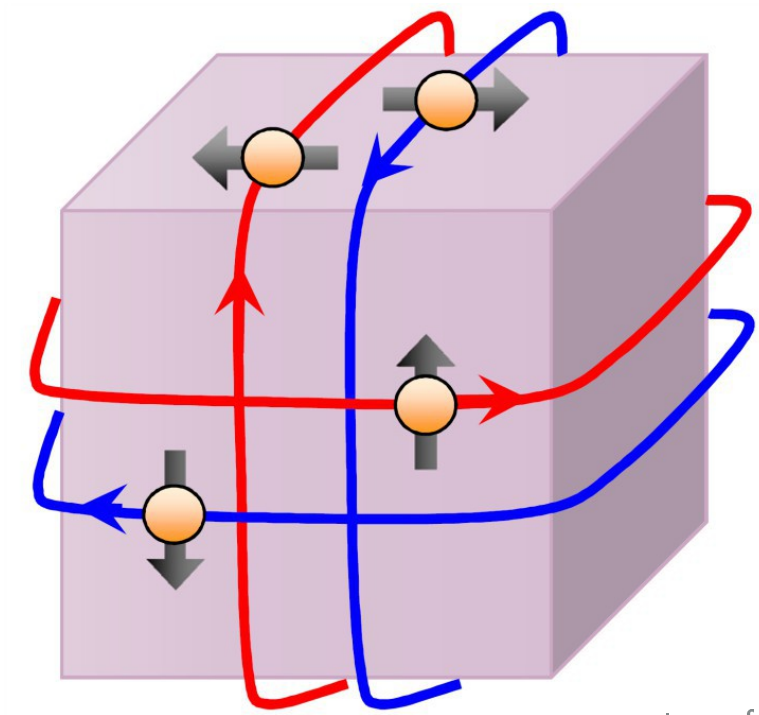
Topological insulators go 3D

bulk-boundary correspondence



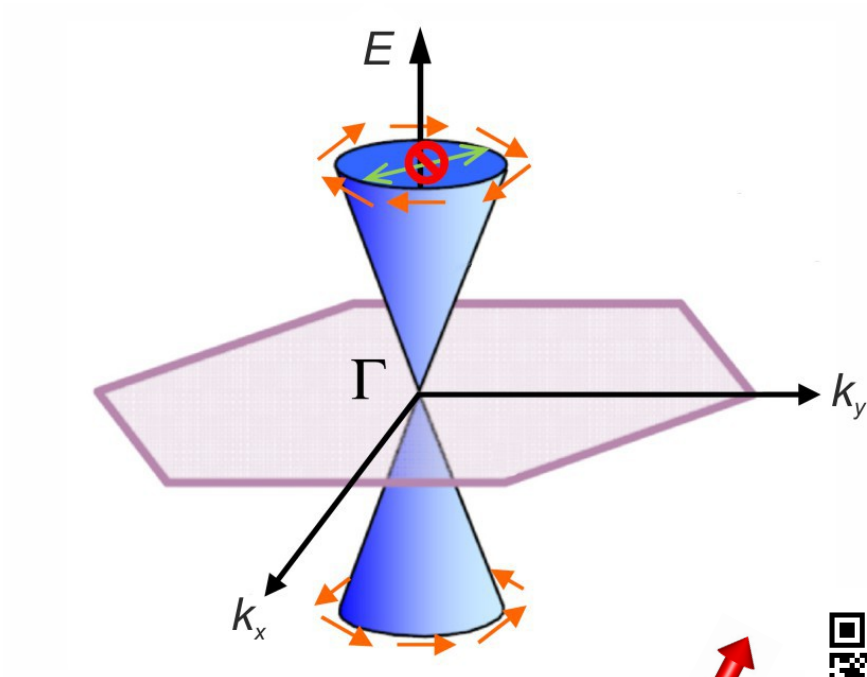
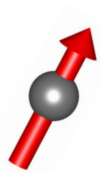
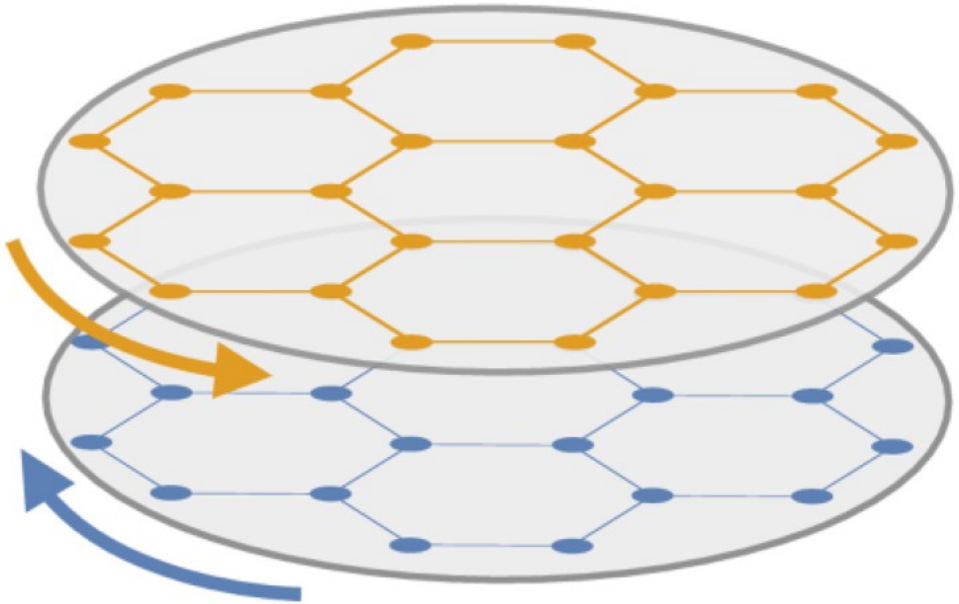


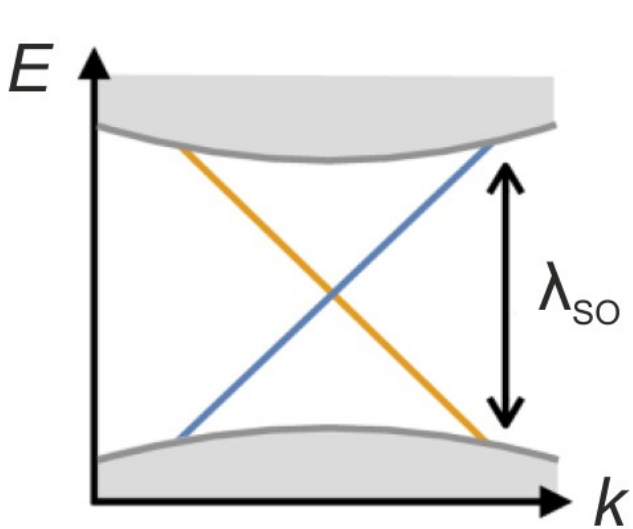
Image from J. Phys. Soc. Jpn. 82, 102001 (2013)



