Introduction

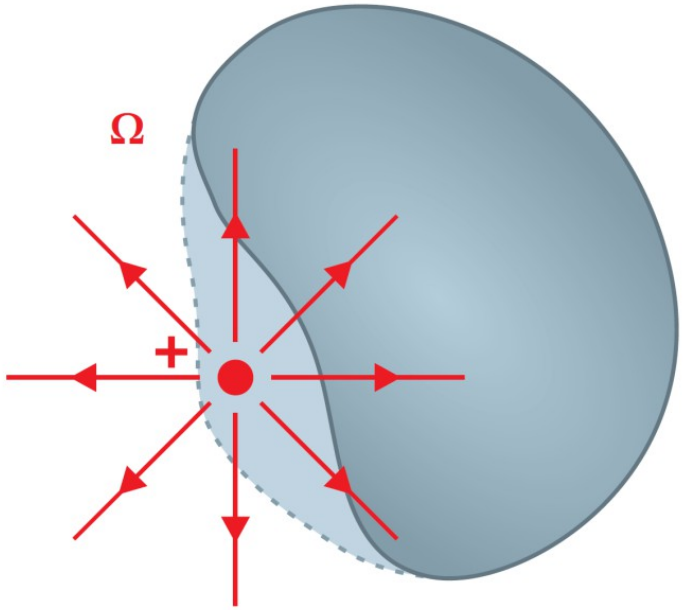
Alexander Tsirlin

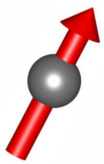
Division of Quantum Magnetism and Superconductivity
Felix Bloch Institute for Solid State Physics

Inti Sodemann

Saranyo Moitra

Quantum Condensed Matter Theory
Institute for Theoretical Physics



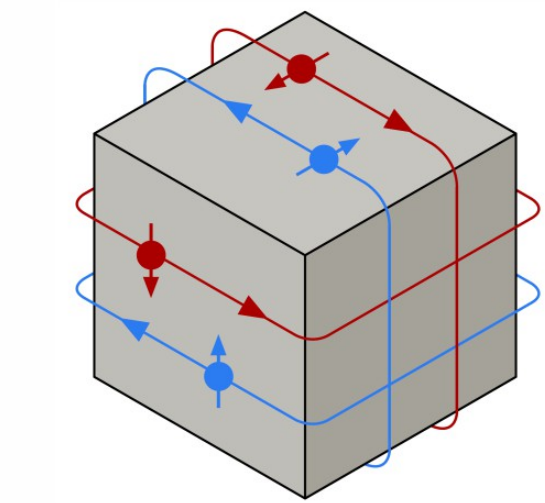


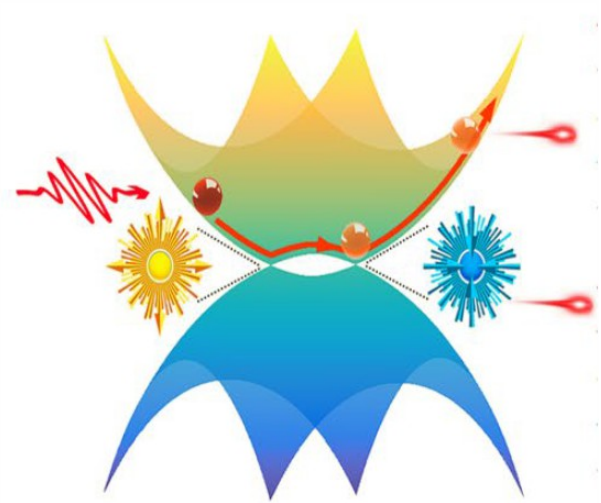
UNIVERSITÄT
LEIPZIG

I. Band topology

non-interacting electrons in special settings

- integer quantum Hall effect
- Berry curvature and Berry phase
- Chern number
- Topological insulators
- Fermi arcs
- all flavors of fermions:
  Dirac, Weyl, Majorana



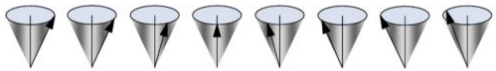


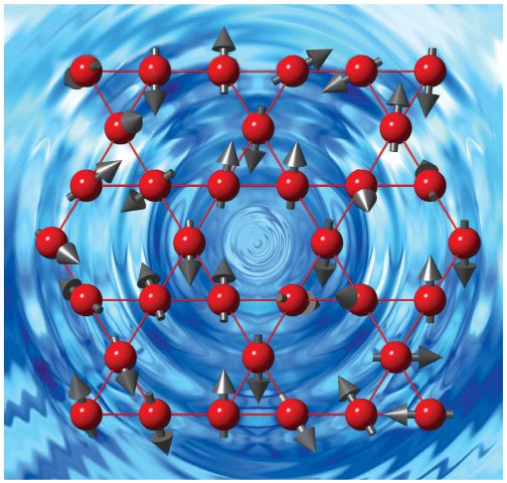
Images from eLight 3, 2 (2023), arXiv:2407.10464, and Phys. Today 73(9), 30 (2020) (title image)

II. Interacting systems and symmetry breaking

new states arising from interactions between the electrons

- Landau Fermi liquid
- superconducting instability (BCS)
- electronic correlations and Hubbard model
- Mott and charge-transfer insulators
- spin waves / magnons
- fractionalization:
  quantum Hall again, and spin liquids





Images from Phys. Today 69(8), 30 (2016) and Hunklinger's Solid-State Physics

Refresh your basic solid-state knowledge

newer textbooks may have some bits and pieces of what we will study here:

- S. Simon, The Oxford Solid State Basics
- R. Gross, A. Marx. Festkörperphysik
  latest German reading for solid-state physics, e-book available

but do not expect them to cover too much...

Literature to part I

- D. Vanderbilt, Berry phases in electronic structure theory
  paper copy only
- David Tong, Lecture notes on The Quantum Hall effect
  available from his web site
- Topology in condensed matter: tying quantum knots
  Online course on topology in condensed matter: Topocondmat

+ review articles that will be suggested on the web page

Literature to part II

- P. Fazekas,
  Lecture notes on electronic correlations and magnetism
  paper copy only

- D. Khomskii, Transition metal compounds
  D. Khomskii, Basic aspects of the quantum theory of solids
  e-books available

+ review articles that will be suggested on the web page

Mo 11:15 and Tu 9:15, SR 218

Web page of the course:

- problem sheets
- seminar topics
- additional literature

Mo 11:15 and Tu 9:15, SR 218

Key concept

Open problem

Web page of the course:

- problem sheets
- seminar topics
- additional literature

W 15:15, SR 224 **every week!**

- 3 problems every week
- written solution to *one of the problems*
  should be submitted at the beginning of the exercise class
- solutions to *two other problems*:
  indicate how much you accomplished,
  and be ready to present the solution in the class

Training in problem solution is essential
for succeeding in the written exam!

