Past, Present and The Future

Vikash Mittal

Department of Physics,
National Tsing Hua University, Hsinchu, TAIWAN

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Overview

- Quantum Walks and its applications

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- SSH Model and it's variations

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- Quantum Entanglement

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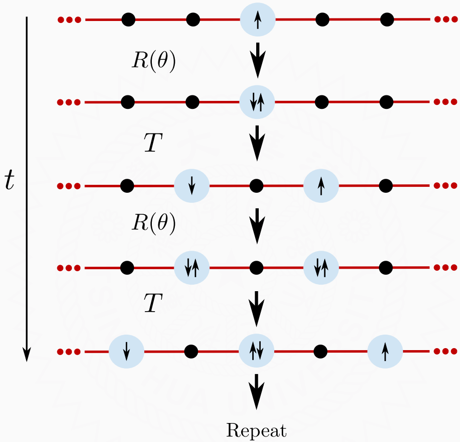
- SSH Model and it's variations
- Quantum Entanglement
- A desire for more and more!!!

1D DTQW



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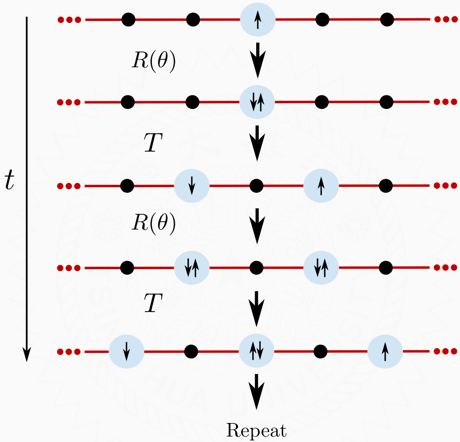
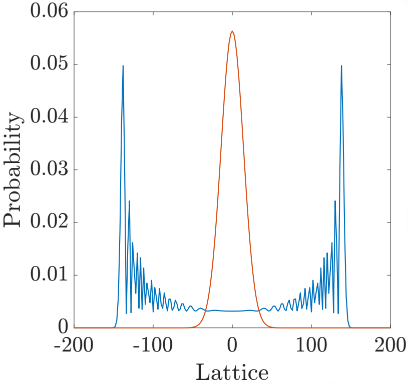
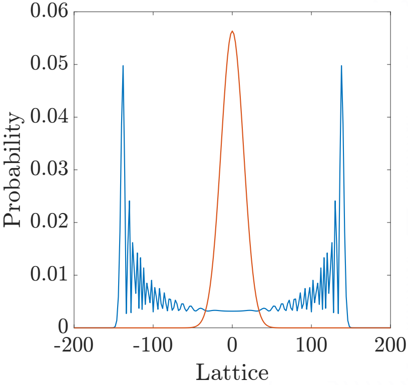


Time evolution operator for 1D DTQW

$$U(\theta) = TR(\theta)$$


0.06
0.05
0.04
0.03
0.02
0.01
0
Probability
-200
-100
0
100
200
Lattice



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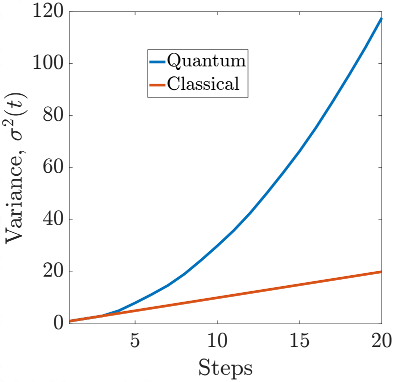
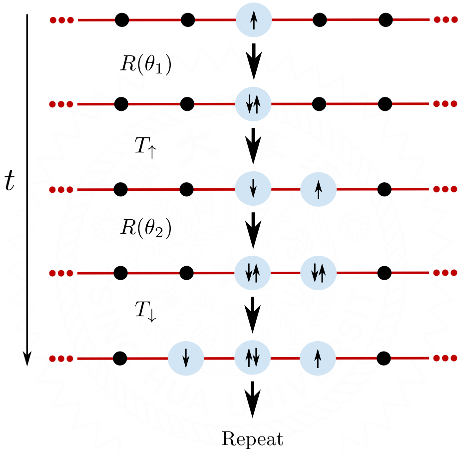
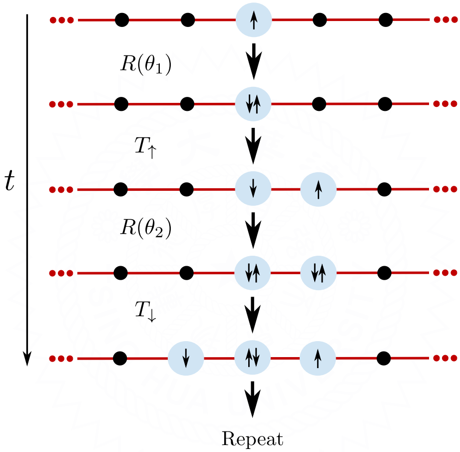


