Free-Kagome

Force-free microstructures reveal distinct switching of chiral transport in AV_3Sb_5 Kagome superconductors

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Theory:

GL theory on CVS:
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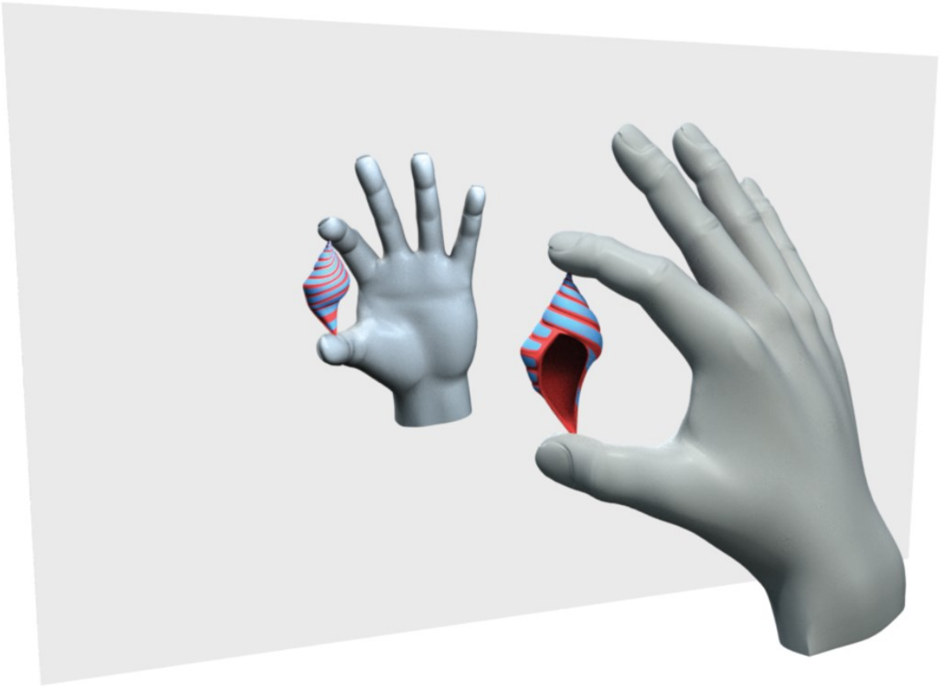
DFT:
Martin Gutierrez-Amigo, Ion Errea, Maia G. Vergniory

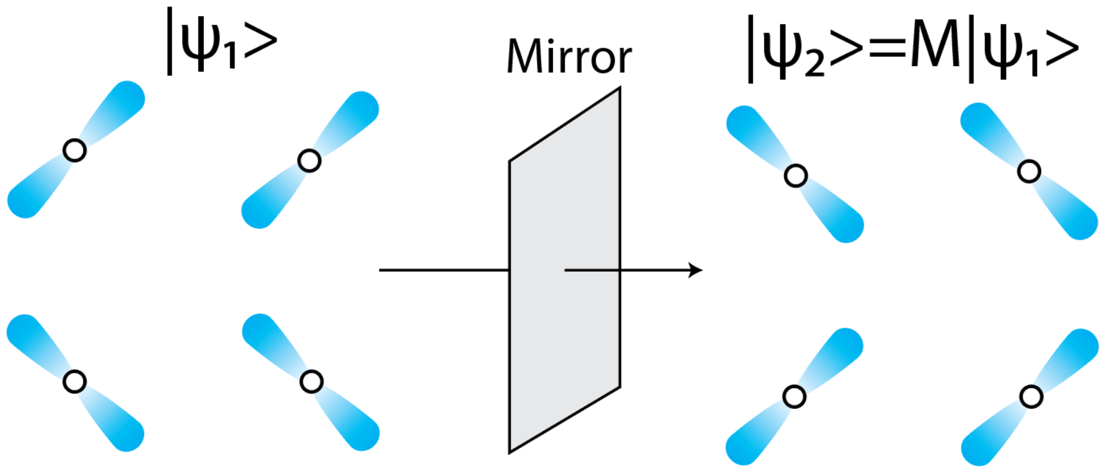
Symmetry in quantum materials

A simple example: mirror symmetry

Mirror symmetry in real life



Mirror symmetry in solid states

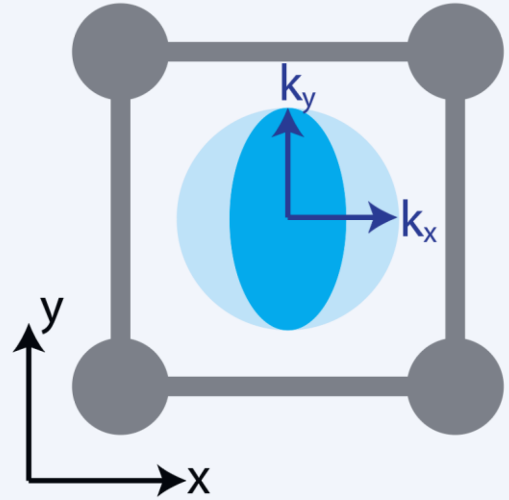


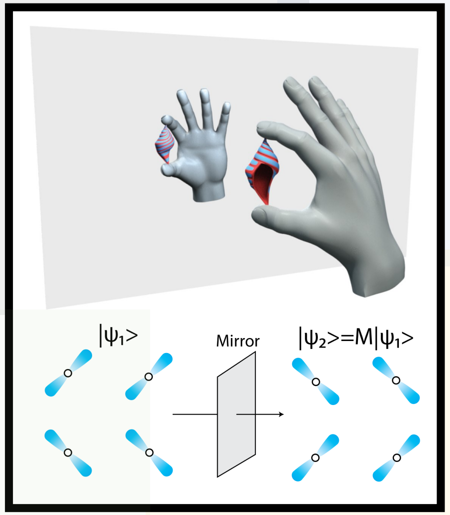
CG et al., Nature physics 18, 813 (2022)