Th 9:15, R 114 (at ITP: Brüderstr. 16) **roughly biweekly**

Short presentations on the course topics:

- small calculations as a follow-up to the lectures
- selected chapter from a textbook or a review article

- 11 topics available on the web page
- select your topic and send it to alexander.tsirlin@uni-leipzig.de (first come, first serve)
- exact assignment will be given 2 weeks before the seminar
- first seminar will be on 7.11

Admission criteria:

- 40% of the homework points
- participation in the seminar, incl. one presentation

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- 40% of the homework points
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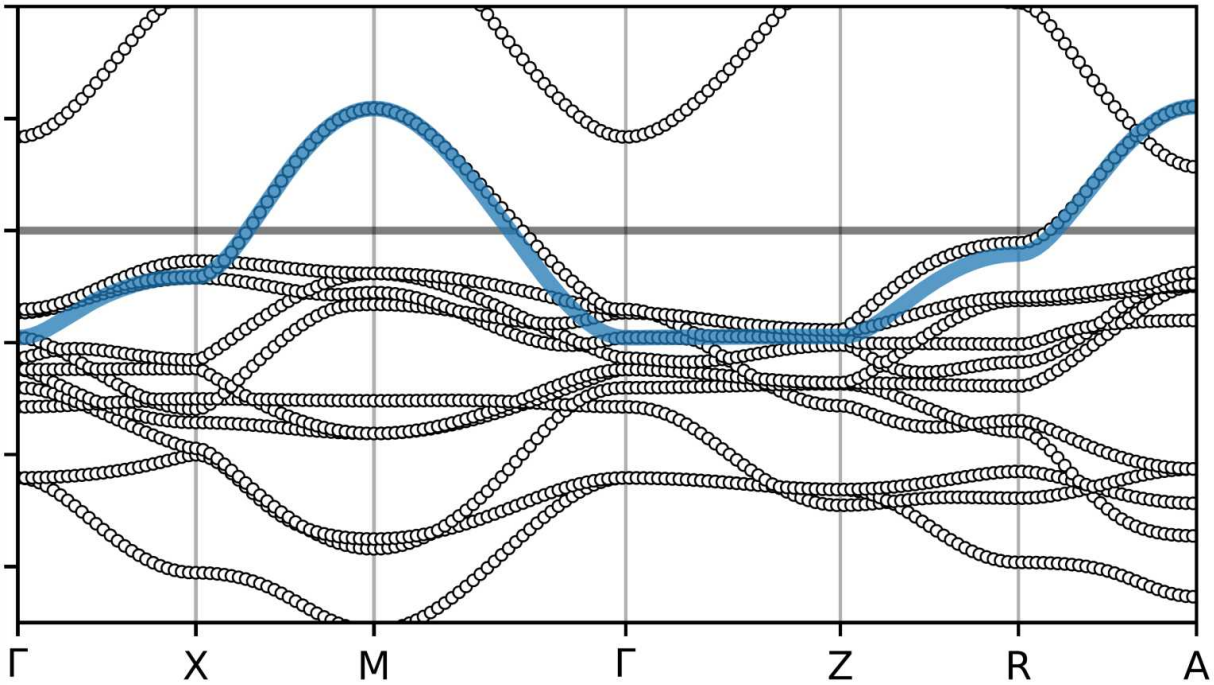
Written exam (3 hours)

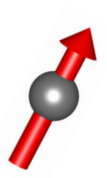
- first attempt: February
- second attempt: March

- several problems (resembling the homeworks)
- questions on the main concepts introduced during the lectures

How to handle band structures?

Tight-binding model





by Alexander Tsirlin, Leipzig University

Lecture 1: October 21, 2024

Band structure of NaCl

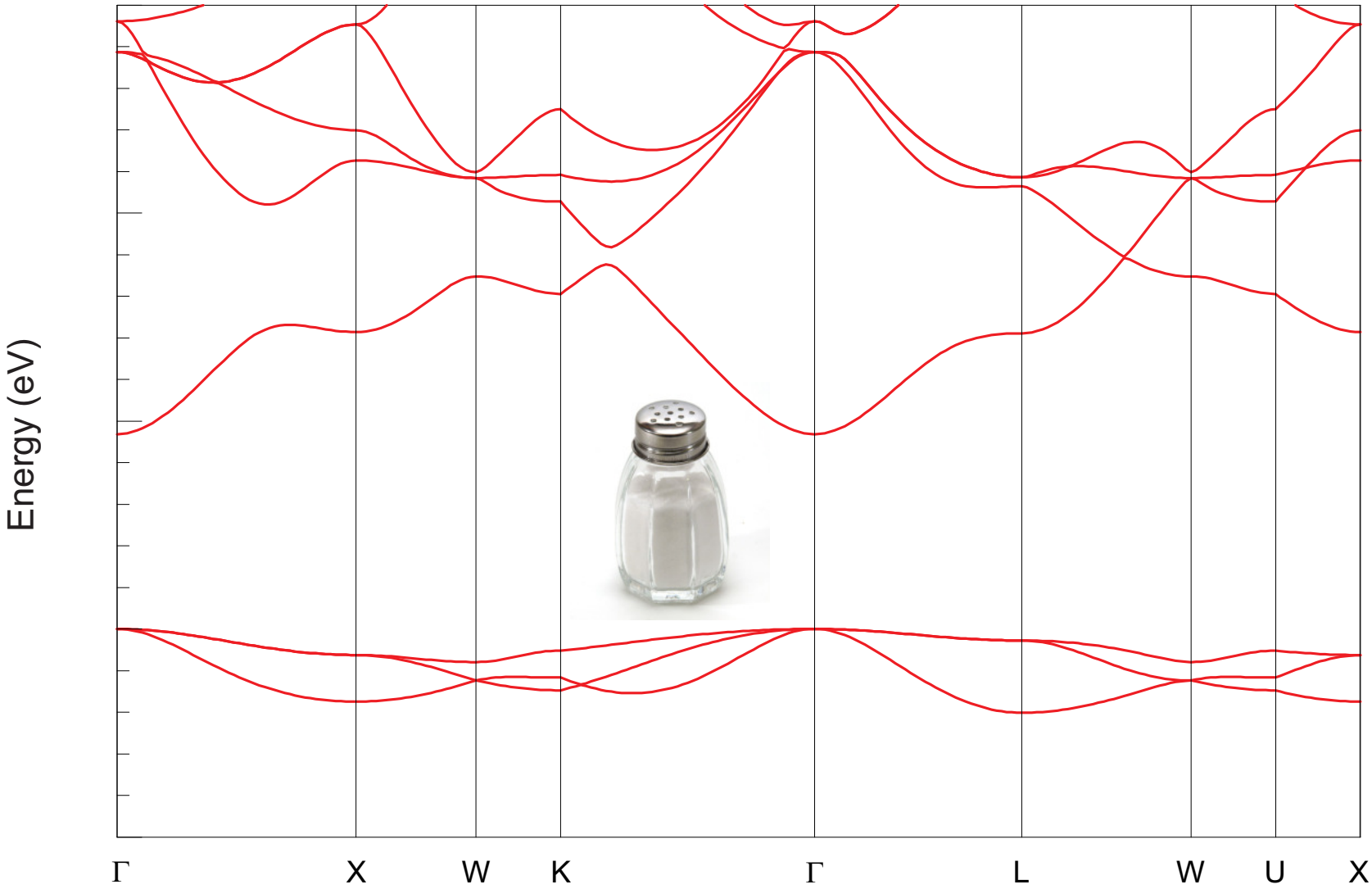


Image credit (salt): Dubravko Sorić (CC-BY)