120
100
80
60
40
20
0
Variance, $\sigma^2(t)$
Quantum
Classical
5
10
15
20
Steps

1D SSQW



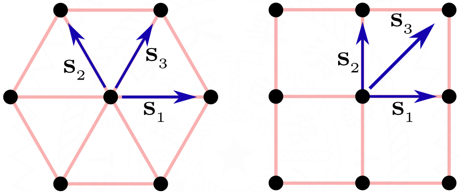
1D SSQW



Time evolution operator for 1D SSQW

$$U_{\mathrm{ss}}(\theta_1, \theta_2) = T_{\downarrow} R(\theta_2) T_{\uparrow} R(\theta_1)$$

2D DTQW



Time evolution operator for 1D SSQW

$$U_{2D}(\theta_1, \theta_2) = T_y R(\theta_1) T_y R(\theta_2) T_x R(\theta_1) T_x.$$

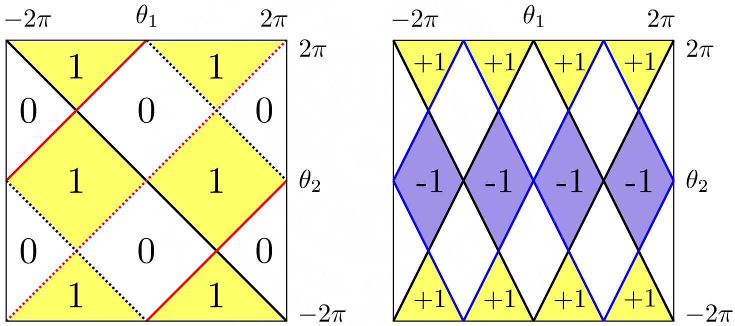
$$U_{\mathsf{SS}} = e^{-iHt} \longrightarrow \; H_k(\theta_1, \theta_2) = \sum_k \underbrace{E_k(\theta_1, \theta_2)[\hat{\mathbf{n}}_k(\theta_1, \theta_2) \cdot \sigma]}_{\mathcal{H}_k(\theta_1, \theta_2)} \otimes |k\rangle\langle k| \,.$$

$$U_{\mathsf{ss}} = e^{-iHt} \longrightarrow\ H_k(\theta_1,\theta_2) = \sum_k \underbrace{E_k(\theta_1,\theta_2)[\hat{\mathbf{n}}_k(\theta_1,\theta_2)\cdot\sigma]}_{\mathcal{H}_k(\theta_1,\theta_2)} \otimes |k\rangle\langle k|\,.$$

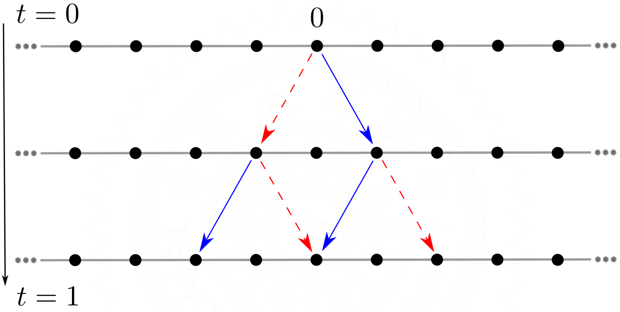
The dispersion relation is given by (Kitagawa, 2010)

$$\cos E_k(\theta_1,\theta_2) = \cos(\theta_1/2)\cos(\theta_2/2)\cos k - \sin(\theta_1/2)\sin(\theta_2/2).$$

Topological Phases in Quantum Walks

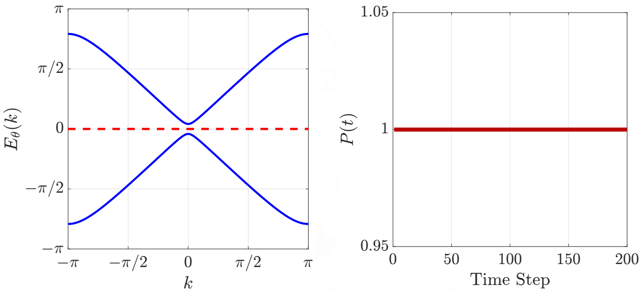


Non-Unitary/Non-Hermitian Quantum Walk

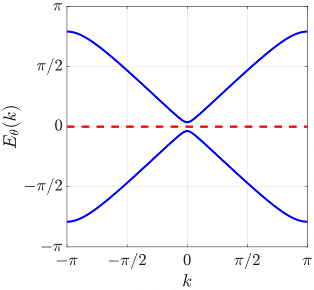


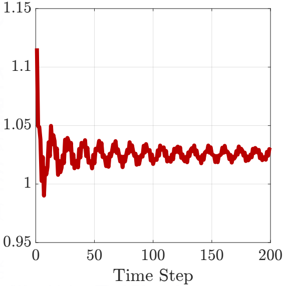
(Regensburger et al (2012))

$$T_{\downarrow} R(\theta_2) T_{\uparrow} R(\theta_1) \xrightarrow{G_{\gamma}=e^{\gamma \sigma_z}} T_{\downarrow} G_{\gamma}^{-1} R(\theta_2) T_{\uparrow} G_{\gamma} R(\theta_1)$$



$$\cos E(k) = \cos(\theta_1/2)\cos(\theta_2/2)\cos k - \sin(\theta_1/2)\sin(\theta_2/2)\cosh 2\gamma$$





