Subleading Corrections to AdS Black Hole Entropy

Marina David

University of Michigan

GR23
5 July 2022

based on
2112.09444 MD, Godet, Liu, Pando Zayas
2106.09730 MD, González Lezcano, Nian, Pando Zayas

Outline

- Introduction and Motivation
- Approaches to Black Hole Entropy
- Gravity - Entropy Corrections in AdS_4
- Concluding Remarks

Introduction

1. microscopic and macroscopic understanding of entropy for black holes in flat and AdS spacetimes

Introduction

1. microscopic and macroscopic understanding of entropy for black holes in flat and AdS spacetimes
   - Bekenstein-Hawking

$$S_{\mathsf{BH}} = \frac{A}{4G}$$

   - Is there a microscopic origin of black hole entropy?

$$S_{\mathsf{BH}} = k_{\mathsf{B}} \log \Omega$$

   - Asymptotically flat black holes [9601029 Strominger, Vafa]

Introduction

1. microscopic and macroscopic understanding of entropy for black holes in flat and AdS spacetimes
   - Bekenstein-Hawking

$$S_{\mathsf{BH}} = \frac{A}{4G}$$

   - Is there a microscopic origin of black hole entropy?

$$S_{\mathsf{BH}} = k_{\mathsf{B}} \log \Omega$$

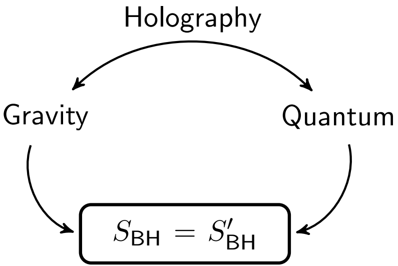
   - Asymptotically flat black holes [9601029 Strominger, Vafa]
   - Asymptotically AdS black holes [1511.04085 Benini, Hristov, Zaffaroni]

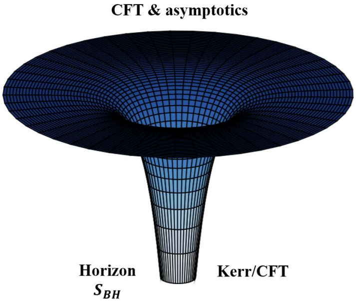
Introduction

2. holography and connection to field theories (AdS/CFT, Kerr/CFT)
   [9711200 Maldacena], [0809.4266 Guica, Hartman, Song, Strominger]

Introduction

2. holography and connection to field theories (AdS/CFT, Kerr/CFT)
   [9711200 Maldacena], [0809.4266 Guica, Hartman, Song, Strominger]





- AdS/CFT $\rightarrow$ counting microstates in the dual field theory
- near-horizon geometry: practical and technical advantages

Motivation

- How much can we uncover about the black hole without the full UV description?
  - What part of the full quantum entropy can be recovered?
  - What can we learn from the horizon? Is the near-horizon enough?

Motivation

- How much can we uncover about the black hole without the full UV description?
  - What part of the full quantum entropy can be recovered?
  - What can we learn from the horizon? Is the near-horizon enough?
- Understanding the Bekenstein Hawking formula at sub-leading order
  - exploring logarithmic corrections in AdS
  - topological/universality of black hole entropy at subleading order and its origin
  - role of supersymmetry in universality

Motivation

- How much can we uncover about the black hole without the full UV description?
  - What part of the full quantum entropy can be recovered?
  - What can we learn from the horizon? Is the near-horizon enough?
- Understanding the Bekenstein Hawking formula at sub-leading order
  - exploring logarithmic corrections in AdS
  - topological/universality of black hole entropy at subleading order and its origin
  - role of supersymmetry in universality
- Flat versus AdS spacetimes
  - AdS fails to be globally hyperbolic
  - in flat spacetimes, degrees of freedom live on the near-horizon

