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## <span id="page-1-0"></span>**Outline**

- **•** Emergence of non-Hermiticity
- Quantum simulation of non-Hermitian physics • Emergence of non-Hermiticity<br>
• Quantum simulation of non-Hermitian physics<br>
• Topological transfer<br>
• Non-Hermitian skin effect<br>
• Summary and outlook<br>
• Summary and outlook<br>
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Topological transfer<br>
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Control of Center Funda Fitian physics<br>  $\gamma_{S_{\text{C}_\text{S}}}}$ 
	- Topological transfer
	- Non-Hermitian skin effect
	- Summary and outlook

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<span id="page-2-0"></span>Non-Hermitian quantum systems?

• Hermiticity central to conventional quantum mechanics

 $\hat{A} = \hat{A}^{\dagger} \Rightarrow$  Real eigenvalues

Parity-Time symmetric non-Hermitian models (Benders et al., 1998) • Parity-1 ime symmetric non-Hermitian models (Benders et al.,<br>
1998)<br>  $\left(\mathcal{PT}H(\mathcal{PT})^{-1} = H \Rightarrow E = E^* \right)$ <br>
• Non-Hermitian quantum mechanics in different contexts<br>
• Feshbach projection<br>
• Quantum trajectory description of Experimental Physics of Hermiticity central to conventional quantum mechanics<br>  $\hat{A} = \hat{A}^{\dagger} \Rightarrow$  Real eigenvalues<br>
• Parity-Time symmetric non-Hermitian models (Benders et al.,<br>
1998)<br>  $\begin{cases}\n\mathcal{P}TH(\mathcal{P}T)^{-1} = H \\
\mathcal{P$ Central to conventional quantum mechanics<br>
central to conventional quantum mechanics<br>
symmetric non-Hermitian models (Benders et al.,<br>  $\begin{cases} \mathcal{PT}H(\mathcal{PT})^{-1} = H \\ \mathcal{PT}|\psi\rangle \sim |\psi\rangle \end{cases} \Rightarrow E = E^*$ <br>
ian quantum mechanics in diffe al quantum mechanics<br>
Real eigenvalues<br>
itian models (Benders et al.,<br>  $= H \Rightarrow E = E^*$ <br>
ics in different contexts<br>
n of open systems<br>
ben systems<br>  $\therefore$  selection<br>  $\frac{25}{100}$ ,  $\frac{23}{105}$ ,  $\frac{23}{105}$ ,  $\frac{23}{105}$ ,  $\frac{2$  $\frac{1}{\sqrt{S}}$ <br>
Example  $\frac{1}{\sqrt{S}}$ <br>
Example  $\frac{1}{\sqrt{S}}$ 

$$
\begin{cases} \mathcal{PT}H\left(\mathcal{PT}\right)^{-1} = H \\ \mathcal{PT}|\psi\rangle \sim |\psi\rangle \end{cases} = E^*
$$

- Non-Hermitian quantum mechanics in different contexts
	- Feshbach projection
	- Quantum trajectory description of open systems
	- Double-space description of open systems
	- Alien quantum mechanics
- Quantum mechanics plus post selection **Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics**, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST Center for Fundamental Physics, AUS

Feshbach projection

- A subsystem P coupled to an environment Q (often continuum)  $\frac{1}{\sqrt{2}}$ <br>Centinuum)
- Project the dynamics into the subsystem

**Feshbach projection**

\n\n- A subsystem *P* coupled to an environment *Q* (often continuum)
\n- Project the dynamics into the subsystem
\n- $$
H_{\text{eff}}(E) = H_{PP} + H_{PQ} \frac{1}{E - H_{QQ}} H_{QP}
$$
\n
$$
= H_{PP} + \Delta(E) - \frac{i}{2} \Gamma
$$
\n
\n- Non-Hermiticity from the poles of 
$$
\frac{1}{E - H_{QQ}}
$$
\n
\n- Resonance between states in *P* and scattering states in *Q*
\n- Relevant for heavy nuclei, quantum resonance, and subradiance/superradiance
\n- H. Feshbach, Ann. Phys. 5, 357 (1958)
\n- J. Ashida, Z. Cong, M. Ueda, Adv. Phys. 69, 3 (2020)
\n- Wet VI (USTC)
\n

