

# INDUCING OR DESTROYING TOPOLOGICAL PHASES THROUGH DISSIPATION IN OPEN QUANTUM SYSTEMS

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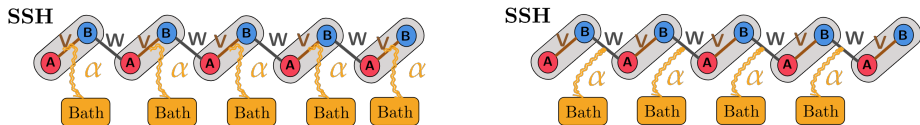
# INTRODUCTION

- Topological condensed matter physics has garnered significant interest in recent years;
- Interactions are able to alter topological phases of matter:
- What about the environment?
  - perfect isolation of quantum systems is impossible;
  - non-perturbative effects.
- Environment leads to quantum decoherence;
- Is the environment only detrimental for topological phases?

# THE MODEL

## SSH CHAIN COUPLED WITH LOCAL BATHS

We consider two different versions of the model:



$$H = H_{SSH} + H_B + H_{SSH-B}$$

We will analyze this model in:

- OBC: **quantitatively** by mean of polarization and Binder parameter evaluated through a QMC approach;
- PBC: **qualitatively** with an analytic approach using Cluster Perturbation Theory (CPT).

# OPEN BOUNDARY CONDITIONS: QMC APPROACH

## POLARIZATION AND BINDER PARAMETER

- Polarization operator:

$$p = \sum_{n=1}^N \left( \frac{2n-1-N}{N-1} \right) (c_{n,A}^\dagger c_{n,A} + c_{n,B}^\dagger c_{n,B})$$

- Binder parameter:

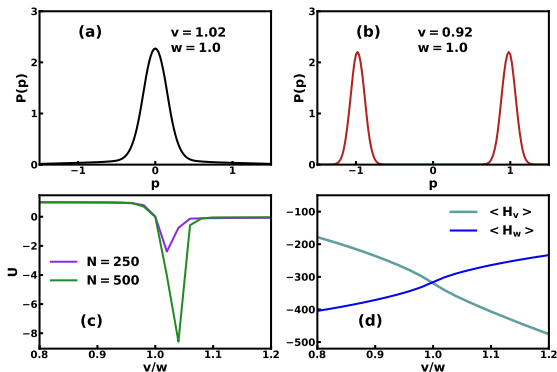
$$U = \frac{1}{2} \left( 3 - \frac{\langle p^4 \rangle}{\langle p^2 \rangle^2} \right)$$

- we apply OBC and use a world-line QMC approach to compute equilibrium values of observables;
- we prove that  $P(p)$  and  $U$  can be used as marker of topological phase transitions.

# OPEN BOUNDARY CONDITIONS: QMC APPROACH

## BARE SSH CHAIN

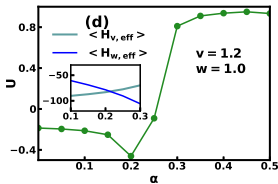
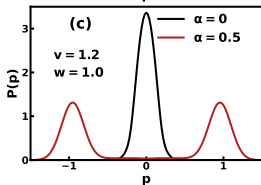
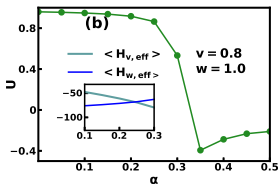
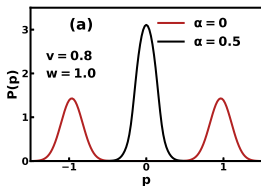
The distribution of Polarization  $P(p)$  and the Binder parameter  $U$  as indicators of topological phase transitions:



# OPEN BOUNDARY CONDITIONS: QMC APPROACH

## SSH CHAIN + BATH

- panels (a) and (b): topological phase ( $v < w$ )  $\xrightarrow{\alpha}$  trivial phase;
- panels (c) and (d): trivial phase ( $v > w$ )  $\xrightarrow{\alpha}$  topological phase.

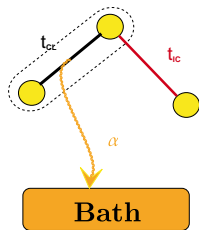


# PERIODIC BOUNDARY CONDITIONS: CPT APPROACH

## CLUSTER PROBLEM AND GREEN'S FUNCTION

Very powerful technique to deal with many-body systems with local interactions:

- divide the whole lattice into a superlattice of identical finite-size cluster;
- the **Cluster** Green's function is solved **exactly**, whereas the hopping connecting **different** Clusters are treated **perturbatively**.



- **minimal cluster**: two sites connected by a hopping  $t_{CL}$  interacting within a bath.
- CPT Green's function:

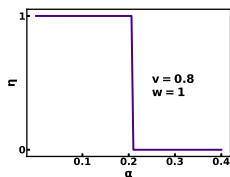
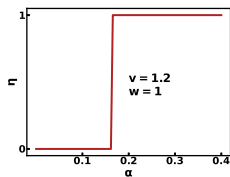
$$G_{CPT}^{-1}(k, \omega) = G_{CL}^{-1}(k, \omega) - t_{IC}(k)$$

- $G_{CL}$  is solved **analytically**.

