0 + \widehat{\varphi_i}$$

$$\chi_i = \chi_i^0 + \widehat{\chi_i}$$

At linear level:

- Decouple $Y(x)$ and h_{ab} from matter degrees of freedom
- Report on conformal dimensions matter sector: $\mathcal{O}_i,\ \Delta_i = \frac{1}{2}(1+\sqrt{1+4m_i^2\ell^2})$



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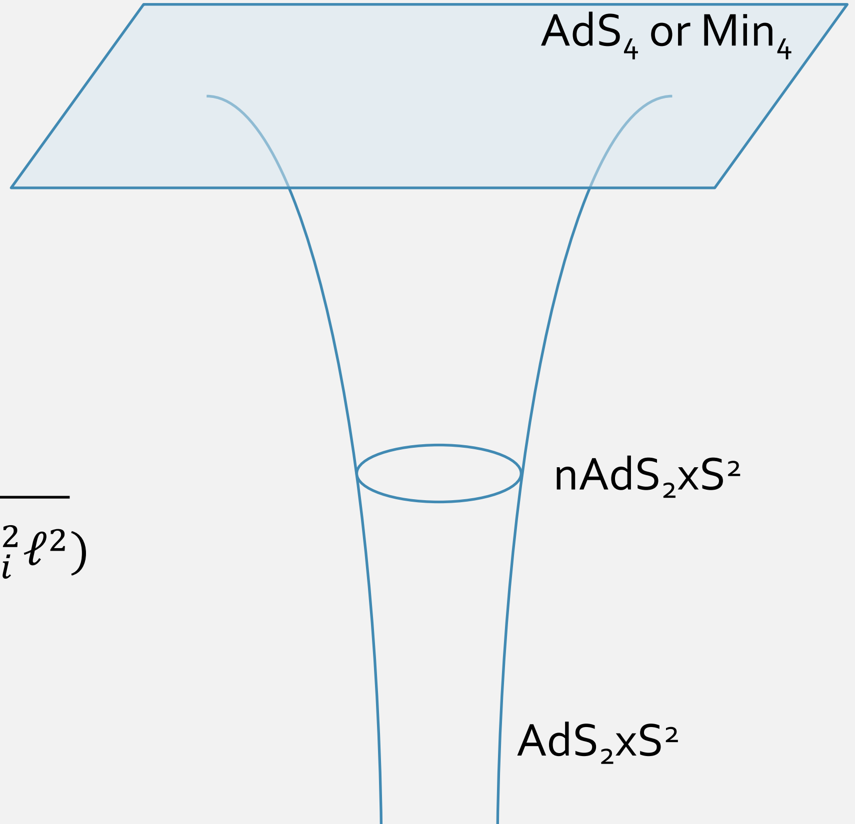

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Spoiler alert: surprises here already!

INTERACTIONS

$$ds^2 = (g^0_{ab} + h_{ab})dx^a dx^b + (\Phi_0^2 + Y(x))\, d\Omega_2^2$$

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INTERACTIONS

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$$I_{eff} = \int d^2x \; (\mathcal{L}_{free} + \mathcal{L}_{int})$$

$$\mathcal{L}_{free} = \frac{1}{2}\partial_a \zeta_i \partial^a \zeta_i + \frac{1}{2} m_i^2 \zeta_i \zeta_i$$

$$\mathcal{L}_{int} = \lambda_{Y\partial\zeta\partial\zeta} Y \partial_a \zeta_i \partial^a \zeta_i + \lambda_{Y\zeta\zeta} Y \zeta_i \zeta_i + \lambda_{\partial Y\zeta\partial\zeta} \partial_a Y \zeta_i \partial^a \zeta_i$$

Note: The fields ζ_i are the orthogonal degrees of freedom coming from $\widehat{\varphi_i}$ and $\widehat{\chi_i}$

