



南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY



安徽理工大学
ANHUI UNIVERSITY OF SCIENCE & TECHNOLOGY

Three-dimensional Topological Photonic Phases

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Outline

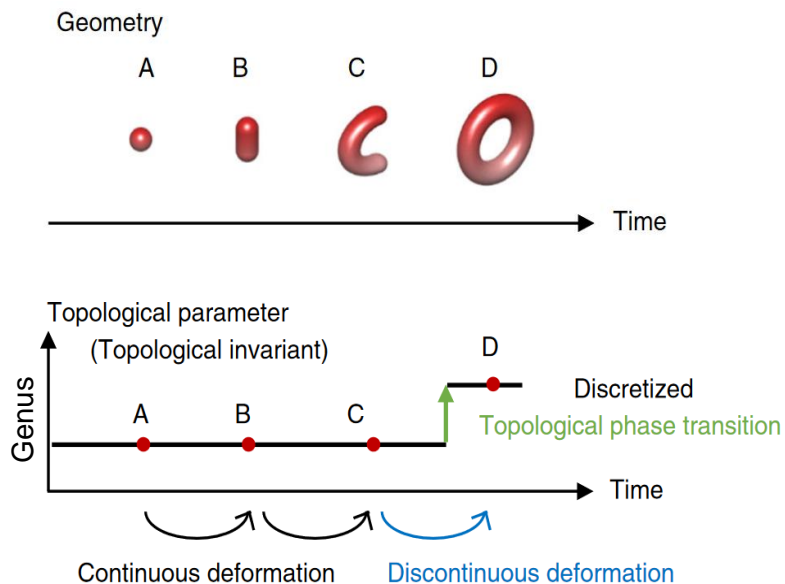
Part I: Introduction

Part II: Reciprocal three-dimensional photonic topological phases

Part III: Nonreciprocal three-dimensional photonic topological phases

What is Topology

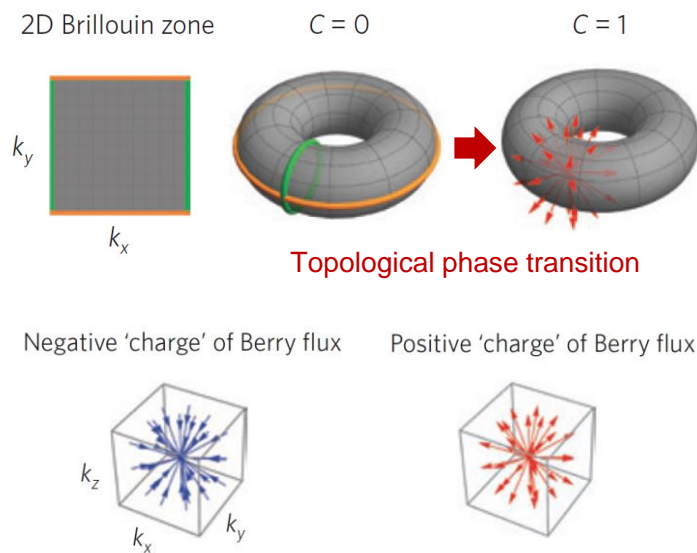
Real space



$$\frac{1}{2\pi} \int_{\text{surface}} \mathcal{K} dA = 2(1 - g)$$

Number of holes on a closed surface

Momentum space



$$C = \frac{1}{2\pi} \oiint \mathcal{F}(\mathbf{k}) \cdot d\mathbf{s}$$

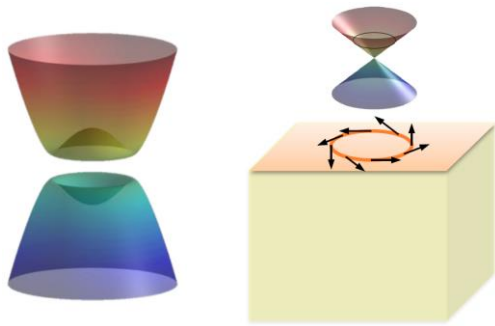
Number of monopoles of Berry flux inside a closed surface

Light: Sci & Appl. 9, 130 (2020)

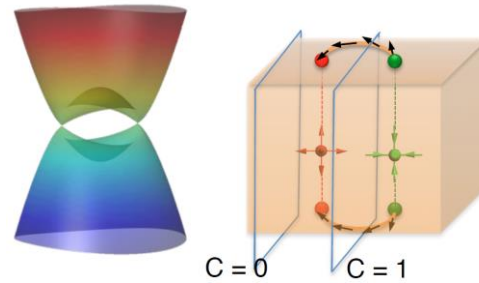
Nat. Photon. 8, 821–829 (2014)

Topological electronics and topological photonics

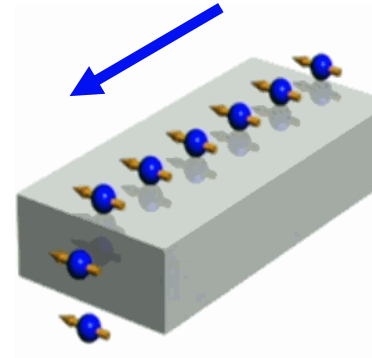
Topological insulator



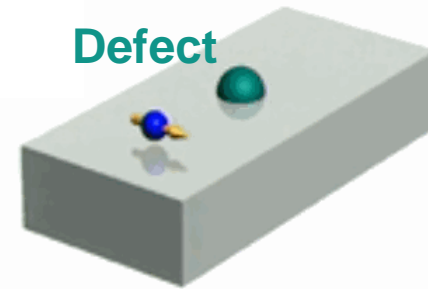
Topological semimetal



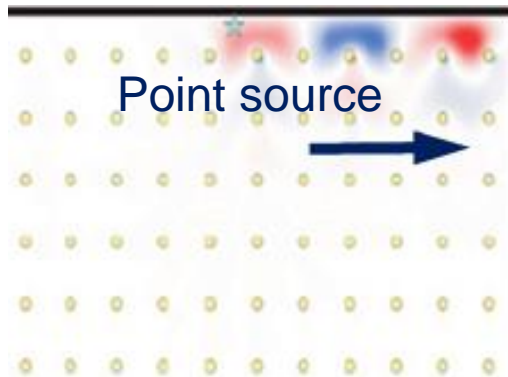
Unidirectional



Defect-immune

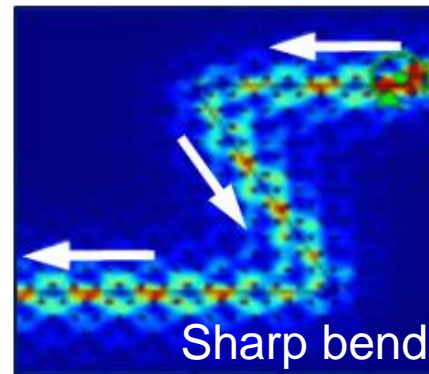


Unidirectional



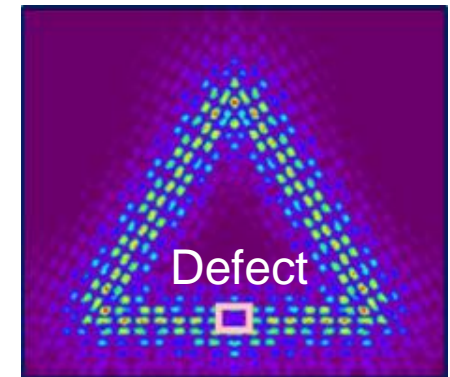
Nature 461, 772 (2009)

Backscattering-immune



Nat. Mater. 15, 542 (2016)

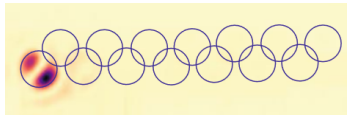
Defect-immune



Nature 578, 219 (2020)

"Dimension" of topological photonics

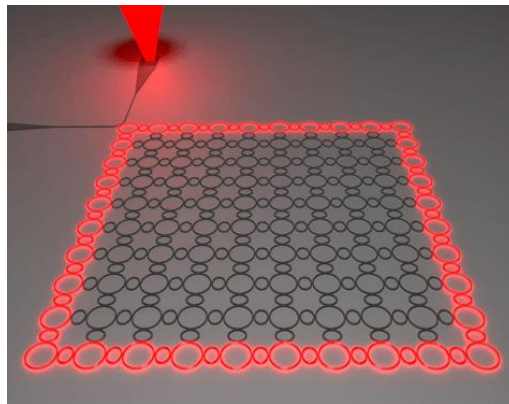
One-dimensional



Topological localized state

Nat. Photon. 11, 651 (2017)

Two-dimensional

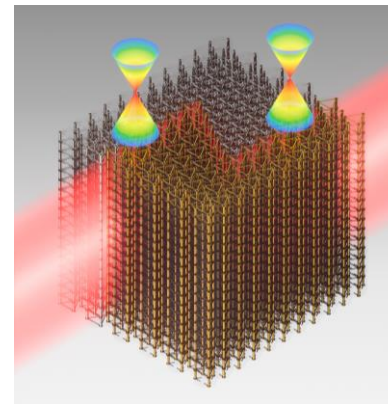


Topological edge state

Science 359, 4003 (2018)

Three-dimensional

3D topological insulator

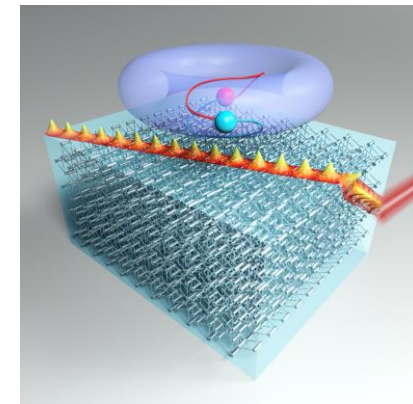


Topological surface state

Nature 565, 622 (2019)

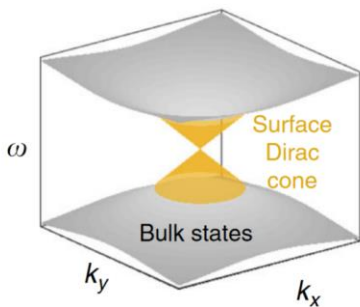
Phys. Rev. Lett. 125, 14300 (2020)

3D topological semimetal



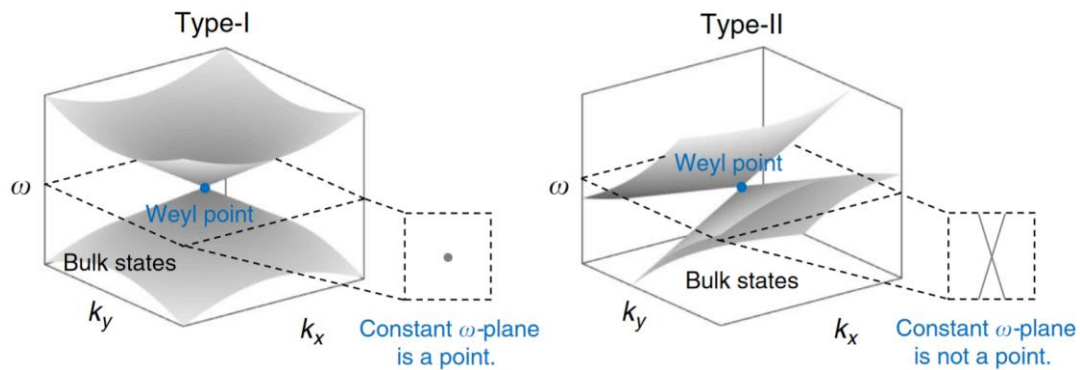
Three-dimensional topological phase classification

3D topological insulator



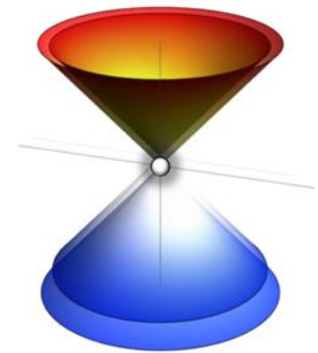
3D gapped topological phase
(3D topological insulating phases)