- Non-Hermiticity from the poles of  $\frac{1}{E-H_{QQ}}$
- Resonance between states in  $P$  and scattering states in  $Q$
- Relevant for heavy nuclei, quantum resonance, and subradiance/superradiance

H. Feshbach, Ann. Phys. 5, 357 (1958)

Y. Ashida, Z. Gong, M. Ueda, Adv. Phys. 69, 3 (2020) The Fundamental Physics, 3537 (1996)<br>
Center Fundamental Physics, AUST Center for Fundamental Physics, Adv. Phys. 69, 3 (2020)<br>
Wei Yi (USTC) Open systems with Markovian reservoir

**•** Lindblad equation

Open systems with Markovian reservoir	Indolated equation
\n $\frac{d}{dt}\rho = -i\left[H,\rho\right] - \frac{1}{2}\Gamma\left(S^{\dagger}S\rho + \rho S^{\dagger}S - 2S\rho S^{\dagger}\right)$ \n	
\n $= -i\left(H_{\text{eff}}\rho - \rho H_{\text{eff}}^{\dagger}\right) + \Gamma S\rho S^{\dagger}$ \n	
\n $H_{\text{eff}} = H - \frac{i}{2}\Gamma S^{\dagger}S$ \n	
\n $Q_{\text{Uantum Langevin equation}}$ \n	
\n $\frac{d}{dt}A = i\left[H_{\text{eff}}, A\right] - i\langle F(t)\rangle$ \n	
\n $q_{\text{H}} = \frac{1}{2} \Gamma S^{\dagger} S$ \n	
\n $Q_{\text{Vatum}$ \n	
\n $\frac{d}{dt}A = i\left[H_{\text{eff}}, A\right] - i\langle F(t)\rangle$ \n	
\n $Q_{\text{Vatum}}$ \n	
\n $Q_{\text{Vatum}}$ \n	
\n $q_{\text{Hatum}}$ \n	
\n $Q_{\text{Vatum}}$ \n	
\n $Q_{\text{Vat$	

• Quantum Langevin equation

$$
\frac{d}{dt}A=i\Big[H_{\rm eff},A\Big]-i\langle F(t)\rangle
$$

- Trace-conserving with quantum jump process
- Basic commutation relations kept intact by the Langevin noise **C** Basic commutation relations kept intact by the Langevin noise<br>Wei Yi (USTC)

Quantum trajectory approach

- Evolve the state (stochastically), rather than the density matrix  $\frac{1}{\sqrt{S}}$ ity matrix
- At each time step, roll a dice:
	- With probability  $1 \delta p$

$$
|\psi(t+\delta t)\rangle = \frac{1}{\sqrt{1-\delta p}}(1-iH_{\text{eff}}\delta t)|\psi(t)\rangle
$$

• With probability  $\delta p$  (quantum jump)

$$
|\psi(t+\delta t)=\frac{1}{\sqrt{\delta p/\delta t}}\sqrt{\Gamma}S|\psi(t)\rangle
$$

Here  $\delta p = \Gamma \delta t \langle \psi(t) | S^{\dagger} S | \psi(t) \rangle$ 

