Black holes and matter in the Euclidean path integral approach to quantum gravity

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Abstract

Microscopic gravitational systems with black holes and matter present quantum and thermodynamic properties that can lead to a better understanding of the microscopical gravitational degrees of freedom. Due to the quantum uncertainty near the black hole event horizon, gravitons and matter field quanta are extracted out from the local vacuum and emitted to infinity with the Hawking temperature. By itself, a black hole loses mass in this emission process until it disappears. To understand the conversion between black holes and hot matter in equilibrium, one encloses the black hole and the matter in a heat reservoir, which is maintained at constant temperature and radius, and which characterizes the statistical mechanics canonical ensemble. A thermodynamic treatment for the black hole plus matter system is then possible. We model the hot matter fields by a hot shell that surrounds a black hole and is inside the heat reservoir. To work out the quantum partition function, from which the thermodynamics emerges, we use the Euclidean path integral approach to quantum gravity that identifies the path integral with the partition function itself. In a zeroth order evaluation, one computes the Euclidean classical action, which at this order is equal to the thermodynamic free energy divided by the temperature. Important consequences related to the energy, the temperature stratification, the entropy, and the stability of the system unfold. A significant result is the finding that the total entropy depends solely on the gravitational radius of the system. This gravitational radius in general is not an event horizon, rather it depends in a specific way on the matter energy density, the radius of the shell, and the black hole radius. Another important finding is that in the ensemble there are several thermodynamic phases, specifically, pure black holes, pure hot shells, hot shells with a black hole, and hot flat spaces, allowing for the establishing of the possible phase transitions between them through the identification of the ground state phase of the ensemble. Yet another result, is that these systems can perform not only as the well-known geometric mimickers, but also as authentic black hole thermodynamic mimickers.

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