

Theory of dynamical phase transitions driven by excited-state quantum phase transitions

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During recent years there has been a growing interest in the different kinds of phase transition that many-body quantum systems may exhibit as well as in the thermodynamic properties associated to the resulting quantum phases. Besides the well-known quantum phase transition, occurring in the ground-state of a physical system as a certain control parameter is varied, and its generalization to high-lying levels, excited-state quantum phase transitions (ESQPTs), two new forms of non-analytic behavior have been explored, especially in models with long-range and infinite-range interaction: they have been termed dynamical phase transitions (DPTs). The first kind, which we call DPT-I, is characterized by an abrupt change of a given order parameter after a quench from an initial value of a control parameter to a final value; these values are in general unrelated to the critical quench leading the system to the (ground-state) quantum phase transition. The second kind of DPT, which we call DPT-II, consists in non-analytic point in the return probability (sometimes also called Loschmidt echo or survival probability) at certain critical times after a quench from an initial state in a broken-symmetry phase where the eigenlevels are pairwise degenerate. The signatures of both kinds of DPTs sharpen as the system size of the model is increased.

In this talk I will present a theory for the two kinds of dynamical quantum phase transitions in a large class of collective many-body systems (that is, with infinite-range interaction). These two DPTs are shown to be rooted in excited-state quantum phase transitions. For quenches below the critical energy of the ESQPT, the existence of an additional conserved charge [1] identifying the corresponding broken-symmetry phase means that the dynamical order parameter of DPTs-I can take on a non-zero value, while it becomes zero for quenches leading the initial state above the ESQPT. This same conserved charge forbids the appearance of non-analyticities in the return probability after a quench ending in the broken-symmetry phase demarcated by the ESQPT, meaning that DPTs-II are forbidden in this phase. The long-time averages of order parameters associated with DPTs-I are described by a generalization of the standard microcanonical ensemble, and we provide an analytical proof for the absence of DPTs-II within the symmetry-broken phase. Our results are exemplified by means of the fully-connected transverse-field Ising model, which is mathematically equivalent to a simple version of the Lipkin-Meshkov-Glick model, as this model shows all four kinds of phase transitions (QPT, ESQPT, DPT-I and DPT-II). These are the main findings reported in [2,3].

References:

- [1] A. L. Corps and A. Relaño, \textit{Constant of Motion Identifying Excited-State Quantum Phases}, Phys. Rev. Lett. \textbf{127}, 130602 (2021).
- [2] A. L. Corps and A. Relaño, \textit{Theory of dynamical phase transitions in collective quantum systems}, arXiv:2205.03443.
- [3] A. L. Corps and A. Relaño, \textit{Dynamical phase transitions in collective quantum systems}, Companion paper, In preparation.

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