Static and dynamic topological modes in interacting non-Hermitian systems with tensor networks

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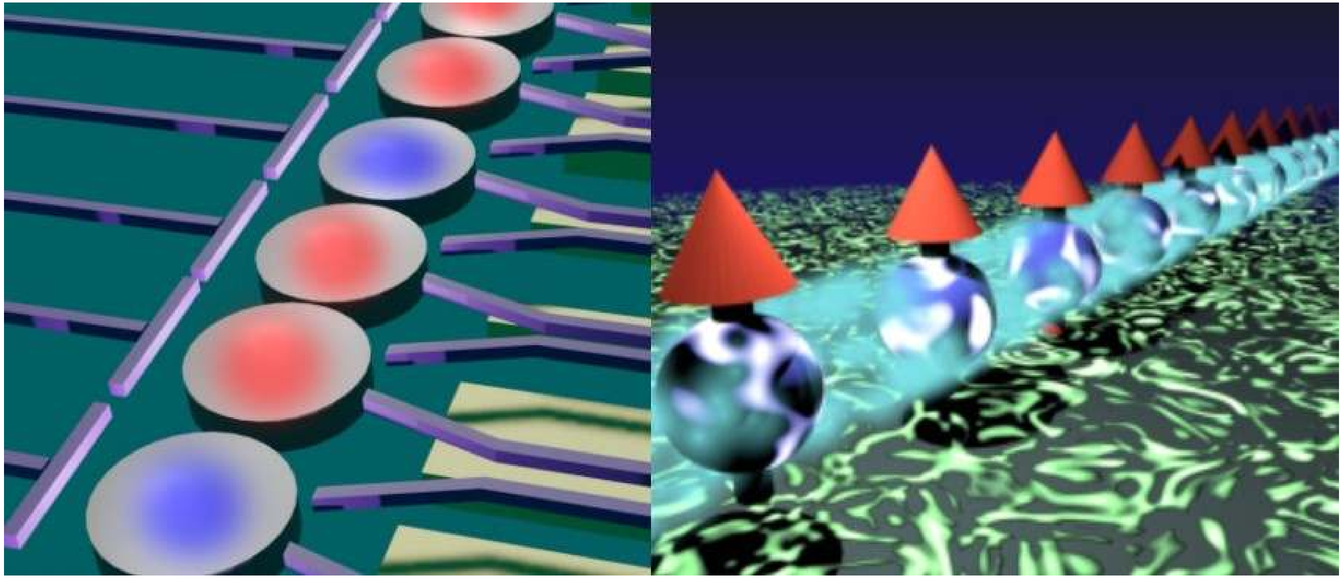
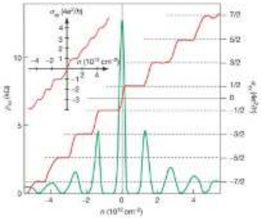


Phys. Rev. Research 4, L012006 (2022)   Phys. Rev. Lett. 130, 100401 (2023)

Non-Hermitian Physics: From classical to quantum, From theory to the lab
June 28th 2023

Topological matter

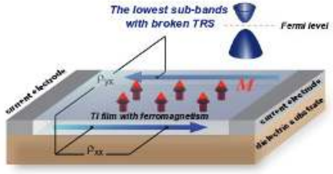
Quantum Hall effect



graphene

Nature 438, 197-200 (2005)

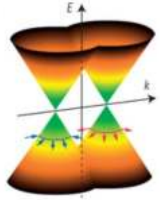
Quantum Anomalous Hall effect



Cr-doped $(Bi,Sb)_2Te_3$

Science 340.6129 (2013): 167-170

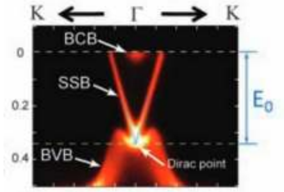
Weyl semimetal



TaAs

Nature Physics 11, 724–727 (2015)

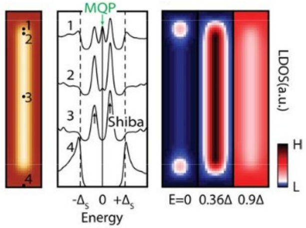
Quantum Spin Hall effect



Bi_2Se_3

Science 325.5937 (2009): 178-181

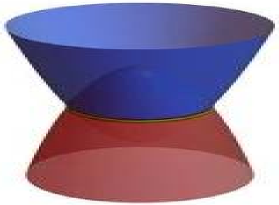
Topological superconductor



Fe@Pb

Science 346.6209 (2014): 602-607

Nodal line semimetals



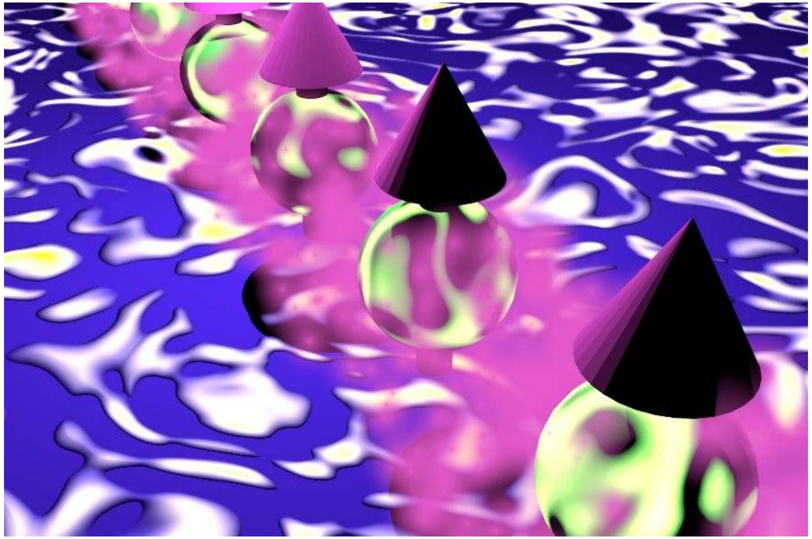
Mg_3Bi_2

Advanced Science 6.4 (2019): 1800897

All these states are described by effective isolated single-particle Hamiltonians

Two major challenges in topological matter

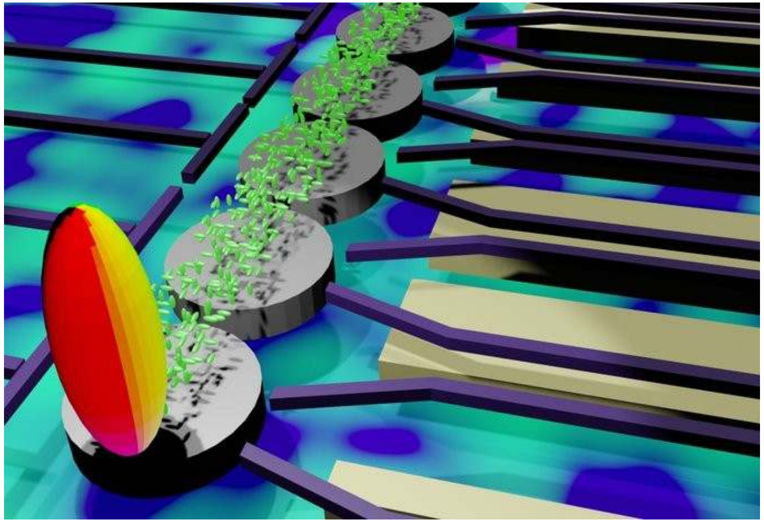
Many-body interactions



Interacting topological matter

Rep. Prog. Phys. 81 116501 (2018)

Coupling to the environment

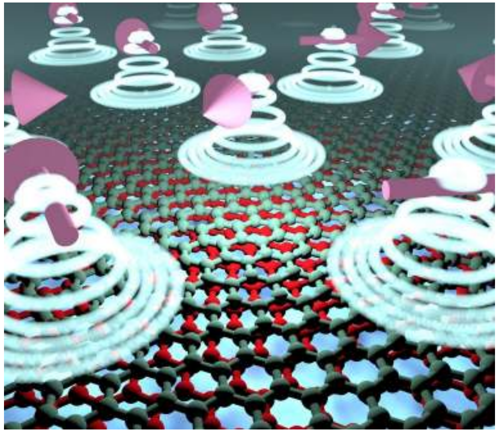


Non-Hermitian topological matter

Rev. Mod. Phys. 93, 015005 (2021)

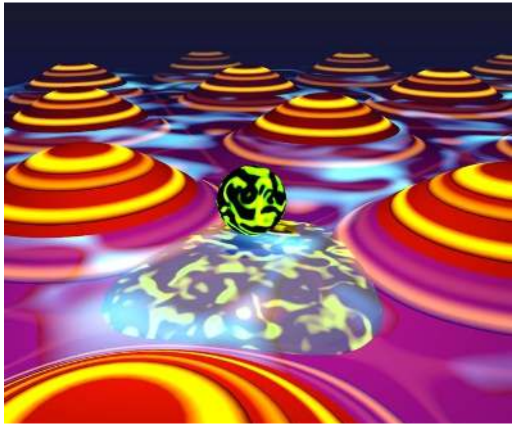
Many-body quantum matter

Quantum spin liquids



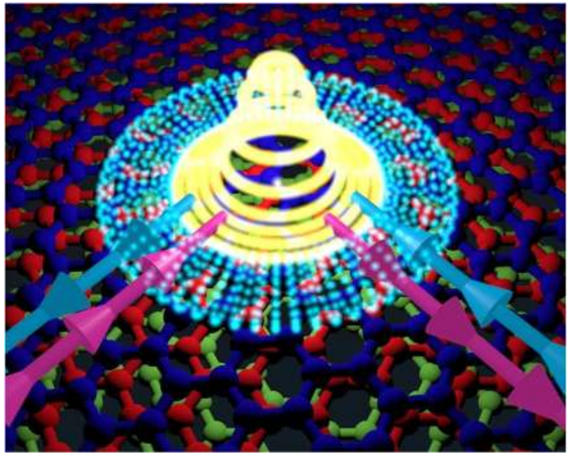
Reports on Progress in Physics 80.1 (2016): 016502.

Fractional Chern insulators



Rev. Mod. Phys. 71, S298 (1999)

Parafermions

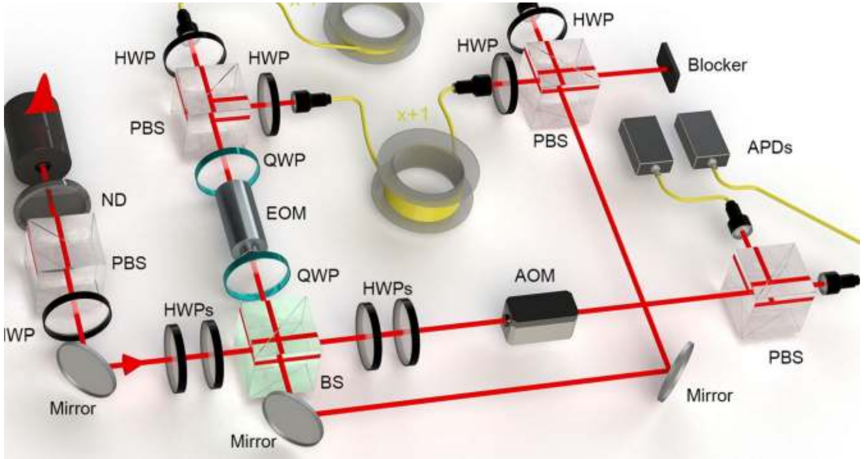


Annual Review of Condensed Matter Physics 7, 119-139 (2016)

Many-body quantum matter represents an exciting critically open challenge

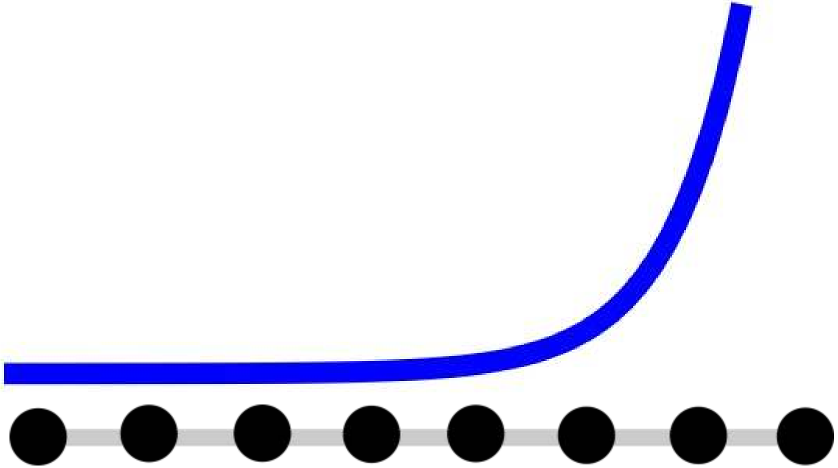
Non-Hermitian quantum matter

Non-Hermitian topology



Nat Comm 13, 3229 (2022)

Non-Hermitian skin effect

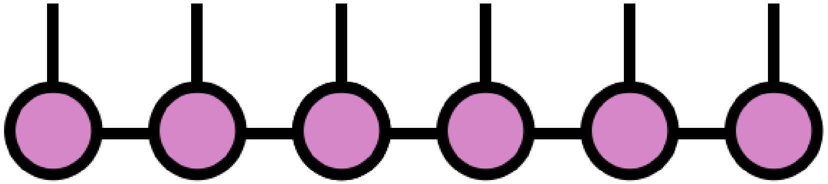


Phys. Rev. Lett. 129, 070401 (2022)

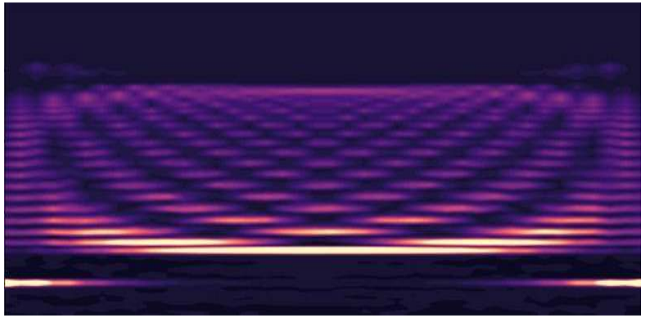
Non-Hermitian quantum matter opens exciting new possibilities in emergent phenomena

Plan for today

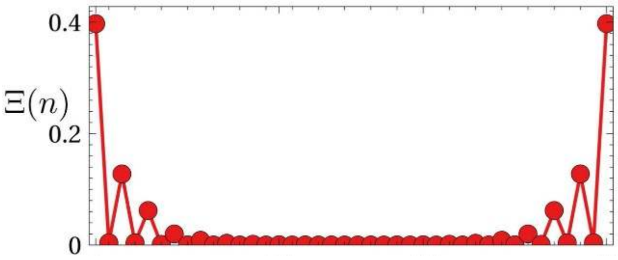
Tensor networks for many-body matter



Dynamical correlators for interacting many-body edge modes

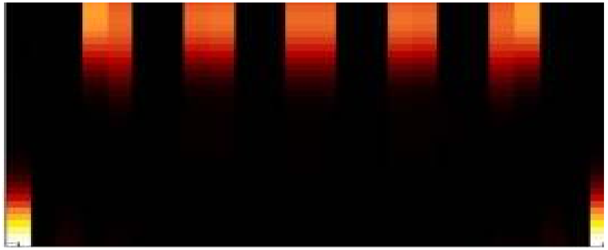


Edge modes from interacting non-Hermitian topology

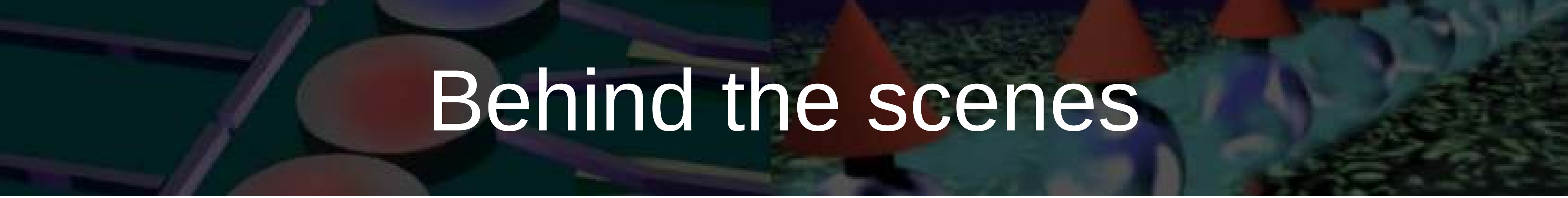


Phys. Rev. Research 4, L012006 (2022)

