Defects and Boundaries in Holography

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Particle Physics School Munich Colloquium

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Outline

- Review of Holography
- Proposals for AdS/BCFT and AdS/DCFT
- Application to the holographic Kondo model

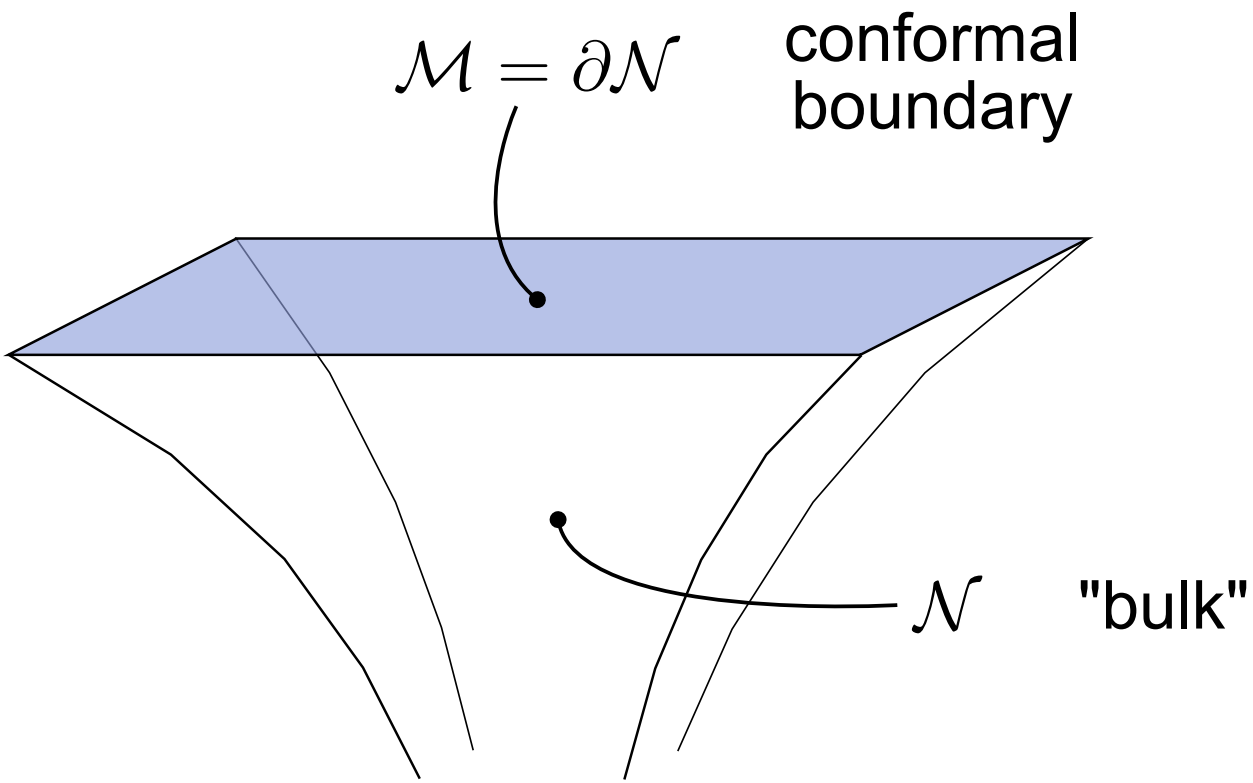
Basic idea of holography

Low energy limit of string theory

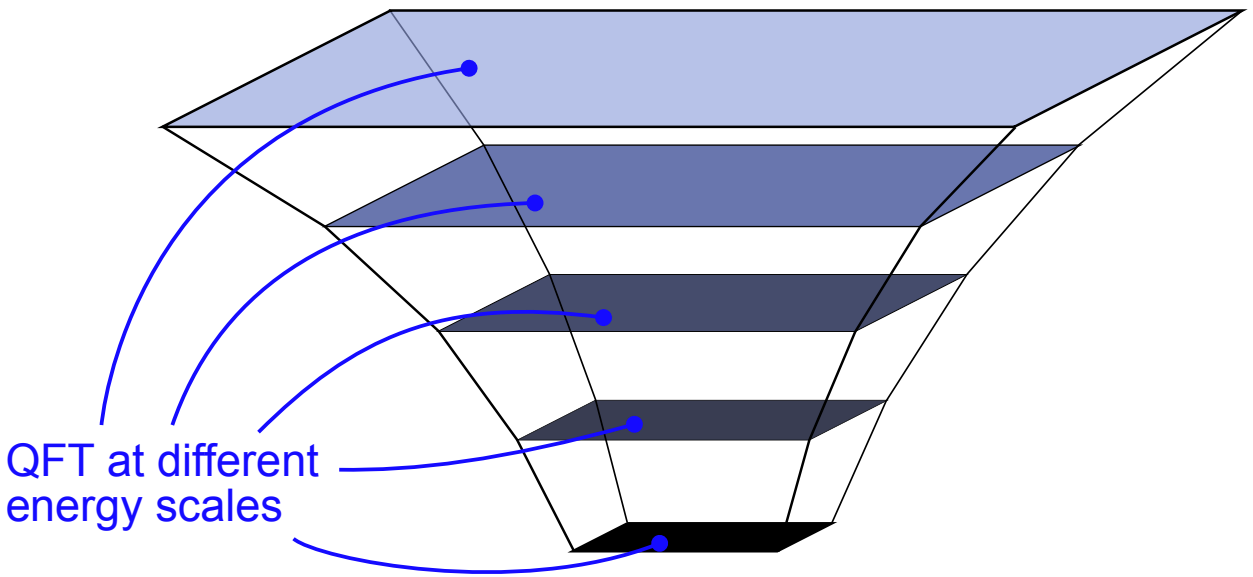
Specific QFTs are equivalent to theories of gravity

- QFT in d dimensions $\Leftrightarrow$ gravity theory in $d + n$ dimensions
- 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