Dynamics driven by  $H_{\text{eff}}$  in the absence of quantum jumps Unconditional vs. conditional dynamics **O** Unconditional vs. conditional dynamics<br>
Wei Yi (USTC)  $|\psi(t + \delta t)\rangle = \frac{1}{\sqrt{1 - \delta p}} (1 - iH_{\text{eff}}\delta t)|\psi(t)\rangle$ <br>
• With probability  $\delta p$  (quantum jump)<br>  $|\psi(t + \delta t)\rangle = \frac{1}{\sqrt{\delta p/\delta t}} \sqrt{\Gamma} S |\psi(t)\rangle$ <br>
• Dynamics driven by  $H_{\text{eff}}$  in the absence of quantum jumps<br>
• Unconditional vs. condition Continue throughout the state (stochastically), rather than the density matrix<br>
• At each time step, roll a dice:<br>
• With probability  $1 - \delta p$ <br>  $|\psi(t + \delta t)\rangle = \frac{1}{\sqrt{1 - \delta p}} (1 - iH_{\text{eff}}\delta t)|\psi(t)\rangle$ <br>
• With probability  $\delta p$  (quan ory approach<br>
centration of the density matrix<br>
e step, roll a dice:<br>
cobability  $1 - \delta p$ <br>  $|\psi(t + \delta t)\rangle = \frac{1}{\sqrt{1 - \delta p}} (1 - iH_{\text{eff}}\delta t)|\psi(t)\rangle$ <br>
cobability  $\delta p$  (quantum jump)<br>  $|\psi(t + \delta t)\rangle = \frac{1}{\sqrt{\delta p/\delta t}} \sqrt{\Gamma} S |\psi(t)\rangle$ <br>  $\psi(t + \delta t)\rangle =$ rather than the density matrix<br>  $\frac{1}{-\delta p}(1 - iH_{\text{eff}}\delta t)|\psi(t)\rangle$ <br>
jump)<br>  $\frac{1}{\sqrt{\delta p/\delta t}}\sqrt{\Gamma}S|\psi(t)\rangle$ <br>
bsence of quantum jumps<br>
namics<br>  $\frac{\partial}{\partial \phi} \frac{\partial S}{\partial \delta t}$   $\frac{6}{31}$ 

# Non-Hermiticity in single-photon interferometry (quantum walk)



#### Introduction

Non-Hermiticity in cold atoms: PT symmetry with cold atoms



• Focusing on the remaining atoms (non-interacting)

J. Li, A. K. Harter, J. Liu, L. de Melo, Y. N. Joglekar, L. Luo, Nat. Commun. 10, 855 (2019) J. Li, A. K. Harter, J. Liu, L. de Melo, Y. N. Joglekar, L. Luo, Nat. Commun. 10, 855 (2019)<br>Wei Yi (USTC)

Double-space formalism

Mapping the density matrix and Lindblad equation

Double-space formalism

\n\n- Mapping the density matrix and Lindblad equation
\n- $$
\rho = \sum_{mn} \rho_{mn} |m\rangle\langle n| \Rightarrow |\Psi\rangle = \sum_{mn} \rho_{mn} |m\rangle \otimes |n\rangle
$$
\n- Lindblad equation 
$$
\Rightarrow (H_R - iH_I)|\Psi\rangle = E|\Psi\rangle
$$
\n- $$
H_R = H \otimes I - I \otimes H^T
$$
\n- $$
H_I = -2S \otimes S^* + (S^{\dagger}S) \otimes I + I \otimes (S^{\dagger}S)^*
$$
\n- Effective non-Hermitian Hamiltonian  $H_R - iH_I$  drives dynamics in the double space
\n- Louisville gap encoded in  $E$  (how steady-state can be approached)
\n- approached)
\n

- $\bullet$  Effective non-Hermitian Hamiltonian  $H_R iH_I$  drives dynamics in the double space
- $\bullet$  Louisville gap encoded in  $E$  (how steady-state can be approached)

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Non-Hermiticity in spin-waves (atomic vapour cell)



Optical Bloch equations

2 **vapour cell**)  
\nOptical Bloch equations  
\n
$$
\begin{cases}\n\rho_{12}^{(1)} = -\gamma_{12}' \rho_{12}^{(1)} + \Gamma_c \rho_{12}^{(2)} - \frac{\Omega_c^{(1)*} \Omega_p^{(1)}}{\gamma_{23}},\\
\rho_{12}^{(2)} = -\gamma_{12}' \rho_{12}^{(2)} + \Gamma_c \rho_{12}^{(1)} - \frac{\Omega_c^{(2)*} \Omega_p^{(2)}}{\gamma_{23}},\\
\Omega e^{i\theta_0}\n\end{cases}
$$
\n4 *a*)  $e^{i\theta_0}$   
\n $\alpha$  *i H*  $\tau$   
\nP. Peng et al., Nat. Phys. 12, 1139 (2016)  
\nX. Meng et al., Photonics Research (2022)  
\n $\frac{\partial}{\partial \phi_0} \frac{\partial}{\partial \phi$ 

