Entanglement entropy in a holographic model of the Kondo effect

Max-Niklas Newrzella

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Outline

- Review of Holography
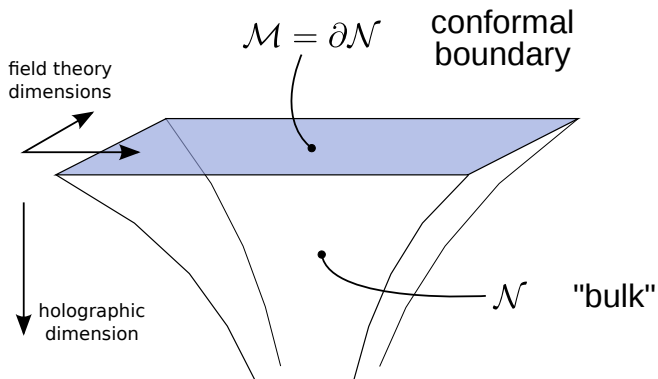
- A holographic Kondo model

- Entanglement entropy

Basic idea of holography

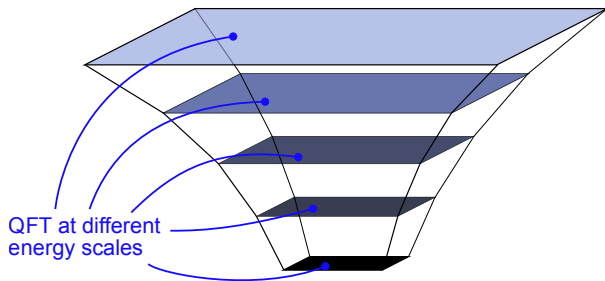## Certain limit of string theory

Specific QFTs can be mapped to classical theories of gravity

- QFT in d dimensions $\Leftrightarrow$ gravity theory in $d + n$ dimensions
- Quantum vs. classical
- Strong coupling $\Leftrightarrow$ Weak coupling
- Hard computation $\Leftrightarrow$ Easy computation
- The gravity theory is asymptotically Anti-de Sitter (AdS)
- The extra "holographic direction" describes the RG flow
- Learn about QFT/gravity from dual theory

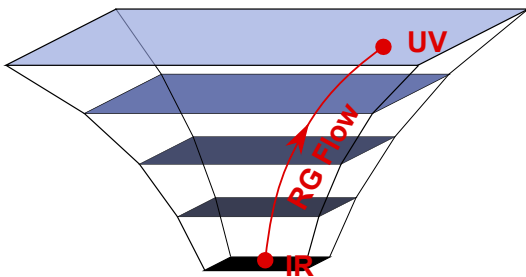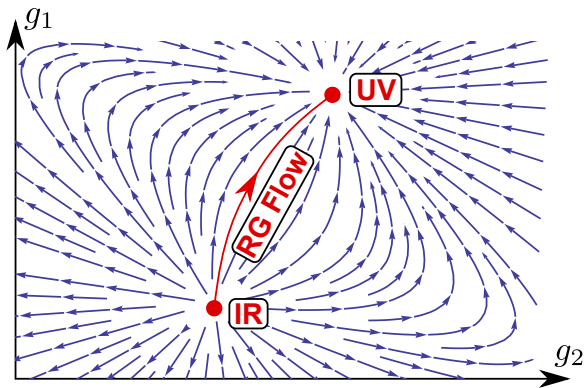# Basic idea of holography

field theory
dimensions

$\mathcal{M} = \partial\mathcal{N}$

conformal
boundary

holographic
dimension

$\mathcal{N}$ "bulk"

