Coulomb-engineered topology

Aalto University

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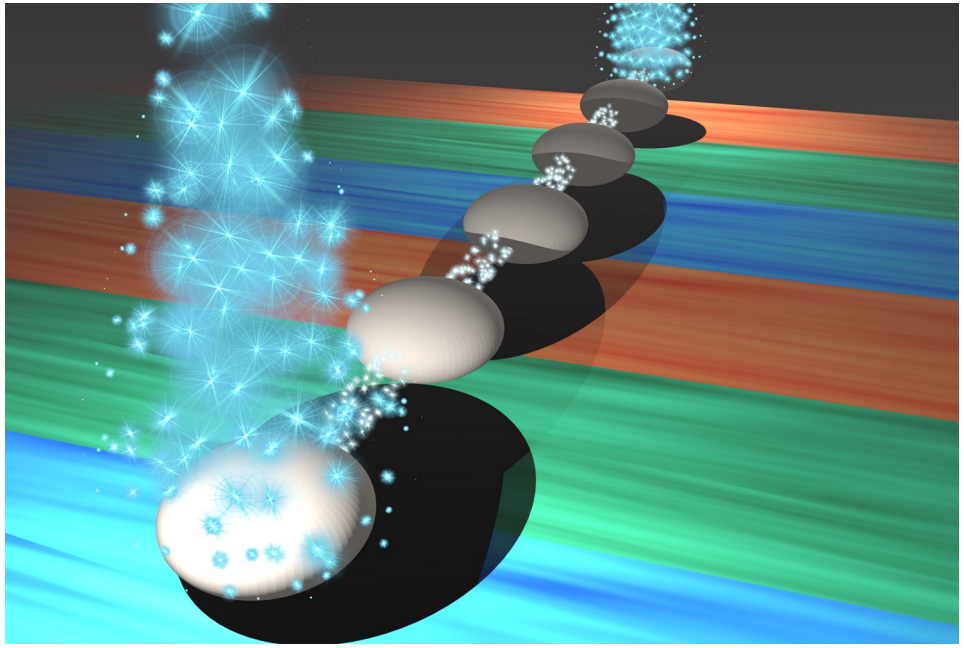
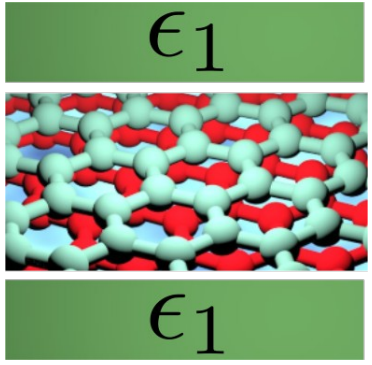


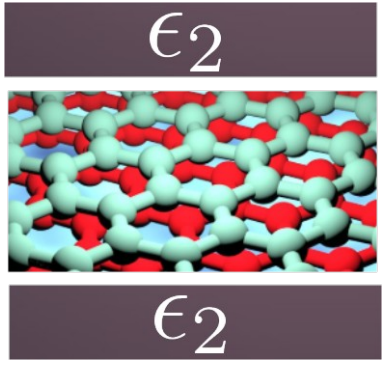
arXiv:2008.07990

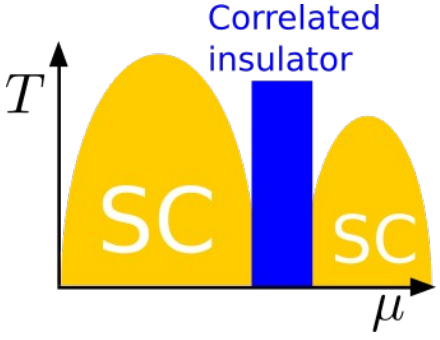
APS March Meeting, March 18th 2021

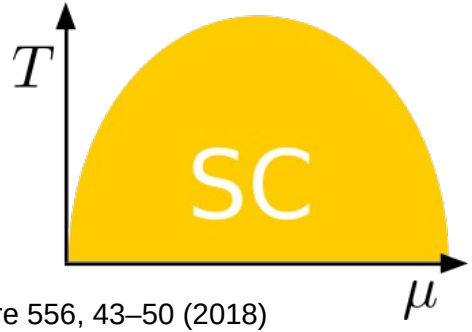
Controlling interactions in topological matter

Screening engineering allows modifying the strength of Coulomb interactions









Nature 556, 43–50 (2018)
Nature Physics 16, 926–930 (2020)
Nature 583, 375–378 (2020)

Effective electronic interaction U

$$U(\epsilon_1) > U(\epsilon_2)$$

Dielectric constants ϵ_1, ϵ_2

The dielectric environment impacts the local interactions

Can we design topological matter by properly designing interactions with dielectric engineering?