INTERACTIONS

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We will report on

$$\langle\mathcal{O}_\zeta(u_1)\mathcal{O}_\zeta(u_2)\rangle = \langle\mathcal{O}_\zeta(u_1)\mathcal{O}_\zeta(u_2)\rangle_{free}\left(1 + a\,\widehat{D}\,\frac{\beta}{2\pi^2}\left(2+\pi\,\frac{1-\frac{u_{12}}{\beta}}{\tan(\frac{\pi u_{12}}{\beta})}\right)\right)$$

INTERACTIONS

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$Y(x) = \frac{a}{z} + \cdots$ source of the deformation in $nAdS_2$

BLACK HOLE ZOO

Towards our Periodic Table

	Ungauged ($g = 0$)	Gauged ($g \neq 0$)
BPS		
Non-BPS		

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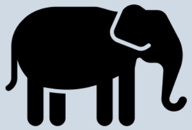
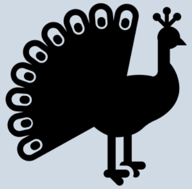
BPS		
Non-BPS		

UNGAUGED & BPS

- Taking away from extremality supersymmetric black holes in STU models.
- Simplest case:

$$ds^2 = (g^0_{ab}+h_{ab})dx^a dx^b + (\Phi_0^2+Y(x))\, d\Omega_2^2$$

$$\left.\begin{aligned} \varphi_i &= \varphi_i^0 + \widehat{\varphi_i} \\ \chi_i &= \chi_i^0 + \widehat{\chi_i} \end{aligned}\right\}$$

All states ζ_i correspond to operators $\mathcal{O}_i$ with $\Delta_i = 2$. Recall $\Delta_Y = 2$.

nAttractor [Larsen 2018]

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nAttractor [Larsen 2018]

- Interactions very simple

$$\langle \mathcal{O}_\zeta(u_1)\mathcal{O}_\zeta(u_2)\rangle = \langle \mathcal{O}_\zeta(u_1)\mathcal{O}_\zeta(u_2)\rangle_{free}\left(1 + a\,\widehat{D}\,\frac{\beta}{2\pi^2}\left(2 + \pi\,\frac{1 - \frac{u_{12}}{\beta}}{\tan(\frac{\pi u_{12}}{\beta})}\right)\right)$$

$$\widehat{D} = \frac{3}{\ell_2^2}$$

UNGAUGED & NON-BPS

- Taking away from extremality non-susy black holes in STU models.
- Sneaky features :

$$ds^2 = (g^0_{ab} + h_{ab})dx^a dx^b + (\Phi_0^2 + Y(x))\, d\Omega_2^2$$

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$$\chi_i = \chi_i^0 + \widehat{\chi_i}$$

Δ_i	$\mathcal{O}_i$
1	2 states
2	3 states
3	1 state

→ Marginal deformations! Flat directions in the attractor mechanism.

UNGAUGED & NON-BPS

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Δ_i	$\mathcal{O}_i$	$\widehat{D}$
1	2 states	Extremal !!!! ∞
2	3 states	$\frac{3}{\ell_2^2}$
3	1 state	$\frac{21}{4\ell_2^2}$

$Y \zeta_i \zeta_i$

$\Delta_Y = \Delta_1 + \Delta_1$

Other ext:

$\Delta_3 = \Delta_1 + \Delta_2$

$\Delta_2 = \Delta_1 + \Delta_1$

vanish. coupling

GAUGED

- One general feature for BHs in AdS_D

$$ds^2 = (g^0_{ab} + h_{ab})dx^a dx^b + (\Phi_0^2 + Y(x))\, d\Omega_2^2$$

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GAUGED

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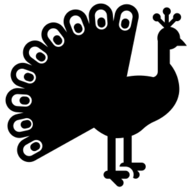
$$\varphi_i = \varphi_i^0 + \widehat{\varphi_i} = \varphi_i^0 + a_{\varphi,i}\, Y + b_i\, \zeta_i$$

$$\chi_i = \chi_i^0 + \widehat{\chi_i} = \varphi_i^0 + \underbrace{a_{\chi,i}\, Y}\, + c_i\, \zeta_i$$

$$h_{ab} = \hat{h}_{ab} + \underbrace{a_i\, \zeta_i}$$

Inhomogenous solutions. Leftover of nAttractor

GAUGED BPS



- Adding temperature to supersymmetric black holes [Cacciatori & Klemm; Benini, Hristov, Zaffaroni]
- Focus on magnetic cases

