

Universal dynamics of 3D Bose gases near the superfluid transition in the collective scattering regime

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Understanding the many-body dynamics of a quantum system after a quench is a central challenge in modern physics. In particular, quantum gases quenched across a phase transition evolve toward so-called nonthermal fixed points, characterized by a critical slowing down and a spatio-temporal scaling of correlations with universal exponents [1]. Recently observed experimentally [2][3], this behavior extends the concept of universality to nonequilibrium systems. In our work, we use a quantum kinetic framework to describe collective scattering that takes place in highly occupied spectral regions. We then theoretically study three-dimensional Bose gases suddenly cooled across their superfluid transition. For weak quenches, we recover early-time inverse and direct energy cascades that are characteristic of weak turbulence where collective scattering is negligible [4]. For strong quenches, collective scattering dominates, thus modifying the dynamical exponents and amplifying the bidirectional nature of the cascades (Fig. 1a). Our work shows that there exists a crossover between two dynamical universality classes, which is entirely controlled by the depth of the quench (Fig. 1b).

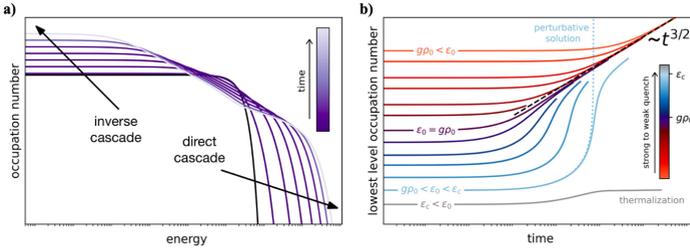


Fig. 1: **a)** Bidirectional cascade for an initial post-quench Gaussian distribution with energy width $\varepsilon_0 = g\rho_0$, where g is the contact potential strength and ρ_0 the gas density. **b)** Focus on the inverse cascade: time evolution of the lowest energy occupation number for different quench depths. Red indicates strong quenches ($\varepsilon_0 < g\rho_0 < \varepsilon_c$) and blue indicates weak quenches ($g\rho_0 < \varepsilon_0 < \varepsilon_c$). At long times, a universal scaling law emerges if $\varepsilon_0 < \varepsilon_c$, which corresponds to the case where the initial post-quench distribution cannot lead to thermalization of the system.

References

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