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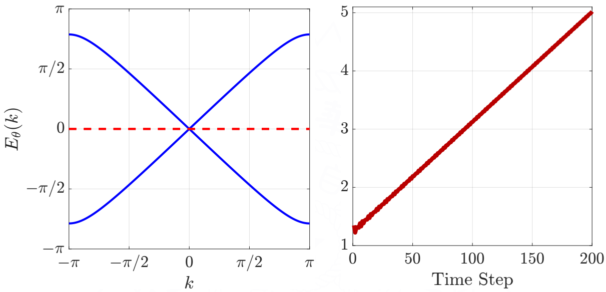

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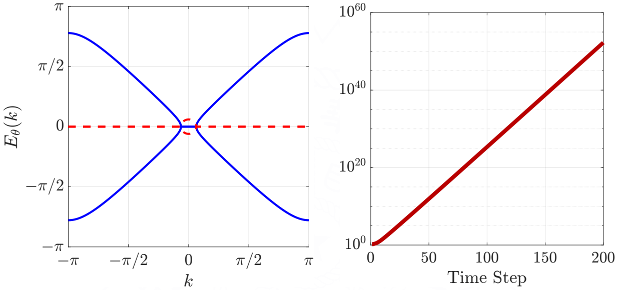

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$\mathcal{PT}$-symmetry

In continuous systems, we have

Parity symmetry (Unitary)

$$\mathcal{P} : x \to -x \text{ and } p \to -p, \ \mathcal{P}^2 = \mathbb{1}$$

Time reveral symmetry (Anti-unitary)

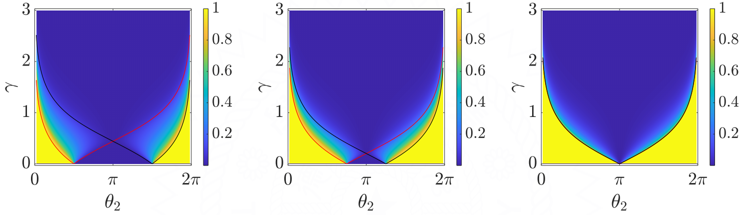
$$\mathcal{T} : t \to -t, \ p \to -p, \ x \to -x, \text{ and } i \to -i$$

such that

$\mathcal{PT}-$symmetric Hamiltonian

$$(\mathcal{PT})H(\mathcal{PT})^{-1} = H$$

1D NH-SSQW



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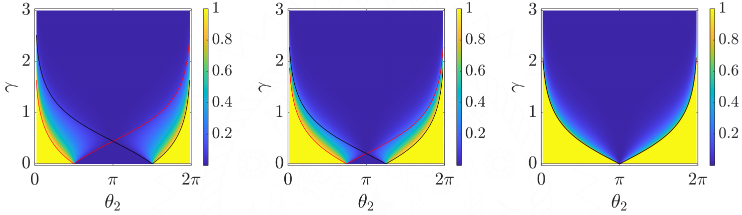
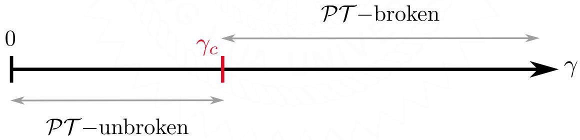
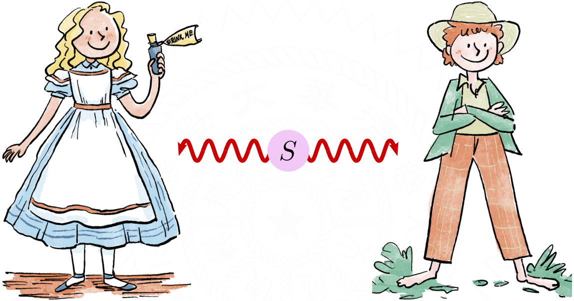




$[H, \mathcal{PT}] = 0$

Quantum Walk and Entanglement



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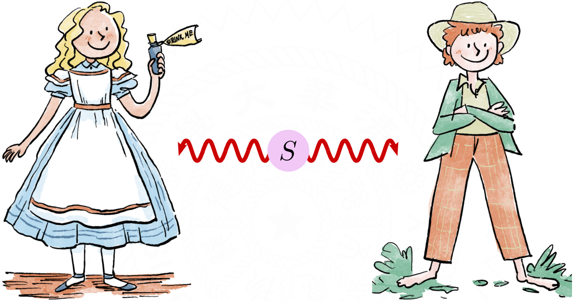

$$|\Psi\rangle_{AB} = \frac{1}{\sqrt{2}}\left(|0\rangle_A |1\rangle_B + |1\rangle_A |0\rangle_B\right)$$

