A New Framework for Quantum Phases in Open Systems: Steady State of Imaginary-Time Lindbladian Evolution

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This study delves into the concept of quantum phases in open quantum systems, examining the shortcomings of existing approaches that focus on steady states of Lindbladians and highlighting their limitations in capturing key phase transitions. In contrast to these methods, we introduce the concept of imaginary-time Lindbladian evolution as an alternative framework. This new approach defines gapped quantum phases in open systems through the spectrum properties of the imaginary-Liouville superoperator. We find that, in addition to all pure gapped ground states, the Gibbs state of a stabilizer Hamiltonian at any finite temperature can also be characterized by our scheme, demonstrated through explicit construction. Moreover, the closing of the imaginary Liouville gap is associated with the divergence of the Markov length, which has recently been proposed as an indicator of phase transitions in open quantum systems. To illustrate the effectiveness of this framework, we apply it to investigate the phase diagram for open systems with $Z_2^\sigma \times Z_2^\tau$ symmetry, including cases with nontrivial average symmetry protected topological order or spontaneous symmetry breaking order. Our findings demonstrate universal properties at quantum criticality, such as nonanalytic behaviors of steady-state observables, divergence of correlation lengths, and closing of the imaginary-Liouville gap. These results advance our understanding of quantum phase transitions in open quantum systems. In contrast, we find that the steady states of real-time Lindbladians do not provide an effective framework for characterizing phase transitions in open systems.

[1] Y. Guo, K. Ding, and S. Yang, Rep. Prog. Phys. 88, 118001 (2025).