Δ_i	$\mathcal{O}_i$
$0 < \Delta_\pm < 1$	2 states
$1 < \Delta < \frac{3}{2}$	1 states
$\frac{3}{2} < \Delta < 2$	2 states
$\Delta > 2$	1 state

GAUGED BPS

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More important than JT sector!!!

GAUGED NON-BPS

- Adding temperature to non-susy black holes
- Focus on magnetic cases

Δ_i	$\mathcal{O}_i$
$\Delta_\pm < 1$	2 states
$\frac{3}{2} < \Delta < 2$	3 states
$\Delta > 2$	1 state

} Violations to BF bound!!!

[AdS/CMT literature]

BIG SUMMARY

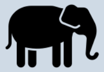
			Spectrum		Interactions
		(Q_I, P^I)	Δ	**Eigenstates**	$\langle \mathfrak{z}\mathfrak{z} \rangle = \langle \mathfrak{z}\mathfrak{z} \rangle_{\text{free}} (1 + \hat{D}(...))$
ungauged	BPS	$Q_I \neq 0$, $P_I \neq 0$	$\Delta_3 = 2$	$\vec{\mathfrak{z}} = (\boldsymbol{\varphi}_i, \boldsymbol{\chi}_i)$	$\hat{D}_3 = \frac{3}{\ell_2^2}$
	non-BPS	(4.9), 7 independent parameters	$\Delta_1 = 1$	$\mathfrak{z}_1 = \boldsymbol{\chi}_1 + \boldsymbol{\chi}_3$ $\mathfrak{z}_2 = c_1\boldsymbol{\varphi}_2 + \boldsymbol{\chi}_1 + c_2\boldsymbol{\chi}_2$	$\hat{D}_1$ undetermined
			$\Delta_2 = 2$	$\mathfrak{z}_3 = \boldsymbol{\varphi}_1$ $\mathfrak{z}_4 = \boldsymbol{\varphi}_3$ $\mathfrak{z}_5 = c_3\boldsymbol{\varphi}_2 + c_4\boldsymbol{\chi}_2$	$\hat{D}_2 = \frac{3}{\ell_2^2}$
			$\Delta_3 = 3$	$\mathfrak{z}_6 = c_1\boldsymbol{\varphi}_2 - \boldsymbol{\chi}_1 + c_2\boldsymbol{\chi}_2 + \boldsymbol{\chi}_3$	$\hat{D}_3 = \frac{21}{4\ell_2^2}$
gauged	BPS	Magnetic, $\mathfrak{n}_1 = 2 - 3\mathfrak{n}_4$ $\mathfrak{n}_2 = \mathfrak{n}_3 = \mathfrak{n}_4$	$0.35 < \Delta_1^- < 0.42$, $0.58 < \Delta_1^+ < 0.65$	$\mathfrak{z}_1 = -\boldsymbol{\chi}_1 + \boldsymbol{\chi}_3$ $\mathfrak{z}_2 = -\boldsymbol{\chi}_1 + 2\boldsymbol{\chi}_2 - \boldsymbol{\chi}_3$	$10.3\,g^2 < \hat{D}_1^- < 12.4\,g^2$, $14.1\,g^2 < \hat{D}_1^+ < 23.5\,g^2$
			$1.15 < \Delta_2 < 1.31$	$\mathfrak{z}_3 = \boldsymbol{\varphi}_1 + \boldsymbol{\varphi}_2 + \boldsymbol{\varphi}_3$	$-19.7\,g^2 < \hat{D}_2 < -4.49\,g^2$
			$1.57 < \Delta_3 < 1.65$	$\mathfrak{z}_4 = -\boldsymbol{\varphi}_1 + \boldsymbol{\varphi}_3$ $\mathfrak{z}_5 = -\boldsymbol{\varphi}_1 + 2\boldsymbol{\varphi}_2 - \boldsymbol{\varphi}_3$	$25.3\,g^2 < \hat{D}_3 < 34.1\,g^2$