Basic idea of holography

QFT at different
energy scales

Basic idea of holography

Basic idea of holography

The holographic dictionary

<div style="text-align:center">

QFT side

</div>
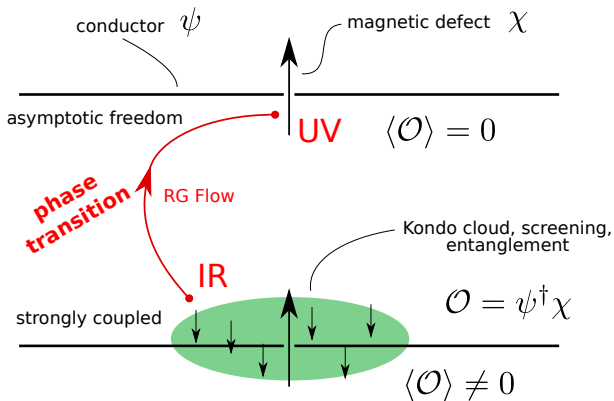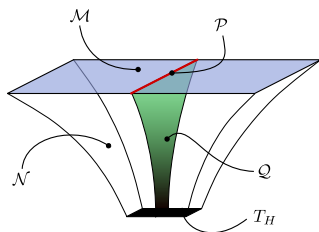
- Operators
- Finite temperature T
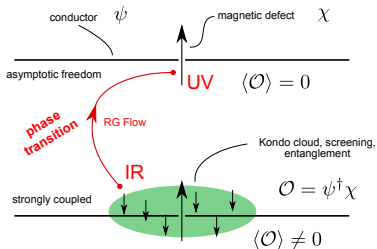- Entanglement entropy
- ...

<div style="text-align:center">

Gravity side

</div>

- Classical fields
- Hawking temperature T_H
- Minimal surface
- ...

What is the Kondo effect?

conductor ψ

magnetic defect χ

asymptotic freedom

UV $\langle \mathcal{O} \rangle = 0$

phase transition

RG Flow

Kondo cloud, screening, entanglement

IR

$\mathcal{O} = \psi^{\dagger} \chi$

strongly coupled

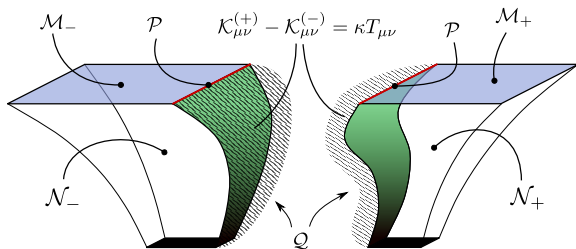$\langle \mathcal{O} \rangle \neq 0$

The holographic Kondo model

[1310.3271]

- $\mathcal{S} = \mathcal{S}_{\mathcal{N}} + \mathcal{S}_{\mathcal{M}} + \mathcal{S}_{\mathcal{Q}} + \mathcal{S}_{\mathcal{P}}$
  $\mathcal{S}_{\mathcal{N}} = \int A \wedge \mathsf{d}A \qquad \mathcal{S}_{\mathcal{Q}} = \int f^2 + |D\Phi|^2$
- No backreaction $\Rightarrow$ Cannot compute entanglement entropy!
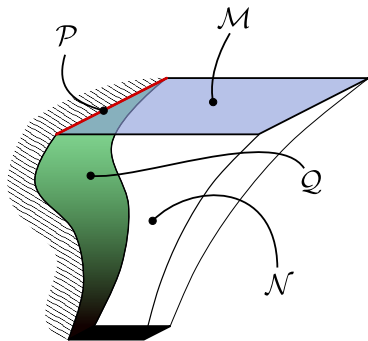
Backreaction in the holographic Kondo model

[1410.7811]

- $\mathcal{S} = \mathcal{S}_{\mathcal{N}_+} + \mathcal{S}_{\mathcal{N}_-} + \mathcal{S}_{\mathcal{M}_+} + \mathcal{S}_{\mathcal{M}_-} + \mathcal{S}_{\mathcal{Q}} + \mathcal{S}_{\mathcal{P}}$
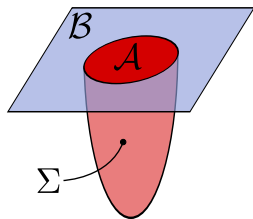- Backreaction: $\kappa \neq 0$ $\Rightarrow$ Israel junction conditions

Simplify the model

- Mirror symmetry
$\mathcal{K}^{(-)} = -\mathcal{K}^{(+)}$

- Take only one side
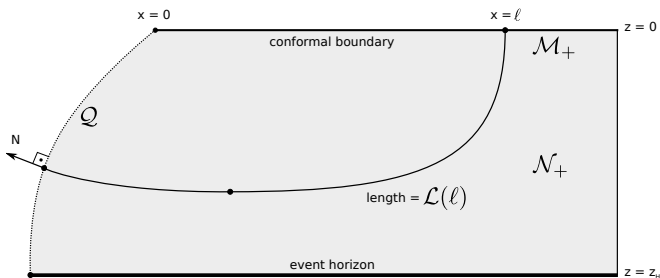$\mathcal{K}^{(+)}_{\mu\nu} = \frac{\kappa}{2} T_{\mu\nu}$