Motivation

- How much can we uncover about the black hole without the full UV description?
  - What part of the full quantum entropy can be recovered?
  - What can we learn from the horizon? Is the near-horizon enough?
- Understanding the Bekenstein Hawking formula at sub-leading order
  - exploring logarithmic corrections in AdS
  - topological/universality of black hole entropy at subleading order and its origin
  - role of supersymmetry in universality
- Flat versus AdS spacetimes
  - AdS fails to be globally hyperbolic
  - in flat spacetimes, degrees of freedom live on the near-horizon
- We answer these questions by
  - studying extremal black holes in 4d and 5d
  - study aspects of entropy corrections

Overview of Main Results

- Kerr-Newman-AdS$_4$

$$\text{Near Horizon} + \text{BPS} \quad \Longleftrightarrow \quad \text{Full Solution} + \text{BPS}$$

Overview of Main Results

- Kerr-Newman-AdS$_4$

$$\text{Near Horizon} + \text{BPS} \quad \Longleftrightarrow \quad \text{Full Solution} + \text{BPS}$$

  - [2112.09444 MD, Godet, Liu, Pando Zayas]
  - near-horizon does indeed contain *some* of the quantum information
  - **non-topological** results contrary to flat black holes and field theory computations

Overview of Main Results

- Kerr-Newman-AdS$_4$

$$\text{Near Horizon} + \text{BPS} \quad \Longleftrightarrow \quad \text{Full Solution} + \text{BPS}$$

  - [2112.09444 MD, Godet, Liu, Pando Zayas]
  - near-horizon does indeed contain *some* of the quantum information
  - **non-topological** results contrary to flat black holes and field theory computations

Highlights - the status of subleading entropy corrections

- asymptotically flat spacetimes
  - [1205.0971, 1109.3706, 1108.3842,...Sen]
  - [1505.01156 Charles, Larsen]
  - [2104.06381 Karan, Panda]

Highlights - the status of subleading entropy corrections

- asymptotically flat spacetimes
  - [1205.0971, 1109.3706, 1108.3842,...Sen]
  - [1505.01156 Charles, Larsen]
  - [2104.06381 Karan, Panda]
- Cardy formula beyond leading order
  - [1612.04833 Pathak, Porfyriadis, Strominger, Varela]
  - [2106.09730 MD, González Lezcano, Nian, Pando Zayas]

Highlights - the status of subleading entropy corrections

- asymptotically flat spacetimes
  - [1205.0971, 1109.3706, 1108.3842,...Sen]
  - [1505.01156 Charles, Larsen]
  - [2104.06381 Karan, Panda]
- Cardy formula beyond leading order
  - [1612.04833 Pathak, Porfyriadis, Strominger, Varela]
  - [2106.09730 MD, González Lezcano, Nian, Pando Zayas]
- asymptotically AdS_4 spacetimes
  - 11d SUGRA:
    - full solution [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
    - near-horizon [1707.04197 Liu, Pando Zayas, Rathee, Zhao]
  - supergravity localization: [2107.12398 Hristov, Reys]
- and more...

One-loop Corrections to the Partition Function

- Einstein-Maxwell-AdS theories
- black hole solution appears as a saddle point of the Euclidean path integral

$$Z\left(\beta,\mu_{\alpha}\right)=\int D\Psi e^{-S_{E}(\Psi)}$$

inverse temperature β, chemical potentials μ^{α}

One-loop Corrections to the Partition Function

- Einstein-Maxwell-AdS theories
- black hole solution appears as a saddle point of the Euclidean path integral

$$Z(\beta, \mu_\alpha) = \int D\Psi e^{-S_E(\Psi)}$$

  inverse temperature β, chemical potentials μ^α
- leading order: $\log Z = -S_E^{\text{classical}}$
- subleading order: vary the fields $\Psi = \{\delta g_{\mu\nu}, \delta A_\mu, \dots\}$

$$Z(\beta, \mu_\alpha) \sim \frac{1}{\sqrt{\det \mathcal{Q}}} e^{-S_E^{\text{classical}}}, \qquad \mathcal{Q} = \frac{\delta^2 S_E}{\delta \Psi^2}$$

