Phase crossover induced by dynamical many-body localization in periodically driven long-range spin systems

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Dynamical many-body freezing occurs in periodic transverse field-driven integrable quantum spin systems. Under freezing conditions, quantum dynamics causes practically infinite hysteresis in the drive response, maintaining its starting value. We find similar resonant freezing in the Lipkin-Meshkov-Glick (LMG) model. In the LMG, the freezing conditions in the driving field suppresses the heating postulated by the *eigenstate thermalization hypothesis* (ETH) by inducing *dynamical many-body localization*, or DMBL. This is in contrast to many-body localization (MBL), which requires disorder to suppress ETH. DMBL has been validated by the inverse participation ratio (IPR) of the quasistationary Floquet modes. Similarly to the TFIM, the LMG exhibits high-frequency localization only at freezing points. IPR localization in the LMG deteriorates with an inverse system size law at lower frequencies, which indicates heating to infinite temperature. Furthermore, adiabatically increasing frequency and amplitude from low values raises the Floquet state IPR in the LMG from nearly zero to unity, indicating a phase crossover. This occurrence enables a future technique to construct an MBL engine in clean systems that can be cycled by adjusting drive parameters only.

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I. INTRODUCTION

In the past few years, periodically driven quantum many-body systems have been of considerable theoretical and experimental interest [1,2]. Under certain conditions in the drive parameters, they can experience dynamical many-body freezing (DMF), which causes the response to freeze completely to its initial value at all times [3–5]. This arises as a consequence of additional approximate symmetries that occur at the freezing points [6]. DMF has been demonstrated via the rotating wave approximation (RWA) in the driven transverse field Ising model (TFIM) with nearest-neighbor interactions [7] and is shown to be protected when translational invariance is explicitly broken (say, by disorder) [8,9].

The utilization of Floquet theory simplifies the analysis of time-periodic systems. For closed quantum systems governed by the time-dependent Schrödinger equation, the *Floquet Hamiltonian* allows for a mapping of the time-dependent dynamics into the dynamics of a time-independent effective Hamiltonian, provided the system is strobed at integer multiples of the time period of the drive. The time-independent eigenstates of the effective Hamiltonian correspond to quasistationary *Floquet Modes* of the original Hamiltonian. The temporal progression of the system comes from phase coefficients that capture the dynamics [10,11].

Any sufficiently complex nonintegrable many-body system is expected to thermalize according to the eigenstate thermalization hypothesis (ETH) despite the fact that closed quantum dynamics preserves the memory of the initial state of the system. This arises due to the properties of the matrix elements of observables in typical states [12]. The ETH can be readily adapted to time-periodic systems using Floquet theory (the Floquet-ETH, or FETH [13–16]). Nonetheless, the conditions for ETH to hold are not particularly strong, and the density matrix of the system can fail to approach one that is described by a thermal expression. Thermal systems must conduct because they exchange energy and particles internally during thermalization. Thus, insulating systems can be naturally athermal; many-body localization (MBL) is a well-studied case [17]. This phenomenon is stable against local perturbations, and constitutes an exotic state of matter with far-reaching implications in theoretical physics, as well as in practical applications [18].

The addition of disorder has been identified as a crucial component in the onset of MBL. In that case, thermalization is prevented by disorder-induced localization. Nonetheless, alternative approaches to MBL in strongly interacting disorder-free systems [19–21], inhomogeneous systems [22–25], and by inducing disorder in the emergent physics [26] and by other effective means [24] (albeit with strong finite-size effects), have been reported. An alternative approach to realizing MBL in disorder-free *homogeneous* many-body systems involve *Floquet engineering*, where a time-periodic drive is introduced, and the drive parameters tuned to introduce a clustering of quasistationary energies in a manner similar to localization [12].

In this article, we use the fact that emergent approximate symmetries can be engineered in Floquet systems [6,27] and apply it to long-range interactions. This results in *dynamical many-body localization* (DMBL) at specific values of the drive parameters, and complete thermal behavior at other values.

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