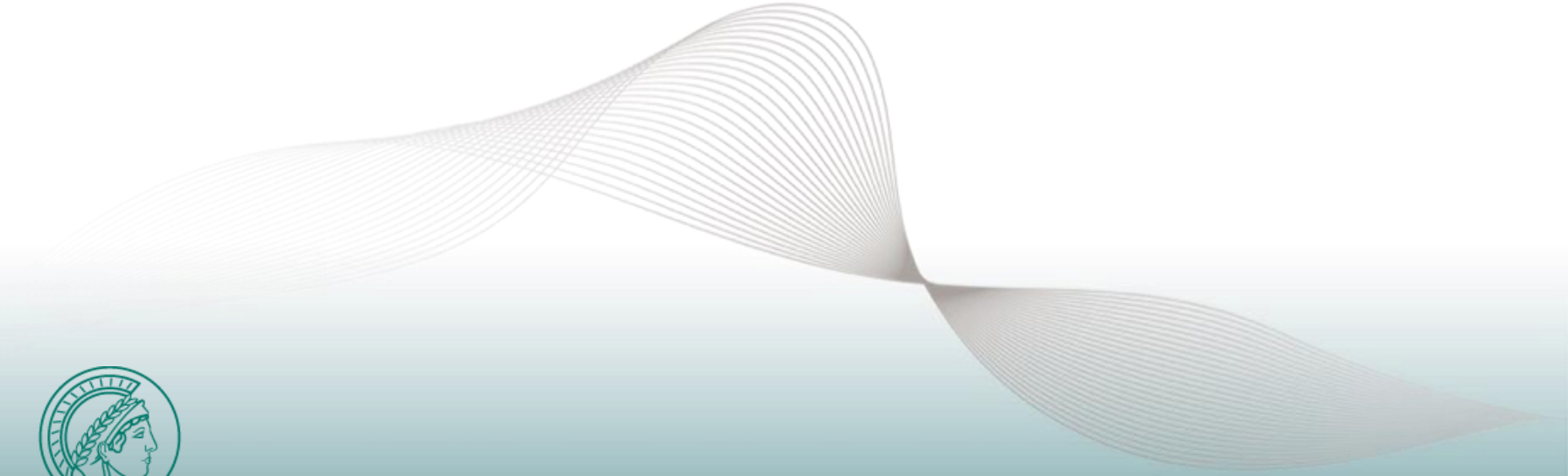
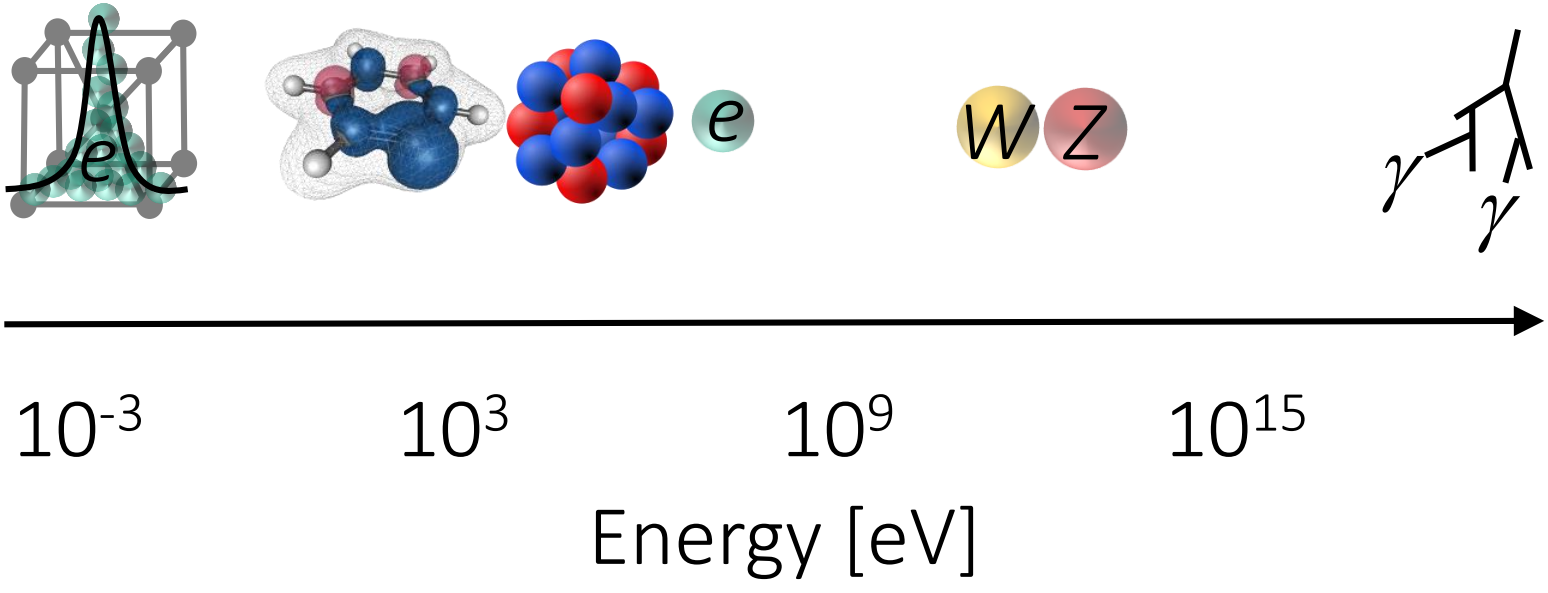
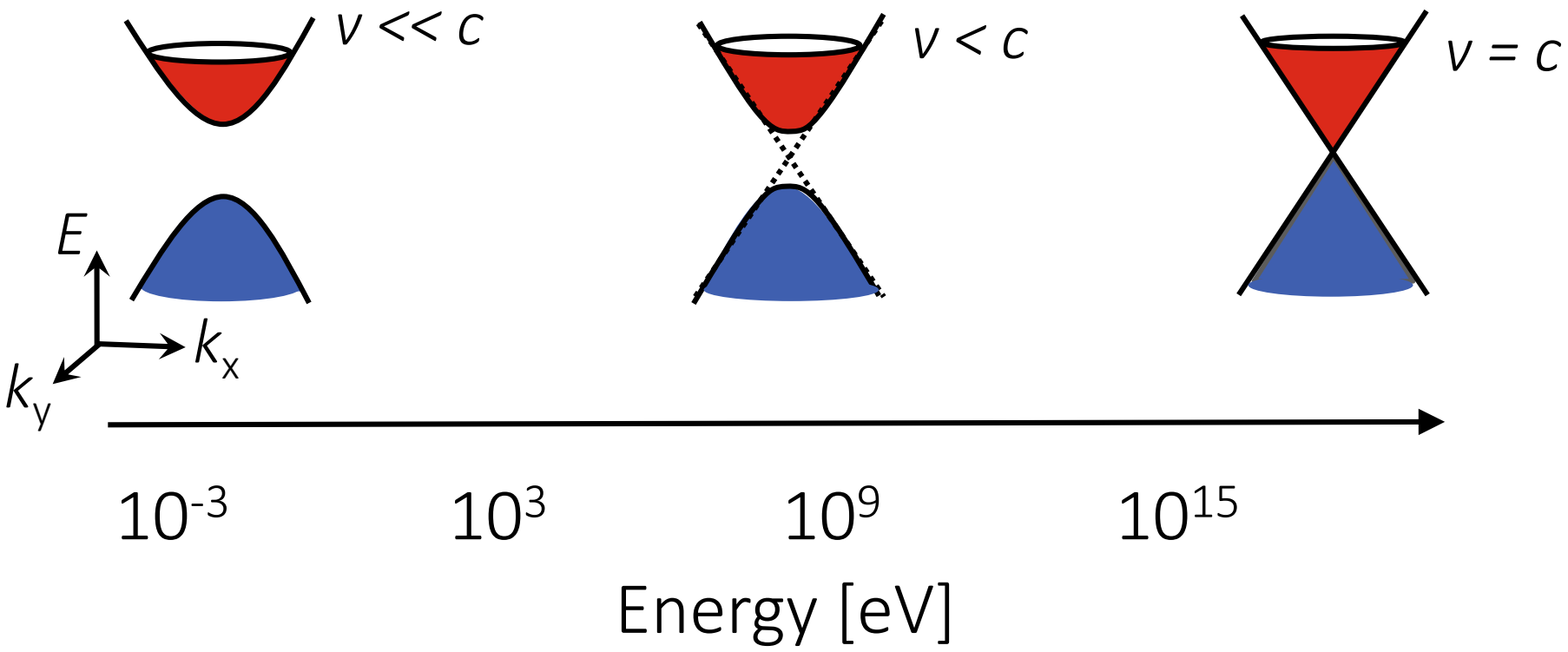
IMPRG Nanostructured Quantum Matter