Symmetry in quantum materials

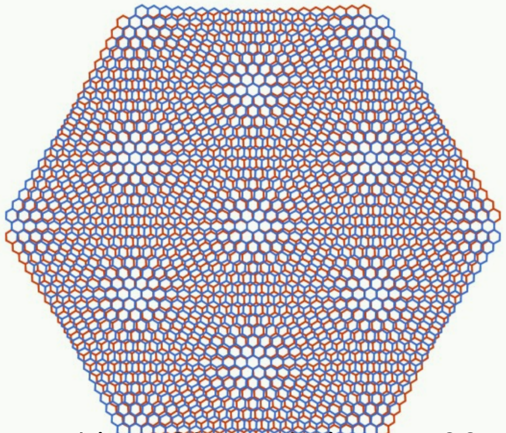
Symmetry to topology

Electronic symmetry

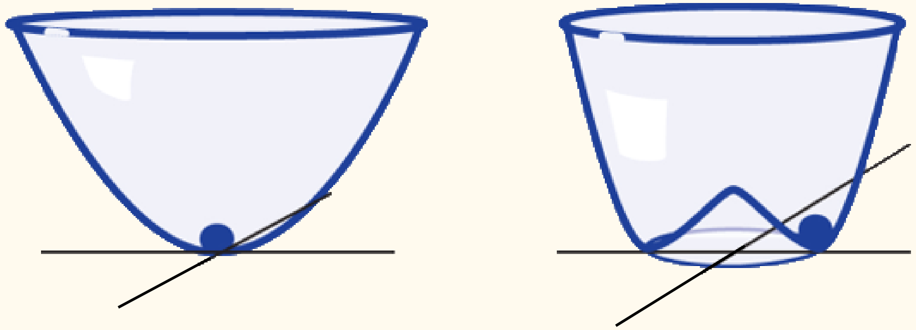




Moiré lattice/magic angle



Spontaneously broken symmetry



Barry Bradlyn et al., Nature 547, 298 (2017)

T. Zhang et al., Nature, 566, 475 (2019)

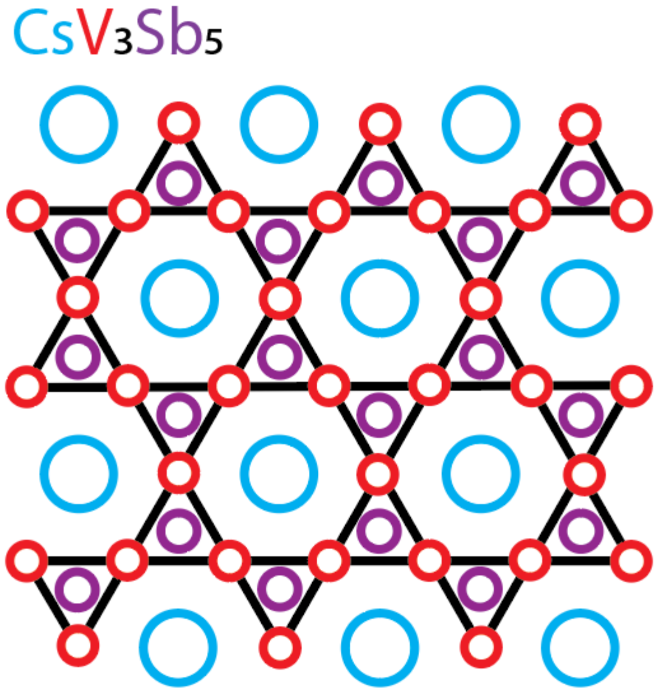
Yuan Cao et al., Nature 556, 43 (2018)

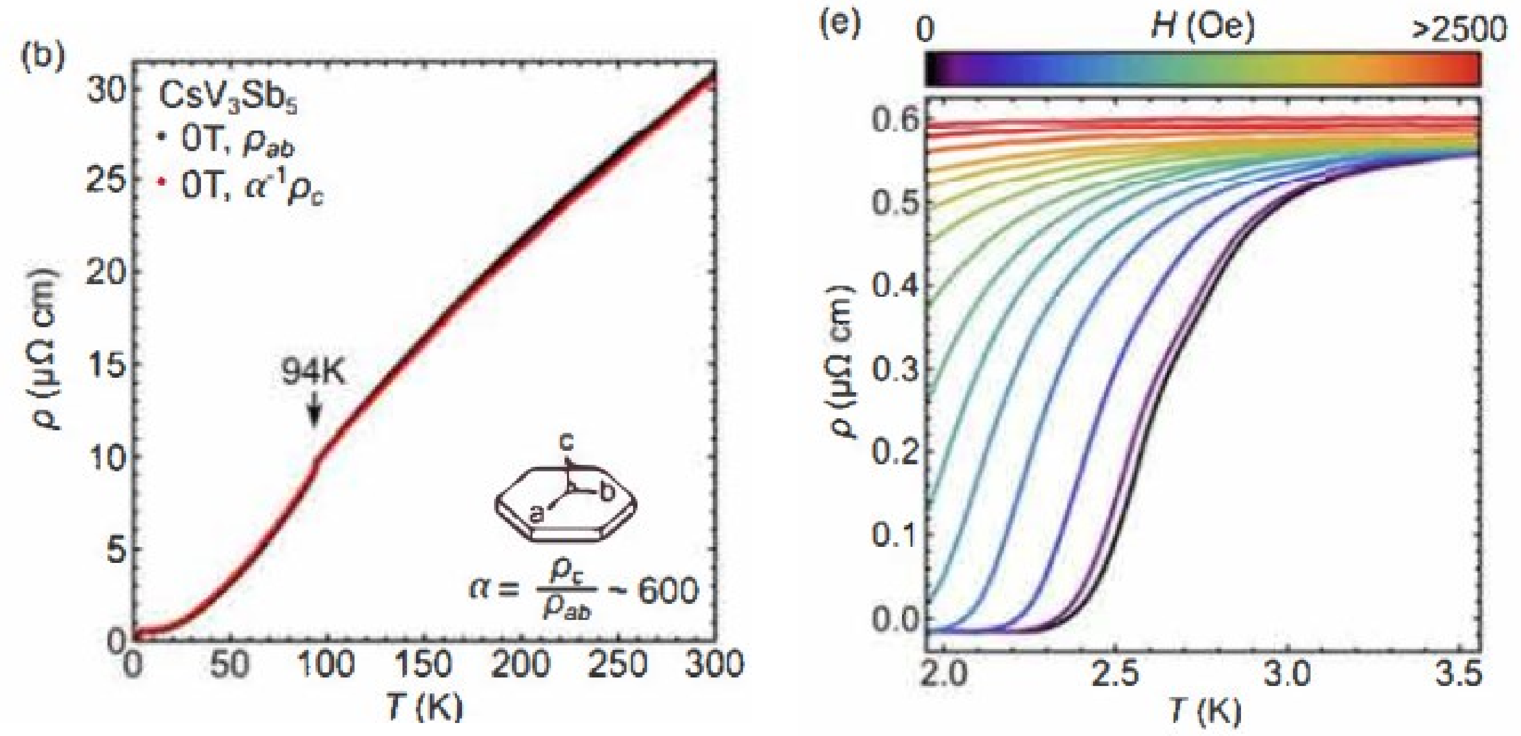
F. Tang et al., Nature, 566, 486 (2019)

Adrian Choc, Science 337,1289(2012).