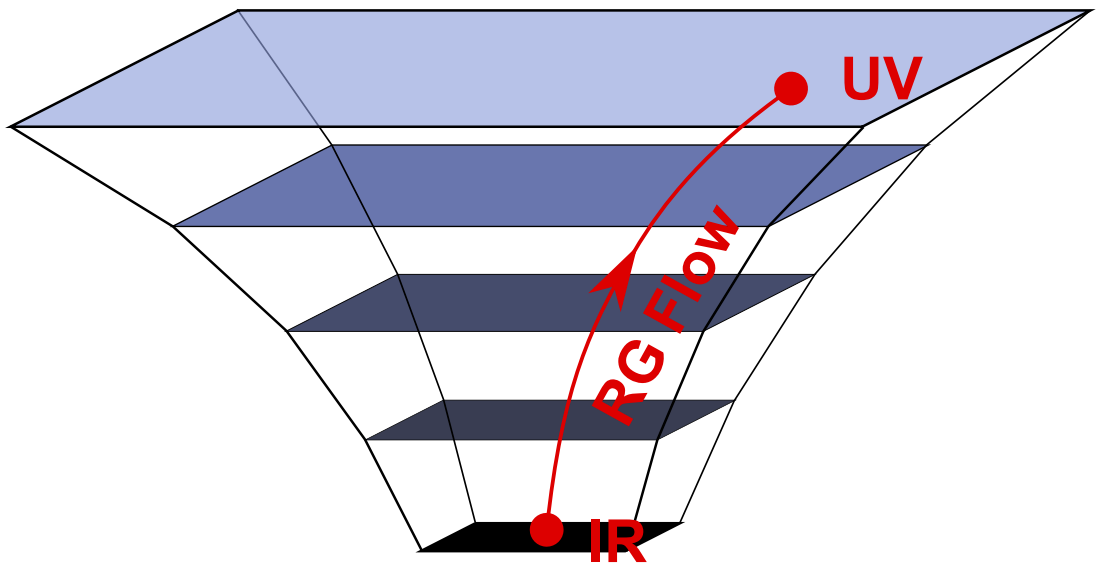
Basic idea of holography



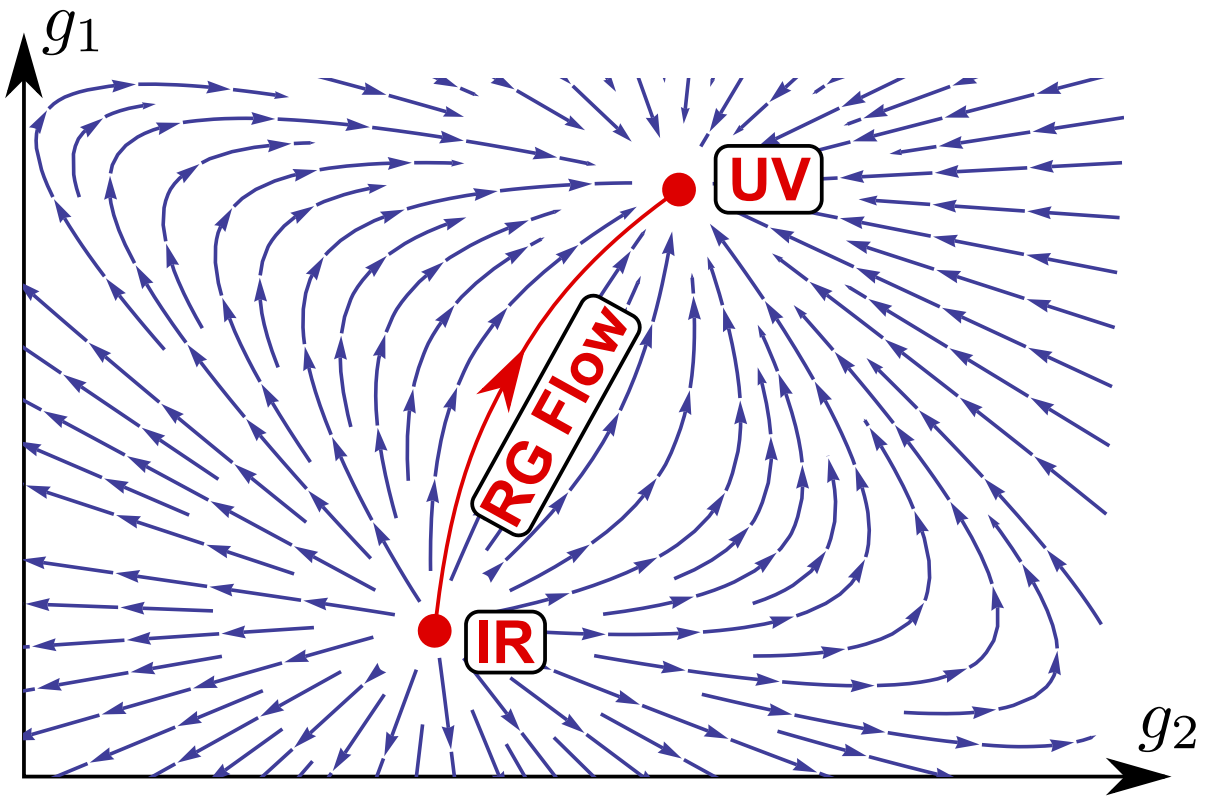
Basic idea of holography



Basic idea of holography



Basic idea of holography



The holographic dictionary

QFT side