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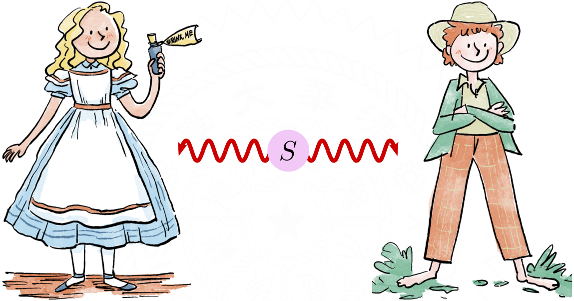

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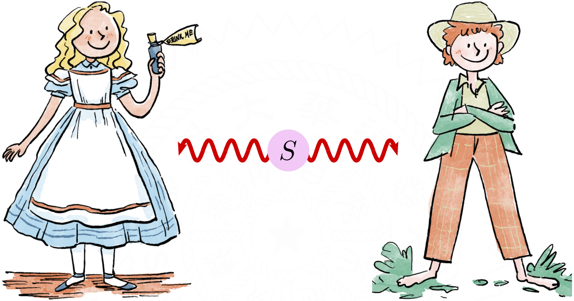
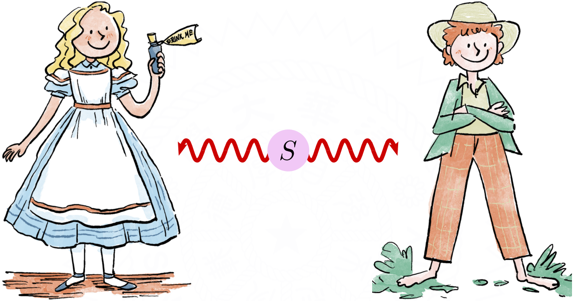
TRANSMISSION EFFICIENCY!!! DETECTION EFFICIENCY!!!

Quantum Walk and Entanglement



$$|\Psi\rangle_{AB} = S_{AB}(\beta)\,|0,0\rangle\,, \quad S_{AB}(\beta) = \exp\Big[\beta(a_A^\dagger a_B^\dagger - a_A a_B)\Big]$$

Quantum Walk and Entanglement



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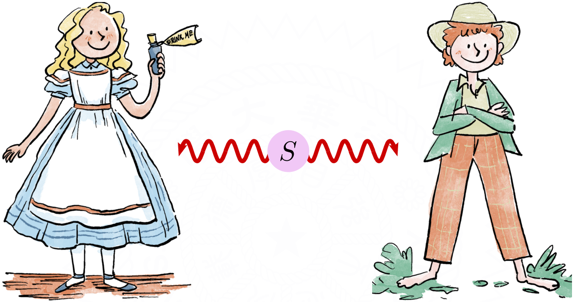
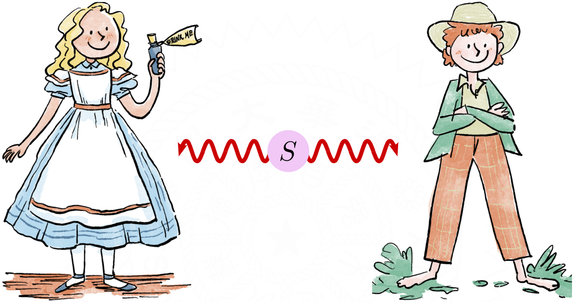
IDEAL HOMODYNE DETECTION AT TELECOM λ's !!!



$$|\Psi\rangle_{AB} = \frac{1}{\sqrt{2}} \left(|0\rangle_A |\alpha_1\rangle_B + |1\rangle_A |\alpha_2\rangle_B \right)$$

Quantum Walk and Entanglement



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Middle ground!! Useful Entanglement over 300 km

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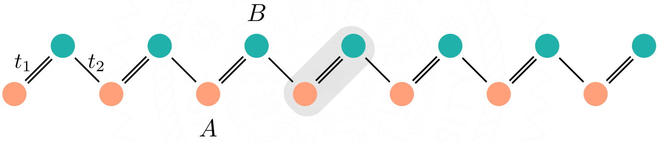
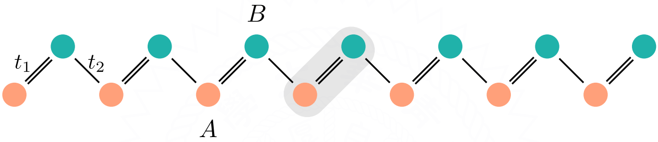
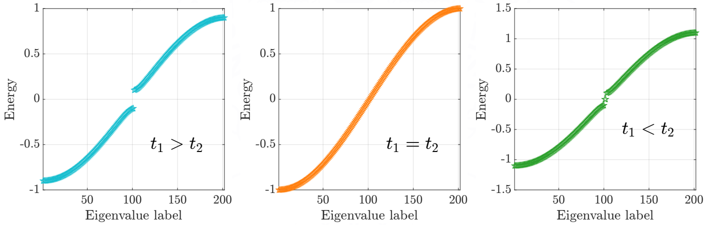
- metric formalism in quantum walks?? (Chia-Yi Ju et al, 2019)
- non-trivial topology and non-local effects??
- topological phase transitions and entanglement??
- analogous to SSH model,

