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Periodically driven ergodic and many-body localized quantum systems

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ABSTRACT

We study dynamics of isolated quantum many-body systems whose Hamiltonian is switched between two different operators periodically in time. The eigenvalue problem of the associated Floquet operator maps onto an effective hopping problem. Using the effective model, we establish conditions on the spectral properties of the two Hamiltonians for the system to localize in energy space. We find that ergodic systems always delocalize in energy space and heat up to infinite temperature, for both local and global driving. In contrast, many-body localized systems with quenched disorder remain localized at finite energy. We support our conclusions by numerical simulations of disordered spin chains. We argue that our results hold for general driving protocols, and discuss their experimental implications.

1. Introduction

Quantum systems coupled to time-varying external fields are ubiquitous in nature. They exhibit many interesting phenomena including the laser, the maser, electron-spin resonance and nuclear magnetic resonance (NMR) [1,2]. The experimental developments in ultra-cold atomic or molecular gases and trapped ions in the last two decades have taken us beyond the few-atom systems into the

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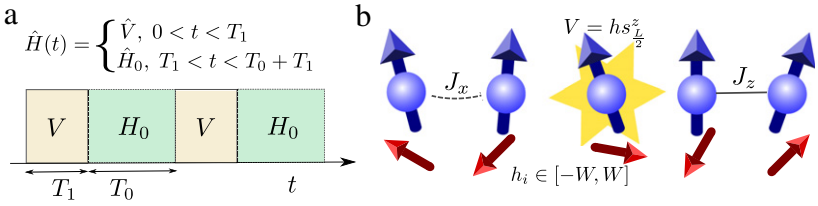

Fig. 1. (Color online) (a) A scheme of the general driving protocol. (b) Example of a 1d XXZ spin chain studied numerically (blue arrows). The Hamiltonian H_0 contains nearest-neighbor hopping and interactions, in the presence of random z-field (red arrows). Driving is performed locally by the local operator $\hat{V} = hs^z_{L/2}$ applied to the middle spin.

regime of isolated *interacting* systems, whose quantum dynamics reveals novel aspects of thermalization, transport and non-linear response [3,4].

Periodically driven systems can exhibit non-trivial steady states, even in the non-interacting limit [5–9]. An illustrative system is the kicked quantum rotor, which can dynamically localize in momentum space [5–8]. Periodic driving can also be used to control the band structure and induce topological states [10–13].

Here we study periodically driven *many-body* systems with local interactions. This problem has recently been addressed by D'Alessio and Polkovnikov [14] who hypothesized that two distinct dynamical regimes are possible: the system either (i) keeps absorbing energy, heating up to infinite temperature (e.g., defined using the time-averaged Hamiltonian) at long times, or (ii) dynamically localizes at a certain energy, similar to the case of the kicked rotor.

The long-time behavior of a driven system is determined by the properties of the so-called Floquet Hamiltonian $\hat{H}_F$, defined in terms of the Floquet operator

$$\hat{F} = e^{-i\hat{H}_F T}, \tag{1}$$

which is the evolution operator over one period,

$$\hat{F} = \mathcal{T} \int_0^T \exp(-i\hat{H}(t)t)\, dt. \tag{2}$$

Here $\hat{H}(t+T) = \hat{H}$ is the system's Hamiltonian, and $\mathcal{T}$ is time-ordering. The Floquet Hamiltonian, which determines the time evolution of the system, can be calculated perturbatively in the driving period T using the Magnus expansion [15]. The convergence of the Magnus expansion implies that there exists a physical $\hat{H}_F$ that is a sum of local terms, such that the driving dynamics is equivalent to a single quench of the Hamiltonian [14]. In this case, the system retains the memory about $\hat{H}_F$ and is at finite temperature with respect to $\hat{H}_F$ after many periods. On the contrary, if the system heats up to infinite temperature at long times, the Magnus expansion does not converge.

Here we establish the conditions under which the two dynamical regimes are realized in locally driven many-body systems. We consider a driving protocol illustrated in Fig. 1(a) where the Hamiltonian is switched between two operators periodically in time,

$$\hat{H}(t) = \begin{cases} \hat{V} & 0 < t < T_1 \\ \hat{H}_0 & T_1 < t < T_0 + T_1 \end{cases} \tag{3}$$

i.e., $\hat{H}_0(\hat{V})$ is applied during time T_0 (T_1), such that the total period $T = T_0 + T_1$. We will consider lattice systems, in which the Hilbert space on every site is finite-dimensional (e.g., an interacting spin system).

In Section 2 we map the spectral problem for the Floquet operator describing this system onto an effective hopping problem, and show that the competition between the typical matrix elements of $\tan(\hat{V}T_1/2)$ between the eigenstates of H_0 and the typical energy spacings determines whether or not the system will heat up to infinite temperature at long times. In Section 3 we discuss some of