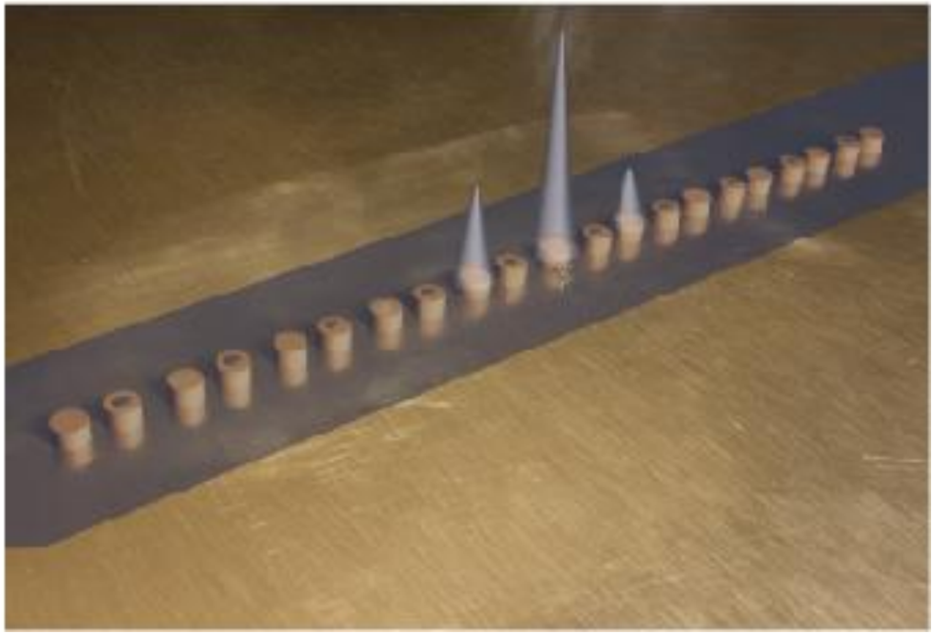


Physics | Lancaster University

The role of charge conjugation symmetry in topological photonics

Henning Schomerus, Lancaster University
Heraklion, 16 June 2016

Classification of electronic topological systems

Time reversal symmetry	$\mathcal{T}$	:	$\mathcal{T}H\mathcal{T} = H$	reciprocity
Chiral symmetry	$\mathcal{X}$	:	$\mathcal{X}H\mathcal{X} = -H$	sublattices, Dirac systems
Charge conj. symmetry	$\mathcal{C}=\mathcal{X}\mathcal{T}$	:	$\mathcal{C}H\mathcal{C} = -H$	superconductors

→ **10 universality classes** with different response to defects, e.g.

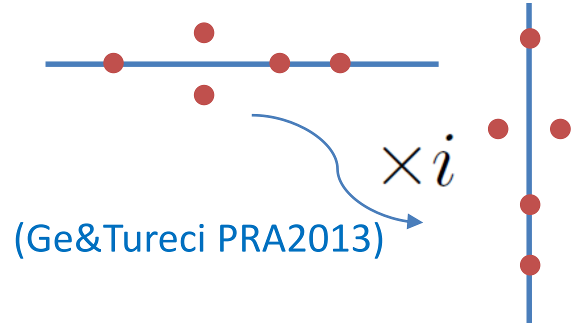
- edge and defect states
- parity/chiral anomaly
- charge fractionalization…

Here: extend to optical systems with loss and gain:
consequence of topological defects and anomalies?

PT symm.: $\mathcal{P} = \sigma_x \otimes 1_N$ (map between equivalent subspaces)

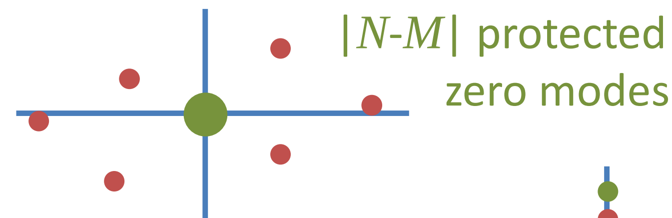
PT $\quad \mathcal{P}H\mathcal{P} = H^* : \quad H = \begin{pmatrix} A & B \\ B^* & A^* \end{pmatrix}$

anti-PT $\quad \mathcal{P}H\mathcal{P} = -H^* : \quad H = \begin{pmatrix} A & B \\ -B^* & -A^* \end{pmatrix}$

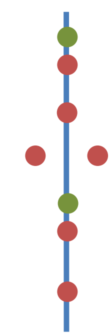


topological variant: $\mathcal{Z} = \begin{pmatrix} 1_N & 0 \\ 0 & -1_M \end{pmatrix}$ ($\mathbb{Z}_2$ gauge transformation)

chiral $\quad \mathcal{Z}H\mathcal{Z} = -H : \quad H = \begin{pmatrix} 0 & B \\ B' & 0 \end{pmatrix}$



charge-conjugate $\quad \mathcal{Z}H\mathcal{Z} = -H^* : \quad H = \begin{pmatrix} iA & B \\ B' & iA' \end{pmatrix}, \quad A, A', B, B'$ real



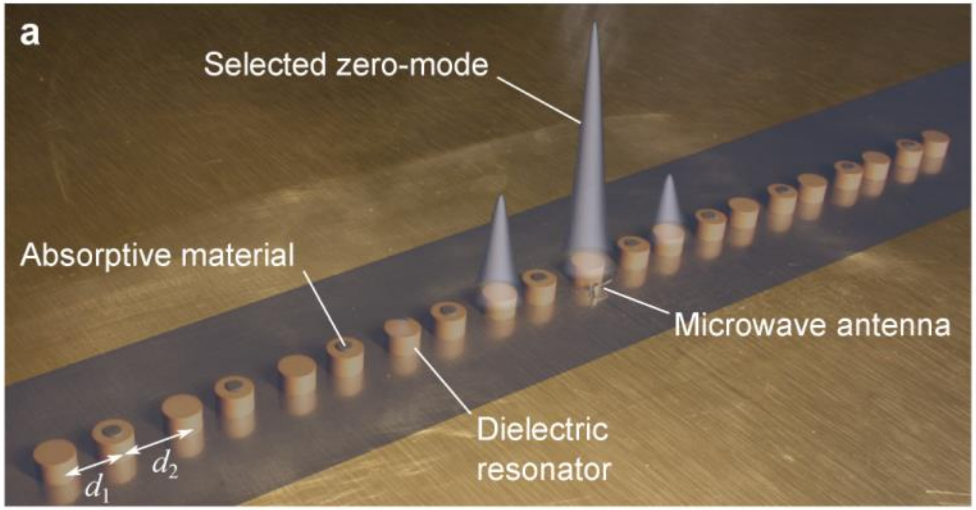
+ reciprocity: $H = H^T, \quad \mathcal{Z}H\mathcal{Z} = -H^\dagger$

$$\langle\psi|\mathcal{Z}H|\psi\rangle = E\langle\mathcal{Z}\rangle = -\langle\psi|H^\dagger\mathcal{Z}|\psi\rangle = -E^*\langle\mathcal{Z}\rangle \quad \Rightarrow \mathrm{Re}\, E = 0 \text{ or } \langle\mathcal{Z}\rangle = 0$$

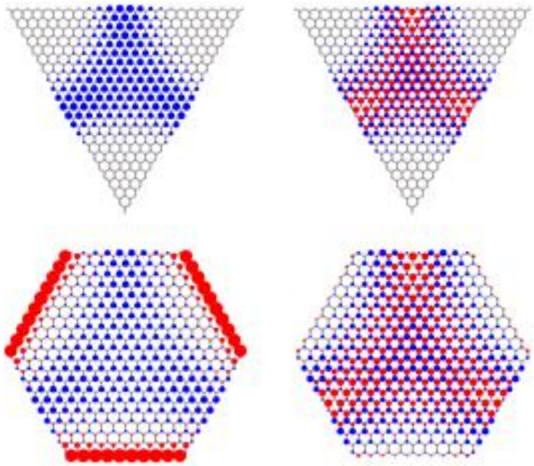
Topological modes have finite $\langle\mathcal{Z}\rangle$: can manipulate selectively