AV_3Sb_5: charge-ordered Kagome superconductors

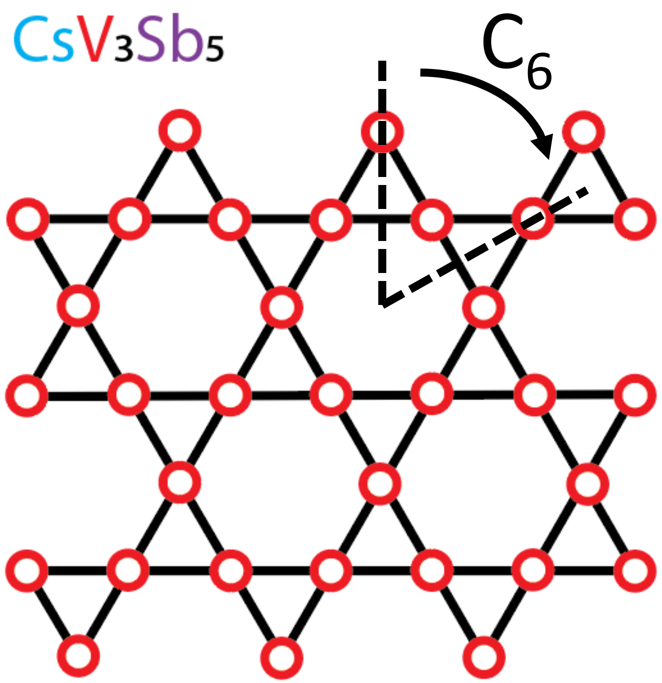
BR Ortiz et al., PRL 125, 247002 (2020)





A Kagome superconductor with charge-order formed below 94 K.