Weyl semimetal



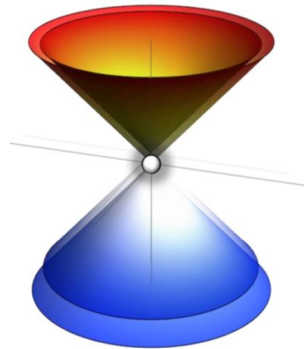
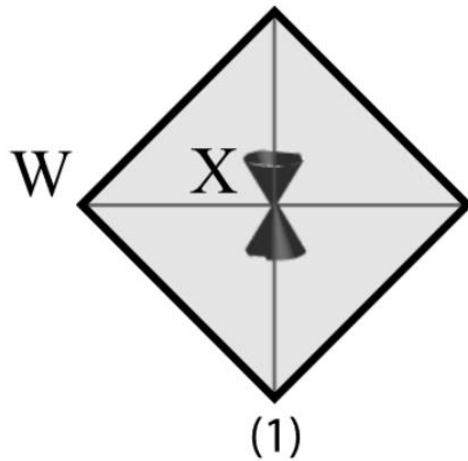
3D gapless topological phases
(3D topological semimetal phases)

Dirac semimetal



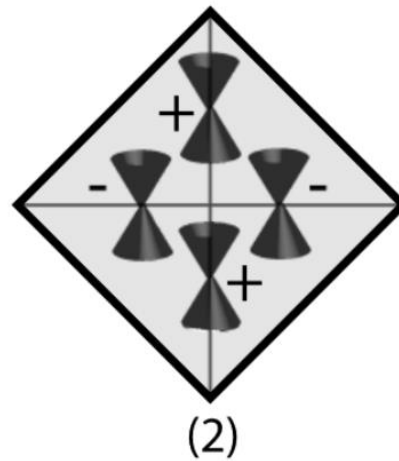
Three-dimensional topological phase transition

Dirac semimetal



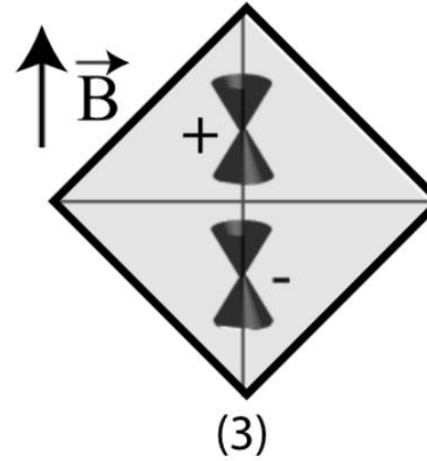
Weyl semimetal

Non-magnetic

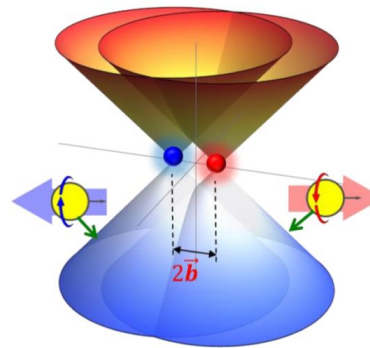


Inversion and mirror symmetry breaking

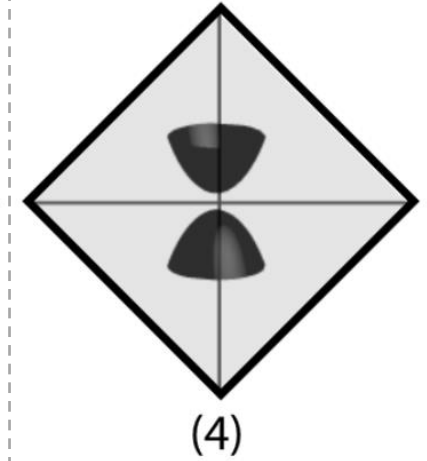
Magnetic



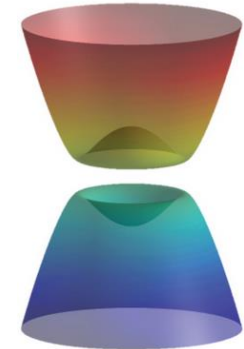
Time-reversal symmetry breaking



Topological insulator

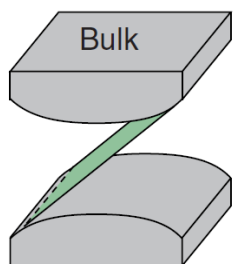


Inversion or time-reversal symmetry breaking



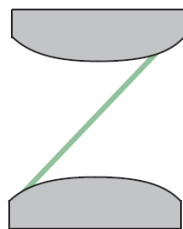
Three-dimensional photonic topological insulator phases

T-breaking 3D topological phases



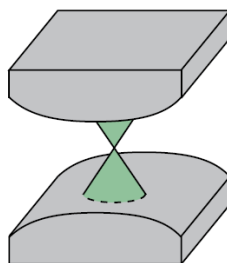
3D Chern crystal
($C^{(1)}, C^{(1)}, C^{(1)}$)
surface sheets

Nature (2022)



One-way fiber
 $C^{(2)}$
dislocation mode

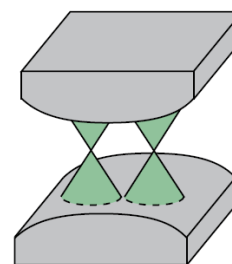
Nat. Commun (2018)



Single surface
Dirac cone
(strong phase, Z_2)
($\nu_0 = 1; \nu_1 \nu_2 \nu_3$)

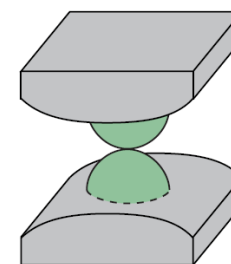
Nat. Phys (2016)

T-invariant 3D topological phases



Two surface Dirac cones
(weak phase)
($\nu_0 = 0; \nu_1 \nu_2 \nu_3$)

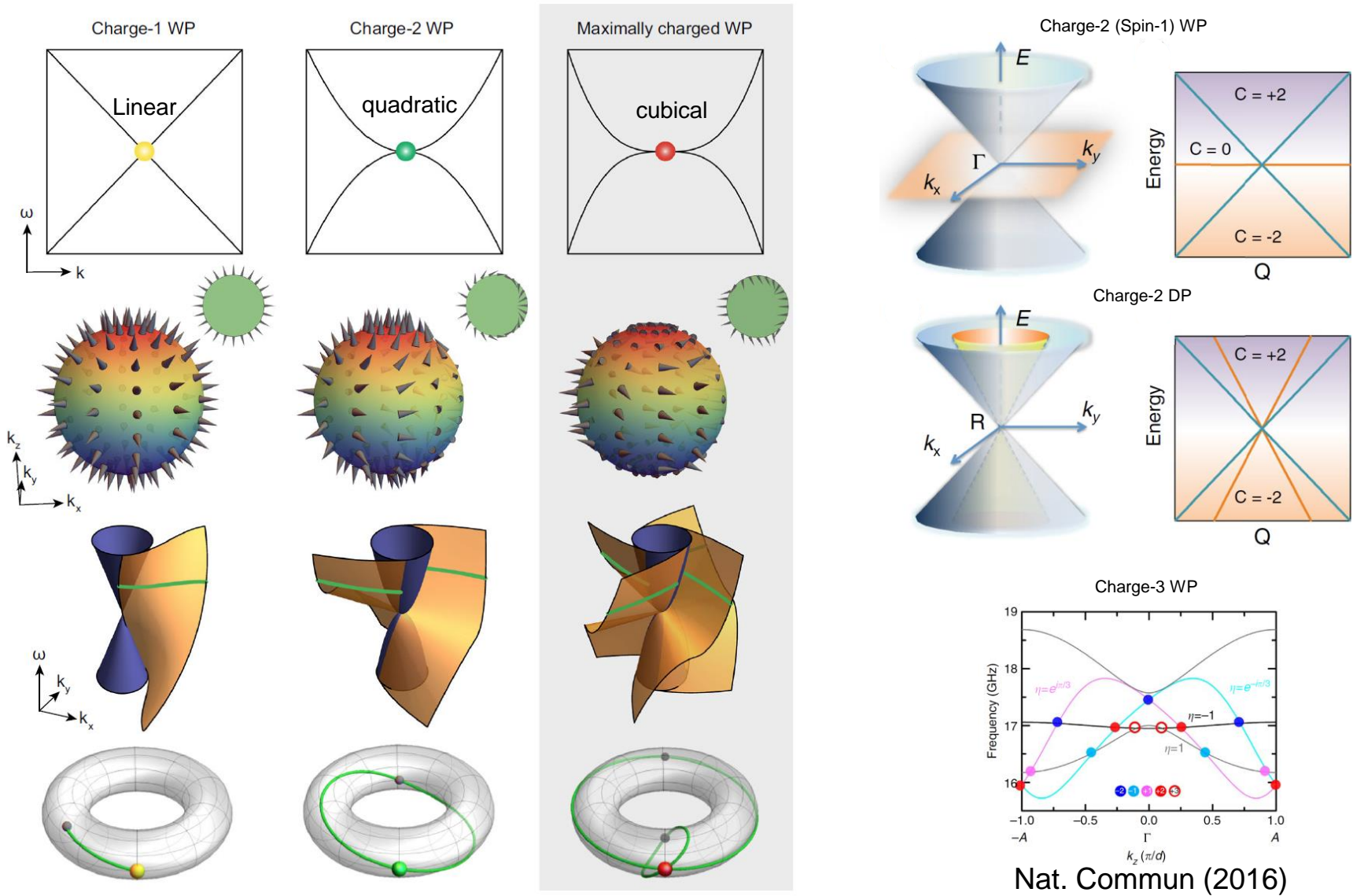
Nature (2019)



Quadratic degeneracies
(Z_2)

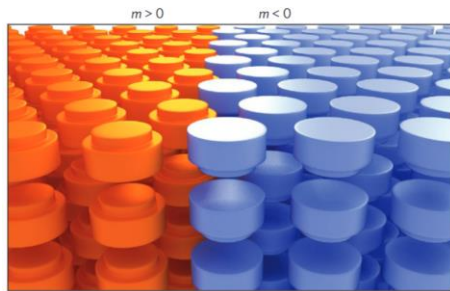
Nat. Commun (2021)

Three-dimensional photonic topological semimetal phases

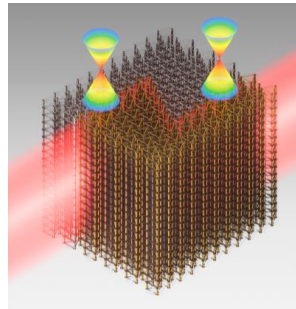
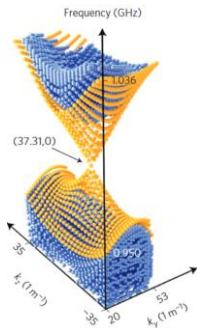


Milestones of three-dimensional topological photonic phases

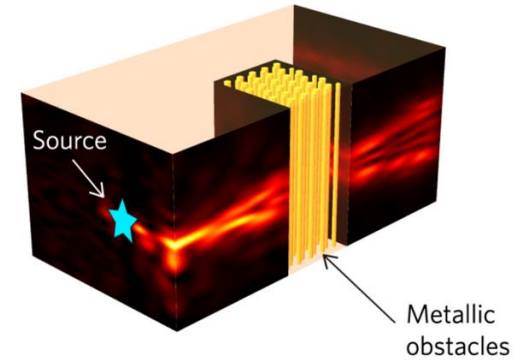
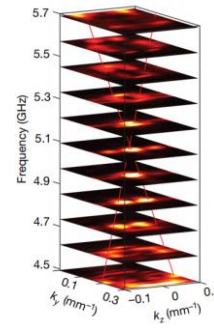
3D topological insulator phase



Nat. Photon. 11, 130–136 (2017)

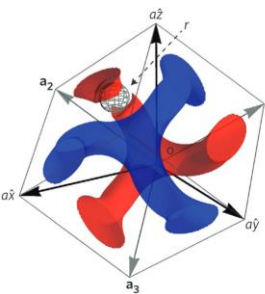


Nature 565, 622 (2019)

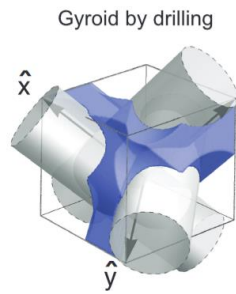
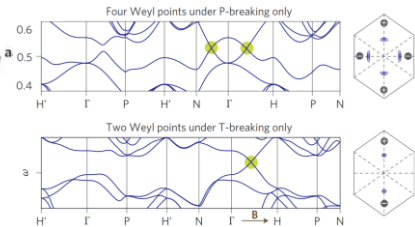


Nature 609, 925–930 (2022)