mode selection via topological anomalies in 1D and 2D

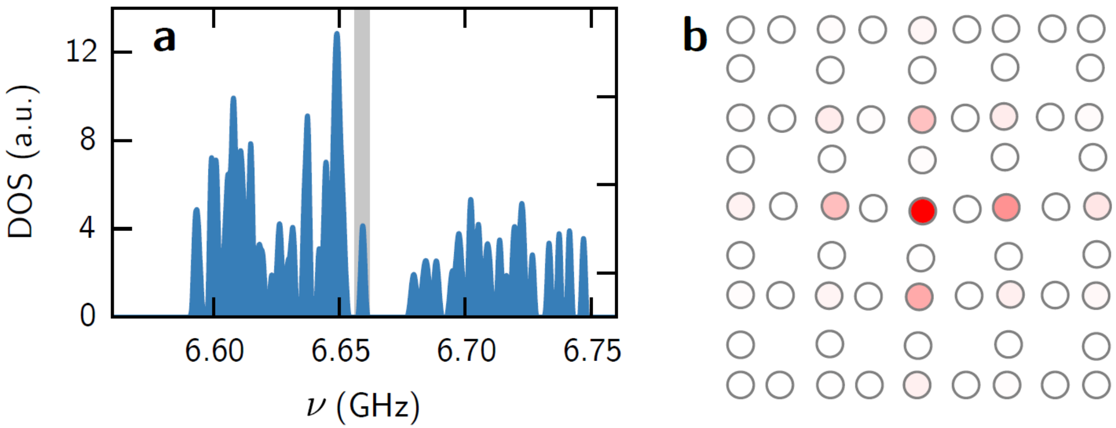
complex SSH chain



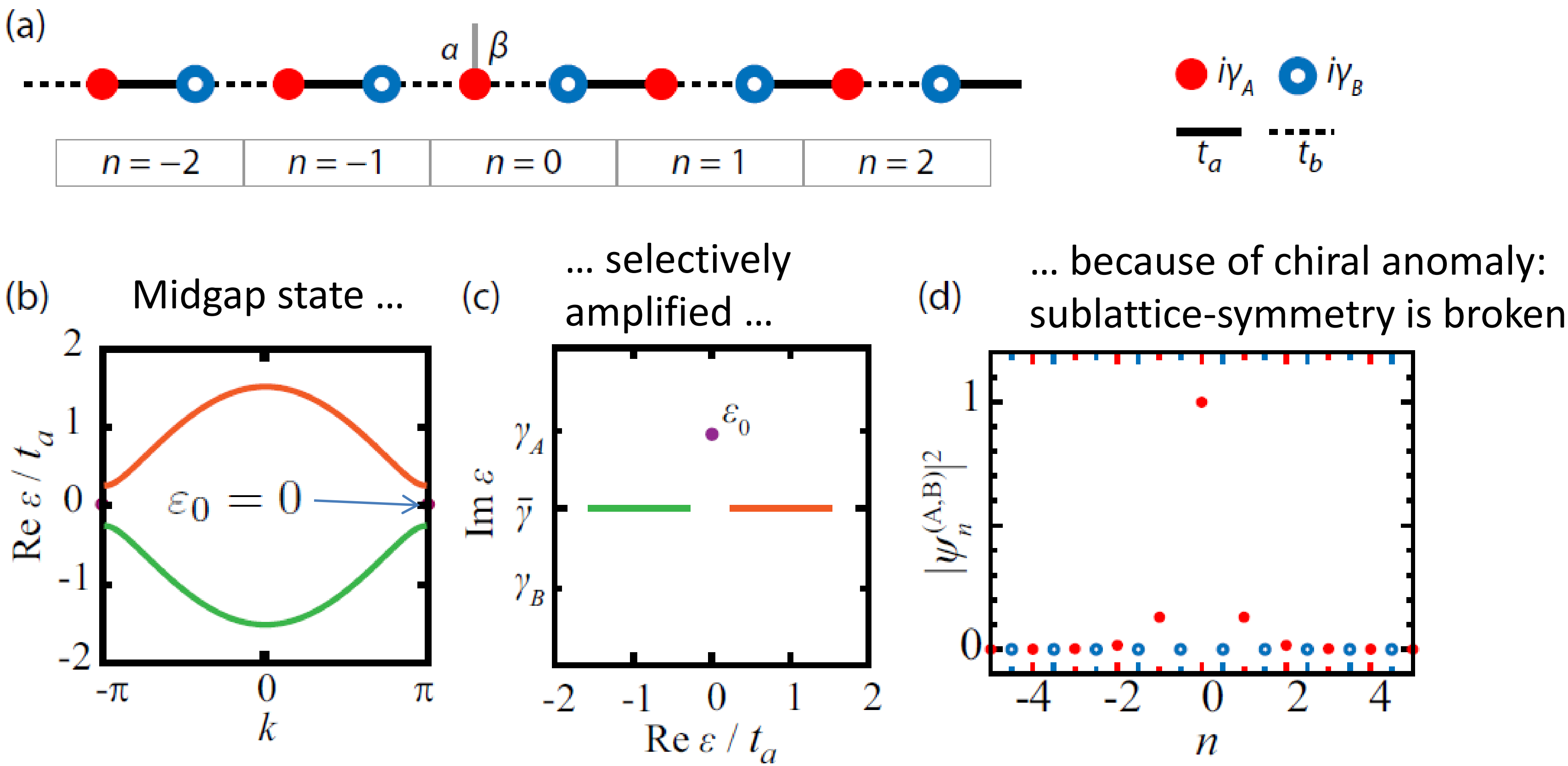
honeycomb lattices



dimerised Lieb lattice



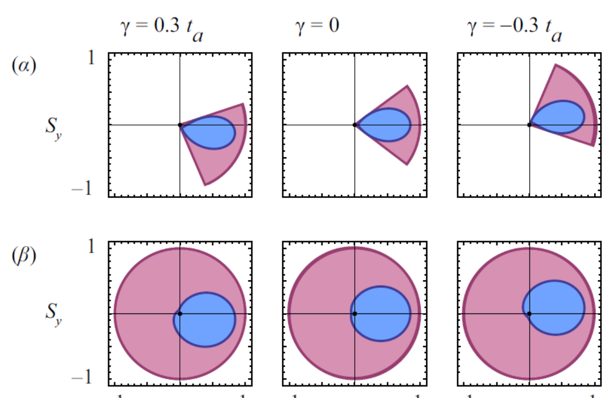
complex SSH chain



Top. characterization survives PT-sym. loss and gain

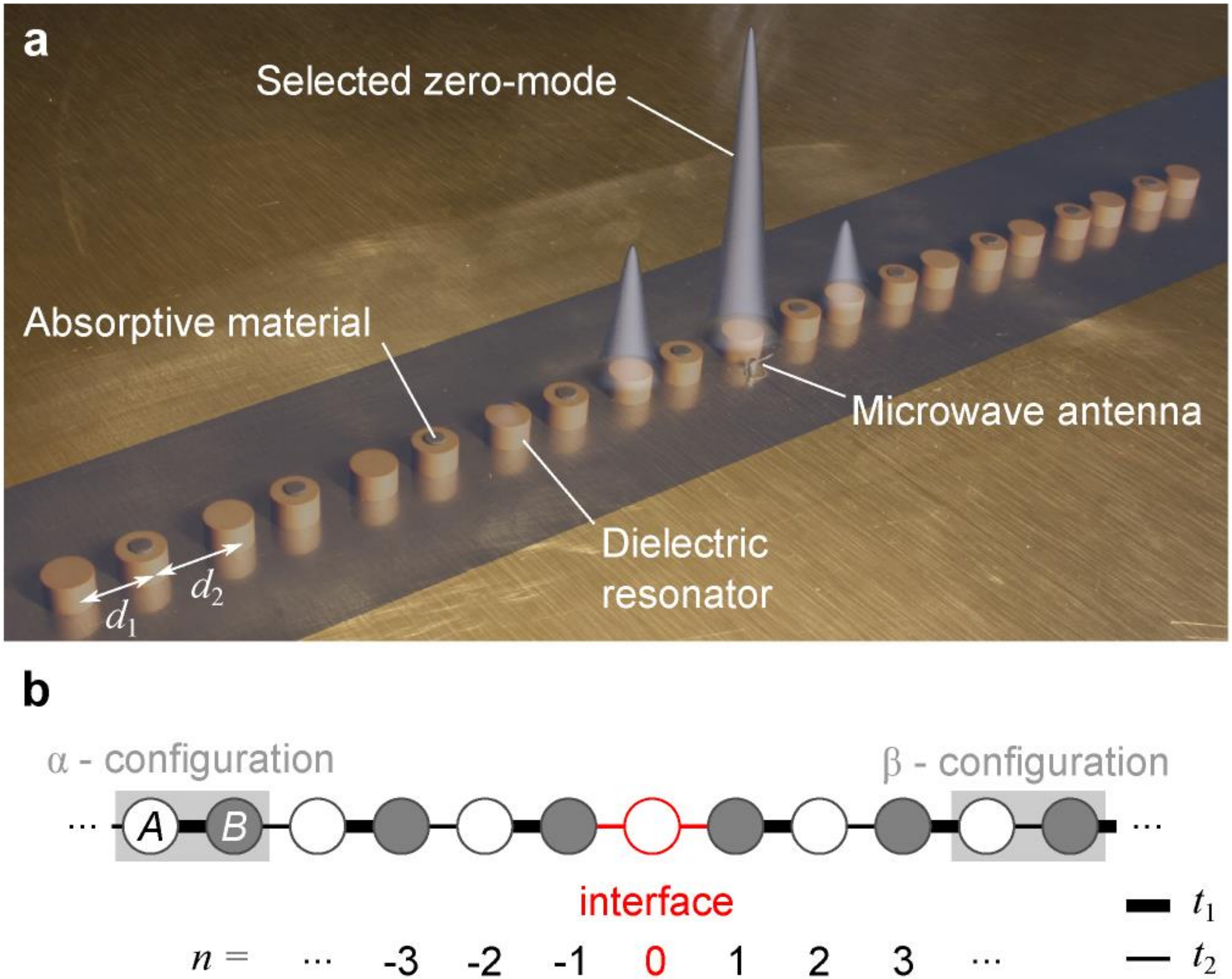
$$\mathbf{S} = \langle(\sigma_x, \sigma_y, \sigma_z)\rangle = (S_x, S_y, S_z)$$