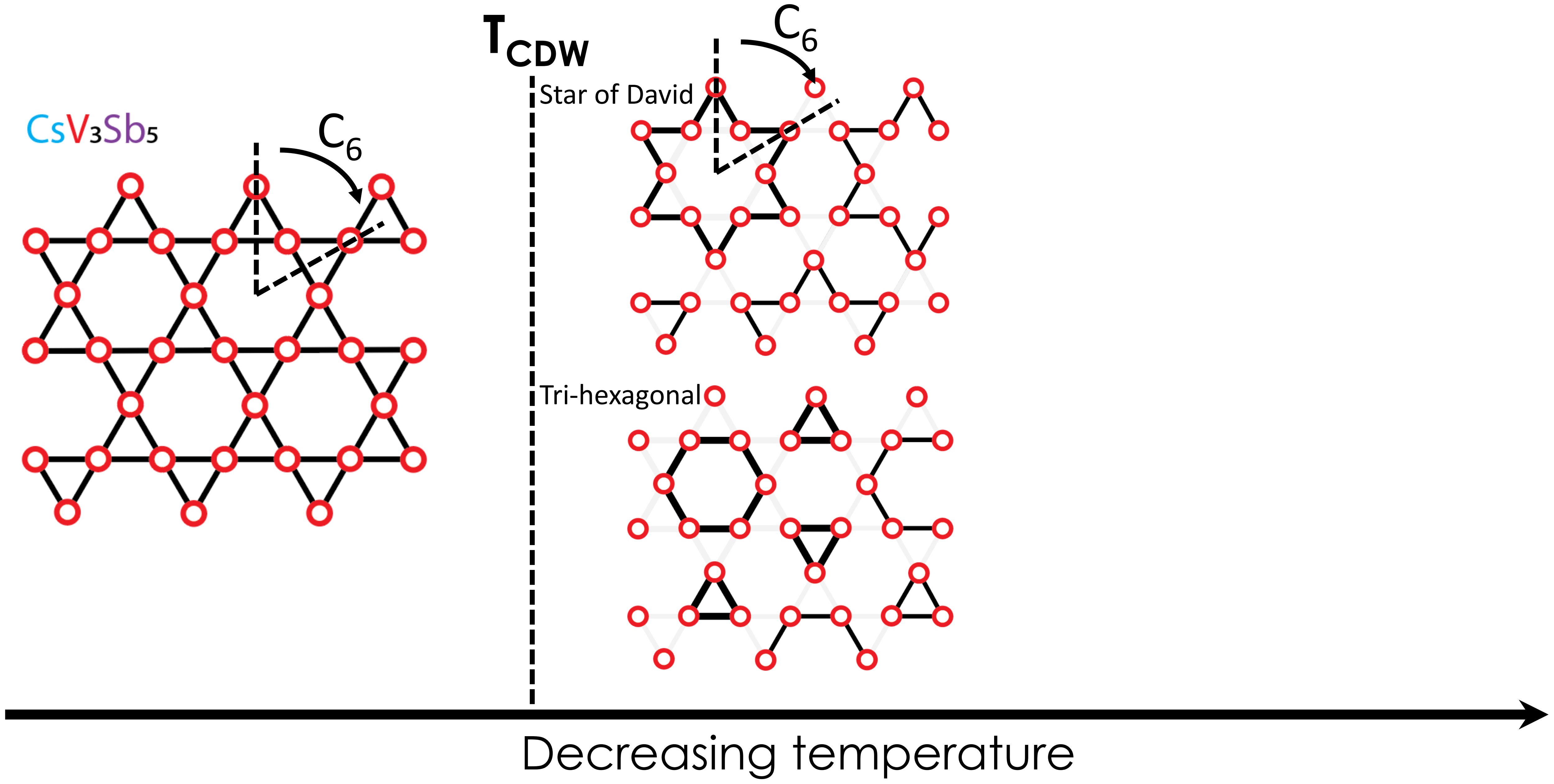
Symmetry breaking in CsV_3Sb_5



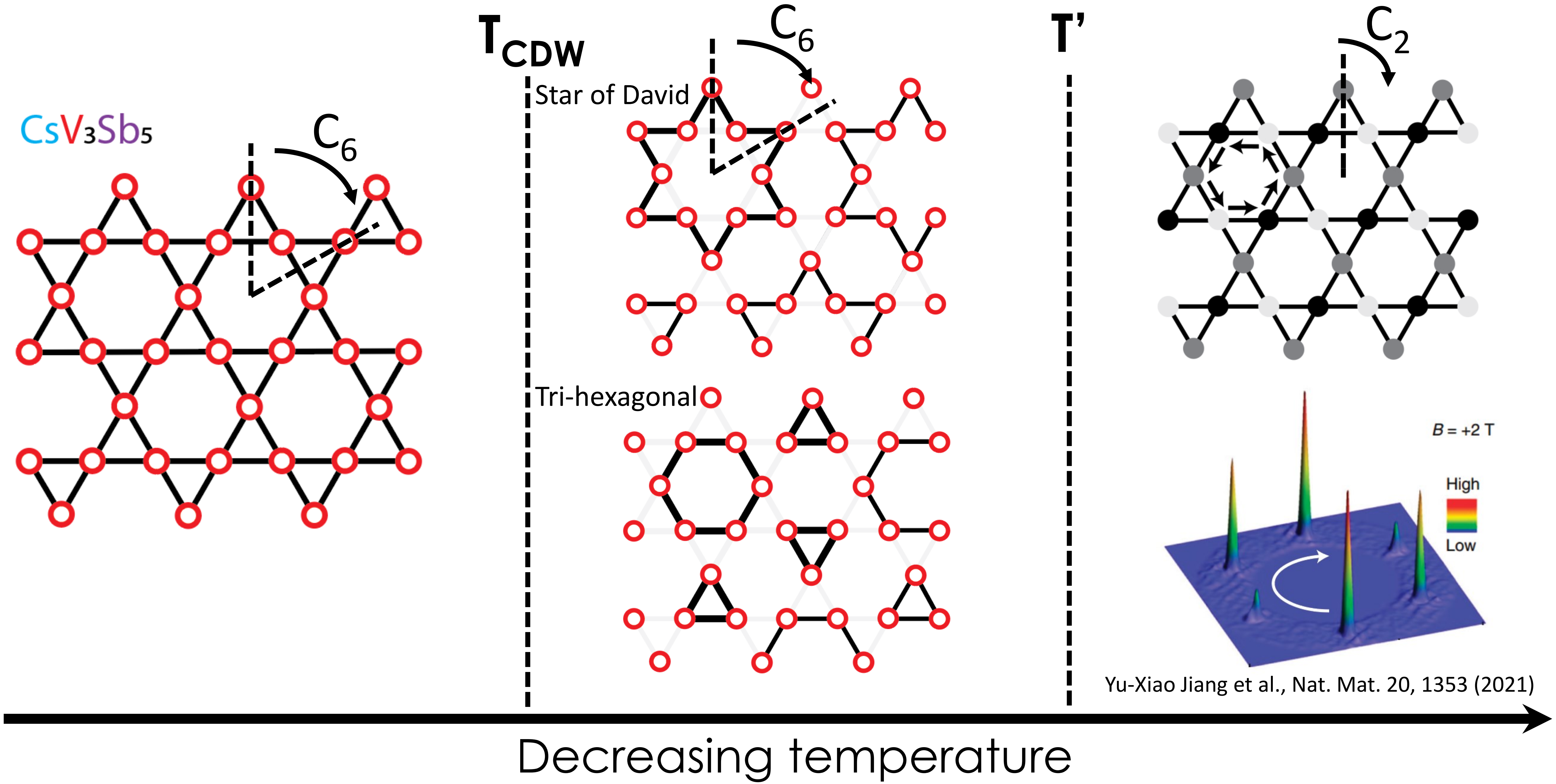
Focus on V-kagome net

Decreasing temperature

Symmetry breaking in CsV_3Sb_5



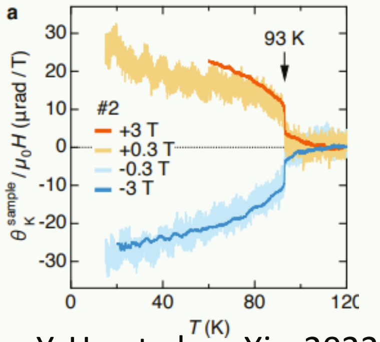
Symmetry breaking in CsV_3Sb_5



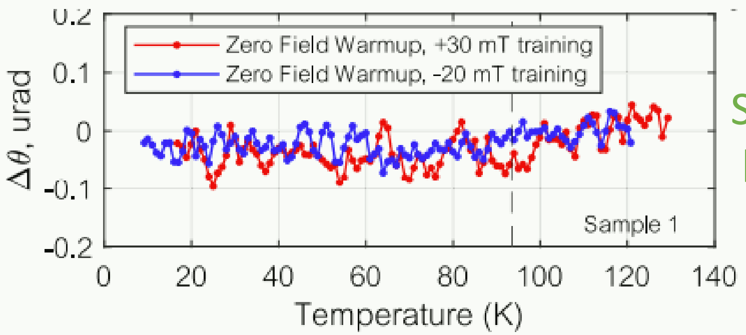
Yu-Xiao Jiang et al., Nat. Mat. 20, 1353 (2021)

AV_3Sb_5 : Conflicting results

The mysterious T’-phase: spontaneous symmetry-breaking?