Dynamical correlators for non-Hermitian many-body topology



Phys. Rev. Lett. 130, 100401 (2023)



Behind the scenes

Edge modes from interacting non-Hermitian topology

Timo Hyart

Phys. Rev. Research 4, L012006 (2022)

Dynamical correlators for non-Hermitian many-body topology

Fei Song

Guangze Chen

Phys. Rev. Lett. 130, 100401 (2023)

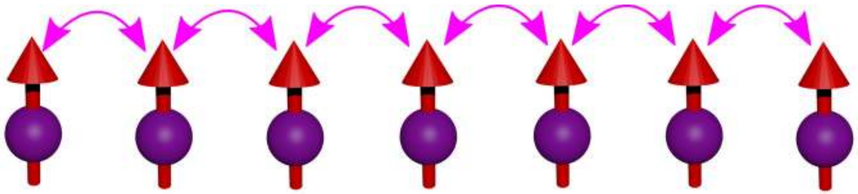
Tensor networks for quantum many-body Hamiltonians

The problem of dimensionality

In a many-body problem, the size of our vectors grows as

2^L where L is the number of sites

$$\mathcal{H} = \sum_{\langle ij \rangle} J \vec{S}_i \cdot \vec{S}_j$$



For a single-particle tight binding problem, we can reach up to 10^8 sites in a laptop

For a many-problem, we cannot even store states for systems bigger than $L = 30$ sites

$$2^{30} \sim 10^9$$

The quantum many-body problem

Let us go back to a simple many-body problem $$\mathcal{H} = \sum_{ij} J_{ij} \vec{S}_i \cdot \vec{S}_j$$

A typical wavefunction is written as

$$|\Psi\rangle = \sum c_{s_1, s_2, \ldots, s_L} |s_1, s_2, \ldots s_L\rangle$$

We need to determine in total 2^L coefficients

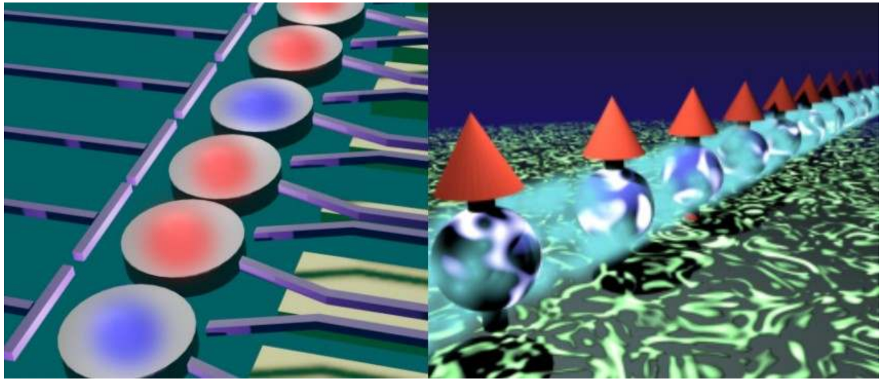
Is there an efficient way of storing so many coefficients?

The fundamental idea of tensor-networks

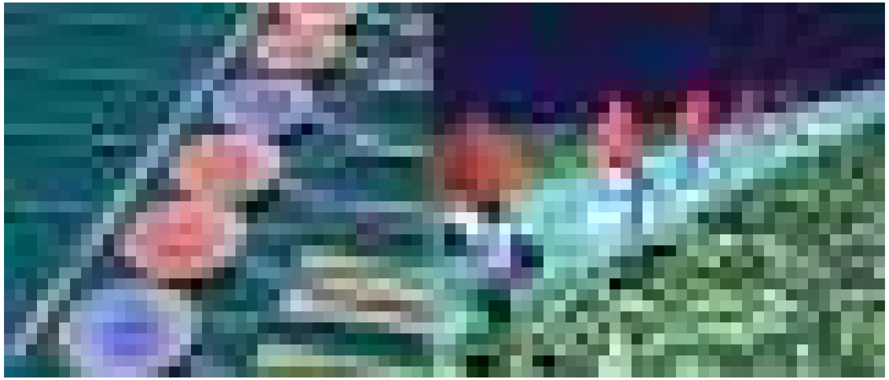
A many-body wavefunction a is a very high dimensional object

$$|\Psi\rangle = \sum c_{s_1,s_2,\dots,s_L} |s_1, s_2, \dots s_L\rangle$$

Tensor-networks allow “compressing” all that information in a very efficient way



“True wavefunction”



“Tensor-network wavefunction”

The matrix-product state ansatz

For this wavefunction $$|\Psi\rangle = \sum c_{s_1,s_2,\ldots,s_L}|s_1, s_2, \ldots s_L\rangle$$

Let us imagine to propose a parametrization in this form

$$c_{s_1,s_2,\ldots.,s_L} = M_1^{s_1} M_2^{s_2} \ldots. M_L^{s_3}$$

dimension 2^L

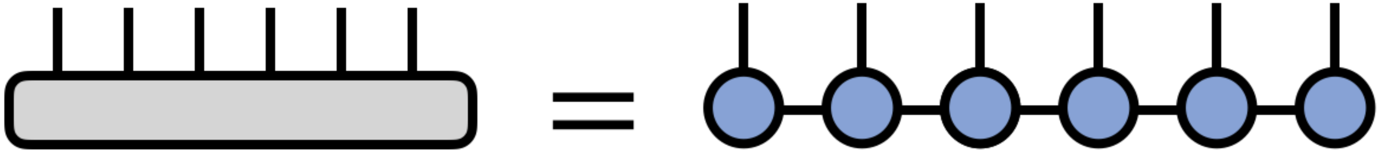
dimension $\sim Lm^2$

(m dimension of the matrix)

State compression with tensor-networks

Given a many-body wavefunction, we can parametrice the components as

$$|\Psi\rangle = \sum_{\{s\}} \mathrm{Tr}\left[M_1^{(s_1)} M_2^{(s_2)} \cdots M_N^{(s_N)}\right] |s_1 s_2 \ldots s_N\rangle$$



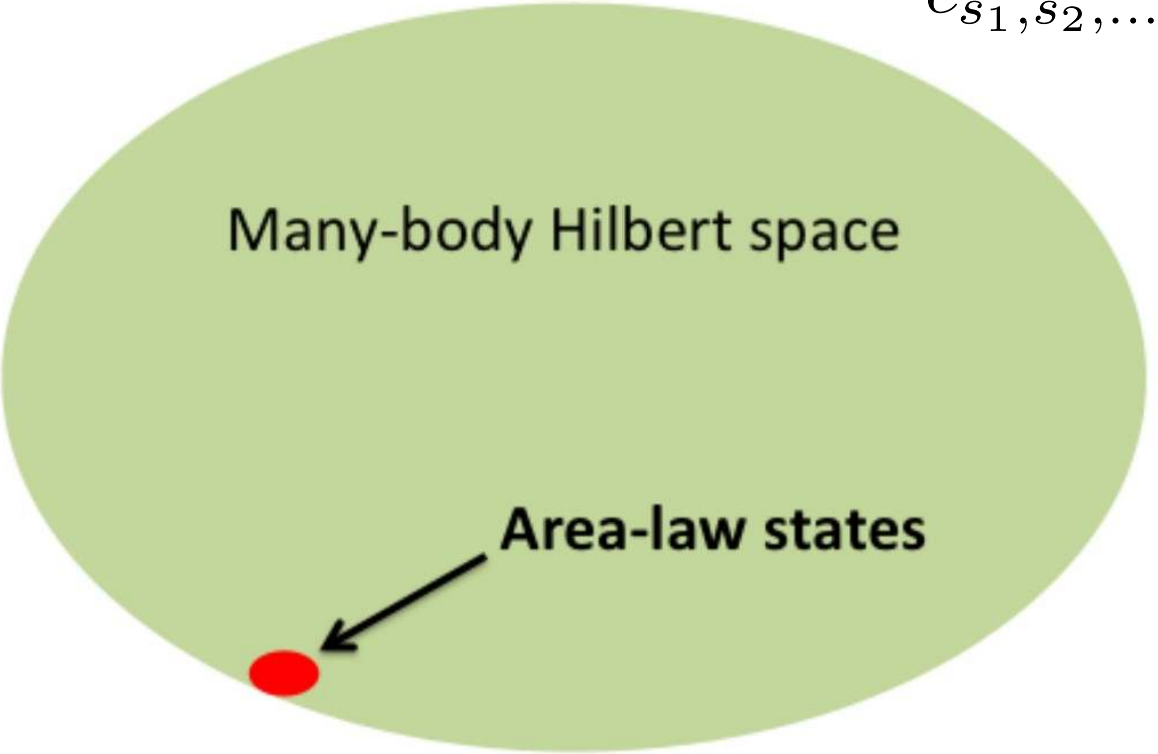
Matrix product state

The previous representation allows drastically reducing the memory required to store a state

Annals of Physics 326, 96 (2011)

MPS as a paramterization of area law states

$$c_{s_1,s_2,....,s_L} = M_1^{s_1} M_2^{s_2} ....M_L^{s_3}$$



The matrix-product state ansatz

- This ansatz enforces a maximum amount of entanglement entropy in the state $S \sim \log m$
- One-dimensional (Hermitian) problems have ground states that can be captured with this ansatz

$$c_{s_1,s_2,\ldots.,s_L} = M_1^{s_1} M_2^{s_2} \ldots. M_L^{s_3}$$

This ansatz can be generalized for time-evolution, excited states, or typical thermal states

Matrix-product states for non-Hermitian systems

MPS are well controlled for Hermitian Hamiltonians, but will/should they work for non-Hermitian systems?

In general, this is not known yet

In practical cases, they do!

How do we find the ground states of non-Hermitian Hamiltonians with MPS?

We can use MPS as a variational manifold and find them iteratively

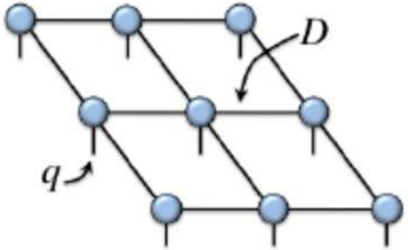
(Arnoldi-Krylov algorithm)

Many-body state compression

Matrix-product states

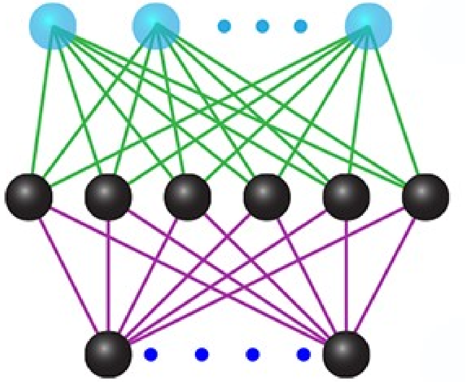
Phys. Rev. Lett. 69, 2863 (1992)

Projected entangled pair-states



Annals of Physics 326, 96 (2011)

Neural-network quantum states



Science 355.6325 (2017): 602-606.

Other compressed many-body states could be potentially used for non-Hermitian interacting many-body systems

Dynamical excitations in quantum many-body systems

Why dynamical correlators

For a single particle model

L eigenstates/eigenenergies

Hilbert space

<u>One particle excitations</u>

For a many-body model

2^L eigenstates/eigenenergies

Fock space

<u>One, two, three... particle excitations</u>

How do we identify single particle excitations in a many-body Hamiltonian?

A single particle Hamiltonian can be solved in any of the two spaces

$$H = \sum_{ij} t_{ij} c_i^\dagger c_j$$

Why dynamical correlators

Take a many-body Hamiltonian $\mathcal{H}$

With ground state $\mathcal{H}|\Omega\rangle = E_0|\Omega_0\rangle$

And excited states $\mathcal{H}|\Psi_n\rangle = E_n|\Psi_n\rangle$

A way to “filter” single particle excitations is by defining

$$A(\omega, l) = \sum_n \delta(\omega - (E_n - E_0))|\langle\Psi_n|c_l^\dagger|\Omega\rangle|^2$$

Dirac delta function

Picks energy differences ω

Only non-zero if they differ by one electron

This is a dynamical correlator

Why dynamical correlators

Dynamical correlator (for single particle electron excitations)

$$A(\omega, n) = \langle \Omega | c_n \delta(\omega - (\mathcal{H} - E_0)) c_n^\dagger | \Omega \rangle$$

for fermionic models

Dynamical correlator (for spin excitations)

$$A(\omega, n) = \langle \Omega | S_n^+ \delta(\omega - (\mathcal{H} - E_0)) S_n^- | \Omega \rangle$$

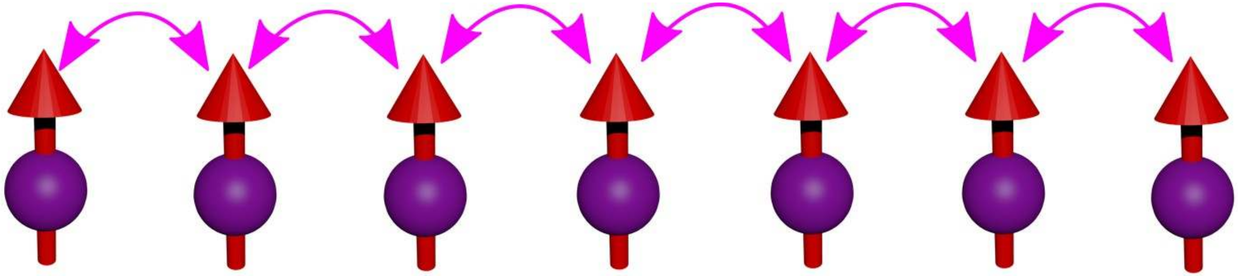
for spin models

Both can be related by a fermion-spin mapping (Jordan-Wigner transformation)

Many-body dynamical correlators

One dimensional Heisenberg Hamiltonian

$$\mathcal{H} = \sum_{\langle ij \rangle} J \vec{S}_i \cdot \vec{S}_j$$



We want to compute the dynamical correlator

$$\mathcal{S}(N,\omega) = \langle GS | S_N^z \delta(\omega - \mathcal{H} + E_0) S_N^z | GS \rangle$$

The kernel-polynomial tensor-network algorithm

Take a many-body Hamiltonian $\mathcal{H} = \sum_{\langle ij \rangle} J \vec{S}_i \cdot \vec{S}_j$