$$|\varphi_A|^2 = |\varphi_B|^2, \text{ thus } S_z = 0$$



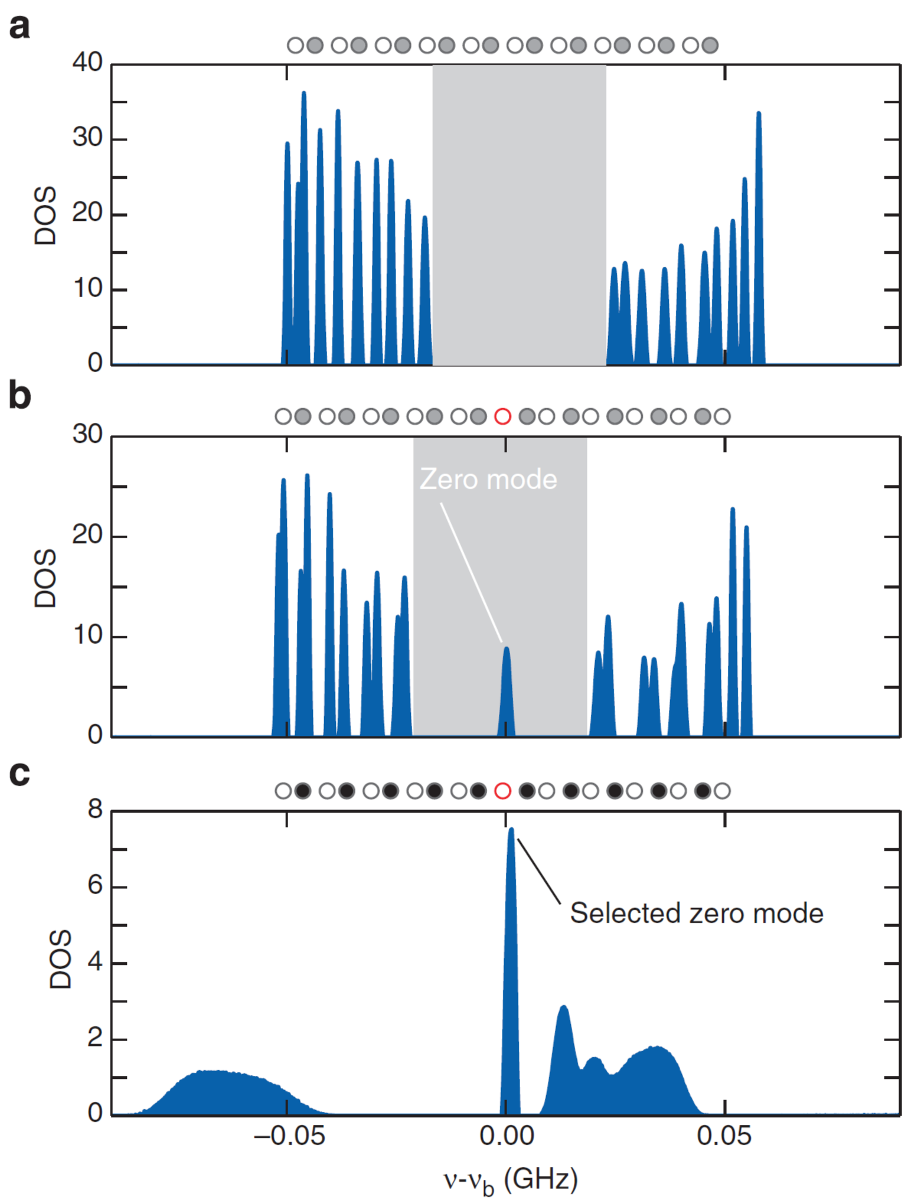
Midgap state breaks this symmetry: $S_z = \pm 1$

Microwave realization

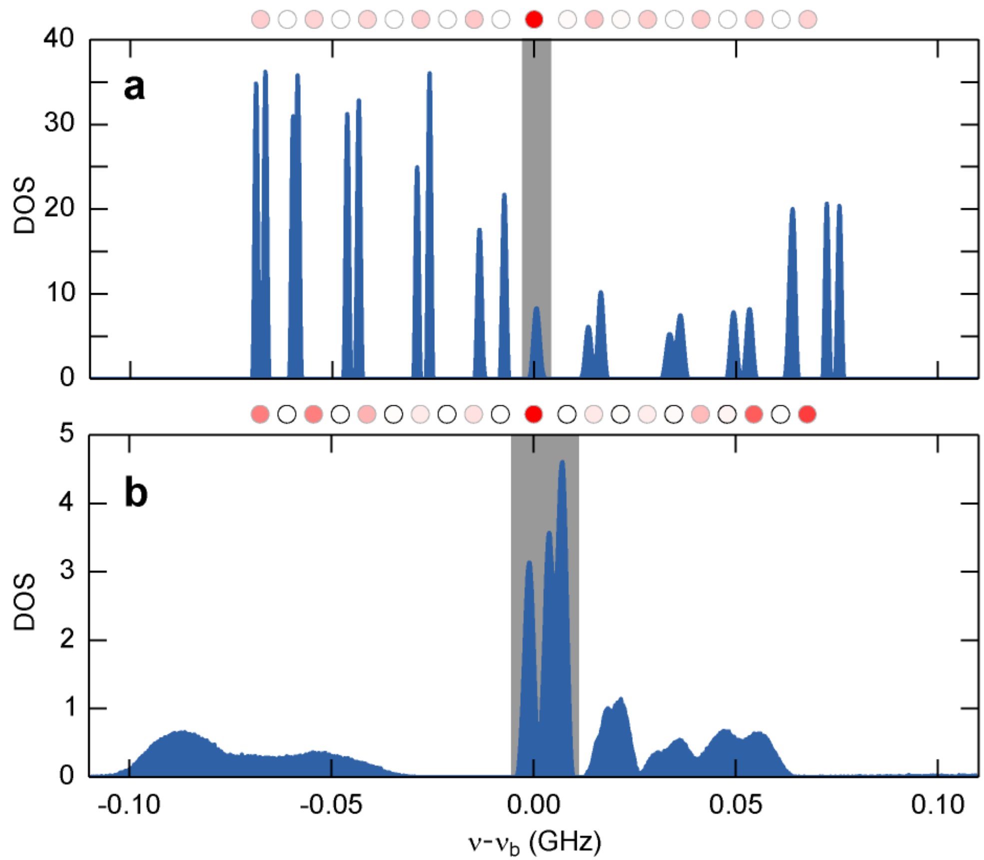


Nature Communications 2015, with Nice group (Poli, Bellec, Kuhl, Mortessagne)