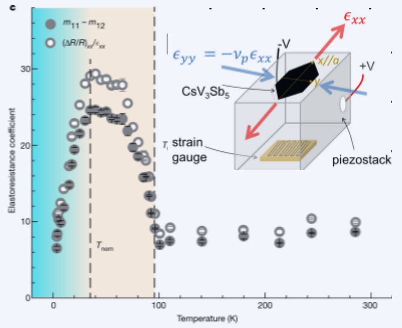


Y. Hu et al., arXiv, 2022

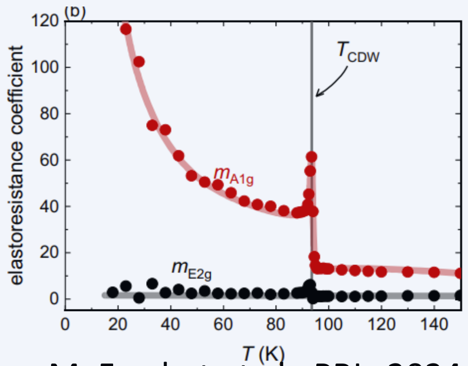


DR Saykin et al., PRL, 2023

Spontaneous TRS breaking versus none

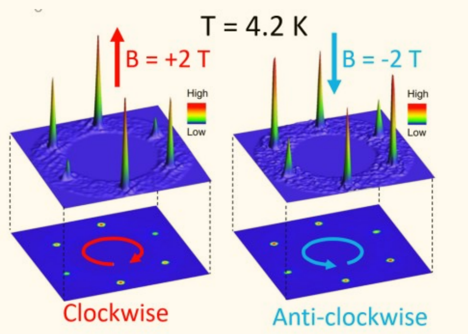


L. Nie et al., Nature, 2022

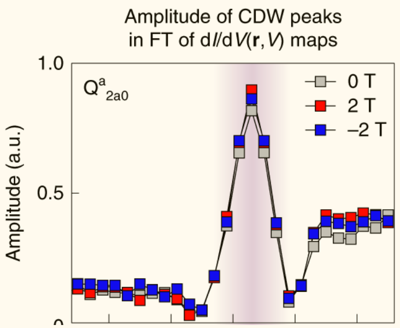


M. Frachet et al., PRL, 2024

Electronic nematicity versus none



YX Jiang et al., Nat. Mat., 2021



H. Li et al., Nat. Phys. 2022

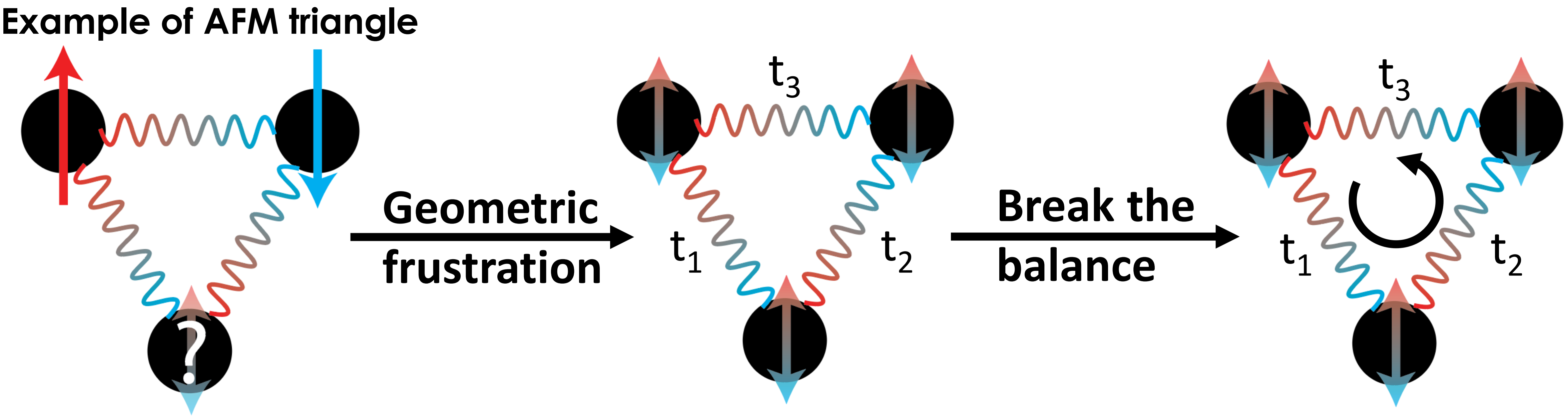
Switchable Chiral charge order versus none

Numerous recent development with diverse conclusions:

L Nie et al., Nature 604, 59 (2022)
H Chen et al., Nature 599,222 (2021)
Q Wu et al., PRB 106,205109 (2022)
Y Xiang et al., Nat. Com. 12,6727 (2021)
C Guo et al., Nature 611,461 (2022)
Y Xu et al., Nat. Phys. 18,1470 (2022)
H Zhao et al., Nature 599, 216 (2021)
Y Jiang et al., Nat. Mat. 20, 1353 (2021)
Y Hu et al., arXiv: 2208.08036v2 (2022)
DR Saykin et al., arXiv: 2209.10570 (2022)
L Yu et al., arXiv: 2107.10714 (2021)
……

What’s the origin?

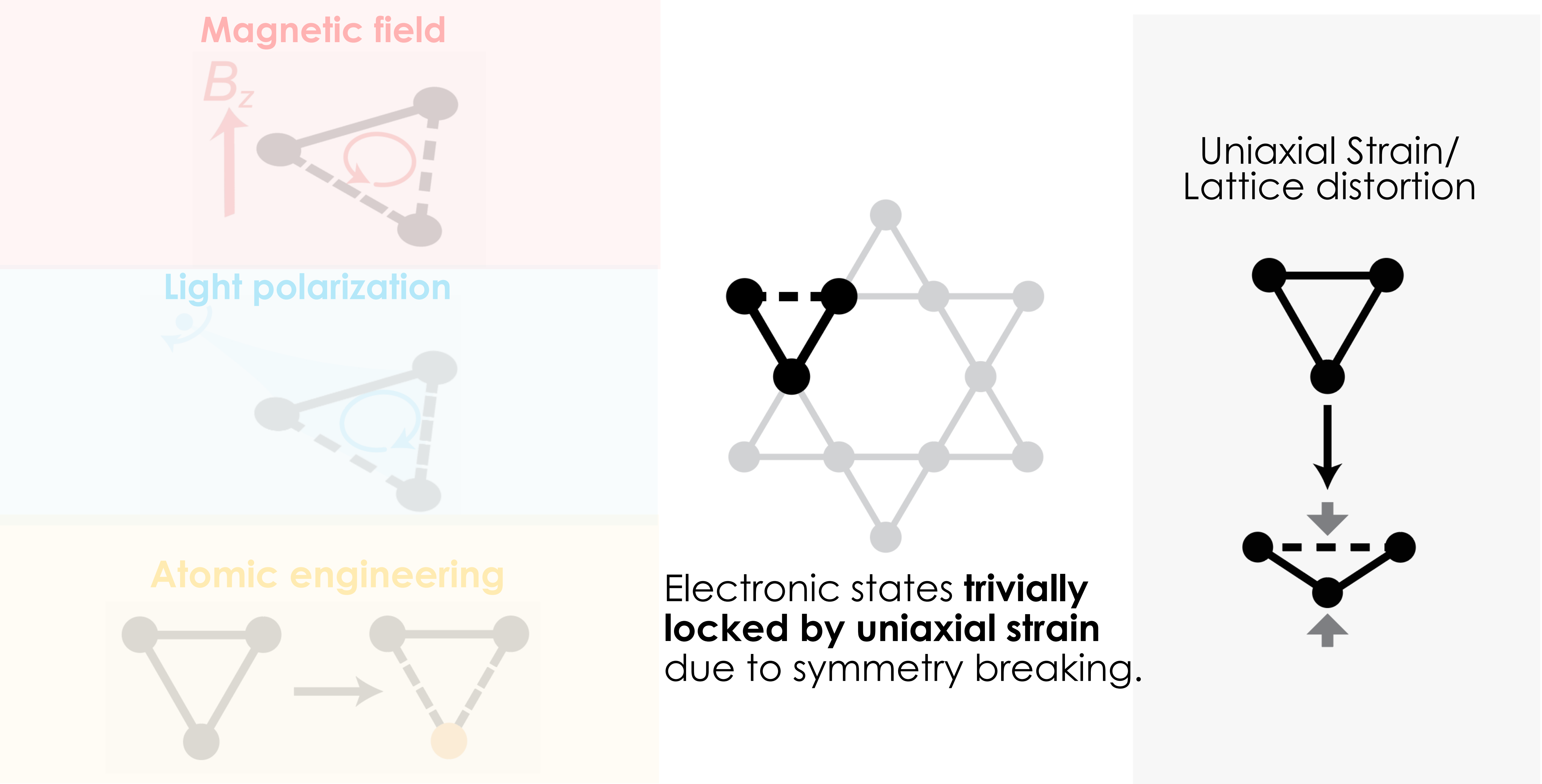
Fragile electronic ground state in CsV_3Sb_5