by Alexander Tsirlin, Leipzig University

Lecture 10: November 19, 2024





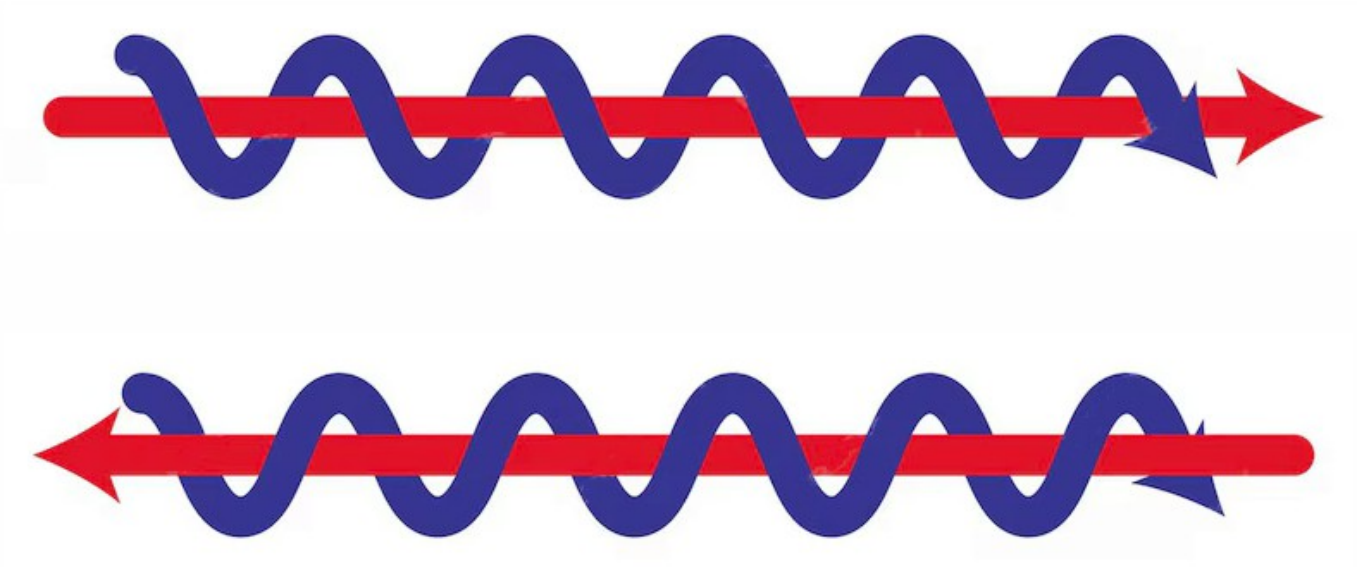
First model of a topological insulator: Kane and Mele (2005)

Topological invariant ($\mathbb{Z}_2$): Fu and Kane (2007)

Extension to 3D: Fu, Kane, and Mele (2007)

Image from Phys. Rev. Research 2, 033071 (2020)

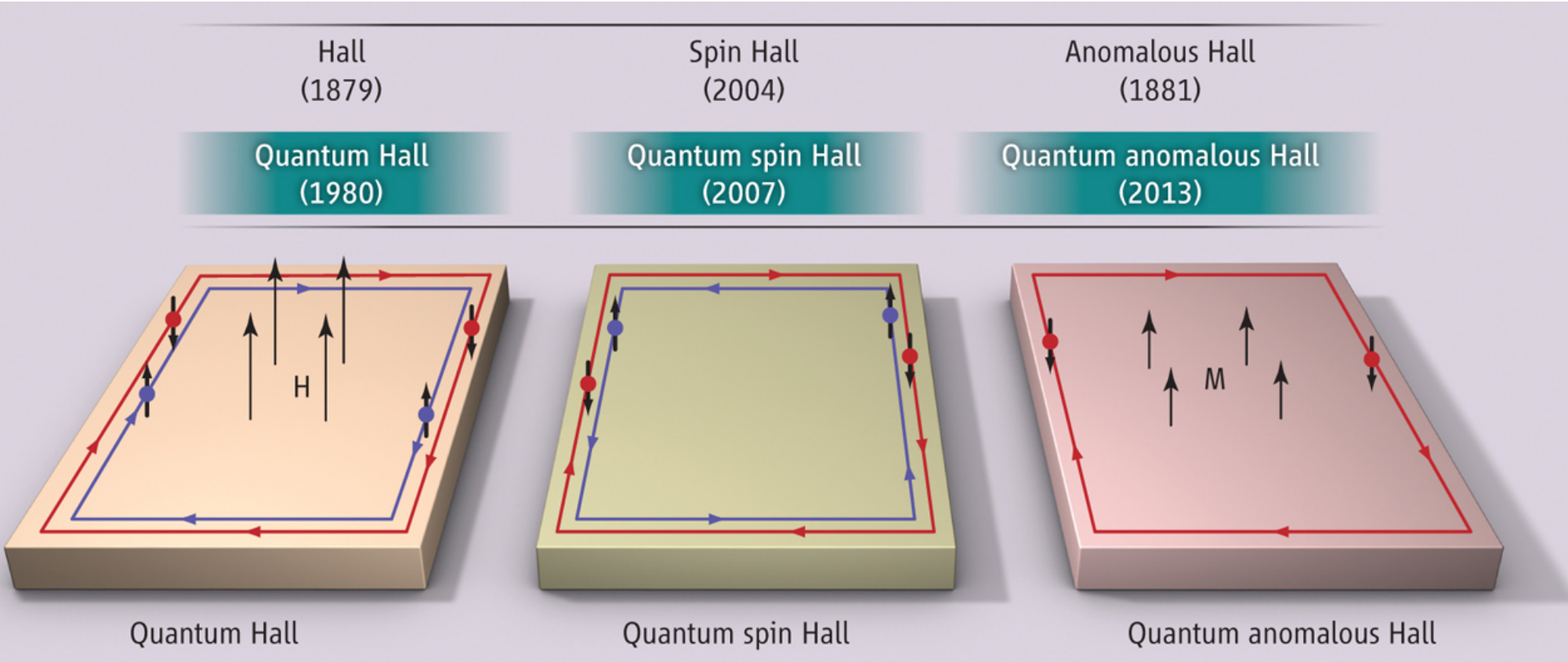
Chiral (helical) states



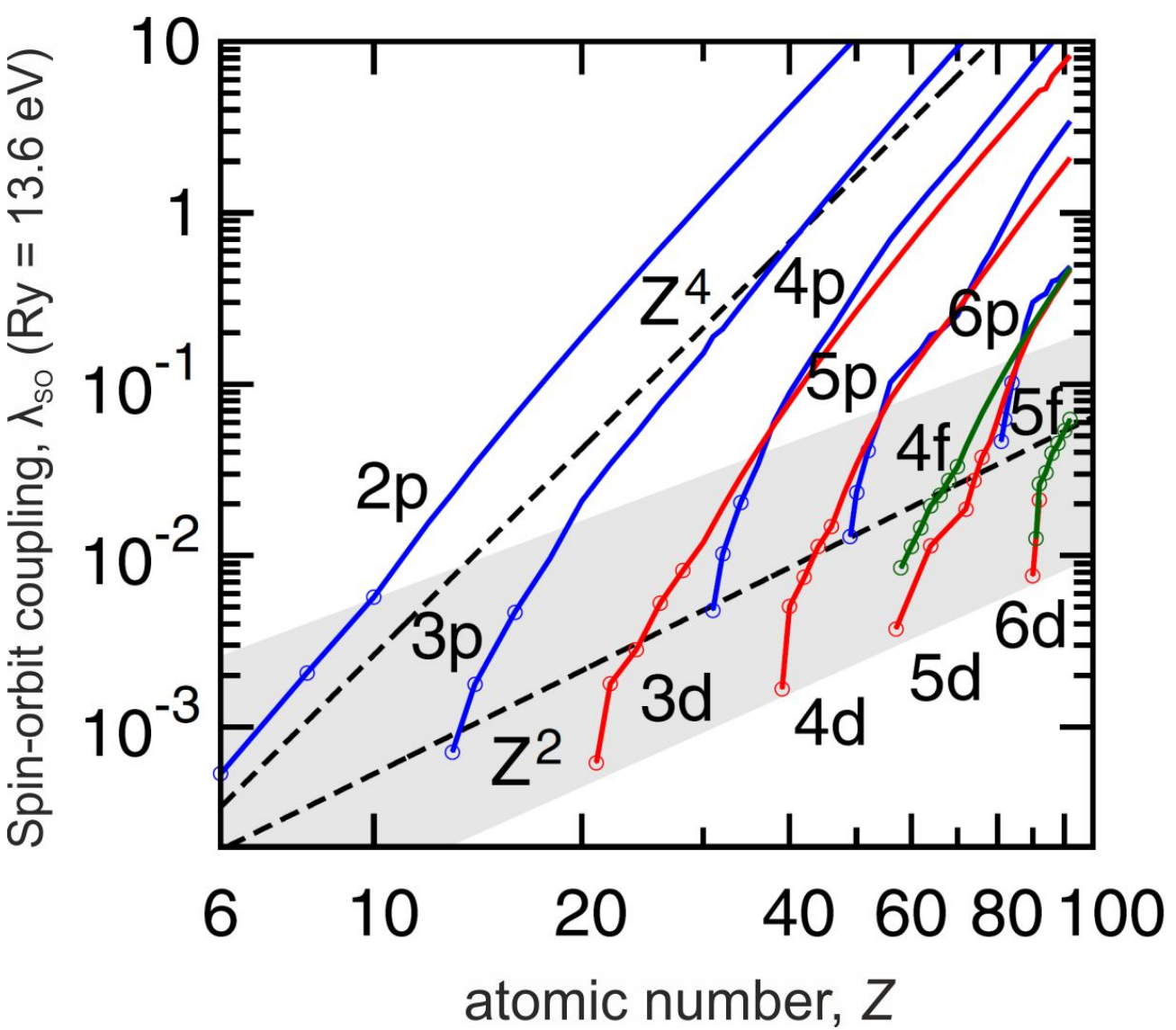
Chiral / helical indicates the unique propagation direction