Phys. Rev. B 92, 085102 (2015)
Nano Lett. 16, 2322 (2016)
Nat. Commun. 8, 1166 (2017)

Controlling interactions in topological matter

Screening engineering allows modifying the strength of Coulomb interactions

Prof. Malte Rösner
(Radboud Uni. Netherlands)

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Designing topological matter from engineered interactions

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Coulomb-engineered topology

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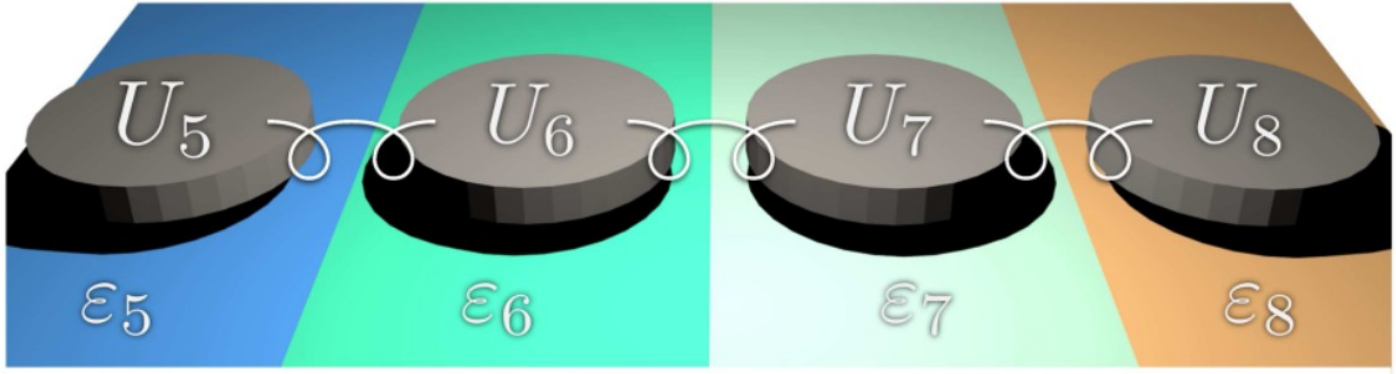
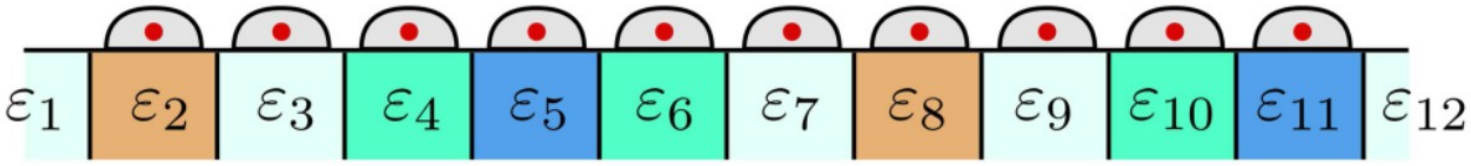
Coulomb-engineering

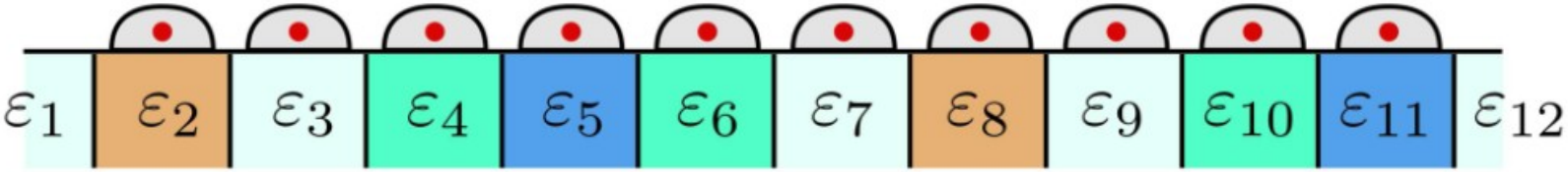
Substrate engineering allow creating spatially dependent interactions