$t_1 = t_2 = t_3$

$t_1 \gtrsim t_2 \gtrsim t_3$

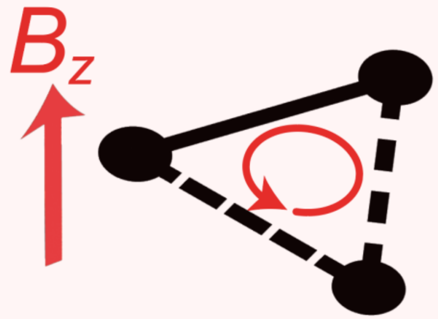
Uniaxial strain trivially locks the exciting path...



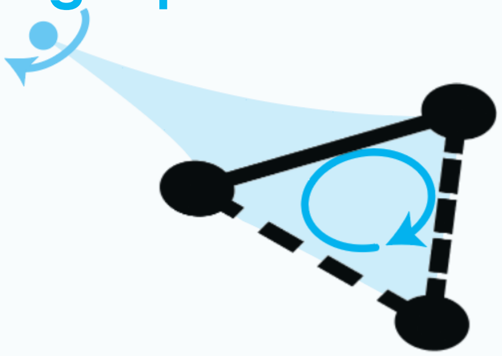
Electronic states **trivially locked by uniaxial strain** due to symmetry breaking.

