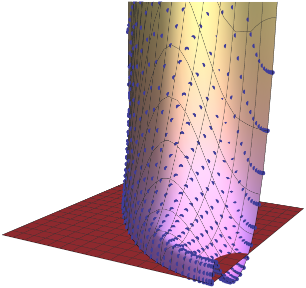
Hovering Black Holes

Jorge E. Santos
CERN



In collaboration with
Gary T. Horowitz, Nabil Iqbal and Benson Way - arXiv:1412.1830 (Today!)

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
    - Common disguise, it is a strong-weak duality - hard to prove!!!

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
    - Common disguise, it is a strong-weak duality - hard to prove!!!
    - Provides the only known definition of stringy quantum gravity at the non-perturbative level.

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
  - Common disguise, it is a strong-weak duality - hard to prove!!!
  - Provides the only known definition of stringy quantum gravity at the non-perturbative level.
  - Allows the study of the properties of some quantum field theories at strong coupling in terms of PDEs!!

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
  - Common disguise, it is a strong-weak duality - hard to prove!!!
  - Provides the only known definition of stringy quantum gravity at the non-perturbative level.
  - Allows the study of the properties of some quantum field theories at strong coupling in terms of PDEs!!

Open questions where strong coupling is likely to be relevant:

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
  - Common disguise, it is a strong-weak duality - hard to prove!!!
  - Provides the only known definition of stringy quantum gravity at the non-perturbative level.
  - Allows the study of the properties of some quantum field theories at strong coupling in terms of PDEs!!

Open questions where strong coupling is likely to be relevant:

- High T_c superconductors and strange metallic phases.

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
  - Common disguise, it is a strong-weak duality - hard to prove!!!
  - Provides the only known definition of stringy quantum gravity at the non-perturbative level.
  - Allows the study of the properties of some quantum field theories at strong coupling in terms of PDEs!!

Open questions where strong coupling is likely to be relevant:

- High T_c superconductors and strange metallic phases.
- Quark-Gluon plasma at the LHC and RHIC.

The Big Picture - 1/3

- The AdS/CFT correspondence maps asymptotically AdS solutions of Einsteins' equations to states of a dual conformal field theory:
  - Common disguise, it is a strong-weak duality - hard to prove!!!
  - Provides the only known definition of stringy quantum gravity at the non-perturbative level.
  - Allows the study of the properties of some quantum field theories at strong coupling in terms of PDEs!!

Open questions where strong coupling is likely to be relevant:

- High T_c superconductors and strange metallic phases.
- Quark-Gluon plasma at the LHC and RHIC.

The Big Picture - 2/3

What we are likely *NOT* to accomplish (in my personal opinion):

Model specific materials, and test in the lab!

The Big Picture - 2/3

What we are likely *NOT* to accomplish (in my personal opinion):

Model specific materials, and test in the lab!

Why do we use it?

The Big Picture - 2/3

What we are likely *NOT* to accomplish (in my personal opinion):

Model specific materials, and test in the lab!

Why do we use it?

- Wrong theory - recall that we know what the underlying theory is: coupled electrons on a lattice.

The Big Picture - 2/3

What we are likely *NOT* to accomplish (in my personal opinion):

Model specific materials, and test in the lab!

Why do we use it?

- Wrong theory - recall that we know what the underlying theory is: coupled electrons on a lattice.
- Using a conjectural duality ...

The Big Picture - 2/3

What we are likely *NOT* to accomplish (in my personal opinion):

Model specific materials, and test in the lab!

Why do we use it?

- Wrong theory - recall that we know what the underlying theory is: coupled electrons on a lattice.
- Using a conjectural duality ...

Why do we use it?

We are desperate!!!

The Big Picture - 3/3

Best case scenario:

The Big Picture - 3/3

Best case scenario:

1. Use holography to describe some know physics in Condensed Matter Theory - CMT.

The Big Picture - 3/3

Best case scenario:

1. Use holography to describe some know physics in Condensed Matter Theory - CMT.
2. Find that holography reproduces most results, but brings something new and Universal!

The Big Picture - 3/3

Best case scenario:

1. Use holography to describe some know physics in Condensed Matter Theory - CMT.
2. Find that holography reproduces most results, but brings something new and Universal!
3. Zoom out from the holographic setup, and find a new broader setup in CMT that is able to encompass the new phenomena found in holography!

The Big Picture - 3/3

Best case scenario:

1. Use holography to describe some know physics in Condensed Matter Theory - CMT.
2. Find that holography reproduces most results, but brings something new and Universal!
3. Zoom out from the holographic setup, and find a new broader setup in CMT that is able to encompass the new phenomena found in holography!

Today:

The Big Picture - 3/3

Best case scenario:

1. Use holography to describe some know physics in Condensed Matter Theory - CMT.
2. Find that holography reproduces most results, but brings something new and Universal!
3. Zoom out from the holographic setup, and find a new broader setup in CMT that is able to encompass the new phenomena found in holography!

Today:

- We will be able to do 1 and 2.

The Big Picture - 3/3

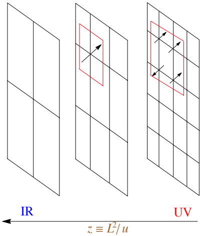
Best case scenario:

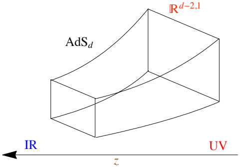
1. Use holography to describe some know physics in Condensed Matter Theory - CMT.
2. Find that holography reproduces most results, but brings something new and Universal!
3. Zoom out from the holographic setup, and find a new broader setup in CMT that is able to encompass the new phenomena found in holography!

Today:

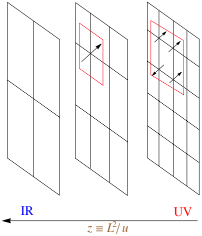
- We will be able to do 1 and 2.
- For 3 we need your help.