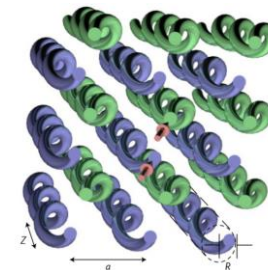
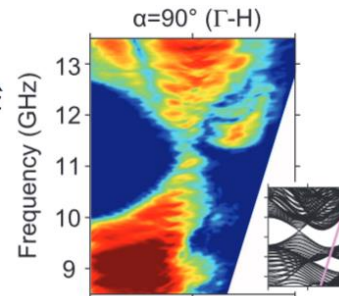
3D topological semimetal phase



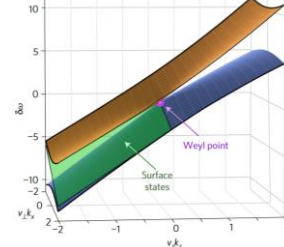
Nat. Photon. 7, 294-299 (2013)



Science 349, 6248 (2015)



Nat. Phys. 13, 611–617 (2017)



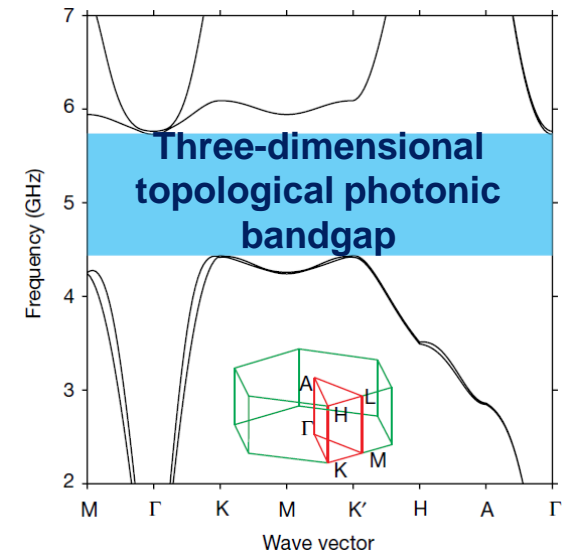
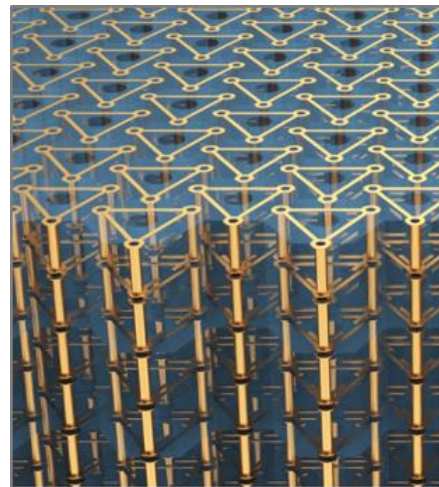
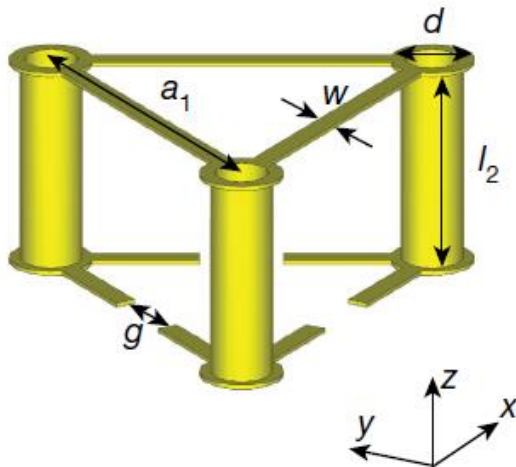
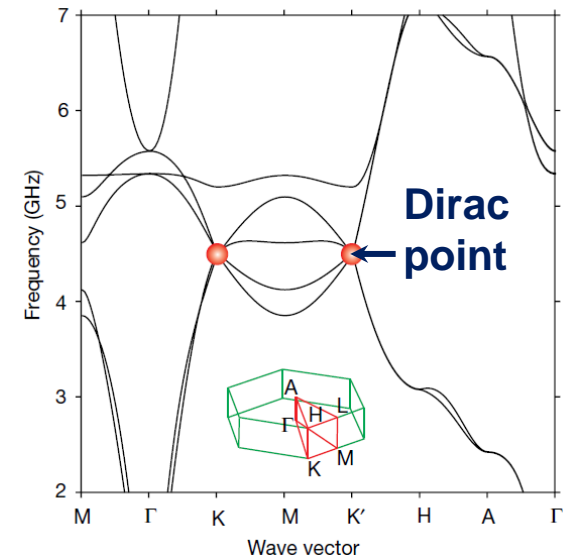
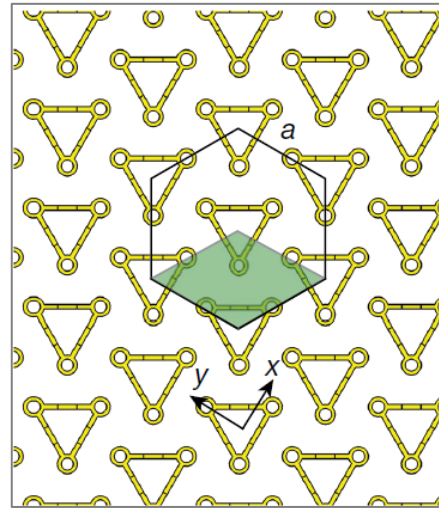
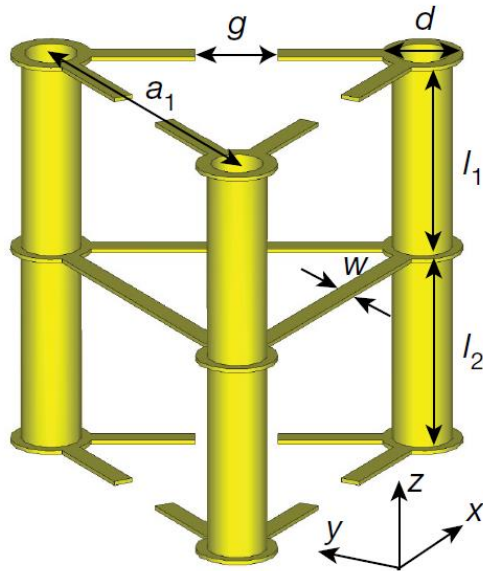
Outline

Part I: Introduction

Part II: Reciprocal three-dimensional photonic topological phases

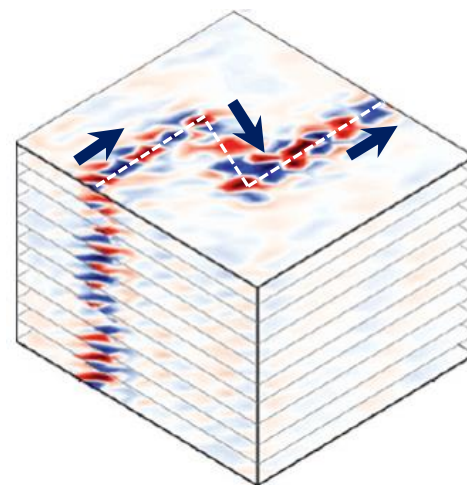
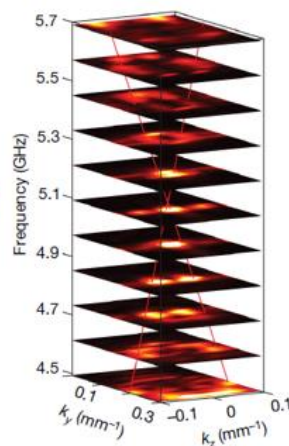
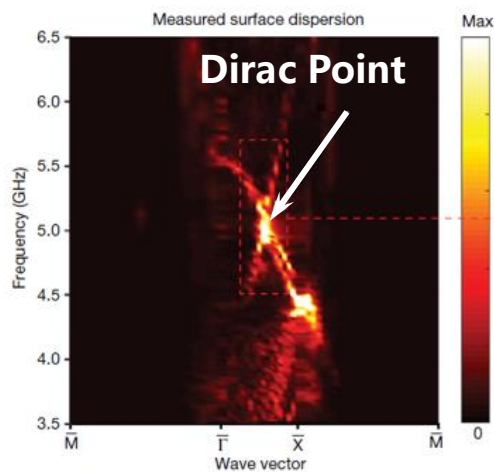
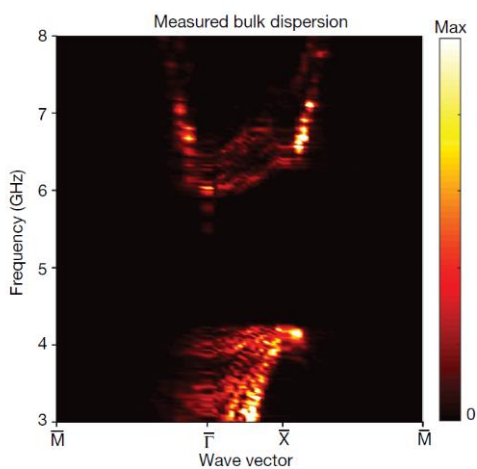
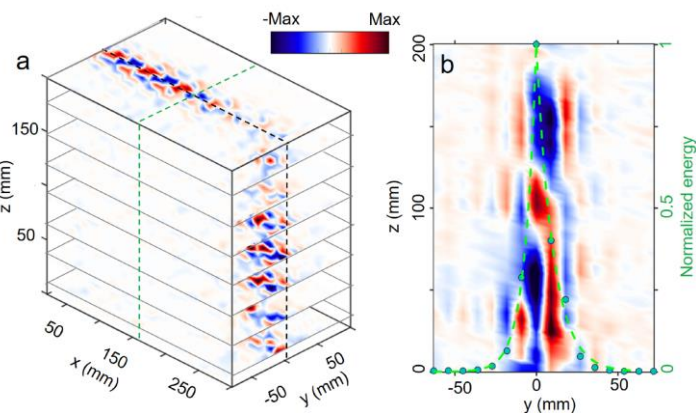
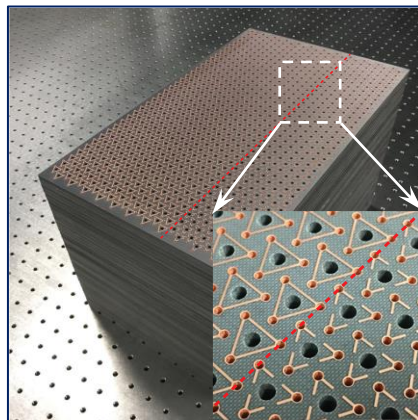
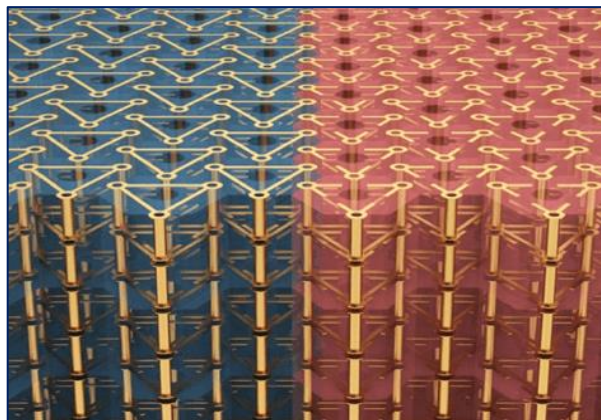
Part III: Nonreciprocal three-dimensional photonic topological phases

Realization of a three-dimensional photonic topological insulator



Nature 565, 622-626 (2019)

Dirac-cone-like photonic topological surface states



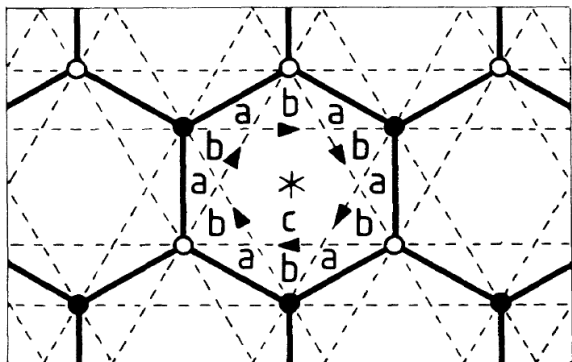
Outline

Part I: Introduction

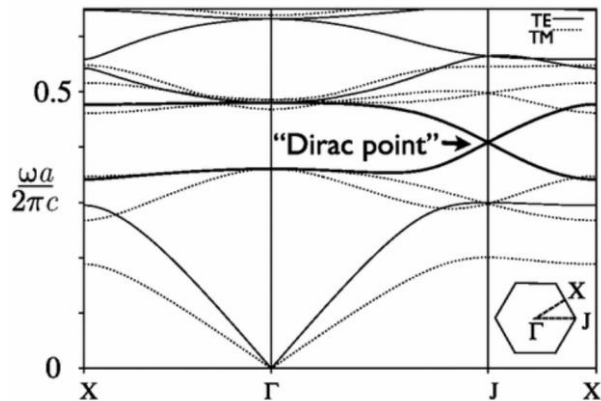
Part II: Reciprocal three-dimensional photonic topological phases