Uniaxial strain trivially locks the exciting path…

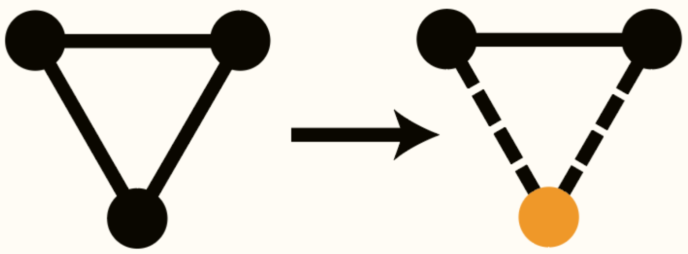
Magnetic field

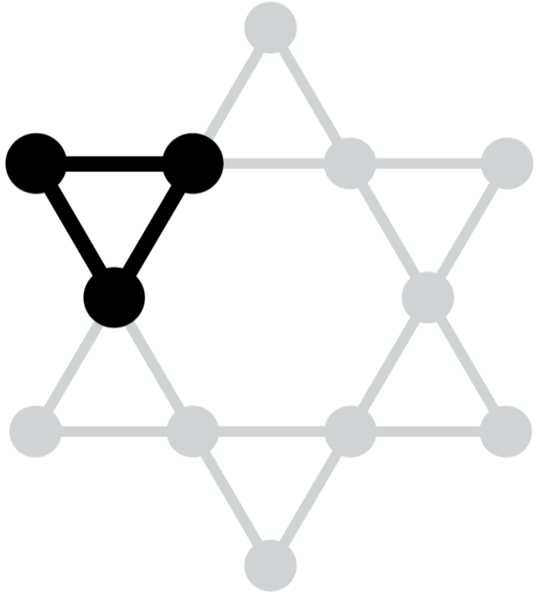


Light polarization

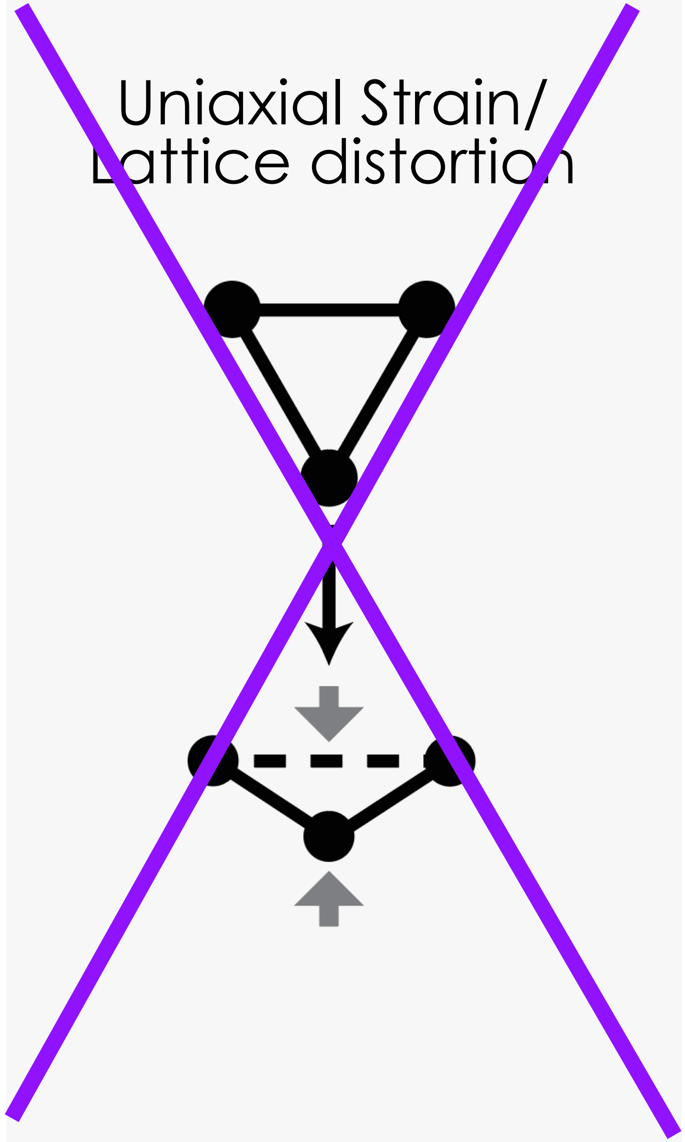


Atomic engineering



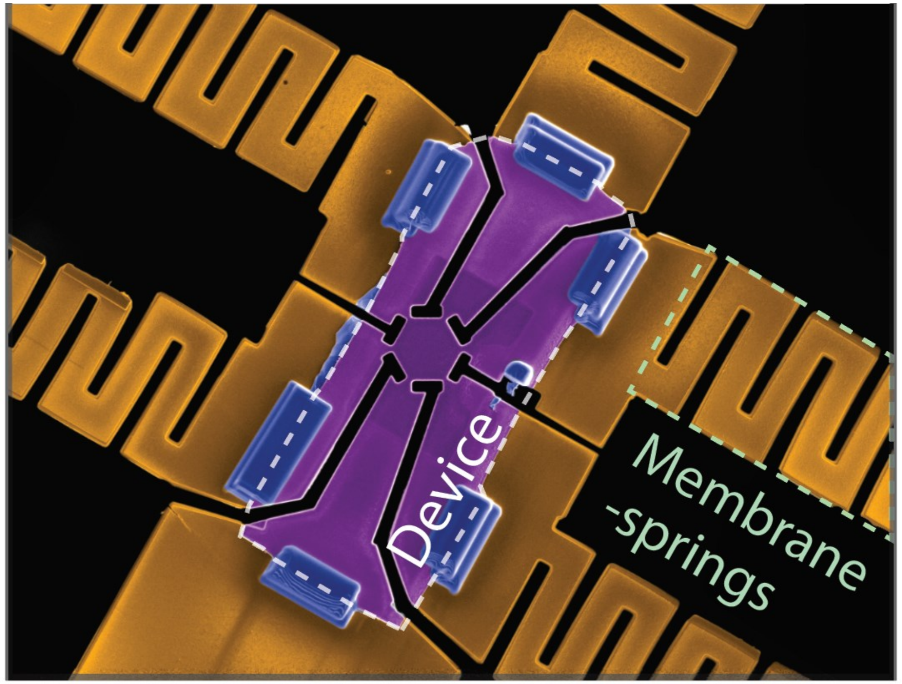


Must be eliminated!!!

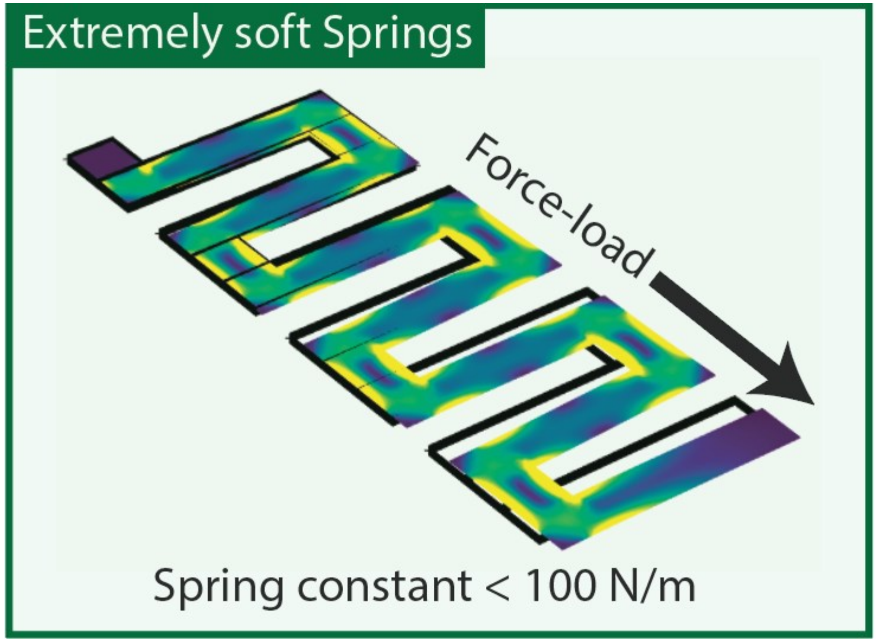


Free-Kagome: designer crystal decoupled from strain-force

Kagome crystal must be set **softly**!



Membrane-springs-connected microdevice.
Successful decoupling of strain!