Obtain a tensor-network representation of the many-body ground state

$|GS\rangle =$ 

And apply the kernel polynomial algorithm in the compressed representation

$$\bar{\chi}(\omega) = \langle \mathrm{GS} | S_N^z \delta(\omega - \bar{H}) S_N^z | \mathrm{GS} \rangle$$

$$\bar{\chi}(\omega) = \frac{1}{\pi\sqrt{1-\omega^2}} \left[\mu_0 + 2 \sum_{l=1}^{N_P} \mu_l T_l(\omega) \right]$$

$$\mu_l = \langle \mathrm{GS} | S_N^z T_l(\bar{H}) S_N^z | \mathrm{GS} \rangle$$

$$\mu_l = \langle \mathrm{GS} | S_N^z | w_l \rangle$$

$$|w_0\rangle = S_N^z |\mathrm{GS}\rangle,$$

$$|w_1\rangle = \bar{H} |w_0\rangle,$$

$$|w_{l+1}\rangle = 2\bar{H}|w_l\rangle - |w_{l-1}\rangle,$$

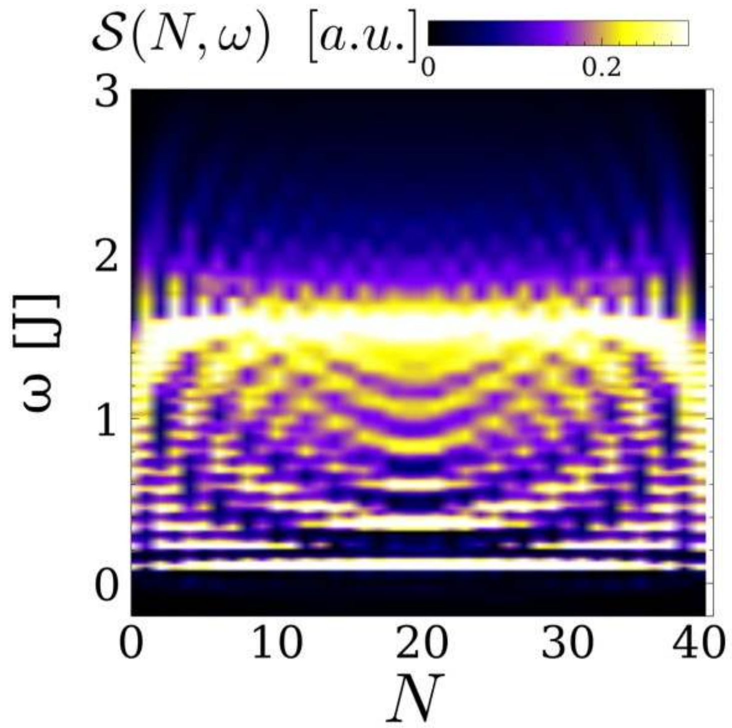
Rev. Mod. Phys. 78, 275 (2006)

Phys. Rev. Research 1, 033009 (2019)

Open-source implementation in *https://github.com/joselado/dmrgpy*

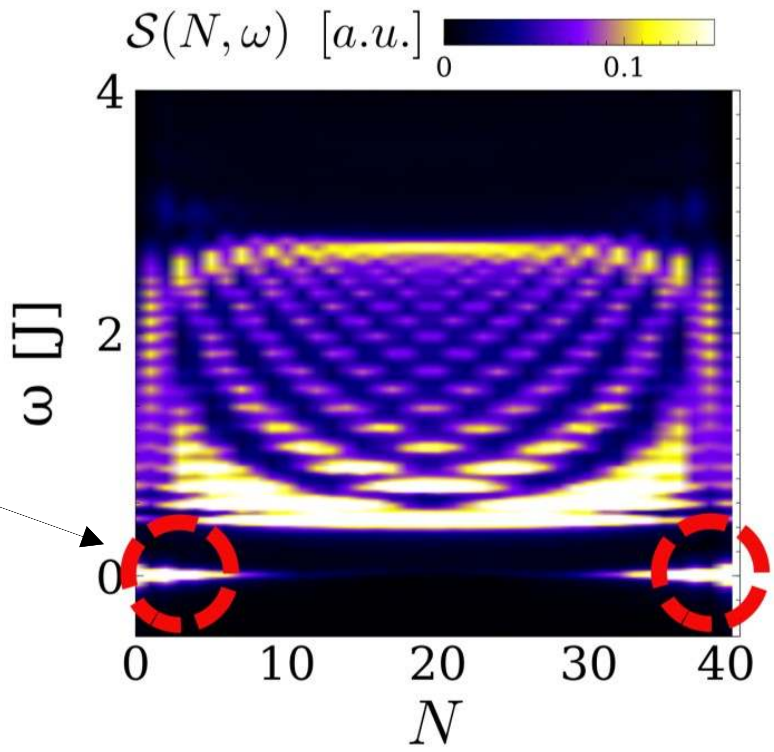
Dynamical structure factor of a Heisenberg model

S=1/2 chain



S=1 chain

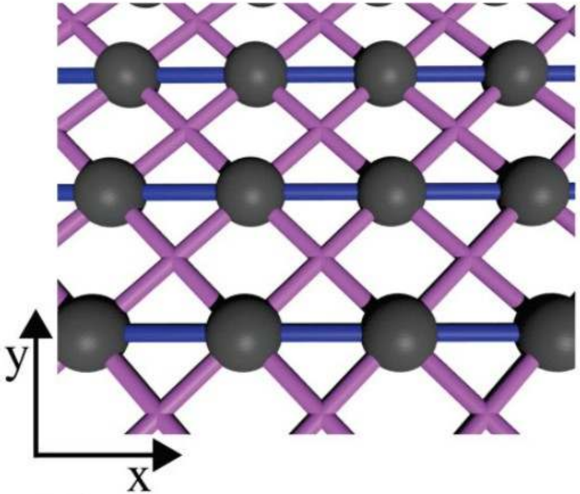
Edge modes



A minimal example of topological modes in a many-body Hamiltonian

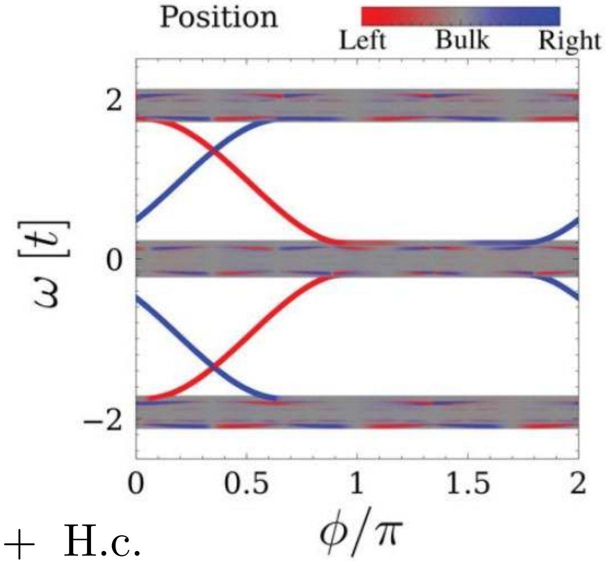
Quasiperiodic topology

Quantum Hall in a two-dimensional lattice



$\sim$

Spectrum of the associated quasiperiodic Hamiltonian



$$H = t\sum_N [1 + \lambda\cos(\alpha N + \phi)] c_N^\dagger c_{N+1} + \text{ H.c.}$$

1D quasiperiodic models can be mapped to 2D quantum Hall states

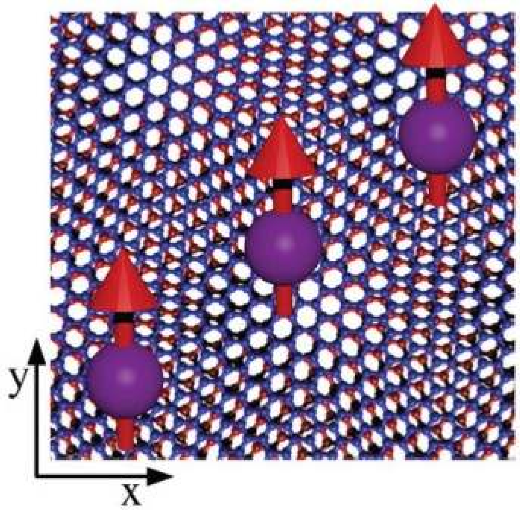
This mapping is only valid in the non-interacting limit

Phys. Rev. Lett. 109, 116404 (2012)

Quasiperiodic spinon topology

Many-body spin Hamiltonians can be intrinsically quasiperiodic

For example, an atomic chain on top of a moire system

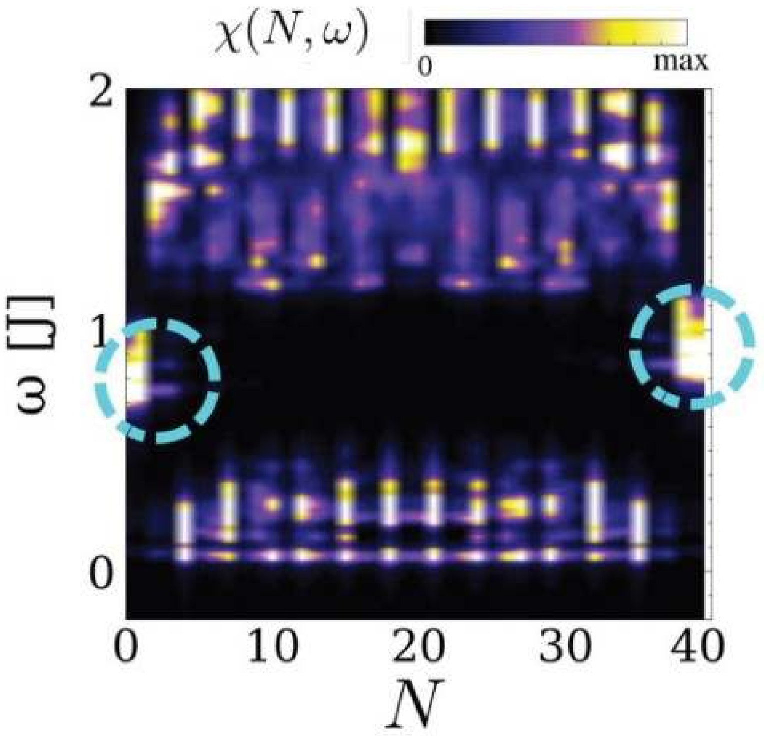


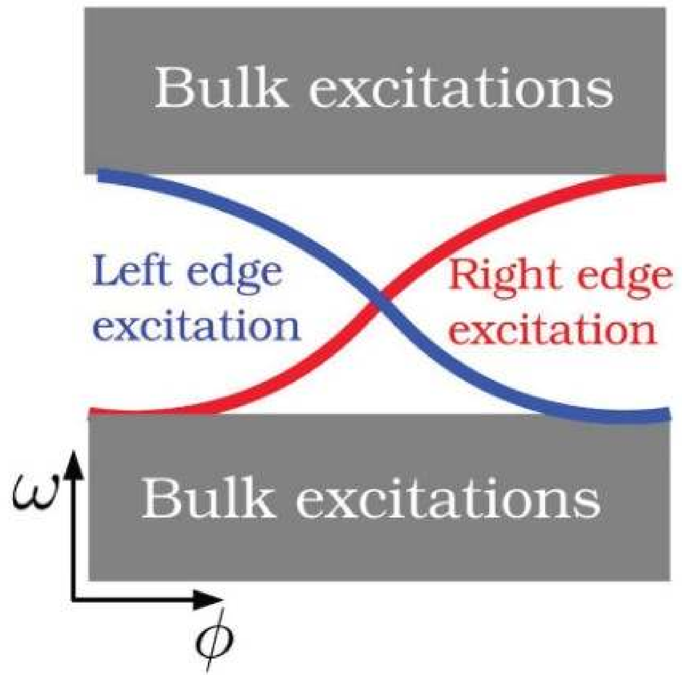
We will consider the generalized quasiperiodic Heisenberg model

$$H = J \sum_N [1 + \lambda \cos(\alpha N + \phi)] \vec{S}_N \cdot \vec{S}_{N+1}$$