One-loop Corrections to the Partition Function

- Einstein-Maxwell-AdS theories
- black hole solution appears as a saddle point of the Euclidean path integral

$$Z\left(\beta, \mu_\alpha\right) = \int D\Psi e^{-S_E(\Psi)}$$

  inverse temperature β, chemical potentials μ^α
- leading order: $\log Z = -S_E^{\text{classical}}$
- subleading order: vary the fields $\Psi = \{\delta g_{\mu\nu}, \delta A_\mu, \dots\}$

$$Z\left(\beta, \mu_\alpha\right) \sim \frac{1}{\sqrt{\det \mathcal{Q}}} e^{-S_E^{\text{classical}}}, \qquad \mathcal{Q} = \frac{\delta^2 S_E}{\delta \Psi^2}$$

- one-loop correction to the black hole entropy

$$\delta S = -\frac{1}{2} \log \det \mathcal{Q}$$

- higher loops do not contribute
- complex solutions ['79 Gibbons Hawking], [2111.06514 Witten]

Methodology

- Subleading corrections to Kerr-Newman AdS_4 black hole entropy via the heat kernel

$$\mathrm{AdS}_4 \xRightarrow[\text{fields}]{\text{expand}} \begin{matrix}\text{Quadratic}\\ \text{Operators}\end{matrix} \xRightarrow[]{\text{heat kernel}} \begin{matrix}\text{logarithmic}\\ \text{corrections}\end{matrix}$$

Methodology

- Subleading corrections to Kerr-Newman AdS_4 black hole entropy via the heat kernel

$$\text{AdS}_4 \xrightarrow[\substack{\text{expand}\\\text{fields}}]{} \substack{\text{Quadratic}\\\text{Operators}} \xrightarrow[\text{heat kernel}]{} \substack{\text{logarithmic}\\\text{corrections}}$$

Subleading Corrections
in AdS_4 Black Holes

General Strategy - The Heat Kernel

- kinetic operator $\mathcal{Q}$

$$\log Z_{\mathsf{nz}} = \log \det{}' \mathcal{Q} = -\frac{1}{2} \sum_n{}' \log \kappa_n,$$

$\kappa_n \neq 0$ are the eigenvalues

General Strategy - The Heat Kernel

- kinetic operator $\mathcal{Q}$

$$\log Z_{\mathsf{nz}} = \log \det{}' \mathcal{Q} = -\frac{1}{2} \sum_n{}' \log \kappa_n ,$$

  $\kappa_n \neq 0$ are the eigenvalues
- heat equation (study of heat distribution at time s)

$$(\partial_s + \mathcal{Q})\, K(s; x, y; \mathcal{Q}) = 0,$$

  with initial and boundary conditions

General Strategy - The Heat Kernel

- kinetic operator $\mathcal{Q}$

$$\log Z_{\mathsf{nz}} = \log \det{}'\mathcal{Q} = -\frac{1}{2}\sum_n{}' \log \kappa_n,$$

  $\kappa_n \neq 0$ are the eigenvalues
- heat equation (study of heat distribution at time s)

$$(\partial_s + \mathcal{Q})\, K(s; x, y; \mathcal{Q}) = 0,$$

  with initial and boundary conditions
- for a flat manifold $\mathcal{M} = \mathbb{R}^D$ and $\bar{\mathcal{Q}} = -\nabla^2 + m^2$

$$K\left(s; x, y; \bar{\mathcal{Q}}\right) = (4\pi s)^{-D/2} \exp\left(-\frac{(x-y)^2}{4s} - sm^2\right)$$

General Strategy - The Heat Kernel

- kinetic operator $\mathcal{Q}$

$$\log Z_{\mathsf{nz}} = \log\det{}'\mathcal{Q} = -\frac{1}{2}\sum_n{}'\log\kappa_n,$$

  $\kappa_n \neq 0$ are the eigenvalues
- heat equation (study of heat distribution at time s)

$$(\partial_s + \mathcal{Q})\, K(s;x,y;\mathcal{Q}) = 0,$$

  with initial and boundary conditions
- for a flat manifold $\mathcal{M} = \mathbb{R}^D$ and $\bar{\mathcal{Q}} = -\nabla^2 + m^2$

$$K\left(s;x,y;\bar{\mathcal{Q}}\right) = (4\pi s)^{-D/2}\exp\left(-\frac{(x-y)^2}{4s} - sm^2\right)$$