Effective Hamiltonian

$$
H\propto (ga^\dagger b - g^*b^\dagger a)e^{i\theta_0}
$$

- Vapor cell as a gate with  $U=e^{-iH\tau}$
- $\bullet$  H inferred from light transport **C**enter Fundamental P. Peng et al., Nat. Phys. 12, 1139 (2016)<br>Wei Yi (USTC) Center for Center for Fundamental Photonics Research (2022)<br>Wei Yi (USTC) Center for Center for Australian Photonics Research (2022)

P. Peng et al., Nat. Phys. 12, 1139 (2016)

X. Meng et al., Photonics Research (2022)

Wei Yi (USTC) 淮南, 23/05/2024 10 / 31

Non-Hermitian quantum mechanics

Orthonormal basis in conventional quantum mechanics

$$
\langle \psi_n | \psi_m \rangle = \delta_{mn}, \quad \sum_n |\psi_n\rangle \langle \psi_n| = I
$$

Non-Hermitian version: left/right eigenstates

$$
\langle \psi_n | \chi_m \rangle = \delta_{mn}, \sum_n |\psi_n\rangle \langle \chi_n| = I
$$
  
with  $H_k | \psi_\mu \rangle = \epsilon_\mu | \psi_\mu \rangle$ ,  $H_k^{\dagger} | \chi_\mu \rangle = \epsilon_\mu^* | \chi_\mu \rangle$ 

Redefine dual space and inner product through the metric  $\eta = \sum_n |\chi_n \rangle \langle \chi_n|$ 

Noto-Hermitian quantum mechanics

\n\n- Orthonormal basis in conventional quantum mechanics
\n- Non-Hermitian version: left/right eigenstates
\n- $$
\langle \psi_n | \psi_m \rangle = \delta_{mn}, \quad \sum_n |\psi_n\rangle \langle \psi_n| = I
$$
\n- Non-Hermitian version: left/right eigenstates
\n- $$
\langle \psi_n | \chi_m \rangle = \delta_{mn}, \quad \sum_n |\psi_n\rangle \langle \chi_n| = I
$$
\n- with  $H_k | \psi_\mu \rangle = \epsilon_\mu | \psi_\mu \rangle, \quad H_k^{\dagger} | \chi_\mu \rangle = \epsilon_\mu^* | \chi_\mu \rangle$
\n- Redefine dual space and inner product through the metric  $\eta = \sum_n |\chi_n\rangle \langle \chi_n|$
\n- $$
|\chi_n \rangle = \eta | \psi_n \rangle \Rightarrow | \phi^{(i)} \rangle = \sum_n d_n^{(i)} | \psi_n \rangle, \quad \langle \phi_{\text{dual}}^{(i)} | = \sum_n d_n^{(i)*} \langle \chi_n |
$$
\n- $$
\langle \phi_{\text{dual}}^{(1)} | \phi^{(2)} \rangle = \sum_n d_n^{(1)*} d_n^{(2)} = \langle \phi_r^{(1)} | \eta | \phi_r^{(2)} \rangle
$$
\n- Weyn (USTC)
\n

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#### Alien quantum mechanics: curved space



 $\bullet$  Hatano-Nelson  $\leftrightarrow$  a strip on a 2D curved surface

C. Lv, R. Zhang, Z. Zhai, Q. Zhou, Nat. Commun. 13, 2184 (2022) C. Lv, R. Zhang, Z. Zhai, Q. Zhou, Nat. Commun. 13, 2184 (2022)<br>Wei Yi (USTC)

