Cooling towards a quantum critical point: Universality and scaling in open quantum systems

Michael Kastner[1,3], Emma C. King[2], and Johannes N. Kriel[1]

[1]*Stellenbosch University, Merensky Building, Stellenbosch 7600, South Africa*
[2]*Universität des Saarlandes, 66123 Saarbrücken, Germany*
[3]*Hanse-Wissenschaftskolleg, 27753 Delmenhorst, Germany*

Signatures of equilibrium phase transitions can be imprinted into the nonequilibrium dynamics of many-body quantum systems, resulting in the emergence of universal scaling laws out of equilibrium, as exemplified by the Kibble-Zurek mechanism. In a similar spirit, but novel setting, I report scaling and universality in open nonequilibrium quantum systems that are cooled towards a quantum critical point. The excess excitation density, which quantifies the degree of adiabaticity of the dynamics, is found to obey scaling laws in the cooling velocity as well as in the initial and final temperatures of the cooling protocol. The scaling laws are universal, governed by the critical exponents of the quantum phase transition. The validity of these statements is shown analytically for a Kitaev quantum wire coupled to Markovian baths, and subsequently argued to be valid under rather general conditions. Remarkably, these results establish that quantum critical properties can be probed dynamically at finite temperature, without even varying the control parameter of the quantum phase transitions.

[1] E. C. King, J. N. Kriel, and M. Kastner, Universal cooling dynamics toward a quantum critical point, Phys. Rev. Lett. **130**, 050401 (2023).

[2] E. C. King, M. Kastner, and J. N. Kriel, Long-range Kitaev chain in a thermal bath: Analytic techniques for time-dependent systems and environments, arXiv:2204.07595.