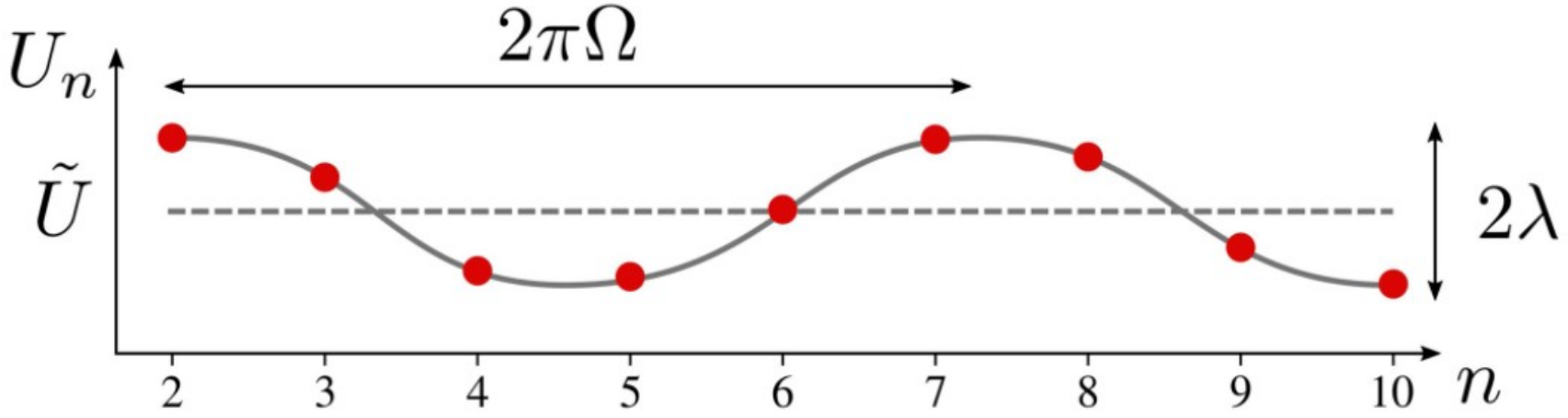




$$H = \sum_{n,s} t\, c^{\dagger}_{n,s} c_{n+1,s} + \sum_{n} U_n c^{\dagger}_{n,\uparrow} c_{n,\uparrow} c^{\dagger}_{n,\downarrow} c_{n,\downarrow} + h.c. \qquad U_n = \tilde{U}[1 + \lambda \cos(\Omega n + \phi)]$$

Coulomb-engineering





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Warm-up: single particle Coulomb-engineered topology

Engineered interacting model

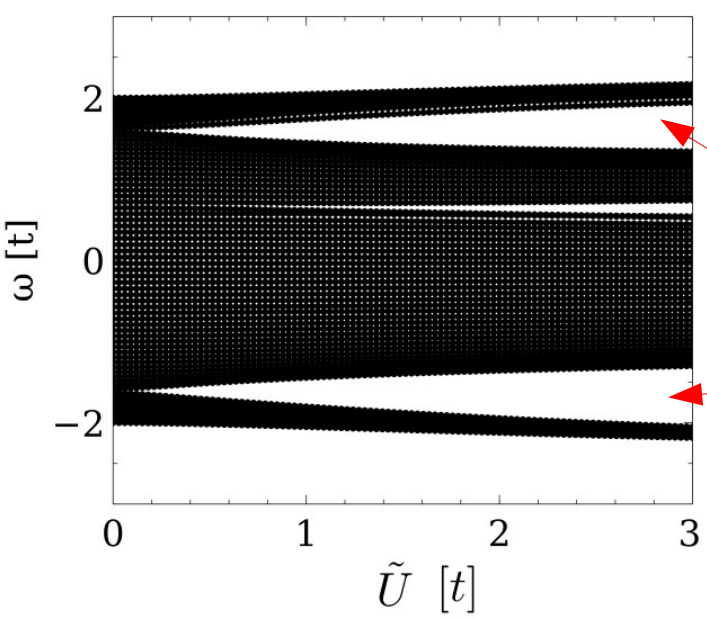
$$H = \sum_{n,s} t\, c^{\dagger}_{n,s} c_{n+1,s} + \sum_{n} U_n c^{\dagger}_{n,\uparrow} c_{n,\uparrow} c^{\dagger}_{n,\downarrow} c_{n,\downarrow} + h.c.$$