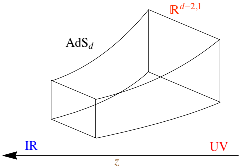
The Gauge-Gravity Duality





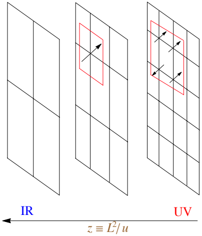
The Gauge-Gravity Duality

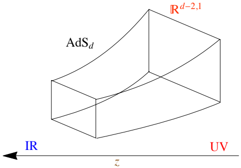




Motivation:

The Gauge-Gravity Duality

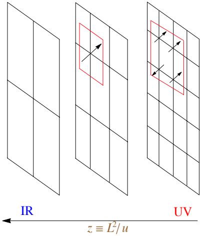


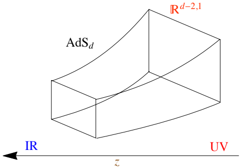


Motivation:

- t'Hooft original arguments: the maximum entropy in a region of space is the area of its boundary, in Planck units.

The Gauge-Gravity Duality

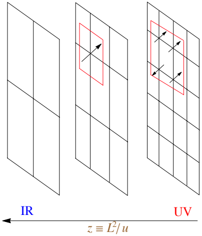


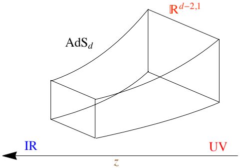


Motivation:

- t'Hooft original arguments: the maximum entropy in a region of space is the area of its boundary, in Planck units.
- Weinberg-Witten: graviton can't be a composite particle.

The Gauge-Gravity Duality



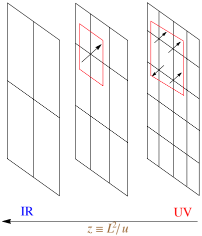


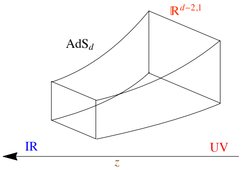
Motivation:

- t'Hooft original arguments: the maximum entropy in a region of space is the area of its boundary, in Planck units.
- Weinberg-Witten: graviton can't be a composite particle.
- RG equations for coupling g are local in the energy scale u:

$$u\partial_u g(u) = \beta(g(u))\,.$$

The Gauge-Gravity Duality



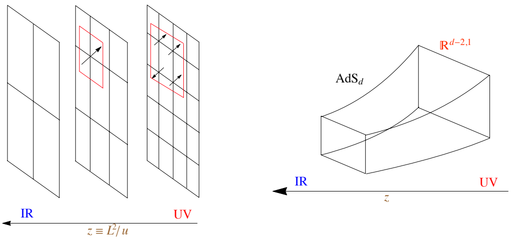


Concrete example where it all stems ('97 Maldacena):

$\mathcal{N} = 4$ SU(N) SYM is dual to IIB String Theory on AdS$_5 \times S^5$

$$Z_{CFT}[\lambda, N, J] = \mathcal{Z}_{IIB}[\Phi^\partial = J, G_N \sim N^{-2}, \alpha'/L^2 \sim \lambda^{-1/2}] \, .$$

The Gauge-Gravity Duality



Concrete example where it all stems ('97 Maldacena):

$\mathcal{N} = 4$ SU(N) SYM is dual to IIB String Theory on AdS$_5 \times S^5$

$$Z_{CFT}[\lambda, N, J] \underset{\lambda, N \to +\infty}{=} \sum_{saddle} e^{-S_{IIB}^{\alpha'=0}(saddle, \Phi^{\partial}=J)}.$$

How does it work?

- Matching the symmetries:

How does it work?

- Matching the symmetries:
    - Organise the operators according to irr. representations.

How does it work?

- Matching the symmetries:
  - Organise the operators according to irr. representations.
- Pick the operator you want to study - say $\langle J^t \rangle$ $(\Delta_{J^t} = 2)$.

How does it work?

- Matching the symmetries:
    - Organise the operators according to irr. representations.
- Pick the operator you want to study - say $\langle J^t \rangle$ ($\Delta_{J^t} = 2$).
- Its source, the chemical potential $a_t = \mu$, has $\Delta_\mu = 1$.

How does it work?

- Matching the symmetries:
    - Organise the operators according to irr. representations.
- Pick the operator you want to study - say $\langle J^t \rangle$ ($\Delta_{J^t} = 2$).
- Its source, the chemical potential $a_t = \mu$, has $\Delta_\mu = 1$.
- We want to deform our theory by adding to our action:

$$\int \mathrm{d}t\, \mathrm{d}^2x\, J^\mu a_\mu\,.$$

How does it work?

- Matching the symmetries:
    - Organise the operators according to irr. representations.
- Pick the operator you want to study - say $\langle J^t \rangle$ ($\Delta_{J^t} = 2$).
- Its source, the chemical potential $a_t = \mu$, has $\Delta_\mu = 1$.
- We want to deform our theory by adding to our action:

$$\int \mathrm{d}t \, \mathrm{d}^2 x \, J^\mu a_\mu \, .$$

- Dictionary: consider a bulk supergravity field, A_μ, whose boundary behaviour is $A_t = a_t$.

How does it work?

- Matching the symmetries:
  - Organise the operators according to irr. representations.
- Pick the operator you want to study - say $\langle J^t \rangle$ ($\Delta_{J^t} = 2$).
- Its source, the chemical potential $a_t = \mu$, has $\Delta_\mu = 1$.
- We want to deform our theory by adding to our action:

$$\int \mathrm{d}t\, \mathrm{d}^2x\, J^\mu a_\mu \,.$$

- Dictionary: consider a bulk supergravity field, A_μ, whose boundary behaviour is $A_t = a_t$.
- $\langle J^t \rangle$ is obtained by reading the sub-leading behaviour of the bulk field A close to the conformal boundary $(z = 0)$

$$A^t = a^t + \langle J^t \rangle\, z + \dots \,.$$

How does it work?