Holographic entanglement entropy

- $S_{\mathcal{A}} := -\mathrm{Tr}(\rho_{\mathcal{A}} \log(\rho_{\mathcal{A}}))$
  $(\rho_{\mathcal{A}} := \mathrm{Tr}_{\mathcal{B}}(\rho))$
- $S_{\mathcal{A}} = \mathrm{area}(\Sigma)/4G_N$
  (Σ minimal area)
- entanglement $\leftrightarrow$ geometry
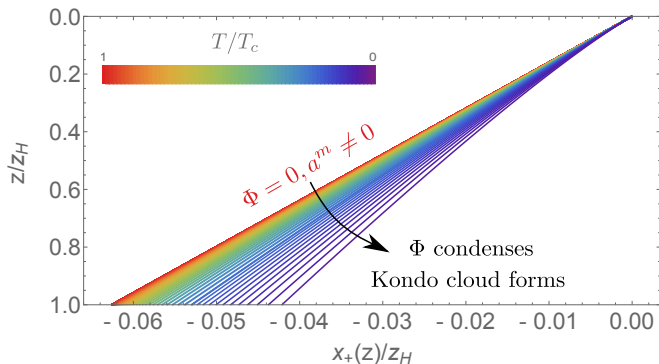

[hep-th/0603001]

Holographic entanglement entropy in our case

- minimal surfaces on equal-time slices are geodesics
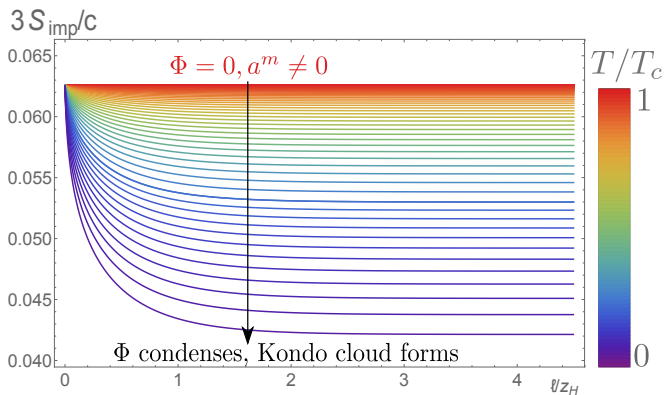- have to start perpendicularly at the brane

$$S_\ell = \mathcal{L}(\ell)/4G_N$$

Familiy of embeddings at finite temperature

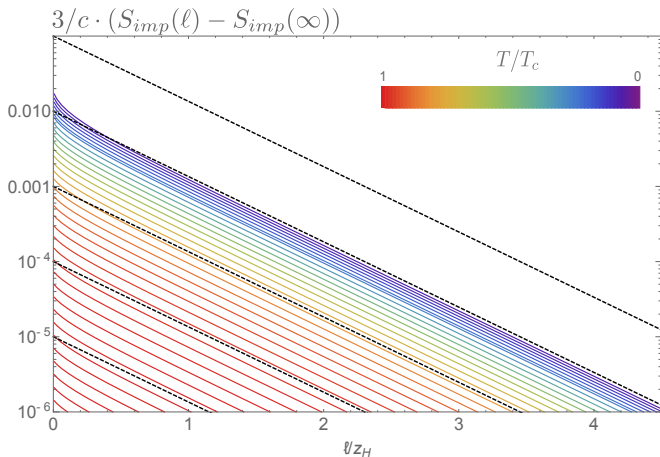these are the shapes of $\mathcal{Q}$ at different temperatures T/T_c

results for entanglement entropy

$$S_{\text{imp}} := S_{\exists\text{impurity}} - S_{\nexists\text{impurity}}$$

satisfies a g-theorem!

results for entanglement entropy

[appears soon]

Summary and Outlook

- Holographic model of the Kondo effect
- Setup for backreaction
- Entanglement entropy agrees with field theory derivations

- Kondo lattices?
- Multi channel Kondo problem?
- Time dependence?

Thank you