Many-body localization from a single-body perspective

Wouter Buijsman (UvA)
Vladimir Gritsev (UvA), Vadim Cheianov (UL)

March 27, 2017
From Anderson to many-body localization

Example: spin-1/2 XX chain with random on-site disorder

\[ H = \frac{1}{2} \sum_{j=1}^{L-1} \left( S_j^+ S_{j+1}^- + S_j^- S_{j+1}^+ \right) + \sum_{j=1}^{L} h_j S_j^z \]

- \( H \) can be mapped on a single-body Hamiltonian by a Jordan-Wigner transformation, non-interacting
- All single-particle states are localized in space, well known as Anderson localization (Anderson, Phys. Rev. 1958)
- Localization persists at strong interactions and high temperatures, many-body localization (Oganesyan, Huse, Phys. Rev. B 2007)
The project

Generic many-body localized Hamiltonian, *local* conserved charges $\tau_i$ (Huse, Nandkishore, Oganesyan, Phys. Rev. B 2014)

$$H = \sum_i h_i \tau_i + \sum_{i,j} J_{ij} \tau_i \tau_j + \sum_{i,j,k} K_{ijk} \tau_i \tau_j \tau_k + \ldots$$

- Local perturbations only affect the wave function locally
- Response to local perturbations can be probed locally
- Phenomenology breaks down out of the many-body localized phase

Project summary

- **Goal** Probe many-body localization by local perturbations
- **Current status** Able to reproduce known phase diagram qualitatively
Many-body localization from a single-body perspective

Spin-1/2 XXZ, disorder $h_j \sim \text{UNIF}(-W, W)$, eigenvalues $E_n$

$$H = \sum_{j=1}^{L-1} \left( S_j^x S_{j+1}^x + S_j^y S_{j+1}^y + \Delta S_j^z S_{j+1}^z \right) + \sum_{j=1}^{L} h_j S_j^z$$

Local perturbation $H \to H + \lambda H'$, $H' = S_1^x S_2^x + S_1^y S_2^y$

Single-particle local Hamiltonian (sites 1 and 2)

$$H_{12} = \frac{1}{2} \begin{pmatrix} h_1 - h_2 - \Delta/2 & 1 + \lambda_1 \\ 1 + \lambda_1 & h_2 - h_1 - \Delta/2 \end{pmatrix}$$

Eigenvalues $\bar{E}_{1,2} = 2\tilde{E}_{1,2}$ characterize many-body localization

$$\frac{d^2\tilde{E}_{1,2}}{d\lambda^2} = \frac{1}{1 + \lambda} \left( \frac{d\tilde{E}_{1,2}}{d\lambda} \right)^3 \left[ \left( \frac{d\tilde{E}_{1,2}}{d\lambda} \right)^{-2} - 1 \right]$$
Results – localized regime

$L = 10$, $W = 5$, $\Delta = 1$, $S^z = 0$, 100 samples

Normalized density

$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
$10^0$

Normalized density

$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
$10^0$
Results – localized regime

$L = 10, W = 5, \Delta = 1, S^z = 0, 100$ samples

$\tilde{E}_{1,2}$

Normalized density

$dE_n/d\lambda$

$d^2E_n/d\lambda^2$

$\tilde{E}_{1,2}$
Results – localized regime

$L = 10, W = 5, \Delta = 1, S^z = 0, 100 \text{ samples}$

Localized states
Results – localized regime

$L = 10, W = 5, \Delta = 1, S_z = 0, 100$ samples

Localized states

'delocalized' states

Wouter Buijsman
MBL from a single-body perspective
March 27, 2017
Results – localized regime

\[ L = 10, \ W = 5, \ \Delta = 1, \ S^z = 0, \ 100 \text{ samples} \]

Localized states

\[ S^z_1 + S^z_2 \in \{-1, 1\} \]

Delocalized states

\[ \tilde{E}_{1,2} \]
Results – delocalized regime

$L = 10, W = 2, \Delta = 1, S^z = 0, 100$ samples
Summary and outlook

Summary

- Developed first steps towards a probe for many-body localization based on single-particle characteristics
- Qualitatively able to reproduce \((E_n, W)\) phase diagram from literature (Luitz, Laflorencie, Alet, Phys. Rev. B 2015)

Outlook

- Generalization: can eigenstates be represented by a single Slater determinant? (Zhang, Mauser, Phys. Rev. A 2016)
- Study the relation between the onset of localization and transport

Related references

- Xu, Vavilov, Phys. Rev. B 2017
- Serbyn, Papić, Abanin, Phys. Rev. X 2015