Band structure of NaCl

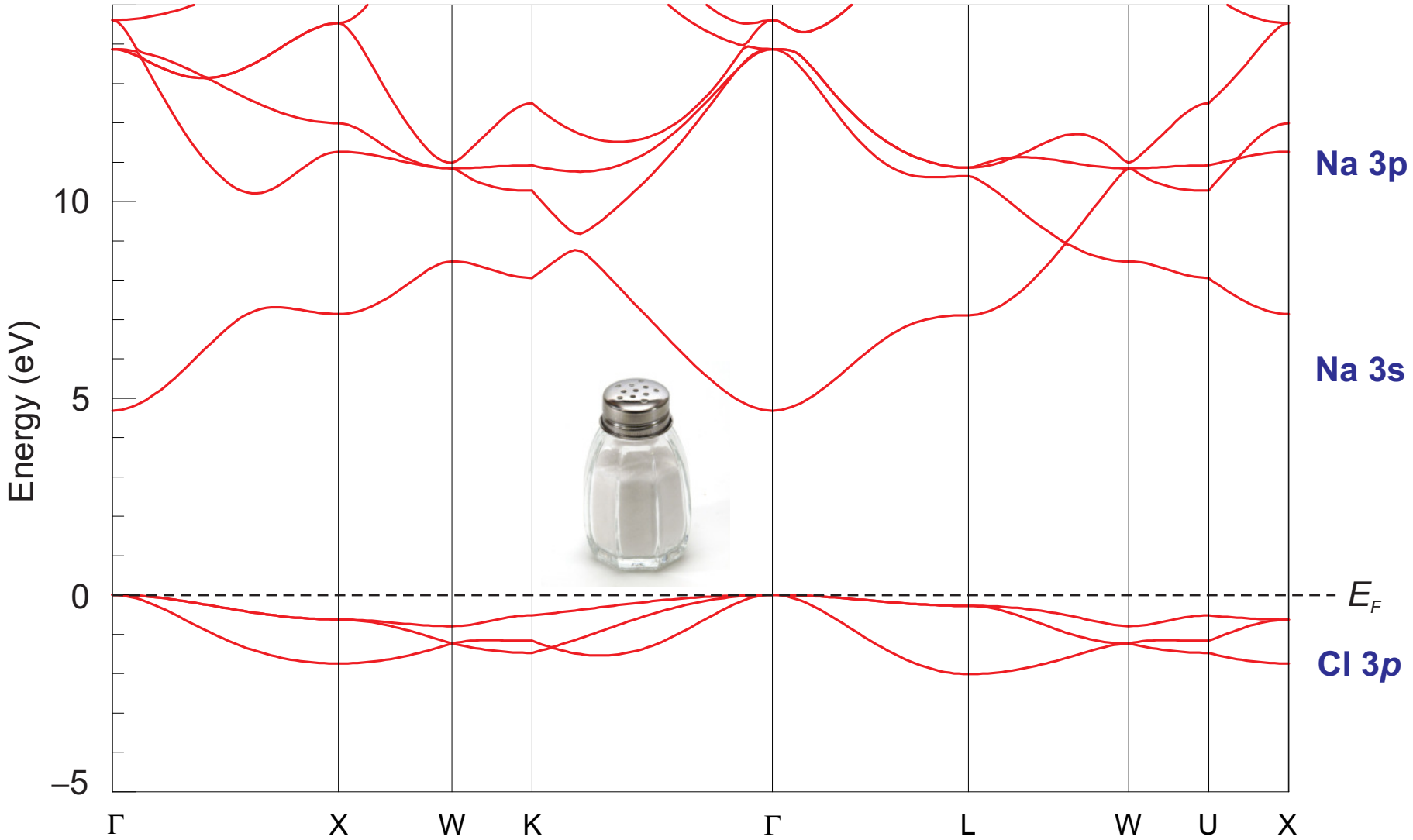
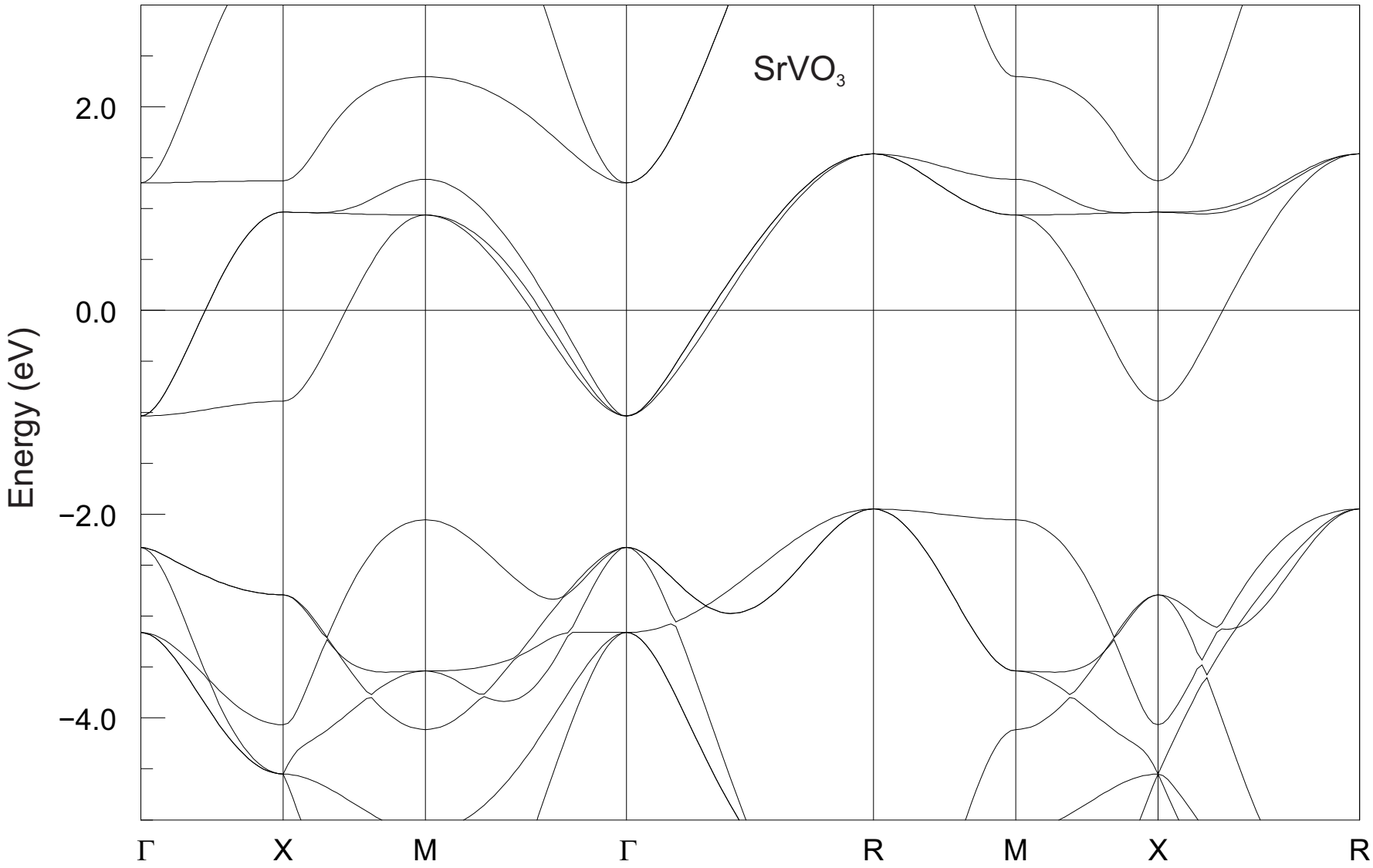
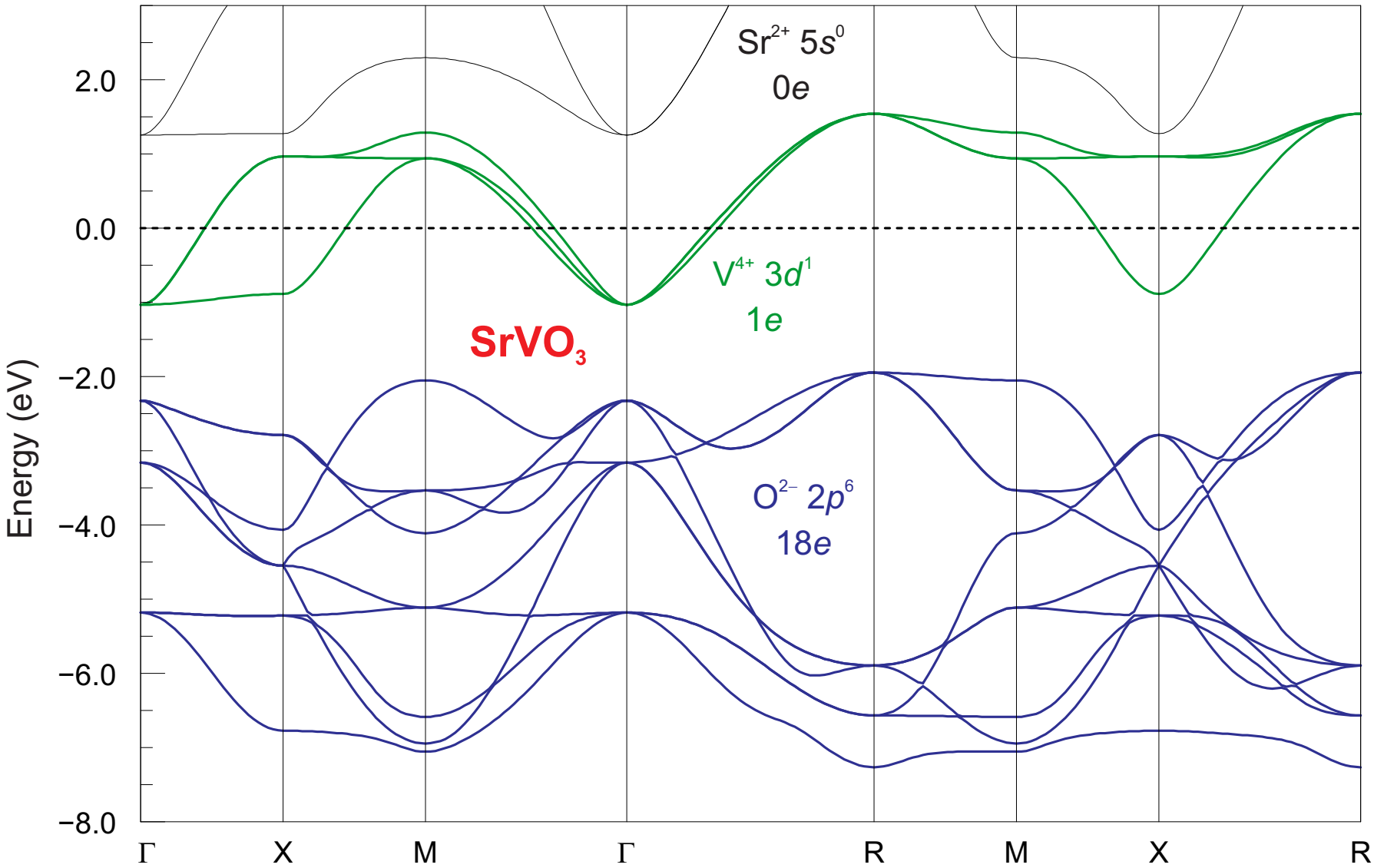