<span id="page-12-0"></span>Chiral state transfer near the exceptional point

• 
$$
\mathcal{PT}
$$
 symmetry  
\n
$$
H \neq H^{\dagger} \Rightarrow E \in \mathbb{C}, \text{ however, under } \mathcal{PT} \text{ symmetry}
$$
\n
$$
\begin{cases}\n\mathcal{PT}H(\mathcal{PT})^{-1} = H \\
\mathcal{PT}|\psi\rangle \sim |\psi\rangle\n\end{cases} \Rightarrow E = E^*
$$

C. M. Bender and S. Boettcher, Phys. Rev. Lett. 80, 5243 (1998)

 $\bullet$   $\mathcal{PT}$  transition and the exceptional point



# Exceptional points in a Fermi gas



# Collective chiral transfer



CCW: adiabatic, state flip CW: non-adiabatic, non-flip

# Decoherence as additional jump processes



Lindblad equation

$$
\dot{\rho} = -i(H_{\text{eff}}\rho - \rho H_{\text{eff}}^{\dagger}) + L_{\phi}\rho L_{\phi}^{\dagger} - \frac{1}{2}L_{\phi}^{\dagger}L_{\phi}\rho - \frac{1}{2}\rho L_{\phi}^{\dagger}L_{\phi},
$$

with

$$
H_{\text{eff}} = H_0 - i\Gamma|2\rangle\langle 2|, \quad L_{\phi} = \sqrt{\gamma_{\phi}}|2\rangle\langle 2|.
$$
\nWei Yi (USTC)

\n

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#### Consequences for the chiral transfer



K. Sun and WY, Phys. Rev. A 108, 013302 (2022)

#### Consequences for the chiral transfer







<span id="page-19-0"></span>S. Yao and Z. Wang, Phys. Rev. Lett. 121, 086803 (2018) T.-S. Deng and WY, Phys. Rev. B 100, 035102 (2019) T.-S. Deng and WY, Phys. Rev. B 100, 035102 (2019)<br>Wei Yi (USTC)

#### Failure of bulk-boundary correspondence



• Bulk topological invariants fail to predict edge states A solution: non-Bloch band theory

S. Yao and Z. Wang, Phys. Rev. Lett. 121, 086803 (2018)

K. Yokomizo and S. Murakami, Phys. Rev. Lett. 123, 066404 (2019) S. Yao and Z. Wang, Phys. Rev. Lett. 121, 086803 (2018)<br>K. Yokomizo and S. Murakami, Phys. Rev. Lett. 123, 066404 (2019)<br>Wei Yi (USTC)

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Non-Bloch band theory to the rescue

**•** Bulk-state ansatz

Non-Hermitian skin effect  
\nOn-Bloch band theory to the rescue  
\nBulk-state ansatz  
\n
$$
|\Psi\rangle = \sum_{j} \left( \psi_{a,j} a_{j}^{\dagger} + \psi_{b,j} b_{j}^{\dagger} \right) |0\rangle
$$
\n
$$
\left( \begin{array}{c} \psi_{a,j} \\ \psi_{b,j} \end{array} \right) = \left( \begin{array}{c} \phi_{a}^{(1)} \\ \phi_{b}^{(1)} \end{array} \right) \beta_{1}^{j} + \left( \begin{array}{c} \phi_{a}^{(2)} \\ \phi_{b}^{(2)} \end{array} \right) \beta_{2}^{j}
$$
\n• Hermitian limit:  $\beta_{1,2} = e^{\pm ik}$   
\nNon-Hermitian (open boundary):  $|\beta_{1,2}| \neq 1$   
\n• Non-Bloch topological invariants:  
\nWinding number calculated over the deformed Brillouin zone  
\n• More generally,  $\beta(k, t)$  in more complicated systems  
\nS. Yao, F. Song, Z. Wang, Phys. Rev. Lett. 121, 136802 (2018)  
\nWeivi (USTC)  
\n#A, 23/05/2024  
\n21/31



