Neural and Tensor Networks for Synthetic Quantum Matter

(NeTeNeSyQuMa)

Daniel Alcalde[1,2], Daniele Contessi[1,2,3], Niklas Tausendpfund[1,2], Erik Weerda[2], Markus Schmitt[1,2], Matteo Rizzi[1,2]
Forschungszentrum Jülich[1], Universität zu Köln[2], University of Trento[3]

Abstract

We investigate different physical problems with high relevance for quantum simulation. We employ and further develop state-of-the-art numerical methods from the family of wave-function-based approaches – tensor networks and neural quantum states. Here, we briefly present a selection of recent results by our group on (i) non-equilibrium dynamics of closed quantum systems, (ii) the usage of noise and measurements as a resource in quantum simulators, (iii) the detection of quantum phase diagrams via full counting statistics, (iv) the low energy regime of frustrated systems with topological features, which are of interest both for fundamental reasons and for the purpose of quantum computing.

Open Quantum Systems

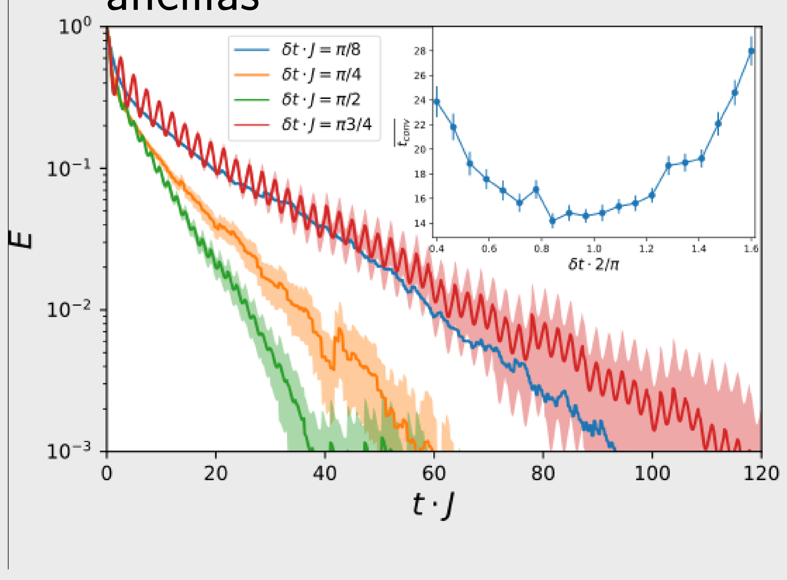
Objective: Use noise/measurement as a resource to prepare quantum states
Methods: Hamiltonian evolution and projective measurement
Simulation Methods: Matrix Product States & Quantum Trajectories
Questions: How long to evolve with Hamiltonian dynamics?
Future Directions: Use Machine Learning to find better dynamics

Hamiltonian driving the dynamics:

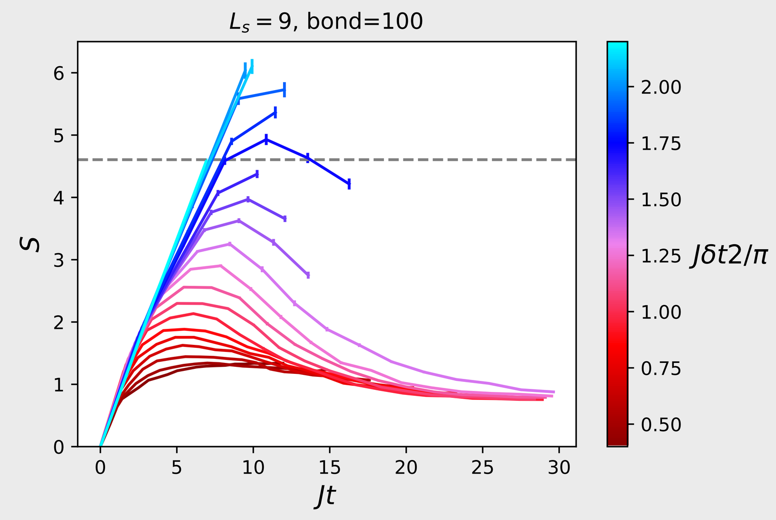
$$H = J \sum_{l,\alpha} \sigma^{+,A}_{l,\alpha} \otimes U^{S}_{l,\alpha} + \mathrm{h.c.}$$