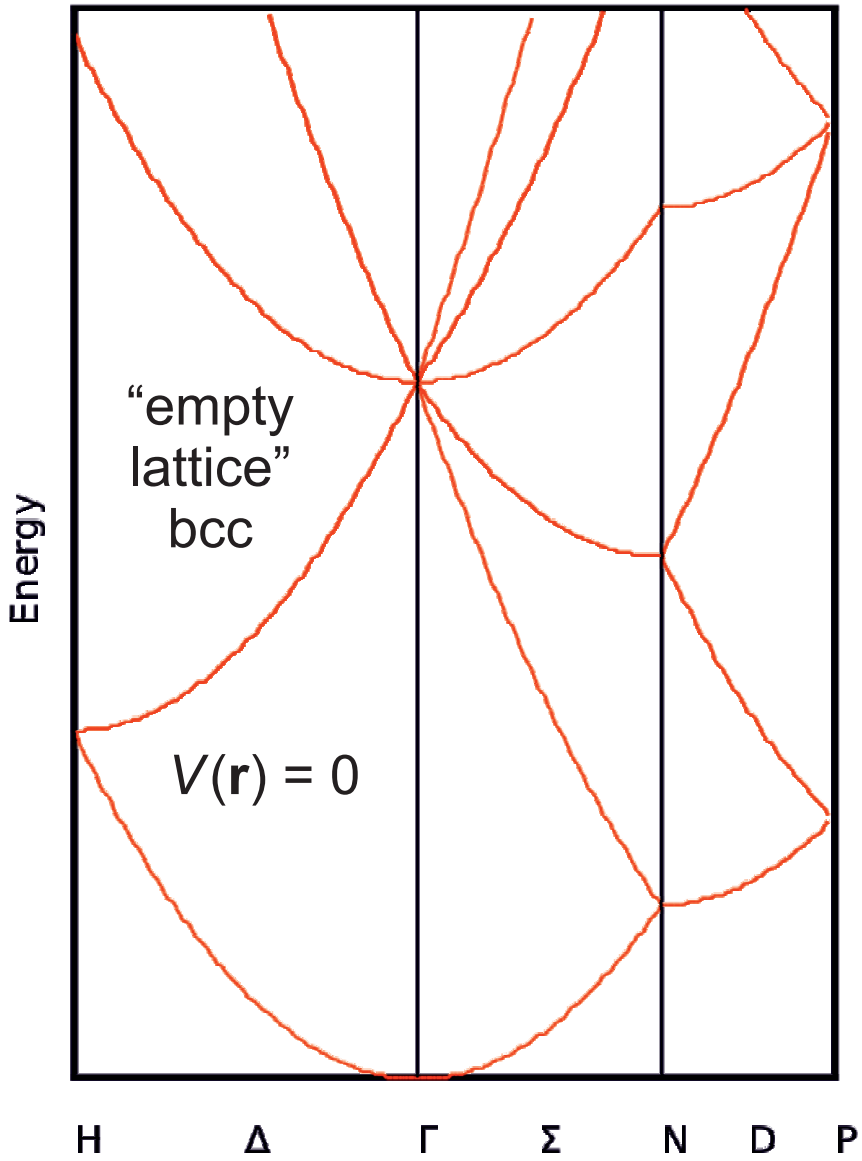
Image credit (salt): Dubravko Sorić (CC-BY)