with $S = 1/2, 1, 3/2, 2$

Topological quasiperiodic spinons for S=1/2

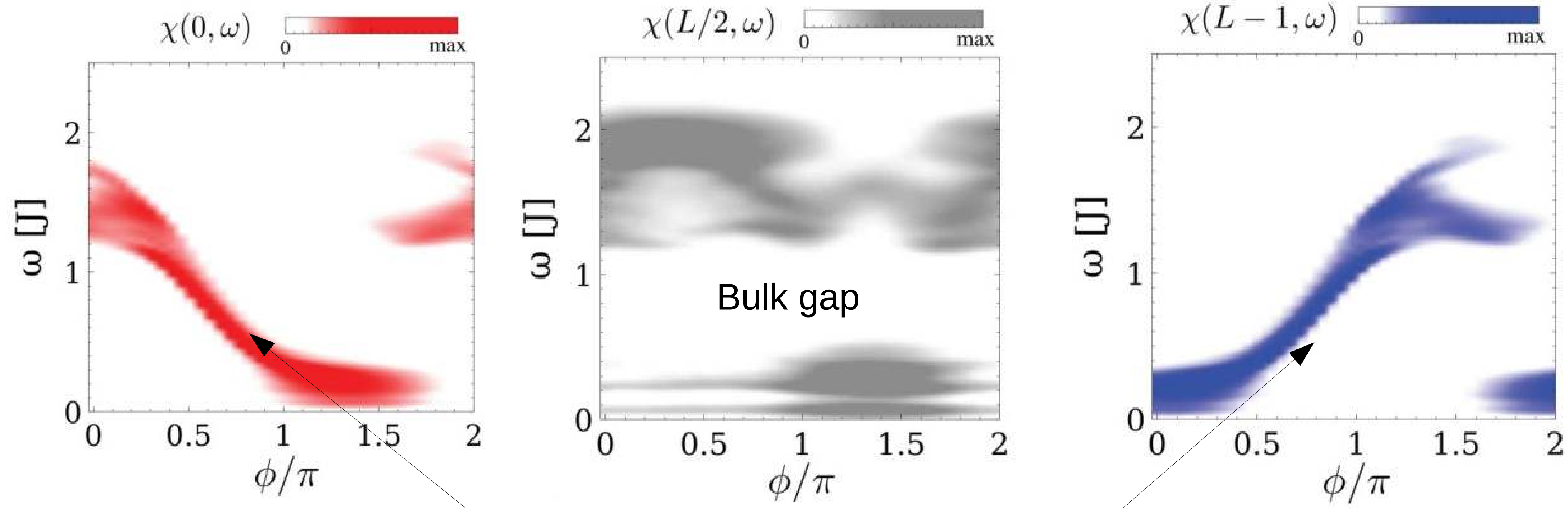




Quasiperiodic many-body interactions create topological spinon modes

Topological quasiperiodic spinons for S=1/2

Left edge ***Bulk*** ***Right edge***

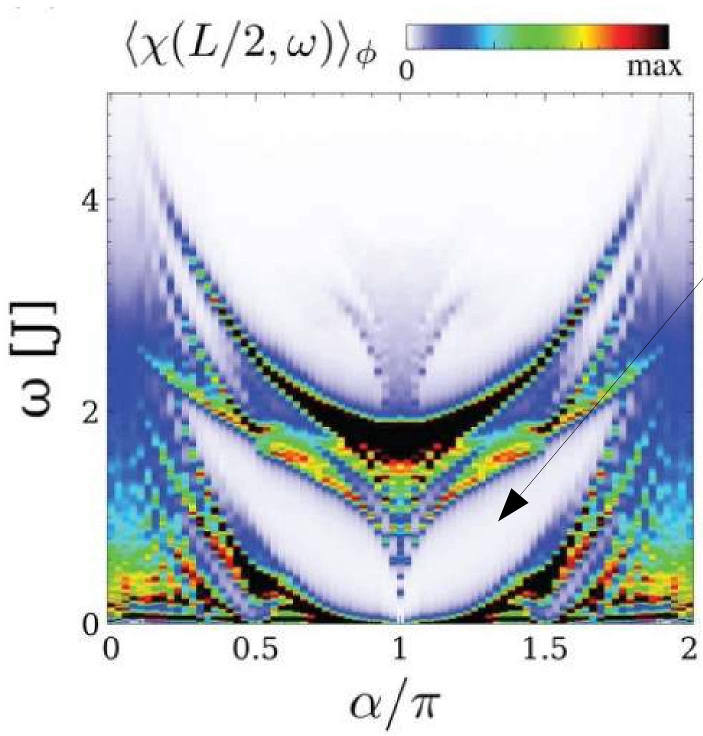


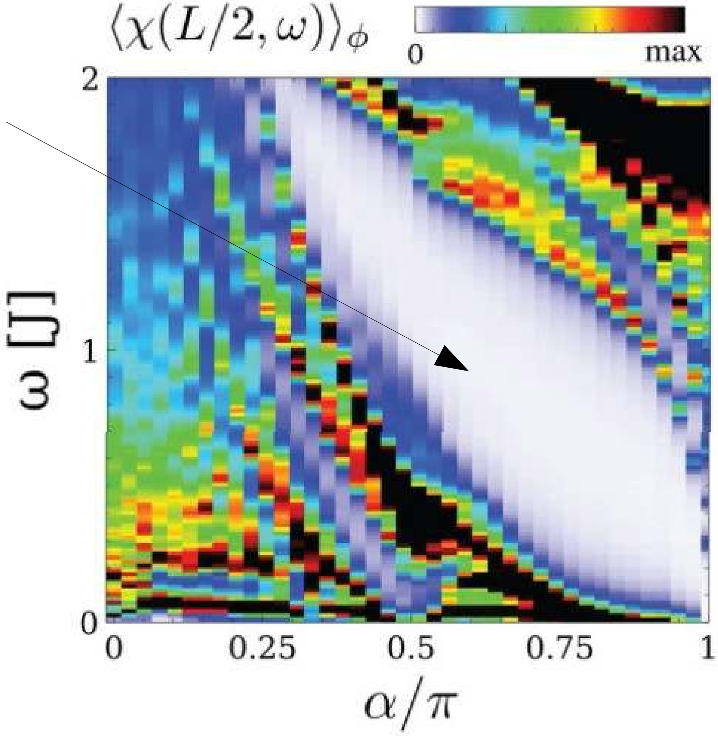
Topological spinon pumping modes

$$H = J\sum_N [1+\lambda\cos(\alpha N+\phi)]\vec{S}_N\cdot\vec{S}_{N+1}$$

Phys. Rev. Research 1, 033009 (2019)

Spinon Hofstadter spectra S=1/2



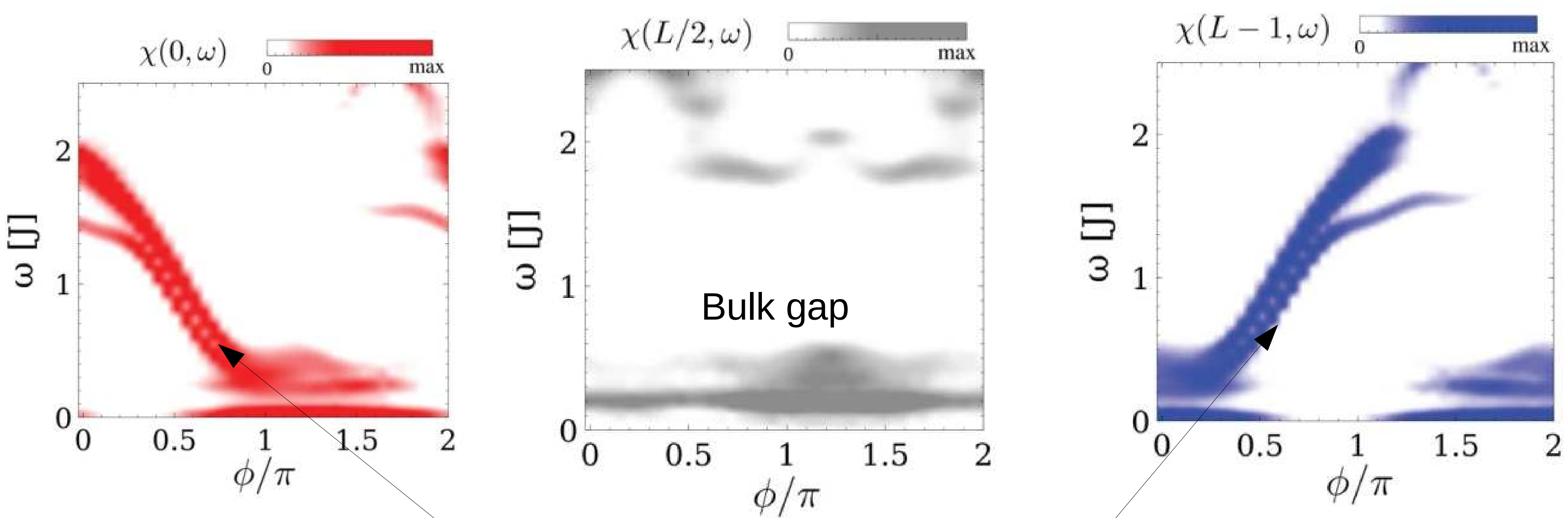


$$H = J\sum_N [1+\lambda\cos(\alpha N+\phi)]\vec{S}_N\cdot\vec{S}_{N+1}$$

Topological gaps appear for arbitrary quasiperiodicity

Topological quasiperiodic spinons for S=1

Left edge ***Bulk*** ***Right edge***



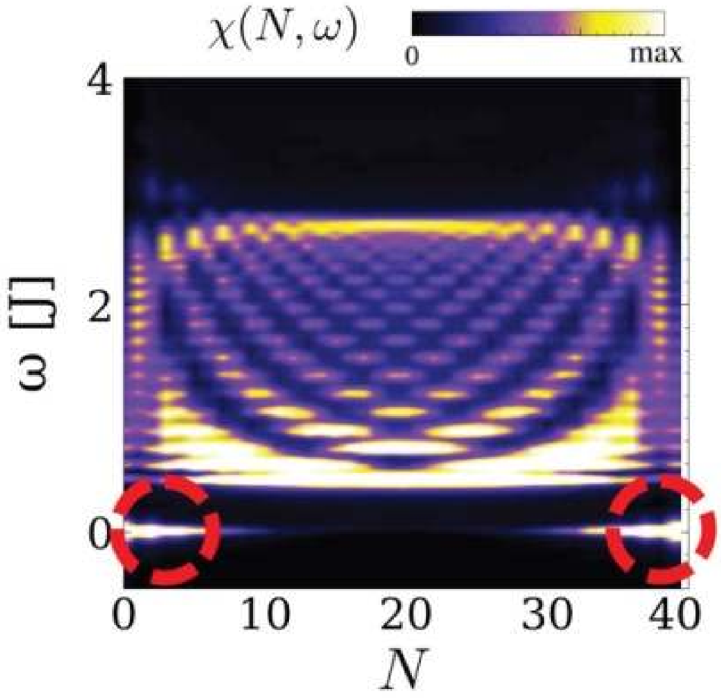
Topological spinon pumping modes

$$H = J\sum_N [1+\lambda\cos(\alpha N+\phi)]\vec{S}_N\cdot\vec{S}_{N+1}$$

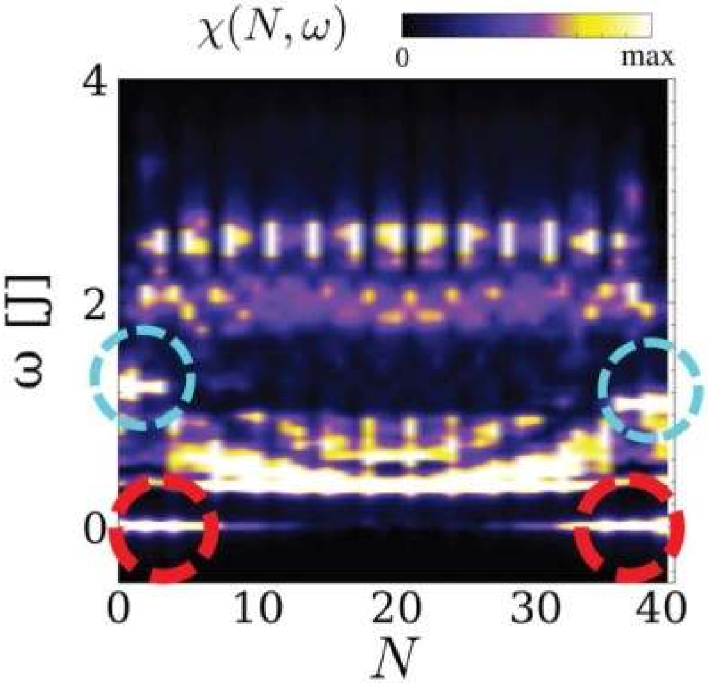
Phys. Rev. Research 1, 033009 (2019)

Topological quasiperiodic spinons for S=1

No modulation



With modulation



Quasiperiodicity creates additional topological modes away from E=0

Non-Hermitian topological many-body excitations

Coupling an electronic system to an environment

Full Hamiltonian of the system

$$H_{\mathrm{full}} = \begin{pmatrix} H_0 & \Gamma \\ \Gamma^\dagger & H_{\mathrm{env}} \end{pmatrix}$$

Selfenergy

$$\Sigma_{\mathrm{env}} = \Gamma(\omega - H_{\mathrm{env}})^{-1}\Gamma^\dagger$$

Green’s function of the coupled system

$$G_0 = (\omega - H_0 - \Sigma_{\mathrm{env}})^{-1}$$

Coupling an electronic system to an environment

Full Hamiltonian of the system

$$H_{\text{full}} = \begin{pmatrix} H_0 & \Gamma \\ \Gamma^\dagger & H_{\text{env}} \end{pmatrix}$$

Effective Hamiltonian associated to the Green's function

$$H_0^{eff} = H_0 + \frac{1}{2}(\Sigma_{\text{env}} + \Sigma_{\text{env}}^\dagger) + \frac{1}{2}(\Sigma_{\text{env}} - \Sigma_{\text{env}}^\dagger)$$

Hermitian renormalization

Non-Hermitian environment induced terms

Coupling an electronic system to an environment

Full Hamiltonian of the system

$$H_{\text{full}} = \begin{pmatrix} H_0 & \Gamma \\ \Gamma^\dagger & H_{\text{env}} \end{pmatrix}$$

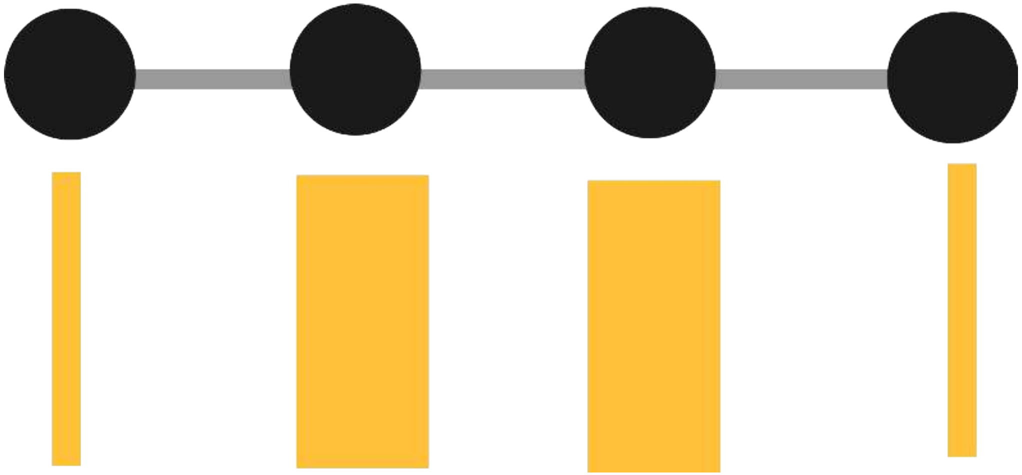
Effective Hamiltonian associated to the Green's function

$$H_0^{eff} = \bar{H}_0 + H_0^{NH}$$

Hermitian terms

Non-Hermitian terms

Non-Hermiticity in quantum dots



Quantum dots

Metallic leads

$$g_n = \mathrm{Im}(\Sigma_n)$$

Hopping

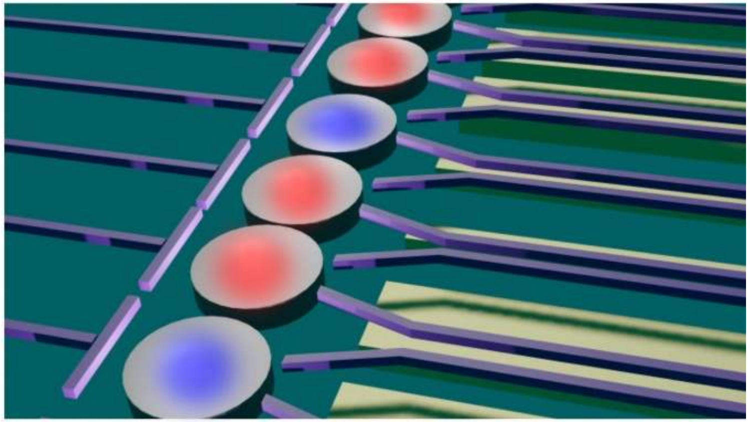
Imaginary
onsite energy

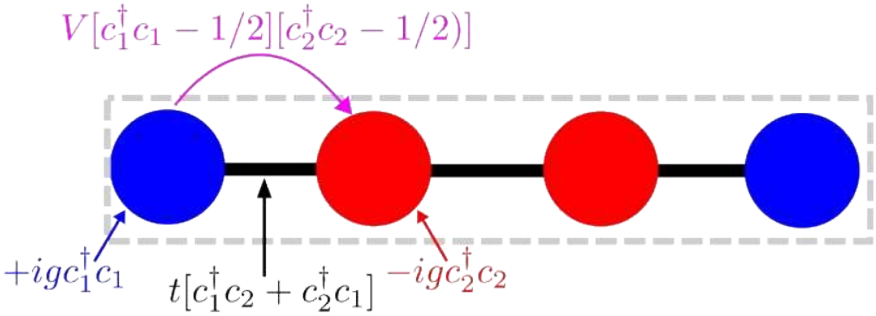
Lead
selfenergy

$$H = c_n^\dagger c_{n+1} + c_{n+1}^\dagger c_n + i g_n c_n^\dagger c_n$$

<u>Coupling to metallic leads generates non-Hermitian terms in an effective Hamiltonian</u>

