Black holes through the holography lens

Alessandra Gnecchi
CERN, Marie Skłodowska-Curie fellow

European Commission | H2020-MSCA-IF-2015
702548 GaugedBH

Marie Curie Day, November 7th, 2017

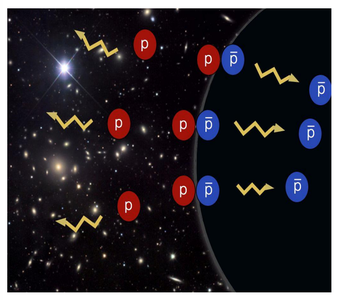
Summary
Important developments in the field of black hole physics have happened over the last few years. From an experimental point of view, direct detection of gravitational waves is providing, for the first time, information on the dynamics of black holes as solutions of general relativity. More than a hundred years from their theoretical derivation, however, there are fundamental questions, bringing together general relativity and quantum mechanics, that cannot find a resolution in the current description of gravity: the information paradox, about the unitarity of black hole evaporation, and the microscopic origin of black hole entropy. Thanks to the development of AdS/CFT correpondence, a holographic setup derived from the String/M-theory framework, many questions can be translated in purely Quantum Field Theory language. In this project, holography and Supergravity techniques are brought together to explore black holes solutions, with broad applications from information paradox and black hole microstates to quantum phase transitions. This interplay between the construction of black hole solutions from Supergravity and the analysis of their properties as states in a dual conformal field theory will shed light on the fundamental structure of spacetime and how it emerges from entanglement of quantum fields.

Introduction

Black holes are the most powerful theoretical laboratory where to test gravity at the quantum level.

Black hole puzzles are gravity *and* quantum mechanics problems:

- what is the origin of black hole entropy?
- how can unitarity be preserved in black hole evaporation?



Near horizon region is a *quantum vacuum*: pair production of particles generates a flux of radiation detected by an asymptotic observer

Hawking radiation

$$S = \frac{c^3 k_B}{\hbar G_N}\frac{A}{4}$$

$$T = \frac{\kappa}{2\pi} \sim \frac{1}{2r_h}$$

***GaugedBH* project's objectives**

1. The information paradox can be formulated in a holographic dual setup, through operators in a **dual Conformal Field Theory (CFT)**.
   - ➢ How can we describe the **black hole interior**?
   - ➢ How do quntum fields interact with gravity near the horizon?

2. Construction of **new solutions** of **AdS black holes** from Gauged Supergravity and their embedding in String Theory.
   - ➢ Explanation for their **microscopic entropy**

***GaugedBH* project's tools and innovation**

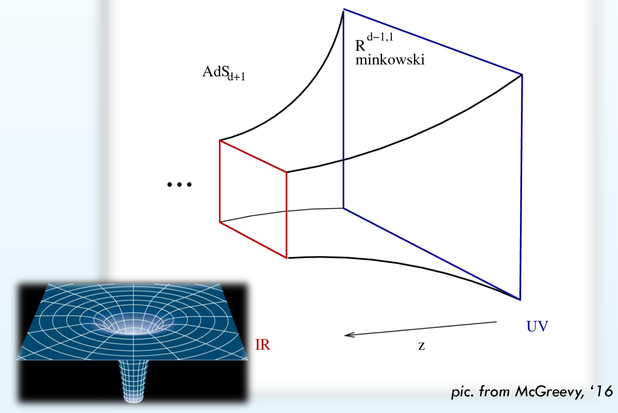
1. **AdS/CFT holography** allows to investigate quantum fields near black holes without restricting to a semiclassical approximation.
   - ➢ New: exploit the systematic approach of (2) to investigate **extremal** black holes.

2. **Supersymmetry** allows to track the origin of black hole microstates and explain their entropy. Explore microstates in a new setup, **Gauged Supergravity**, a theory that allows for solutions in Anti de Sitter.
   - ➢ New: **connect** their supersymmetric properties with the dual CFT theory living at the bounrary.

1. The power of AdS/CFT **holography**

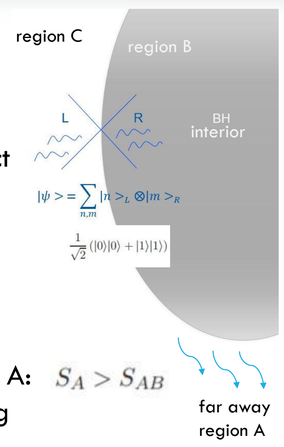
Black holes in curved space (Anti-de Sitter) are equivalent to states in a (conformal) quantum field theory *without* gravity. This theory can be identified at the boundary of Anti-de Sitter spacetime

- ➢ Study black holes through operators and observables in the *dual CFT,* at strong coupling



pic. from McGreevy, '16

Information paradox and quantum entanglement



→ Near horizon Minkowski is tensor product of two Rindler wedges $\mathcal{H}_M = \tilde{\mathcal{H}}_R \otimes \mathcal{H}_R$
→ Left and right modes are *entangled*, measure of entanglement: $S_B = -\mathrm{Tr}\,(\rho_B \log \rho_B)$
→ The pair produced near the horizon is *maximally entangled:* $S_{BC} \approx 0.$
→ For an *old black hole* radiation in region A: $S_A > S_{AB}$
But the last two conditions violate the strong subadditivity principle:

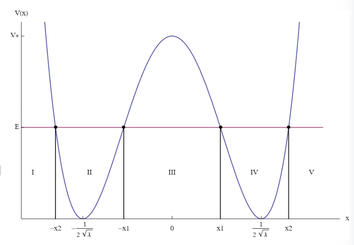
$$S_A + S_C \leq S_{AB} + S_{BC}$$

Are black hole horizons empty space or firewalls?