Modulated interactions

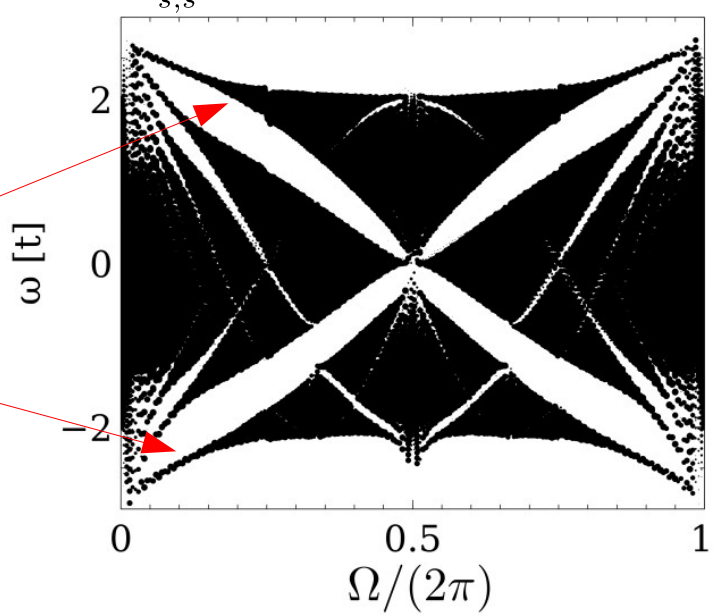
$$U_n = \tilde{U}[1 + \lambda \cos(\Omega n + \phi)]$$

Solved at the Hartree-Fock level

$$\sum_{s,s'} \langle \vec{\sigma}_{s,s'} c^{\dagger}_{n,s} c_{n,s'} \rangle = 0$$



Topological gap opening



Warm-up: single particle Coulomb-engineered topology

Engineered interacting model

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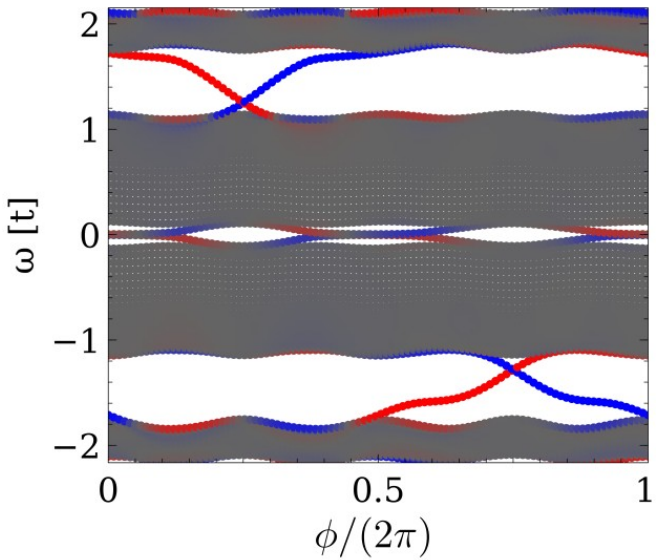
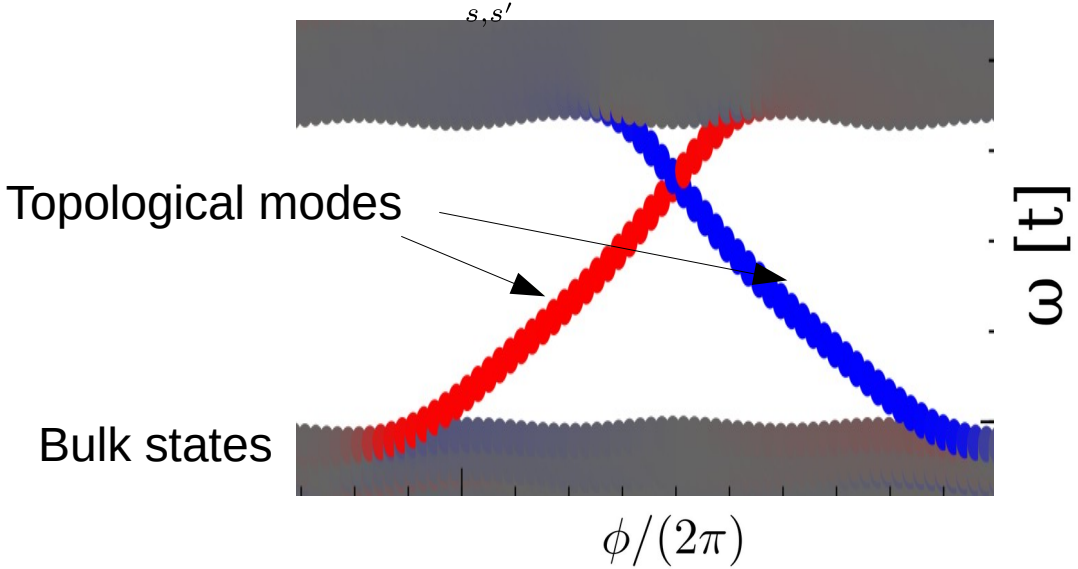
Modulated interactions