Part III: Nonreciprocal three-dimensional photonic topological phases

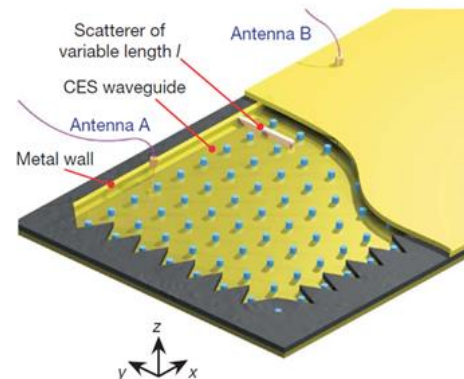
Two-dimensional nonreciprocal topological photonics



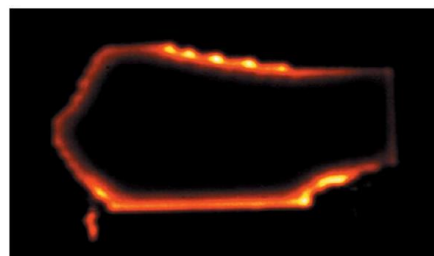
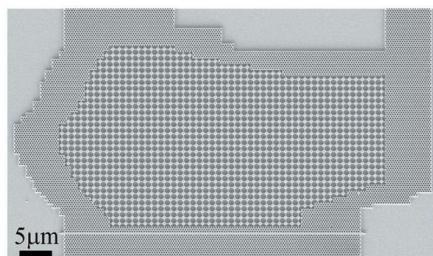
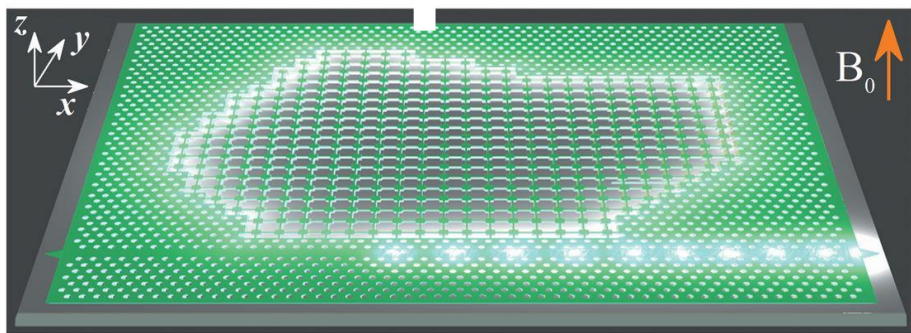
Phys. Rev. Lett. 61, 2015 (1988)



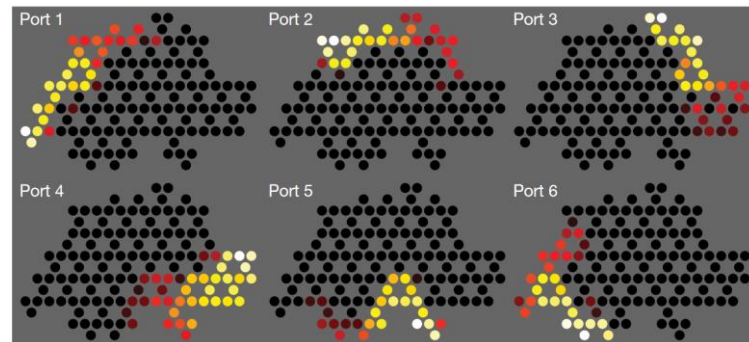
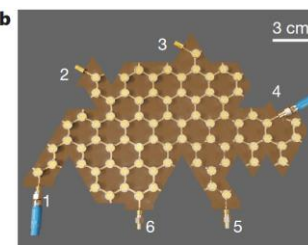
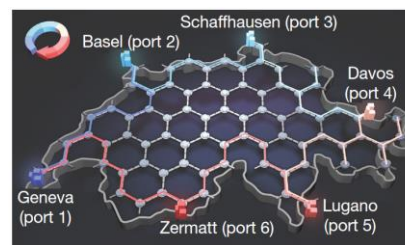
Phys. Rev. Lett. 100, 013904 (2008)



Nature 461, 772–775 (2009)

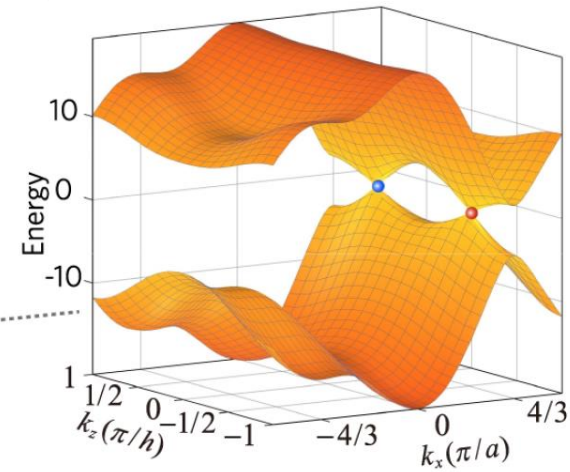
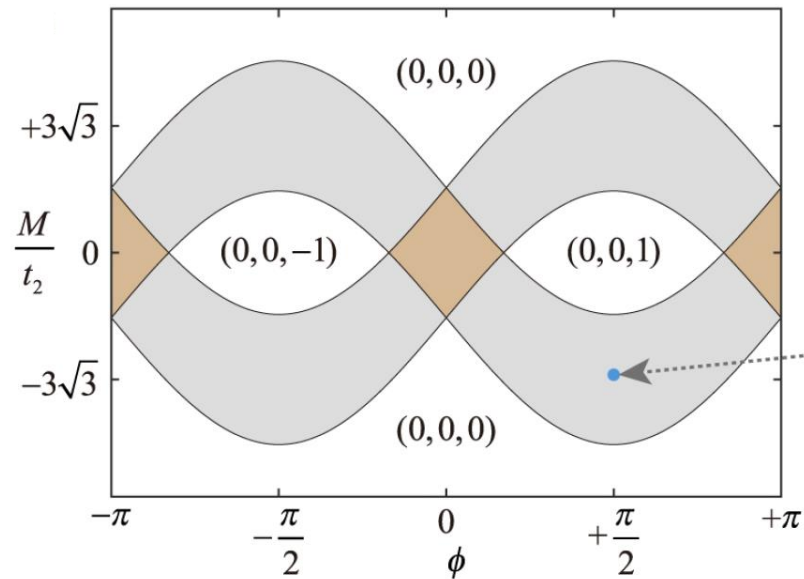
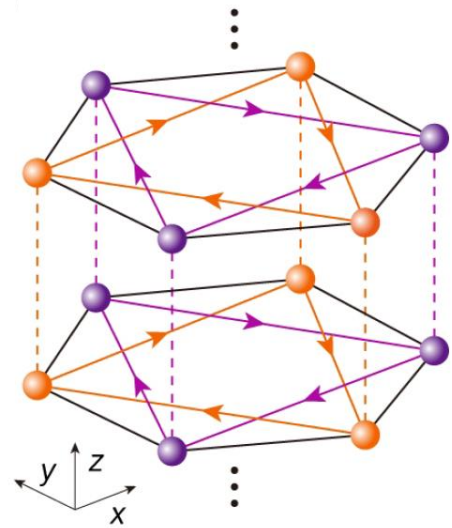


Science 358, 636-640 (2017)



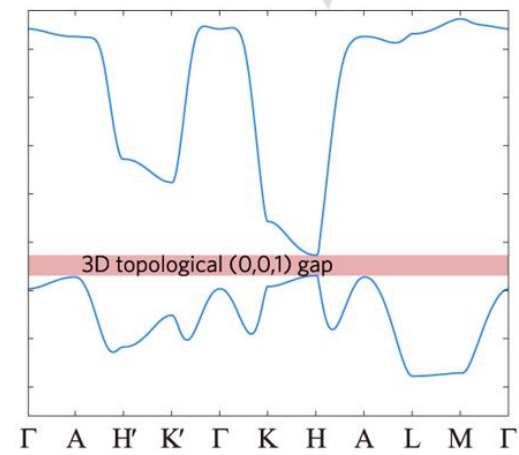
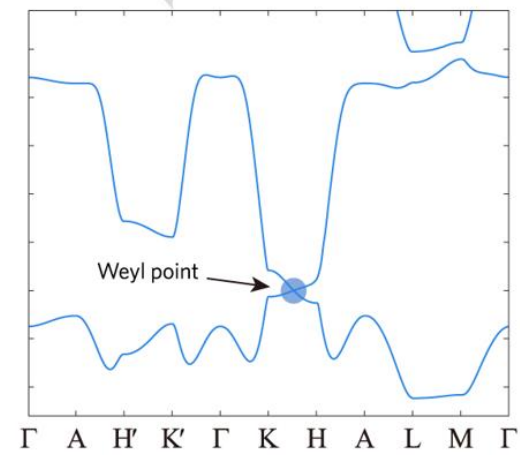
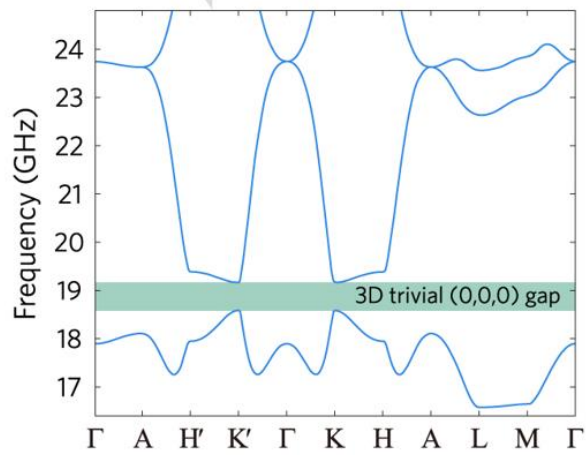
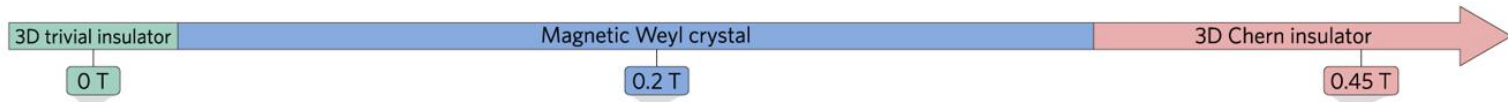
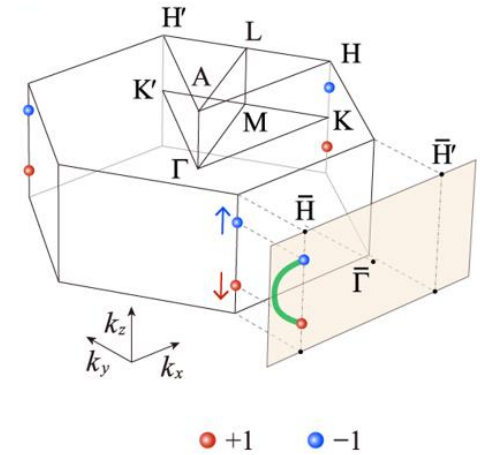
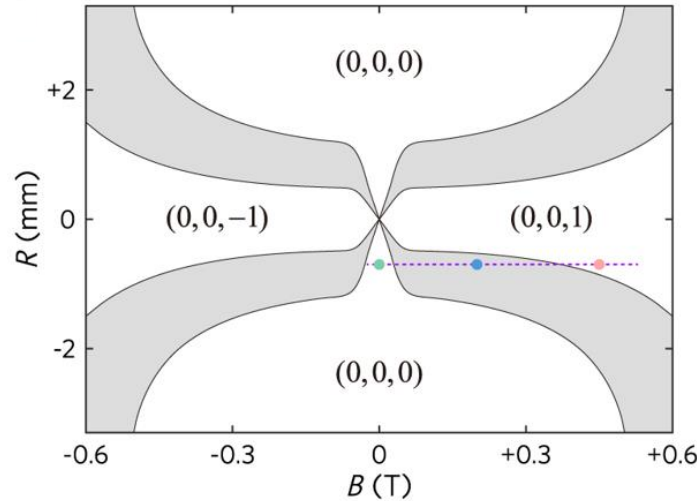
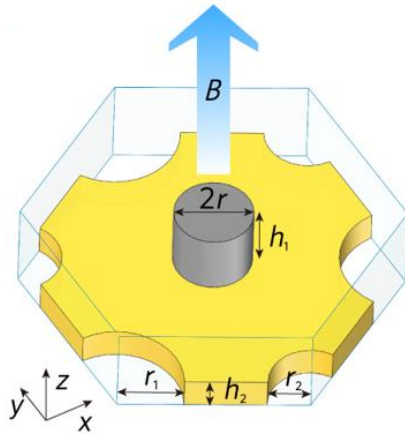
Nature 598, 293–297 (2021)

