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Quantum thermal machines in black hole spacetime

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We present a general framework for understanding the finite-time operation of relativistic quantum thermal machines, focusing on their energy optimization. As an example, we introduce an Otto thermodynamic cycle where the working medium is a qubit Unruh-DeWitt detector interacting with a massless, conformally coupled scalar field in the Hartle-Hawking vacuum of a (2+1)-dimensional BTZ black hole spacetime. The thermal properties of the field are employed to model the heat and cold reservoirs driving the cycle. Modeling the detector as an open quantum system, we use a master equation to study its finite-time dynamics during each cycle stroke. We evaluate the output performance of the Otto heat engine and refrigerator by computing, respectively, the total work output and the cooling power. Additionally, we evaluate the optimal performance of the thermal machine by analyzing its efficiency at maximum power output and ecological impact.

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