Topological excitations driven by modulated losses





Bloch Hamiltonian

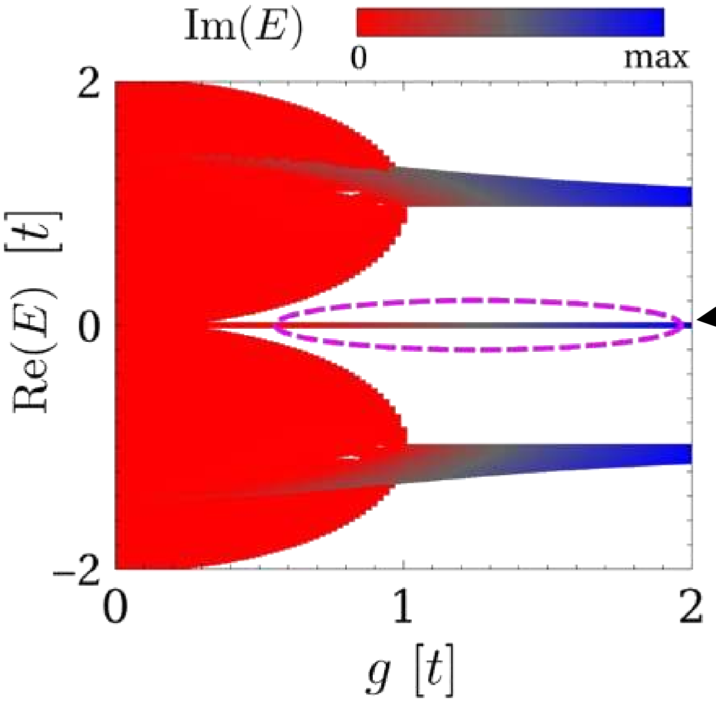
$$H_k = \begin{pmatrix} ig_1 & t & 0 & te^{-ik} \\ t & ig_2 & t & 0 \\ 0 & t & ig_3 & t \\ te^{ik} & 0 & t & ig_4 \end{pmatrix}$$

Losses coming from a self-energy

$$g_n = \mathrm{Im}(\Sigma_n)$$

Edge mode driven by losses

Non-interacting spectra



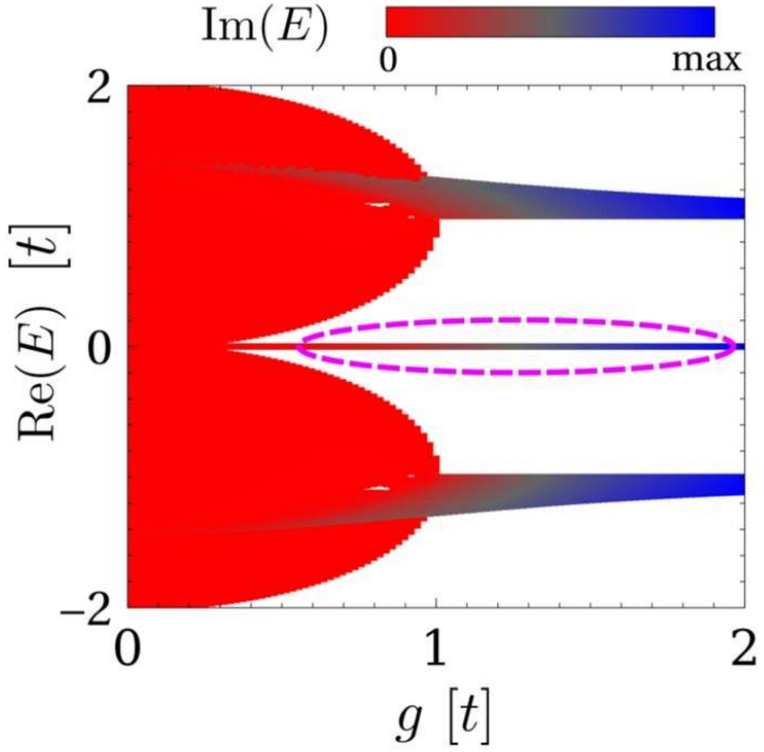
Edge state

Phys. Rev. Lett. 121, 213902 (2018)
Phys. Rev. B 100, 161105® (2019)

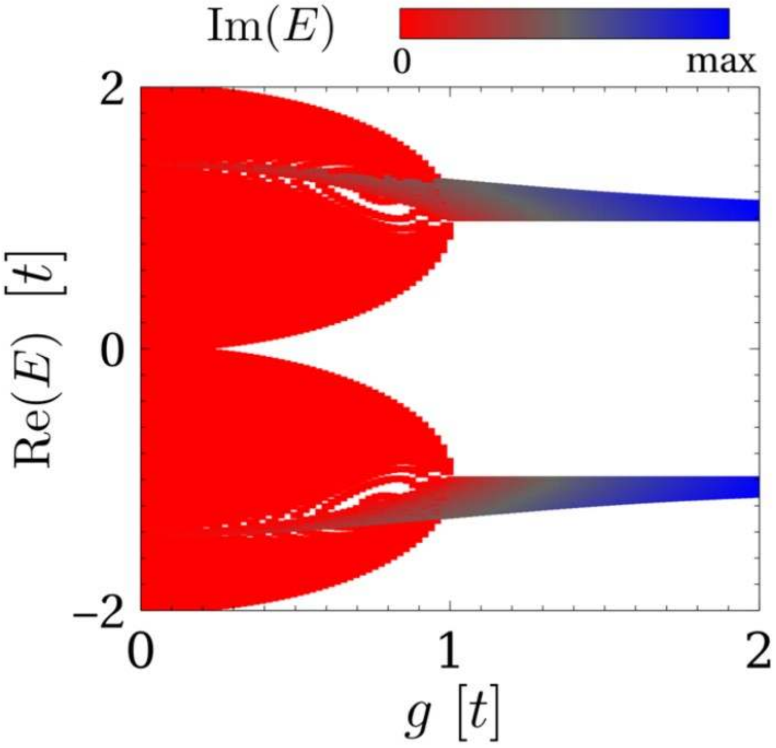
Does this topological mode survive the presence of many-body interactions?

Edge mode driven by losses

Open boundary conditions



Closed boundary conditions



Going to the many-body limit

Let us now add interacting to the non-Hermitian Hamiltonian

$$\mathcal{H} = \mathcal{H}_0 + \mathcal{H}_I$$

Non-Hermitian single particle term

$$\mathcal{H}_0 = c_n^\dagger c_{n+1} + c_{n+1}^\dagger c_n + i g_n c_n^\dagger c_n$$

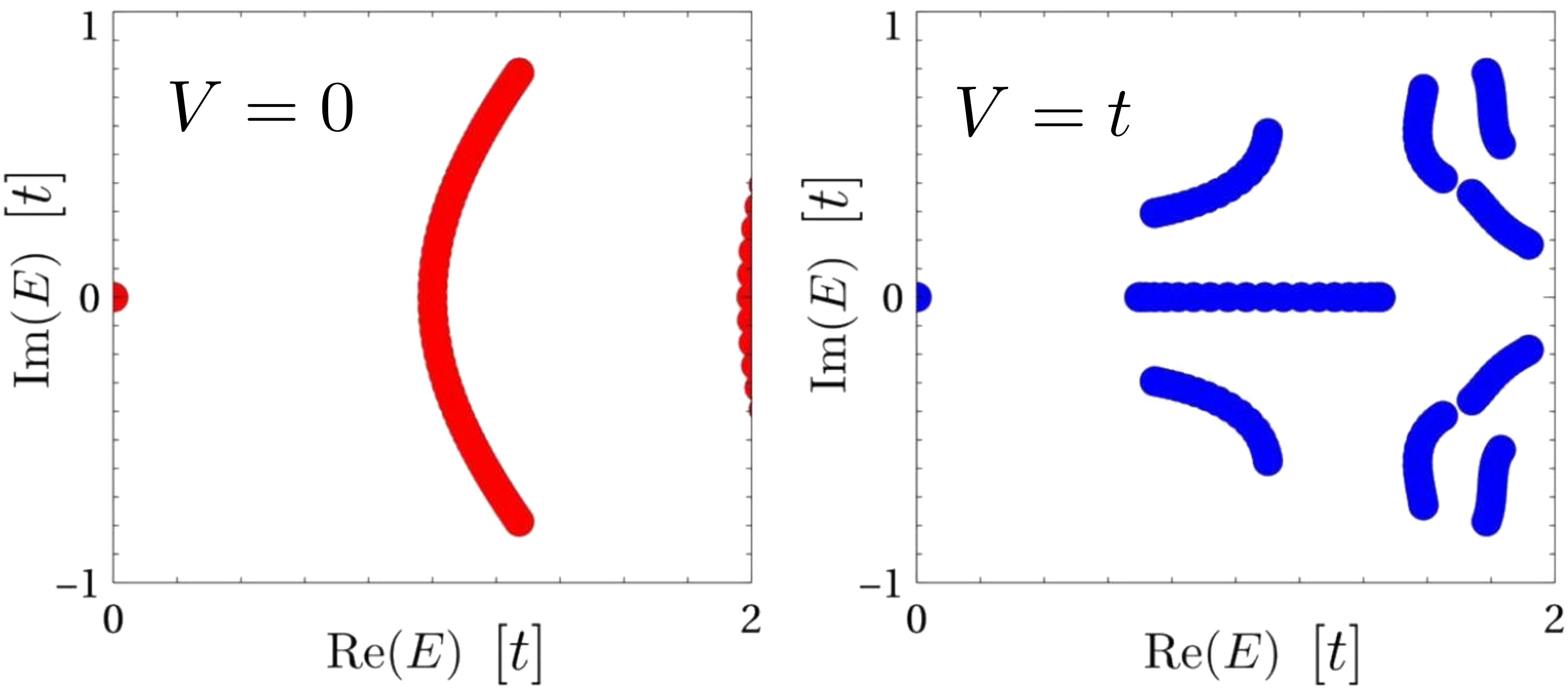
Interacting term

$$\mathcal{H}_I = V \sum_n \left(c_n^\dagger c_n - 1/2\right)\left(c_{n+1}^\dagger c_{n+1} - 1/2\right)$$

How do we asses the existence of edge modes in the interacting many-body case?

Adiabatic connection between non interacting and interacting limits

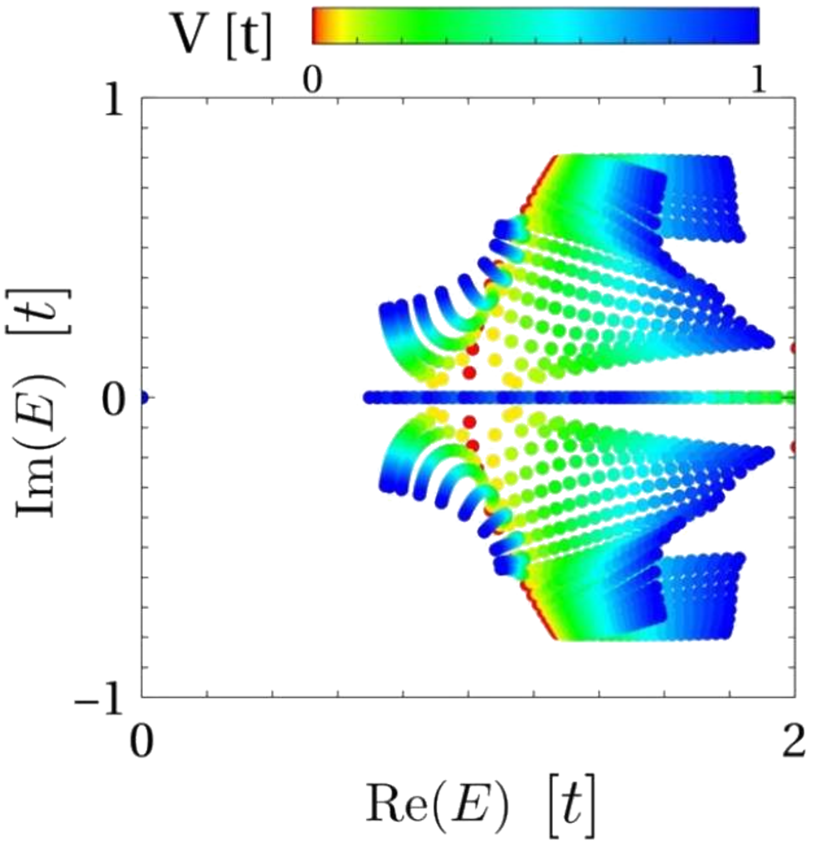
Many-body eigenenergies of the interacting non-Hermitian Hamiltonian



A many-body gap remains open from the non-interacting to the interacting limit

Adiabatic connection between non interacting and interacting limits

As interactions are ramped up, a many-body gap remains open with closed boundary conditions



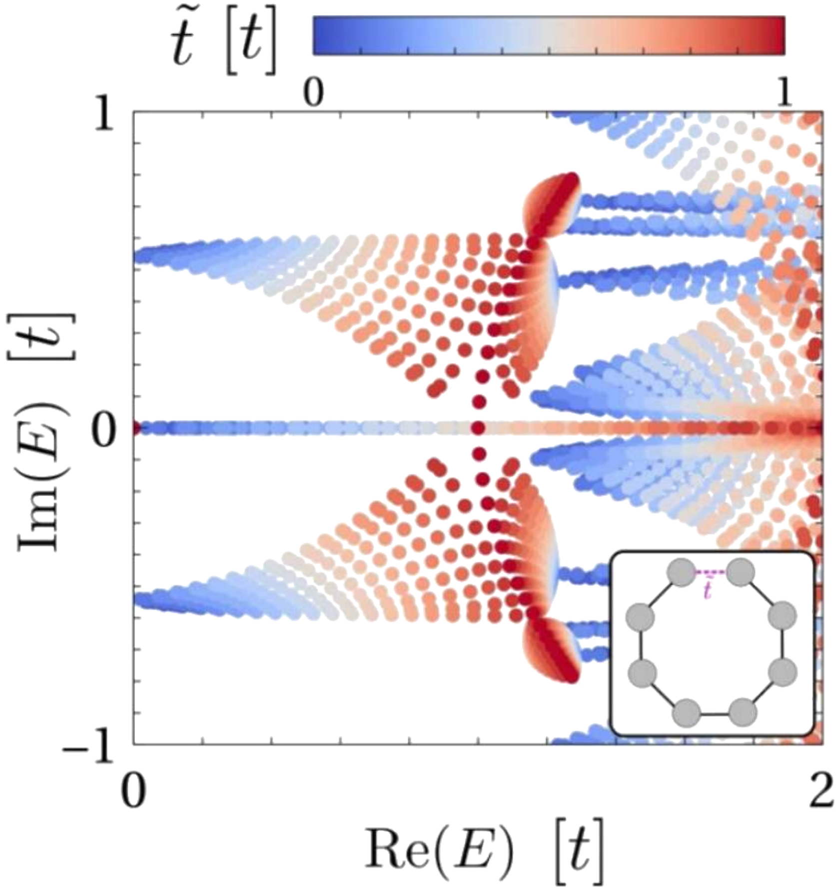
A many-body gap remains open from the non-interacting to the interacting limit

From closed to open boundary conditions

As a bond is disconnected, a topological degeneracy in the real part of the energy emerges