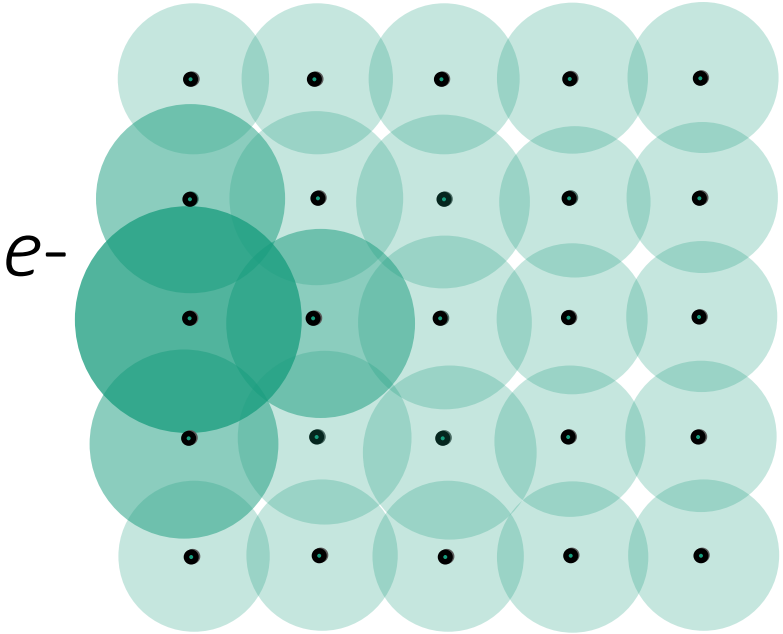
Energy scales



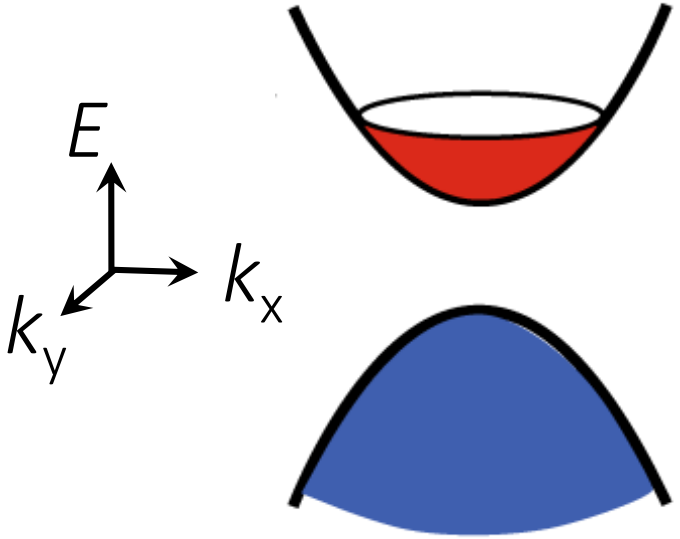
Energy scales



Electron quasiparticle

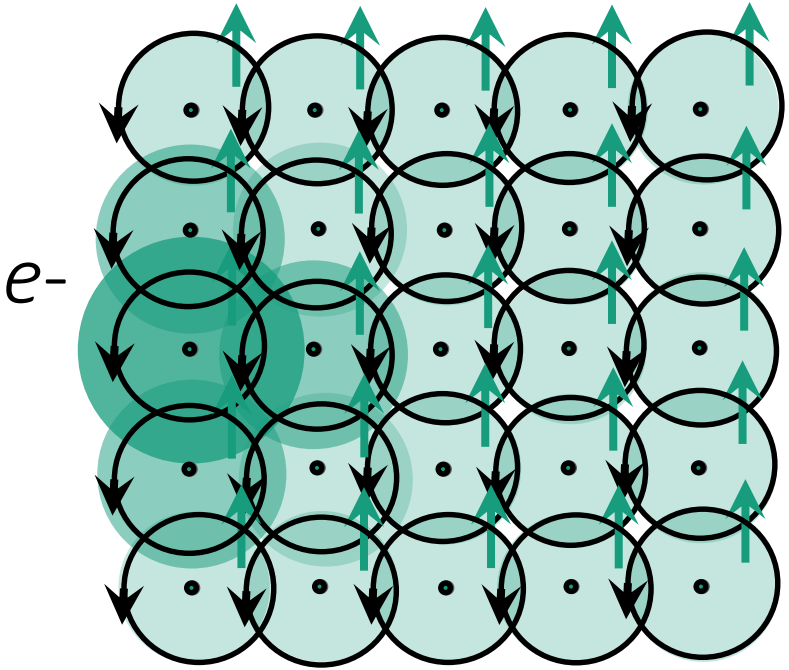


classical fermion

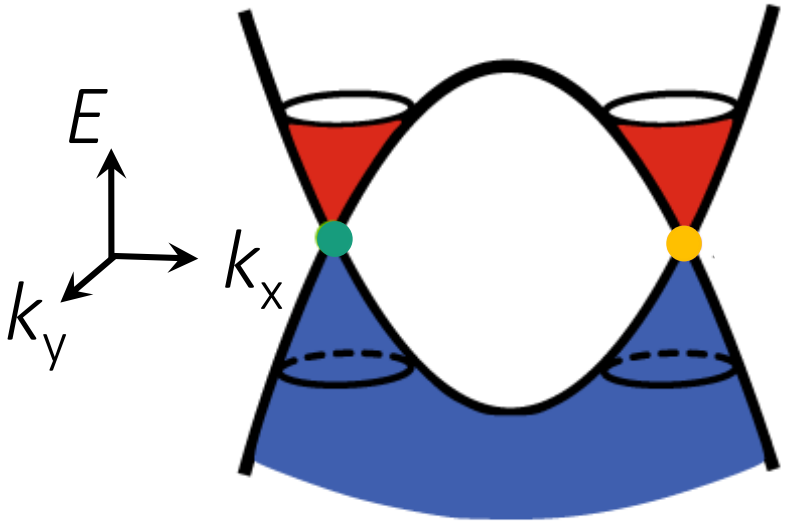


$$E = \hbar^2 k^2 / 2m$$

Electron quasiparticle



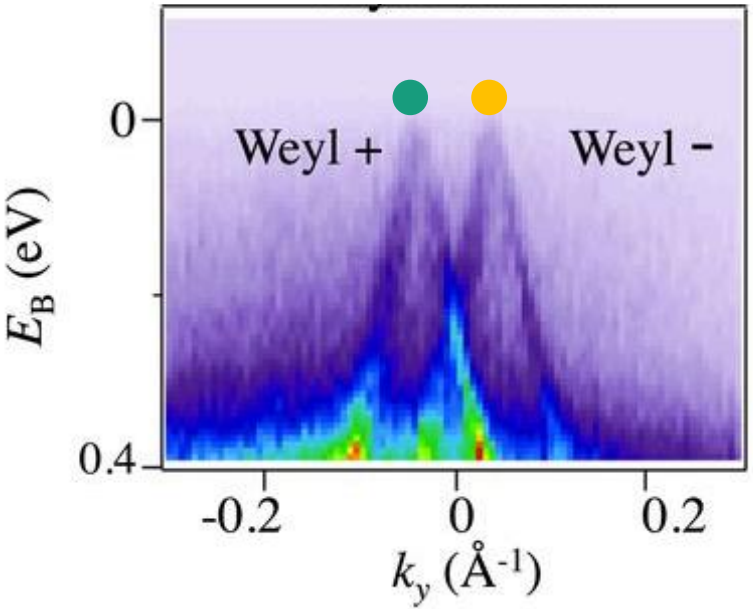
„relativistic“ fermion

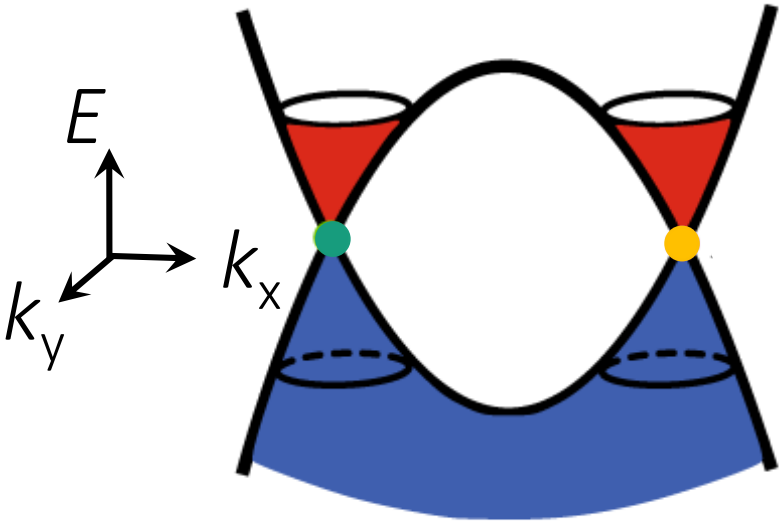


$$E = |\hbar v_F k|$$

Weyl fermion quasiparticle

„relativistic“ fermion





$$E = |\hbar v_F k|$$

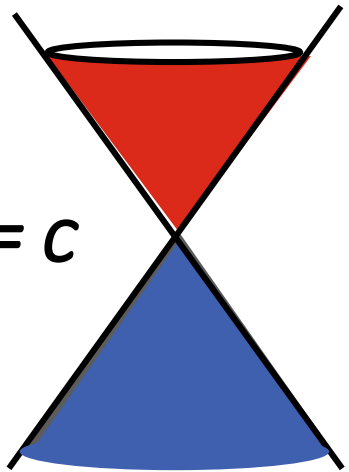
B. Yan and C. Felser, *Ann. Rev.* (2017)