Image credit: Freepik

Trio of Hall effects



Science 340, 153 (2013)

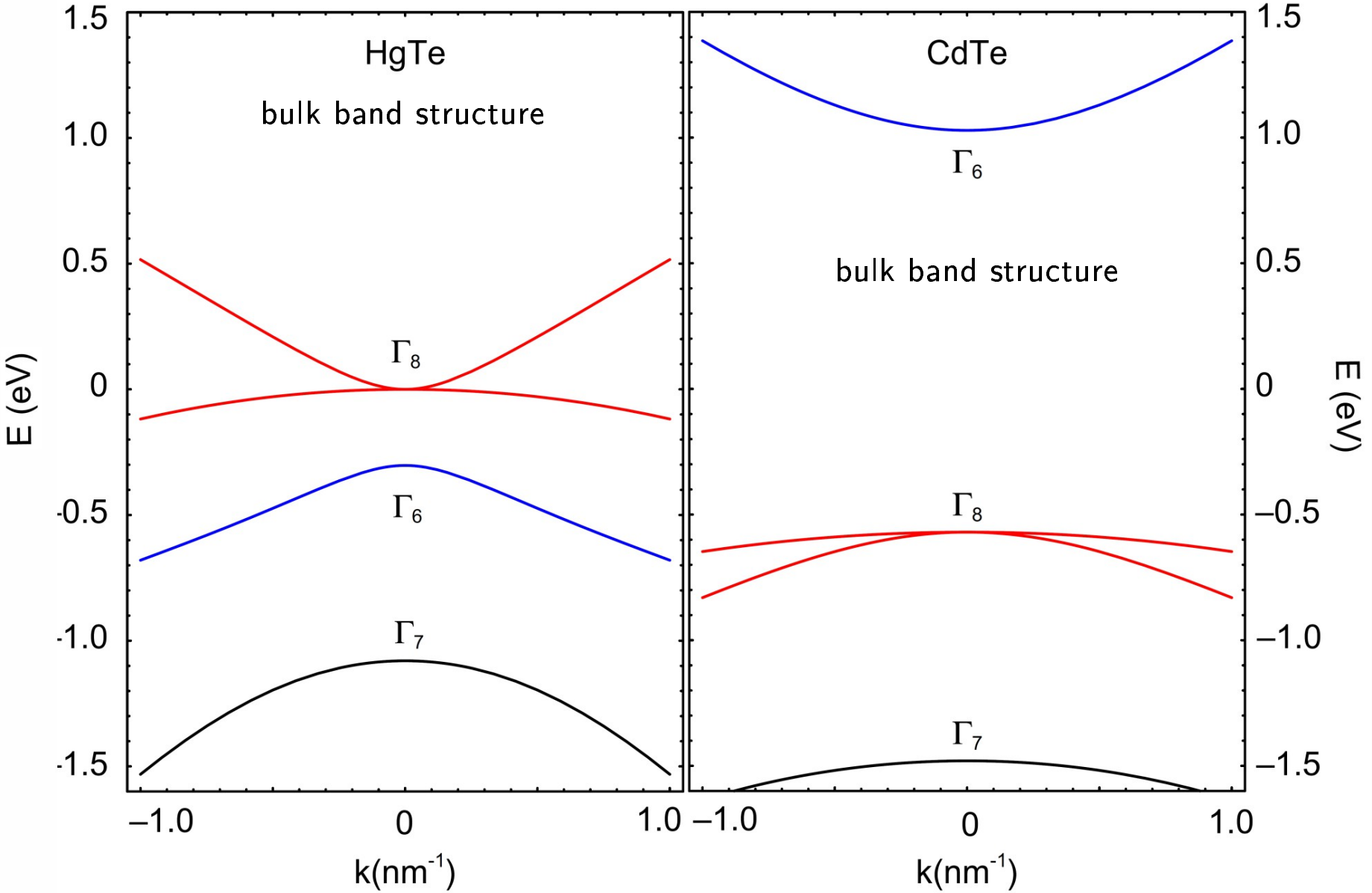


$\lambda_{SO} \sim Z^4$
within each
nl-manifold

$\lambda_{SO} \sim Z^2$
between them

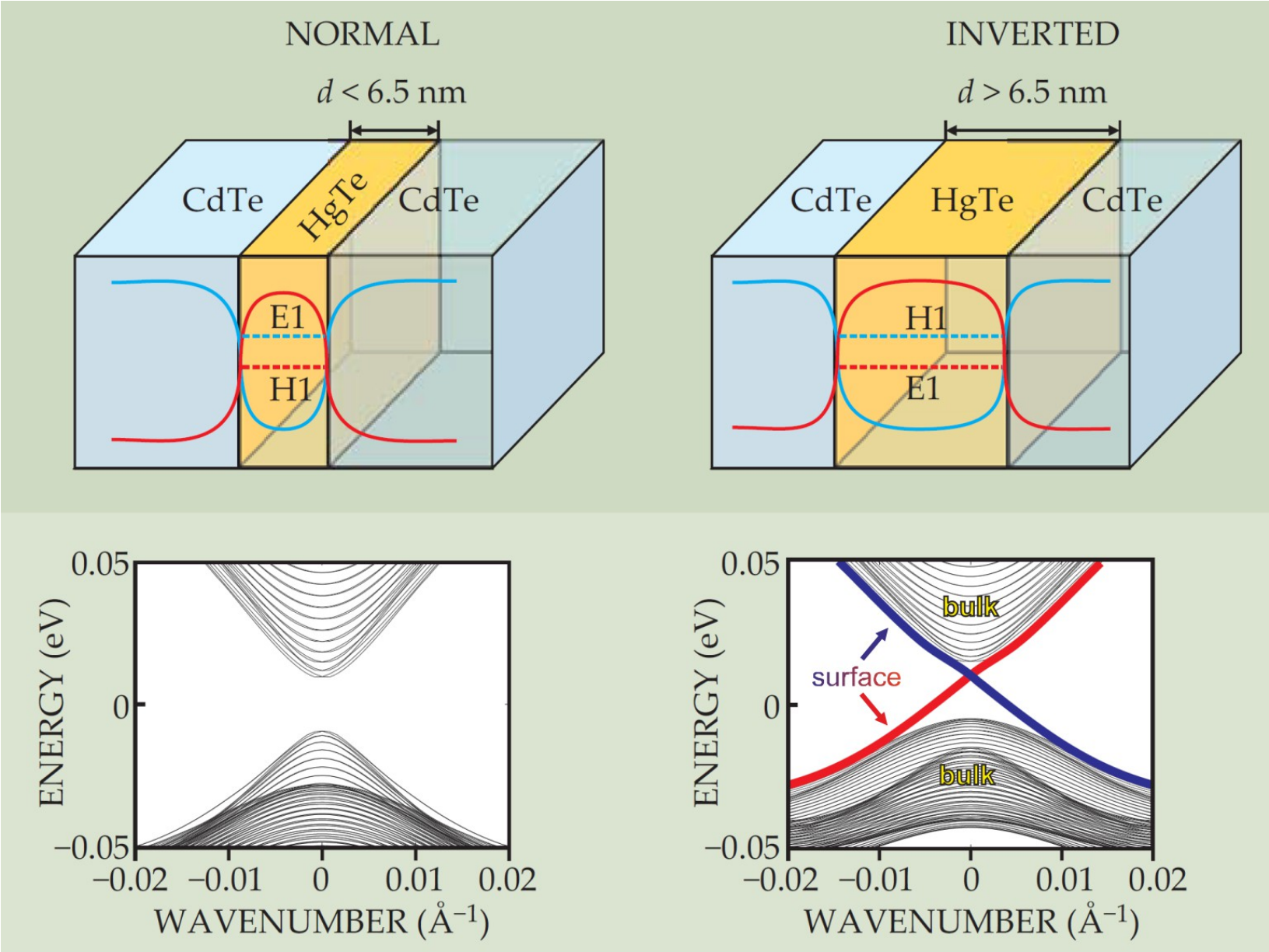
Phys. Rev. B 92, 035135 (2015)