- Operators
- Finite temperature T
- Entanglement entropy
- Boundaries and defects

Gravity side

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

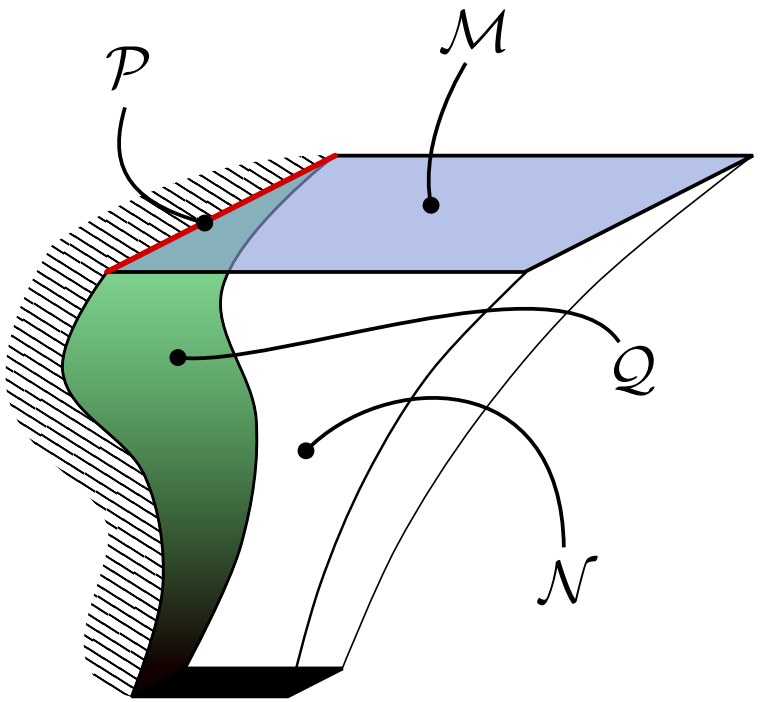
Defects and Boundaries in Quantum Field Theory