- Matching the symmetries:
  - Organise the operators according to irr. representations.
- Pick the operator you want to study - say $\langle J^t \rangle$ ($\Delta_{J^t} = 2$).
- Its source, the chemical potential $a_t = \mu$, has $\Delta_\mu = 1$.
- We want to deform our theory by adding to our action:

$$\int \mathrm{d}t\, \mathrm{d}^2x\, J^\mu a_\mu \,.$$

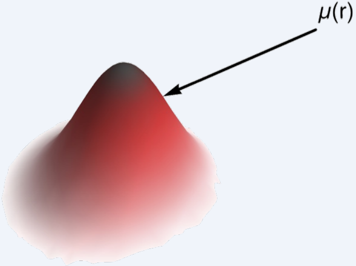
- Dictionary: consider a bulk supergravity field, A_μ, whose boundary behaviour is $A_t = a_t$.
- $\langle J^t \rangle$ is obtained by reading the sub-leading behaviour of the bulk field A close to the conformal boundary ($z = 0$)

$$A^t = a^t + \langle J^t \rangle\, z + \ldots \,.$$

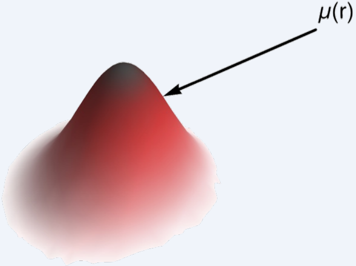
Solve a field theory problem by solving PDEs!

What do we want to model?

What do we want to model?



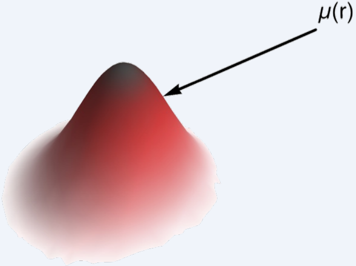
What do we want to model?



Questions?

- What is the charge density doing?

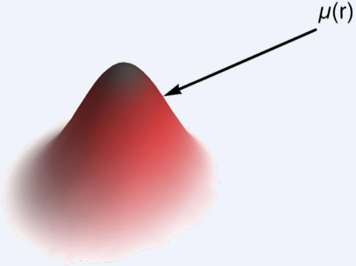
What do we want to model?



Questions?

- What is the charge density doing?
- Does the theory flow to a new fixed point in the IR?

What do we want to model?



Questions?

- What is the charge density doing?
- Does the theory flow to a new fixed point in the IR?
- Does the shape of the impurity matter?

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G}\int \mathrm{d}^4x\,\sqrt{-g}\left[R - F^{ab}F_{ab} + \frac{6}{L^2}\right]\,,$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS_4 length scale.

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G} \int \mathrm{d}^4x \sqrt{-g} \left[R - F^{ab}F_{ab} + \frac{6}{L^2} \right] ,$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS_4 length scale.

Comments:

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G}\int \mathrm{d}^4x\,\sqrt{-g}\left[R - F^{ab}F_{ab} + \frac{6}{L^2}\right],$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS$_4$ length scale.

Comments:

- Field content: gravity and Maxwell field

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G}\int \mathrm{d}^4x\,\sqrt{-g}\left[R - F^{ab}F_{ab} + \frac{6}{L^2}\right],$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS$_4$ length scale.

Comments:

- Field content: gravity and Maxwell field
- Consider solutions in the Poincaré patch with fixed boundary metric

$$\mathrm{d}s^2_\partial = -\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\mathrm{d}\varphi^2$$

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G}\int \mathrm{d}^4x\,\sqrt{-g}\left[R - F^{ab}F_{ab} + \frac{6}{L^2}\right],$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS_4 length scale.

Comments:

- Field content: gravity and Maxwell field
- Consider solutions in the Poincaré patch with fixed boundary metric

$$\mathrm{d}s_\partial^2 = -\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\mathrm{d}\varphi^2$$

- Translational invariance is explicitly broken via the boundary behaviour of A_t:

$$A_t(z,r,\varphi) = \mu(r,\varphi) + \langle\rho(r,\varphi)\rangle\, z + \ldots$$

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G}\int \mathrm{d}^4x\,\sqrt{-g}\left[R - F^{ab}F_{ab} + \frac{6}{L^2}\right],$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS$_4$ length scale.

Comments:

- Field content: gravity and Maxwell field
- Consider solutions in the Poincaré patch with fixed boundary metric
$$\mathrm{d}s_\partial^2 = -\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\mathrm{d}\varphi^2$$
- Translational invariance is explicitly broken via the boundary behaviour of A_t:
$$A_t(z,r,\varphi) = \mu(r,\varphi) + \langle\rho(r,\varphi)\rangle\, z + \ldots$$
- Take $\mu(r) = \mathcal{A}\, F(r/\sigma)$ for several profiles $F(x)$ - impurity.

The bulk theory we study is governed by the Lagrangian

$$S = \frac{1}{16\pi G}\int \mathrm{d}^4x\,\sqrt{-g}\left[R - F^{ab}F_{ab} + \frac{6}{L^2}\right],$$

where $F = \mathrm{d}A$, G is Newton's constant and L is the AdS$_4$ length scale.

Comments:

- Field content: gravity and Maxwell field
- Consider solutions in the Poincaré patch with fixed boundary metric

$$\mathrm{d}s^2_\partial = -\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\mathrm{d}\varphi^2$$

- Translational invariance is explicitly broken via the boundary behaviour of A_t:

$$A_t(z, r, \varphi) = \mu(r, \varphi) + \langle\rho(r, \varphi)\rangle\, z + \ldots$$

- Take $\mu(r) = \mathcal{A}\, F(r/\sigma)$ for several profiles $F(x)$ - impurity.
- At $T = 0$, moduli space space of solutions is 1D: $a_0 \equiv \mathcal{A}\sigma$.

A case for dimensional analysis

- From the field theory it is simple to see how the decay of F at large r can affect the IR.

A case for dimensional analysis

- From the field theory it is simple to see how the decay of F at large r can affect the IR.
- The chemical potential is a source for $\langle J \rangle$ and has conformal dimension 1.

A case for dimensional analysis

- From the field theory it is simple to see how the decay of F at large r can affect the IR.
- The chemical potential is a source for $\langle J \rangle$ and has conformal dimension 1.
- Gauss's law at the boundary tell us that, unless $\mu(r) \propto a/r$ at large r, the total charge is either 0 or ∞.