$$U_n = \tilde{U}[1 + \lambda \cos(\Omega n + \phi)]$$

Solved at the Hartree-Fock level

$$\sum_{s,s'} \langle \vec{\sigma}_{s,s'} c^{\dagger}_{n,s} c_{n,s'} \rangle = 0$$





Modulated local interactions create topological modes

Many-body topology

Let us focus in an interacting Hamiltonian with a trivial mean-field Hamiltonian

$$H = \sum_{n,s} t\, c^\dagger_{n,s} c_{n+1,s} + \sum_n U_n \left(c^\dagger_{n,\uparrow} c_{n,\uparrow} - \frac{1}{2} \right) \left(c^\dagger_{n,\downarrow} c_{n,\downarrow} - \frac{1}{2} \right) + h.c.$$

One electron-per site

$$\sum_s \langle c^\dagger_{n,s} c_{n,s} \rangle = 1$$

Non-magnetic ground state

$$\sum_{s,s'} \langle \vec{\sigma}_{s,s'} c^\dagger_{n,s} c_{n,s'} \rangle = 0$$

No non-trivial Hartree-Fock solution fulfills those conditions

In the following we will solve the interacting problem exactly using the **Kernel polynomial tensor network formalism**

https://itensor.org/

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

https://github.com/joselado/dmrgpy

Many-body topology

Let us focus in an interacting Hamiltonian with a trivial mean-field Hamiltonian

$$H = \sum_{n,s} t\, c^{\dagger}_{n,s} c_{n+1,s} + \sum_{n} U_n \left(c^{\dagger}_{n,\uparrow} c_{n,\uparrow} - \frac{1}{2} \right) \left(c^{\dagger}_{n,\downarrow} c_{n,\downarrow} - \frac{1}{2} \right) + h.c.$$

In the many-body setting, we will look at the dynamical spin excitation spectra

$$\mathcal{S}(\omega, n) = \langle GS | S^z_n \delta(\omega - H + E_{GS}) S^z_n | GS \rangle$$

Computed with the kernel polynomial tensor network formalism

$$\mathcal{S}(\omega, n) = \frac{1}{\pi \sqrt{1-\omega^2}} [\mu_0 + 2 \sum_{k=1}^{N} \mu_k T_k(\omega)] \qquad \mu_k = \langle GS | S^z_n T_k(H) S^z_n | GS \rangle$$