- logarithmic term is $D = 2n$ via curvative invariants

$$K(s;x,y;\mathcal{Q}) = K\left(s;x,y;\bar{\mathcal{Q}}\right)\underbrace{\left(1 + s a_2(x,y) + s^2 a_4(x,y) + \ldots\right)}_{a_i \text{ are the Seeley-DeWitt coefficients}}$$

General Strategy - The Heat Kernel

- logarithmic corrections to the entropy computed via the heat kernel

General Strategy - The Heat Kernel

- logarithmic corrections to the entropy computed via the heat kernel
- compute curvature invariants instead of the eigenvalues of the 1-loop operators

General Strategy - The Heat Kernel

- logarithmic corrections to the entropy computed via the heat kernel
- compute curvature invariants instead of the eigenvalues of the 1-loop operators
- each contribution to the logarithmic correction depends on spin

General Strategy - The Heat Kernel

- logarithmic corrections to the entropy computed via the heat kernel
- compute curvature invariants instead of the eigenvalues of the 1-loop operators
- each contribution to the logarithmic correction depends on spin
- both a local and global contribution

General Structure

- Einstein-Maxwell-AdS$_4$ theories

$$(4\pi)^2 \operatorname{Tr} a_4(x) = -a_{\mathrm{E}} E_4 + cW^2 + \underbrace{b_1 R^2 + b_2 R F_{\mu\nu} F^{\mu\nu}}_{\text{vanish in flat spacetimes}}$$

$$E_4 \equiv R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} - 4 R_{\mu\nu} R^{\mu\nu} + R^2$$
$$W^2 \equiv R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma} - 2 R_{\mu\nu} R^{\mu\nu} + \frac{1}{3} R^2$$

	a_E	c	b_1	b_2
Einstein-Maxwell	$\frac{53}{45}$	$\frac{137}{60}$	$-\frac{13}{36}$	0
$\mathcal{N}=2$ gravitini	$-\frac{589}{360}$	$-\frac{137}{60}$	0	$\frac{13}{18}$
$\mathcal{N}=2$ gravity multiplet	$-\frac{11}{24}$	0	$-\frac{13}{36}$	$\frac{13}{18}$

- Goal: compute entropy correction of Kerr-Newman-AdS for **(1)** non-extremal full solution **(2)** extremal/BPS for full and NH

Kerr-Newman-AdS$_4$ Black Hole

- has a regular BPS limit unlike the Reissner-Nordstrom counterpart
- Carter, 1968, Plebanski, Demianski, 1976, Caldarelli, Cognola, Klemm 9908022

$$
\begin{aligned}
ds^2 = -\frac{\Delta_r}{\rho^2}\left(dt - \frac{a\sin^2\theta}{\Xi}d\phi\right)^2 + \frac{\rho^2 dr^2}{\Delta_r} + \frac{\rho^2 d\theta^2}{\Delta_\theta} \\
+ \frac{\Delta_\theta \sin^2\theta}{\rho^2}\left(adt - \frac{r^2+a^2}{\Xi}d\phi\right)^2
\end{aligned}
$$

$$
A = -\frac{q_e r}{\rho^2}\left(dt - \frac{a\sin^2\theta}{\Xi}d\phi\right) - \frac{q_m\cos\theta}{\rho^2}\left(adt - \frac{r^2+a^2}{\Xi}d\phi\right)
$$

- parameter space: (m, a, q_e, q_m), $a^2 < \ell^2$
- $G_N = 1$
- physical mass and charges scale with Ξ
- 4 independent physical quantities: (T_H, J, Q_e, Q_m)

The Extremal Limit

- thermal circle is infinite making the Euclidean on-shell action divergent

The Extremal Limit

- thermal circle is infinite making the Euclidean on-shell action divergent
- careful limiting procedure for $\beta \to \infty$