Important examples of strongly coupled QFTs include defects or boundaries with localised degrees of freedom

- Famous examples: Kondo effect and Quantum Hall effect
- Boundary/defect should be represented in the bulk
- How is this done consistently?

AdS/BCFT

- $\mathcal{P}$ is represented by $\mathcal{Q}$
- von Neumann bnd. cond.
  $\mathcal{K}_{\mu\nu} = \kappa T_{\mu\nu}$
  $(\mathcal{K}_{\mu\nu} := K_{\mu\nu} - \gamma_{\mu\nu} K)$



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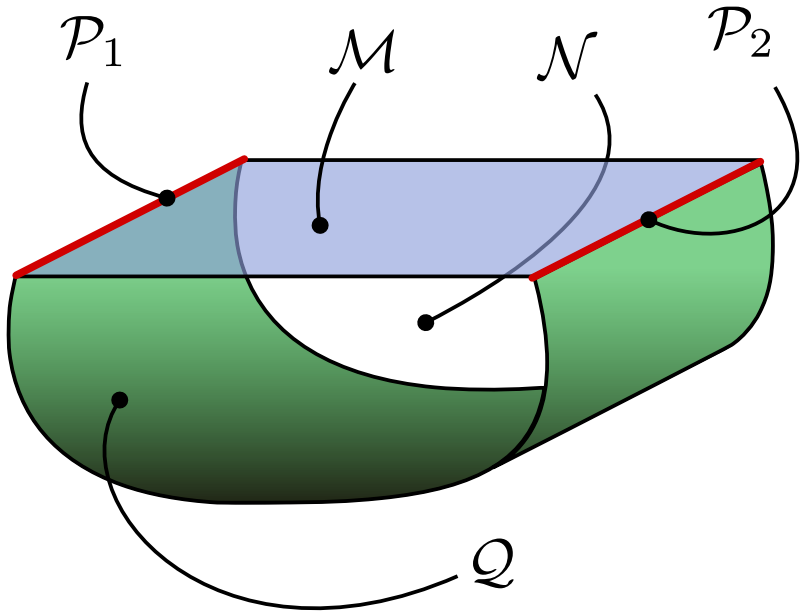
AdS/BCFT

- $\mathcal{P}$ is represented by $\mathcal{Q}$
- von Neumann bnd. cond.
  $\mathcal{K}_{\mu\nu} = \kappa T_{\mu\nu}$
  $(\mathcal{K}_{\mu\nu} := K_{\mu\nu} - \gamma_{\mu\nu} K)$
- Impose energy conditions
- Brane bends back!
- Mass gap!