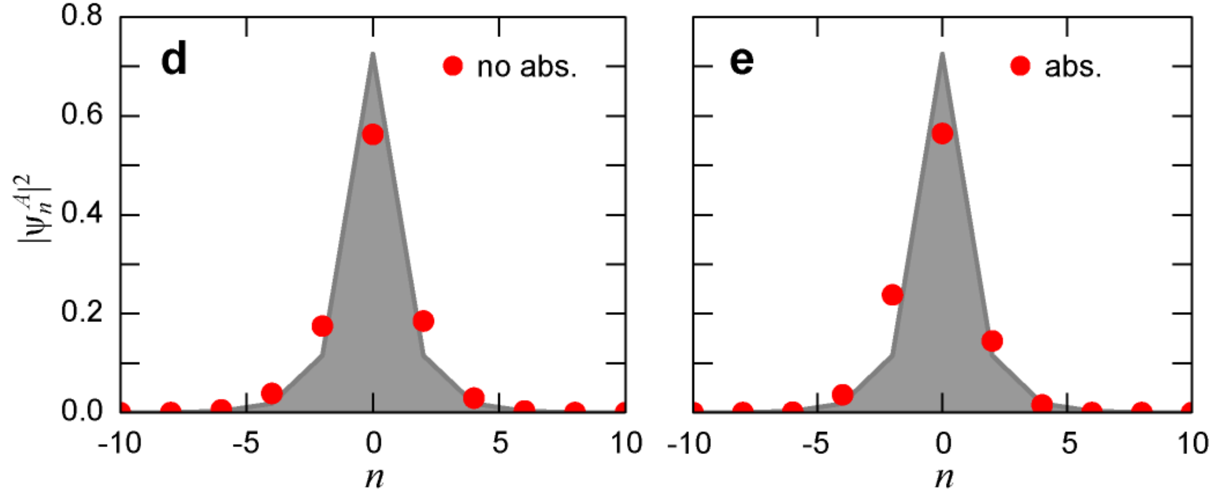
Density of states



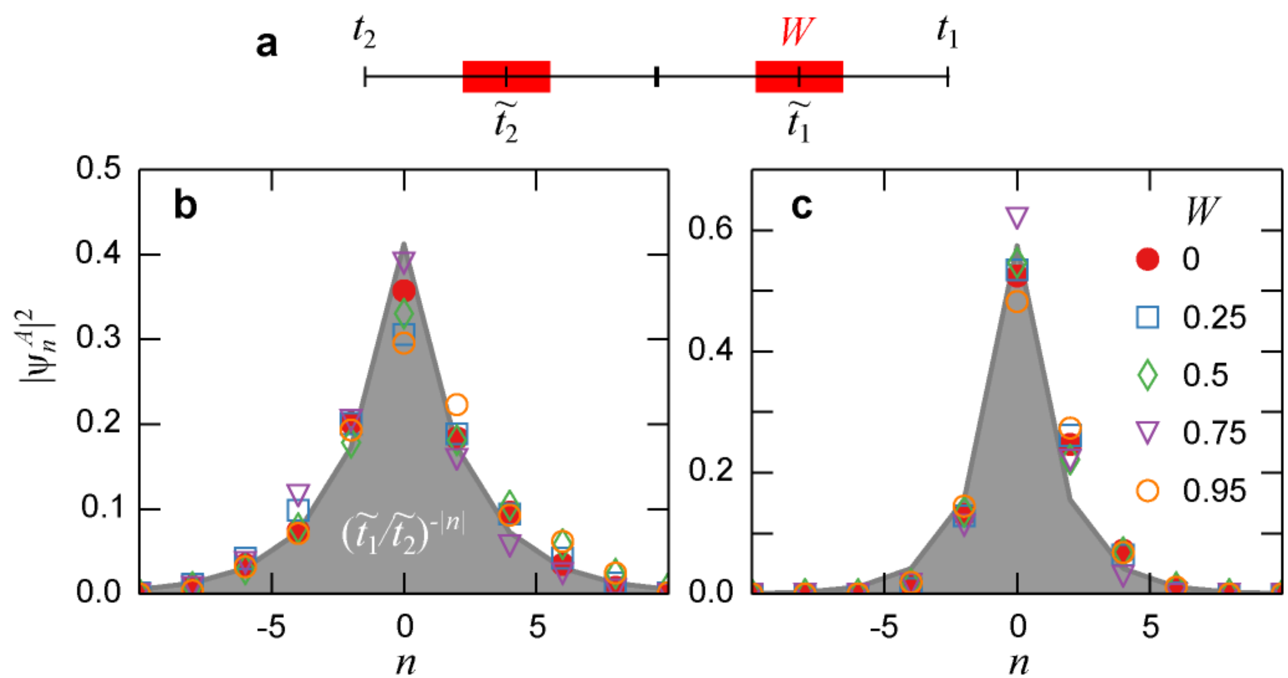
Compare to nontopological defect



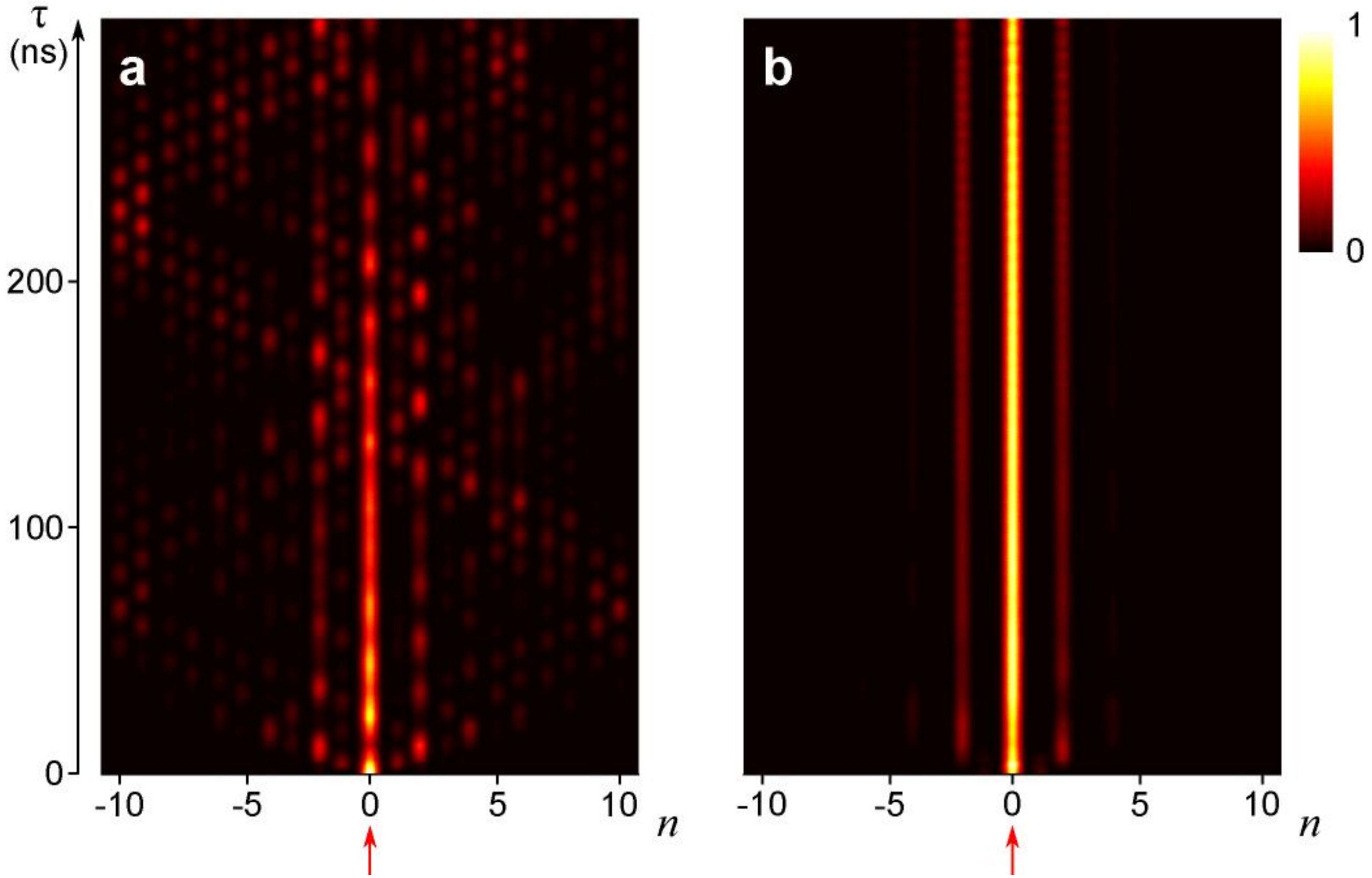
Mode profiles



Robustness to structural disorder



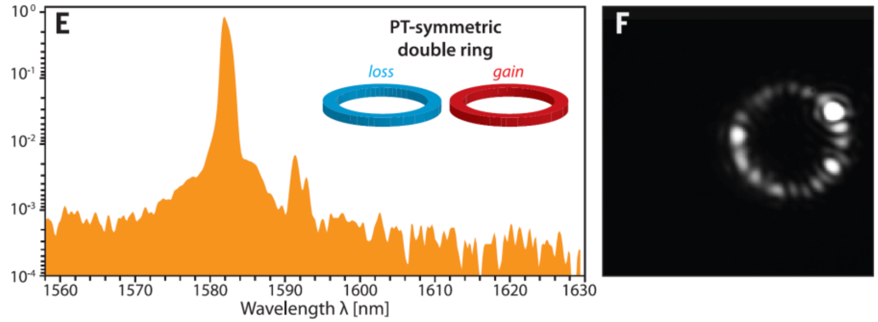
Pulse propagation



PT lasers YD Chong et al PRL 2011; S Longhi PRA 2010; HS, PRL 2010; Guo, Sim, HS PRA 2011

Parity-time–symmetric microring lasers

Hossein Hodaei, Mohammad-Ali Miri, Matthias Heinrich,* Demetrios N. Christodoulides, Mercedeh Khajavikhan†

