Spacetimes of quantum black holes

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Popular abstract of the project

According to Einstein's classical theory, the horizon of a black hole separates two regions of space-time, one stationary the other collapsing and producing singularities. From under the horizon, no information gets out to the outside world. The classical theory also predicts the opposite situation, reflected in time. We call it a white hole. Then the interior of space-time expands, and the horizon separating it from the outside does not allow information to pass inside. Quantum models of the gravitational field predict that the collapse occurring inside the black hole stops, next the interior of the black hole expands and then it turns into the interior of a white hole. This effect is called bouncing. While on the question of the bouncing of the interior of the black/white hole all the models derived from Loop Quantum Gravity (LQG) are in qualitative agreement, a large discrepancy in predictions concerns the black hole exterior spacetime. We briefly describe now the most important various concepts known in the literature.

According to the Ashtekar-Bojowald paradigm, the quantum dynamics of the black hole's interior will manifest itself externally in the form of evaporation, similar to the known phenomenon predicted by Hawking, but with a different mechanism. The difference also lies in the balance of information - in the AB paradigm nothing is lost, because at the level of quantum theory the evolution of the state of geometry and matter is unitary.

The quantum-classical Rovelli-Haggard spacetime in the past is isometric to the exterior spacetime of the Schwarzschild black hole. In particular, it has the corresponding horizon. However, the horizon enters a quantum region that appears in its path. A new horizon that leaves the quantum region is located so that it is just like a white hole horizon. The presence of the quantum region legitimizes the interpretation of this structure as a black hole / white hole transition.

Husain and collaborators tracked the formation, evolution and disappearance of the horizons using effective quantum-modified Einstein equations and their solutions: effective quantum-modified spacetimes. They concluded that the reflection of the interior is accompanied by a shock wave passing through the exterior.

The common feature of the above three scenarios is the process of disintegration of the black hole initiated by the bounce of its interior. They differ as to whether it will be an evaporation, a transition into a white hole or a shock wave.

Qualitatively different scenario comes from Ashtekar, Olmedo and Singh deriving the black hole from the within. The effective metric tensor found there leads to a spacetime extension taking the form of an infinite tower of modified Schwarzschild spacetimes. The bounce of the vacuum interior spacetime occurs below the horizon and remains there, the interior expands into another copy of spacetime. Similar conclusion was drawn by Bobula and later by the author of this project and collaborators from the analysis of the quantum Oppenheimer-Snyder model they derived.

The goal of our project is to investigate this discrepancy in more depth. What is the effect on space-time outside the black hole that, thanks to quantum effects, the collapsing interior instead of falling into the singularity bounces and then expands smoothing the singularity?

The quantum effects can also affect the spacetime of black holes from the outside. Indeed, realistic black holes are immersed in the cosmological universe that is expanding after the Big Bounce according to the Loop Quantum Cosmology models. That leads to a next question:

What effect do the quantum properties of the surrounding bouncing universe have on the black hole coexisting with it, in particular, when the universe was highly compressed so the black hole contained within it was highly squeezed?

To find answers to those questions, we will study the mechanism for the generation of the effective modified Einstein's equations from LQG models and investigate the equations themselves. We will explore their solutions, known effective spaces, as well as possible new ones we discover. We will investigate the consistency problem between regions of spacetime containing collapsing matter on one side of a junction surface and empty effective spacetime on the other side. In classical relativity it is related with the Oppenheimer-Snyder model. We will investigate its quantum-modified version. We will also construct and examine the hybrid quantum-classical spacetimes, to what new space-times they lead and whether they are physically justified.

The departure of an effective gravitational field from the classical Einstein equations may be viewed as a presence of unknown source of gravity. After all the energy-momentum tensor defined by classical Einstein's equations is not zero. Can this effect be similar to that called the dark matter?