A case for dimensional analysis

- From the field theory it is simple to see how the decay of F at large r can affect the IR.
- The chemical potential is a source for $\langle J \rangle$ and has conformal dimension 1.
- Gauss's law at the boundary tell us that, unless $\mu(r) \propto a/r$ at large r, the total charge is either 0 or ∞.
- At large r, let us assume that:

$$\mu(r) \simeq \frac{a}{r^{\beta}}\,.$$

A case for dimensional analysis

- From the field theory it is simple to see how the decay of F at large r can affect the IR.
- The chemical potential is a source for $\langle J \rangle$ and has conformal dimension 1.
- Gauss's law at the boundary tell us that, unless $\mu(r) \propto a/r$ at large r, the total charge is either 0 or ∞.
- At large r, let us assume that:

$$\mu(r) \simeq \frac{a}{r^\beta} \Rightarrow [a] = 1 - \beta\,.$$

A case for dimensional analysis

- From the field theory it is simple to see how the decay of F at large r can affect the IR.
- The chemical potential is a source for $\langle J \rangle$ and has conformal dimension 1.
- Gauss's law at the boundary tell us that, unless $\mu(r) \propto a/r$ at large r, the total charge is either 0 or ∞.
- At large r, let us assume that:

$$\mu(r) \simeq \frac{a}{r^{\beta}} \Rightarrow [a] = 1 - \beta\,.$$

A simple criterion:

$\beta < 1$: impurity destroys the IR, *i.e.* is relevant.
$\beta = 1$: impurity marginally deforms the IR.
$\beta > 1$: impurity should be irrelevant in the IR.

For simple profiles $F(x)$, analytic solutions can be found:

$F(r) = 0$

$$\mathrm{d}s^2 = \frac{L^2}{z^2}\Big[-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\mathrm{d}\varphi^2 + \mathrm{d}z^2\Big],$$
$$A = 0\,.$$

For simple profiles $F(x)$, analytic solutions can be found:

$F(r) = \mathcal{A}/r$

$$ds^2 = \frac{L^2}{r^2 z^2}\left\{-dt^2 + dr^2 + r^2\left[g(z)d\varphi^2 + \frac{dz^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \ \text{ with } \ g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}\,.$$

Experts: it is the 2× Wick rotated magnetically charged 4D $\mathbb{H}$ hole

For simple profiles $F(x)$, analytic solutions can be found:

$F(r) = \mathcal{A}/r$

$$\mathrm{d}s^2 = \frac{L^2}{r^2 z^2}\left\{-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\left[g(z)\mathrm{d}\varphi^2 + \frac{\mathrm{d}z^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \text{ with } g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}\,.$$

Experts: it is the 2× Wick rotated magnetically charged 4D $\mathbb{H}$ hole

- Cherry pick $\mathcal{A}$ to avoid conical singularity at $z = z_+$.

For simple profiles $F(x)$, analytic solutions can be found:

$F(r) = \mathcal{A}/r$

$$\mathrm{d}s^2 = \frac{L^2}{r^2 z^2}\left\{-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\left[g(z)\mathrm{d}\varphi^2 + \frac{\mathrm{d}z^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \;\; \text{with} \;\; g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}\,.$$

Experts: it is the 2× Wick rotated magnetically charged 4D $\mathbb{H}$ hole

- Cherry pick $\mathcal{A}$ to avoid conical singularity at $z = z_+$.
- One parameter family of solutions parametrised by $z_+ \geq 1$.

For simple profiles $F(x)$, analytic solutions can be found:

$F(r) = \mathcal{A}/r$

$$\mathrm{d}s^2 = \frac{L^2}{r^2 z^2}\left\{-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\left[g(z)\mathrm{d}\varphi^2 + \frac{\mathrm{d}z^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \;\; \text{with} \;\; g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}\,.$$

Experts: it is the $2\times$ Wick rotated magnetically charged 4D $\mathbb{H}$ hole

- Cherry pick $\mathcal{A}$ to avoid conical singularity at $z = z_+$.
- One parameter family of solutions parametrised by $z_+ \geq 1$.
- Compute regularised entropy ΔS.

For simple profiles $F(x)$, analytic solutions can be found:

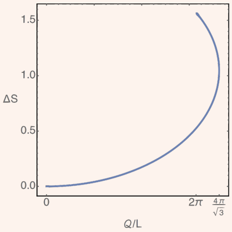
$F(r) = \mathcal{A}/r$

$$\mathrm{d}s^2 = \frac{L^2}{r^2 z^2}\left\{-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\left[g(z)\mathrm{d}\varphi^2 + \frac{\mathrm{d}z^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \;\text{ with }\; g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}\,.$$

Experts: it is the 2× Wick rotated magnetically charged 4D $\mathbb{H}$ hole

- Cherry pick $\mathcal{A}$ to avoid conical singularity at $z = z_+$.
- One parameter family of solutions parametrised by $z_+ \geq 1$.
- Compute regularised entropy ΔS.



For simple profiles $F(x)$, analytic solutions can be found:

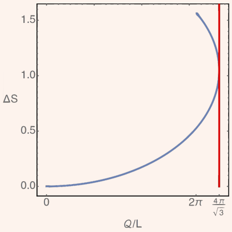
$F(r) = \mathcal{A}/r$

$$\mathrm{d}s^2 = \frac{L^2}{r^2 z^2}\left\{-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\left[g(z)\mathrm{d}\varphi^2 + \frac{\mathrm{d}z^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \ \text{ with } \ g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}\,.$$

Experts: it is the $2\times$ Wick rotated magnetically charged 4D $\mathbb{H}$ hole

- Cherry pick $\mathcal{A}$ to avoid conical singularity at $z = z_+$.
- One parameter family of solutions parametrised by $z_+ \geq 1$.
- Compute regularised entropy ΔS.
- $\exists \quad \mathcal{Q}^{max} = 4\pi/\sqrt{3}$.



For simple profiles $F(x)$, analytic solutions can be found:

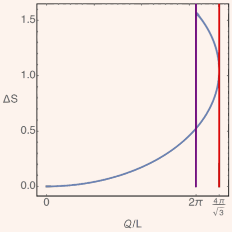
$F(r) = \mathcal{A}/r$

$$\mathrm{d}s^2 = \frac{L^2}{r^2 z^2}\left\{-\mathrm{d}t^2 + \mathrm{d}r^2 + r^2\left[g(z)\mathrm{d}\varphi^2 + \frac{\mathrm{d}z^2}{g(z)}\right]\right\},$$

$$A_t = \frac{\mathcal{A}}{r} + \mathcal{Q}(\mathcal{A}, z_+)\delta(r) \;\text{ with }\; g(z) = 1 - z^2 - \mathcal{A}^2 z^4 - (1 - z_+^2 - \mathcal{A}^2 z_+^4)\frac{z^3}{z_+^3}.$$

Experts: it is the $2\times$ Wick rotated magnetically charged 4D $\mathbb{H}$ hole

- Cherry pick $\mathcal{A}$ to avoid conical singularity at $z = z_+$.
- One parameter family of solutions parametrised by $z_+ \geq 1$.
- Compute regularised entropy ΔS.
- $\exists$ $\mathcal{Q}^{max} = 4\pi/\sqrt{3}$.
- If $\mathcal{Q} \geq 2\pi$, two solutions $\exists$.