- Hermitian limit:  $\beta_{1,2} = e^{\pm i k}$ Non-Hermitian (open boundary):  $|\beta_{1,2}| \neq$
- Non-Bloch topological invariants: Winding number calculated over the deformed Brillioun zone  $\begin{pmatrix} \psi_{a,j} \\ \psi_{b,j} \end{pmatrix} = \begin{pmatrix} \phi_a^{(1)} \\ \phi_b^{(1)} \end{pmatrix} \beta_1^j + \begin{pmatrix} \phi_a^{(2)} \\ \phi_b^{(2)} \end{pmatrix} \beta_2^j$ <br>
• Hermitian limit:  $\beta_{1,2} = e^{\pm ik}$ <br>
Non-Hermitian (open boundary):  $|\beta_{1,2}| \neq 1$ <br>
• Non-Bloch topological invariants:<br>
Win
	- More generally,  $\beta(k, t)$  in more complicated systems

S. Yao, F. Song, Z. Wang, Phys. Rev. Lett. 121, 136802 (2018) S. Yao, F. Song, Z. Wang, Phys. Rev. Lett. 121, 136802 (2018)<br>
Wei Yi (USTC)

## Experiments on skin effects/b.b.c.



Topoelectrical circuits: Nat. Phys. 16, 747 (2020) Mechanics: PNAS 117, 29561 (2020)







Photonic quantum walk: Nat. Phys. 16, 761 (2020) Center for Fundamental Physics, AUST Center for Fundamental Physics, AUST



Optical fibre: Science 368, 311 (2020)

#### Simulating non-Hermitian skin effect with QWs



Floquet operator  $U = R(\frac{\theta_1}{2})$  $\frac{\theta_1}{2}$ ) $S_2R(\frac{\theta_2}{2})$  $\frac{\theta_2}{2})MR(\frac{\theta_2}{2})$  $\frac{\theta_2}{2}$ ) $S_1R(\frac{\theta_1}{2})$  $\frac{y_1}{2}$ ) with

 $M = \mathbb{1}_w \otimes (e^{\gamma} | \uparrow \rangle \langle \uparrow | + e^{-\gamma} | \downarrow \rangle \langle \downarrow |)$ 

L. Xiao, T. Deng, K. Wang, G. Zhu, Z. Wang, WY, P. Xue, Nat. Phys. 16, 761 (2020) Center Fundamental Physics, Australian Physics, Australian Physics, Australian Physics, Australian Physics, Au<br>The Fundamental Physics, Australian Physics, Australian Physics, Australian Physics, Australian Physics, Austr

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# Comparison with non-Hermitian SSH model Non-Hermitian SSH model

$$
H_k = (t_1 + t_2 \cos k)\sigma_x + (t_2 \sin k + i\frac{\gamma}{2})\sigma_y
$$

Quantum walk with skin effect

Non-Hermitian skin effect	
Comparison with non-Hermitian SSH model	
• Non-Hermitian SSH model	
$H_k = (t_1 + t_2 \cos k)\sigma_x + (t_2 \sin k + i\frac{\gamma}{2})\sigma_y$	
• Quantum walk with skin effect	
$U_k = d_0\sigma_0 - id_1\sigma_x - id_2\sigma_y - id_3\sigma_z$	
$d_0 = -\cosh \gamma \sin \theta_1 \sin \theta_2 + \cosh \gamma \cos k \cos \theta_1 \cos \theta_2 + i \sinh \gamma \cos \theta_1 \sin k$	
$d_1 = 0$ ,	
$d_2 = \cosh \gamma \cos \theta_1 \sin \theta_2 + \cos k \cosh \gamma \cos \theta_2 \sin \theta_1 + i \sin k \sinh \gamma \sin \theta_1$	
$d_3 = -\sin k \cosh \gamma \cos \theta_2 + i \cos k \sinh \gamma$	
In the low-k limit	
$d_2 = a_2 + b_2 \cos k$	
$d_3 = a_3 \sin k + ib_3$	
• Lattice model still quite different	
•	$\frac{a_1 \sin \theta_2}{a_2 \sin \theta_1 \sin \theta_2} = \frac{a_2 \sin \theta_2}{a_2 \sin \theta_2 \sin \theta_2}$
•	$\frac{a_1 \sin \theta_2}{a_2 \cos \theta_2}$
•	$\frac{a_2 \sin \theta_2}{a_2 \cos \theta_2}$
•	$\frac{a_3 \sin \theta_2}{a_3 \cos \theta_2}$
•	$\frac{a_2 \sin \theta_2}{a_3 \cos \theta_2}$