The Extremal Limit

- thermal circle is infinite making the Euclidean on-shell action divergent
- careful limiting procedure for $\beta \to \infty$
- $\beta \to \infty$ while fixing the charges, then imposing the extremal values of the charges

The Extremal Limit

- thermal circle is infinite making the Euclidean on-shell action divergent
- careful limiting procedure for $\beta \to \infty$
- $\beta \to \infty$ while fixing the charges, then imposing the extremal values of the charges

$$r_+ = r_0 + \frac{2\pi \ell_2^2}{\beta} + O\left(\beta^{-2}\right)$$

$$r_0^2 = \frac{1}{6}\ell\left(\sqrt{\ell^2 + 12q^2} - \ell\right), \quad \ell_2^2 = \frac{r_0^2}{1 + \frac{6r_0^2}{\ell^2}}$$

- in the extremal limit:

$$\int d^4x \sqrt{g} a_4(x) = \underbrace{C_1 \beta}_{\text{Casimir}} + C_0 + O\left(\beta^{-1}\right)$$

$C_1 \beta$ is the shift of the ground state energy

Near Horizon Geometry

- Near-horizon geometry, [9905099 Bardeen, Horowitz] with co-rotating frame

$$r \to r_0 + \epsilon\,\widetilde{r}\,, \quad t \to \frac{\widetilde{t}}{\epsilon}\,, \quad \underbrace{\phi \to \widetilde{\phi} + \frac{\widetilde{t}}{\epsilon}}_{\text{nonzero rotation}}\,, \quad \epsilon \to 0$$

Near Horizon Geometry

- Near-horizon geometry, [9905099 Bardeen, Horowitz] with co-rotating frame

$$r \to r_0 + \epsilon\,\widetilde{r}\,, \quad t \to \frac{\widetilde{t}}{\epsilon}\,, \quad \underbrace{\phi \to \widetilde{\phi} + \frac{\widetilde{t}}{\epsilon}}_{\text{nonzero rotation}}\,, \quad \epsilon \to 0$$

- near horizon extremal Kerr (NHEK)

Near Horizon Geometry

- Near-horizon geometry, [9905099 Bardeen, Horowitz] with co-rotating frame

$$r \to r_0 + \epsilon\,\widetilde{r}\,, \quad t \to \frac{\widetilde{t}}{\epsilon}\,, \quad \underbrace{\phi \to \widetilde{\phi} + \frac{\widetilde{t}}{\epsilon}}_{\text{nonzero rotation}}\,, \quad \epsilon \to 0$$

- near horizon extremal Kerr (NHEK)

$$\begin{aligned} d\tilde{s}^2 = &\frac{\ell_2^2\left(r_0^2 + a^2\cos^2\theta\right)}{a^2 + r_0^2} ds^2_{\mathsf{AdS}_2} + \frac{\ell^2\left(r_0^2 + a^2\cos^2\theta\right)}{\ell^2 - a^2\cos^2\theta} d\theta^2 \\ &+ \frac{\ell^2\left(a^2 + r_0^2\right)^2\left(\ell^2 - a^2\cos^2\theta\right)\sin^2\theta}{\left(\ell^2 - a^2\right)^2\left(r_0^2 + a^2\cos^2\theta\right)}\left(d\phi - \frac{2\ell_2^2 a r_0\left(\ell^2 - a^2\right)}{\ell^2\left(a^2 + r_0^2\right)^2} i\widetilde{r}d\widetilde{t}\right)^2, \end{aligned}$$

- parameter space reduced
- matches the previous result of C_{local}!