Three-dimensional Haldane model

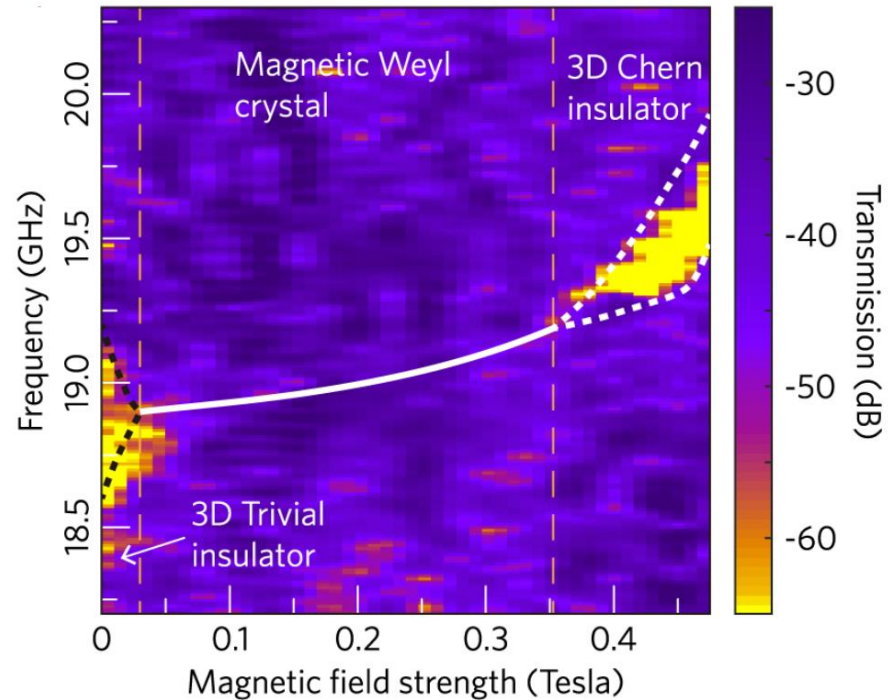
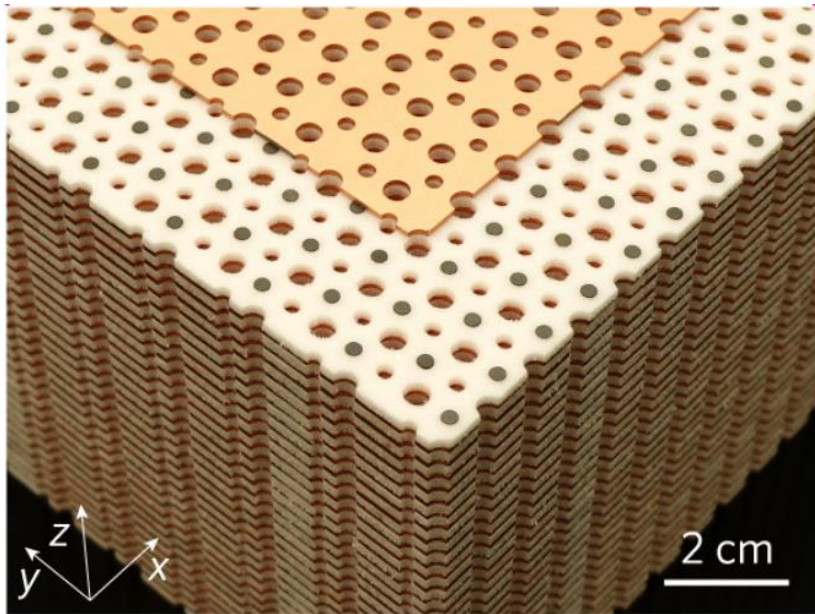


● +1 ● -1

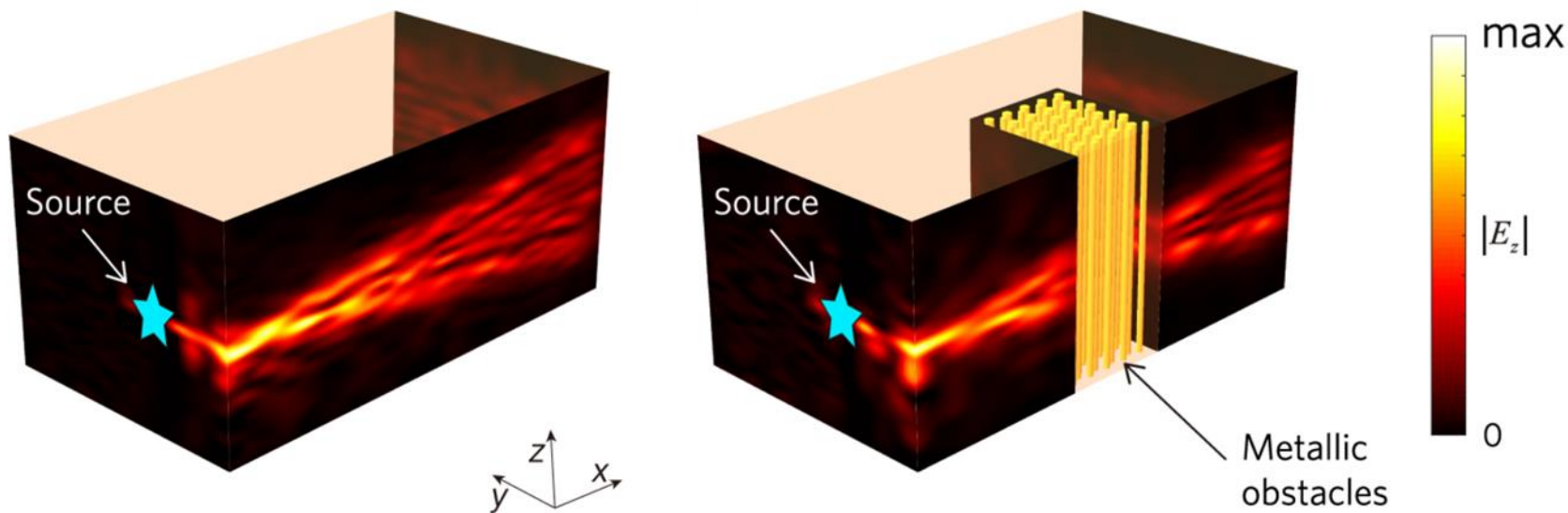
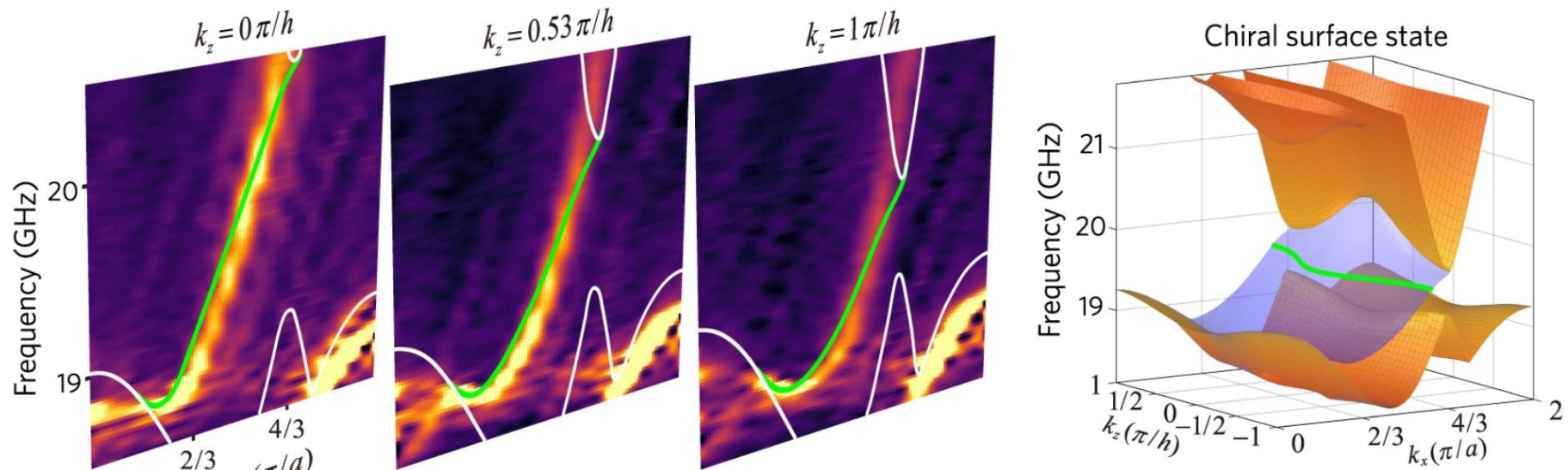
Three-dimensional photonic Chern insulator



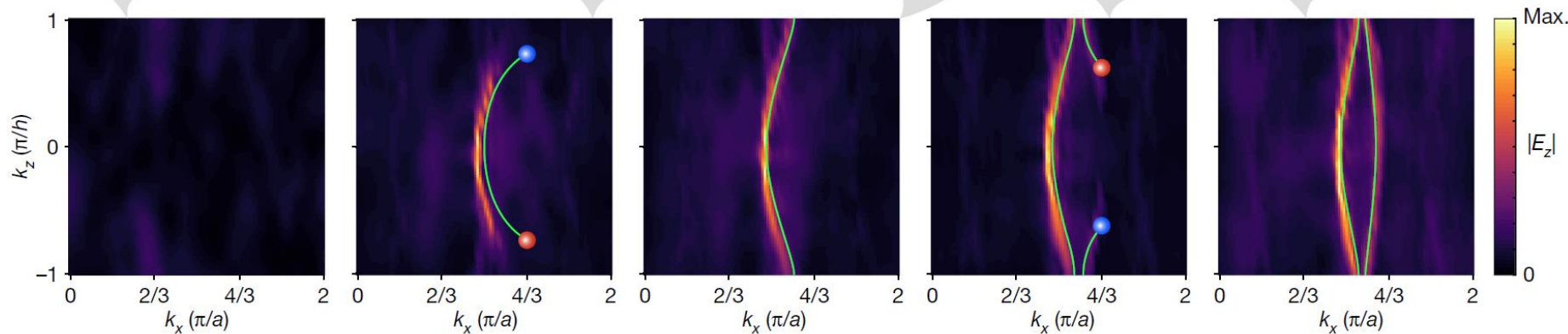
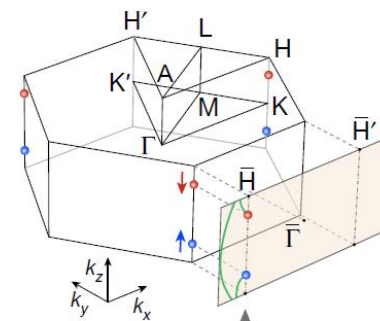
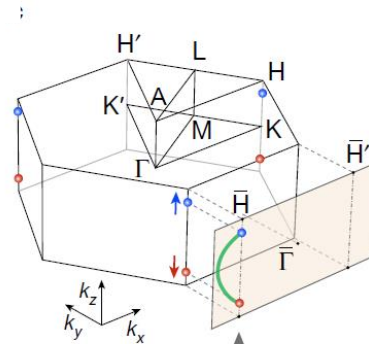
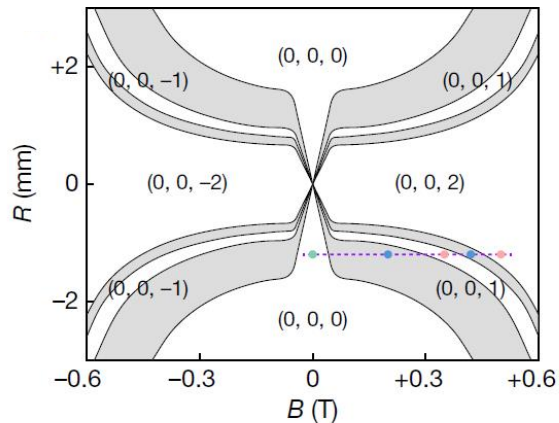
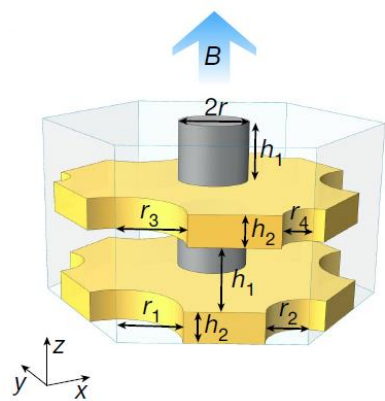
Topological phase transition in a 3D magnetic photonic crystals



