Non-equilibrium quantum matter through the prism of quantum entanglement

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The remarkable experimental advances made it possible to create highly tunable quantum systems of ultracold atoms and trapped ions. These platforms proved to be uniquely suited for probing non-equilibrium behavior of interacting quantum systems. From statistical mechanics, we expect that a non-equilibrium system will thermalize, settling to a state of thermodynamic equilibrium. Surprisingly, there are classes of systems which do not follow this expectation. I will give examples of systems which avoid thermalization, thanks to disorder-induced localization and other mechanisms. While thermalization leads to “scrambling” of quantum information, its absence may protect local quantum coherence. This enables non-equilibrium states of matter not envisioned within the framework of statistical mechanics. I will highlight the recent theoretical insights into the remarkable physical properties of such states, based on the underlying patterns of quantum entanglement. I will finally describe our attempts to find new kinds of non-thermalizing dynamics, including quantum many-body scars, and a possible route towards developing a classification of dynamical universality classes in many-body systems.