The vacuum and band structures

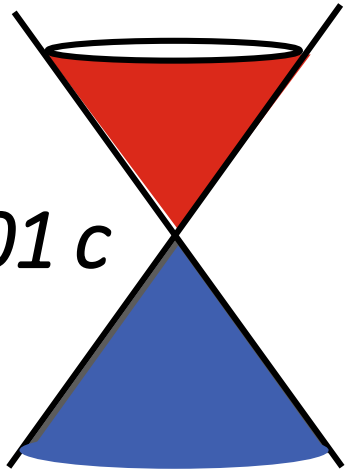
particles

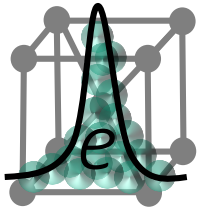
“electrons“

$v = c$



$v = v_F \approx 0.001\ c$

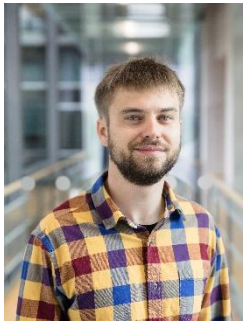




anti-particles

“ holes“

The people

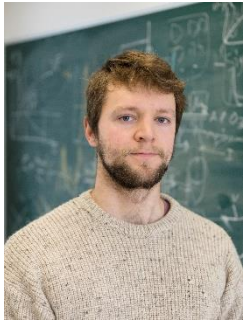


Rafał Wawrzyńczak

Stanislaw Galeski

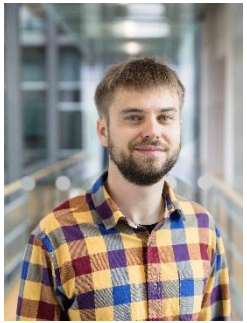
Narayan Kunchur

Wajdi Abdel-Haq



Clemens Schindler

The people



Rafał Wawrzyńczak

Stanislaw Galeski

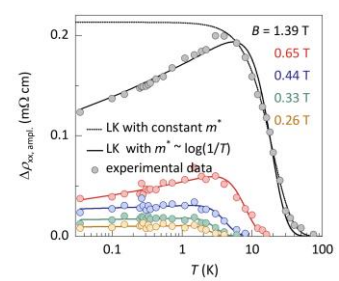
Narayan Kunchur

Wajdi Abdel-Haq

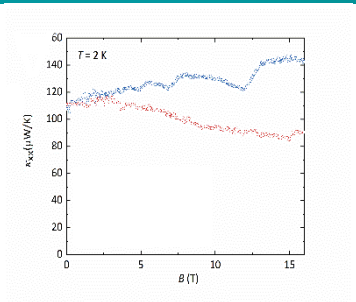
Clemens Schindler

The labs

The science

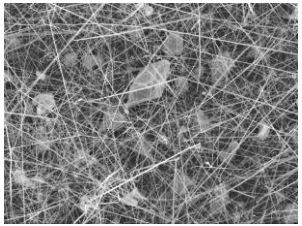


Diluted semimetals

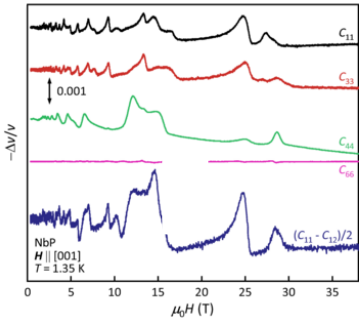


Quantum anomalies

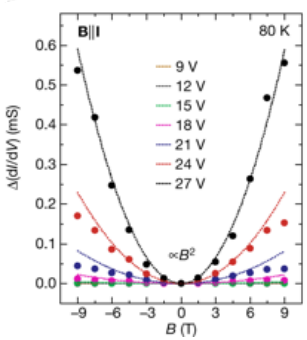
Curved crystals



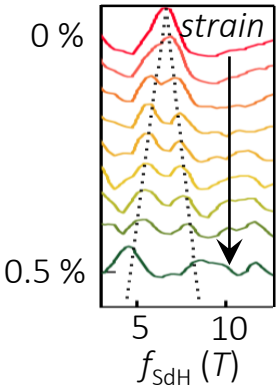
Dirac and Weyl semimetal nanostructures



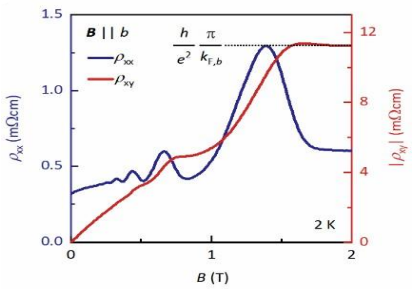
Sound waves in Weyl and Dirac semimetals