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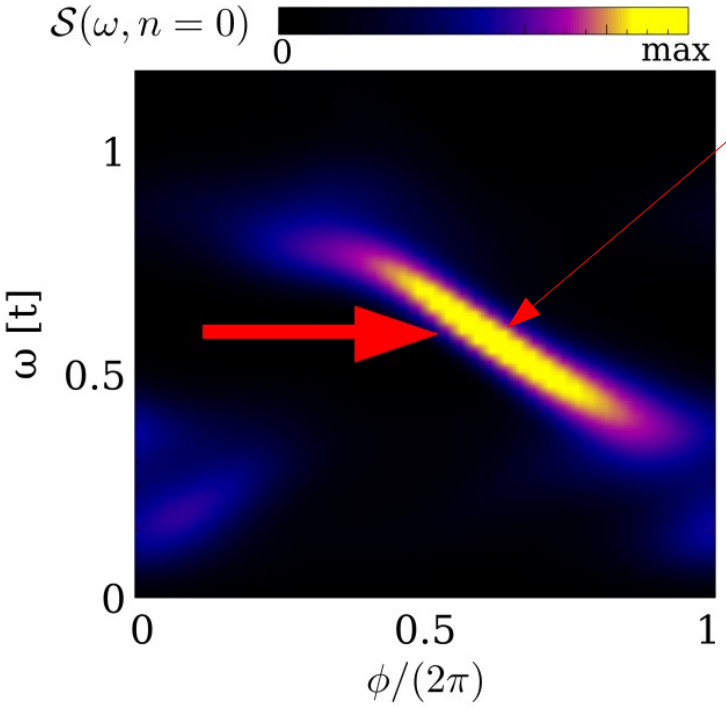
Many-body topological modes