How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 \;=\; \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 \;=\; \frac{L^2}{z^2}\Big[-\,A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 \;=\; \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
    - What about gauge freedom?

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 \; = \; \frac{L^2}{z^2}\Big[- A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
    - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 = \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
  - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
  - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$ds^2 = \frac{L^2}{z^2}\Big[- A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
    - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
    - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.
    - $\bar{g}$ is a given reference metric that must share $\mathcal{H}_g \cup \mathcal{I}_g$.

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$ds^2 = \frac{L^2}{z^2}\Big[-A\,dt^2 + S_1\,(dr + K\,dz)^2 + S_2\,r^2 d\varphi^2 + B\,dz^2\Big],$$

$$A = \psi\,dt\,.$$

- How do we solve the Einstein-Maxwell field equations?
  - What about gauge freedom?

- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
  - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.
  - $\bar{g}$ is a given reference metric that must share $\mathcal{H}_g \cup \mathcal{I}_g$.
  - Huge pay off: $G^H = 0$ is a well defined set of Elliptic PDEs!

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 = \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
  - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
  - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.
  - $\bar{g}$ is a given reference metric that must share $\mathcal{H}_g \cup \mathcal{I}_g$.
  - Huge pay off: $G^H = 0$ is a well defined set of Elliptic PDEs!
  - Want to solve $G = 0$: choose boundary conditions that ensure $\xi = 0$ on solutions of $G^H = 0$.

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 \;=\; \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
  - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
  - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.
  - $\bar{g}$ is a given reference metric that must share $\mathcal{H}_g \cup \mathcal{I}_g$.
  - Huge pay off: $G^H = 0$ is a well defined set of Elliptic PDEs!
  - Want to solve $G = 0$: choose boundary conditions that ensure $\xi = 0$ on solutions of $G^H = 0$.
  - In simple examples one can show that $G = 0 \Leftrightarrow G^H = 0$.

How to construct generic solutions for arbitrary profiles F

The most general ansatz

$$\mathrm{d}s^2 = \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
  - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
  - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.
  - $\bar{g}$ is a given reference metric that must share $\mathcal{H}_g \cup \mathcal{I}_g$.
  - Huge pay off: $G^H = 0$ is a well defined set of Elliptic PDEs!
  - Want to solve $G = 0$: choose boundary conditions that ensure $\xi = 0$ on solutions of $G^H = 0$.
  - In practice, trust ellipticity: solution locally unique.

How to construct generic solutions for arbitrary profiles F

The most general ansatz

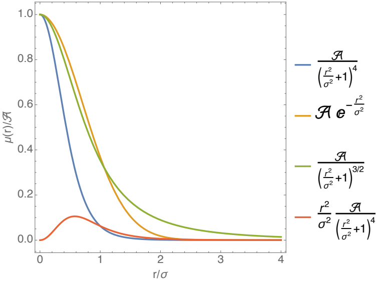
$$\mathrm{d}s^2 = \frac{L^2}{z^2}\Big[-A\,\mathrm{d}t^2 + S_1\,(\mathrm{d}r + K\,\mathrm{d}z)^2 + S_2\,r^2\mathrm{d}\varphi^2 + B\,\mathrm{d}z^2\Big],$$

$$A = \psi\,\mathrm{d}t\,.$$

- How do we solve the Einstein-Maxwell field equations?
  - What about gauge freedom?
- Einstein-DeTurck: solve $G^H_{ab} \equiv G_{ab} - \nabla_{(a}\xi_{b)} = 0$ instead:
  - ξ can be arbitrary, here choose: $\xi^a = g^{cd}[\Gamma^a_{cd}(g) - \Gamma^a_{cd}(\bar{g})]$.
  - $\bar{g}$ is a given reference metric that must share $\mathcal{H}_g \cup \mathcal{I}_g$.
  - Huge pay off: $G^H = 0$ is a well defined set of Elliptic PDEs!
  - Want to solve $G = 0$: choose boundary conditions that ensure $\xi = 0$ on solutions of $G^H = 0$.
  - In practice, trust ellipticity: solution locally unique.
  - Equations of motion solve for gauge defined by $\xi = 0$.

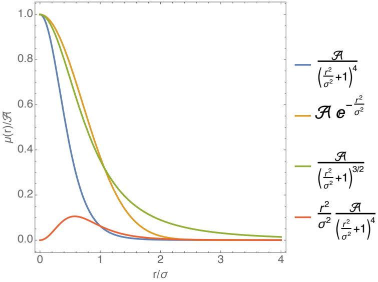
The irrelevant case 1/6

We have considered a total of four distinct profiles for the irrelevant case:



The irrelevant case 1/6

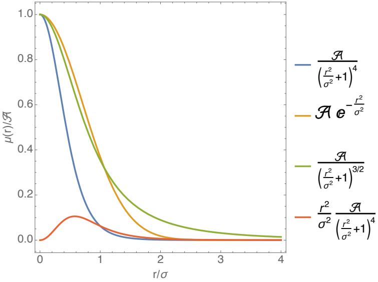
We have considered a total of four distinct profiles for the irrelevant case:



- For all of the profiles above, we find that there is a maximum value for $a \equiv \mathcal{A}\sigma$ ($a_{\max}$) beyond which we cannot find a regular solution.