Correlation in Weyl semimetals / Axion insulators



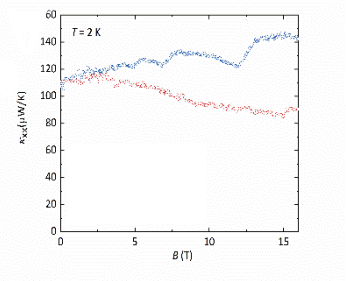
Strain in Dirac and Weyl semimetals



Quantum Hall-physics in 3D metals

The science

Diluted semimetals

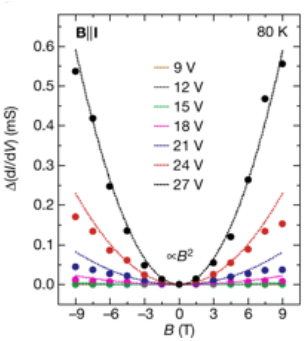


Quantum anomalies

Curved crystals

Dirac and Weyl semimetal nanostructures

Sound waves in Weyl and Dirac semimetals

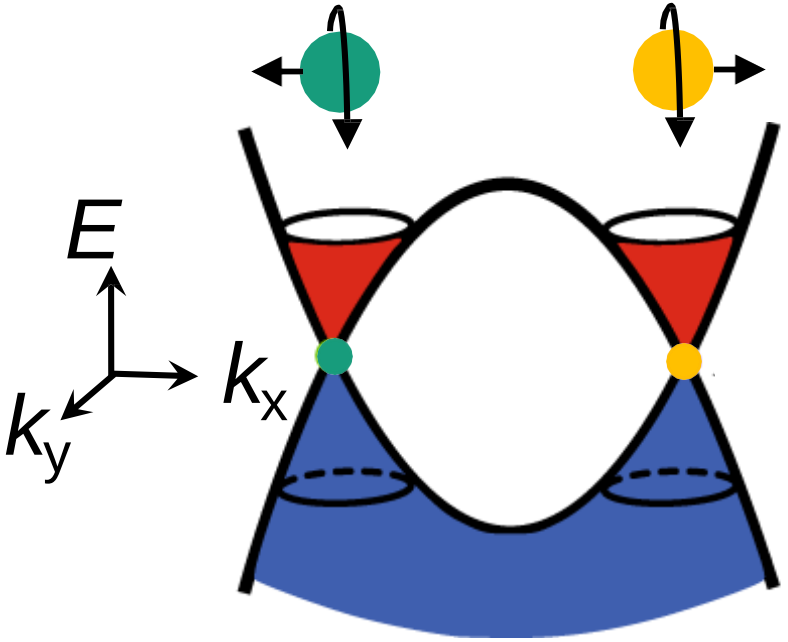


Correlation in Weyl semimetals / Axion insulators

Strain in Dirac and Weyl semimetals

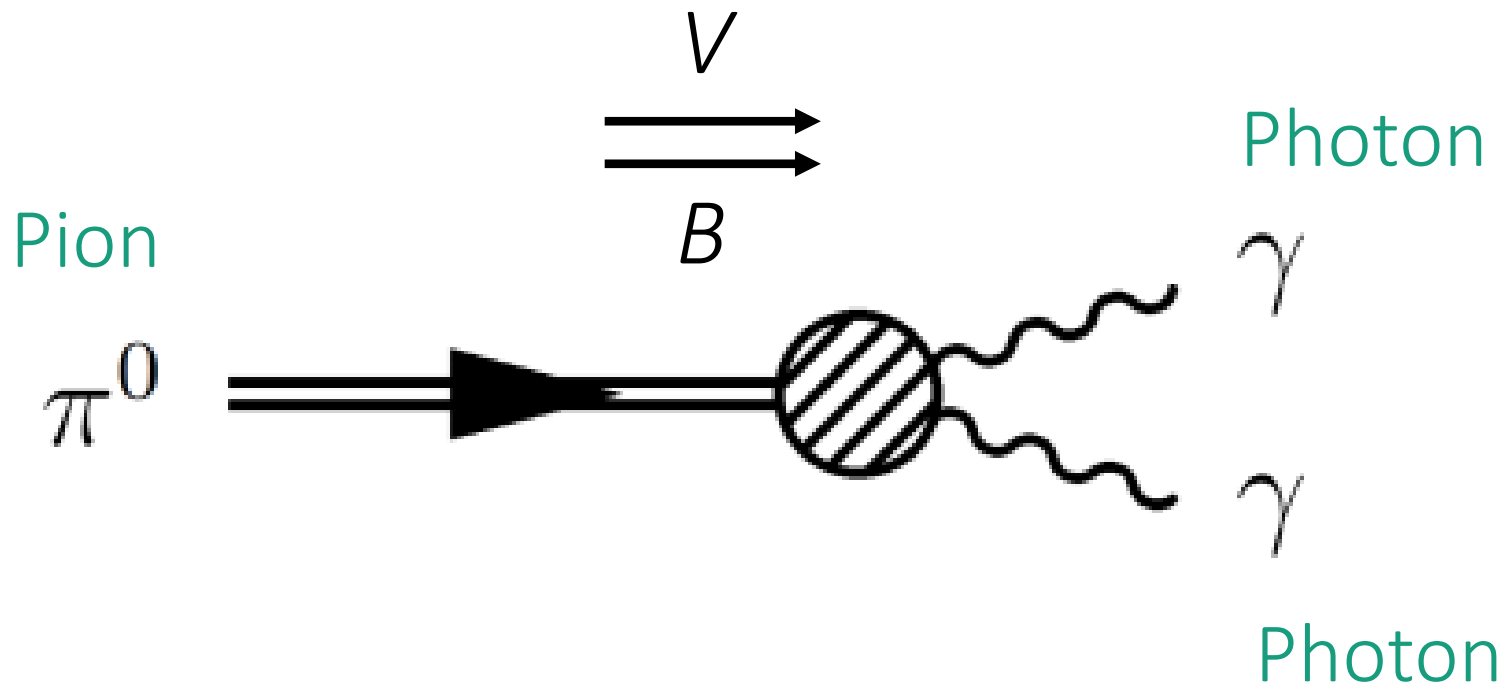
Quantum Hall-physics in 3D metals

Chirality



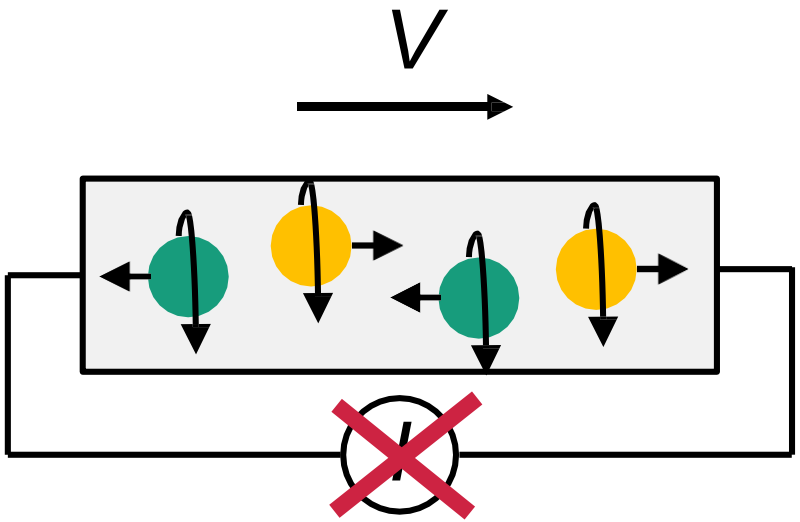
$\chi = +1 \quad \chi = -1$

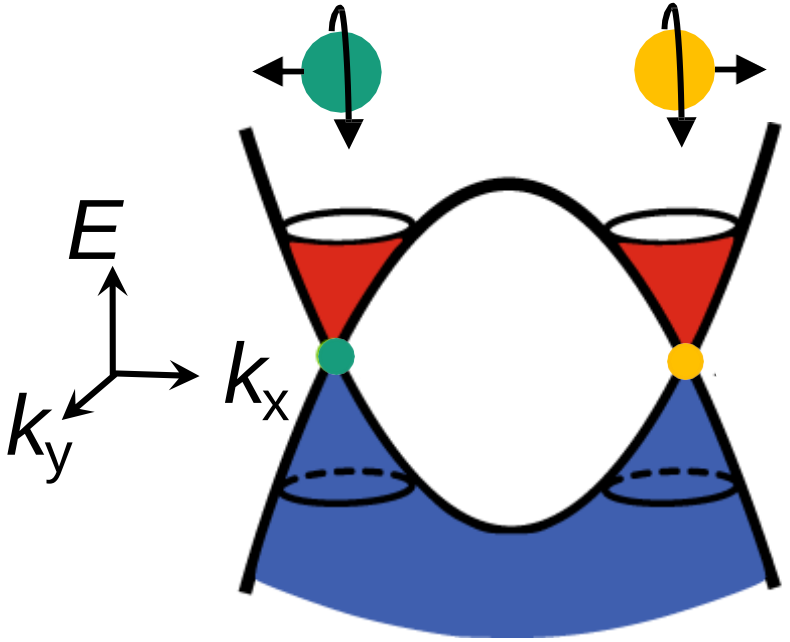
Chiral anomaly



S. L. Adler, *Phys. Rev.* 1969
J. S. Bell & R. Jackiw, *Nuovo Cim.* 1969

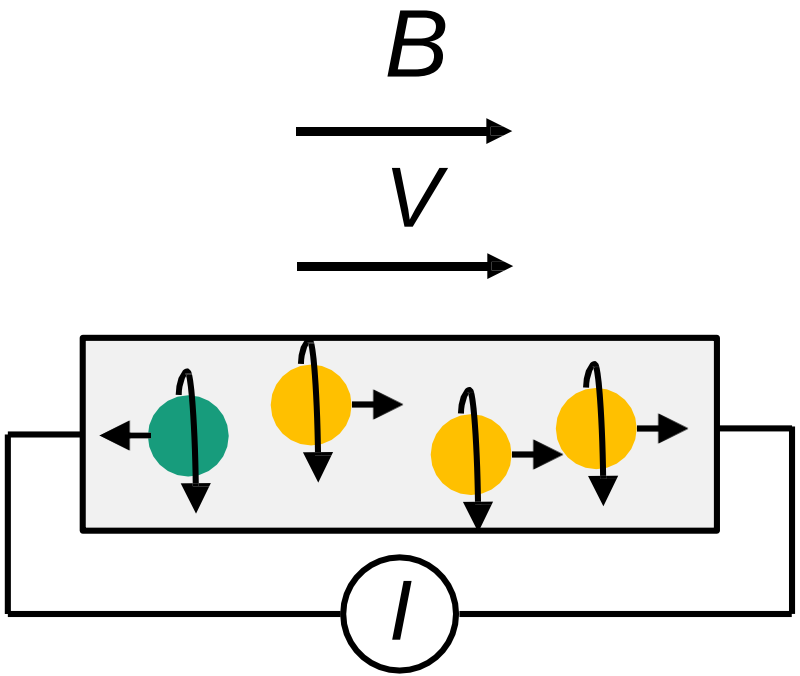
Conservation of chirality

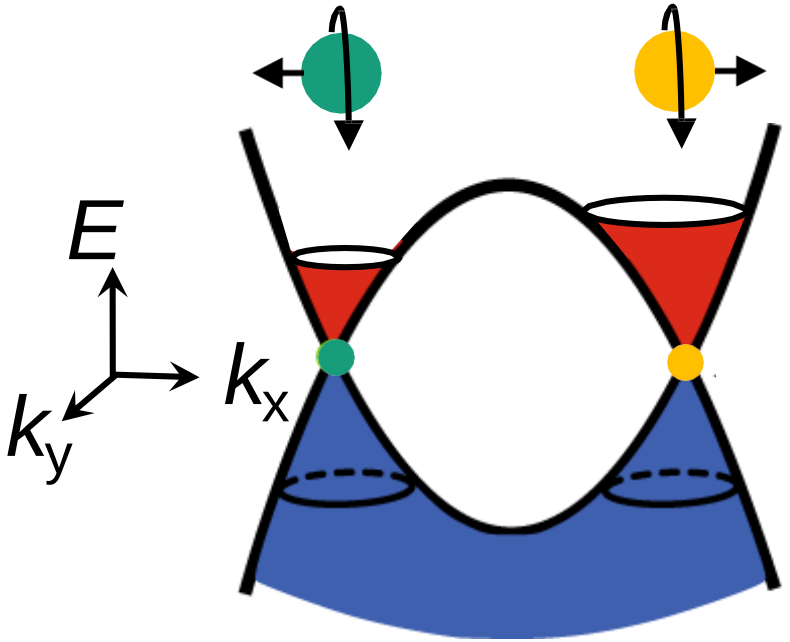




$\chi = +1$ $\chi = -1$

Chiral anomaly

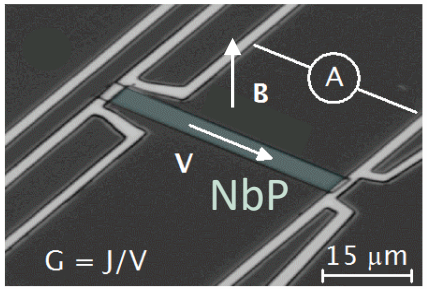


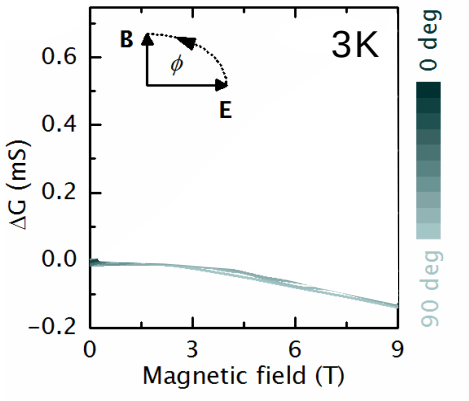


$$G = I/U = d_c + c_1 a_\chi B_\parallel^2$$

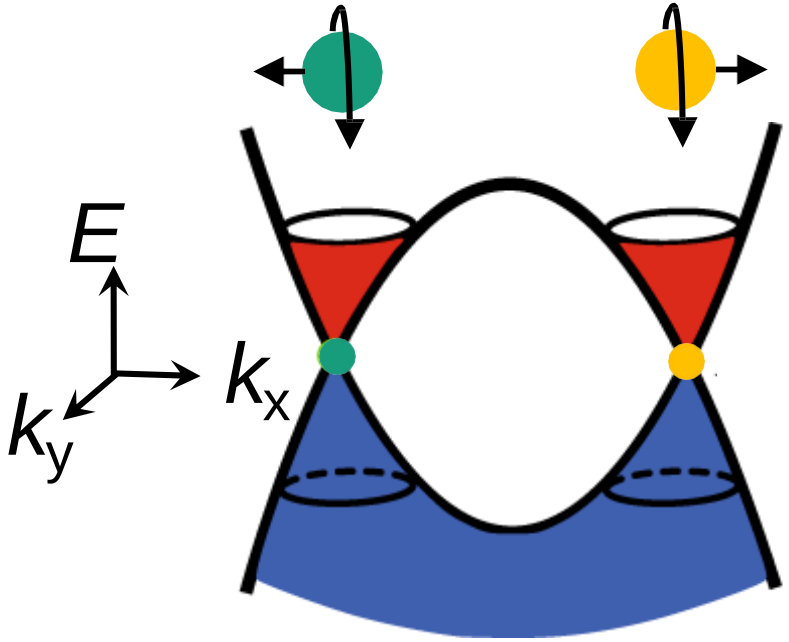
$\chi = +1$ $\chi = -1$

Conservation of chirality



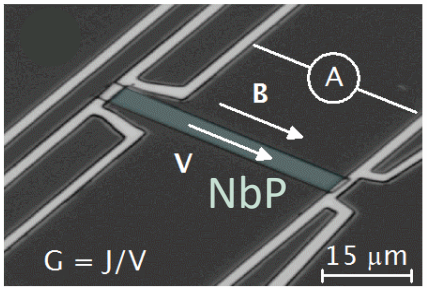


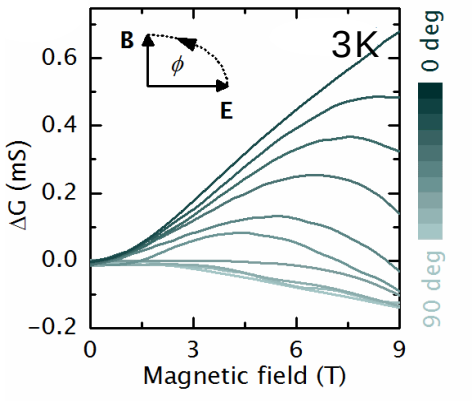
J. Gooth et al., *Nature* (2017)