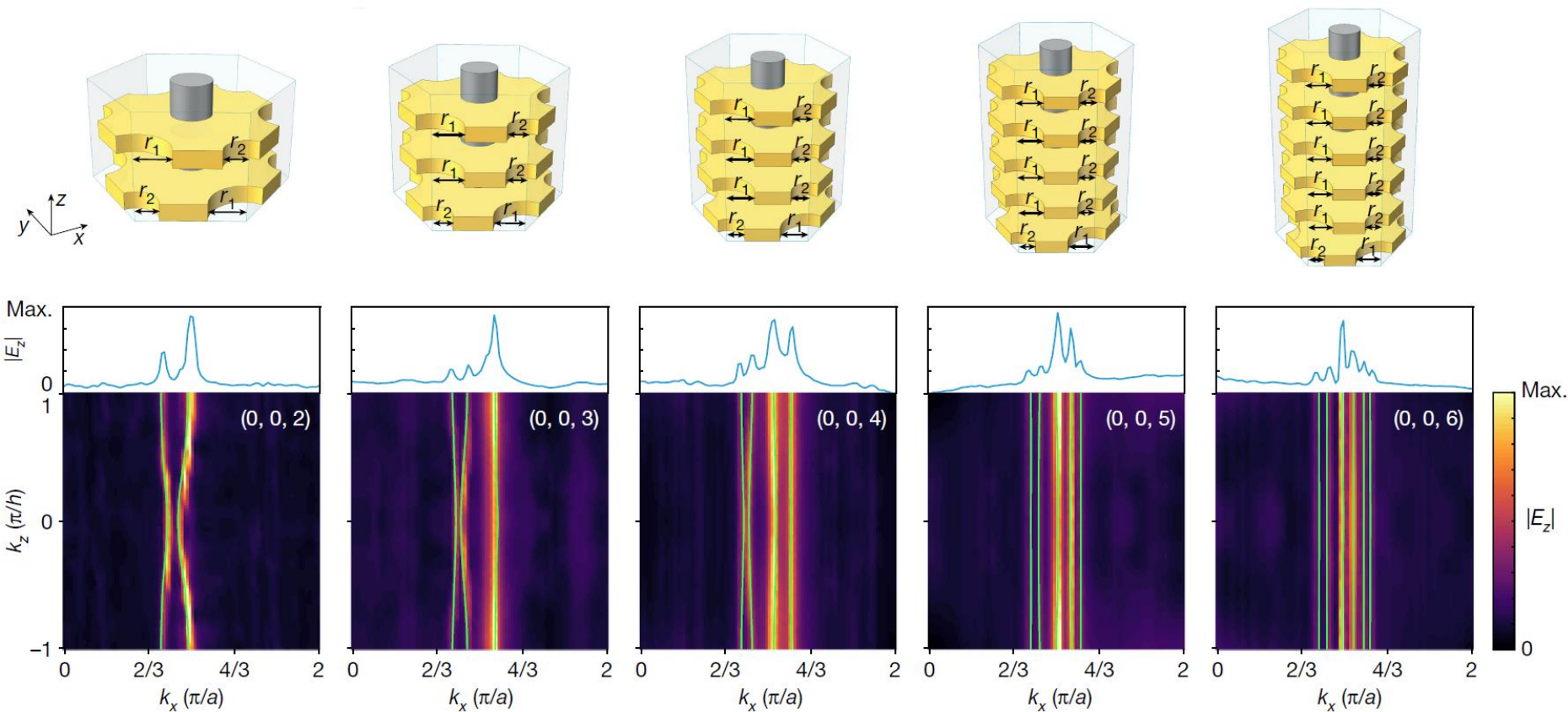
Topological chiral surface states



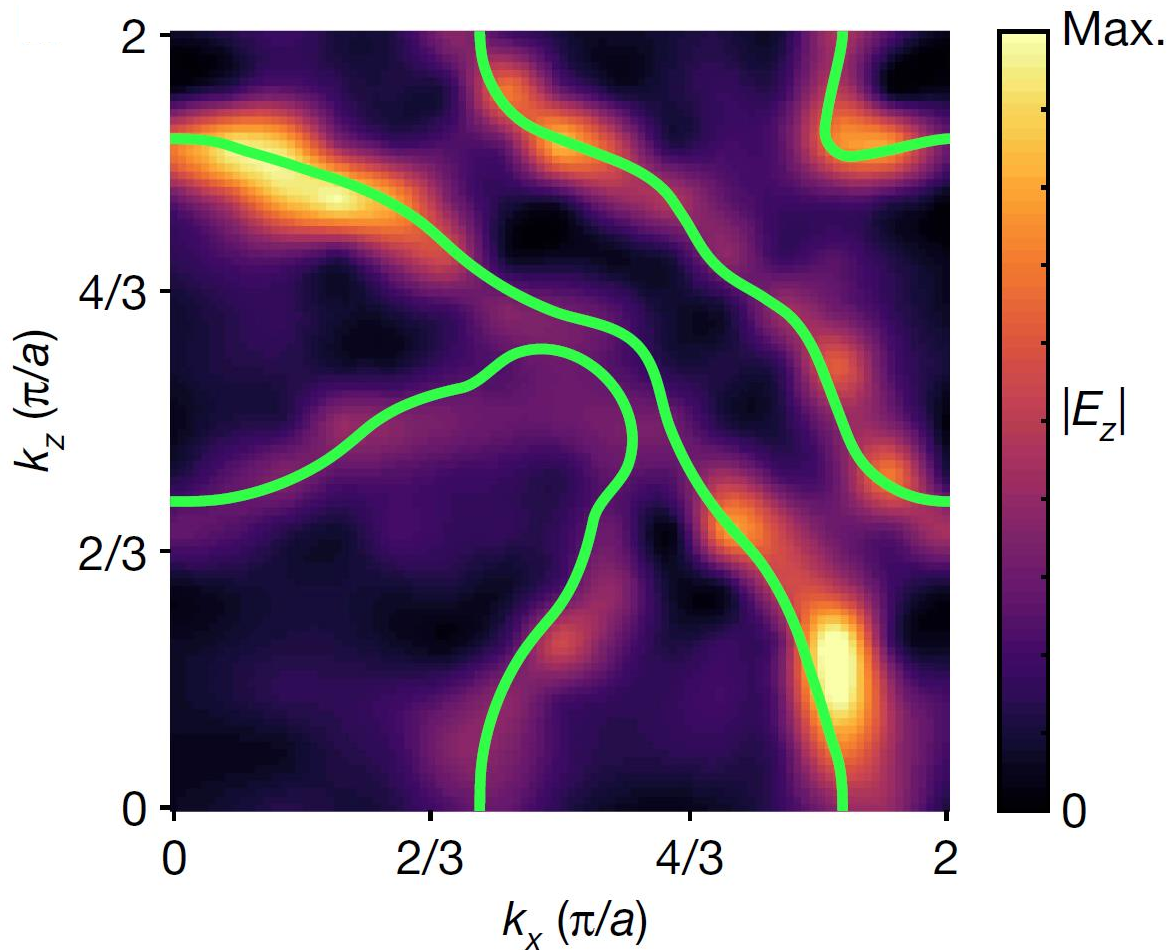
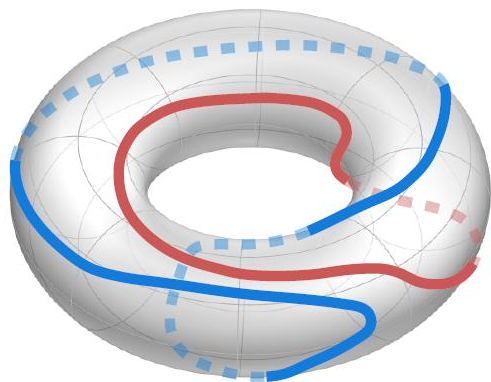
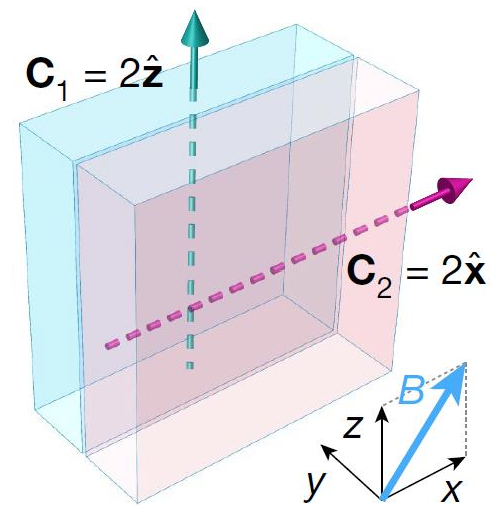
Large Chern vector