Kerr-Newman-AdS$_4$ C_{local}

- extremal (full or near-horizon):

$$
\begin{aligned}
C_{\text{local}} = -4a_{\text{E}} + \frac{1}{2ar_0^5\left(\ell^2-a^2\right)\left(a^2+r_0^2\right)\left(a^2+\ell^2+6r_0^2\right)} \Big[& -3a^7 r_0 \left(16b_1 r_0^4 + c\left(\ell^2-r_0^2\right)^2\right) \\
& + a^5 r_0^3 \left(c\ell^4 + 2\left(11c-12b_2\right)\ell^2 r_0^2 - 3\left(13c-8b_2+80b_1\right) r_0^4\right) \\
& + a^3 r_0^5 \left(15c\ell^4 + 2\left(25c+24b_2\right)\ell^2 r_0^2 - \left(49c+336b_1-48b_2\right) r_0^4 - 48b_2\ell^2 q_m^2\right) \\
& + 3ar_0^7 \left(c\ell^4 + 2\left(3c-4b_2\right)\ell^2 r_0^2 - \left(7c+48b_1+24b_2\right) r_0^4 + 16b_2\ell^2 q_m^2\right) \\
& -3c\left(a^2+r_0^2\right)\left(a^2\left(r_0^2-\ell^2\right)+r_0^2\left(\ell^2+3r_0^2\right)\right)^2 \arctan\left(a/r_0\right)\Big]
\end{aligned}
$$

Kerr-Newman-AdS$_4$ C_{local}

- extremal (full or near-horizon):

$$C_{\text{local}} = -4a_{\text{E}} + \frac{1}{2ar_0^5\left(\ell^2 - a^2\right)\left(a^2 + r_0^2\right)\left(a^2 + \ell^2 + 6r_0^2\right)}\left[-3a^7 r_0\left(16b_1 r_0^4 + c\left(\ell^2 - r_0^2\right)^2\right)\right.$$
$$+ a^5 r_0^3\left(c\ell^4 + 2\left(11c - 12b_2\right)\ell^2 r_0^2 - 3\left(13c - 8b_2 + 80b_1\right)r_0^4\right)$$
$$+ a^3 r_0^5\left(15c\ell^4 + 2\left(25c + 24b_2\right)\ell^2 r_0^2 - \left(49c + 336b_1 - 48b_2\right)r_0^4 - 48b_2\ell^2 q_m^2\right)$$
$$+ 3ar_0^7\left(c\ell^4 + 2\left(3c - 4b_2\right)\ell^2 r_0^2 - \left(7c + 48b_1 + 24b_2\right)r_0^4 + 16b_2\ell^2 q_m^2\right)$$
$$\left.-3c\left(a^2 + r_0^2\right)\left(a^2\left(r_0^2 - \ell^2\right) + r_0^2\left(\ell^2 + 3r_0^2\right)\right)^2 \arctan\left(a/r_0\right)\right]$$

- BPS conditions and BPS bound

$$r_0 = \sqrt{a\ell}, \qquad q_m = 0, \qquad M = Q_e + \frac{J}{\ell}$$

$$C_{\text{local}} = -4a_{\text{E}} + \frac{3\ell_2^2}{2a\ell^2\left(\ell^2 - a^2\right)}\left[\left(9c - 8b_2\right)a\ell^2 - \left(9c + 48b_1 - 8b_2\right)a^2\ell\right.$$
$$\left.- \left(c + 16b_1\right)a^3 + c\ell^3 - \frac{c(a+\ell)^4}{\sqrt{al}}\arctan(\sqrt{a/\ell})\right]$$

Kerr-Newman-AdS$_4$ BPS Curvature Invariants

- minimal $\mathcal{N} = 4$ gauged supergravity

$$\mathcal{L}_b = R - 2\Lambda - F_{\mu\nu}F^{\mu\nu}$$
$$\mathcal{L}_f = \frac{1}{2}\bar{\psi}_\mu \gamma^{\mu\nu\rho} D_\nu \psi_\rho + \frac{i}{4} F^{\mu\nu} \bar{\psi}_\rho \gamma_\mu \gamma^{\rho\sigma} \gamma_\nu \psi_\sigma - \frac{1}{2\ell} \bar{\psi}_\mu \gamma^{\mu\nu} \psi_\nu$$

- logarithmic correction is *non-topological*

$$C_{\text{local}} = \frac{11}{6} - \frac{26}{3} \frac{a\left(\ell^2 - 4a\ell - a^2\right)}{(\ell - a)\left(a^2 + 6a\ell + \ell^2\right)}$$