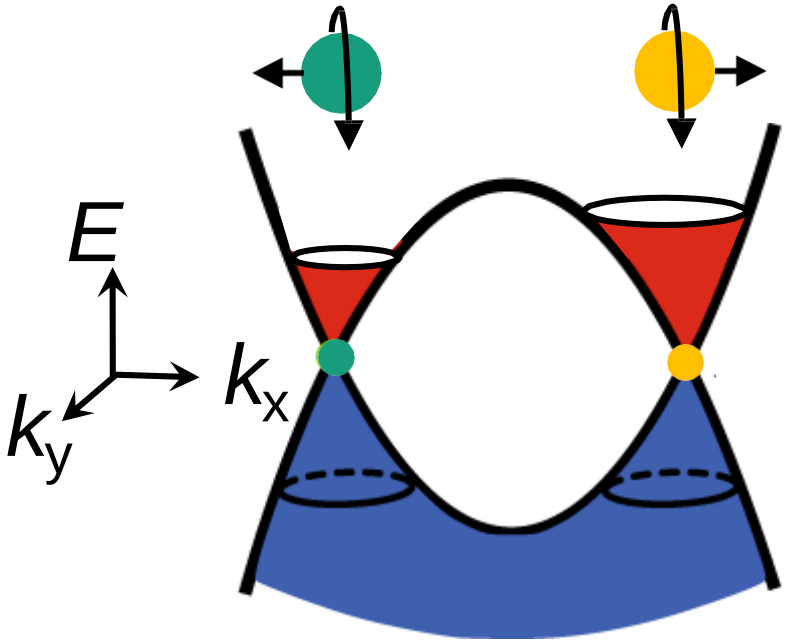
$\chi = +1 \quad \chi = -1$

Chiral anomaly



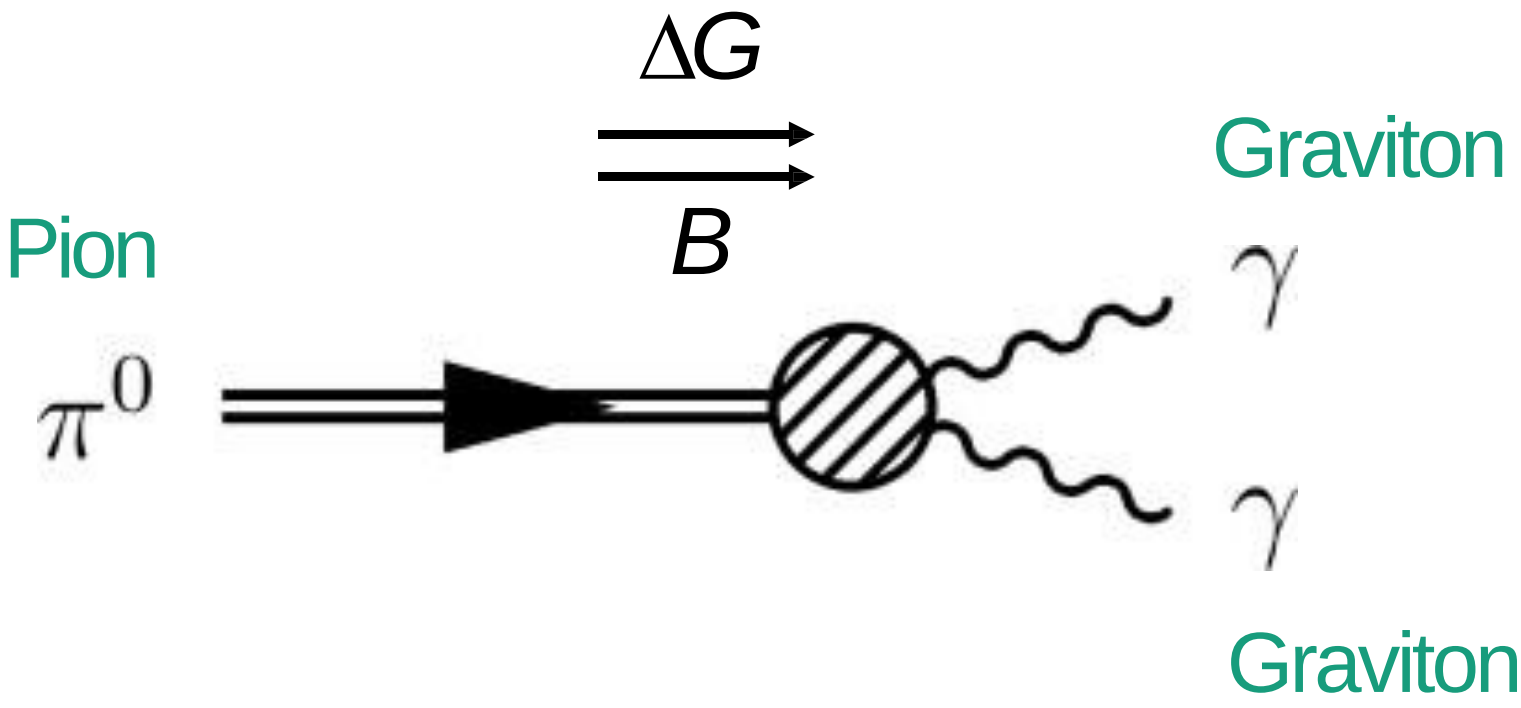


J. Gooth et al., *Nature* (2017)



$\chi = +1 \quad \chi = -1$

Mixed axial-gravitational anomaly



L. Alvarez-Gaumé & E. Witten, *Nucl. Phys. B* (1984)

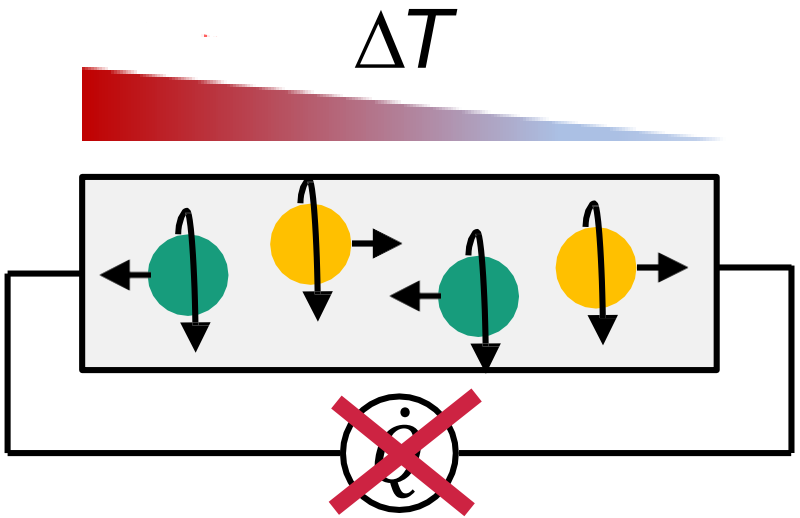
Thermal transport and temperature gradients

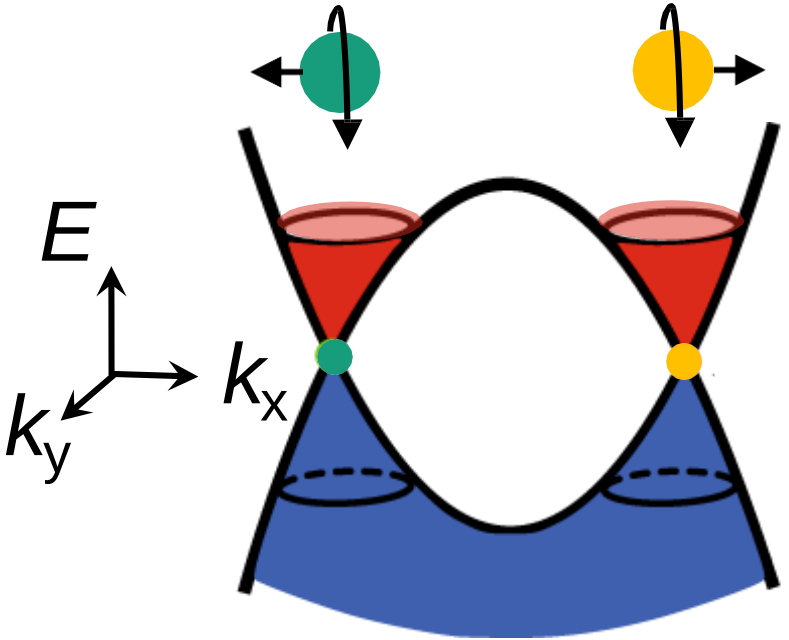
PHYSICAL REVIEW VOLUME 135, NUMBER 6A 14 SEPTEMBER 1964

Theory of Thermal Transport Coefficients*

J. M. LUTTINGER
Department of Physics, Columbia University, New York, New York
(Received 20 April 1964)

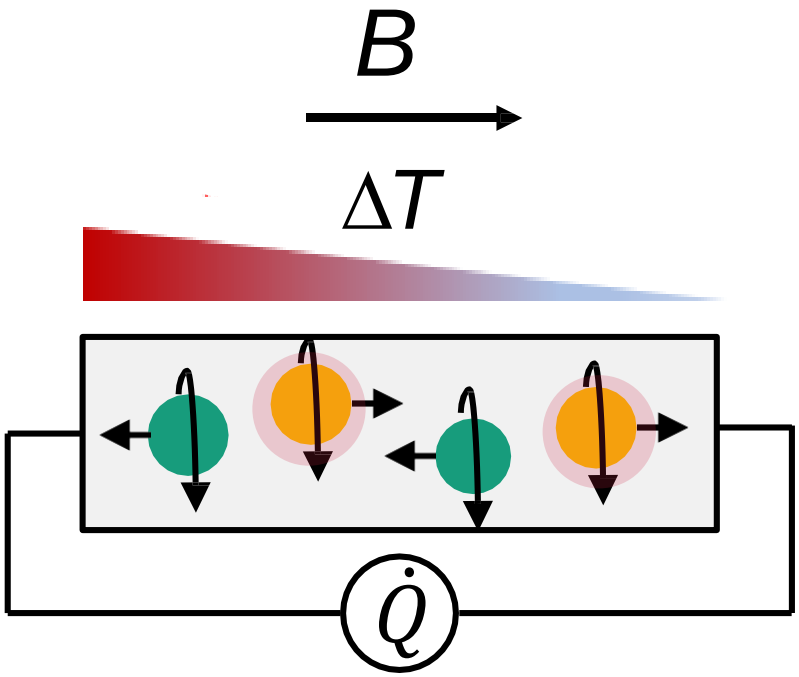
Conservation of the energy-momentum tensor