$\tilde{t} = 1$ Closed boundary

$\tilde{t} = 0$ Open boundary



Probing the edge modes with tunneling

The zero bias conductance becomes proportional to

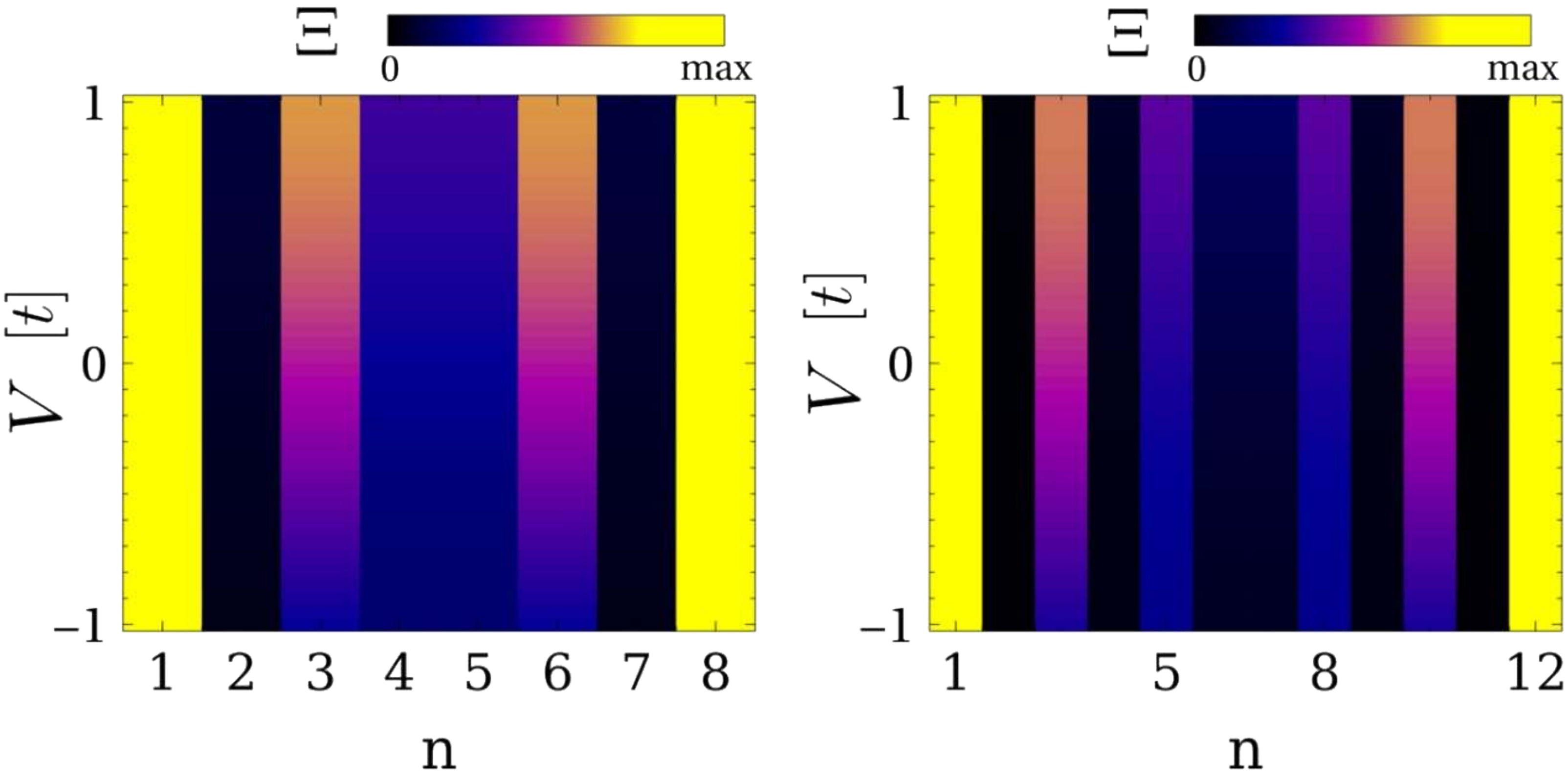
$$\Xi(n) = \sum_i \left| \langle \Psi_i \left| c_n \right| \Omega \rangle \right|^2$$

Degenerate ground state manifold

Ground state

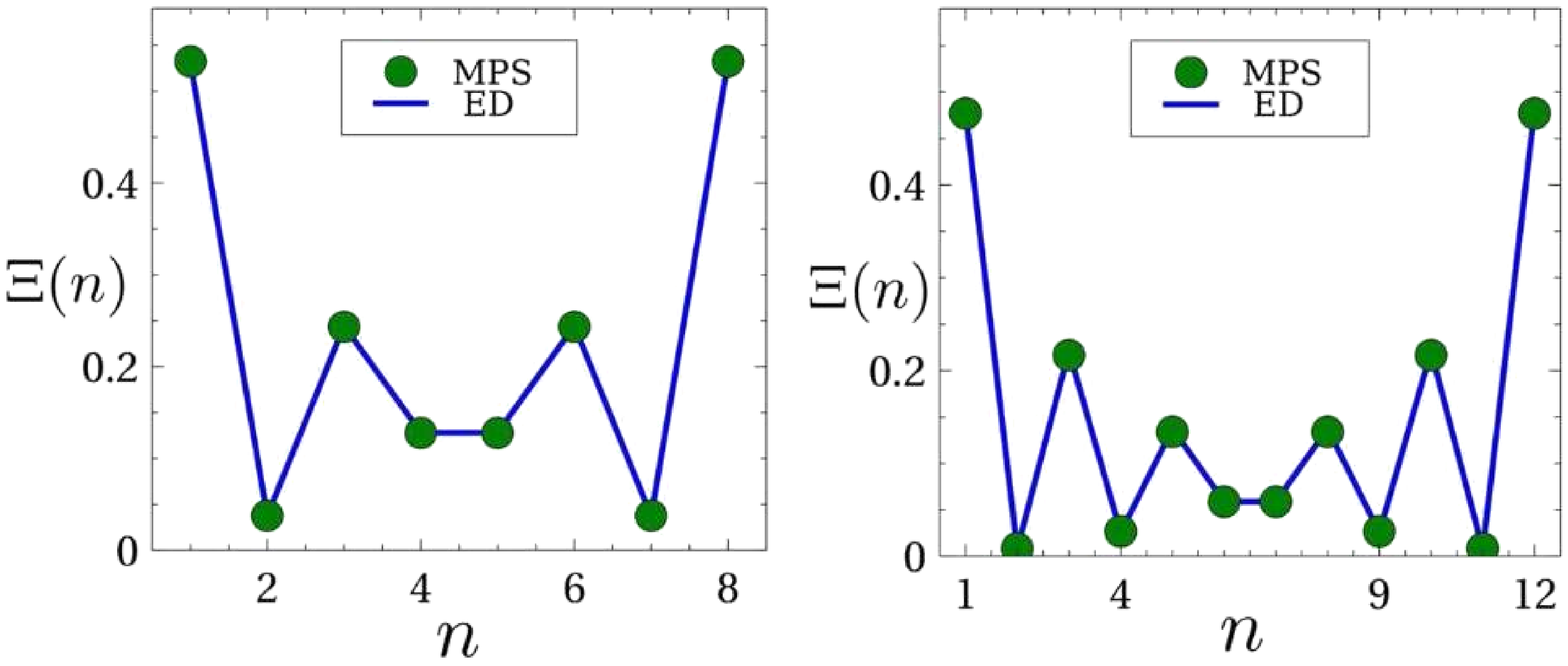
This quantity allow to visualize edge modes in the many-body limit

Edge modes with finite many-body interactions



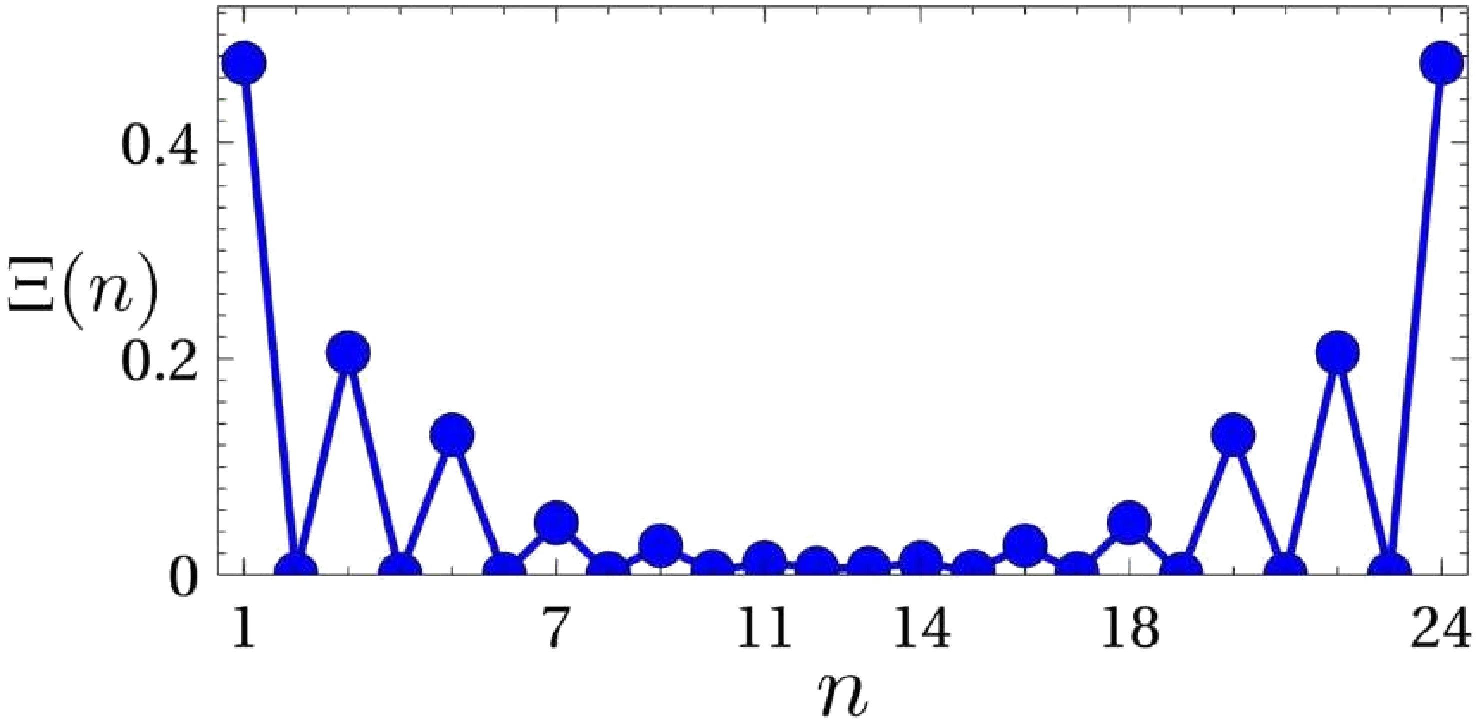
Edge modes remain in the presence of many-body interactions

Non-Hermitian edge modes



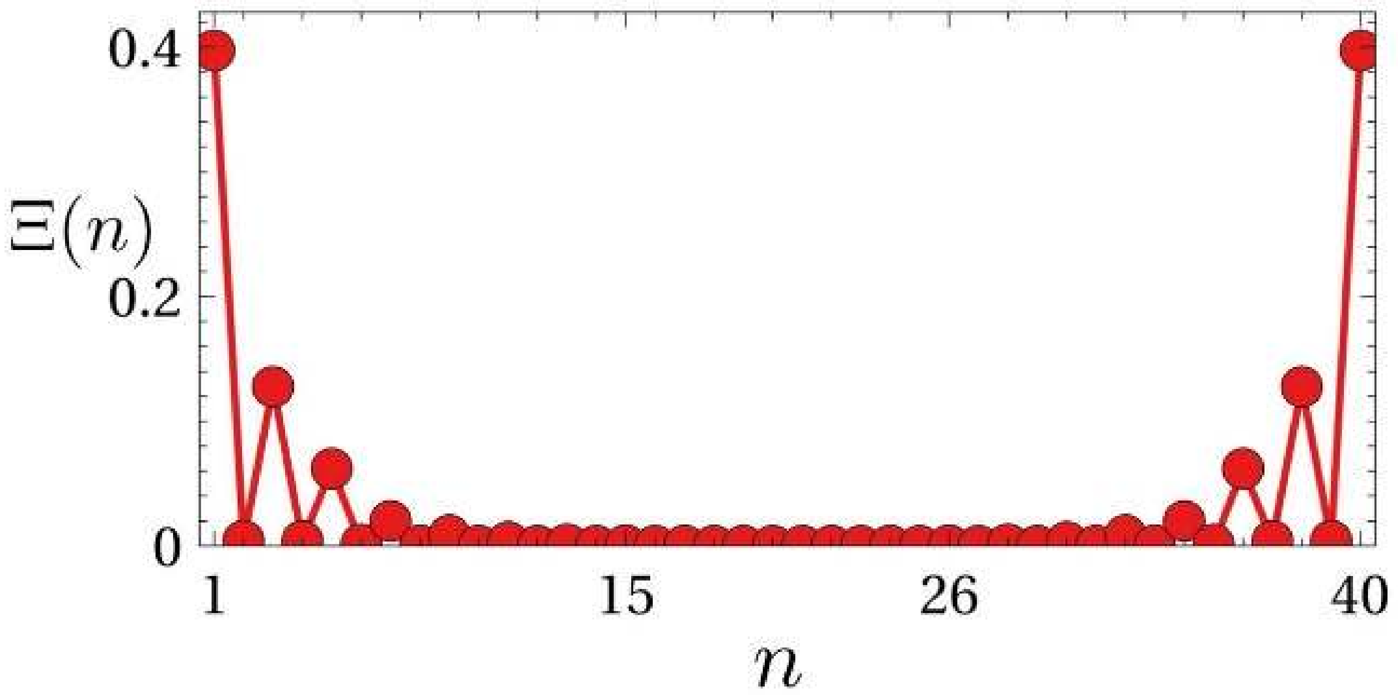
In short chains two overlapping edge modes appear in the correlator

Non-Hermitian edge modes



In long chains solved with MPS, the non-Hermitian mode becomes well localized at the edge

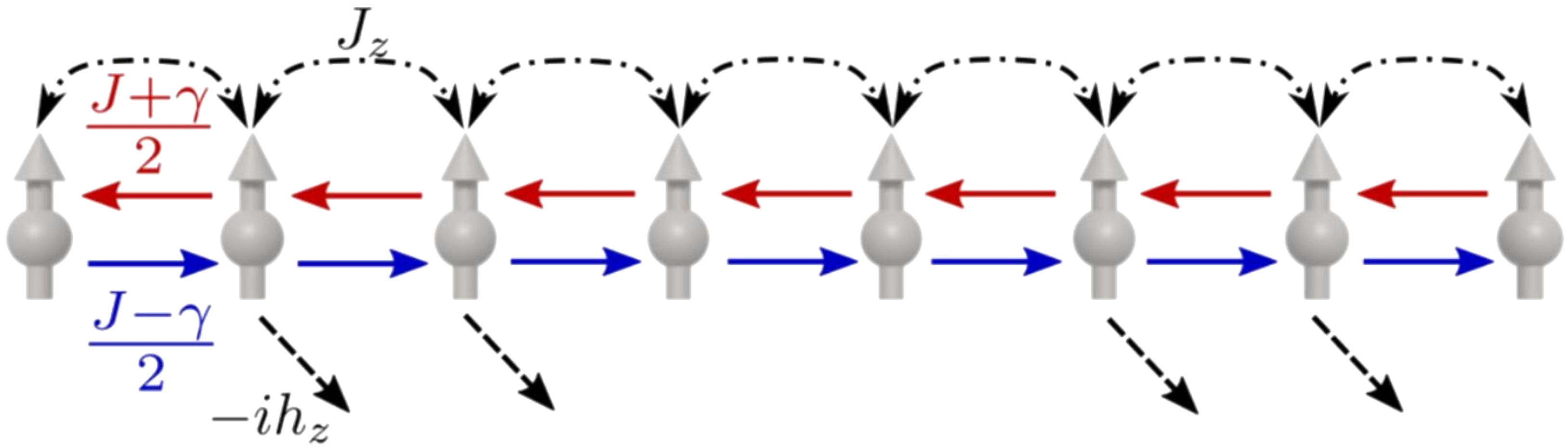
Non-Hermitian edge modes



In long chains solved with MPS, the non-Hermitian mode becomes well localized at the edge