Kerr-Newman-AdS$_4$ BPS Curvature Invariants

- minimal $\mathcal{N}=4$ gauged supergravity

$$\mathcal{L}_b = R - 2\Lambda - F_{\mu\nu}F^{\mu\nu}$$
$$\mathcal{L}_f = \frac{1}{2}\bar{\psi}_\mu \gamma^{\mu\nu\rho} D_\nu \psi_\rho + \frac{i}{4} F^{\mu\nu} \bar{\psi}_\rho \gamma_\mu \gamma^{\rho\sigma} \gamma_\nu \psi_\sigma - \frac{1}{2\ell} \bar{\psi}_\mu \gamma^{\mu\nu} \psi_\nu$$

- logarithmic correction is *non-topological*

$$C_{\text{local}} = \frac{11}{6} - \frac{26}{3} \frac{a\left(\ell^2 - 4a\ell - a^2\right)}{(\ell - a)\left(a^2 + 6a\ell + \ell^2\right)}$$

- role of SUSY in topological corrections
  - SUSY ensures c cancels in flat and AdS spacetimes but not b_1, b_2
  - non-universality is a special property of AdS
  - SUSY does not imply universality

Kerr-Newman-AdS$_4$ BPS Curvature Invariants

- minimal $\mathcal{N} = 4$ gauged supergravity

$$\mathcal{L}_b = R - 2\Lambda - F_{\mu\nu}F^{\mu\nu}$$

$$\mathcal{L}_f = \frac{1}{2}\bar{\psi}_\mu \gamma^{\mu\nu\rho} D_\nu \psi_\rho + \frac{i}{4}F^{\mu\nu}\bar{\psi}_\rho \gamma_\mu \gamma^{\rho\sigma}\gamma_\nu \psi_\sigma - \frac{1}{2\ell}\bar{\psi}_\mu \gamma^{\mu\nu}\psi_\nu$$

- logarithmic correction is *non-topological*

$$C_{\text{local}} = \frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2 - 4a\ell - a^2\right)}{\left(\ell - a\right)\left(a^2 + 6a\ell + \ell^2\right)}$$

- role of SUSY in topological corrections
  - SUSY ensures c cancels in flat and AdS spacetimes but not b_1, b_2
  - non-universality is a special property of AdS
  - SUSY does not imply universality
- gravity multiplet is not a consistent low-energy effective theory
- KK-modes and additional multiplets are not included
- universality could distinguish which low energy theories admit a UV completion

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}
  (1) [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
  (2) [1707.04197 Liu, Pando Zayas, Rathee, Zhao]

	Full solution AdS$_4$ with S^3 boundary (1)	Near-horizon AdS$_4$ with $S^1 \times S^2$ boundary (2)	Full solution KN-AdS$_4$	Near-horizon KN-AdS$_4$
C_{local}	0		$\frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2-4a\ell-a^2\right)}{(\ell-a)(a^2+6a\ell+\ell^2)}$	
zero modes	$-\frac{1}{4}$	-2	0	5
field theory	$-\frac{1}{4}$	$-\frac{1}{2}$	–	–

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}
  (1) [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
  (2) [1707.04197 Liu, Pando Zayas, Rathee, Zhao]

	Full solution AdS$_4$ with S^3 boundary (1)	Near-horizon AdS$_4$ with $S^1 \times S^2$ boundary (2)	Full solution KN-AdS$_4$	Near-horizon KN-AdS$_4$
C_{local}	0		$\frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2-4a\ell-a^2\right)}{(\ell-a)(a^2+6a\ell+\ell^2)}$	
zero modes	$-\frac{1}{4}$	-2	0	5
field theory	$-\frac{1}{4}$	$-\frac{1}{2}$	$-$	$-$

- local contributions match for full solution and near horizon

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}
  (1) [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
  (2) [1707.04197 Liu, Pando Zayas, Rathee, Zhao]