Our beloved SSH

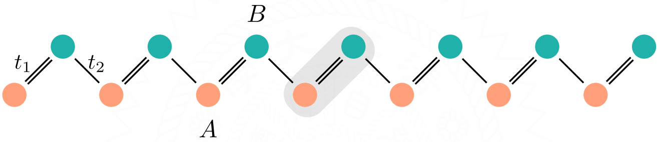


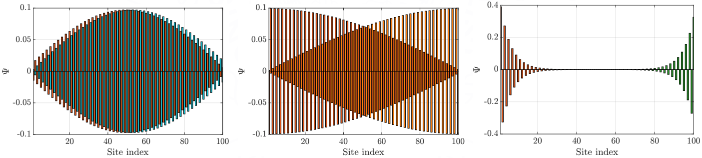
Our beloved SSH

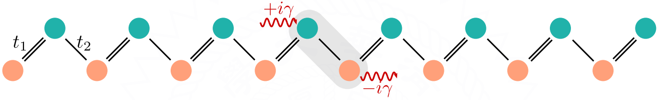




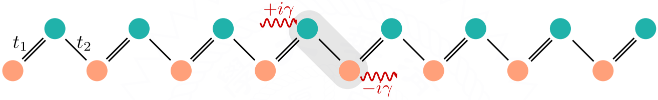
Our beloved SSH

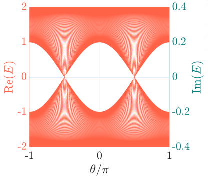





t_1
t_2
$+i\gamma$
$-i\gamma$

Siblings of SSH (Even)





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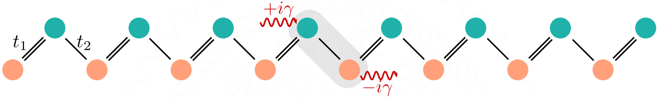

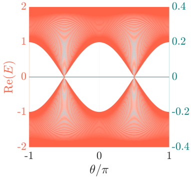

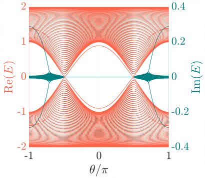

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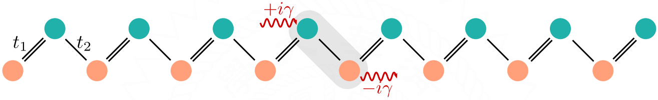

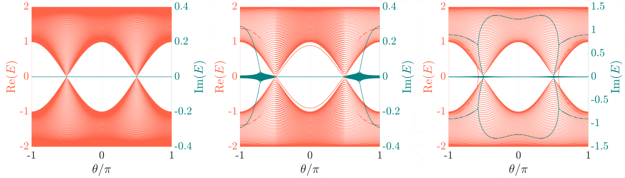

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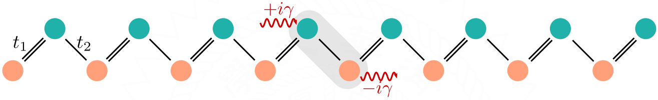
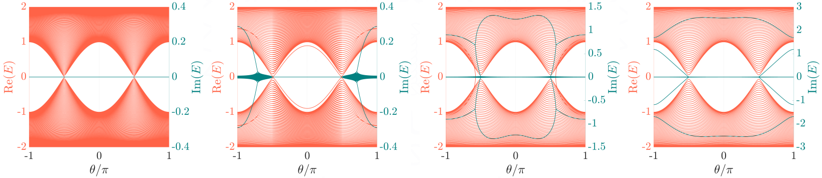
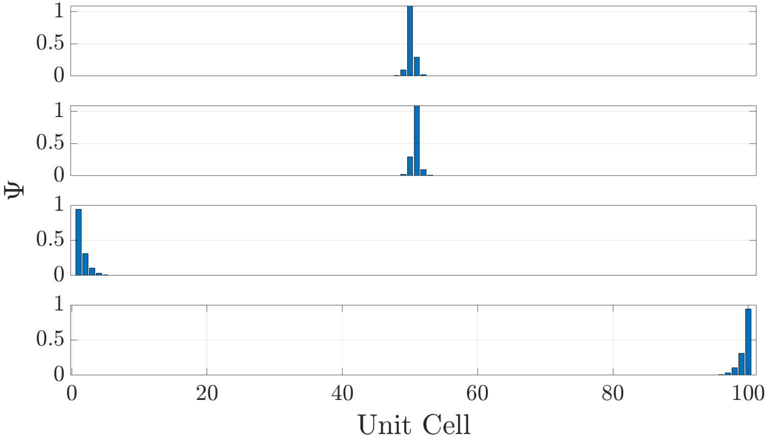
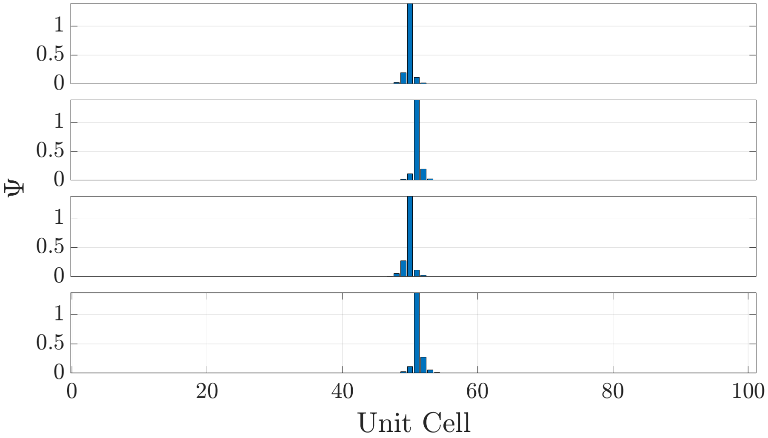