Ancillas: $A \rightarrow$ Stroboscopic Reset every δt to $|0\rangle$
System: $S \rightarrow$ Slowly steers into the desired state

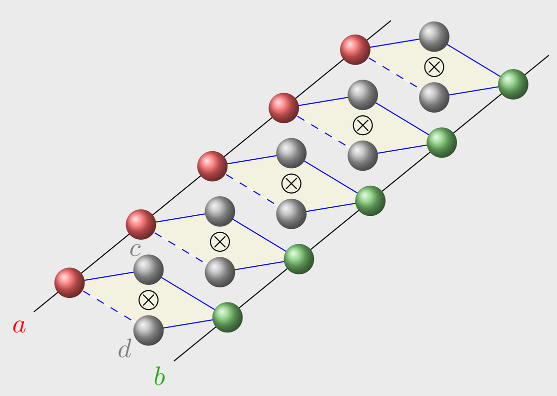
- Steering from $|\uparrow\uparrow\uparrow \dots\rangle \rightarrow |\mathrm{AKLT}\rangle$
- Stroboscopic resetting of the ancillas



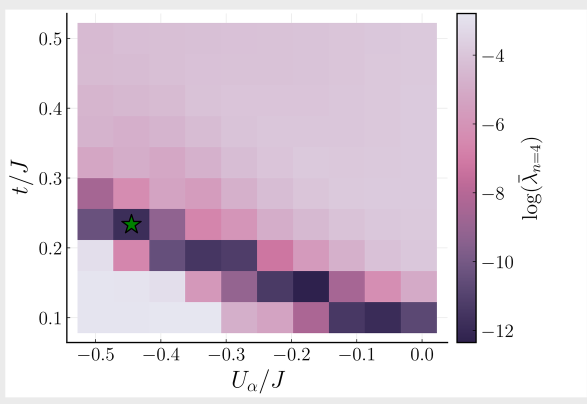
- $t_{\mathrm{conv}} \equiv$ no ancilla flip
- Best reset time $\delta t \approx 0.9\frac{\pi}{2}$
- $t_{\mathrm{conv}} \propto L$

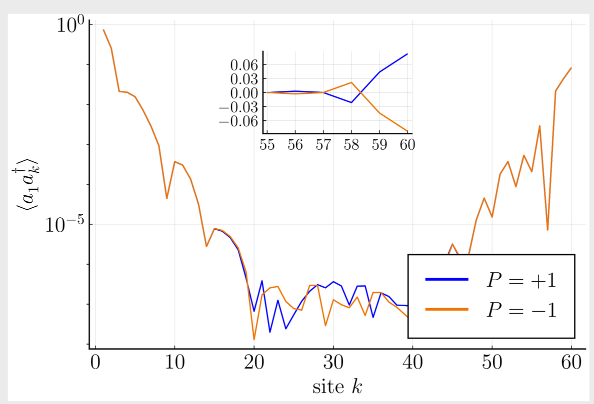


Low Energy Physics

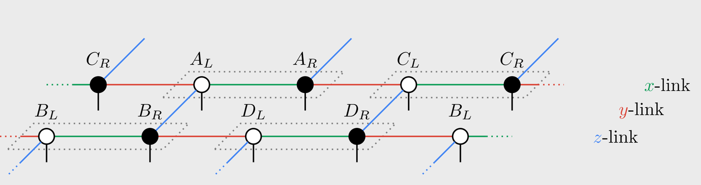


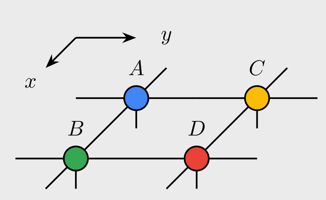
- Four site model coupled using Aharonov-Bohm-Cages
- Exact cancellation of single particle transitions
- Generation of pair transitions via generic interactions