Band structure of $SrVO_3$

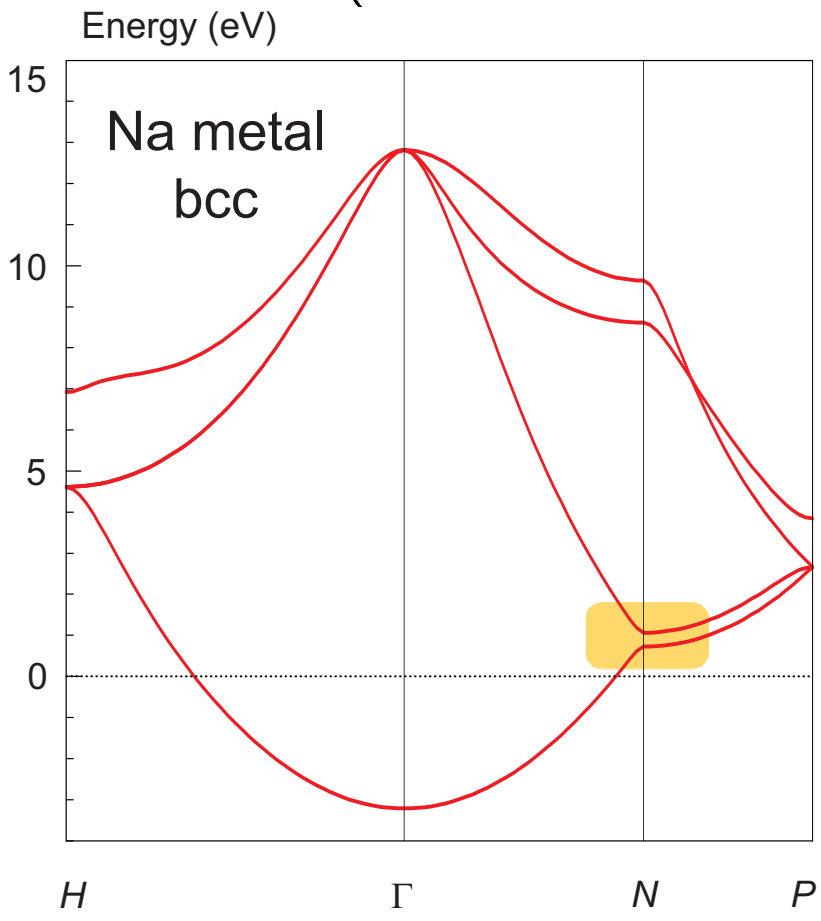


Band structure of $SrVO_3$

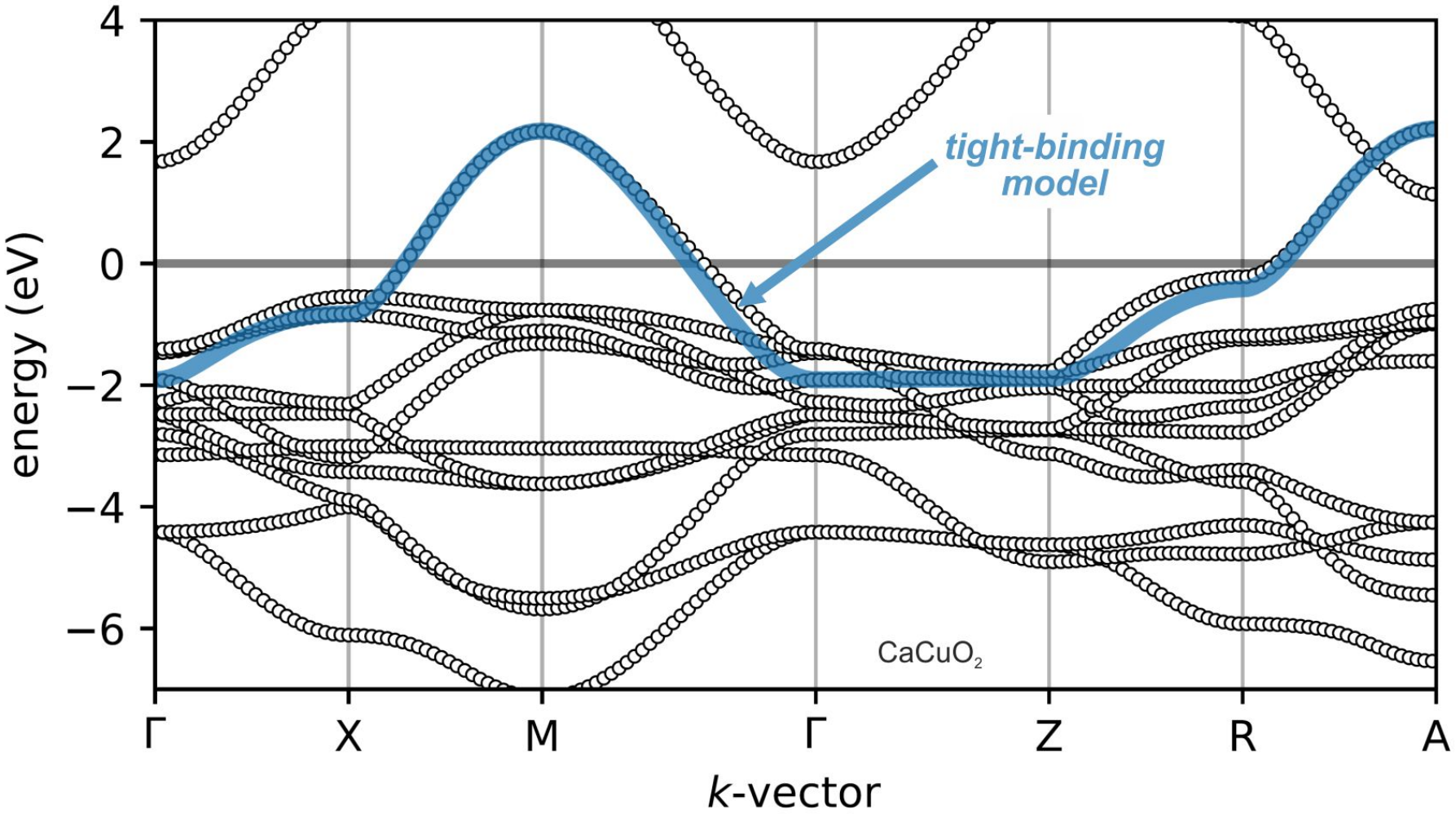




Parabolic bands are a fingerprint of simple metals (almost free electrons)