Choosing the right material



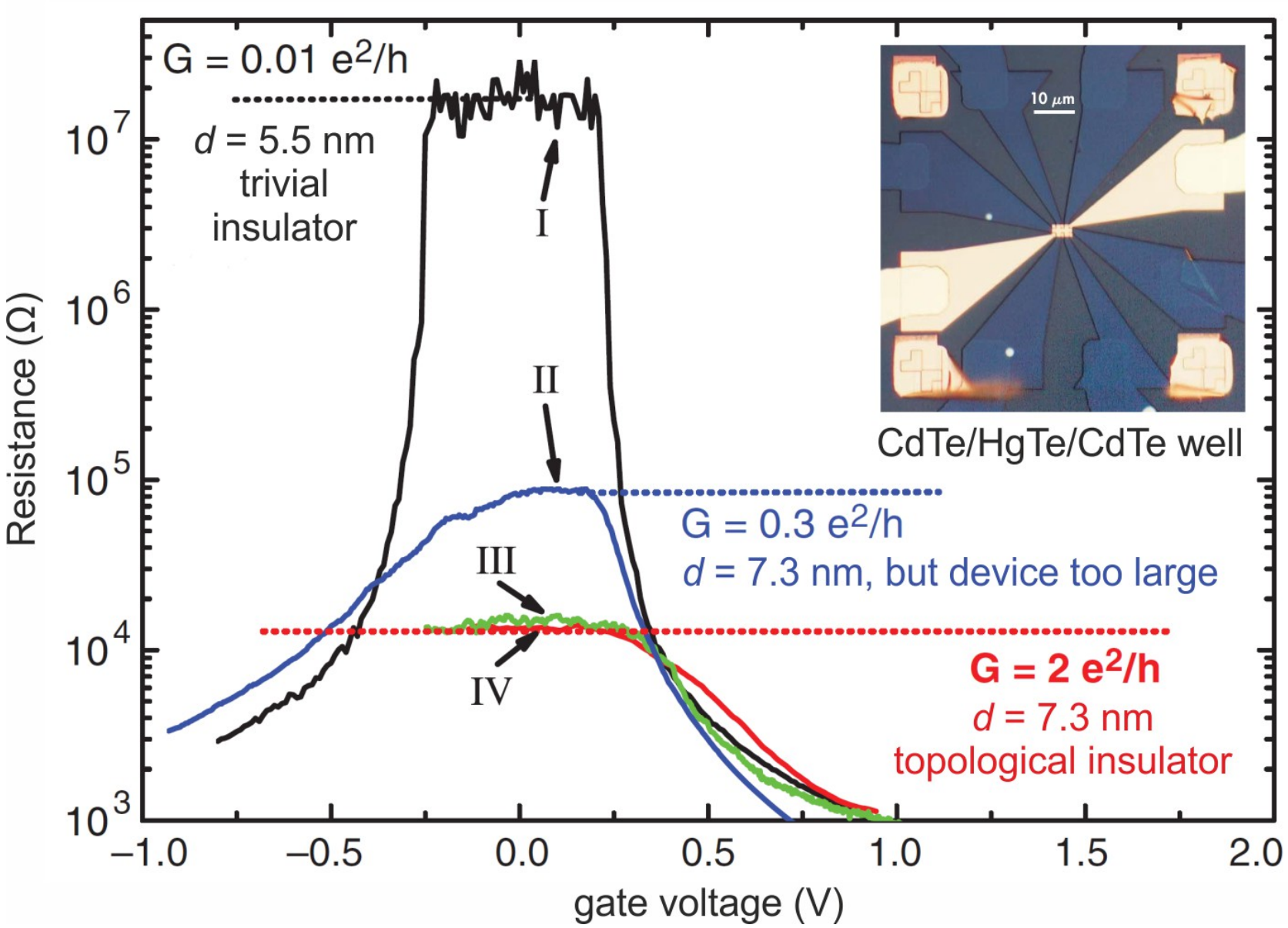
Science 314, 1757 (2006)

Realistic theoretical proposal: quantum well



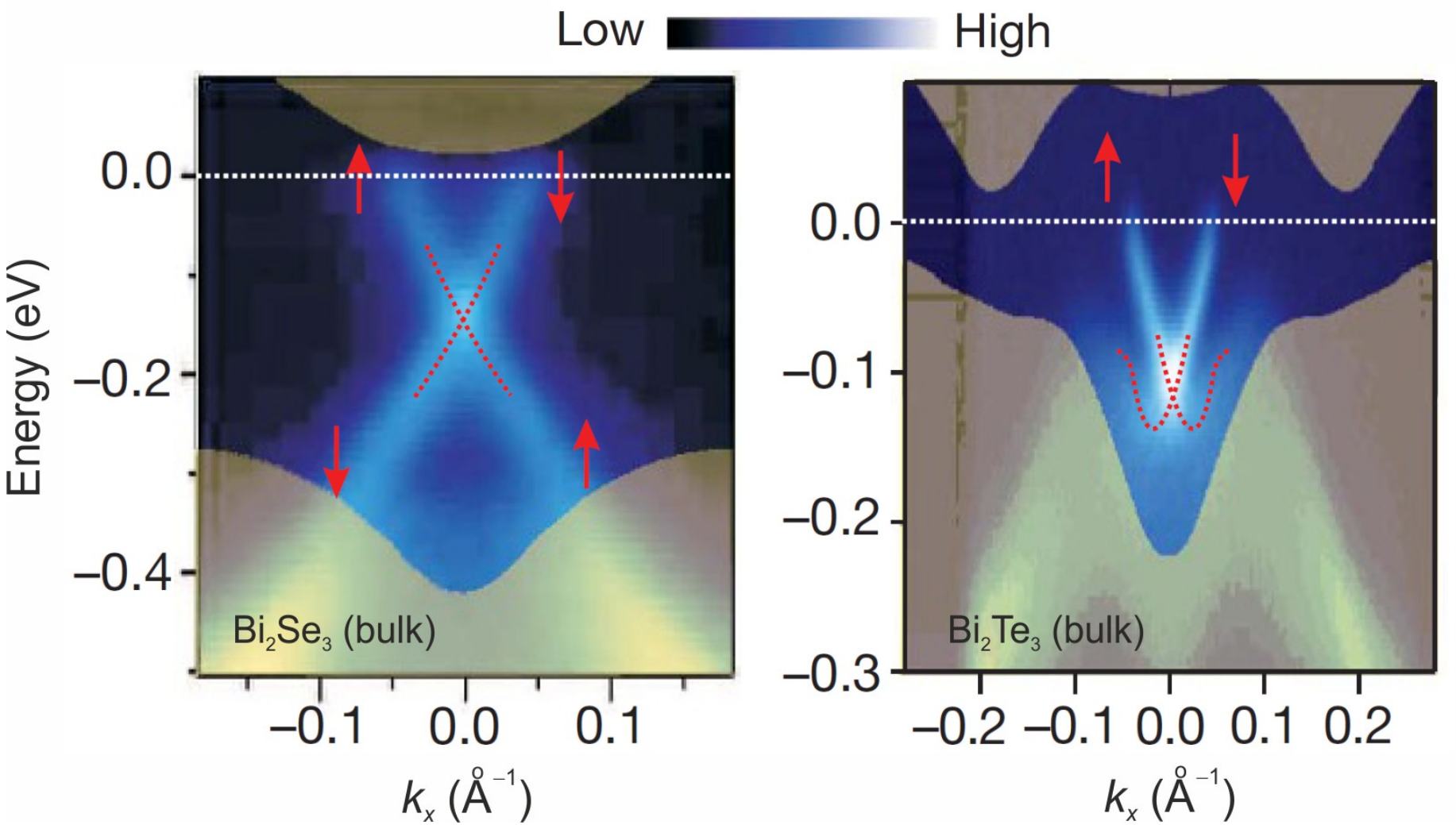
Science 314, 1757 (2006); Phys. Today 63(1), 33 (2010)