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AdS/DCFT

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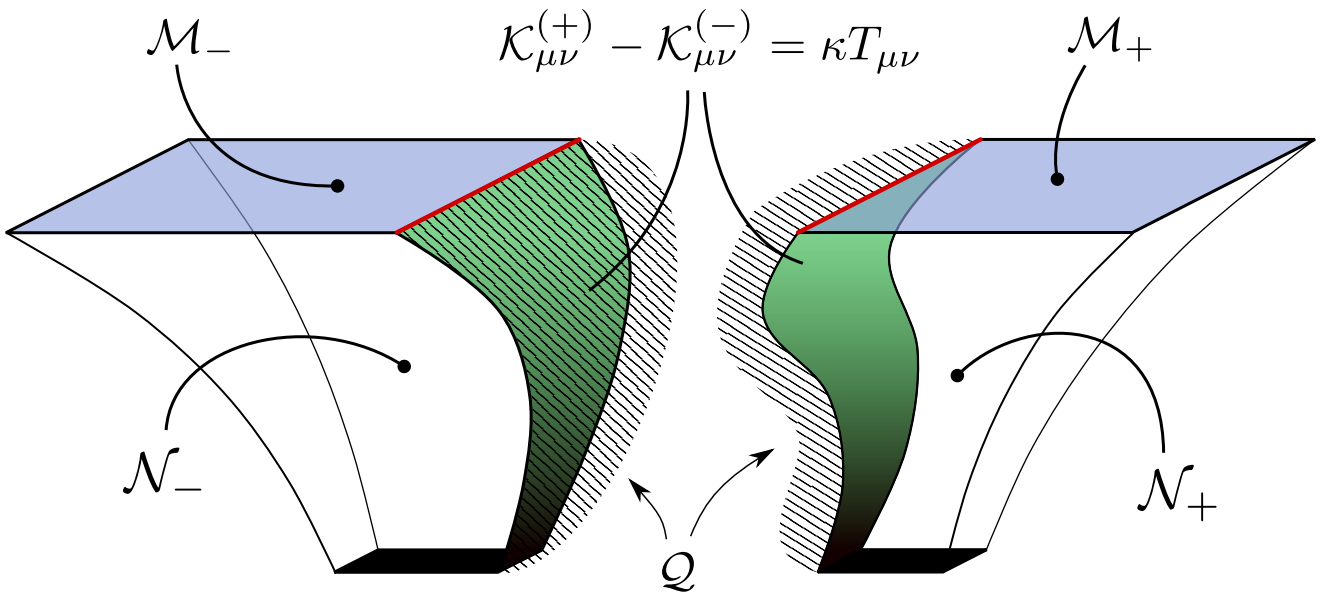
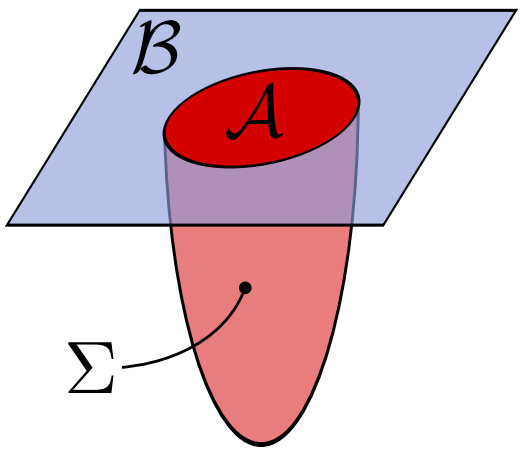


$$\mathcal{S} = \mathcal{S}_{\mathcal{N}_+} + \mathcal{S}_{\mathcal{N}_-} + \mathcal{S}_{\mathcal{M}_+} + \mathcal{S}_{\mathcal{M}_-} + \mathcal{S}_{\mathcal{Q}} + \mathcal{S}_{\mathcal{P}}$$