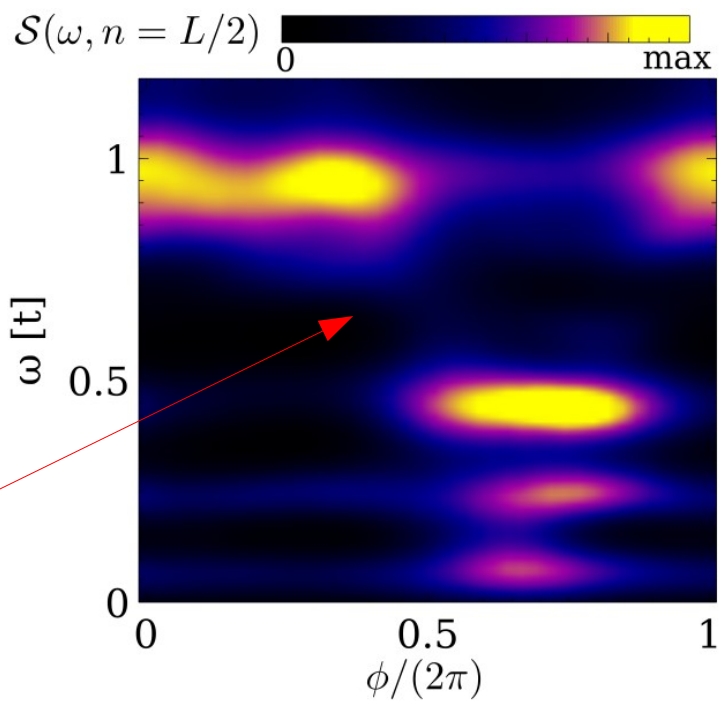
Edge spectral function



Topological edge mode

Topological bulk gap

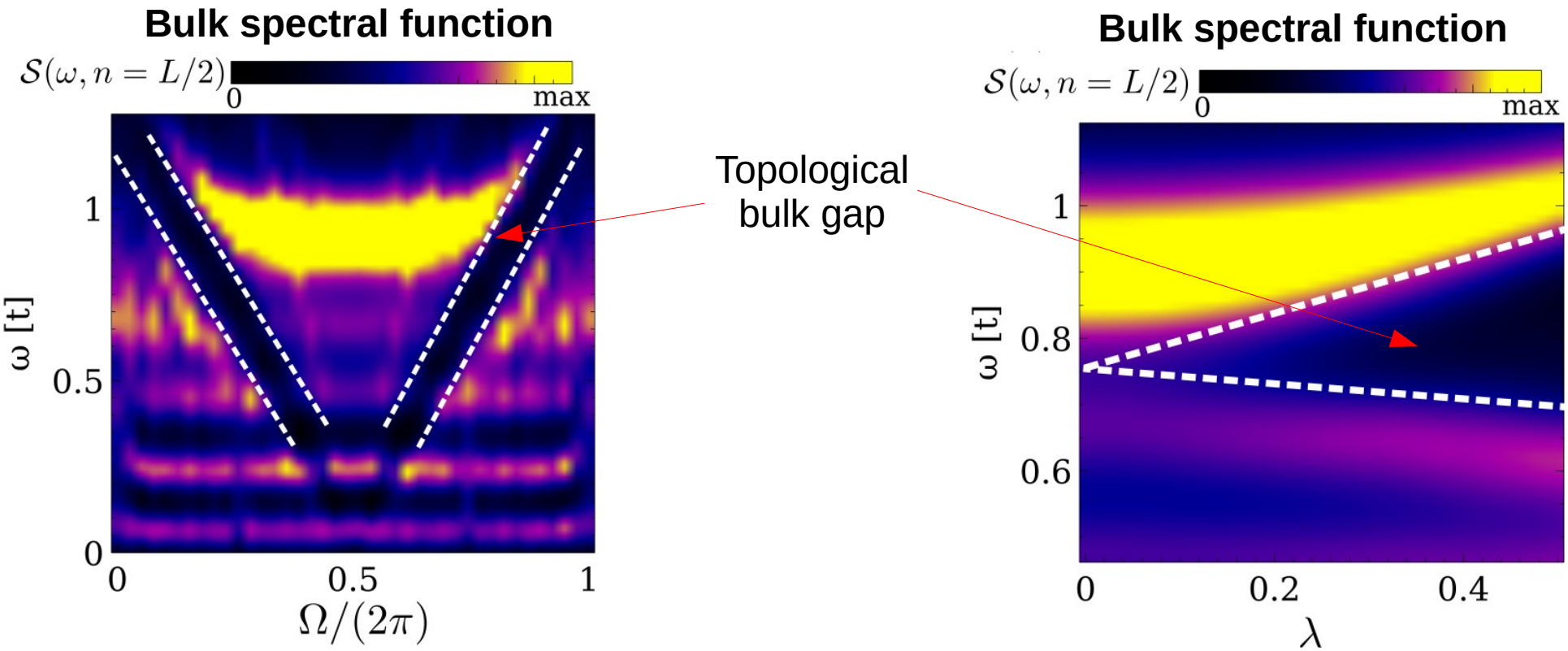
Bulk spectral function



Topological modes protected by a many-body quasiperiodic Chern invariant

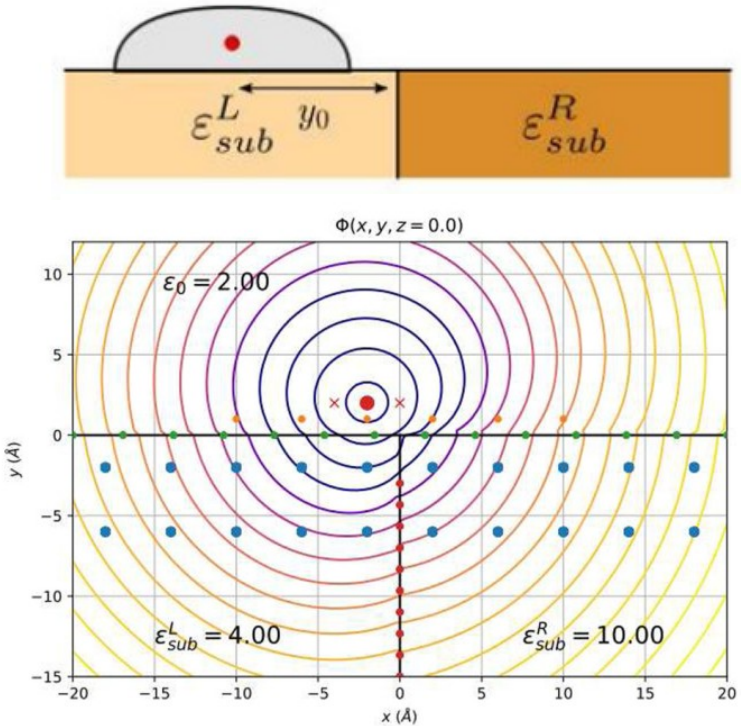
Phys. Rev. Research 1, 033009 (2020) *arXiv:2009.03752* *arXiv:2010.06171*