In (2) a proposal was formulated in which the three systems *A,B* and C are not independent. Operators acting on the interior are built from the boundary CFT ones.

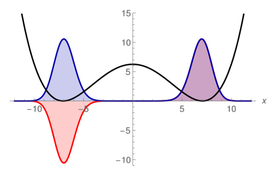
→ Explore black hole interior and inner horizons of extremal black holes

Explore the effective theory with a toy model



In (5) we show how a quantum mechanical system reproduces some of the black hole paradoxes from a QFT dual perspective

$$\psi = \psi_L + \psi_R \quad \rightarrow \quad \psi^{dbl} = \psi_L \otimes \psi_R$$

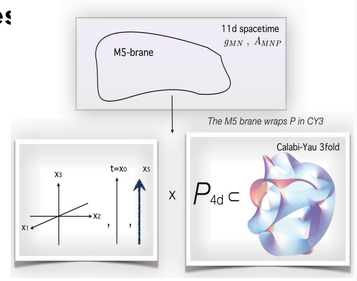


Construction of effective theory creates degeneracy among the states

2. Framework for microscopic states: **Supersymmetry**

Identify black hole **microstates** in the **String/M-theory** construction

First results had been obtained for flat space



How to describe solutions in curved space (AdS)?
➢ *Gauged Supergravity*

$$AdS_2 \times S^2 \longleftrightarrow AdS_4$$

$$\partial_i \frac{|\mathcal{Z}|}{|\mathcal{W}|} = 0 \qquad \partial_i |\mathcal{W}| = 0$$

In (1) the supergravity setup has been given for black holes *attractor equations* in AdS.
It was shown in (4) that they to correspond to an extremization mechanism that reproduces the entropy from the dual CFT.

Multidisciplinarity
Investigate quantum phase transitions with 4D black holes

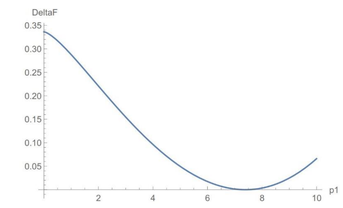
Euclidean path integral formulation of gravity at the semiclassical level

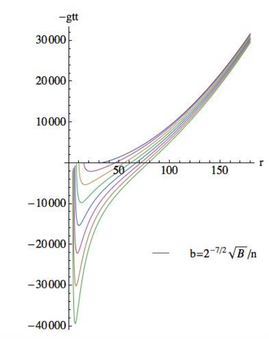
$$Z = \int d[g_{\mu\nu}]d[\phi]\exp\{iI_e[g_{\mu\nu},\phi]\}$$

The partition function defines a free energy, which, within a saddle point approximation, corresponds to the Euclidean on-shell action

$$-\beta F = \ln Z = iI_e[g^*,\phi^*]$$

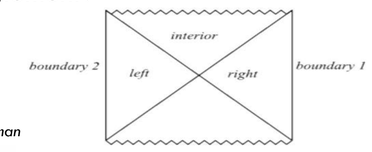
In (3), configurations with fixed magnetic charge *p* are explored:
➢ Thermal gas: limit of a family of solutions which becomes singular





Prospects and work in progress

➢ Entanglement and wormholes: how is geometry senstitive to the details of entanglement?



pic. from T. Hartman

Double sided black hole in AdS
- Dual theory is given by two CFT x CFT
- Dual state is a *specifically entangled* state

$$|\Psi_{\mathrm{tfd}}\rangle = \frac{1}{\sqrt{Z_\beta}}\sum e^{-\frac{\beta E}{2}}|E\rangle \otimes |E\rangle,$$

- What are the microstates?

➢ Zero temperature black hoels and horizon instabilities: what reveals the instabilities in the dual CFT?
➢ 5D Supersymmetric black holes and their entropy as states of the dual SYM theory from attractor equations

MSCA Fellowship
has an impact on my career path

Experienced researcher:
Previous activity in
Utrecht (NL) and Leuven (BE)

International Platform
Interactions with
experts and visitors
provide broad and effective
results dissemination

Knowledge transfer
Supergravity and Holography as complementary tools in the study of black holes
Exchange of expertise within CERN Theory group

References
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(3) A.G., Gursoy, Papadoulaki, Toldo, 1609 (2016) 090, *A magnetically induced quantum critical point in holography*
(4) Benini, Hristov, Zaffaroni, JHEP 1605 (2016) 054, *Black hole microstates in AdS4 from supersymmetric localization*
(5) Bzowski, A.G., Hertog, 2017