Dynamical correlators in topological interacting non-Hermitian systems

A generic non-Hermitian quantum many-body model



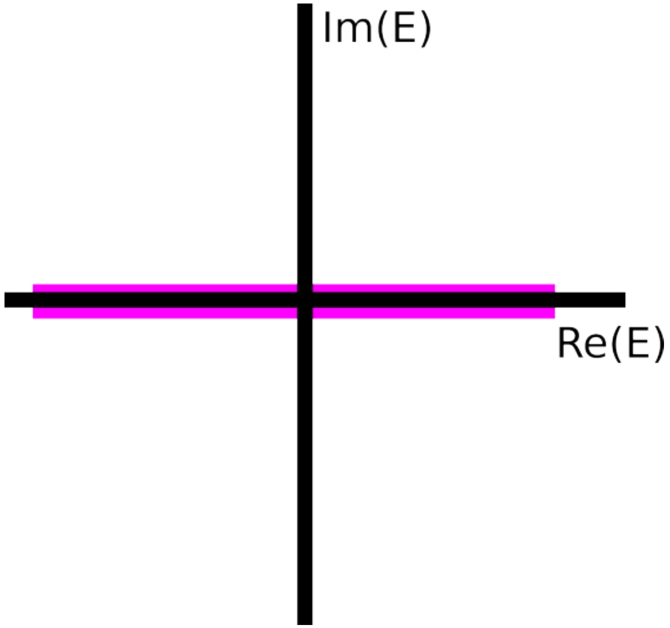
$$\tilde{H} = \sum_{l=1}^{L-1} \left(\frac{J+\gamma}{2} c_l^\dagger c_{l+1} + \frac{J-\gamma}{2} c_{l+1}^\dagger c_l + J_z \left(c_l^\dagger c_l - \frac{1}{2} \right) \left(c_{l+1}^\dagger c_{l+1} - \frac{1}{2} \right) \right) + \sum_{l=1}^{L} i h_l^z \left(c_l^\dagger c_l - \frac{1}{2} \right)$$

Drives skin effect Many-body interaction Local loss

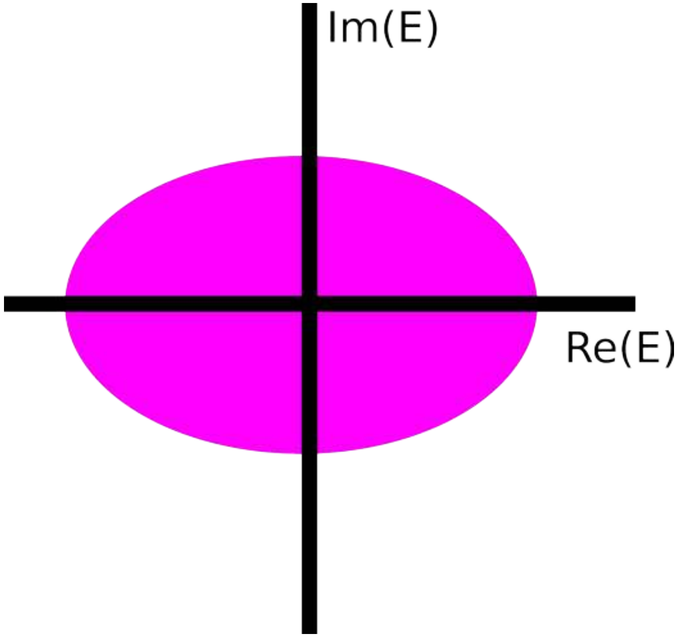
(in the fermionic Jordan Wigner representation)

Dynamical correlators in non-Hermitian models

In the Hermitian case



In the non-Hermitian case



In the non-Hermitian case, dynamical correlators are defined in the complex energy plane

Dynamical correlator of a many-body non-Hermitian model

In a non-Hermitian model, the dynamical correlator cannot be compute with a usual Kernel polynomial expansion

$$\mathrm{S}(\omega, l) = \left\langle \mathrm{GS_L} \left| c_l \delta^2 \left(\omega + E_{\mathrm{GS}} - H\right) c_l^\dagger \right| \mathrm{GS_R} \right\rangle + \left\langle \mathrm{GS_L} \left| c_l^\dagger \delta^2 \left(\omega + E_{\mathrm{GS}} - H\right) c_l \right| \mathrm{GS_R} \right\rangle$$

$$\delta^2(\omega - H) = \sum_n \delta(\Re(\omega - E_n))\, \delta\left(\Im\left(\omega - E_n\right)\right) \left|\Psi_{\mathrm{R},n}\right\rangle \left\langle\Psi_{\mathrm{L},n}\right|$$

We define a Hermitrized Hamiltonian

$$\mathcal{H} = \begin{pmatrix} & \omega - H \\ \omega^* - H^\dagger & \end{pmatrix}$$

And perform a KPM expansion of

$$f(\omega) = \langle \psi_{\mathrm{L}} | \delta^2(\omega - H) | \psi_{\mathrm{R}} \rangle$$

$$f(\omega) = \frac{1}{\pi} \partial_{\omega^*} G(E = 0)$$

$$G(E) = \langle \mathrm{L} | (E - \mathcal{H})^{-1} | \mathrm{R} \rangle$$

Dynamical correlator of a topological non-Hermitian model

We take the following non-Hermitian model

$$\tilde{H} = \sum_{l=1}^{L-1} \left(\frac{J+\gamma}{2} c_l^\dagger c_{l+1} + \frac{J-\gamma}{2} c_{l+1}^\dagger c_l + J_z \left(c_l^\dagger c_l - \frac{1}{2} \right) \left(c_{l+1}^\dagger c_{l+1} - \frac{1}{2} \right) \right) + \sum_{l=1}^{L} i h_l^z \left(c_l^\dagger c_l - \frac{1}{2} \right)$$

Drives skin effect

Many-body interaction

Local loss

Full dynamical correlator

$$\mathrm{S}(\omega, l) = \left\langle \mathrm{GS_L} \middle| c_l \delta^2 \left(\omega + E_{\mathrm{GS}} - H \right) c_l^\dagger \middle| \mathrm{GS_R} \right\rangle + \left\langle \mathrm{GS_L} \middle| c_l^\dagger \delta^2 \left(\omega + E_{\mathrm{GS}} - H \right) c_l \middle| \mathrm{GS_R} \right\rangle$$

Integrated in the imaginary axis

(equivalent to the Hermitian one)

$$\tilde{\rho}(E \in \mathbb{R}, l) = \left| \int \mathcal{S}(E + iy, l) dy \right|$$

Single particle Hermitian VS many-body non-Hermitian dynamical correlators

Single particle Hermitian

Local density of states

$$\rho(\omega, l)$$

Total density of states

$$\rho_{tot}(\omega) = \sum_{l=1}^{L} \rho(\omega, l)$$

Many-body non-Hermitian

Local dynamical correlator

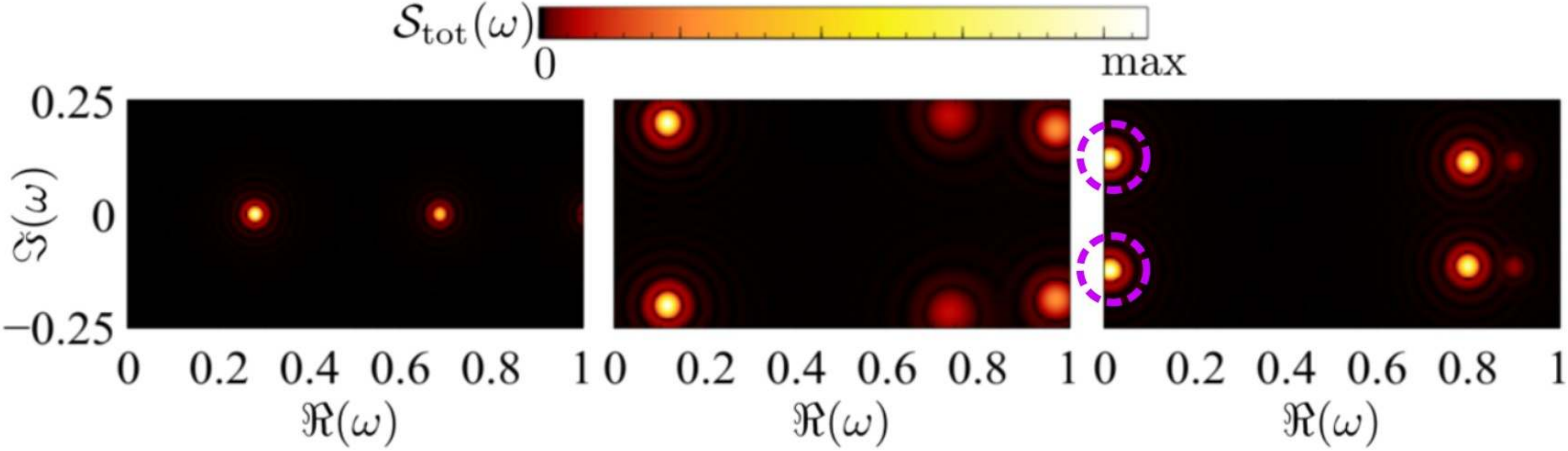
$$\mathcal{S}(\omega, l)$$

Total dynamical correlator

$$\tilde{\mathcal{S}}_{\mathrm{tot}}(\omega) = \sum_{l=1}^{L} \mathcal{S}(\omega, l)$$

Topological degeneracies in a dynamical correlator

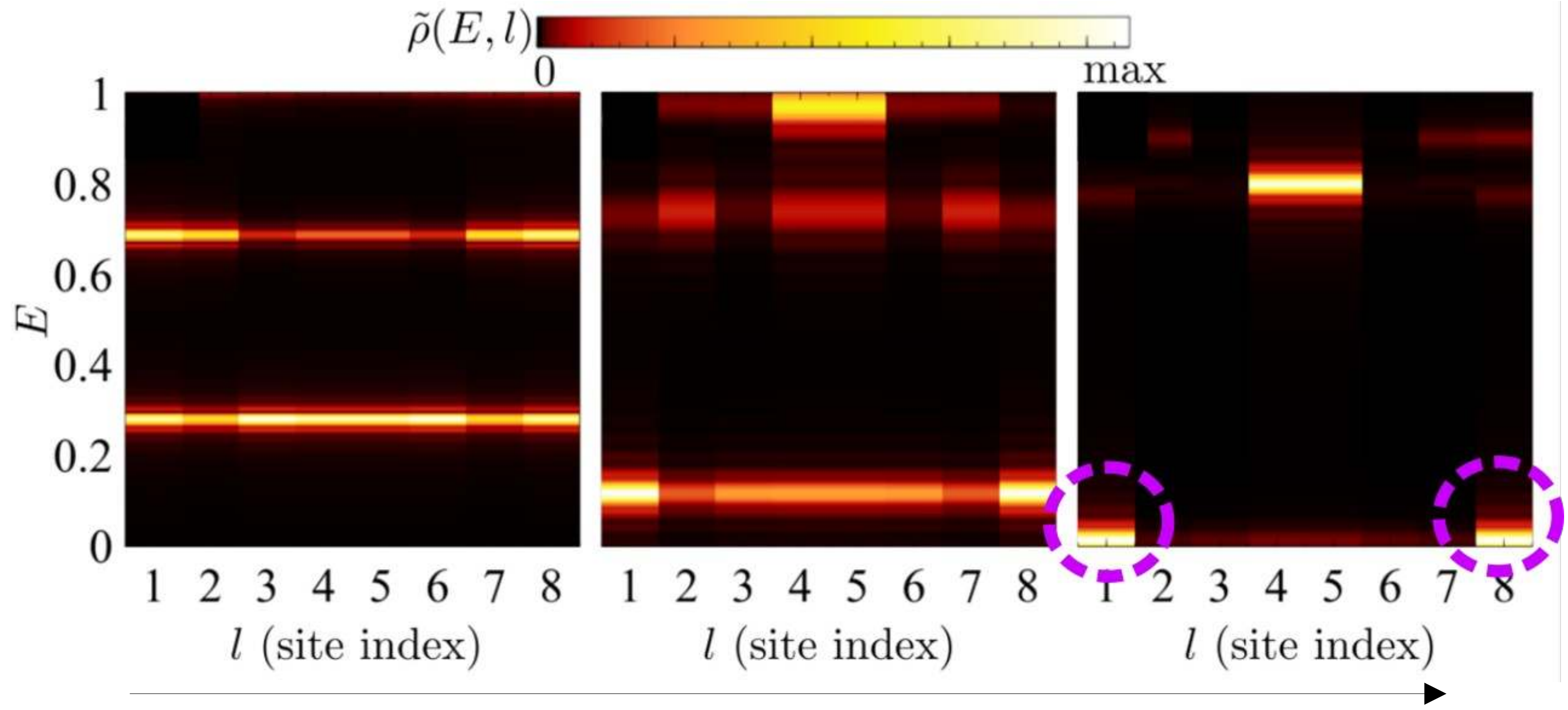
Total structure factor $\tilde{S}_{\text{tot}}(\omega) = \left| \sum_{l=1}^{L} \mathcal{S}(\omega, l) \right|$



Increasing topological gap

As the topological gap gets bigger, degeneracies at zero real frequency emerge

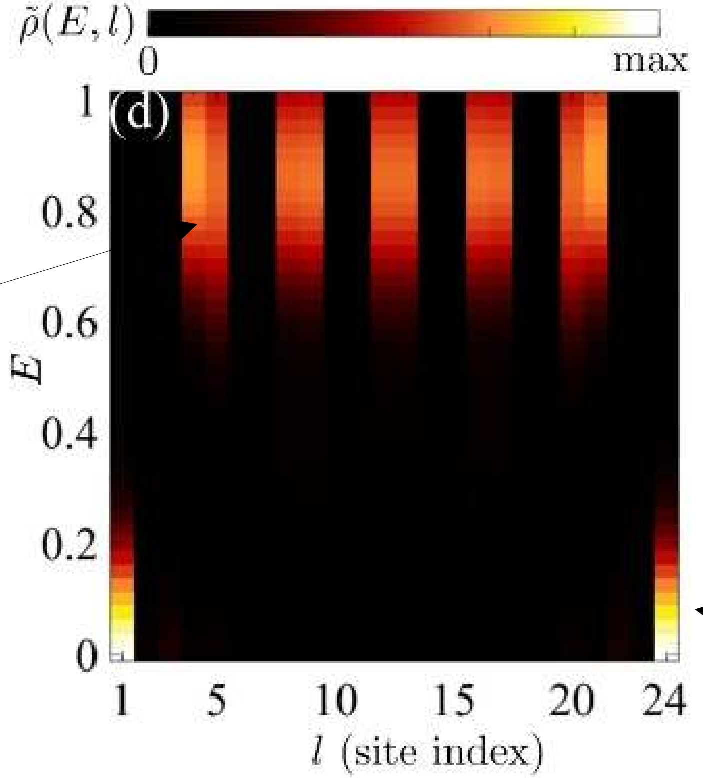
Topological modes in the local dynamical correlator