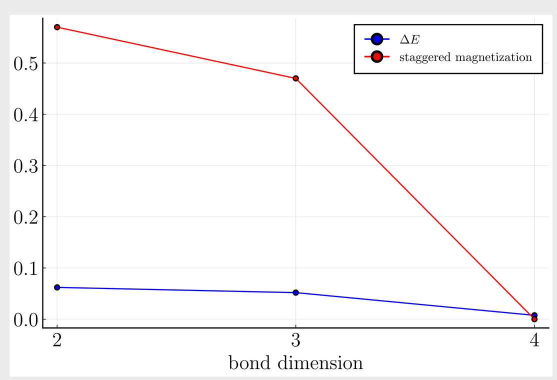


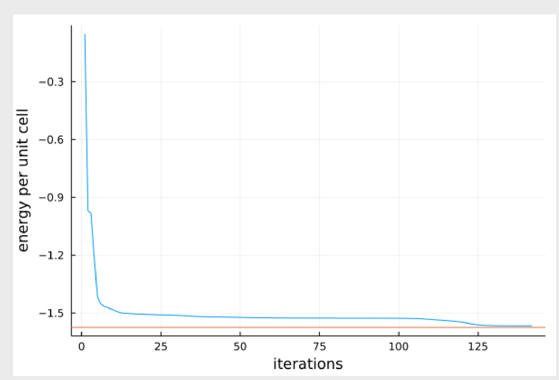
- Extended gapless phase with Majorana Edge Modes
- Footprints of topological zero modes. (left) Entanglement degeneracy, (right) non-local corraltion function
- arXiv:2208.09382





- Mapping from honeycomb to square lattice with general unit cell





- Benchmarking iPEPS code for Kitaev honeycomb model
- Variational ground-state search aided by algorithmic differentiation
- (left) expectation values, (right) convergence behaviour

Future Directions:

- Finite temperature consideration of Majorana physics
- Phase diagram investigation of the Kitaev-Gamma model
- Tree-tensor calculations for non-local properties in Majorana phases

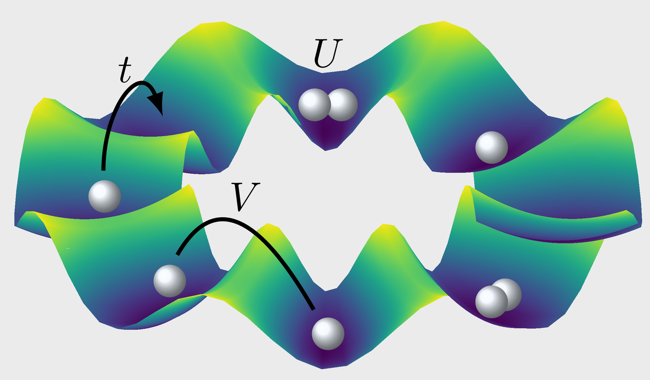
Phase diagram with FCS

1D Extended Bose-Hubbard model:

$$H = \sum_{j=1}^{L} \left(-t(b^{\dagger}_{j+1} b_j + \mathrm{h.c.}) + \frac{U}{2} n_j (n_j - 1) + V n_j n_{j+1} \right),$$

- MPS ansatz
- Very rich phase diagram: superfluid, Mott insulator, Haldane insulator and charge density order
- Unitary filling, globally conserved number of particles