The irrelevant case 1/6

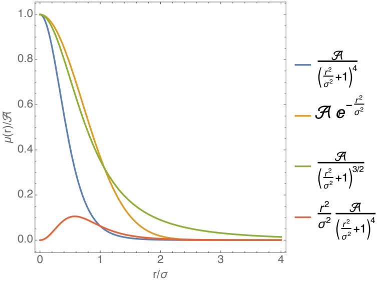
We have considered a total of four distinct profiles for the irrelevant case:



- For all of the profiles above, we find that there is a maximum value for $a \equiv \mathcal{A}\sigma$ ($a_{\rm max}$) beyond which we cannot find a regular solution.
- In all cases, the IR geometry is always AdS_4 - irrelevant.

The irrelevant case 1/6

We have considered a total of four distinct profiles for the irrelevant case:



- For all of the profiles above, we find that there is a maximum value for $a \equiv \mathcal{A}\sigma$ $(a_{\rm max})$ beyond which we cannot find a regular solution.
- In all cases, the IR geometry is always AdS_4 - irrelevant.
- We can only find one family of solutions for each value of $a \leq a_{\rm max}$ - in stark contrast with the Point Particle.

The irrelevant case 2/6

Static orbits:

We searched for locus in our manifold where

$$U^a \nabla_a U_b = \frac{q}{m} F_{ba} U^a \quad \text{with} \quad U_a U^a = -1\,,$$

i.e. studied the possible existence of static orbits where we can put a tiny black hole of mass m and charge q.

The irrelevant case 2/6

Static orbits:

We searched for locus in our manifold where

$$U^a \nabla_a U_b = \frac{q}{m} F_{ba} U^a \quad \text{with} \quad U_a U^a = -1\,,$$

i.e. studied the possible existence of static orbits where we can put a tiny black hole of mass m and charge q.

- Note that extremal black holes with, *i.e.* $q = m$, can be arbitrarily small.

The irrelevant case 2/6

Static orbits:

We searched for locus in our manifold where

$$U^a \nabla_a U_b = \frac{q}{m} F_{ba} U^a \quad \text{with} \quad U_a U^a = -1\,,$$

i.e. studied the possible existence of static orbits where we can put a tiny black hole of mass m and charge q.

- Note that extremal black holes with, *i.e.* $q = m$, can be arbitrarily small.
- For static orbits, the equation above reduces to checking if

$$\mathcal{V} = \sqrt{-g_{tt}} - \frac{q}{m} A_t \quad \text{admits extrema.}$$

The irrelevant case 2/6

Static orbits:

We searched for locus in our manifold where

$$U^a \nabla_a U_b = \frac{q}{m} F_{ba} U^a \quad \text{with} \quad U_a U^a = -1\,,$$

i.e. studied the possible existence of static orbits where we can put a tiny black hole of mass m and charge q.

- Note that extremal black holes with, *i.e.* $q = m$, can be arbitrarily small.
- For static orbits, the equation above reduces to checking if

$$\mathcal{V} = \sqrt{-g_{tt}} - \frac{q}{m} A_t \quad \text{admits extrema.}$$

- If the extrema is a minimum, the solution should be stable.

The irrelevant case 2/6

Static orbits:

We searched for locus in our manifold where

$$U^a \nabla_a U_b = \frac{q}{m} F_{ba} U^a \quad \text{with} \quad U_a U^a = -1\,,$$

i.e. studied the possible existence of static orbits where we can put a tiny black hole of mass m and charge q.

- Note that extremal black holes with, *i.e.* $q = m$, can be arbitrarily small.
- For static orbits, the equation above reduces to checking if

$$\mathcal{V} = \sqrt{-g_{tt}} - \frac{q}{m} A_t \quad \text{admits extrema.}$$

- If the extrema is a minimum, the solution should be stable.
- If the minimum is absolute, the solution should play a role even at finite N, *i.e.* not a large N artefact.

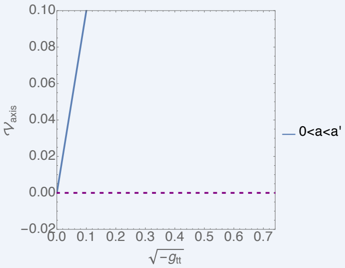
The irrelevant case 3/6

Four different regimes for $q = m$:

The irrelevant case 3/6

Four different regimes for $q = m$:

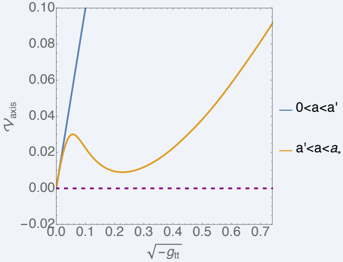
- $0 < a < a'$ no orbits can be found.



The irrelevant case 3/6

Four different regimes for $q = m$:

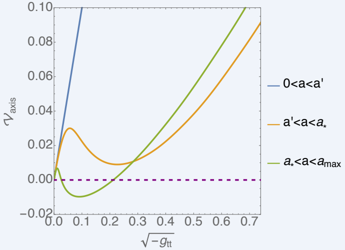
- $0 < a < a'$ no orbits can be found.
- $a' < a < a_\star$ orbits are found but $\mathcal{V}_{\min} > 0$.



The irrelevant case 3/6

Four different regimes for $q = m$:

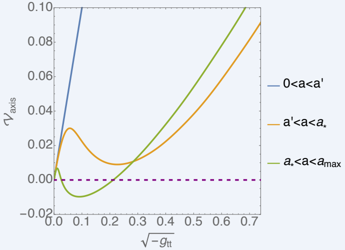
- $0 < a < a'$ no orbits can be found.
- $a' < a < a_\star$ orbits are found but $\mathcal{V}_{\min} > 0$.
- $a_\star < a < a_{\max}$ orbits are found with $\mathcal{V}_{\min} < 0$.



The irrelevant case 3/6

Four different regimes for $q = m$:

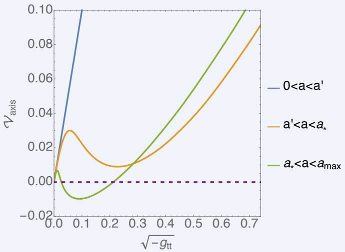
- $0 < a < a'$ no orbits can be found.
- $a' < a < a_\star$ orbits are found but $\mathcal{V}_{\min} > 0$.
- $a_\star < a < a_{\max}$ orbits are found with $\mathcal{V}_{\min} < 0$.
- $a > a_{\max}$ we can no longer find a solution.