Experimental realization



Science 318, 767 (2007); Phys. Today 63(1), 33 (2010)

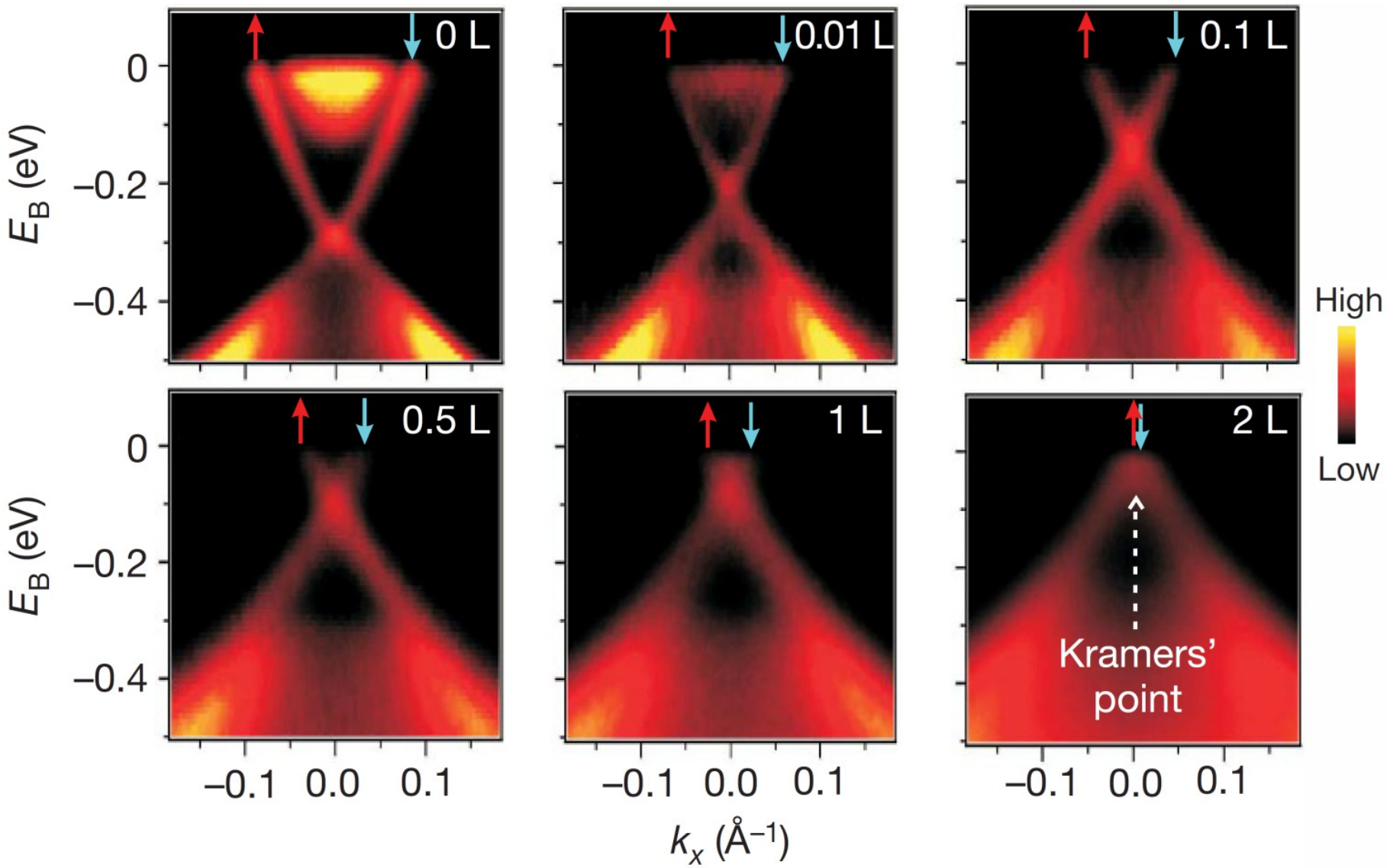
Observation of the Dirac cone



now at room temperature!

Nature 460, 1101 (2009)

Tuning of the Fermi level

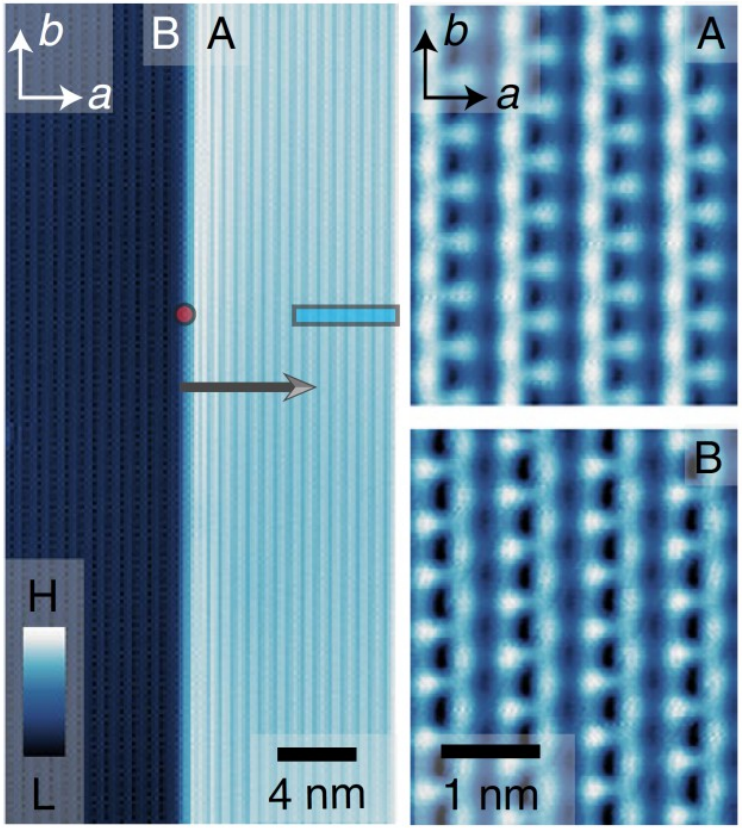


Dosing Bi_2Se_3 with NO_2 (1 L indicates the dosage)

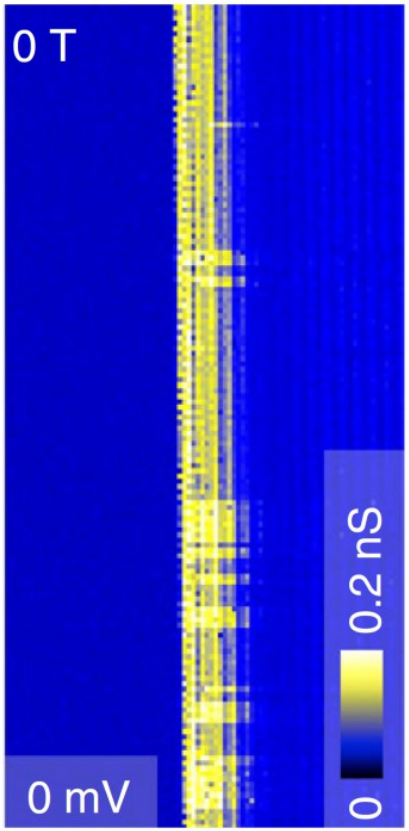
Nature 460, 1101 (2009)