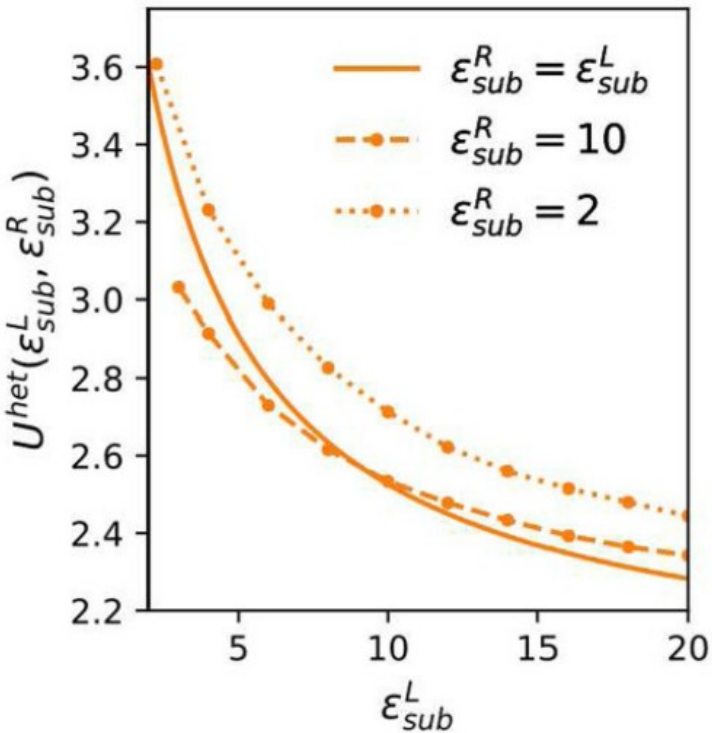
Many-body topological gaps



Topological gaps appear for generic modulation frequencies and strengths

Microscopic modeling of the screening



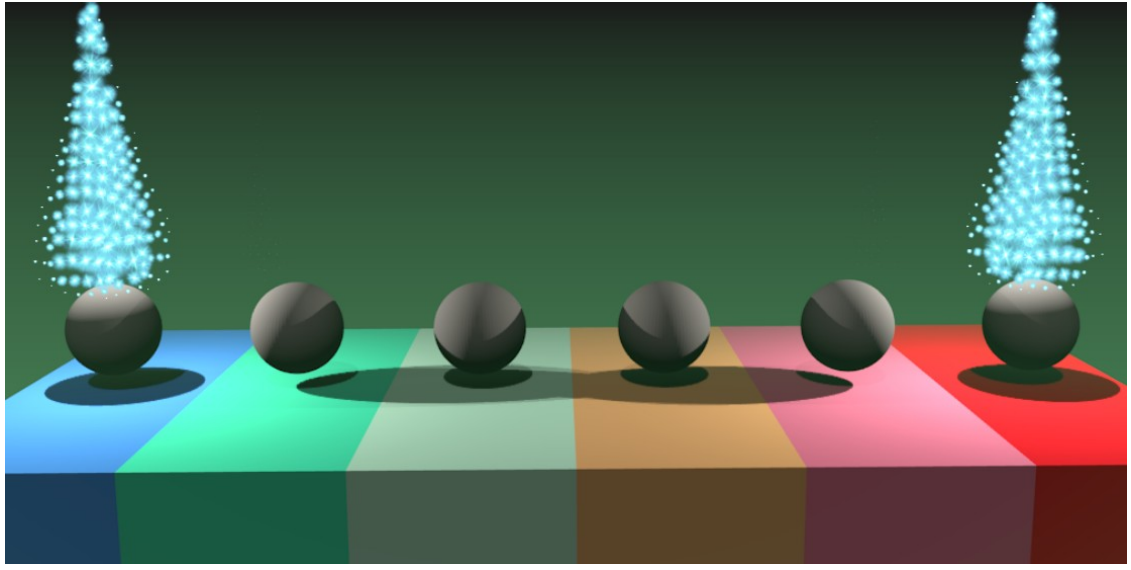


Realistic microscopic calculations of the screening yield an effective $\lambda = 0.3$

Phys. Rev. B 92, 085102 (2015) *Nano Lett. 16, 2322 (2016)* *Nat. Commun. 8, 1166 (2017)*

Take home

Dielectric Coulomb engineering allows generating many-body topological states



Thank you!

arXiv:2008.07990

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