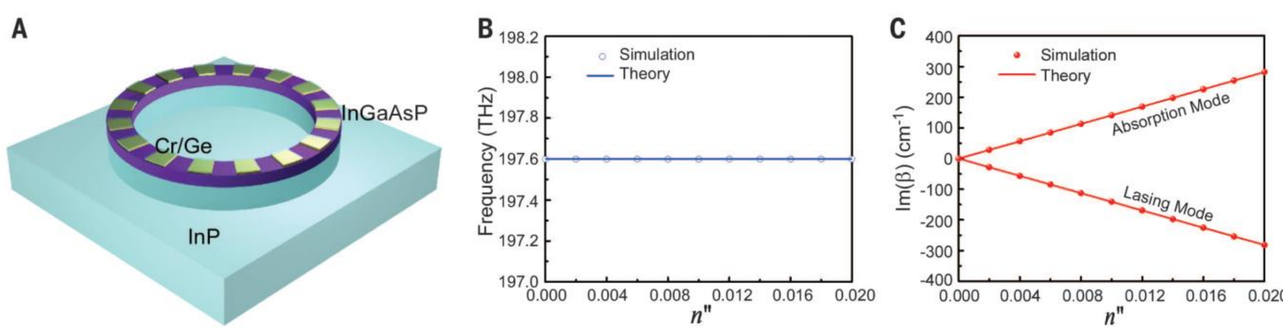


REPORTS

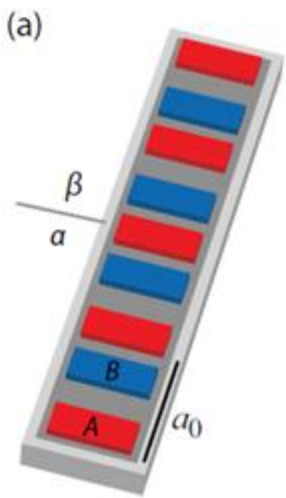
OPTICS

Single-mode laser by parity-time symmetry breaking

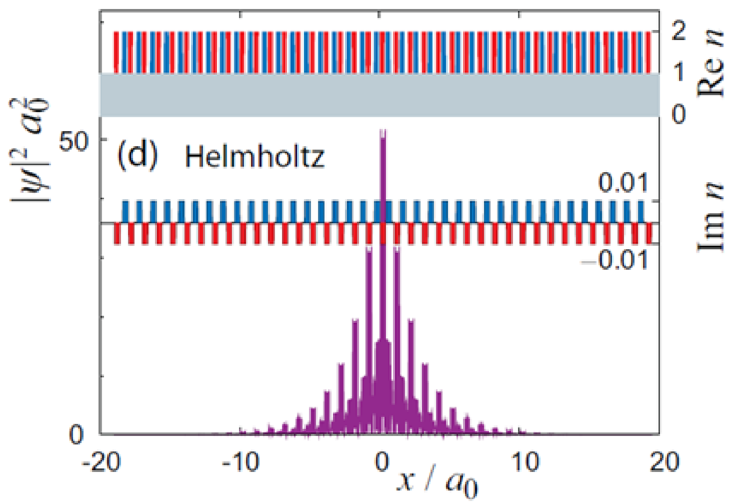
Liang Feng,[1*] Zi Jing Wong,[1*] Ren-Min Ma,[1*] Yuan Wang,[1,2] Xiang Zhang[1,2]†

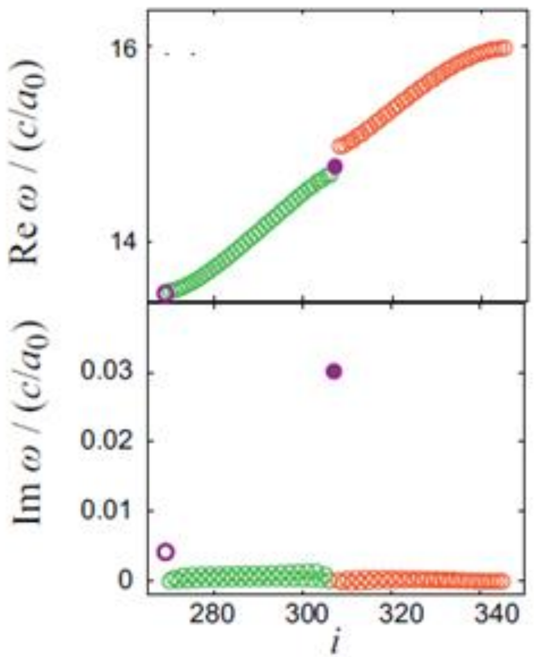


Topological Lasers

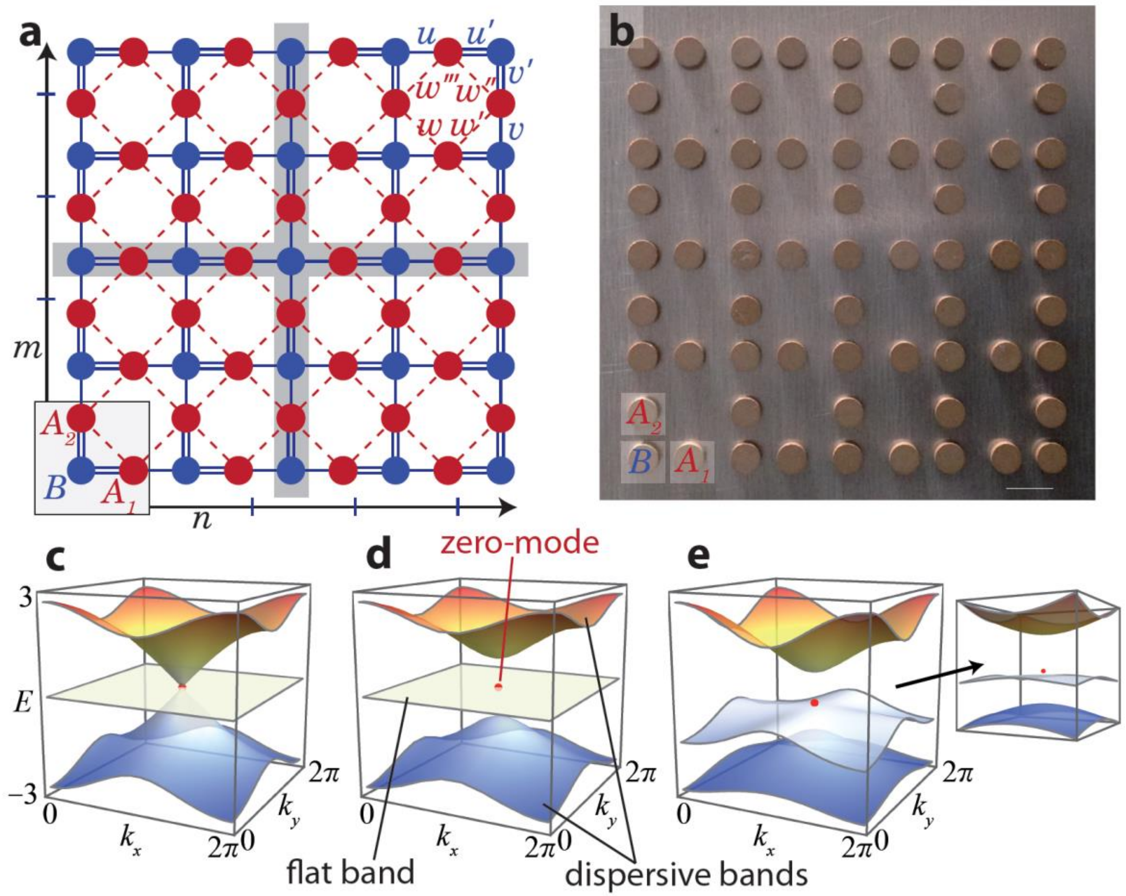


$$n_A = 2 - 0.01i$$
$$n_B = 2 + 0.01i$$
$$(\partial_x^2 + n^2(x)\omega^2/c^2)\psi(x) = 0$$





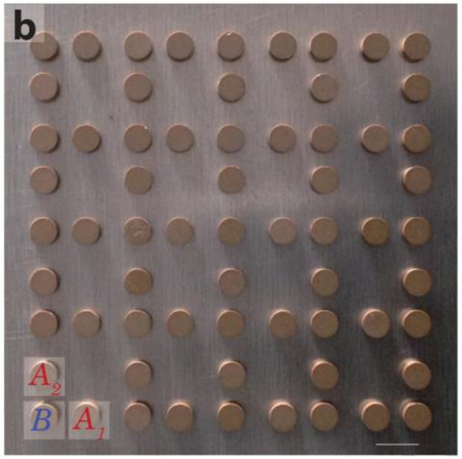
2D version of SSH model: dimerised Lieb lattice