Arbitrary large Chern vector

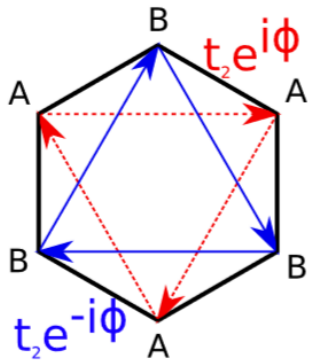


Topological Hopf link surface states

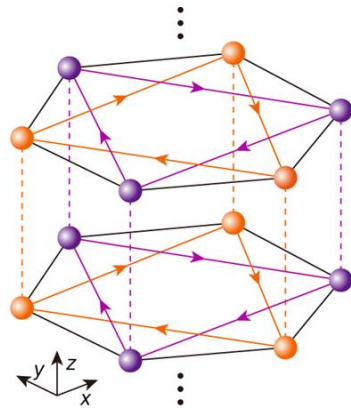


Classification of nonreciprocal topological photonic phases

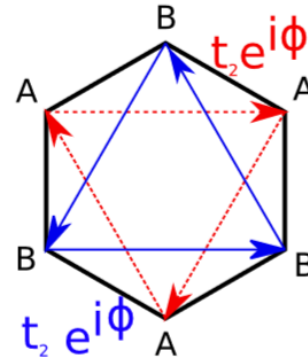
2D Haldane model



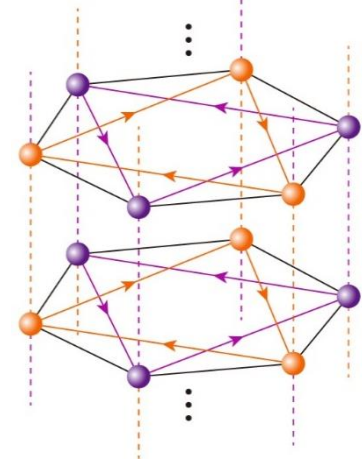
3D Haldane model



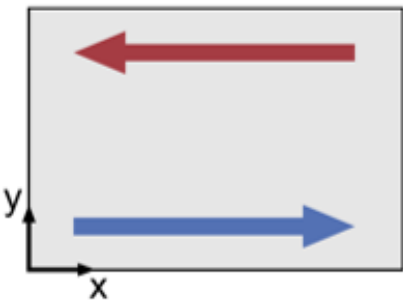
2D modified Haldane model



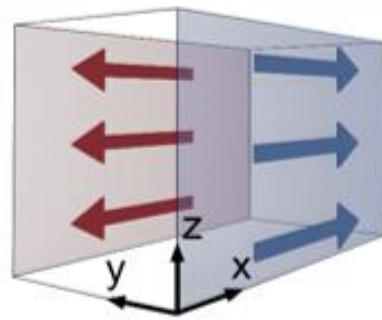
3D modified Haldane model



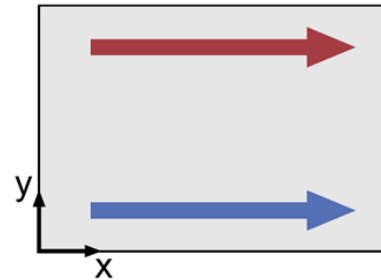
Chiral edge states



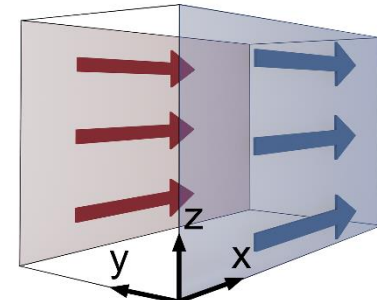
Chiral surface states



Antichiral edge states



Antichiral surface states



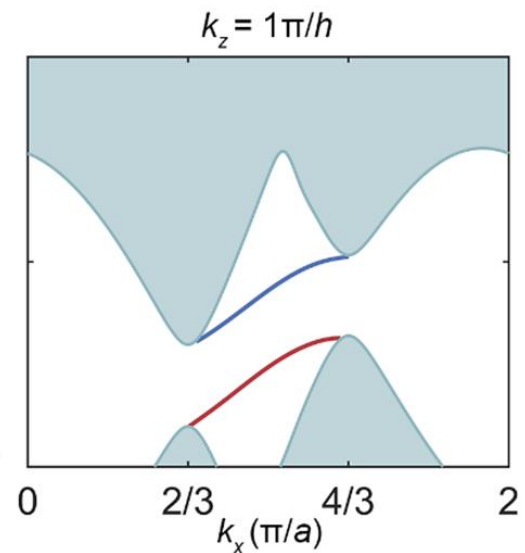
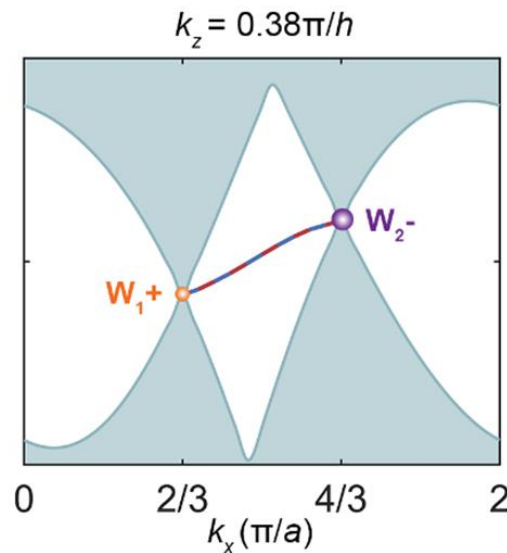
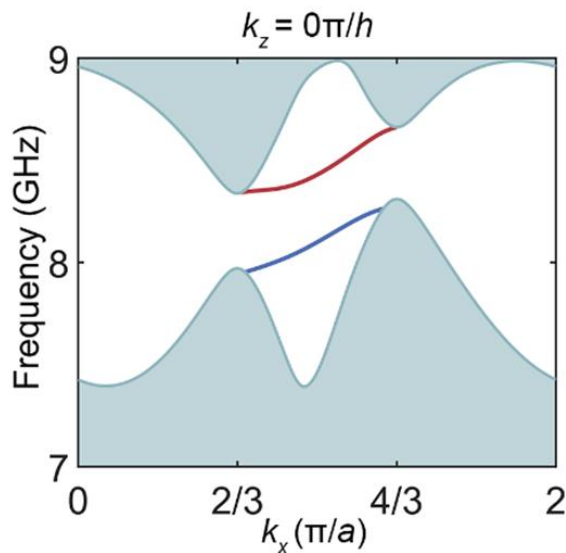
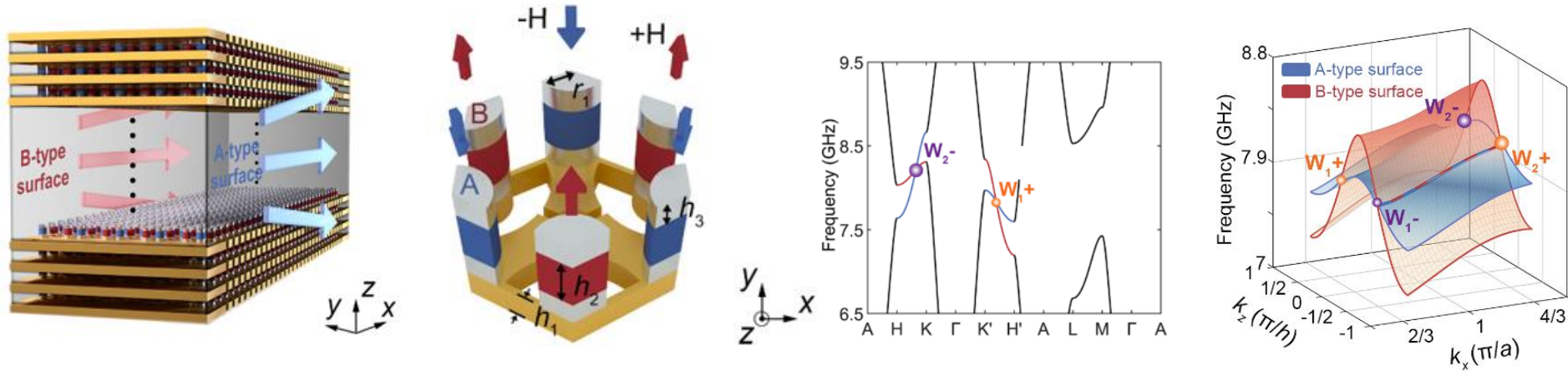
Phys. Rev. Lett. 100, 013904 (2008)
Nature 461, 7265 (2009)

Nature 609, 925–930 (2022)

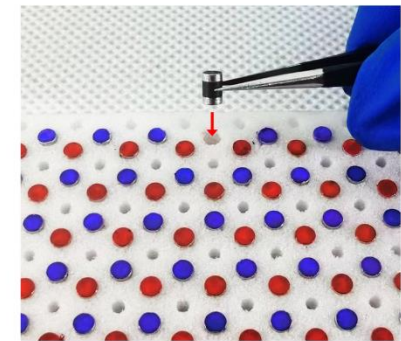
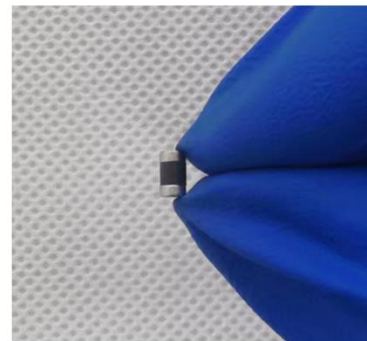
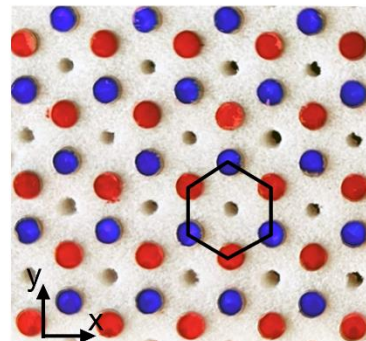
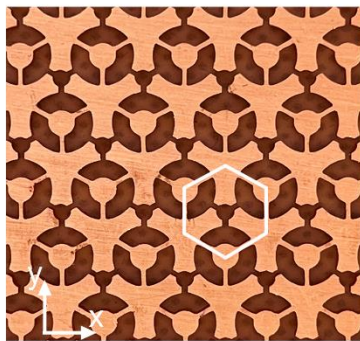
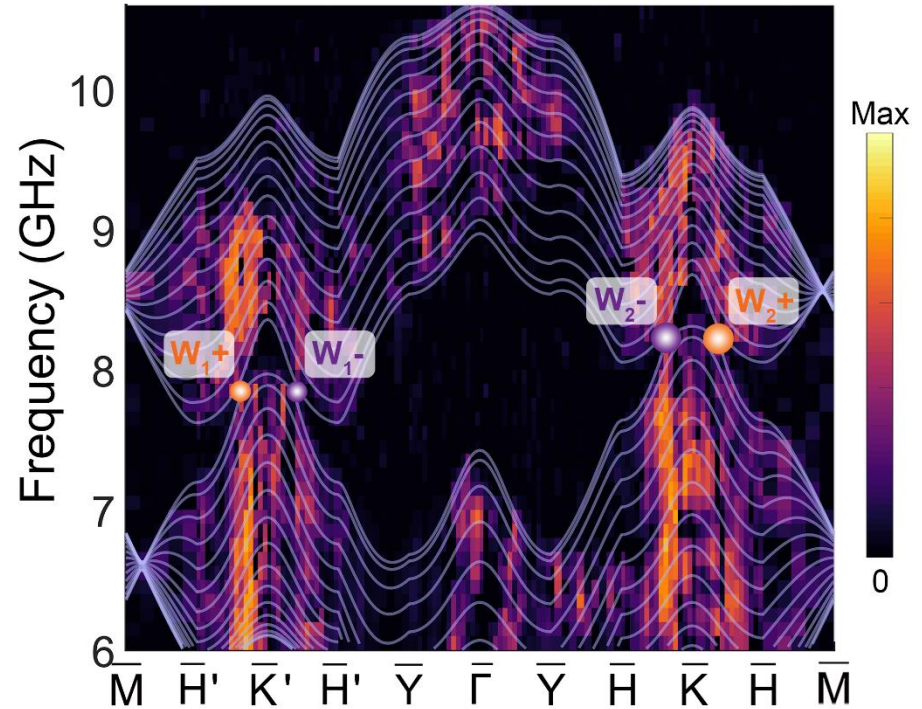
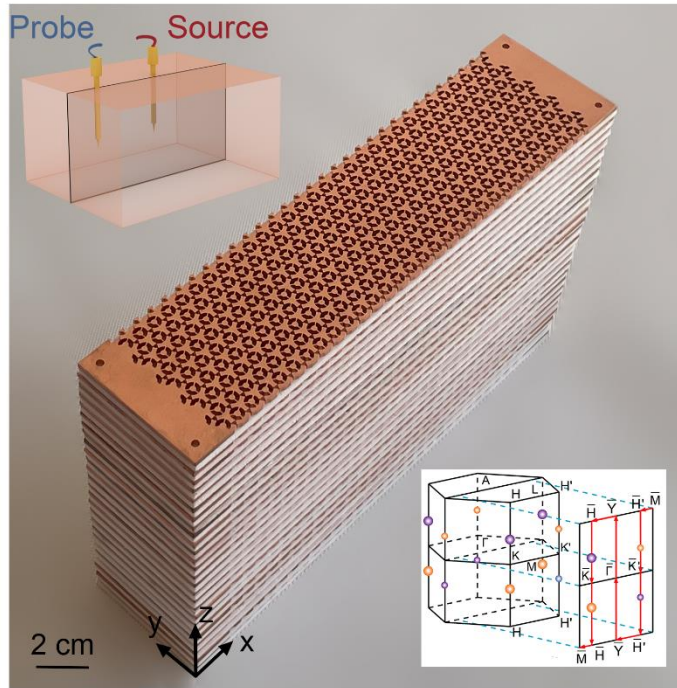
Phys. Rev. Lett. 120, 086603 (2018)
Phys. Rev. Lett. 125, 263603 (2020)

Nat. Commun. 14, 1991 (2023)