symmetry $\Rightarrow$ mirror spacetime $\Rightarrow$ DCFT$\Leftrightarrow$BCFT

Entanglement entropy in holography

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



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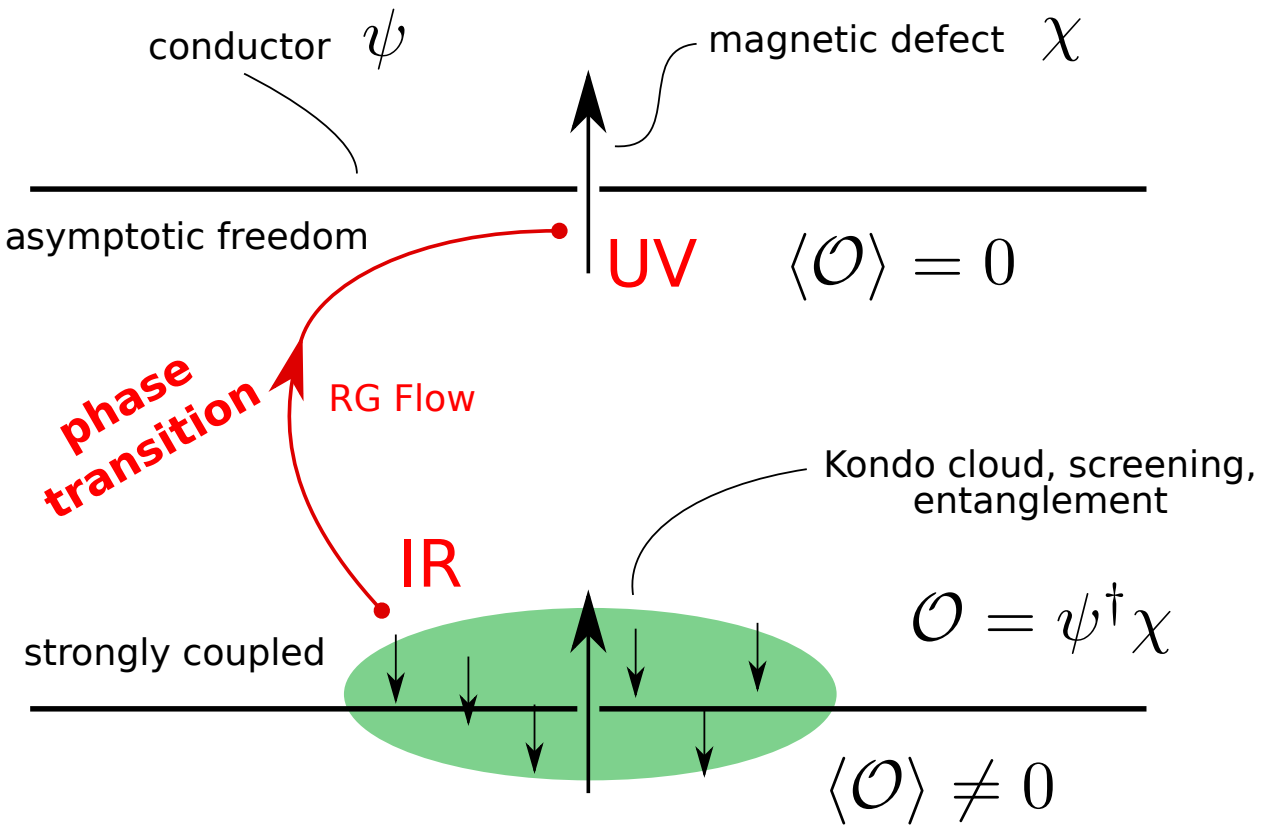
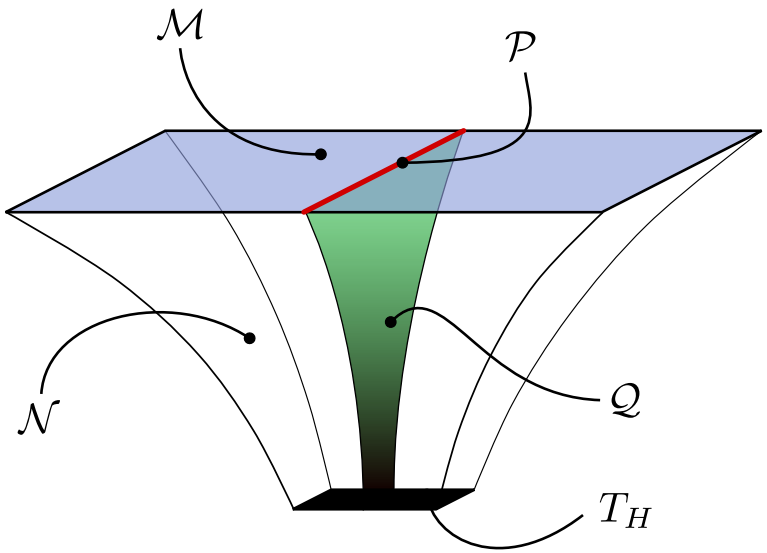
What is the Kondo effect?