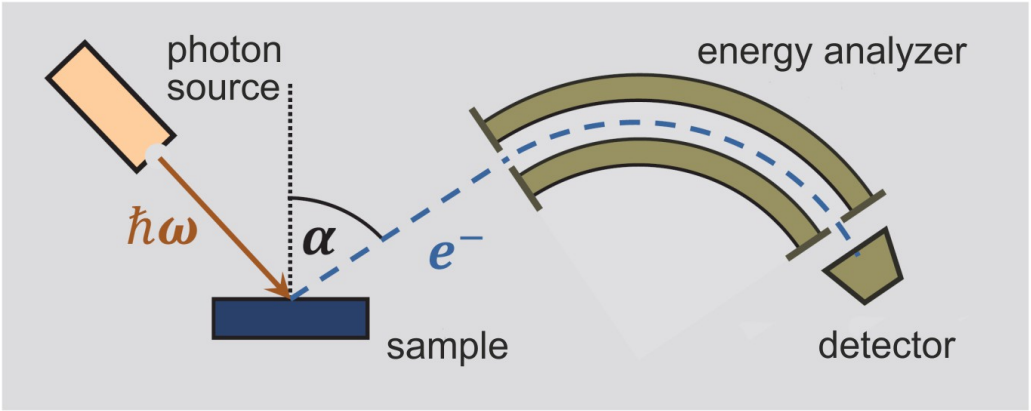


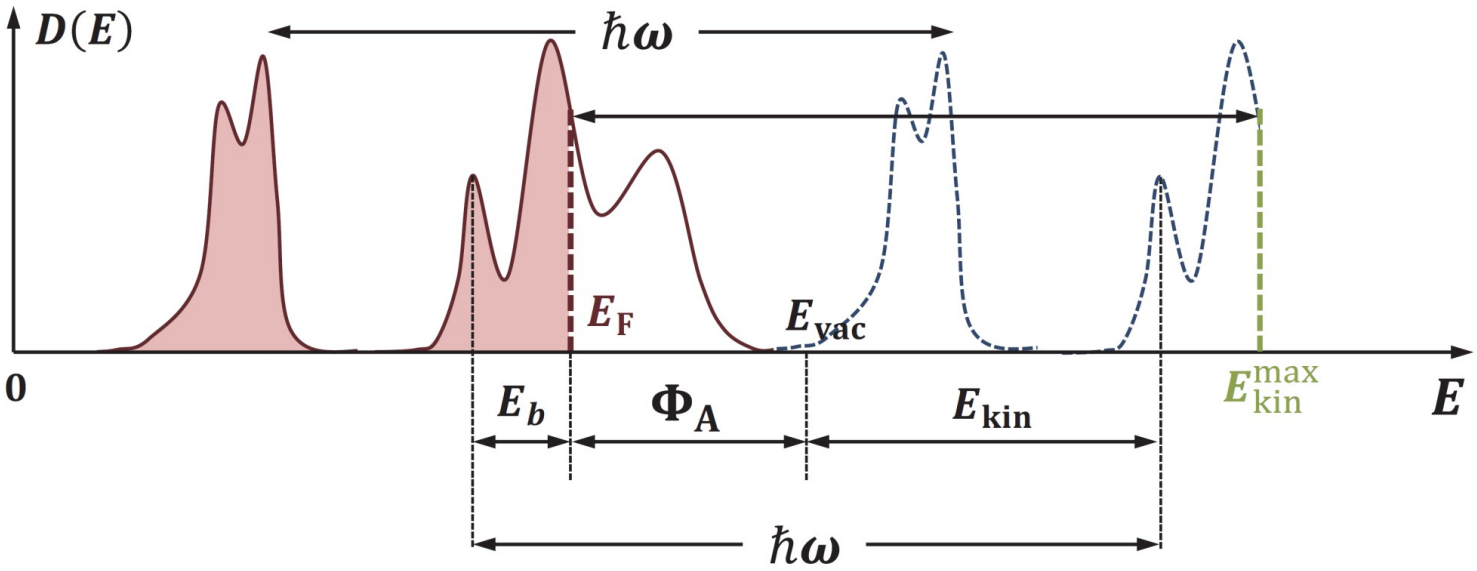
Tight-binding model



Phys. Rev. B 107, 235135 (2023)