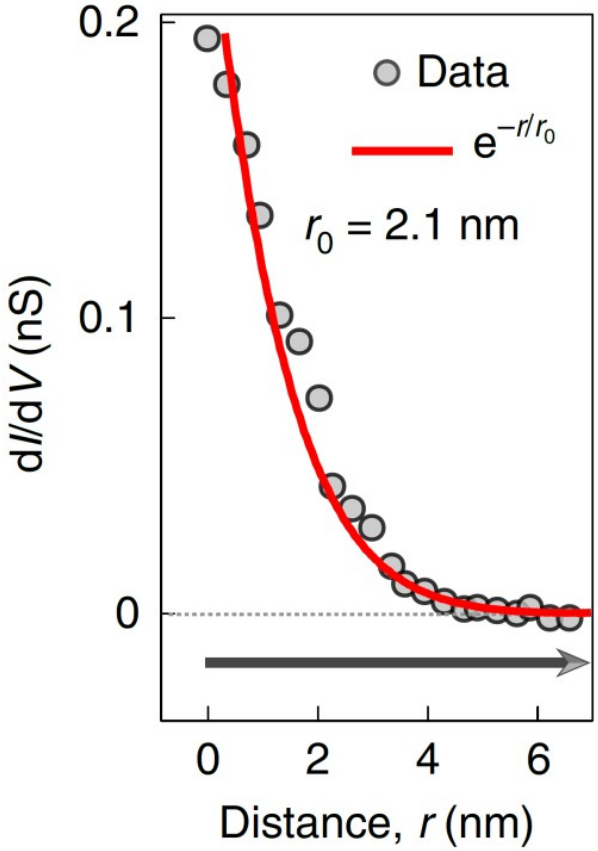
Observation of edge states

imaging of step edge
on the surface



local conductivity measured by
scanning tunneling spectroscopy

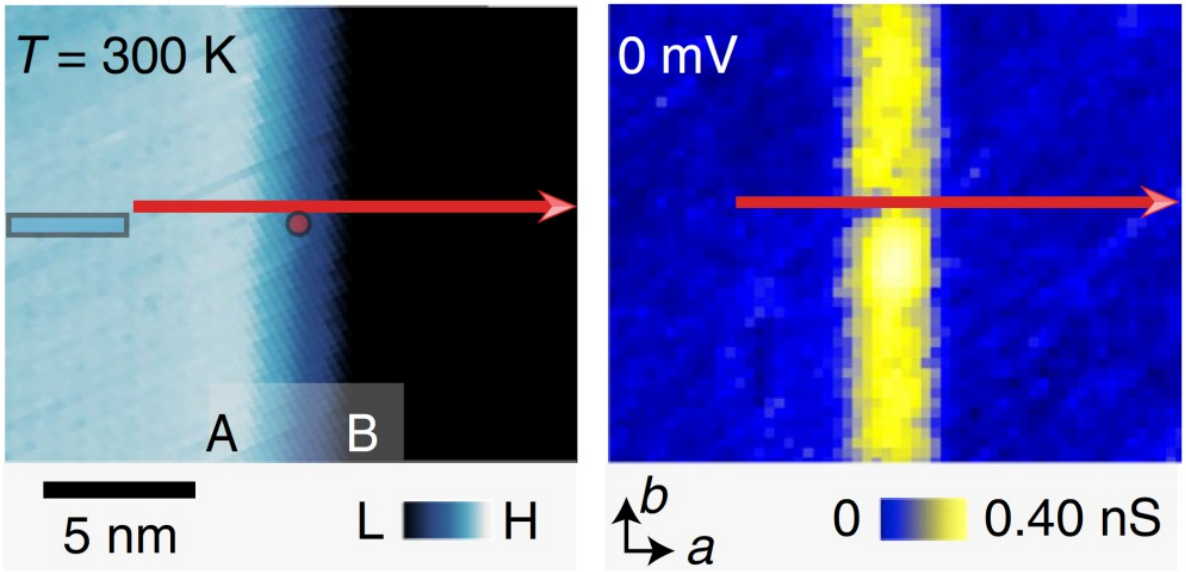


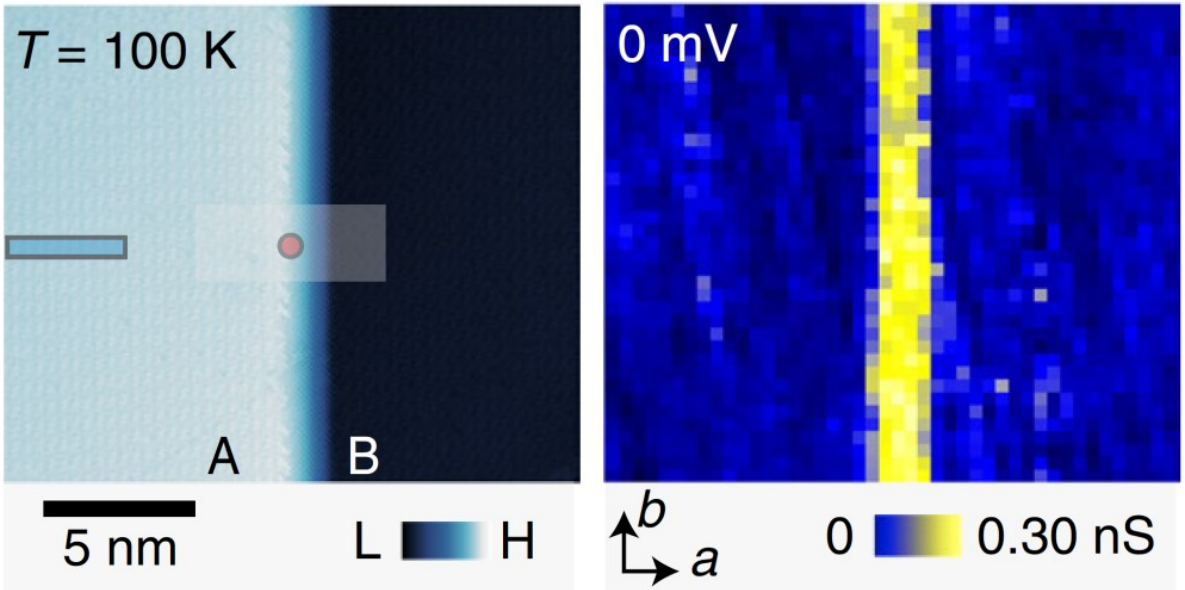


Material: Bi_4Br_4

Nature Mater. 21, 1111 (2022)