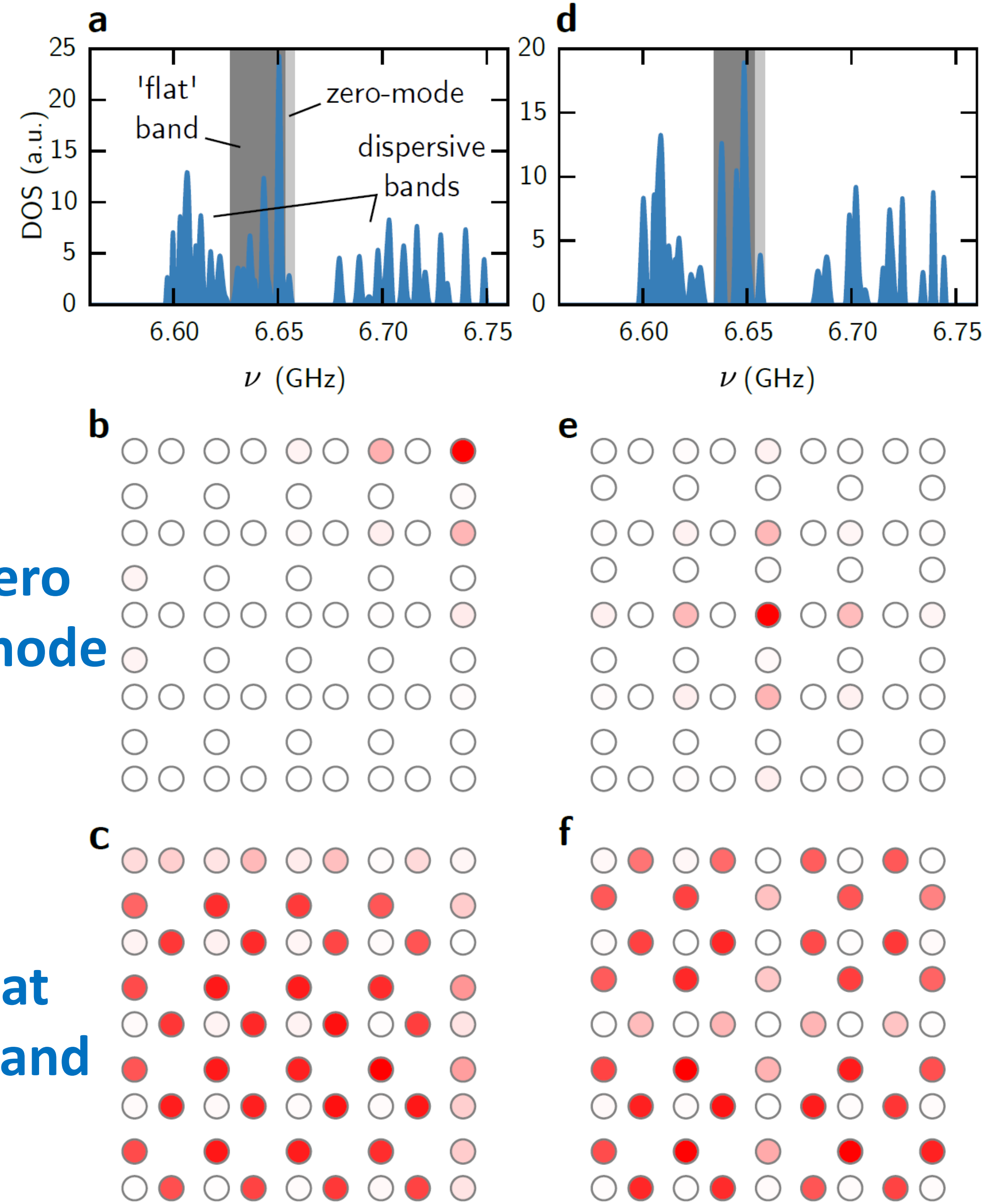


Flat band competes with point-defect states

- generate isolated point defect state
- NNN coupling: remove flat band

Experiment





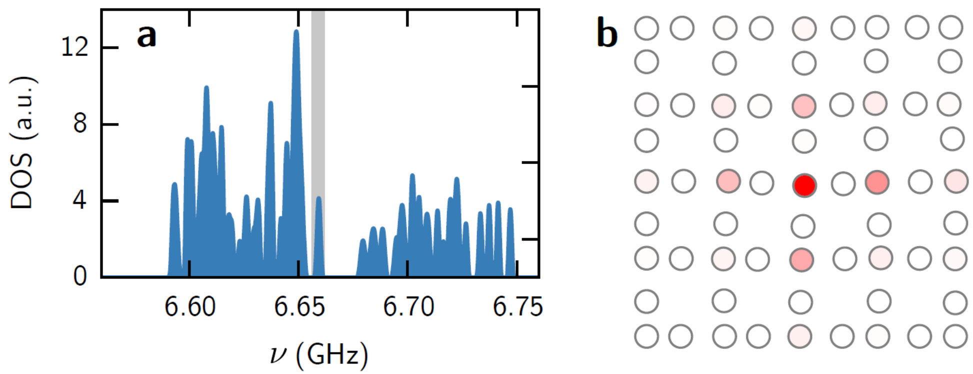
zero mode

flat band

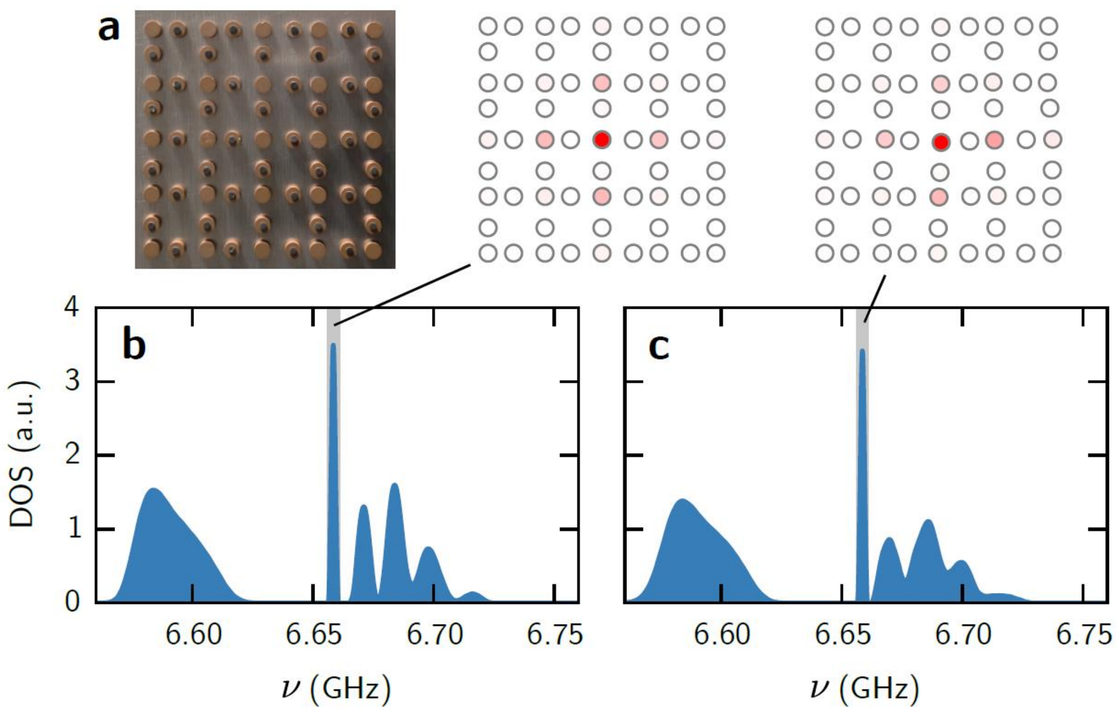
corner

centre

disorder



staggered absorption … + disorder



Pseudo-landau levels

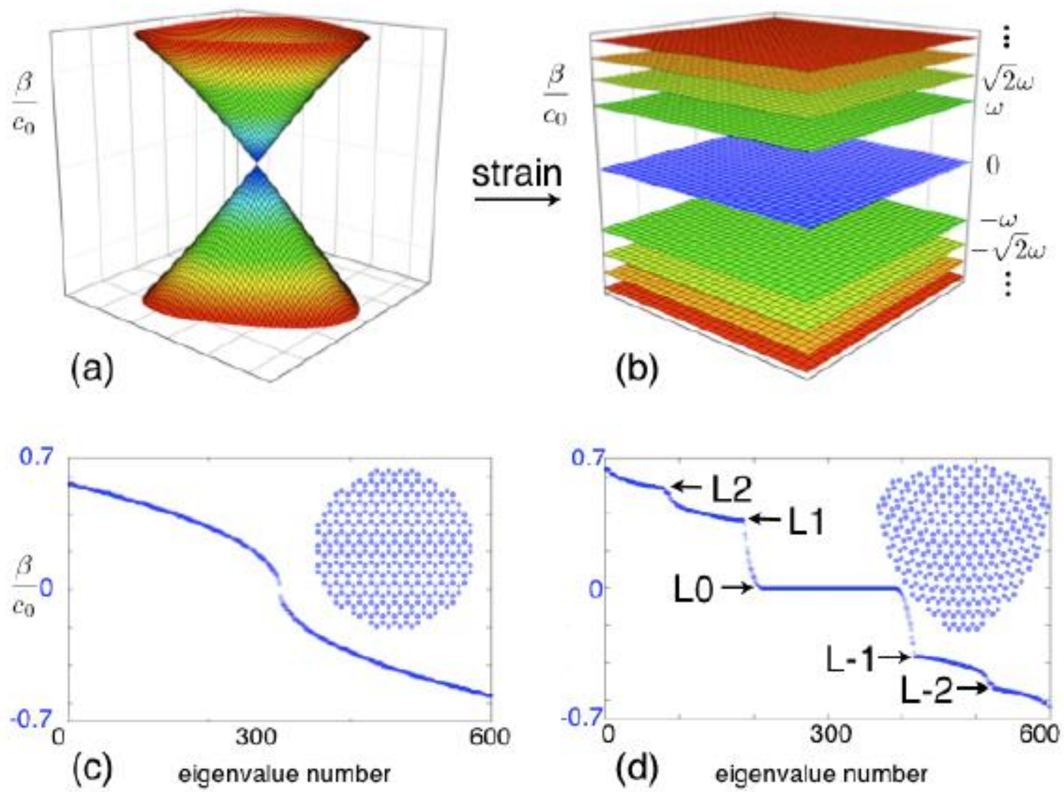
nature photonics

ARTICLES

PUBLISHED ONLINE: 9 DECEMBER 2012 | DOI: 10.1038/NPHOTON.2012.302

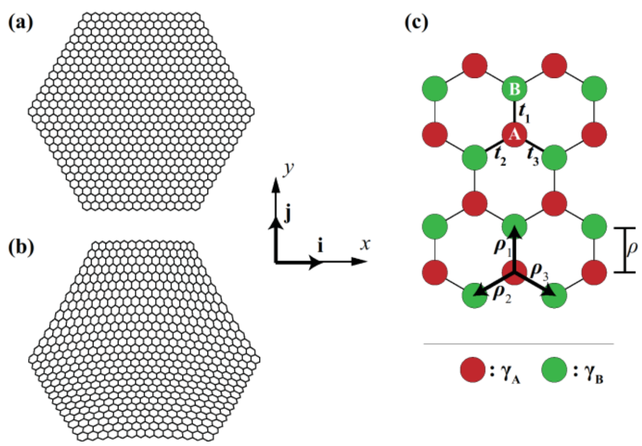
Strain-induced pseudomagnetic field and photonic Landau levels in dielectric structures