The holographic Kondo model



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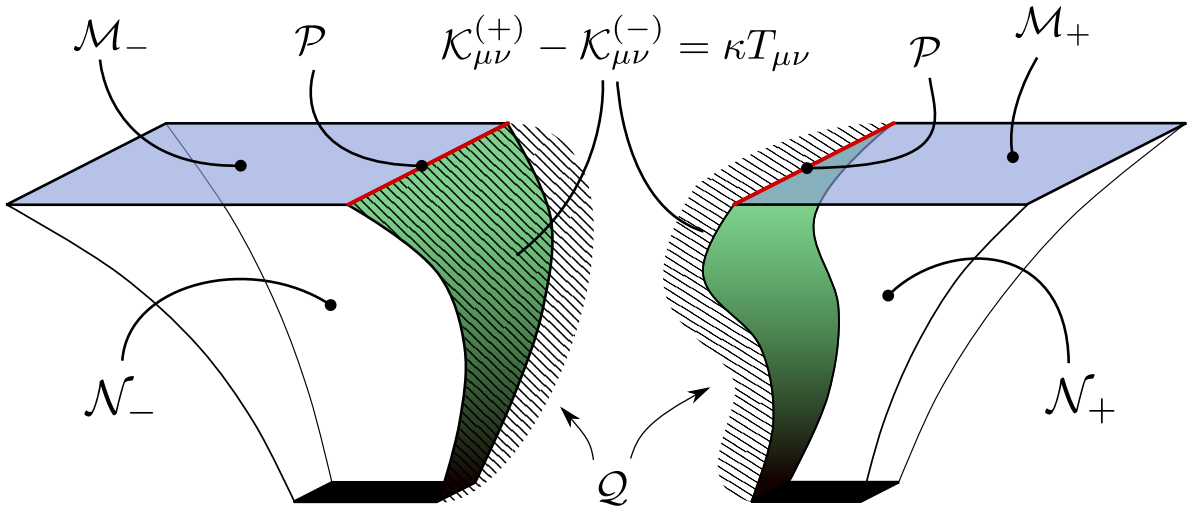
- $\mathcal{S} = \mathcal{S}_{\mathcal{N}} + \mathcal{S}_{\mathcal{M}} + \mathcal{S}_{\mathcal{Q}} + \mathcal{S}_{\mathcal{P}}$
  $\mathcal{S}_{\mathcal{N}} = \int A \wedge \mathrm{d}A \qquad \mathcal{S}_{\mathcal{Q}} = \int f^2 + |D\Phi|^2$
- No backreaction: $\kappa = 0 \Rightarrow \mathcal{K}_{\mu\nu} = 0$
- $\Rightarrow$ Cannot compute entanglement entropy!