Ψ
1
0.5
0
0
20
40
60
80
100
Unit Cell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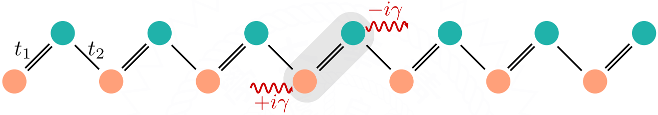
Siblings of SSH (Odd)



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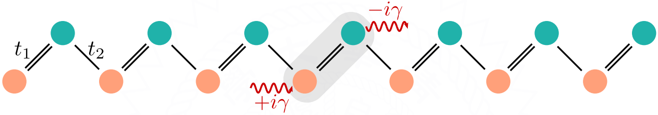

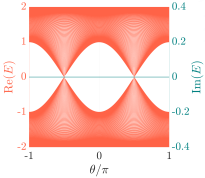

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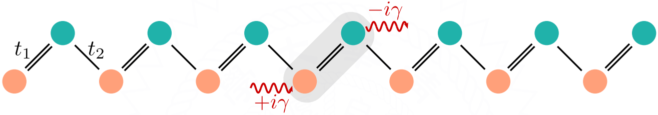

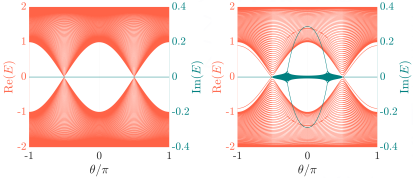

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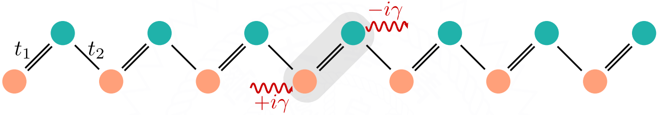

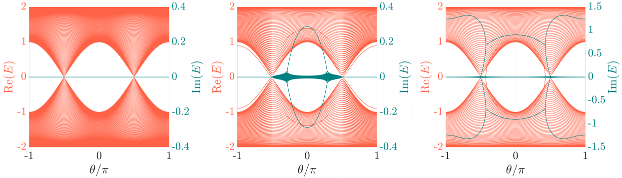

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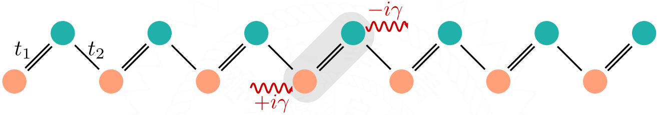