	Full solution AdS_4 with S^3 boundary (1)	Near-horizon AdS_4 with $S^1 \times S^2$ boundary (2)	Full solution KN-AdS_4	Near-horizon KN-AdS_4
C_{local}	0		$\frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2-4a\ell-a^2\right)}{(\ell-a)(a^2+6a\ell+\ell^2)}$	
zero modes	$-\frac{1}{4}$	-2	0	5
field theory	$-\frac{1}{4}$	$-\frac{1}{2}$	–	–

- local contributions match for full solution and near horizon
- distinction comes from global piece and is consistent with other AdS_4 computations

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}
  (1) [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
  (2) [1707.04197 Liu, Pando Zayas, Rathee, Zhao]

	Full solution AdS$_4$ with S^3 boundary (1)	Near-horizon AdS$_4$ with $S^1 \times S^2$ boundary (2)	Full solution KN-AdS$_4$	Near-horizon KN-AdS$_4$
C_{local}	0		$\frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2-4a\ell-a^2\right)}{(\ell-a)(a^2+6a\ell+\ell^2)}$	
zero modes	$-\frac{1}{4}$	-2	0	5
field theory	$-\frac{1}{4}$	$-\frac{1}{2}$	–	–

- local contributions match for full solution and near horizon
- distinction comes from global piece and is consistent with other AdS$_4$ computations
- supergravity localization [2107.12398 Hristov, Reys]

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}
  (1) [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
  (2) [1707.04197 Liu, Pando Zayas, Rathee, Zhao]

	Full solution AdS_4 with S^3 boundary (1)	Near-horizon AdS_4 with $S^1 \times S^2$ boundary (2)	Full solution KN-AdS_4	Near-horizon KN-AdS_4
C_{local}	0		$\frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2-4a\ell-a^2\right)}{(\ell-a)(a^2+6a\ell+\ell^2)}$	
zero modes	$-\frac{1}{4}$	-2	0	5
field theory	$-\frac{1}{4}$	$-\frac{1}{2}$	$-$	$-$

- local contributions match for full solution and near horizon
- distinction comes from global piece and is consistent with other AdS_4 computations
- supergravity localization [2107.12398 Hristov, Reys]
  - corrections depend on dynamical coefficient (all supergravity multiplets & KK tower) and topological data

Full solution versus near-horizon

- extremal limit of non-extremal C_{local} matches near-horizon C_{local}
  (1) [1210.6057 Bhattacharyya, Grassi, Marino, Sen]
  (2) [1707.04197 Liu, Pando Zayas, Rathee, Zhao]

	Full solution AdS$_4$ with S^3 boundary (1)	Near-horizon AdS$_4$ with $S^1 \times S^2$ boundary (2)	Full solution KN-AdS$_4$	Near-horizon KN-AdS$_4$
C_{local}	0		$\frac{11}{6} - \frac{26}{3}\frac{a\left(\ell^2-4a\ell-a^2\right)}{(\ell-a)(a^2+6a\ell+\ell^2)}$	
zero modes	$-\frac{1}{4}$	-2	0	5
field theory	$-\frac{1}{4}$	$-\frac{1}{2}$	–	–

- local contributions match for full solution and near horizon
- distinction comes from global piece and is consistent with other AdS$_4$ computations
- supergravity localization [2107.12398 Hristov, Reys]
  - corrections depend on dynamical coefficient (all supergravity multiplets & KK tower) and topological data

Conclusion and Outlook

- Conclusion
  - understand the nature and properties of logarithmic corrections via gravity multiplet
  - non-topological results for BPS AdS_4 black hole
  - uncover information using near horizon without full UV theory

Conclusion and Outlook

- Conclusion
  - understand the nature and properties of logarithmic corrections via gravity multiplet
  - non-topological results for BPS AdS_4 black hole
  - uncover information using near horizon without full UV theory
- Outlook/Future Directions
  - using the heat kernel to compute corrections in 10d supergravity
  - logarithmic corrections in non-minimal gauged supergravity
  - computation of KK tower as a consistency check