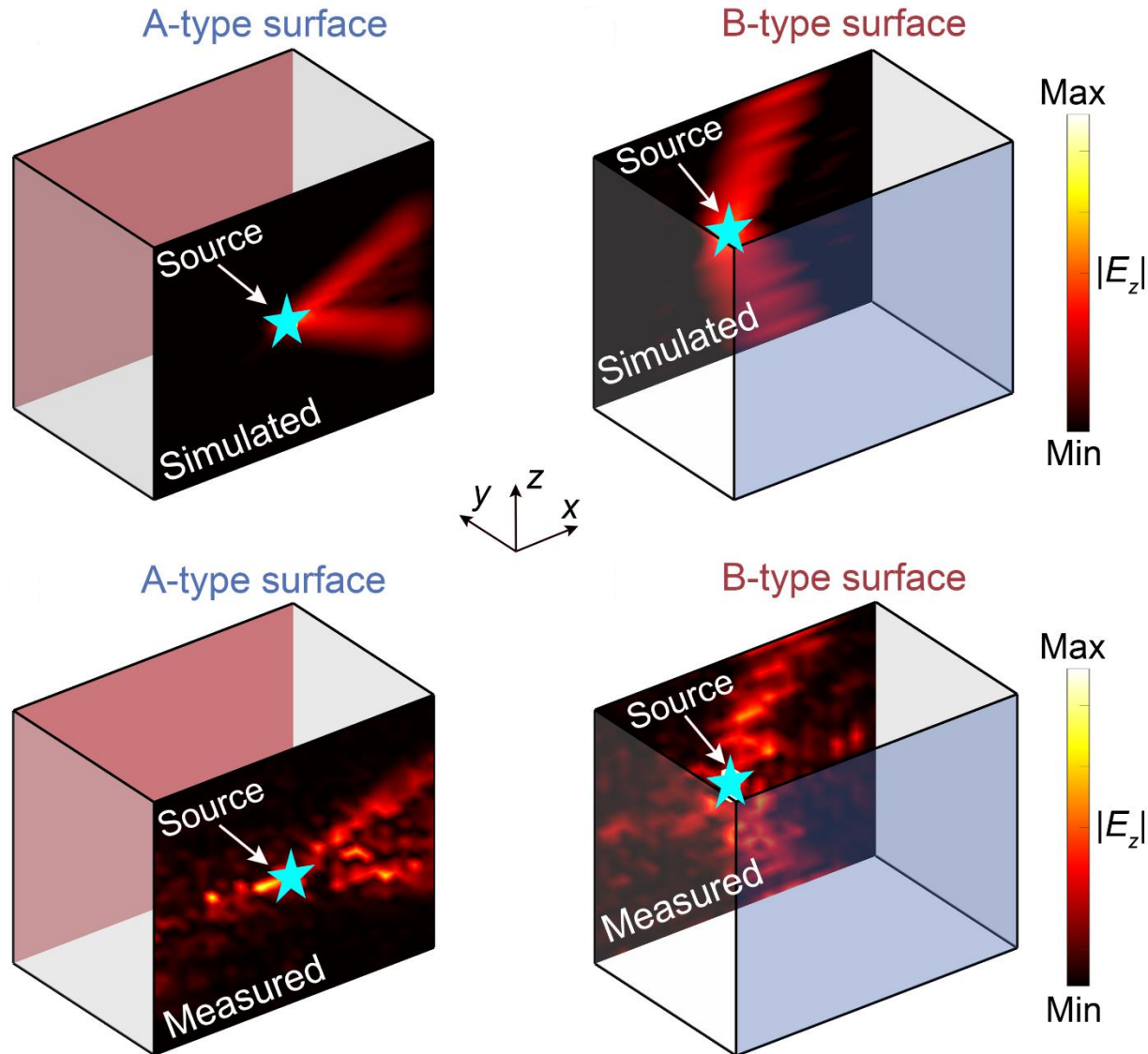
Topological antichiral surface states in a magnetic Weyl photonic crystal



Frequency-shifted Weyl points

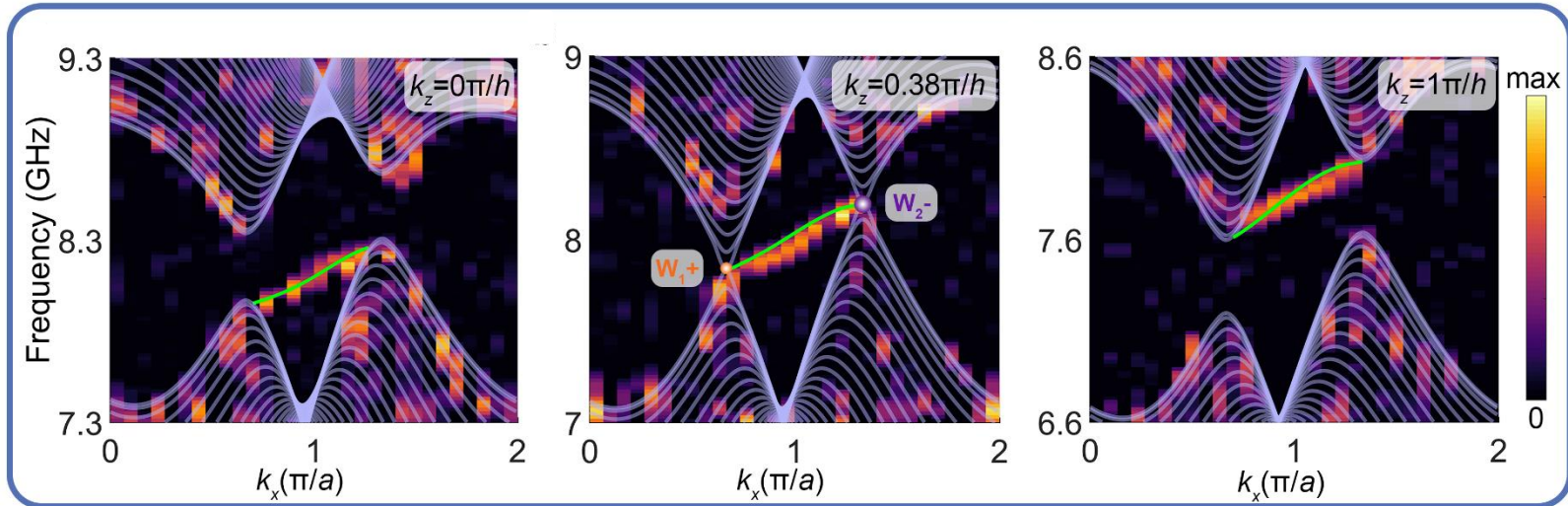


Topological antichiral surface states in a magnetic Weyl photonic crystal

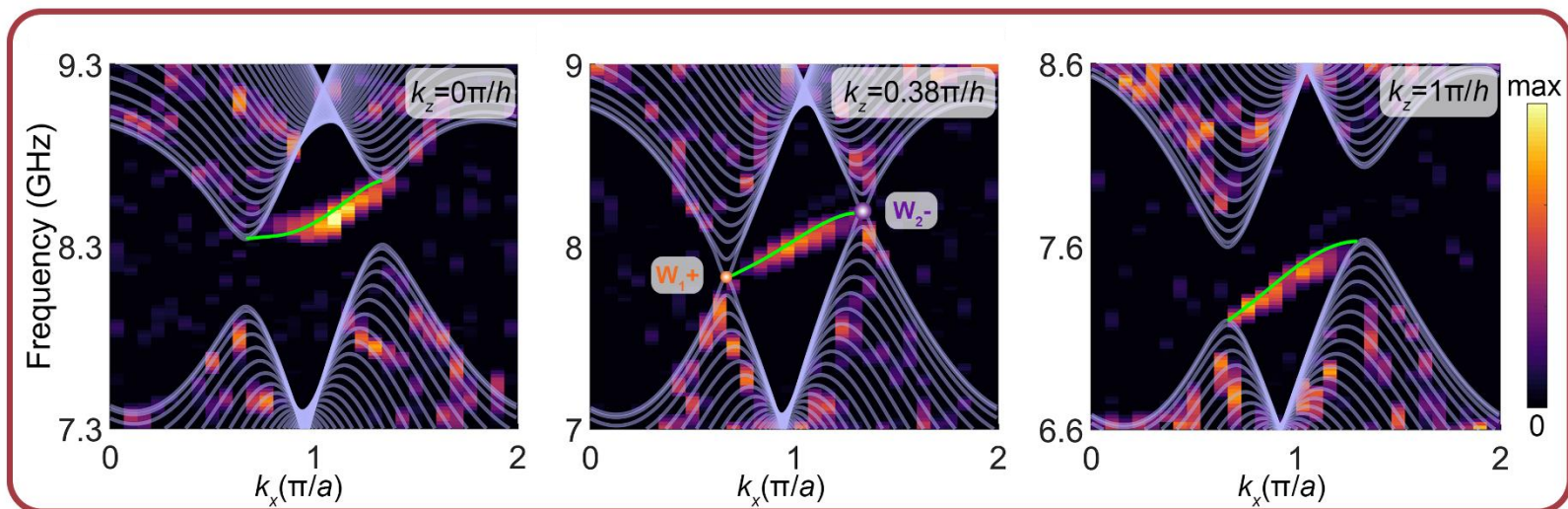


Tilted dispersions of topological antichiral surface states

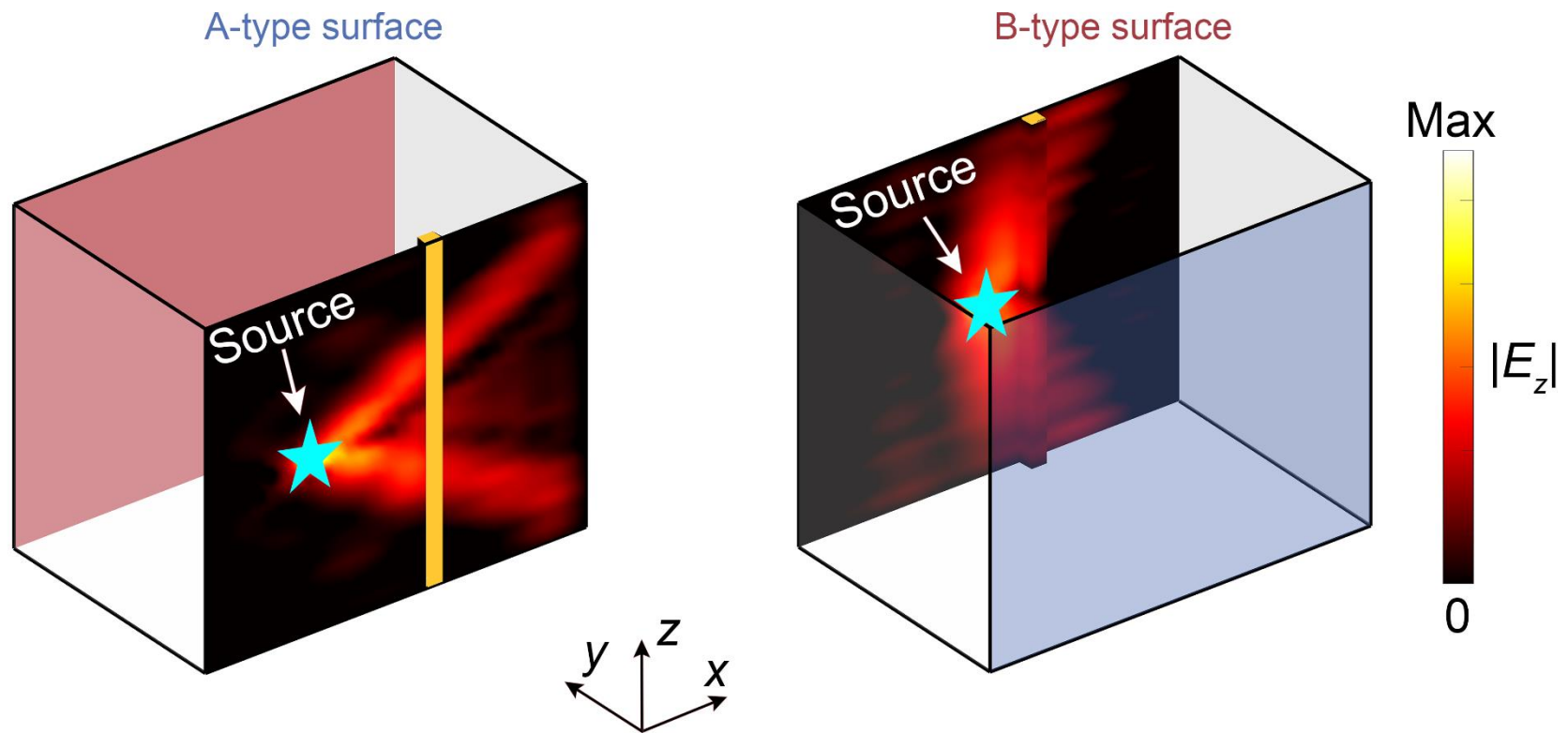
A-type surface



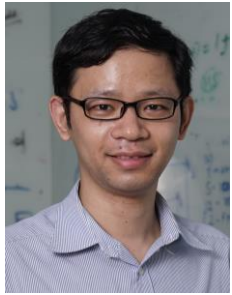
B-type surface



Robustness of topological antichiral surface states



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Prof. F. Gao



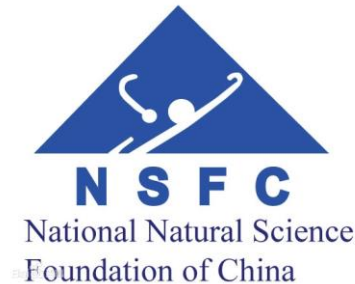
Prof. G. G. Liu



Dr. X. Xi



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Thanks