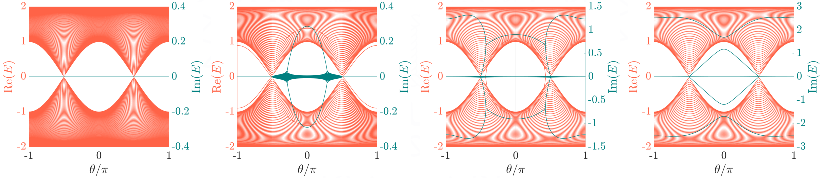

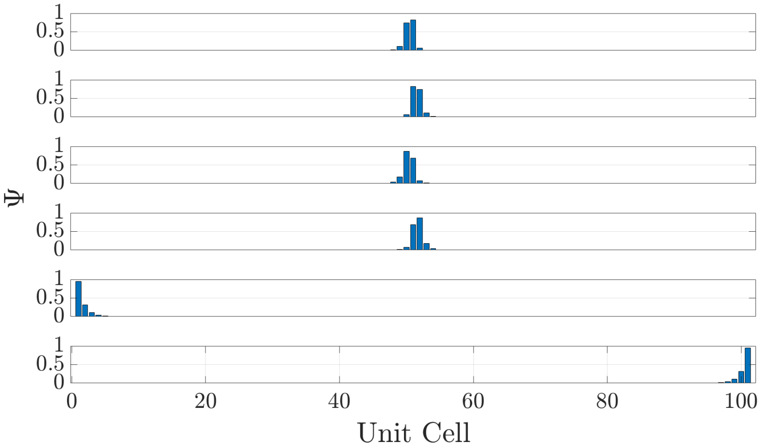
1
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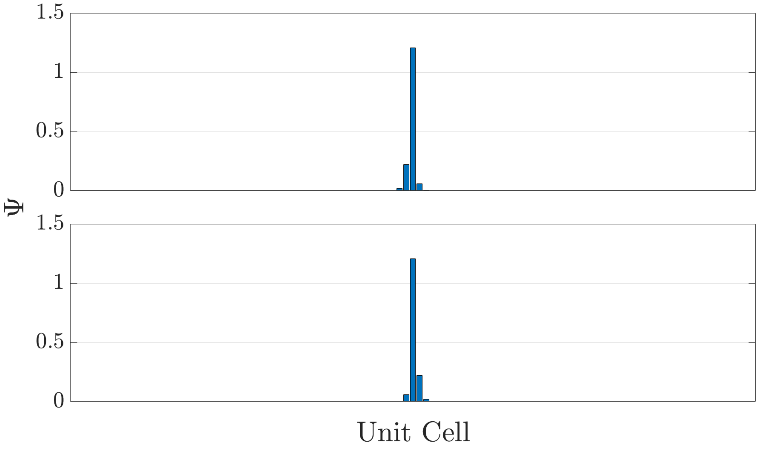
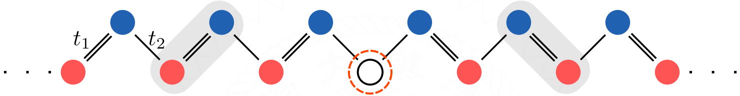
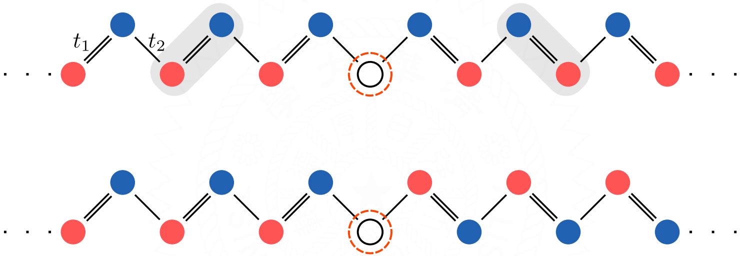
100
Unit Cell


1.5
1
0.5
0
Ψ
1.5
1
0.5
0
Unit Cell

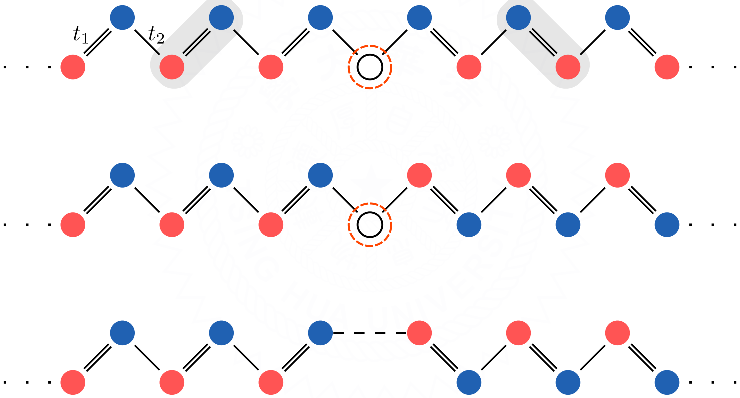
Other siblings of SSH Model



Other siblings of SSH Model



Other siblings of SSH Model



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PAPER

Non-Hermitian topological phases and dynamical quantum phase transitions: a generic connection

Longwen Zhou* **and Qianqian Du**

Department of Physics, College of Information Science and Engineering, Ocean University of China, Qingdao 266100, People's Republic of China

* Author to whom any correspondence should be addressed.

E-mail: zhoulw13@u.nus.edu

Keywords: non-Hermitian physics, dynamical quantum phase transition, topological phases of matter

Abstract

The dynamical and topological properties of non-Hermitian systems have attracted great attention in recent years. In this work, we establish an intrinsic connection between two classes of intriguing phenomena—topological phases and dynamical quantum phase transitions (DQPTs)—in non-Hermitian systems. Focusing on one-dimensional models with chiral symmetry, we find DQPTs following the quench from a trivial to a non-Hermitian topological phase. Moreover, the critical momenta and critical time of the DQPTs are found to be directly related to the topological invariants of the non-Hermitian system. We further demonstrate our theory in three prototypical non-Hermitian lattice models, the lossy Kitaev chain (LKC), the LKC with next-nearest-neighbor hoppings, and the nonreciprocal Su–Schrieffer–Heeger model. Finally, we suggest a proposal to experimentally verify the found connection by a nitrogen-vacancy center in diamond.

