Thermal inclusions in the many-body localized phase in higher dimensions

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Many-body localized (MBL) systems fail to locally equilibrate themselves under their quantum dynamics and thus lie outside the framework of equilibrium statistical mechanics. They have been observed experimentally in cold atom and trapped ion systems in many different physical settings. Although a lot is known about the MBL phase in one dimension, even basic features like the stability of MBL systems to thermalizing inclusions in dimensions greater than one, and the nature of the dynamical transition between the MBL and thermalizing phases are poorly understood. In this talk, I will present a simple model to address these questions: a two level system interacting with strength J with N 1 localized bits subject to random fields. On increasing J, the system transitions from a MBL to a thermalizing phase on the scale $J_c(N)1/N$, where these interactions do not contribute to the $N \to \infty$ thermodynamics, but have strong effects on the dynamics. I will argue that the transition is sharp in the thermodynamic limit and derive a modified Harris criterion for the transition. The transition is driven by second order flip-flop processes of certain pairs of l-bits that proliferate at $J_c(N)$. In the transition region, the single-site eigenstate entanglement entropies (and other single-site observables) exhibit bi-modal distributions, so that localized bits are either on (strongly entangled) or off (weakly entangled) in eigenstates. The clusters of on bits vary significantly between eigenstates of the same sample, which provides evidence for a heterogenous discontinuous transition in single-site observables. We obtain these results by perturbative arguments at small J and also by using numerical exact diagonalization of the full many-body system up to N=11 localized bits. Our results also imply that the MBL phase is unstable to large thermal inclusions in systems with short-range interactions in dimensions d that are high but finite. Our work leaves open the possibility that MBL phases can remain stable in higher d in nonrandom systems with quasiperiodic fields or potentials that do not produce such rare thermalizing inclusions.