

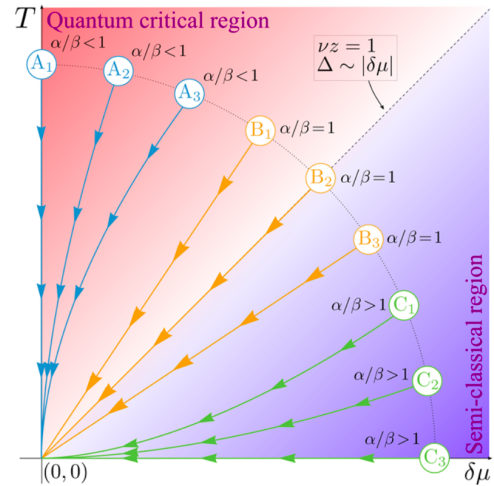
Nonlinear quantum Kibble-Zurek ramps in open systems at finite temperature

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A popular strategy for observing scaling behaviour and universality in non-equilibrium settings is to drive a system out of equilibrium in such a way that the properties of an underlying equilibrium phase transition imprint on certain non-equilibrium quantities. A prime example of this is the quantum Kibble-Zurek mechanism [1,2,3]: For a system in equilibrium at zero temperature and at some initial parameter value μ far from its critical value μ_c , a gradual ramp of μ results in adiabatic dynamics and leaves the system equilibrated. When μ gets sufficiently close to μ_c , critical slowing down forces the system out of equilibrium. Suitably chosen quantities then display scaling laws governed by the critical exponents of the underlying phase transition.

In open quantum systems the presence of a zero temperature phase transition can imprint on physical quantities at low, nonzero temperatures. This suggests devising ramping protocols that operate at nonzero temperatures, but nonetheless lead to scaling laws governed by the underlying critical point [4,5,6]. However, performing a similar parameter ramp at a fixed, nonzero temperature introduces an additional timescale, resulting in the "clean" power-law scaling getting polluted. Relevant observables now no longer exhibit power-law scaling at leading order in the ramp velocity. An approach that circumvents this problem was put forward in [7], where it was shown that clean scaling laws, governed by quantum critical exponents, can be obtained by ramping the temperature from a nonzero initial value to a nonzero finite value. Here we extend the approach of [7] and analyse quantum systems under a broad class of protocols in which the temperature and a Hamiltonian control parameter are ramped simultaneously, and possibly non-linearly, toward a quantum critical point. Using an open-system version of a Kitaev quantum wire as an example, we show that these protocols allow us to probe, in an out-of-equilibrium situation and at finite temperature, the universality class of an equilibrium quantum phase transition. Key to this is the identification of ramps in which both coherent and incoherent parts of the open-system dynamics affect the excitation density in a non-negligible way. We also identify the specific ramps for which sub-leading corrections to the asymptotic scaling laws are suppressed, which may serve as a guide to dynamically probing quantum critical exponents in finite-temperature situations [8].



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