The irrelevant case 3/6

Four different regimes for $q = m$:

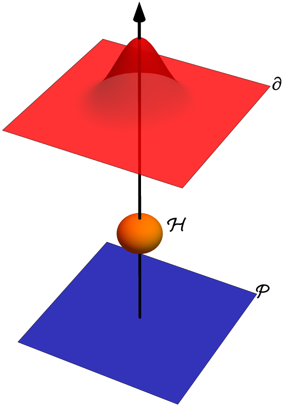
- $0 < a < a'$ no orbits can be found.
- $a' < a < a_\star$ orbits are found but $\mathcal{V}_{\min} > 0$.
- $a_\star < a < a_{\max}$ orbits are found with $\mathcal{V}_{\min} < 0$.
- $a > a_{\max}$ we can no longer find a solution.



Can we go beyond the probe approximation and construct the solutions where the extremal hole hovers the Poincaré horizon?

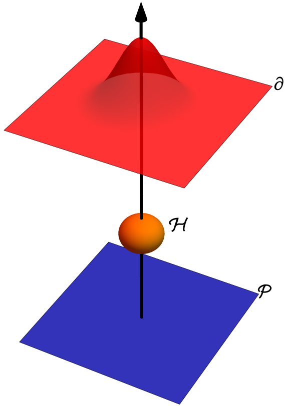
The irrelevant case 4/6

- This is the picture you should have in mind, and that gives the title to this talk.



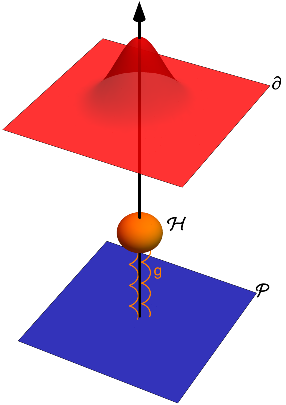
The irrelevant case 4/6

- This is the picture you should have in mind, and that gives the title to this talk.
- Why do they exist in the first place?



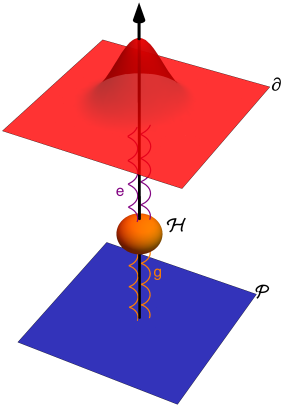
The irrelevant case 4/6

- This is the picture you should have in mind, and that gives the title to this talk.
- Why do they exist in the first place?
    - Gravitational pull wants to make them cross the horizon.



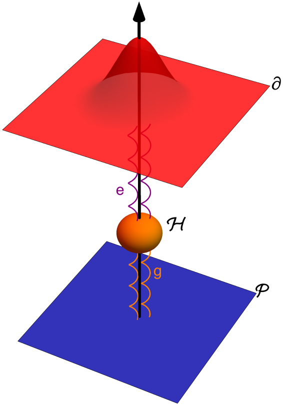
The irrelevant case 4/6

- This is the picture you should have in mind, and that gives the title to this talk.
- Why do they exist in the first place?
  - Gravitational pull wants to make them cross the horizon.
  - Electric attraction wants to pull them towards the boundary.



The irrelevant case 4/6

- This is the picture you should have in mind, and that gives the title to this talk.
- Why do they exist in the first place?
  - Gravitational pull wants to make them cross the horizon.
  - Electric attraction wants to pull them towards the boundary.
- This cannot be the all story because it would suggest an unstable solution.



The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_{\star}$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.
2. The hovering solution is exactly a spherical extremal RN black hole (we do not impose this on the numerics).

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.
2. The hovering solution is exactly a spherical extremal RN black hole (we do not impose this on the numerics).
3. Solutions exists even when $r_+ > L$.

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.
2. The hovering solution is exactly a spherical extremal RN black hole (we do not impose this on the numerics).
3. Solutions exists even when $r_+ > L$.
4. For $a_\star < a < a_{\max}$ hovering solutions and non-hovering solutions coexist.

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.
2. The hovering solution is exactly a spherical extremal RN black hole (we do not impose this on the numerics).
3. Solutions exists even when $r_+ > L$.
4. For $a_\star < a < a_{\max}$ hovering solutions and non-hovering solutions coexist.
5. They dominate the micro and grand canonical ensembles.

The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.
2. The hovering solution is exactly a spherical extremal RN black hole (we do not impose this on the numerics).
3. Solutions exists even when $r_+ > L$.
4. For $a_\star < a < a_{\max}$ hovering solutions and non-hovering solutions coexist.
5. They dominate the micro and grand canonical ensembles.
6. Phase transition is second order.

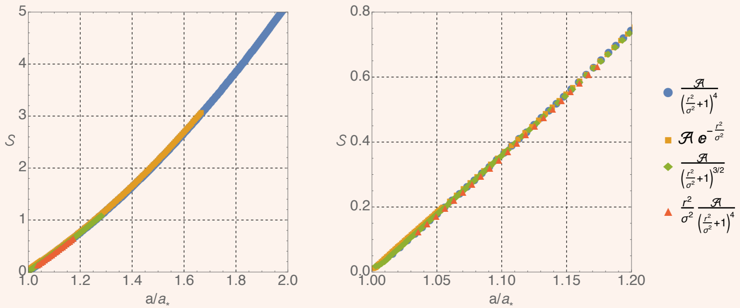
The irrelevant case 5/6

The Seven Pillars of Hovering Solutions (sorry T. E. Lawrence):

1. Hovering holes exist only when $\mathcal{V}_{\min} \leq 0$, *i.e.* $a \geq a_\star$!
   - Solutions with $\mathcal{V}_{\min} > 0$ are likely to exist, but should exhibit slow time dependence.
   - In global AdS, a minimum *always* exists for extremal charged particles, but holes only form when $\mathcal{V}_{\min} \leq 0$.
2. The hovering solution is exactly a spherical extremal RN black hole (we do not impose this on the numerics).
3. Solutions exists even when $r_+ > L$.
4. For $a_\star < a < a_{\max}$ hovering solutions and non-hovering solutions coexist.
5. They dominate the micro and grand canonical ensembles.
6. Phase transition is second order.
7. Entropy has a universal scaling with $(a/a_\star - 1)$!