Although the cluster is minimal,  $G_{CPT}(k, \omega)$  captures **qualitatively** the correct physical behaviour.

# PERIODIC BOUNDARY CONDITIONS: CPT APPROACH

## WINDING NUMBER AND CRITICAL COUPLING



- From the Green's function we can evaluate the topological invariant:

$$\eta = \frac{1}{4\pi i} \int_{-\pi}^{\pi} dk \text{Tr} \left\{ \sigma_z G_{CPT}(k, 0) \partial_k G_{CPT}^{-1}(k, 0) \right\}$$

- the discontinuity signals the unique critical coupling  $\alpha_c \implies$  the phonon interaction induces a topological phase transition.
- (red) coupled within  $w$ : trivial phase ( $\nu > w$ )  $\xrightarrow{\alpha}$  topological phase.
- (blue) coupled within  $\nu$ : topological phase ( $\nu < w$ )  $\xrightarrow{\alpha}$  trivial phase;

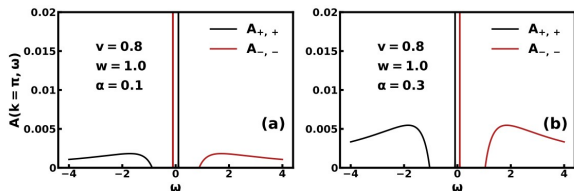
# PERIODIC BOUNDARY CONDITIONS: CPT APPROACH

## SPECTRAL FUNCTIONS

One can consider the Green's functions corresponding to the quasiparticle operators  $\{\gamma_{k,+}, \gamma_{k,-}\}$  such that  $H(k) = \sum_{k,\mu=\pm} E_{k,\mu} \gamma_{k,\mu}^\dagger \gamma_{k,\mu}$  for the bare SSH model.

Spectral Functions:

$$A_{\pm,\pm}(k,\omega) = -\frac{1}{\pi} \Im G_{\pm,\pm}(k,\omega)$$

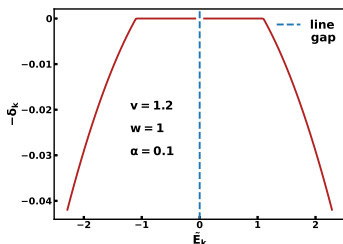


- At  $\alpha = 0$ ,  $A_{+,+}(k,\omega) = \delta(\omega - E_{k,+})$  and  $A_{-,-}(k,\omega) = \delta(\omega - E_{k,-})$ ;
- for  $\alpha < \alpha_c$ , the two principal peaks become closer and closer;
- at  $\alpha = \alpha_c$  the two peaks become coincident (**closure of the gap**) and then for  $\alpha > \alpha_c$  swap;
- growing of polaronic tails due to the interaction.

# PERIODIC BOUNDARY CONDITIONS: CPT APPROACH

## ENERGY SPECTRUM AND NON-HERMITIAN MODEL

From the poles of quasiparticle Green's function we obtain the energy spectrum  $(\pm\tilde{E}_k - i\delta_k, \text{ with } \delta_k \geq 0)$   $\implies$  mapping to an effective non-Hermitian model:



$$H_1 = -i \sum_{n, \delta n} \mu(\delta n) \left[ c_{A, n+\delta n}^\dagger c_{A, n} + c_{B, n+\delta n}^\dagger c_{B, n} + h.c. \right],$$

$$H_2 = \sum_{n, \delta n} \tilde{v}(\delta n) \left[ c_{A, n+\delta n}^\dagger c_{B, n} + c_{B, n}^\dagger c_{A, n+\delta n} \right] \quad H_3 = \sum_{n, \delta n} \tilde{w}(\delta n) \left[ c_{A, n+\delta n}^\dagger c_{B, n} + c_{B, n}^\dagger c_{A, n+\delta n} \right]$$

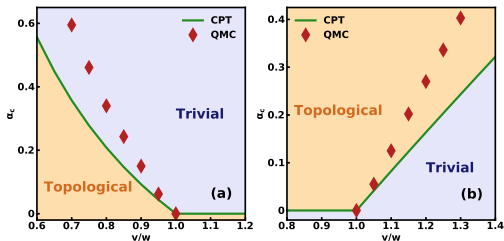
# PHASE DIAGRAM

## CRITICAL POINTS: CPT VS QMC

Comparison the values of  $\alpha_c$  obtained thanks QMC and CPT.

where:

- (a): local baths coupled with  $v$ -hoppings;
- (b): local baths coupled with  $w$ -hoppings.



# CONCLUSIONS

By studying the model in OBC and PBC and by mean of QMC and CPT, we have shown that:

- the probability of polarization  $P(p)$  and the Binder parameter  $U$  can be used as markers of topological phase transitions;
- depending on which hopping interacts with the bath, the environment can be detrimental or favourable to topological phase;
- the interaction with the bath gives rise to an effective non-Hermitian model.

Paper submitted on ArXiv: "Witnessing Environment Induced Topological Phase Transitions via Quantum Monte Carlo and Cluster Perturbation Theory Studies" [arXiv:2309.04719](https://arxiv.org/abs/2309.04719)

Thanks for the attention