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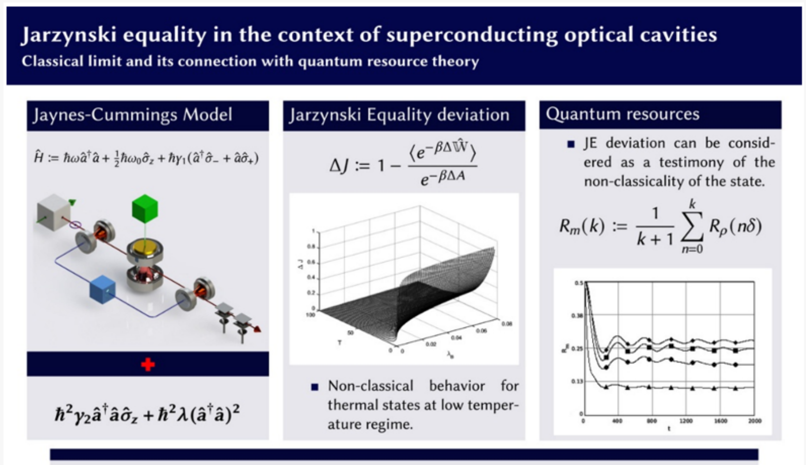

Jarzynski equality in the context of superconducting optical cavities: Classical limit and its connection with quantum resource theory

FAYETTEVILLE, GA, UNITED STATES, March 13, 2026 /EINPresswire.com/ -- This article investigates the classical limit of the Jarzynski equality in quantum systems, specifically using a nonlinear Jaynes-Cummings model representing a superconducting optical cavity with Kerr nonlinearity.
Key Findings:
Two Distinct Regimes: The study reveals a classical regime at high temperatures and low Kerr intensities where the Jarzynski equality holds, and a quantum regime at low temperatures and high Kerr intensities where it fails.
Quantum Resource Identification: The Kerr nonlinearity term creates quantum behavior that can be identified as a quantum resource for quantum computing advantages in non-zero temperature environments.
Work Operator Definition: The authors use a work operator in the interaction picture and apply Dyson expansion to evaluate the averaged exponentiated work.
Temperature-Nonlinearity Interplay: An intricate relationship between Kerr nonlinearity and temperature governs the quantum-to-classical transition and determines the validity domain of the Jarzynski equality.
Nonclassical Behavior: External work increases the state's nonclassicality, with deviations from Jarzynski equality serving as evidence of quantum behavior.

A new study published in KeAi's Quantum Review Letters examines the classical limit of a quantum formulation of the Jarzynski equality using a nonlinear Jaynes–Cummings Hamiltonian that models a field in a superconducting optical cavity with a Kerr medium.

I.P. Vieira, the lead and co-corresponding author, said the work aims to clarify "where the quantum version of the Jarzynski equality reproduces classical behaviour, and where genuinely quantum effects begin to dominate."

To evaluate the averaged exponentiated work, the authors applied a Dyson expansion and defined the work operator in the interaction picture. This yielded an analytical expression that can be used to probe the Jarzynski equality in the quantum regime. “By making the work operator explicit in the interaction picture, the analysis becomes tractable in a way that also remains closely tied to the underlying physics of the model,” explains Vieira.

Computational results identified two distinct operating regimes: a classical regime at high temperatures and low Kerr intensities, and a quantum regime at low temperatures and high Kerr intensities. Because the system remains in equilibrium with a thermal bath, the researchers attribute the emergence of the quantum regime specifically to the Kerr nonlinearity. “The transition does not come from driving the system out of equilibrium; it comes from the Kerr term itself, which reshapes the energy landscape and makes quantum signatures persist even at non-zero temperature,” shares Vieira.

The findings suggest that Kerr-induced nonlinearity can function as a quantum resource in thermal settings, offering a route to quantum advantages under realistic, finite-temperature conditions. “If the Kerr contribution can be controlled, it becomes more than a modelling detail — it becomes a handle for engineering useful quantum behaviour in environments where temperature cannot be ignored,” adds Vieira.

References
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