As the topological gap gets bigger, edge modes at zero real frequency emerge

Non-Hermitian topological modes

Bulk modes

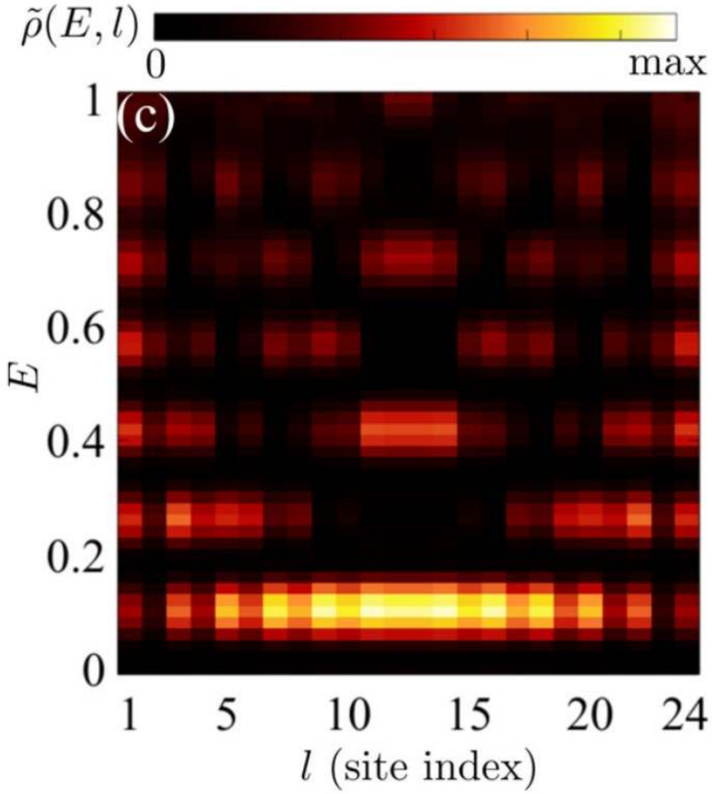


Edge modes

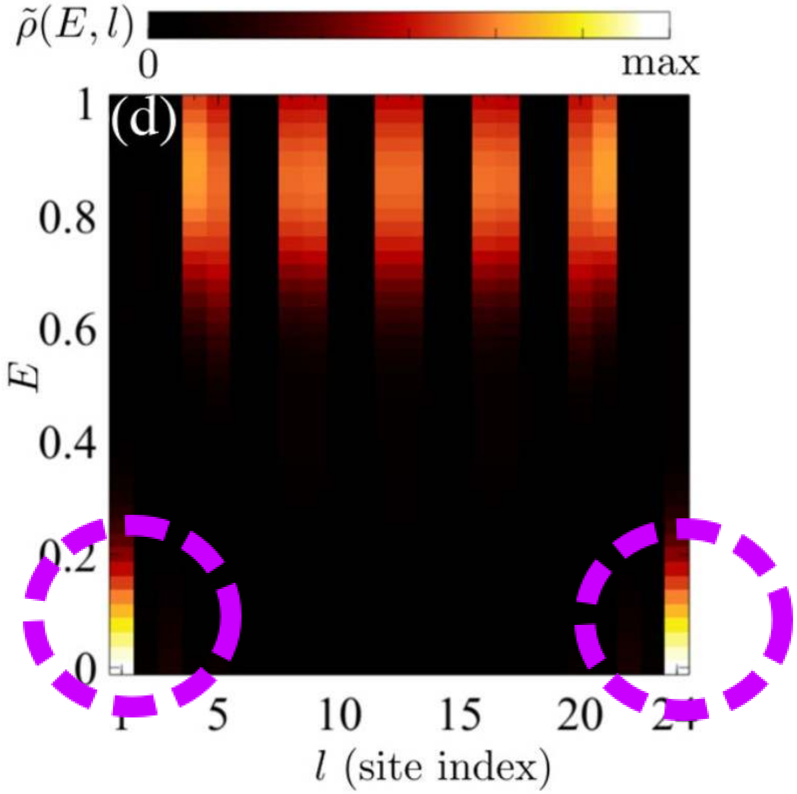
The non-Hermitian dynamical correlator allows visualizing the topological modes

Trivial VS topological spectral functions

Non-topological case



Topological case

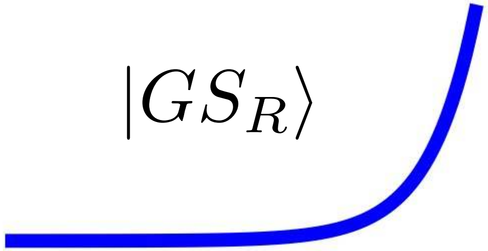


Skin effect and topological modes

In the presence of skin effect, left/right eigenvectors get localized in one edge

$|GS_L\rangle$

$|GS_R\rangle$



With the definition of the dynamical correlator mirror symmetry is recovered

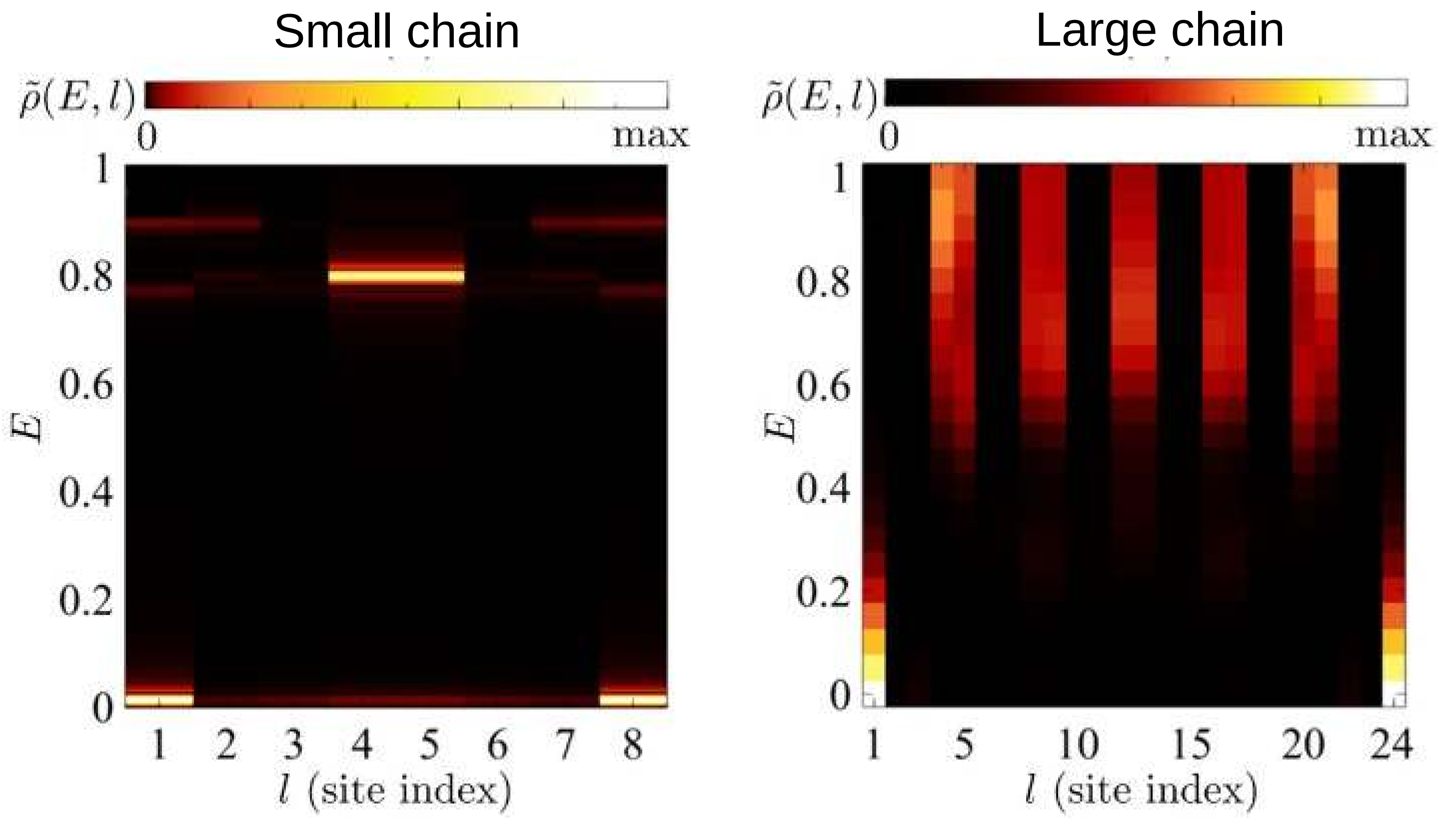
$$\mathcal{S}(\omega,l)\sim\left\langle \mathrm{GS_L}\left| c_l\delta^2\left(\omega+E_{\mathrm{GS}}-H\right)c_l^\dagger\right|\mathrm{GS_R}\right\rangle$$

Right eigenvector

<u>*They localize in opposite edges*</u>

Right eigenvector

Topological modes in the presence of skin effect



The non-Hermitian dynamical correlator allows visualizing the topological modes

Open-source software for topological matter

Open-source software for tensor-network kernel polynomial algorithms

<u>For general interacting models</u>

dmrgpy https://github.com/joselado/dmrgpy

```python
from dmrgpy import spinchain
spins = ["S=1" for i in range(40)] # S=1 chain
sc = spinchain.Spin_Chain(spins) # create spin chain object
h = 0 # initialize Hamiltonian
for i in range(len(spins)-1):
  h = h + sc.Sx[i]*sc.Sx[i+1]
  h = h + sc.Sy[i]*sc.Sy[i+1]
  h = h + sc.Sz[i]*sc.Sz[i+1]
sc.set_hamiltonian(h)
sc.get_dynamical_correlator(name=(sc.Sz[0],sc.Sz[0]))
```

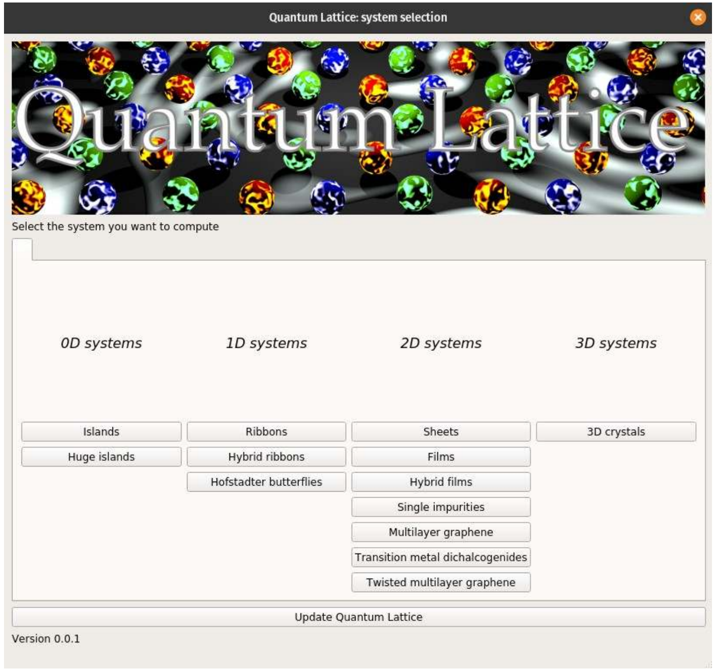
Generic Python library for tensor-network kernel polynomial algorithms for spins, fermions, parafermions, with static solvers for Hermitian and non-Hermitian modes

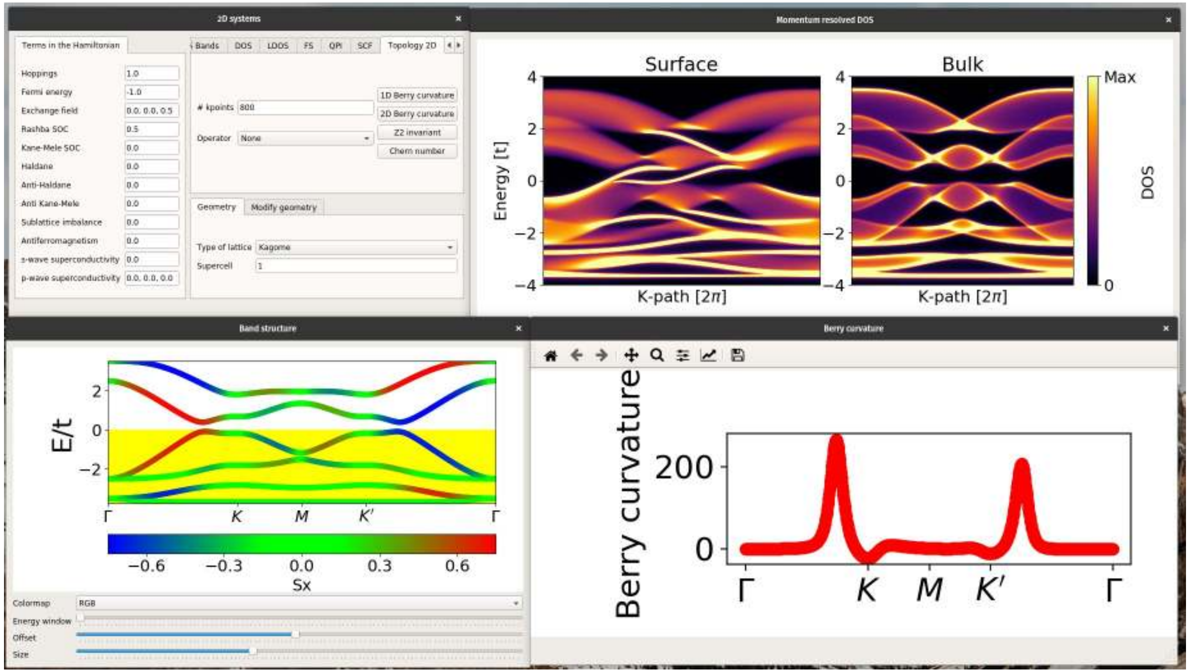
<u>Specialized non-Hermitian kernel polynomial algorithm</u>

NHKPM.jl https://github.com/GUANGZECHEN/NHKPM.jl

Based on ITensor

Quantum Lattice: A user interface to compute electronic properties



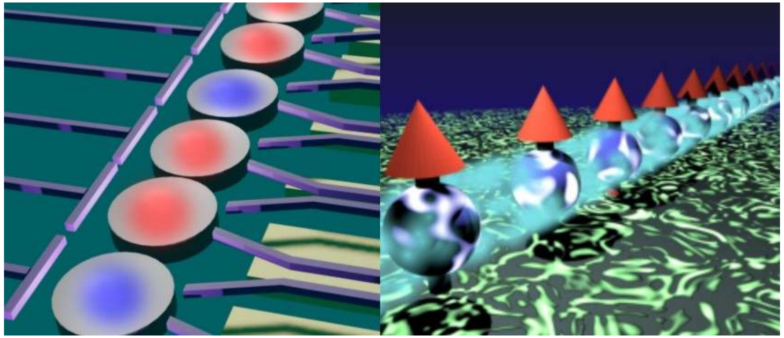


Quantum Lattice: open source interactive interface for tight binding modeling

https://github.com/joselado/quantum-lattice

Take home

Tensor-network kernel polynomial algorithms allow computing dynamical excitations in interacting non-Hermitian quantum many-body systems



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