In the low- $k$  limit

$$
d_2 = a_2 + b_2 \cos k
$$
  

$$
d_3 = a_3 \sin k + ib_3
$$

Lattice model still quite different **O** Lattice model still quite different<br>
Very (USTC) Center for Fundamental Physics, AUST Center for Fundamenta

#### Experimental implementation and observation



Single photons

## Experimental implementation and observation



- Single photons
- Non-Hermitian skin effect: probability localization in the absence of topological edge states **O** Non-Hermitian skin effect:<br>probability localization in the absence of topological edge states<br>weixi (USTC)

How to detect edge states?

**•** Time-dependent wave function

$$
|\Phi(t)\rangle = U^t |\Phi(0)\rangle = \sum_n e^{-iE_n t} \Phi_n |\psi_n\rangle
$$

with  $(\varPhi_n = \langle \chi_n | \varPhi(0) \rangle$ 

**•** Time-integrated wave function

$$
|\varPhi_\epsilon(t)\rangle=\textstyle{\sum_{t'=0}^t}\,\tfrac{e^{i\epsilon t'}}{t+1}|\varPhi(t')\rangle\quad(\epsilon=0,\pi)
$$

- Only components with  $\epsilon = 0, \pi$  remain in the summation  $|\Phi_{\epsilon}(t)\rangle = \sum_{n} f_{\epsilon}(E_n) \Phi_n |\psi_n\rangle$ **CENTE:** The integrated wave function<br>  $|\Phi_{\epsilon}(t)\rangle = \sum_{t'=0}^{t} \frac{e^{i\epsilon t'}}{t+1} |\Phi(t')\rangle \quad (\epsilon = 0, \pi)$ <br> **O** Only components with  $\epsilon = 0, \pi$  remain in the summation<br>  $|\Phi_{\epsilon}(t)\rangle = \sum_{n} f_{\epsilon}(E_{n}) \Phi_{n} |\psi_{n}\rangle$ <br>  $\mathcal{O}_{\epsilon}$  Full resolutio Now to detect edge states?<br>
• Time-dependent wave function<br>  $|\Phi(t)\rangle = U^t|\Phi(0)\rangle = \sum_n e^{-iE_nt}\Phi_n|\psi_n\rangle$ <br>
with  $(\Phi_n = \langle \chi_n | \Phi(0) \rangle$ <br>
• Time-integrated wave function<br>  $|\Phi_{\epsilon}(t)\rangle = \sum_{t'=0}^{t} \frac{e^{i\epsilon t'}}{t+1} |\Phi(t')\rangle$   $(\epsilon = 0, \pi)$ <br>
• Only co Non-Hermitian skin effect<br>  $U^t|\Phi(0)\rangle = \sum_n e^{-iE_n t}\Phi_n|\psi_n\rangle$   $=\langle \chi_n|\Phi(0)\rangle$   $\text{grated wave function}$   $\sum_{t'=0}^t \frac{e^{i\epsilon t'}}{t+1}|\Phi(t')\rangle \quad (\epsilon=0,\pi)$ ponents with  $\epsilon=0, \pi$  remain in the summation<br>  $\sum_n f_{\epsilon}(E_n)\Phi_n|\psi_n\rangle$ <br>
ution of the edge states<br>  $\begin{CD} \epsilon^t \Phi_n | \psi_n \rangle \end{CD}$ <br>  $\epsilon = 0, \pi$ <br>  $\tau$  remain in the summation<br>  $\begin{CD} \epsilon = \sqrt{\frac{26}{31}} \end{CD}$ <br>  $(\mu = \pm)$ <br>  $\begin{CD} \frac{26}{31} & \frac{23}{95}/2024 & \frac{26}{31} \end{CD}$ Center Fundamental Physics,
	- Full resolution of the edge states

$$
\Phi_{\epsilon,\mu}(x) = \left| \left( \langle x | \otimes \langle \mu | \right) | \Phi_{\epsilon}(t) \rangle \right| \quad (\mu = \pm)
$$
\nWei Yi (USTC)