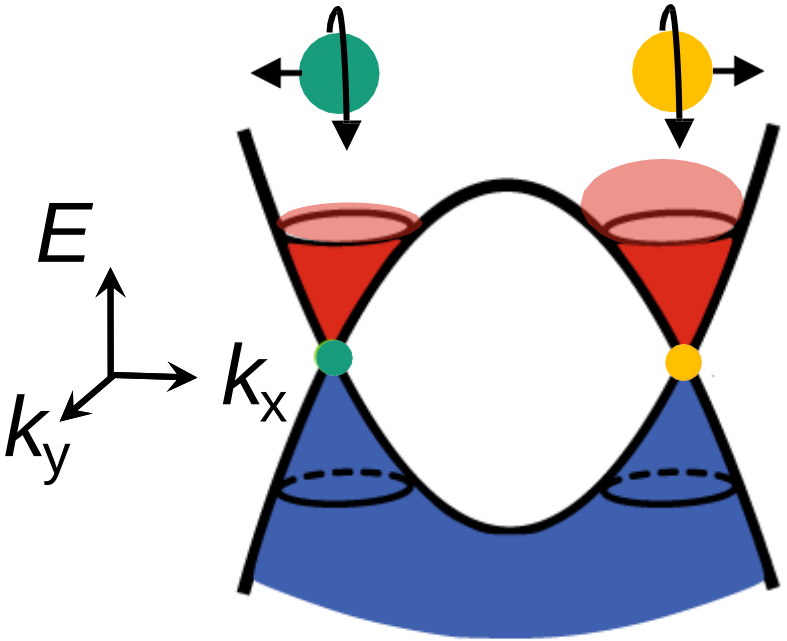




$\chi = +1 \quad \chi = -1$

Gravitational anomaly

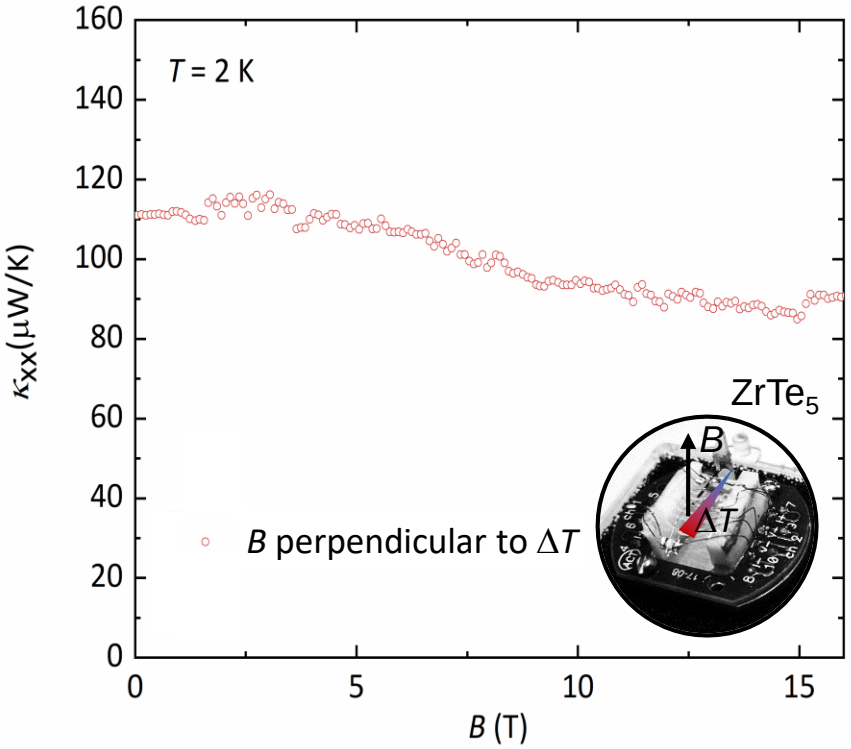


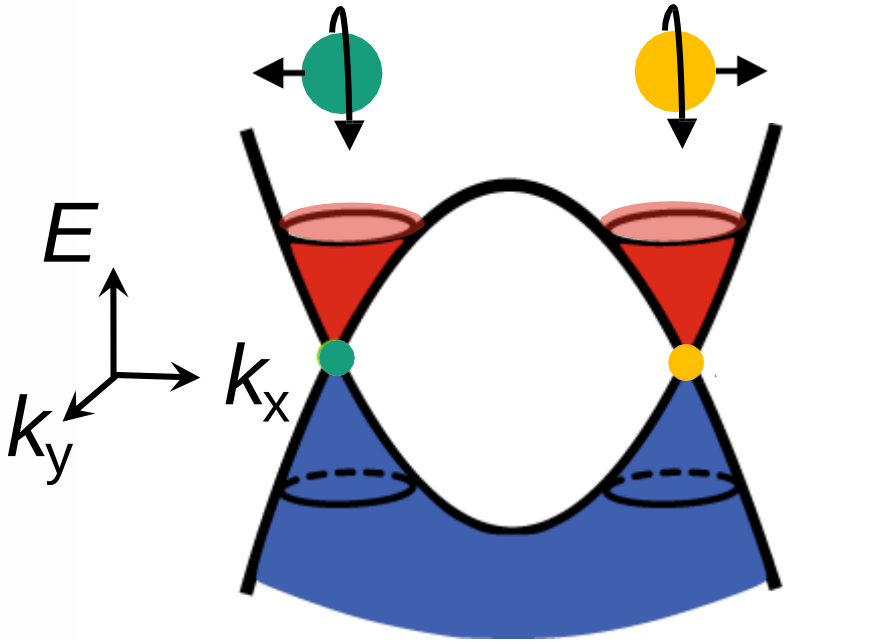


$$K_{th} = \dot{Q} / \Delta T = d_{th} + c_2 a_g B_{||}^2$$

$\chi = +1$ $\chi = -1$

Conservation of the energy-momentum tensor

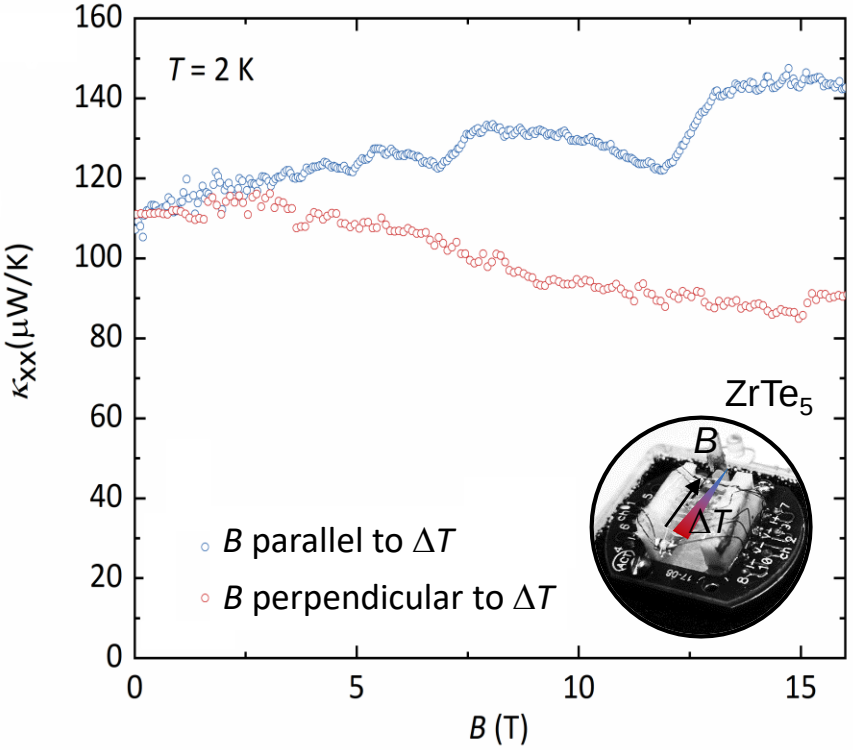


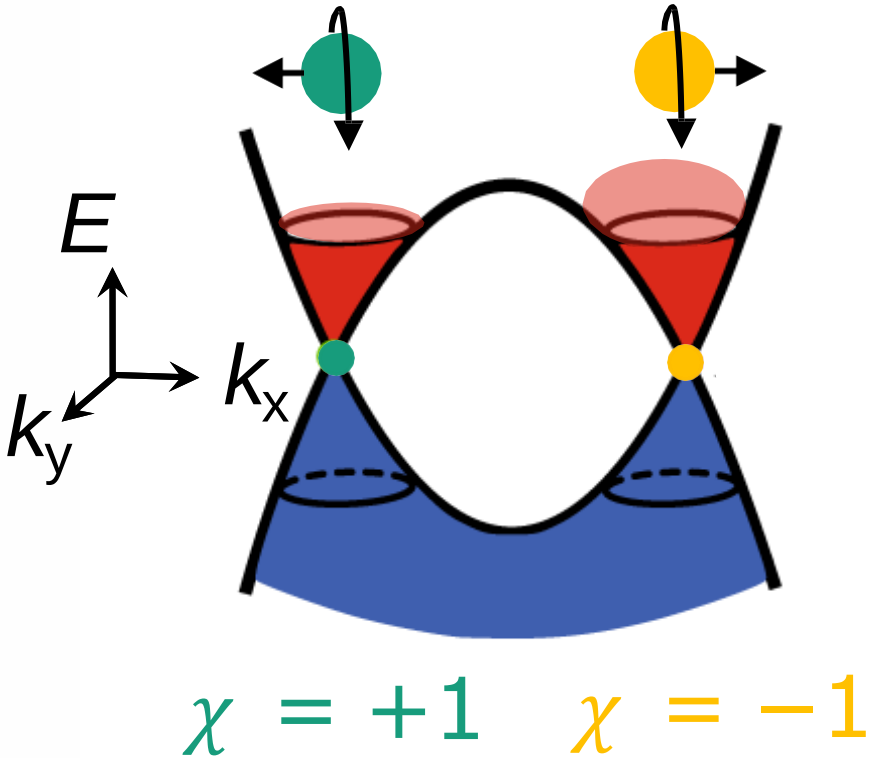


$\chi = +1 \quad \chi = -1$

S. Galeski et al. unpublished

Gravitational anomaly





S. Galeski et al. unpublished

The Axion

Strong CP problem

Charge-parity symmetry should be violated, but this is not observed.

