Quantum many-body scars using QuSpin

The goal of this project is to study the phenomenon of quantum many-body scars and reveal the nature of special states in the spectrum of ergodic Hamiltonians which do not obey the Eigenstate Thermalization Hypothesis (ETH). In particular, we will consider the PXP spin chain

$$\hat{H}(t) = \sum_{j=1}^{L} P_j \sigma^x_{j+1} P_{j+2}, \tag{1}$$

where σ^α_j denote the Pauli matrices, and the projector operators $P_j = (1 - \sigma^z_j)/2$ ensure that nearby spins are not simultaneously in their excited state. This project is based on the paper *Quantum many-body scars* by Turner *et al.*, Nature Physics volume 14, pages745–749 (2018). This project is mostly numerical and makes use of QuSpin.

- Make yourself familiar with the quspin implementation of the basis for the above Hamiltonian; an example is given here. Why do we need to customize the user basis?
- reproduce the result of Fig. 2 from Nature Physics volume 14, pages745–749 (2018). Note that it is not required to use the iTEBD algorithm used in the paper (but you should feel free to do so if you know already how it works); instead you can focus on the small system sizes reachable with quspin.

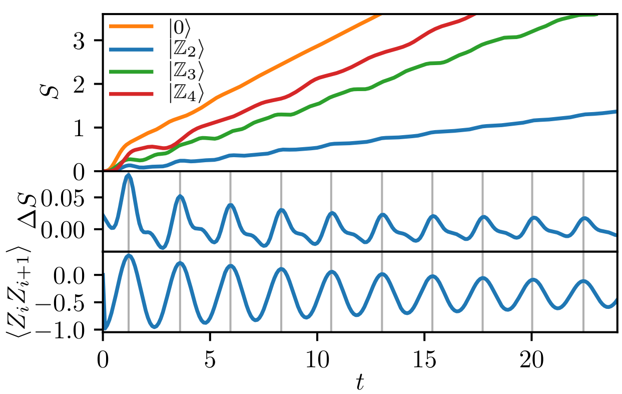

Figure 1: Entanglement entropy displays linear growth starting from various initial density-wave product states, as well as the fully polarized state. Bottom panels illustrate that for $|\mathbb{Z}_2\rangle$ initial state entanglement oscillates around the linear growth with the same frequency as local correlation functions. (For more details, see reference.)

- Reproduce the result of Fig. 3a,b,c from Nature Physics volume 14, pages745–749 (2018) using your quspin code.
- Optional goals: Study what happens when deviations are added to the initial state. Explore the deviations in the scarred quantum dynamics from ETH. Discuss the differences between weak and strong ETH and find numerical examples to illustrate these differences
- Additional literature: https://doi.org/10.1146/annurev-conmatphys-031620-101617

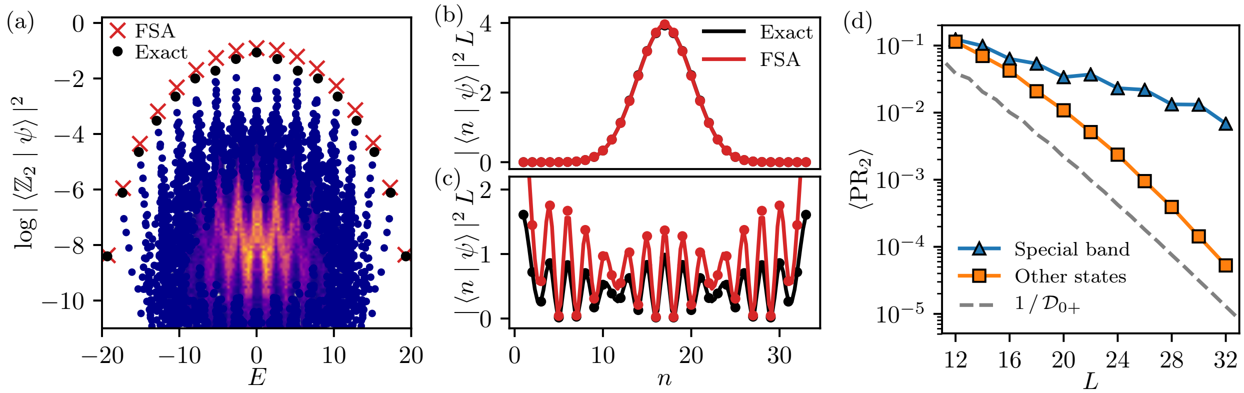

Figure 2: (a) Scatter plot of the overlap of many-body eigenstates of the Hamiltonian with $|\mathbb{Z}_2\rangle$ product state reveals a band of special eigenstates separated from the remaining eigenstates. (For a description of (b) and (c), see reference.)