

Research

Loop Quantum Gravity and black holes

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The black hole information paradox

In 1976, Hawking understood that his theory of black hole thermodynamics implied a curious phenomenon. If a black hole shrinks by emitting thermal radiation to infinity, what happens to the information that has fallen into the black hole after it has completely evaporated? According to quantum mechanics, no realistic process can destroy information. However, Hawking's computation suggests that it does, because the radiation emitted to infinity from the black hole carries no information at all about what has fallen into the black hole. This is the information problem, probably the most ambitious and fundamental problem in modern theoretical physics, because it confronts directly two theories thought to be incompatible: general relativity and quantum field theory. Its resolution could unravel quantum gravity, considered to be the grail of physics, teaching us how to solve the problem of the singularity inside black holes and the problem of the origin of the universe.

During his PhD thesis, Sami, in collaboration with Alejandro Perez, came up with an audacious idea. The information is not destroyed in the black hole, but is dissipated into the gravitational microscopic degrees of freedom close to the singularity, where the quantum effects can no longer be neglected. Therefore, the information is conserved, in accordance with quantum mechanics, but untractable for all practical purposes. Think about dropping an egg. When it meets the floor, the egg cracks, and most of the information about its internal structure is lost through microscopic correlations between the elements constituting the egg and the atoms of the floor. Of course, one cannot recover the information about the initial state of the egg in practice, but it is only due to our own limitations. In principle, one could analyze the correlations induced by the impact and recover everything that can be said about the egg.

Sami and Alejandro understood that a similar story could apply during a black hole collapse. Here the role played by the correlations modifying the state of the atoms of the floor is induced an additional parameter they introduced in a microscopic description of gravity, labeling the different "microstates" of the quantum gravitational field and inspired by quantum gravity models such as loop quantum gravity. They explained how such a parameter could store parts of the initial information that has fallen into a black hole. Through their work, they opened the door to a new avenue of research that could lead to a complete description of the fate of information swollen into a black hole. In addition, by outlining the presence and the importance of additional microscopic degrees of freedom, the ideas defended by Sami and Alejandro brought new insights about possible new phenomenologies based on transfers of energy and information from the macroscopic level to the microscopic world.

These results were published in Entropy 25 (2023) 11, 1479: <https://arxiv.org/pdf/2307.10254>.

Are models of quantum gravity compatible with effective field theory?

The modern understanding of our best theories of the fundamental interactions is that these theories are effective: they are a low-energy description of more fundamental but experimentally inaccessible degrees of freedom. Therefore, as long as one performs experiments blind to such large energy scales, the outcomes should be explained from a theory involving only low energy degrees of freedom. Indeed, one does not need to take into account quark-gluon interactions to describe Newton mechanics or fluid dynamics. Similarly, if nowadays a complete description of gravity at arbitrarily large scales is still considered to be out of reach, some quantum gravity effects might still be observed at low energy.

If general relativity, our most powerful and precise classical theory of gravity, cannot be quantized as a ultraviolet complete (i.e. at arbitrary short scale or large energy) field theory, it can still be quantized as an effective field theory, i.e. it means that one can get a useful description of quantum gravity as long as one does not explore energy scales close to the Planckian regime. Therefore, it is a very interesting task to compare some ultraviolet complete models of quantum gravity, such as loop quantum gravity or string theory, to quantum gravity on an effective level. These comparisons can be a powerful tool in order to rule out some of these models, since quantum gravity as an effective field theory is a very reliable theory, and if the ultraviolet description does not match the effective theory predictions then the reasons of this mismatch should be carefully investigated, and may even be a strong reason to rule out the chosen ultraviolet description.

Absence of experimental tests of quantum gravity has led us to a vast landscape of speculative theories whose connection to more well understood and well established descriptions of gravity. In his paper, Sami compared models of quantum gravity used to explain the quantum transitions between a black hole and a white hole to the effective field theory predictions of quantum gravity. His results showed that many spacetime metrics used for these models are in fact incompatible with this effective description of quantum gravity, strongly suggesting that these models cannot be a fundamental description of nature. Moreover, he computed the parameters of these symmetry-reduced models used in this kind of analysis ensuring compatibility with the effective description. These results provide an explicit link between a low-energy description of quantum gravity and more speculative high-energy completions.