Quantum Complexity from Quantum Field Theories to Quantum Gravity (QComplexity)
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Quantum field theories (QFTs) are our best models to describe nature, from new phases of matter to black holes. Still, to simulate them efficiently, we need to know the best ways to create interesting quantum states from the basic building blocks used in computation. This problem necessitates a precise definition of “quantum complexity”, to quantify what is hard and what is easy in QFTs, and its provision is one of the most urgent problems at the interplay between theoretical physics, quantum information and computation.

This project aims to develop precise measures of the complexity of states and operators in QFTs and apply them, in the holographic correspondence, as new probes of black hole interiors.

Recent attempts to quantify complexity, pioneered by PI and his group, have explored geometric, path integral and Krylov methods, preparing the ground for a universal approach to complexity in quantum systems. Building on this, the project objectives are to:

- synthesise and develop complexity measures for QFTs,
- formulate them in exact holographic models,
- apply them to shed new light on the physics behind black-hole horizons and spacetime singularities.

Developing complexity measures in open quantum systems, models with additional symmetries and quantum scars, and quantifying the complexity of modular evolution are among the key milestones to achieve the objectives. Our methods will involve analytical and numerical computations in free and interacting QFTs, including integrability, conformal symmetry, Krylov basis, Arnoldi algorithm, and finally, the AdS/CFT correspondence and quantum gravity. This interdisciplinary and timely project will push the boundaries of our understanding of QFTs and black holes. The new tools that we will develop will allow us to chart the complexity frontier of quantum many-body systems, help to understand thermalisation, and shed light on the behaviour of matter near cosmological singularities relevant to our early universe.