Thermalization propagation front and robustness against avalanches in localized systems

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We investigate a many-body localized (MBL) spin chain left-side-coupled to a $T = \infty$ thermal bath. We find a logarithmically slow propagation of heat that provides a parameter range where MBL is robust to instabilities.

Thermalization in quantum systems occurs by a mechanism called eigenstate thermalization hypothesis (ETH) [1–3]: Eigenstates are locally equivalent to thermal density matrices. A possible way for a system to avoid thermalization occurs in disordered systems with small enough interactions: In this case the system is still space localized and non thermalizing, a phenomenon called many-body localization (MBL) [4]. Following the works [5, 6], this topic has been tremendously explored over the last years (see the review [7]).

The stability of this phase has been questioned in the thermodynamic limit: Many-body localized systems may be unstable towards rare regions of small disorder by a mechanism dubbed "quantum avalanches" [8], a phenomenon widely studied [9–14]. An ergodic inclusion (that occurs almost certainly if the system is large enough) can thermalize the whole chain if the thermalization time of any subchain is short enough [15]. This time is numerically estimated by taking a subchain and coupling it to a thermal bath by one of its ends (that simulates the part of the chain that has already thermalized). If the slowest thermalization time (t_s), corresponding to the thermalization time of the spin farthest from the thermal bath, scales slowly enough with the size of the subchain (fast thermalization) then the avalanche propagates and the system thermalizes [15, 16].

In this framework, we estimate t_s by looking at the propagation of the thermalization front through the system, a novel approach that, to the best of our knowledge, has not yet been used in this context. Heat propagates through the system, from the bath at the leftmost site, and at any time there is a subchain on the left side that has already thermalized [see the cartoon in Fig. 1(a)]. We estimate the length of this thermalized subchain by defining a thermalization length scale $h(t)$ based on the behavior of the local magnetizations. More specifically, we take an MBL system (the disordered spin chain of [17]), couple it by one of its extremities to a $T = \infty$ onsite thermal bath (the one in [18]).

We find that in the localized chain $h(t)$ increases logarithmically in time [see Fig. 1(b)]. We can use this logarithmic increase to estimate the time when the chain is fully thermalized, and so lower bound t_s. We find that this time scale exponentially increases with the system size, and there is a regime of parameters where this exponential increase is fast enough that localization is robust against thermalization induced by avalanches. The results presented in this extended abstract can be found in [19].

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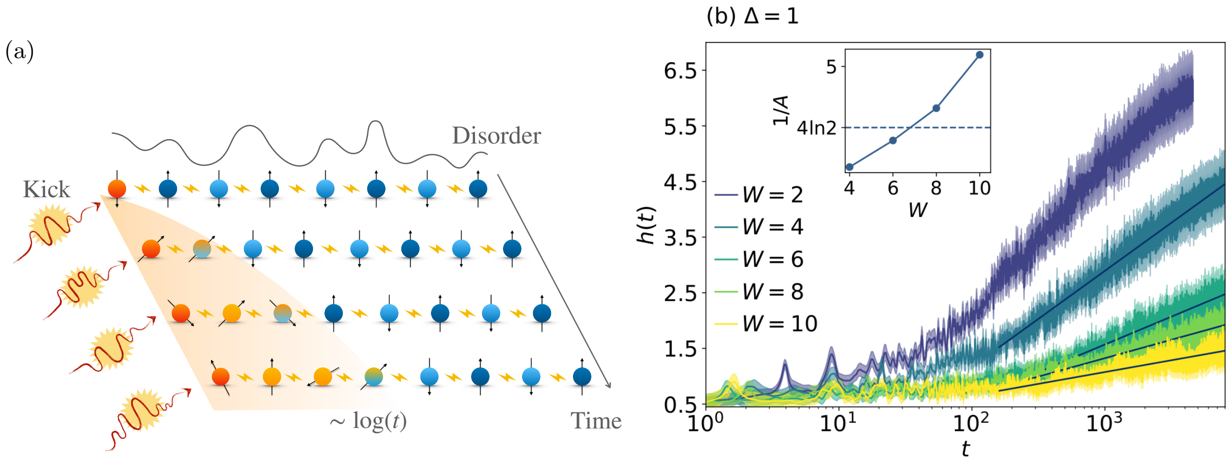

FIG. 1. (Panel a) Scheme of a 1D chain of interacting 1/2 spins with a fixed disorder profile, starting from the Néel state, and with open boundary conditions. Different copies of the system mean different subsequent times, as indicated by the time arrow on the right. The leftmost spin is coupled to a $T = \infty$ thermal bath (a time-dependent kick) and a thermalization front (shaded area) propagates logarithmically slowly. (Panel b) (Main panel) Thermalization length scale $h(t)$ versus t in a MBL chain left-coupled to a thermal bath. W is the disorder strength, notice the logarithmic scale on the horizontal axis. (Inset) $1/A$ versus W, where A is the slope obtained linearly fitting $h(t)$ versus $\ln t$, applying the fit for times large enough that the linear in $\ln t$ regime has already set in. In the inset the horizontal line marks the reference value $1/A = 4\ln 2$, above which MBL is robust against thermalization induced by avalanches.

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