Universal Self-Organization Dynamics in a Strongly Interacting Fermi Gas

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Cavity-coupled many-body systems constitute a new emergent field in condensed matter systems, where complex quantum materials are combined with cavity quantum electrodynamics (cQED) to substantially modify material properties by strong light-matter coupling [1, 2]. One particularly fascinating perspective is the modification of superconductivity with light [3–5]. However, due to the complexity of condensed matter systems, numerous fundamental questions remain unanswered. By combining cQED with a strongly interacting Fermi gas [6], we bridge the gap between ultracold bosonic gases [7] and condensed matter systems, providing an ideal, microscopically controllable platform for the study of collective light-matter coupling in strongly correlated matter. Our most recent research explores the interplay of strong, short-range collisional interactions in the Bose-Einstein condensate to Bardeen-Cooper-Schrieffer (BEC-BCS) crossover and engineered, long-range cavity-mediated interactions [8]. In our latest experiments, we advance our understanding of density-wave ordering by investigating the out-of-equilibrium dynamics of quenches across the quantum phase transition in the BEC-BCS Crossover. By observing the photons leaking from the optical cavity following a quench in atom-light coupling, we reveal the universal behaviour of the critical slow-down in this driven-dissipative system. Additionally, in a separate series of experiments, we introduce a new type of cQED many-body system, where long-range interactions between pairs and atoms are engineered by performing self-organization close to a photoassociation transition.

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