The irrelevant case 6/6

Why?



Close to $a_\star$, we find $S \propto (a/a_\star - 1)^1$ - boring exponent!

The marginal case 1/2

- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.

The marginal case 1/2

- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.

The marginal case 1/2

- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:

The marginal case 1/2

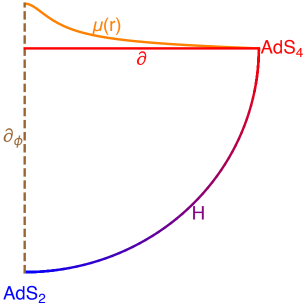
- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:
    - Makes sense since Point Particle reduces to AdS_4 for $\mathcal{Q} = 0$.

The marginal case 1/2

- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:
  - Makes sense since Point Particle reduces to AdS_4 for $\mathcal{Q} = 0$.
  - Only for this decay is the charge $\mathcal{Q}$ finite.

The marginal case 1/2

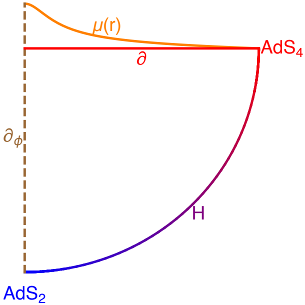
- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:
  - Makes sense since Point Particle reduces to AdS_4 for $\mathcal{Q} = 0$.
  - Only for this decay is the charge $\mathcal{Q}$ finite.



The marginal case 1/2

- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:
  - Makes sense since Point Particle reduces to AdS_4 for $\mathcal{Q} = 0$.
  - Only for this decay is the charge $\mathcal{Q}$ finite.

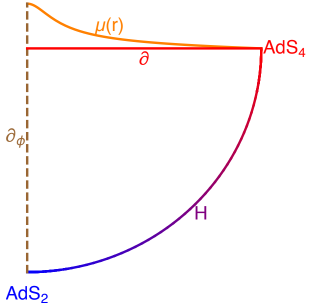
- Only found a solution for the lower branch.



The marginal case 1/2

- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:
  - Makes sense since Point Particle reduces to AdS_4 for $\mathcal{Q} = 0$.
  - Only for this decay is the charge $\mathcal{Q}$ finite.

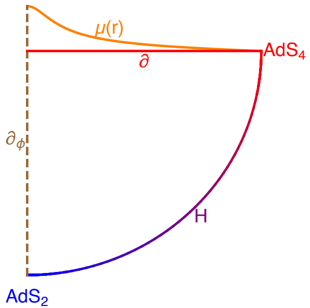
- Only found a solution for the lower branch.
- In this case, small hovering black holes also form!



The marginal case 1/2

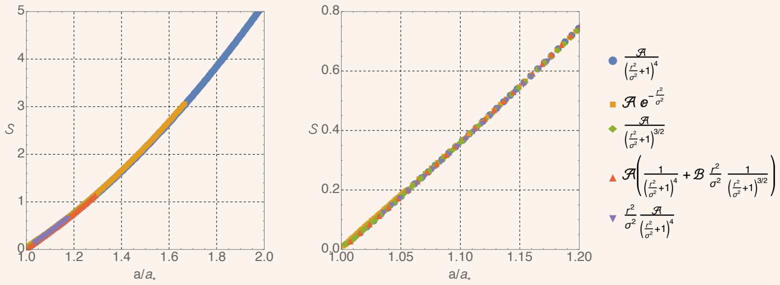
- Recall that in this case, we need $\mu(r) \propto a/r$ at large r.
- For intermediate values of r, $\mu(r)$ is still arbitrary.
- In this case, the IR geometry is changed to the Point Particle:
  - Makes sense since Point Particle reduces to AdS_4 for $\mathcal{Q} = 0$.
  - Only for this decay is the charge $\mathcal{Q}$ finite.

- Only found a solution for the lower branch.
- In this case, small hovering black holes also form!
- Curves for the entropy are equal to the marginal case.



The marginal case 2/2

Why?



The relevant case

Honest answer:

Have no idea!

The relevant case

What have we done:

The relevant case

What have we done:

- Tried to construct the solution at zero temperature - failed miserably, code does not converge.

The relevant case

What have we done:

- Tried to construct the solution at zero temperature - failed miserably, code does not converge.
- Generated many, many solutions at finite temperature.

The relevant case

What have we done:

- Tried to construct the solution at zero temperature - failed miserably, code does not converge.
- Generated many, many solutions at finite temperature.
- One thing seems clear: black holes in the domain of outer communications do not seem to form.

The relevant case

What have we done:

- Tried to construct the solution at zero temperature - failed miserably, code does not converge.
- Generated many, many solutions at finite temperature.
- One thing seems clear: black holes in the domain of outer communications do not seem to form.
- The extrapolated $T = 0$ solutions looks badly singular.

The relevant case

What have we done:

- Tried to construct the solution at zero temperature - failed miserably, code does not converge.
- Generated many, many solutions at finite temperature.
- One thing seems clear: black holes in the domain of outer communications do not seem to form.
- The extrapolated $T = 0$ solutions looks badly singular.
- The horizon, seems to repel extremal charged particles.

Conclusions:

- We have constructed the holographic dual of an impurity.
- Power counting of field theory works like a charm.
- Found a new phase, which is stable to finite N corrections, for which we don't have a field theory interpretation.

Conclusions:

- We have constructed the holographic dual of an impurity.
- Power counting of field theory works like a charm.
- Found a new phase, which is stable to finite N corrections, for which we don't have a field theory interpretation.

What to ask me after the talk:

- What about finite chemical potential at the boundary?
  - Can you still find orbits?
- Can you do a lattice of these defects? What is the IR?

Conclusions:

- We have constructed the holographic dual of an impurity.
- Power counting of field theory works like a charm.
- Found a new phase, which is stable to finite N corrections, for which we don't have a field theory interpretation.

What to ask me after the talk:

- What about finite chemical potential at the boundary?
  - Can you still find orbits?
- Can you do a lattice of these defects? What is the IR?

Outlook:

- What is the field theory interpretation of this phenomenon?
- Can we make a connection with glassy physics?
- ...