Edge states at room temperature

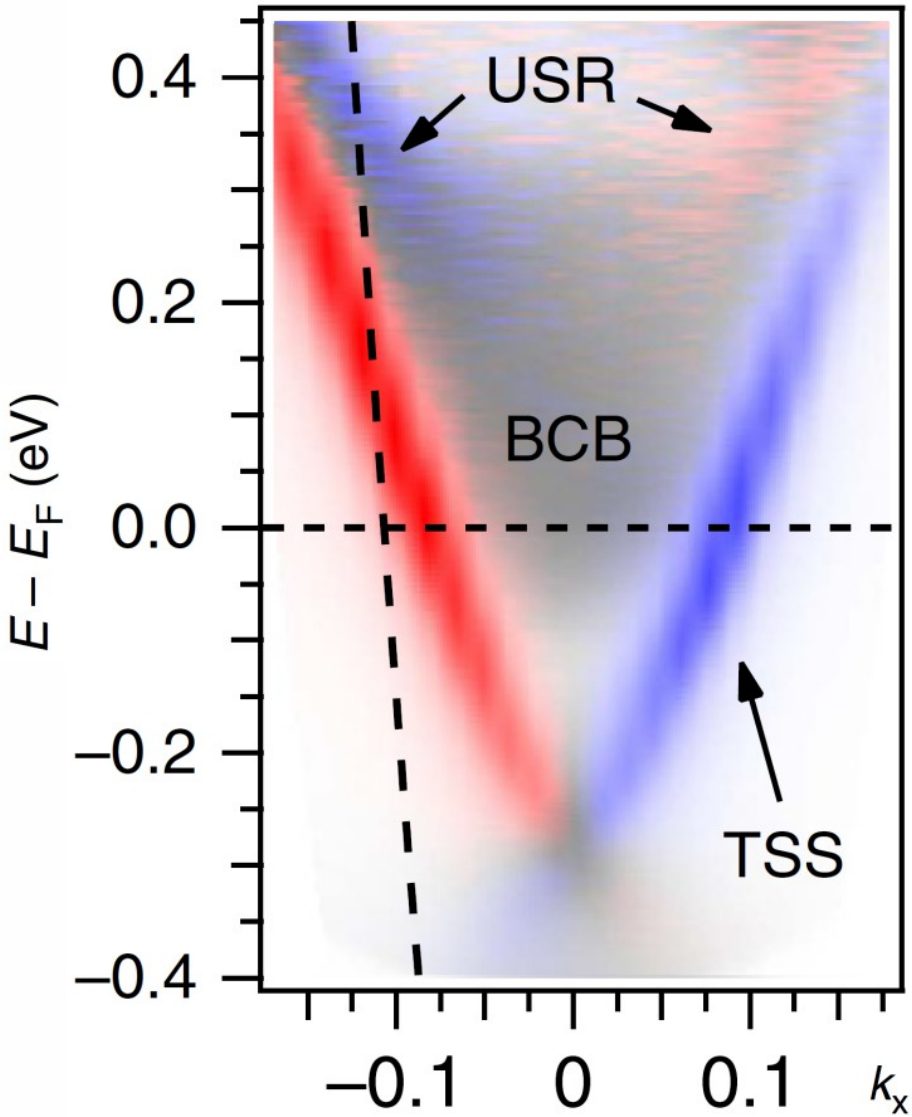


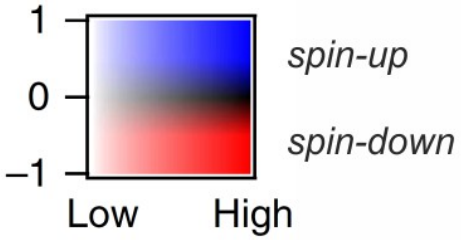


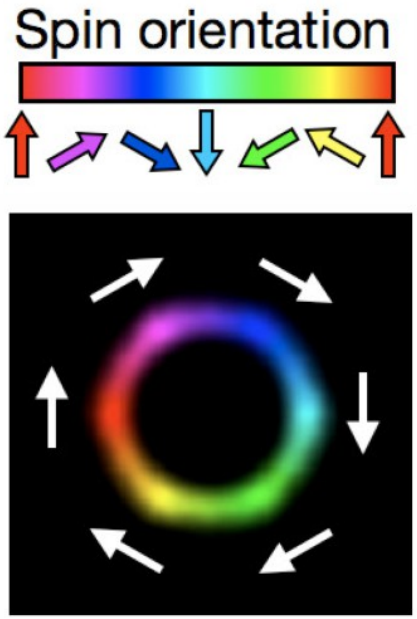
Material: Bi_4Br_4

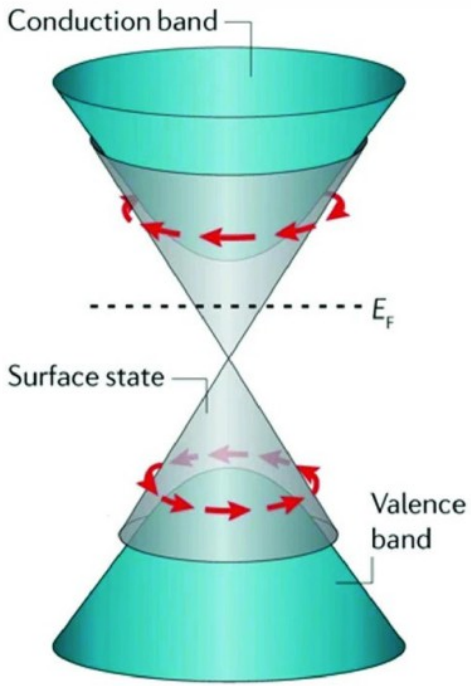
Nature Mater. 21, 1111 (2022)

Spin texture of the Dirac cone





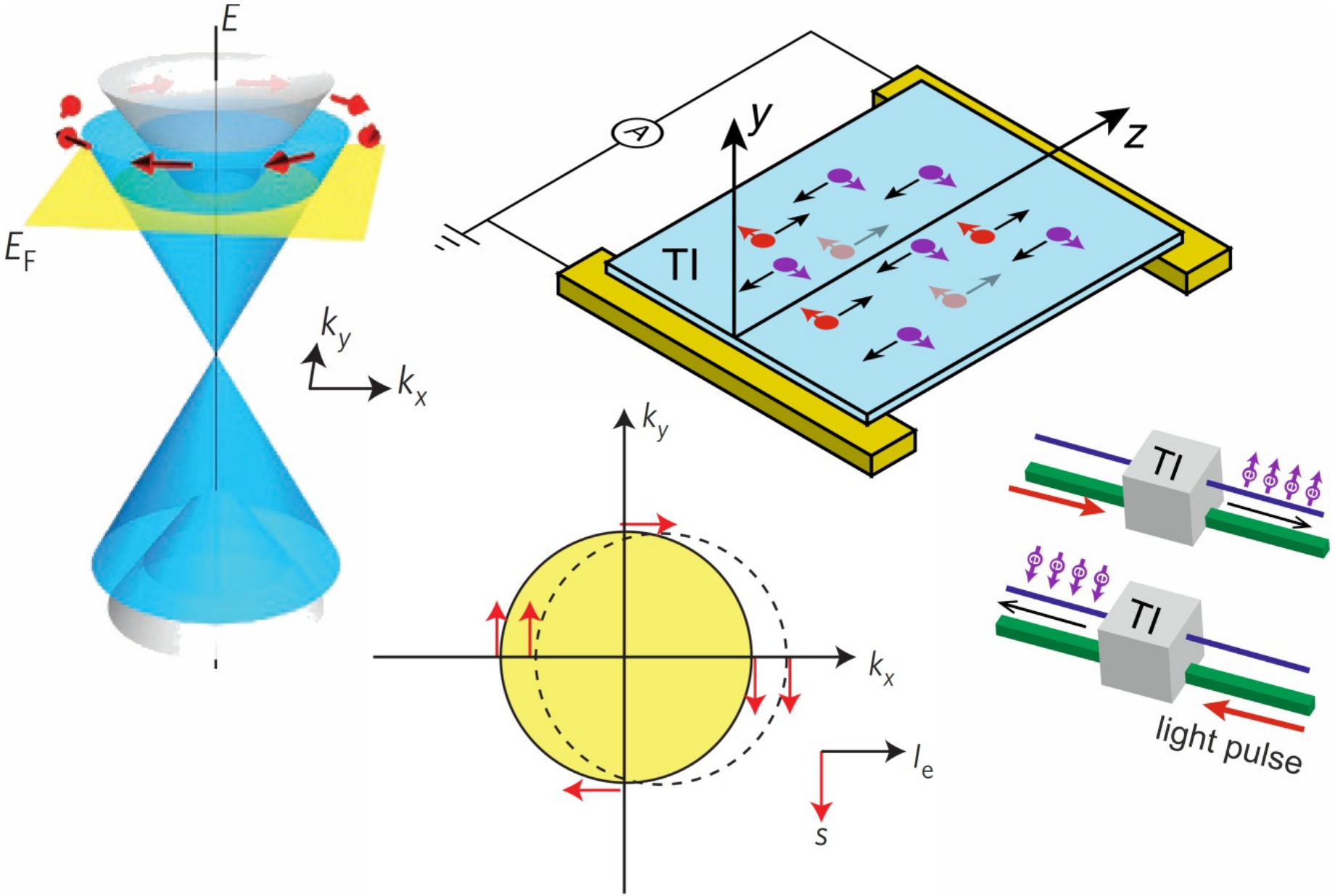




Materials:
Bi_2Se_3 and Sb

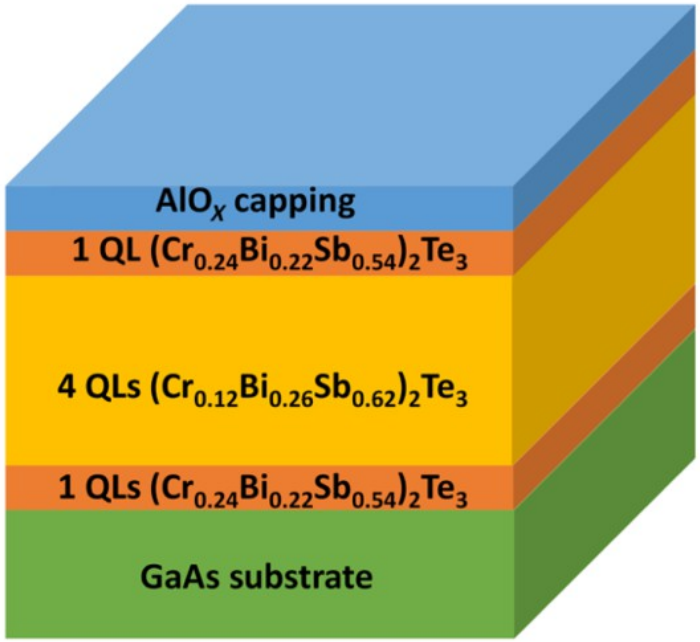
Nature Comm. 7, 13143 (2026); arXiv:0909.0921; Emergent Transport Properties of Magnetic Topological Insulator Heterostructures (2020)