\n

# Confirming non-Hermitian bbc



# Confirming non-Hermitian bbc



 $\blacktriangleright$  Edge states with  $\epsilon = 0, \pi$ 

# Confirming non-Hermitian bbc

![](_page_30_Figure_2.jpeg)

![](_page_31_Figure_2.jpeg)

$$
\sum_{a} \frac{1}{t} \frac{1}{b} \frac{1}{t} \frac{1}{a} \frac{1}{b} \frac{1}{t} \frac{1}{b} \dots
$$
\n
$$
n=0 \qquad n=1 \qquad n=2
$$
\n
$$
\sum_{n=0} \frac{1}{n} \left[ \Delta(c_{m,a}^{\dagger} c_{m,a} + c_{m,b}^{\dagger} c_{m,b}) + t_{1}(c_{m+1,a}^{\dagger} c_{m,b} + \text{H.c.}) + (t + \tilde{\gamma})c_{m,a}^{\dagger} c_{m,b} + (t - \tilde{\gamma})c_{m,b}^{\dagger} c_{m,a} \right]
$$
\n
$$
W. \text{ Gou et al., Phys. Rev. Lett. 124, 070402 (2020)
$$
\n
$$
W = \frac{1}{2} \left[ \frac{\Delta}{2} \left( \frac{1}{b} \frac{1}{b} \frac{1}{b} \frac{1}{b} \frac{1}{c_{m,a}} \frac{1
$$

W. Gou et al., Phys. Rev. Lett. 124, 070402 (2020)

**Center Fundamental Physics** 

![](_page_32_Figure_2.jpeg)

• AB chain in synthetic dimensions **C** Laser-induced loss

Q. Liang et al., Phys. Rev. Lett. 129, 070401 (2022) H. Li, WY, Phys. Rev. A 106, 053311 (2022) Q. Liang et al., Phys. Rev. Lett. 129, 070401 (2022)<br>
H. Li, WY, Phys. Rev. A 106, 053311 (2022)<br>
Wei Yi (USTC) 31

![](_page_33_Figure_2.jpeg)

**Growth-rate and spectral measurements** 

Q. Liang et al., Phys. Rev. Lett. 129, 070401 (2022) Q. Liang et al., Phys. Rev. Lett. 129, 070401 (2022)<br>
H. Li, WY, Phys. Rev. A 106, 053311 (2022)<br>
Wei Yi (USTC) 30/31

H. Li, WY, Phys. Rev. A 106, 053311 (2022)

![](_page_34_Figure_2.jpeg)

**Growth-rate and spectral measurements** 

Q. Liang et al., Phys. Rev. Lett. 129, 070401 (2022) Q. Liang et al., Phys. Rev. Lett. 129, 070401 (2022)<br>
H. Li, WY, Phys. Rev. A 106, 053311 (2022)<br>
Wei Yi (USTC) 30/31

H. Li, WY, Phys. Rev. A 106, 053311 (2022)

![](_page_34_Picture_6.jpeg)

# <span id="page-35-0"></span>Summary and outlook

Revealing non-Hermitian physics through dynamics

- Topological and critical dynamics near exceptional points Revealing non-Hermitian physics through dynamics<br>
• Topological and critical dynamics near exceptional points<br>
• Non-Hermitian-skin-effect-related phenomena<br>
• Many-body scenario?<br>
• Many-body scenario?<br>
• Many-body scenar Summary<br>
Center for Fundamental Physics through dynamics<br>
• Topological and critical dynamics near exceptional points<br>
• Non-Hermitian-skin-effect-related phenomena<br>
• Many-body scenario?<br>
• Many-body scenario?<br>
• Many Log Summary<br>
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and critical dynamics near exceptional points<br>
and simple the Fundamental Phenomena<br>
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	- Non-Hermitian-skin-effect-related phenomena
	- Many-body scenario?