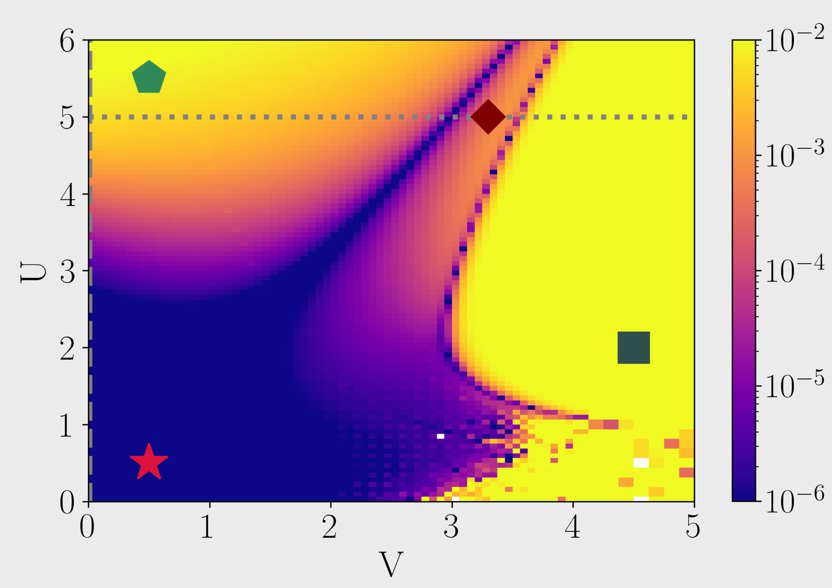
arXiv:2207.01478



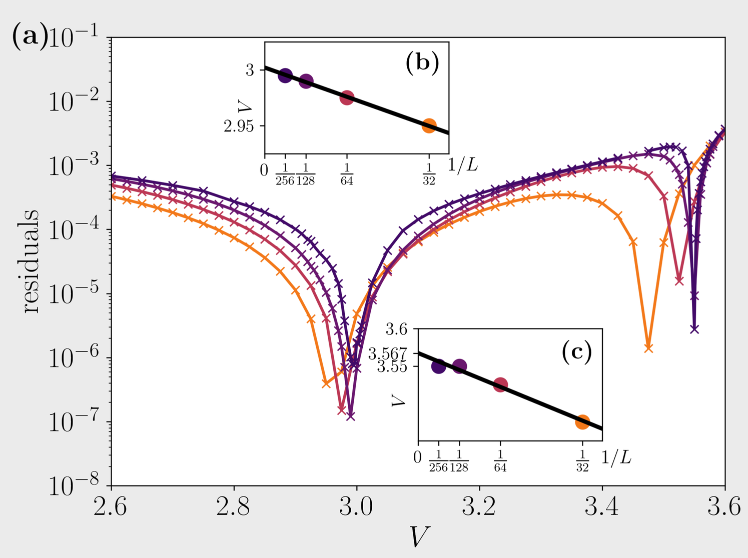
We fit the probability distribution of a deviation $\delta n = m$ from the average density in half of the system

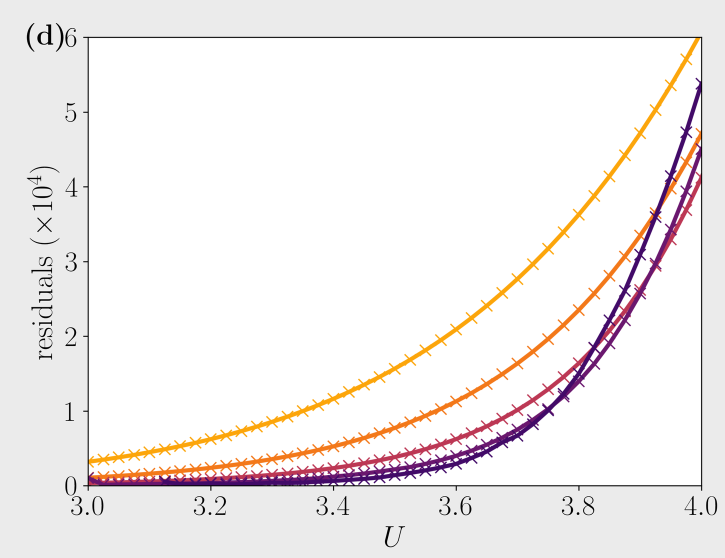
$$p(\delta n = m) = \mathrm{Tr}(\rho_A \Pi_{N/2+m}) = \sum_{\alpha} \lambda^{(m)}_{\alpha},$$

$\lambda^{(m)}_{\alpha}$ squared Schmidt values in m sector



- Extraction of residuals from a gaussian fit allows to draw the phase diagram (left)
- (bottom-left) Gapped-to-gapped with scalings
- (bottom-right) Gapless-to-gapped BKT





Contact: m.rizzi@fz-juelich.de **Website:** www.thp.uni-koeln.de/rizzi