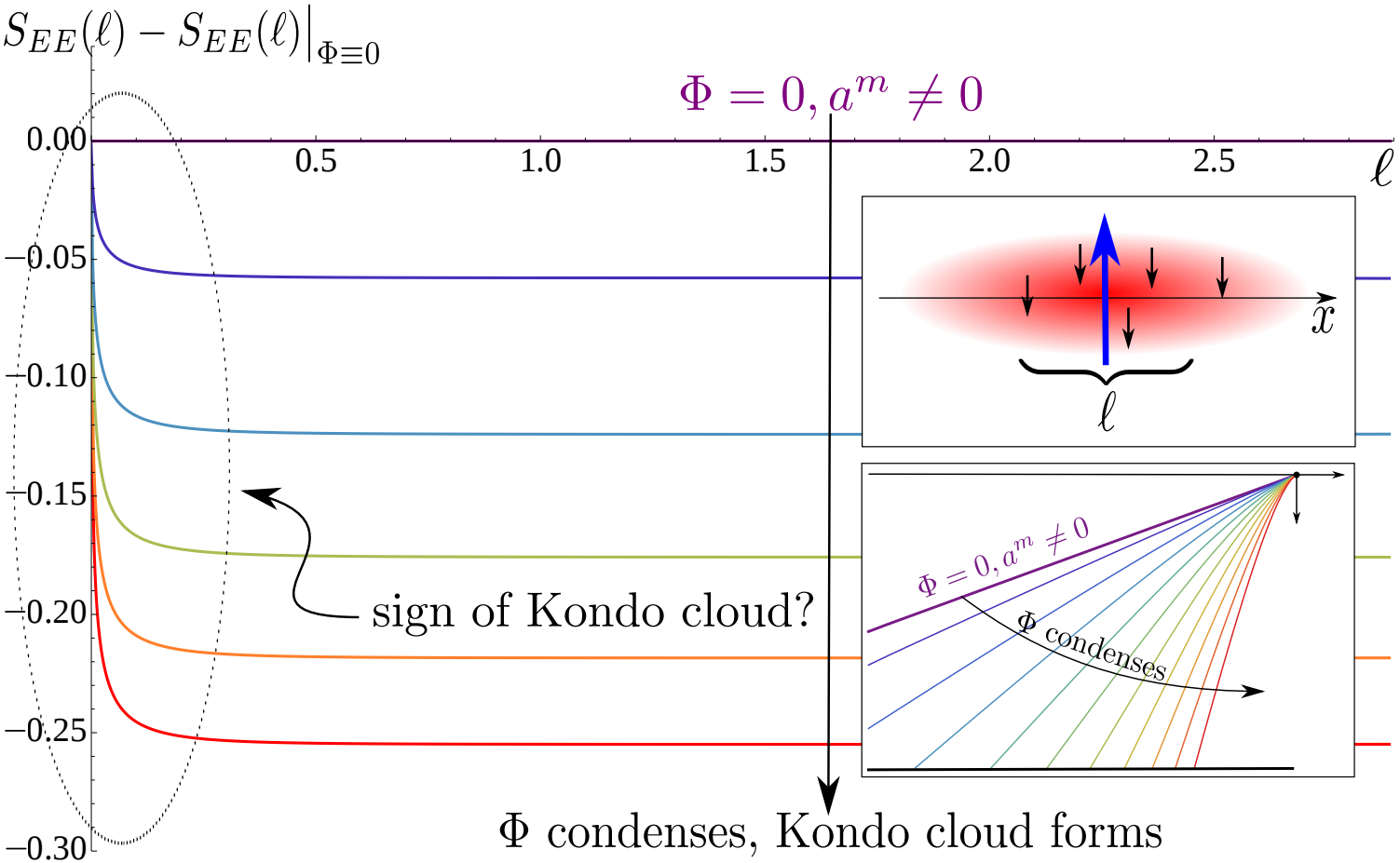
The holographic Kondo model



[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

The holographic Kondo model



[forthcoming]

Summary and Outlook

- Defects and Boundaries are represented by boundaries in the spacetime and appropriate junction conditions
- Approach to entanglement entropy in holographic Kondo model

- Kondo lattices?
- Multi channel Kondo problem?

Thank you

Null energy condition (NEC)

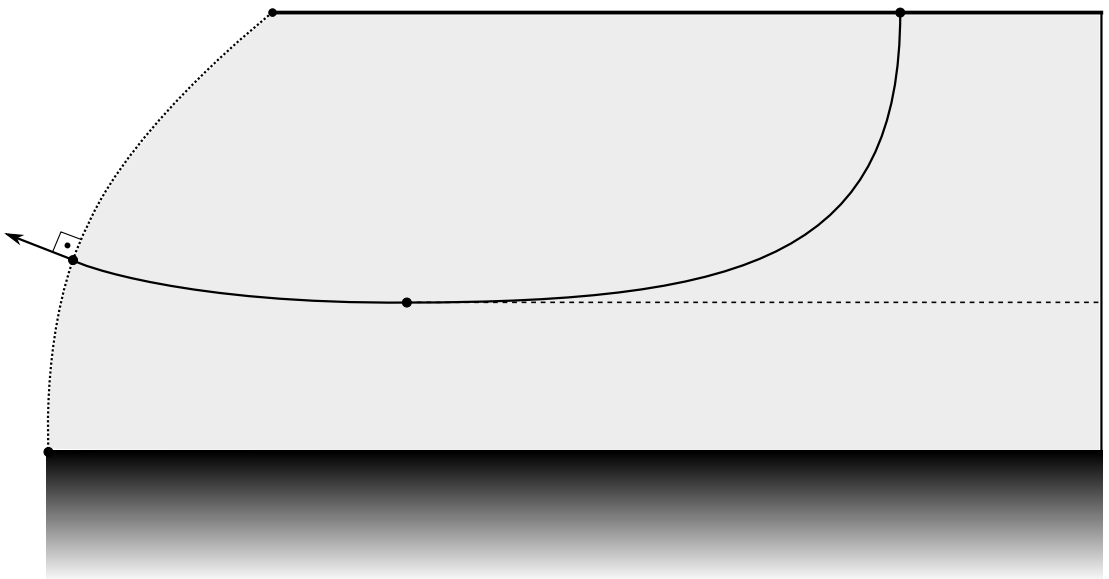
$$T_{\mu\nu}N^\mu N^\nu \geq 0 \qquad N \text{ null}$$

Weak energy condition (WEC)

$$T_{\mu\nu}N^\mu N^\nu \geq 0 \qquad N \text{ timelike}$$

Strong energy condition (SEC)

$$(T_{\mu\nu} - T\gamma_{\mu\nu})N^\mu N^\nu \geq 0 \qquad N \text{ timelike}$$



- minimal surfaces start perpendicularly at the brane
- constant brane tension $\Rightarrow$ geodesic flow