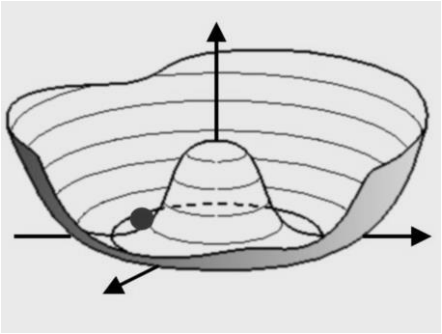
C: particle ↔ anti-particle

P: x ↔ -x

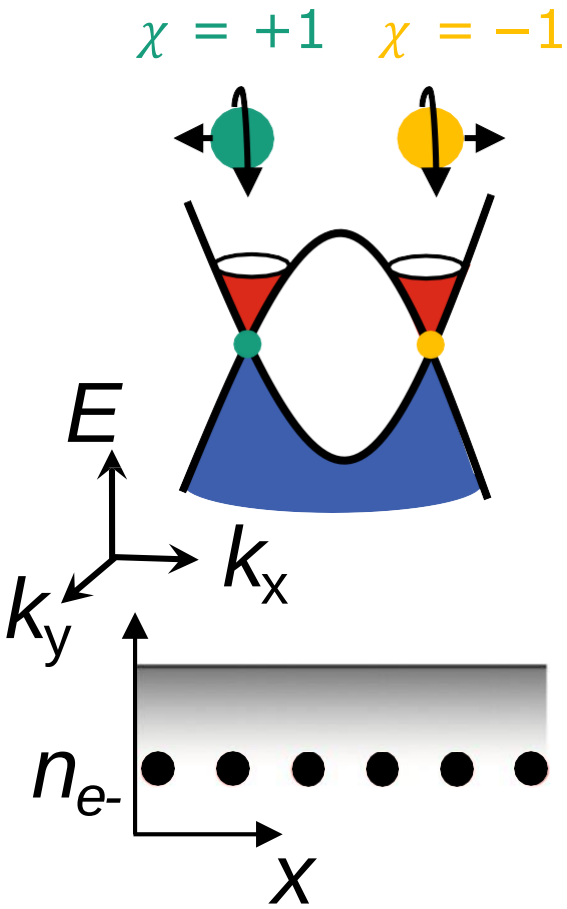
F. Wilczek, Phys. Rev. Lett. (1987)

Solution

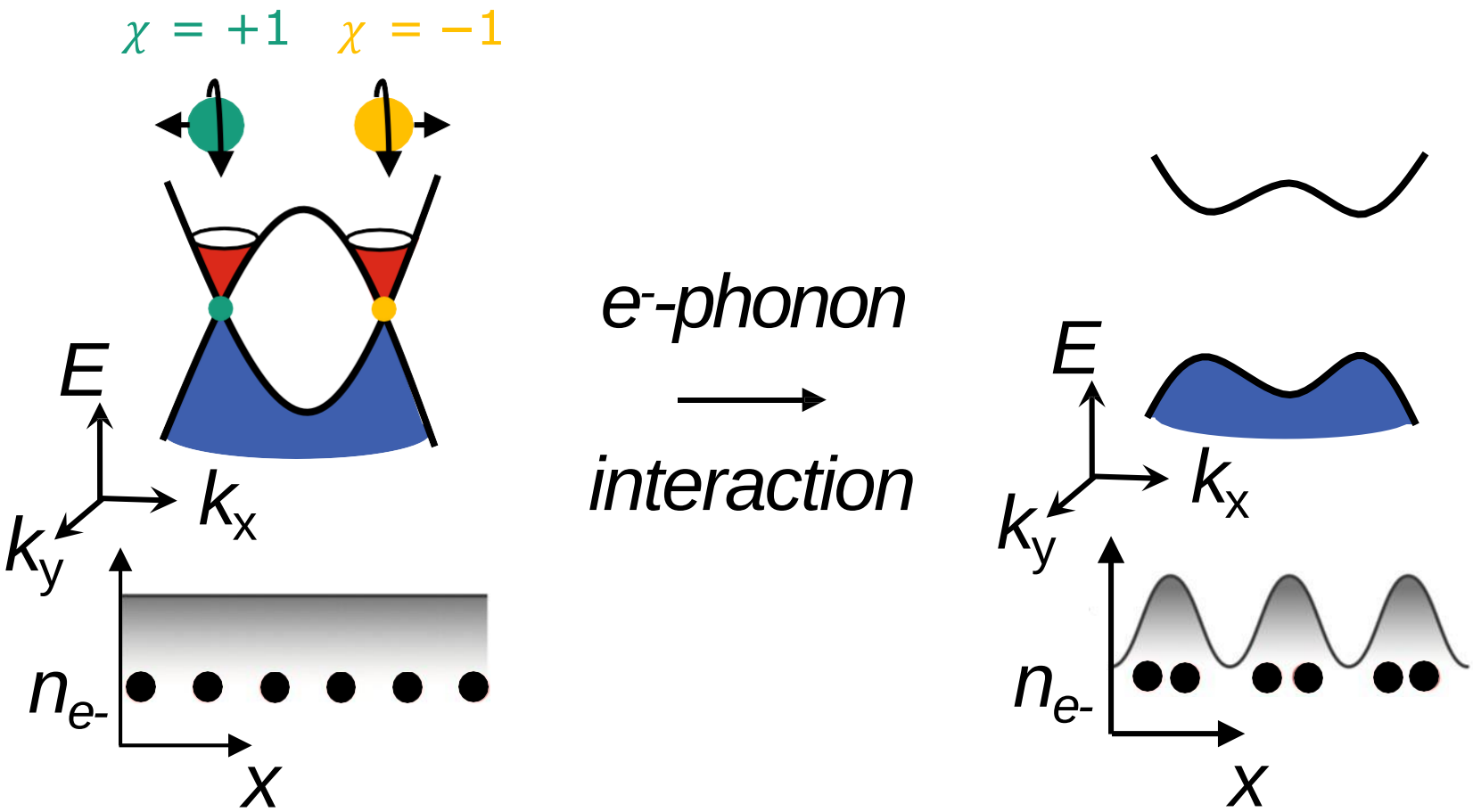
The axion: A new particle that breaks chiral symmetry instead.



