QUANTUM THEORY OF CONDENSED MATTER

REPORT INSTRUCTIONS

Implement in QuSpin the one dimensional Su-Schrieffer-Heeger bosonic model (for simplicity fix $J = 1.0$)

$$H = -\sum_i (J + (-1)^i \delta J)(b_i^\dagger b_{i+1} + h.c.) + \frac{U}{2}\sum_i n_i(n_i - 1)$$

a) Discuss how this Hamiltonian can be realized in an atomic quantum simulator working at ultracold temperature

b) Fix the bosonic density to half-filling $N/L = 0.5$ where N is the number of bosons and L the number of lattice sites. For a single value of U, show in separate figures when the ground state energy $E_{GS}(N, L)$ of H is symmetric under the transformation $\delta J \leftrightarrow -\delta J$ for the following cases: 1) open-boundary-conditions with an even number of sites; 2) open-boundary-conditions with an odd number of sites; 3) periodic-boundary-conditions with even number of sites; 4) periodic-boundary-conditions with an odd number of sites.

c) For the same density, extrapolate in the thermodynamic limit the value of the charge gap $\Delta_c = E_{GS}(N+1, L) + E_{GS}(N-1, L) - 2E_{GS}(N, L)$ at fixed δJ. Discuss and show in a figure when, as a function of U, the system becomes an insulator. Advice: *use periodic boundary conditions; pay attention to the sign of δJ*

d) Show by plotting the expectation value of the local density operator $\langle n_i \rangle$, or at least discuss, when the ground state of H develops topological properties. Advice: fix the particle number $N = L/2 + 1$*; pay attention to the boundary conditions*

Useful references: https://arxiv.org/abs/1212.0572; https://arxiv.org/abs/1810.13286; https://arxiv.org/abs/cond-mat/0410614; https://arxiv.org/abs/1301.7242; https://arxiv.org/abs/2106.15457; https://arxiv.org/abs/1803.06957

Please send this report to luca.barbiero@polito.it at least one week before the day of the oral examination