Mikael C. Rechtsman[1†*], Julia M. Zeuner[2†], Andreas Tünnermann[2], Stefan Nolte[2], Mordechai Segev[1] and Alexander Szameit[2]



Parity anomaly: strained honeycomb lattices with gain and loss

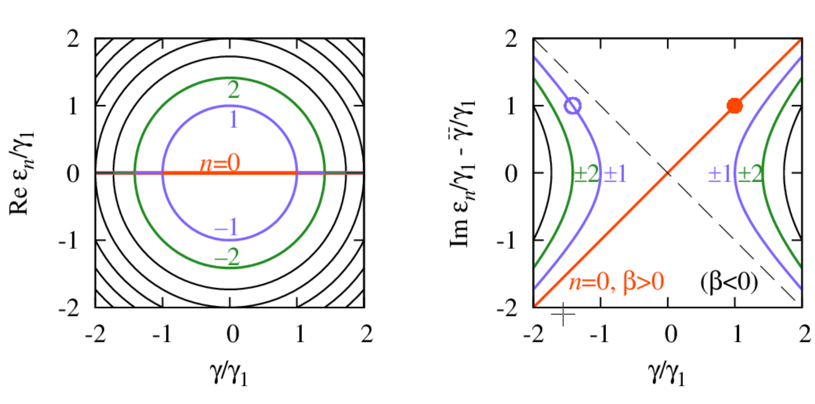
sublattices A and B have amplification rates γ_A and γ_B,



Low-energy theory: SUSY

$$\mathcal{H} = \begin{pmatrix} i\gamma_A & v\sqrt{2\beta}\Pi^\dagger \\ v\sqrt{2\beta}\Pi & i\gamma_B \end{pmatrix}, \quad [\Pi, \Pi^\dagger] = 1$$

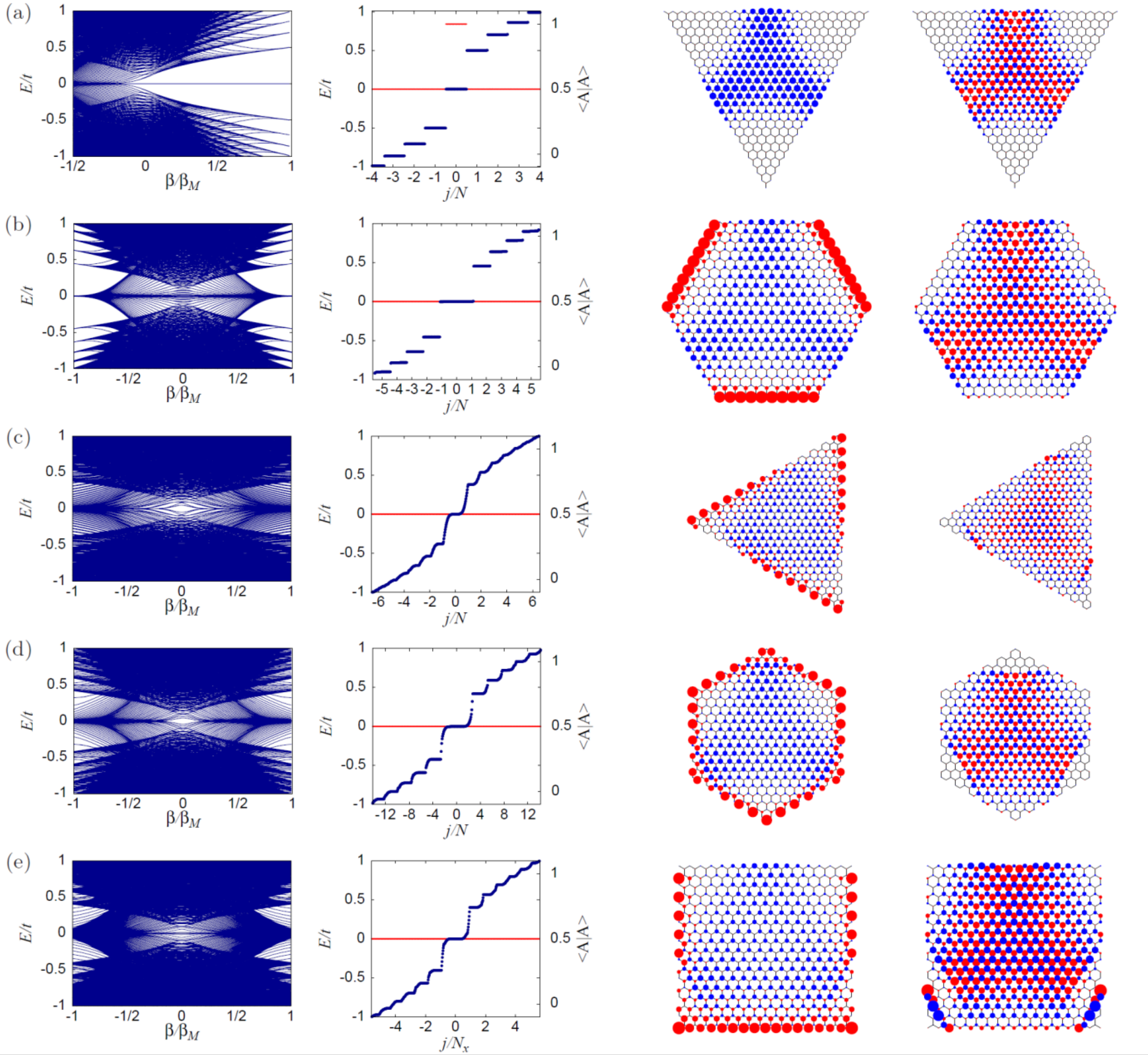
pseudo-Landau level laser



0^{th} LL: sublattice polarized, thresholdless amplification

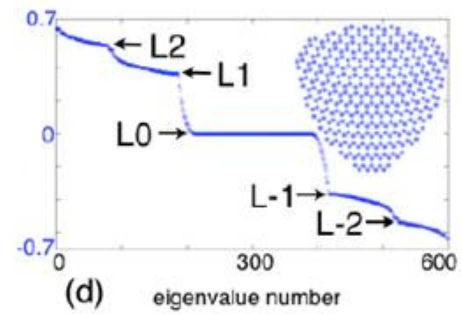
higher LLs: not polarized and amplified until PT symmetry spontaneously broken

HS, N Yunger Halpern, PRL 2013

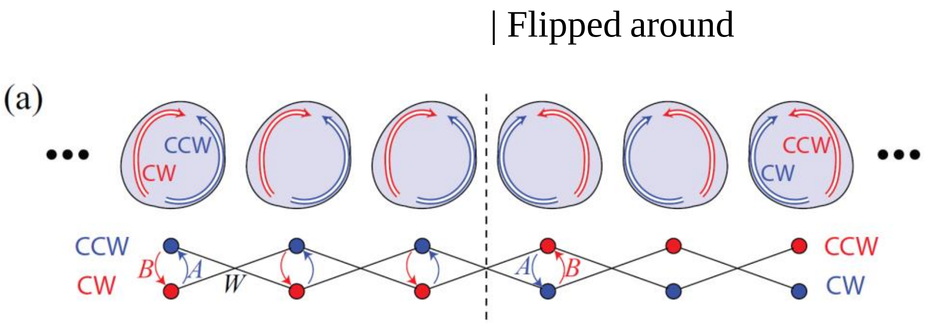


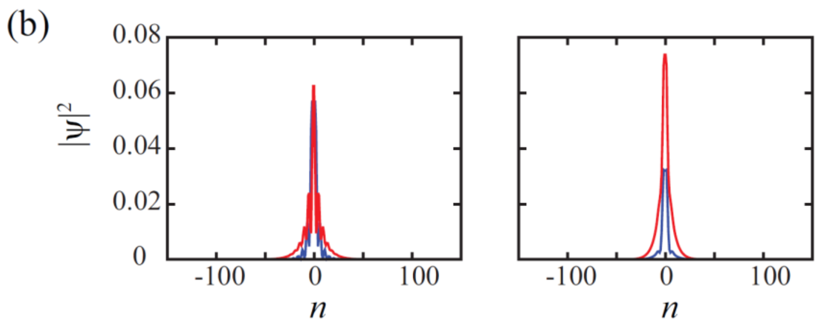
Finite sys: sublattice polarization of 0th pseudo-LL is geometry-dependent