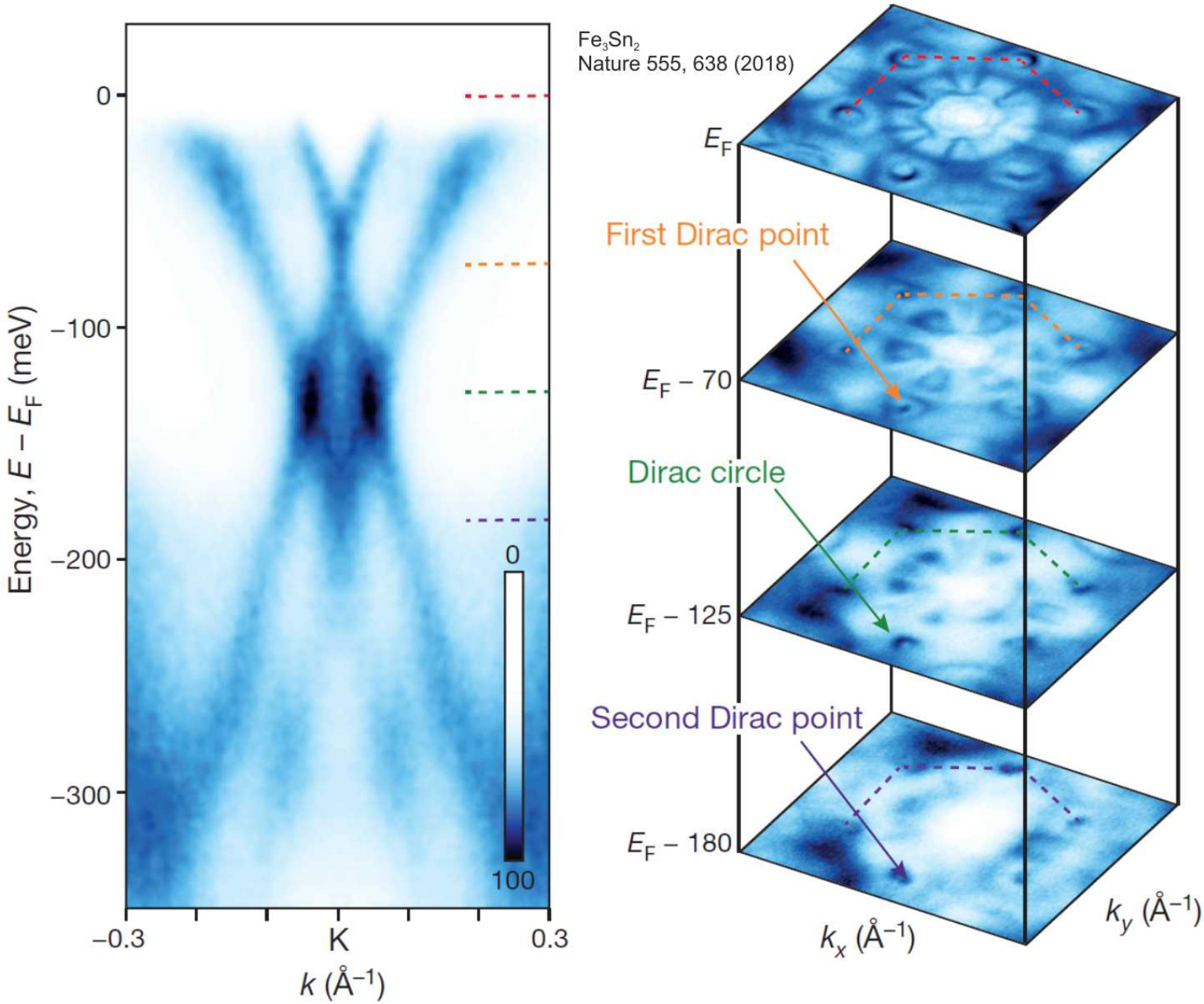
Gross and Marx,
Festkörperphysik



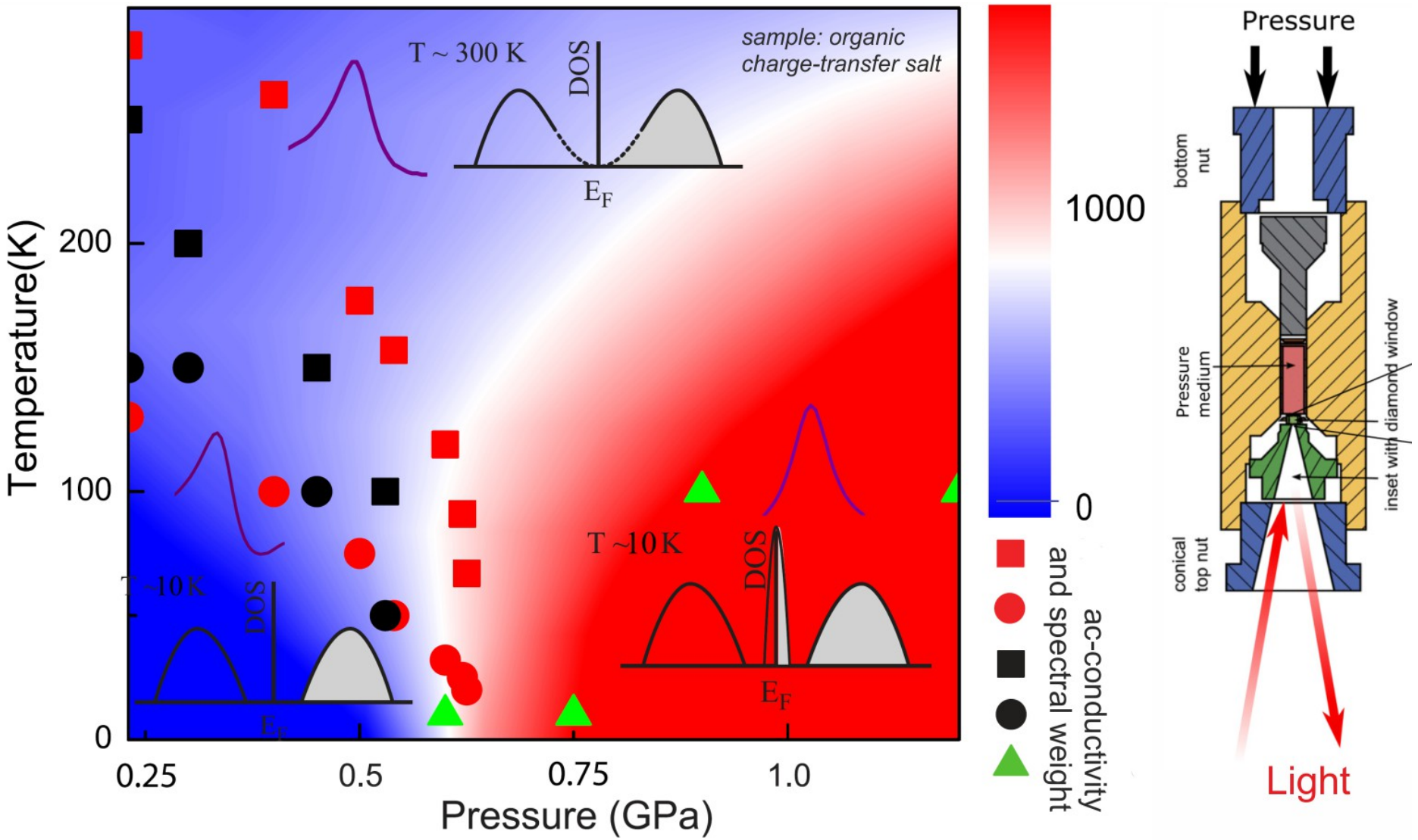


ARPES = angle-resolved photoemission spectroscopy

ARPES spectra

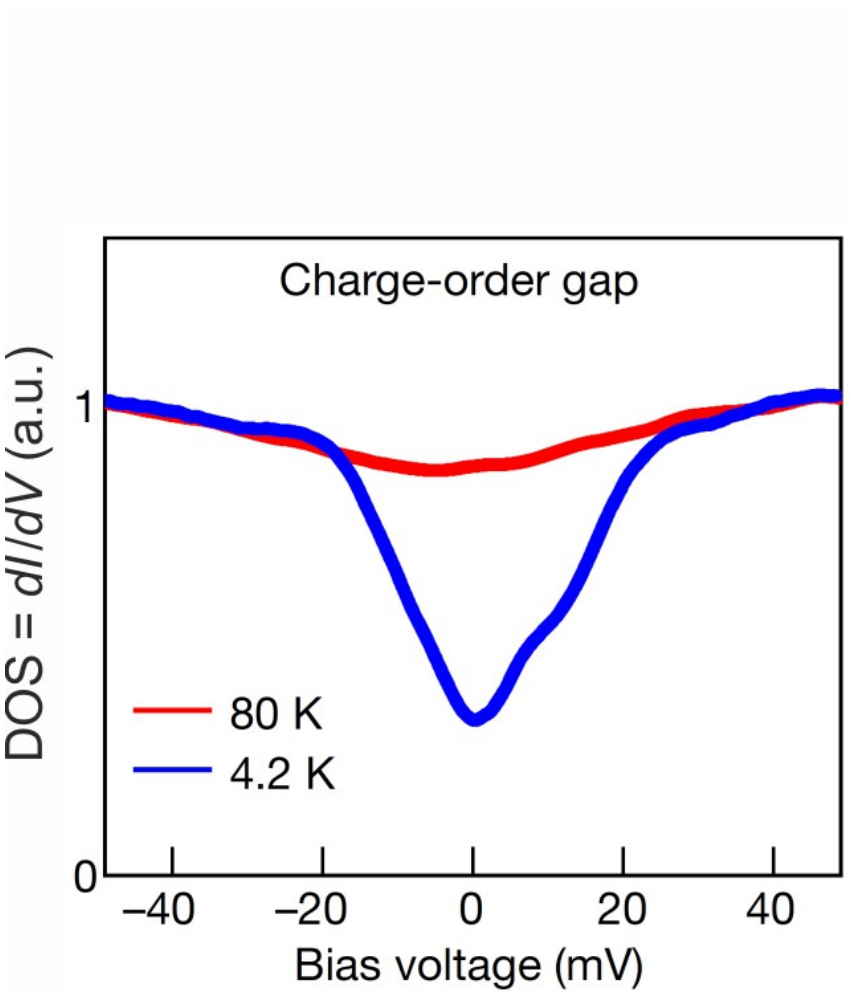


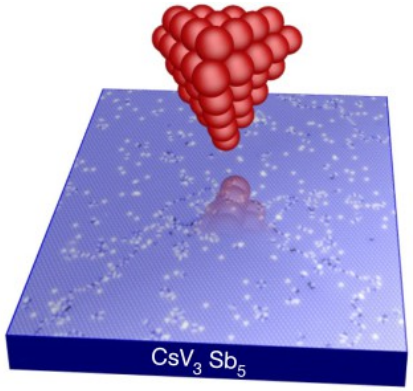
Probe of band structure: optics

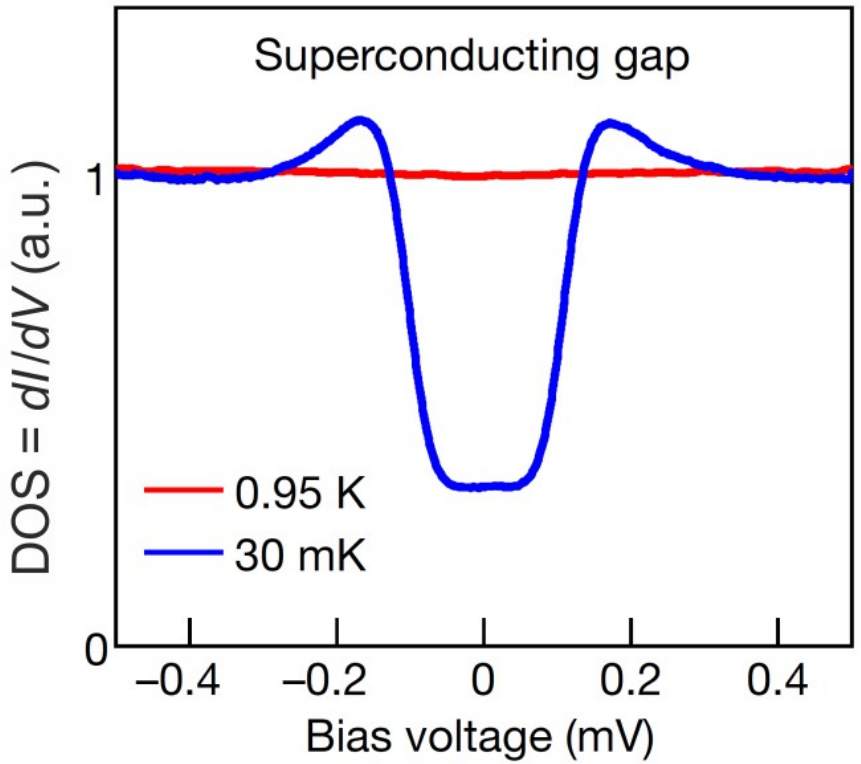


Phys. Rev. B 99, 115137 (2019)