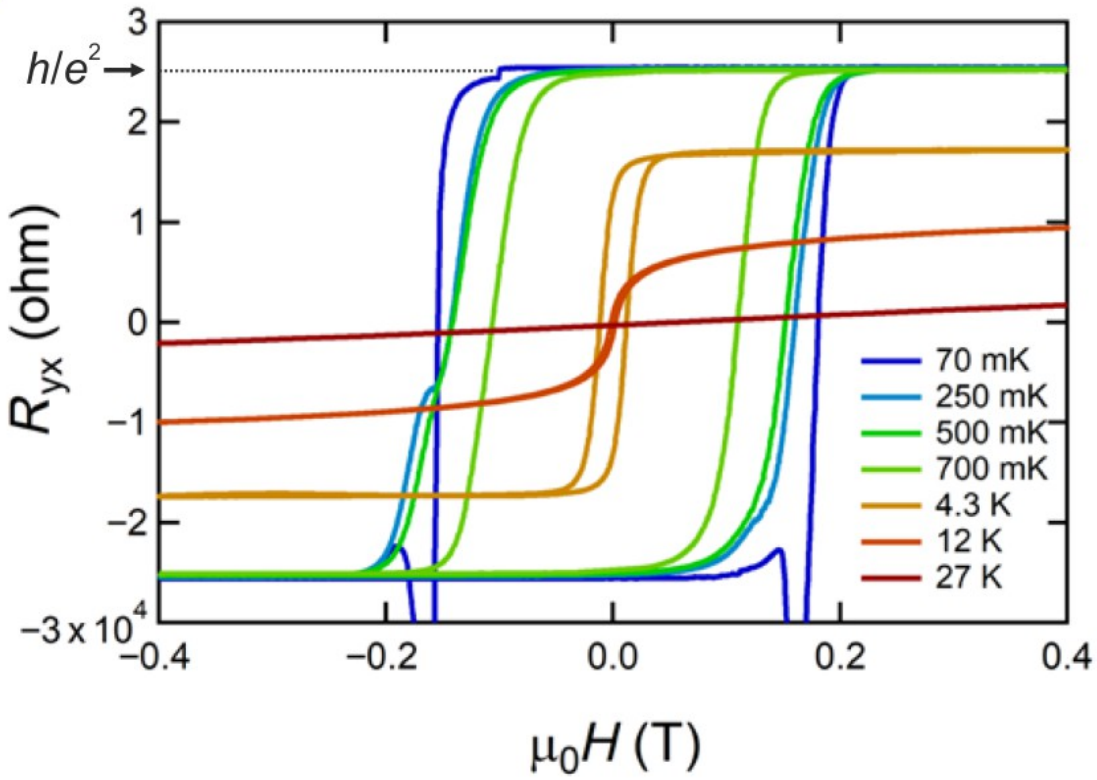
Spin-momentum locking



Nature Comm. 8, 2141 (2017) and Nature Nanotech. 9, 218 (2014)

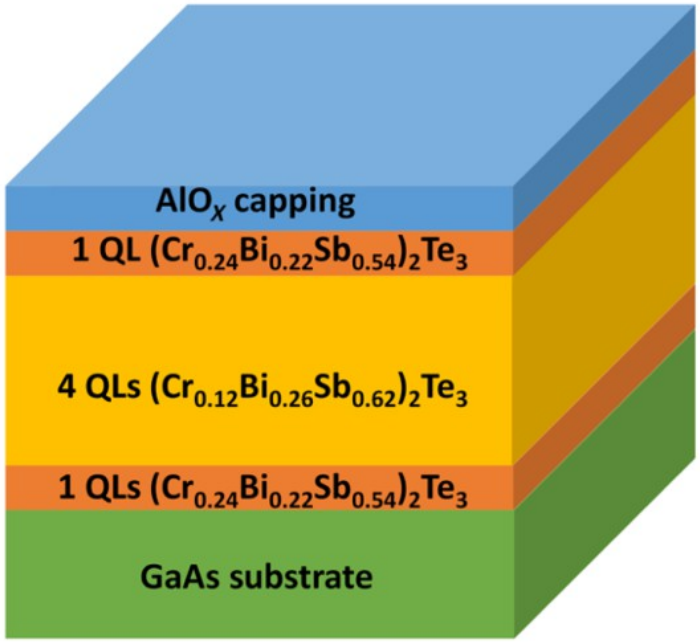
Magnetic topological insulator: Chern insulator





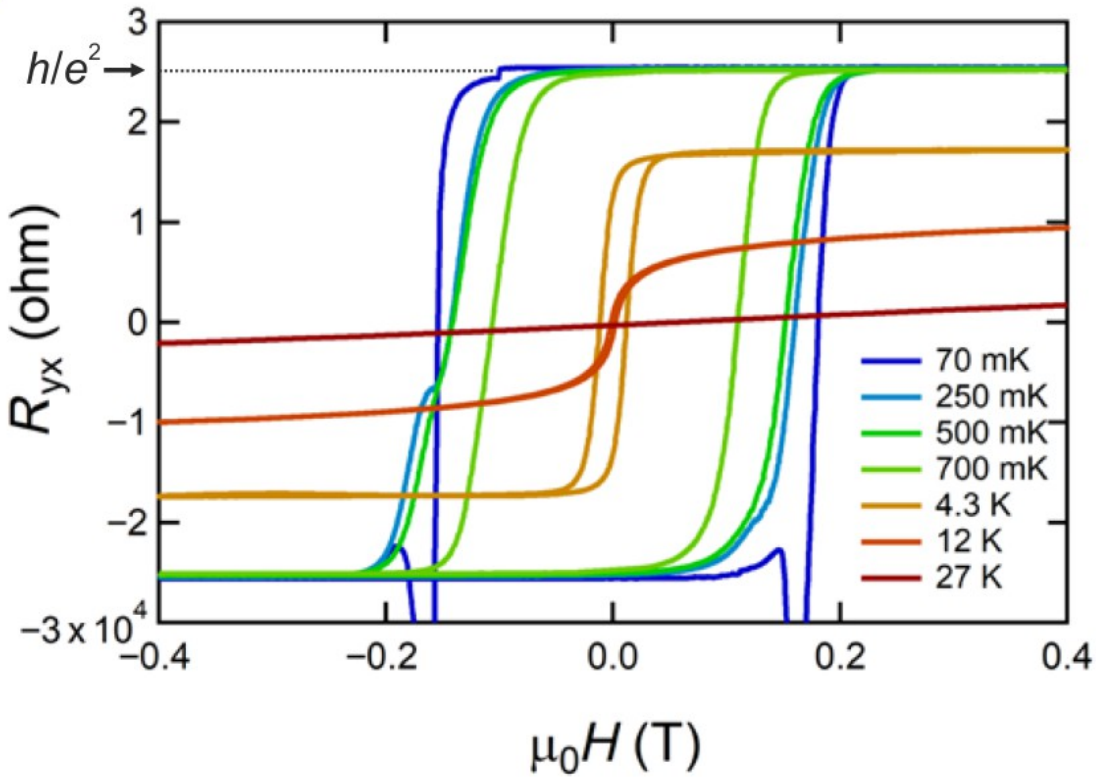
Sci. Advances 6, eaaz3595 (2020)

Magnetic topological insulator: Chern insulator



Laughlin pump realized
in a similar material:

Nature Phys. **19**, 333 (2023)



"Weak" topological state,
very low T's required

Sci. Advances 6, eaaz3595 (2020)