			$2.15 < \Delta_4 < 2.31$	$\mathfrak{z}_6 = \boldsymbol{\chi}_1 + \boldsymbol{\chi}_2 + \boldsymbol{\chi}_3$	$35.4\,g^2 < \hat{D}_4 < 48.7\,g^2$
	non-BPS	Magnetic, $P^1 = P^2 = P^3$ $P^4 = P^1$	$1.46 < \Delta_3 \leq 2$	$\vec{\mathfrak{z}} = (\boldsymbol{\varphi}_i, \boldsymbol{\chi}_i)$	$2.19 < \ell_2^2 \hat{D}_3 \leq 3$
		Magnetic, $P^1 = P^2 = P^3$ $P^4 = -P^1$	$\Delta_1^* \leq 1$	$\mathfrak{z}_1 = -\boldsymbol{\chi}_1 + \boldsymbol{\chi}_3$ $\mathfrak{z}_2 = -\boldsymbol{\chi}_1 + 2\boldsymbol{\chi}_2 - \boldsymbol{\chi}_3$	$\hat{D}_1 > 0$
			$1.46 < \Delta_\varphi \leq 2$	$\mathfrak{z}_{i+2} = \boldsymbol{\varphi}_i,\; i = 1, 2, 3$	$2.19 < \ell_2^2 \hat{D}_\varphi \leq 3$
			$2.2 < \Delta_4 \leq 3$	$\mathfrak{z}_6 = \boldsymbol{\chi}_1 + \boldsymbol{\chi}_2 + \boldsymbol{\chi}_3$	$3.93 < \ell_2^2 \hat{D}_4 \leq \frac{21}{4}$
		Dyonic, $P^1 = \pm Q_1$ $P^{I \neq 1} = 0$ $Q_{I \neq 1} = 0$	$\Delta_1^* \leq 1$	$\mathfrak{z}_4 = \boldsymbol{\varphi}_1 + \boldsymbol{\varphi}_3$ $\mathfrak{z}_5 = \boldsymbol{\varphi}_1 + 2\boldsymbol{\varphi}_2 - \boldsymbol{\varphi}_3$	$\hat{D}_1 > 0$
			$1.46 < \Delta_\chi \leq 2$	$\mathfrak{z}_i = \boldsymbol{\chi}_i,\; i = 1, 2, 3$	$2.19 < \ell_2^2 \hat{D}_\chi \leq 3$
			$2.2 < \Delta_2 \leq 3$	$\mathfrak{z}_6 = -\boldsymbol{\varphi}_1 + \boldsymbol{\varphi}_2 + \boldsymbol{\varphi}_3$	$3.93 < \ell_2^2 \hat{D}_2 \leq \frac{21}{4}$

OUTLOOK

Lessons and Future Directions

LESSONS

- Supersymmetry is key
- Gauged versus Ungauged
- Flavors of operators: relevant, marginal, irrelevant
- Expected and unexpected pathologies
- Not easy to reproduce $\hat{D}$. SYK-like models are too simple.

	Ungauged $(g = 0)$	Gauged $(g \neq 0)$
BPS		
Non-BPS		

FUTURE DIRECTIONS

- From UV to IR : connect $nAdS_2$ analysis with our understanding in AdS_4 and known brane constructions.
- Quantum corrections and spectrum near extremality: gap versus no gap, log corrections.
  [Iliesiu, Turiaci; Heydeman, Iliesiu, Turiaci, Zhao; Castro, Godet, Larsen, Zeng]
- More animals in the zoo: rotation, topology, additional charges, higher dimensions.
- Integrability conditions in AdS_4: not every non-extremal BH is consistent.
  [Lu, Pang, Pope; Compere, Chow]

THANK YOU!