量子物理学・ナノサイエンス第 94 回特別セミナー

Kibble-Zurek mechanism for nonequilibrium phase transitions in driven systems with quenched disorder

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概　要

The Kibble-Zurek (KZ) mechanism describes the density of defects as a system is quenched through an equilibrium phase transition. The KZ scenario predicts a universal power law scaling and has implications for continuum phase transitions in the early universe, materials science, and condensed matter systems [1,2]. An open question is whether the KZ scenario also holds for nonequilibrium phase transitions. We show that the Kibble-Zurek mechanism applies to nonequilibrium phase transitions found in driven assemblies of superconducting vortices and colloidal particles moving over quenched disorder where a transition occurs from a plastic disordered flowing state to a moving anisotropic crystal. We measure the density of topological defects as a function of quench rate through the nonequilibrium phase transition, and find that on the ordered side of the transition, the topological defect density ρ_d scales as a power law with t_q, the quench time duration, consistent with the Kibble-Zurek mechanism. We show that scaling with the same exponent holds for varied strengths of quenched disorder and that the exponents fall in the directed percolation (DP) universality class [3]. Our results suggest that the Kibble-Zurek mechanism can be applied to the broader class of systems that exhibit absorbing phase transitions. We also examine a system of skyrmions with a strong Magnus force component that are driven over random disorder and exhibit a dynamic transition from a fluid to a two-dimensional crystal. In this case we find a different set of exponents and we argue that the critical behavior is associated with coarsening since the defects can both climb and glide [4]. We discuss how systems with non-equilibrium phase transitions such as glasses, turbulence, time crystals, or systems exhibiting a reversible-irreversible transition could also be interesting places to look for Kibble-Zurek type dynamics.

(*Collaboration with Cynthia Reichhardt and Adolfo del Campo)

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[3] C.J.O. Reichhardt, A. del Campo, and C. Reichhardt, "Kibble-Zurek mechanism for nonequilibrium phase transitions in driven systems with quenched disorder." Commun. Phys. **5,** 173 (2022).
[4] S. Maegochi, K. Ienaga, and S. Okuma, "Kibble-Zurek mechanism for dynamical ordering in a driven vortex system." Phys. Rev. Lett. **129,** 227001 (2022).
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