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PHYSICAL REVIEW A **107**, 032201 (2023)

Topological invariants in quantum walks

Andrzej Grudka,[1] Marcin Karczewski,[2] Paweł Kurzyński,[1] Jan Wójcik,[3] and Antoni Wójcik[1]

[1] *Institute of Spintronics and Quantum Information, Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland*

[2] *International Centre for Theory of Quantum Technologies, University of Gdańsk, 80-309 Gdańsk, Poland*

[3] *Faculty of Physics, Adam Mickiewicz University, 61-614 Poznań, Poland*

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Discrete-time quantum walks (DTQWs) provide a convenient platform for a realization of many topological phases in noninteracting systems. They often offer more possibilities than systems with a static Hamiltonian. Nevertheless, researchers are still looking for DTQW symmetries protecting topological phases and for definitions of appropriate topological invariants. Although the majority of DTQW studies on this topic focus on the so-called split-step quantum walk, two distinct topological phases can be observed in more basic models. Here we infer topological properties of the basic DTQWs directly from the mapping of the Brillouin zone to the Bloch Hamiltonian. We show that for translation-symmetric systems they can be characterized by a homotopy relative to special points. We also propose a topological invariant corresponding to this concept. This invariant indicates the number of edge states at the interface between two distinct phases.

DOI: 10.1103/PhysRevA.107.032201

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PHYSICAL REVIEW LETTERS **131**, 100202 (2023)

Speeding Up Entanglement Generation by Proximity to Higher-Order Exceptional Points

Zeng-Zhao Li,[1,2,*] Weijian Chen,[3,†] Maryam Abbasi,[3] Kater W. Murch,[3] and K. Birgitta Whaley[1,2,‡]
[1]*Department of Chemistry, University of California, Berkeley, California 94720, USA*
[2]*Berkeley Center for Quantum Information and Computation, Berkeley, California 94720, USA*
[3]*Department of Physics, Washington University, St. Louis, Missouri 63130, USA*

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Entanglement is a key resource for quantum information technologies ranging from quantum sensing to quantum computing. Conventionally, the entanglement between two coupled qubits is established at the timescale of the inverse of the coupling strength. In this Letter, we study two weakly coupled non-Hermitian qubits and observe entanglement generation at a significantly shorter timescale by proximity to a higher-order exceptional point. We establish a non-Hermitian perturbation theory based on constructing a biorthogonal complete basis and further identify the optimal condition to obtain the maximally entangled state. Our study of speeding up entanglement generation in non-Hermitian quantum systems opens new avenues for harnessing coherent nonunitary dissipation for quantum technologies.

DOI: 10.1103/PhysRevLett.131.100202

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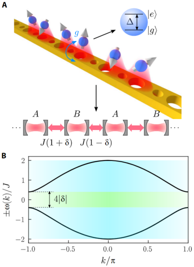
SCIENCE ADVANCES | RESEARCH ARTICLE

PHYSICS

Unconventional quantum optics in topological waveguide QED

M. Bello[1], G. Platero[1], J. I. Cirac[2], A. González-Tudela[2,3]*

The discovery of topological materials has motivated recent developments to export topological concepts into photonics to make light behave in exotic ways. Here, we predict several unconventional quantum optical phenomena that occur when quantum emitters interact with a topological waveguide quantum electrodynamics bath, namely, the photonic analog of the Su-Schrieffer-Heeger model. When the emitters' frequency lies within the topological bandgap, a chiral bound state emerges, which is located on just one side (right or left) of the emitter. In the presence of several emitters, this bound state mediates topological, tunable interactions between them, which can give rise to exotic many-body phases such as double Néel ordered states. Furthermore, when the emitters' optical transition is resonant with the bands, we find unconventional scattering properties and different super/subradiant states depending on the band topology. Last, we propose several implementations where these phenomena can be observed with state-of-the-art technology.



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PHYSICAL REVIEW B **108**, 085126 (2023)

Quantum quench dynamics of Berry and Uhlmann phases in topological systems

Zhan Gao and Yan He*

College of Physics, Sichuan University, Chengdu, Sichuan 610064, China

(Received 30 March 2023; revised 18 June 2023; accepted 9 August 2023; published 21 August 2023)

We study the time evolution of geometric phases of one-dimensional topological models under the quench dynamics. Taking the Creutz ladder model as an example, it is found that the Berry phase is fixed as the parameter is suddenly tuned across the topological phase boundary, given that the inversion symmetry of the model is preserved. At finite temperature, the Uhlmann phase displays abrupt jumps between the two quantized values, which indicates the topological transition at certain times after the quench. Both the Berry and Uhlmann phase will deviate from quantized values if the inversion symmetry if the model is broken.

DOI: 10.1103/PhysRevB.108.085126

हज़ारों ख़्वाहिशें ऐसी कि हर ख़्वाहिश पे दम निकले
बहुत निकले मिरे अरमान लेकिन फिर भी कम निकले

मिर्ज़ा ग़ालिब

I have a thousand yearnings , each one afflicts me so
Many were fulfilled for sure, not enough although