[C Poli, J Arkinstall and HS, PRB 2014]

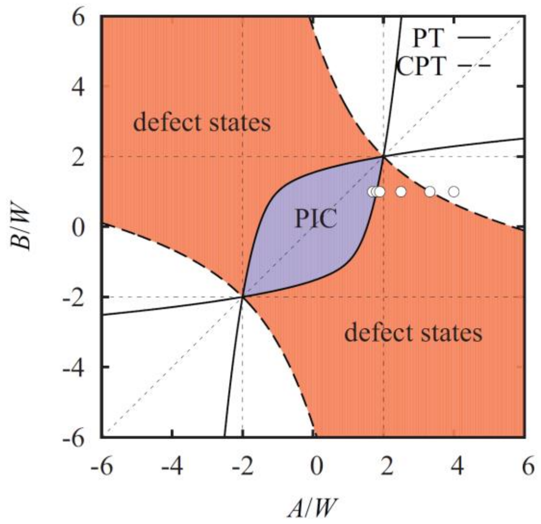


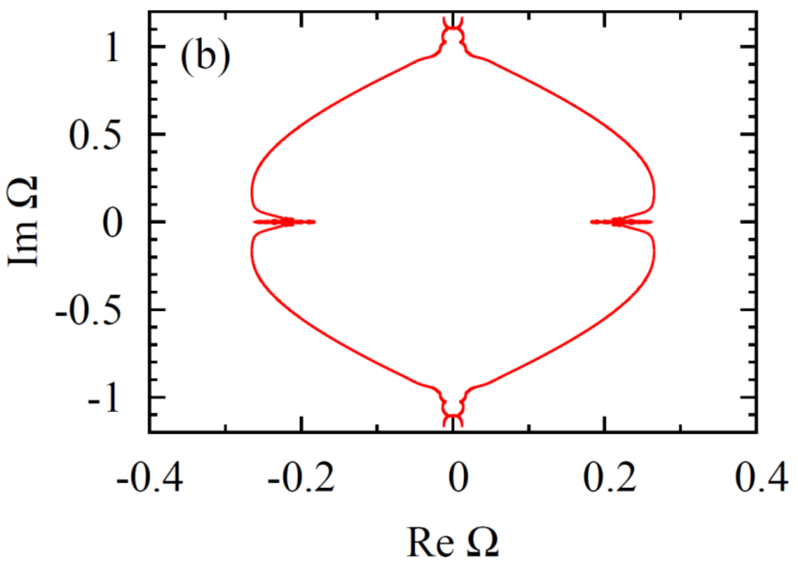
Open sys: ‘nontopological’ defect… …becomes topological





…via EPs on real and imaginary axis:





HS & J Wiersig, PRA 2014; Malzard, Poli, HS, PRL 2015

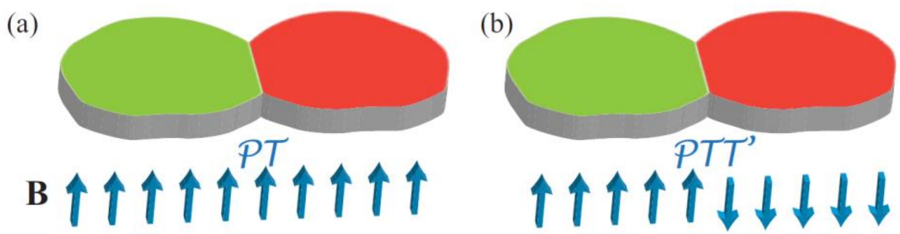
Final notes: beyond reciprocity

Instead of PT:

$\mathcal{X}\, H\mathcal{X}=H^* \rightarrow \mathcal{X}\, \mathbf{S(E)^*}\mathcal{X} = [\mathbf{S^{-1}(E^*)}]$

can also do magneto-optics with PTT':

$\mathcal{X}\, H\mathcal{X}=H^\dagger \rightarrow \mathcal{X}\, \mathbf{S(E)^\dagger}\mathcal{X} = [\mathbf{S^{-1}(E^*)}]$



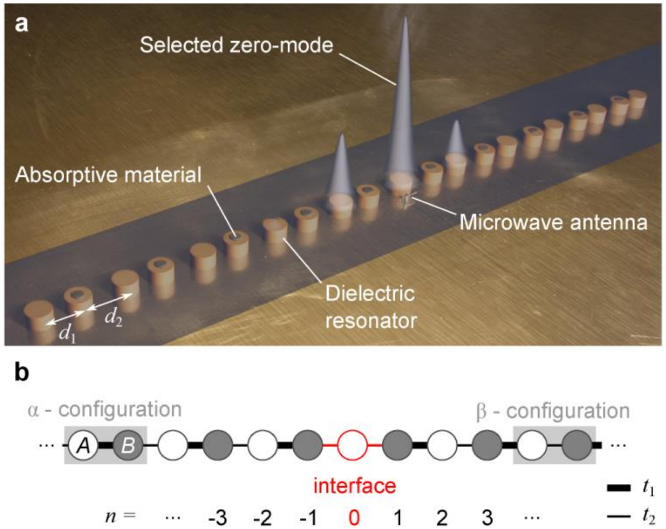
[or even 'skew-Hamiltonian' $\mathcal{J}\, H\mathcal{J}=H^\dagger$ **where** $\mathcal{J}^T = -\mathcal{J}$ **]**

which all have no electronic analogue

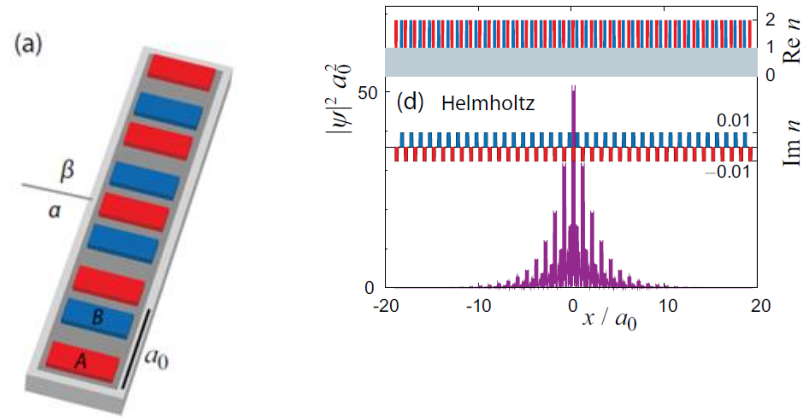
HS PRL 2010, PRA 2012, Phil. Trans. R. Soc. A 2013

Summary: topological anomalies → selectively amplified states

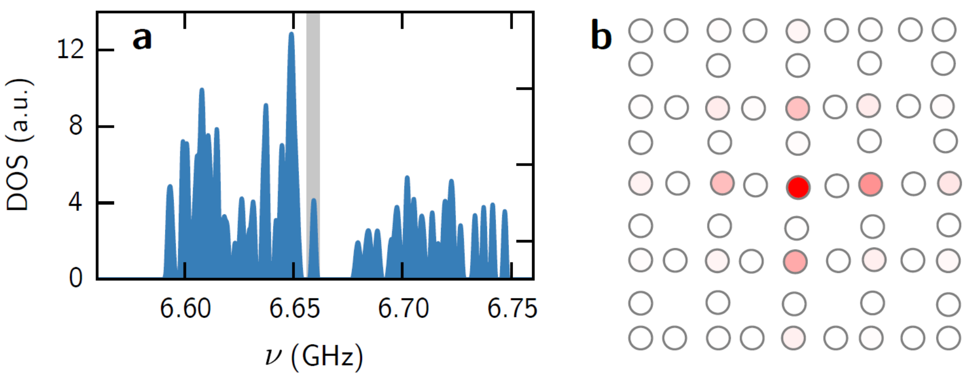
Complex SSH model



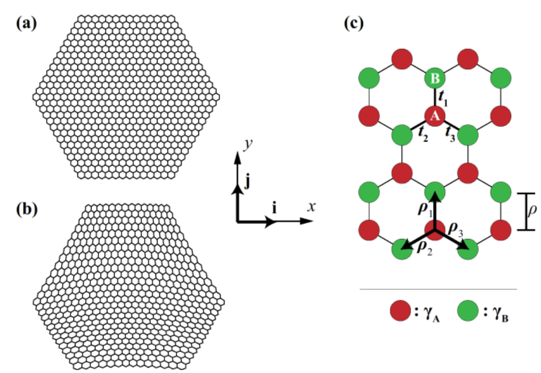
↗ lasers



Point defects



Landau levels



HS, Opt Lett 2013; C Poli, HS, M Bellec, U Kuhl, F Mortessagne, Nat Commun 2015; +subm.
HS & N Yunger Halpern, PRL 2013; Malzard, Poli, HS, PRL 2015