Probe of band structure: STS



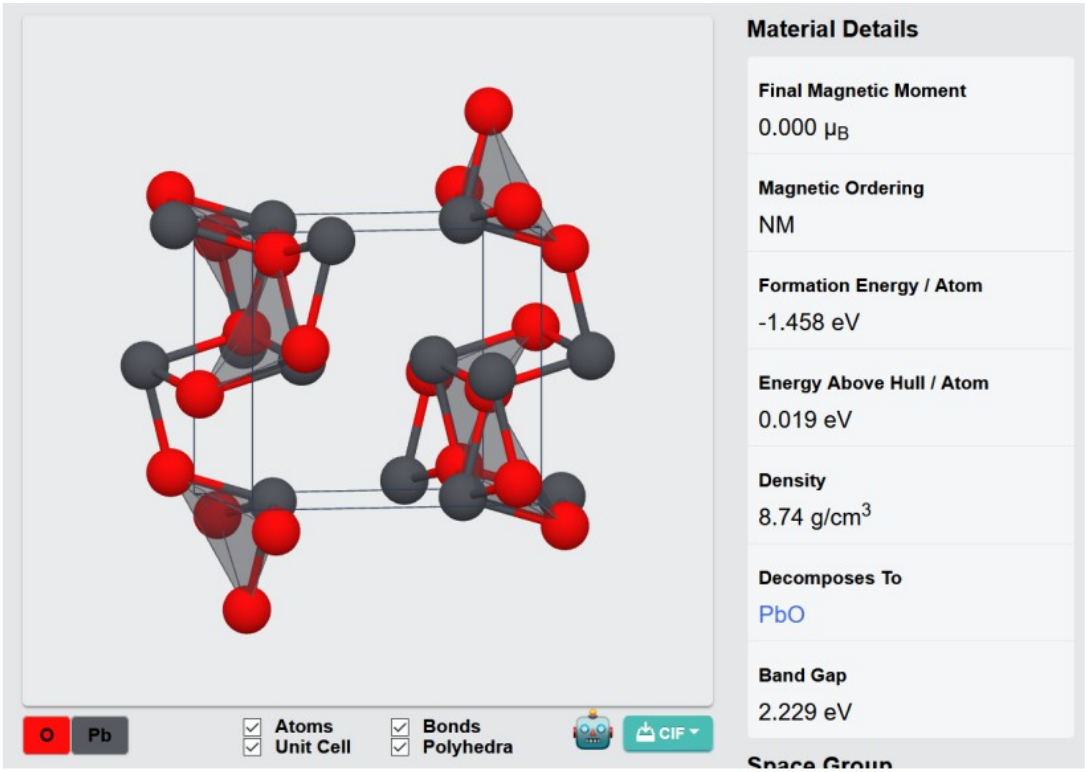




Nature 632, 775 (2024) and Nature 599, 222 (2021)

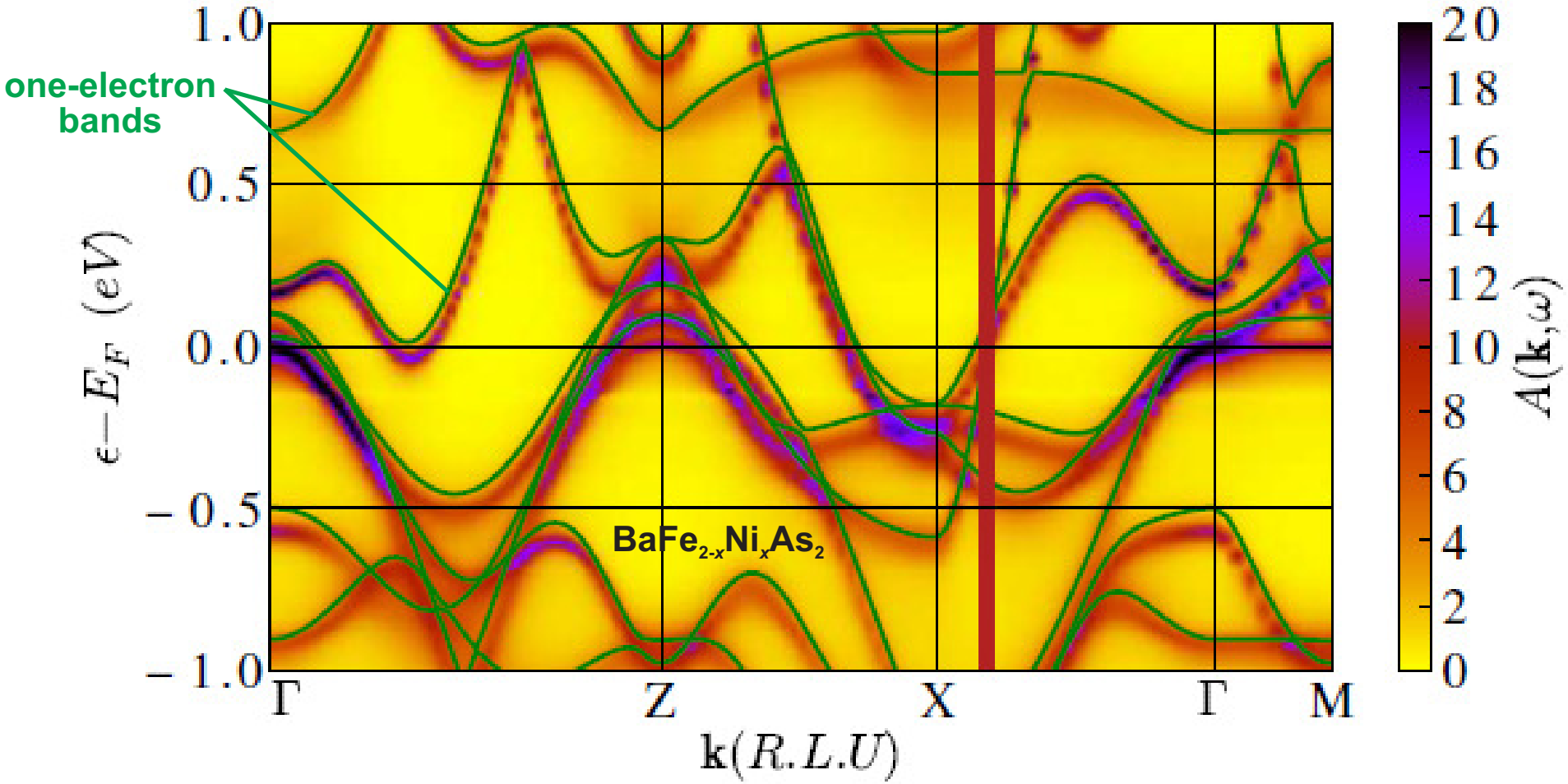
The Materials Project

https://materialsproject.org



Collects band structures for all known and many predicted materials

(the data are **not** experimental)



$A(\mathbf{k}, \omega)$ is known as Bloch spectral function