

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>.

Updated 2026-03-22 19:43:42 UTC by malika