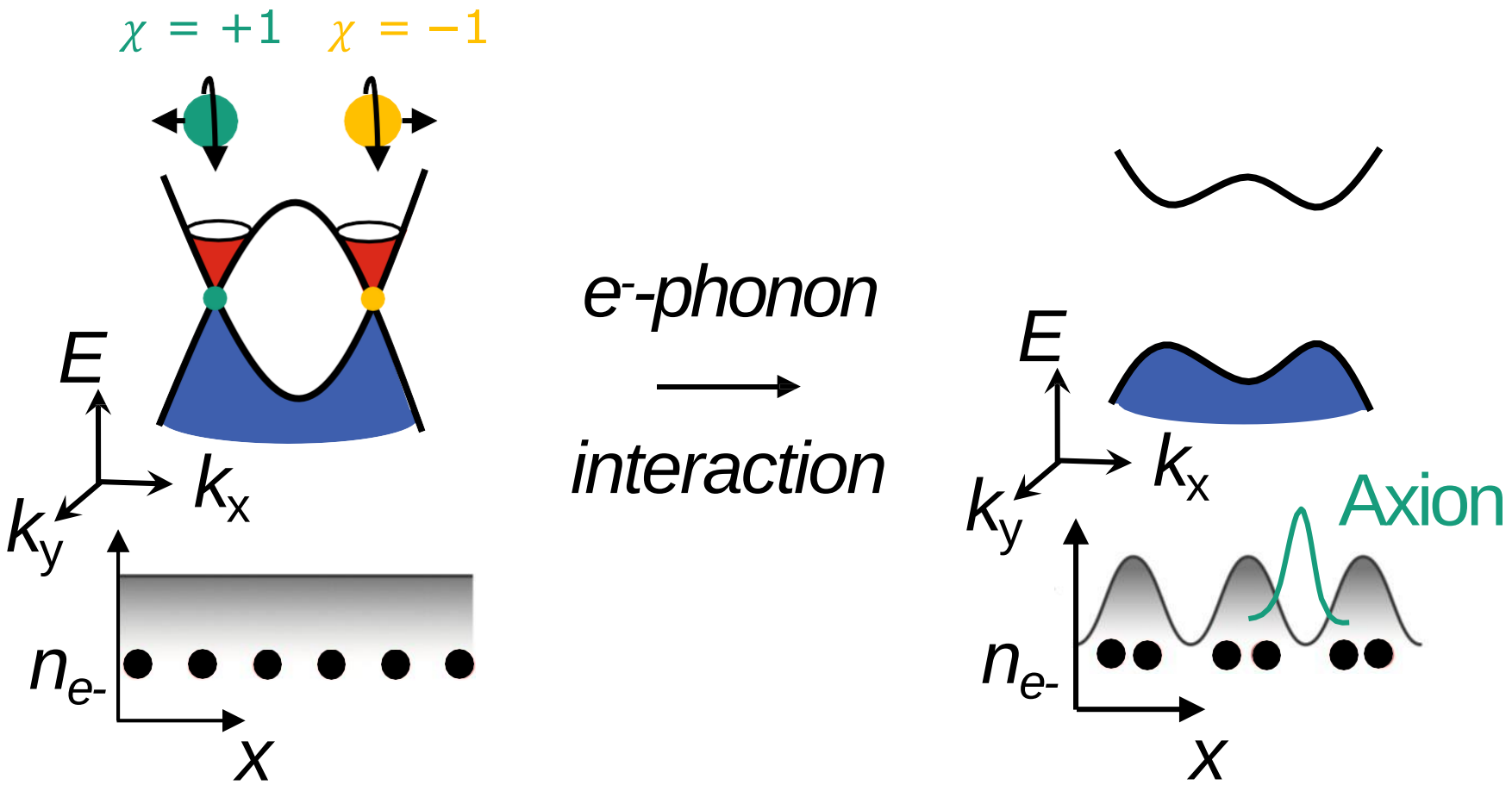
The Axion quasiparticle



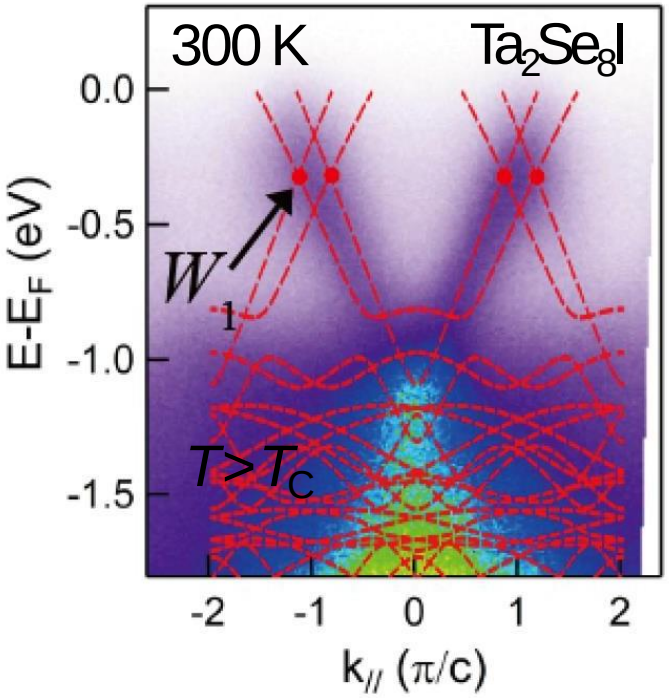
The Axion quasiparticle



The Axion quasiparticle

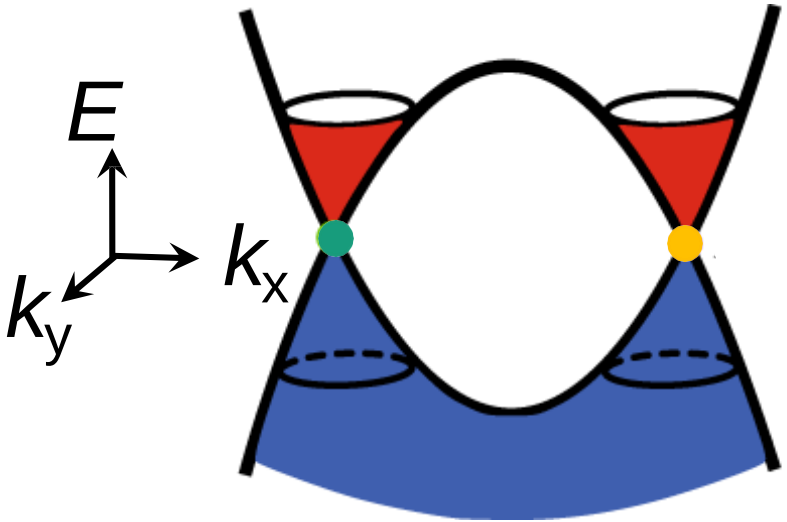


Weyl semimetal $(TaSe_4)I_2$ at 300 K



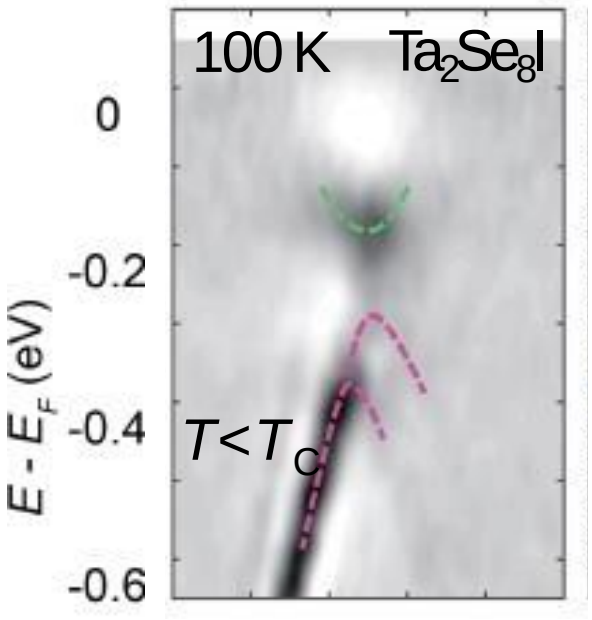
W. Shi et al., *Nat. Phys.* (2020)

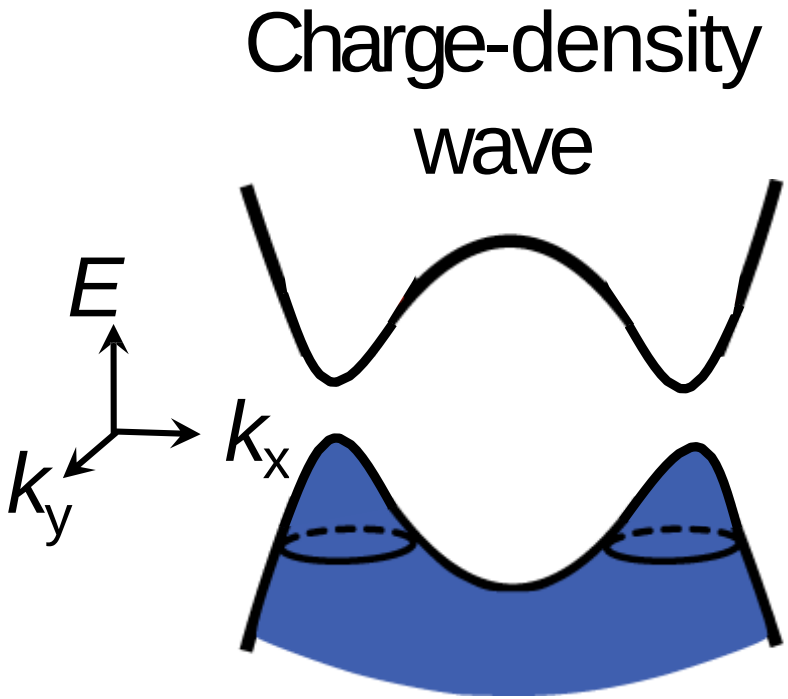
Weyl metal



$$E = |\hbar v_F k|$$

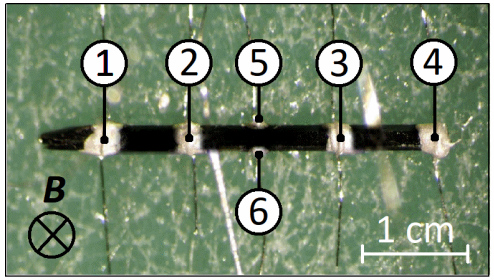
CDW Weyl semimetal $(TaSe_4)I_2$ at 100 K

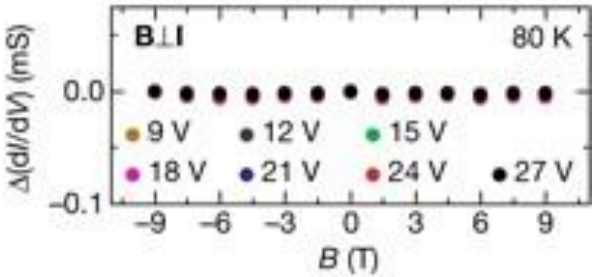


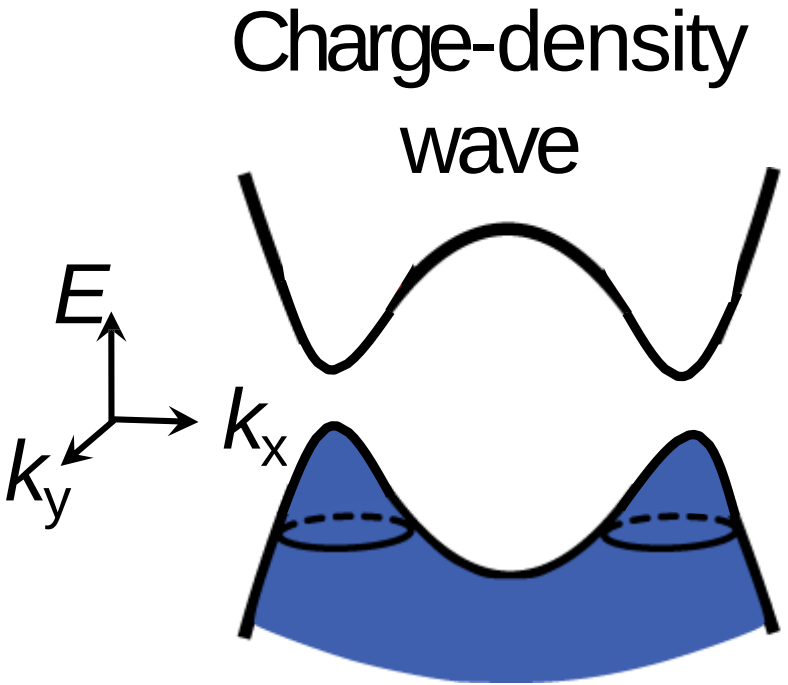


W. Shi et al., *Nat. Phys.* (2020)

Axion quasiparticle $(TaSe_4)I_2$







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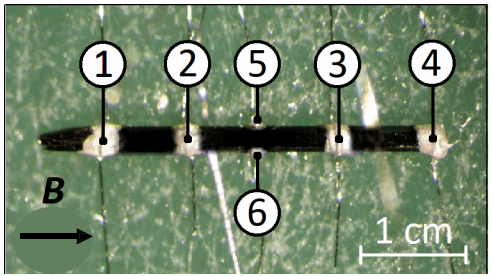
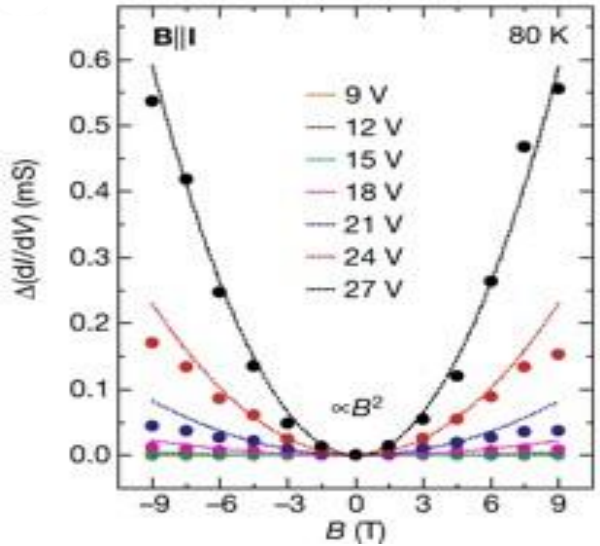
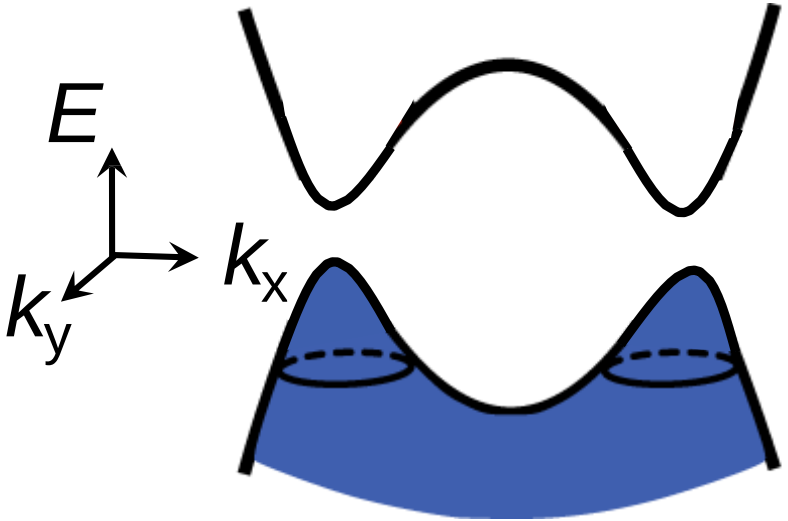
Axion quasiparticle $(TaSe_4)I_2$





Axion insulator



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Professorship in Bonn

Chair of experimental condensed matter physics