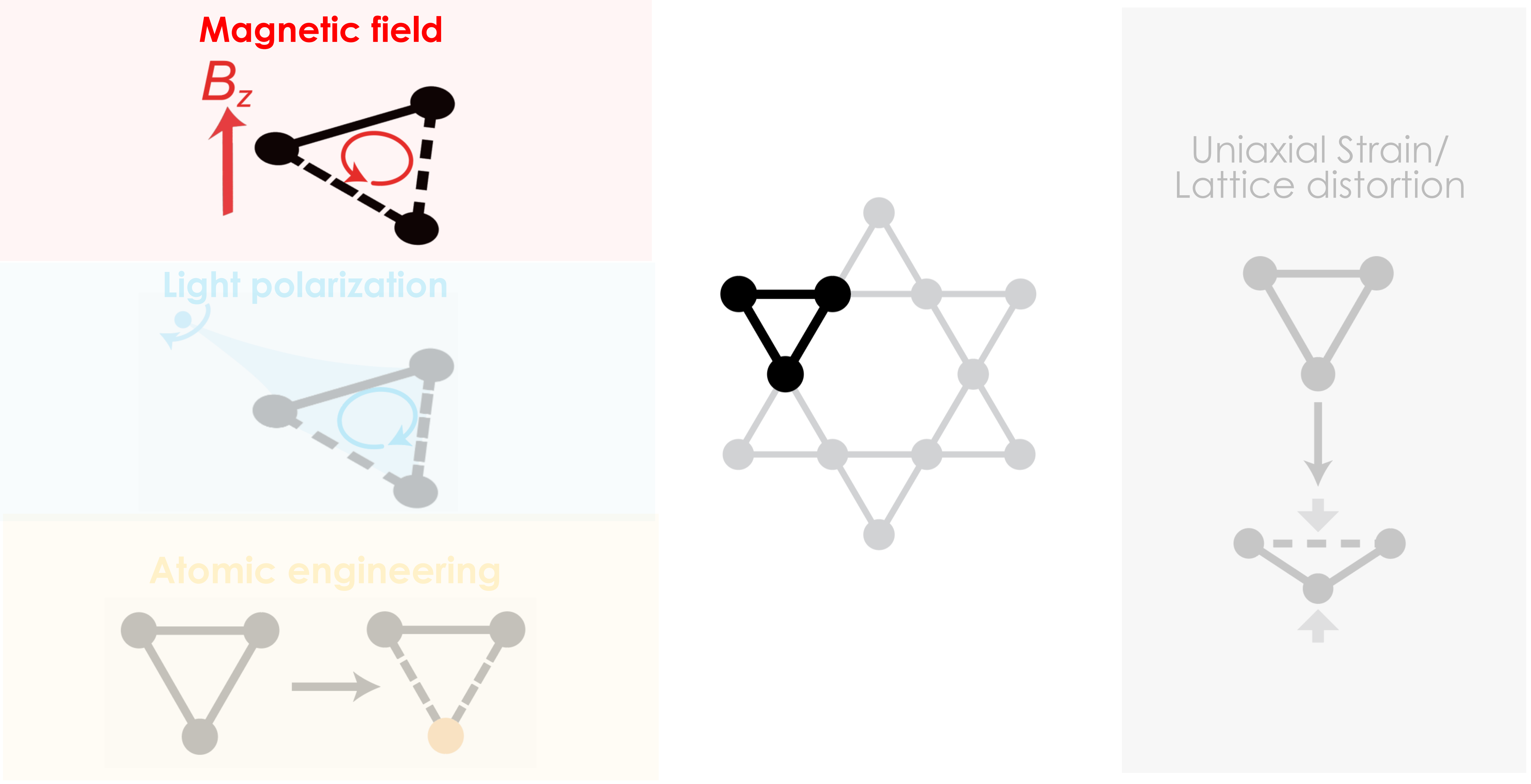


Strain reduction >99%

Ready to explore intrinsic Kagome physics!

CG et al., Nature 2022
X. Huang et al., PRB 2022
CG et al., npj QM, 2024
CG et al., Nature Physics 2024

Field-switchable electronic chirality?



Electric magneto-chiral anisotropy (eMChA)

Origin

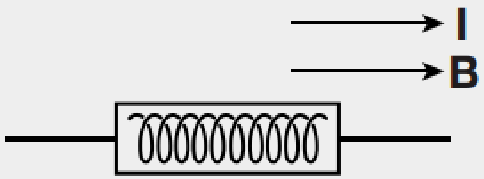
Normal conductor

$R(\mathbf{B}) = R_0(1+\mu^2\mathbf{B}^2)$

$R(\mathbf{I},\mathbf{B}) = R(-\mathbf{I},\mathbf{B})$

$R(\mathbf{I},\mathbf{B}) = R(\mathbf{I},-\mathbf{B})$

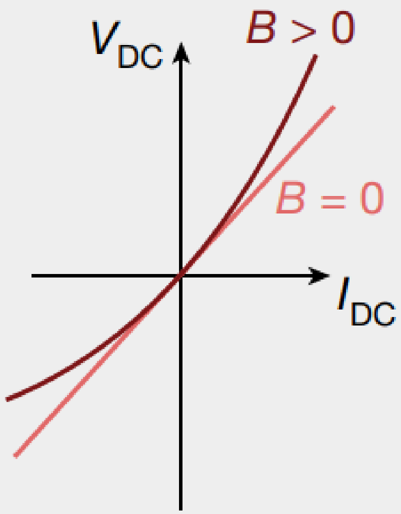
Chiral conductor

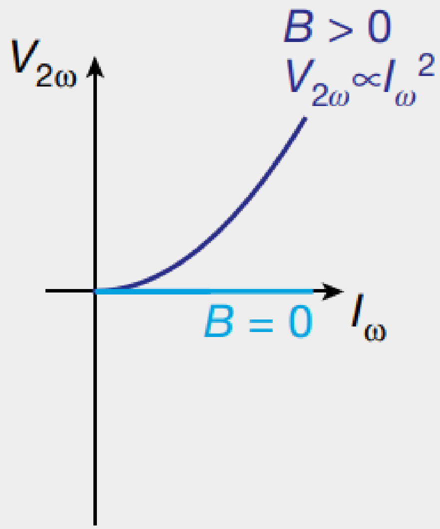


$R(\mathbf{I},\mathbf{B}) = R_0(1+\mu^2\mathbf{B}^2+\gamma\mathbf{B}_i\mathbf{I}_i)$

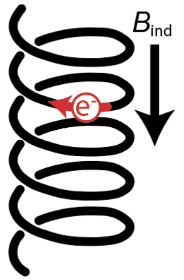
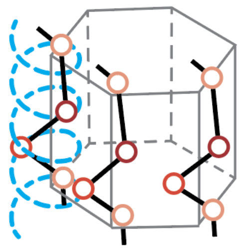
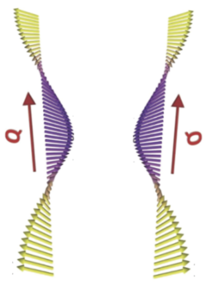
$R(\mathbf{I},\mathbf{B}) \neq R(-\mathbf{I},\mathbf{B})$

$R(\mathbf{I},\mathbf{B}) \neq R(\mathbf{I},-\mathbf{B})$





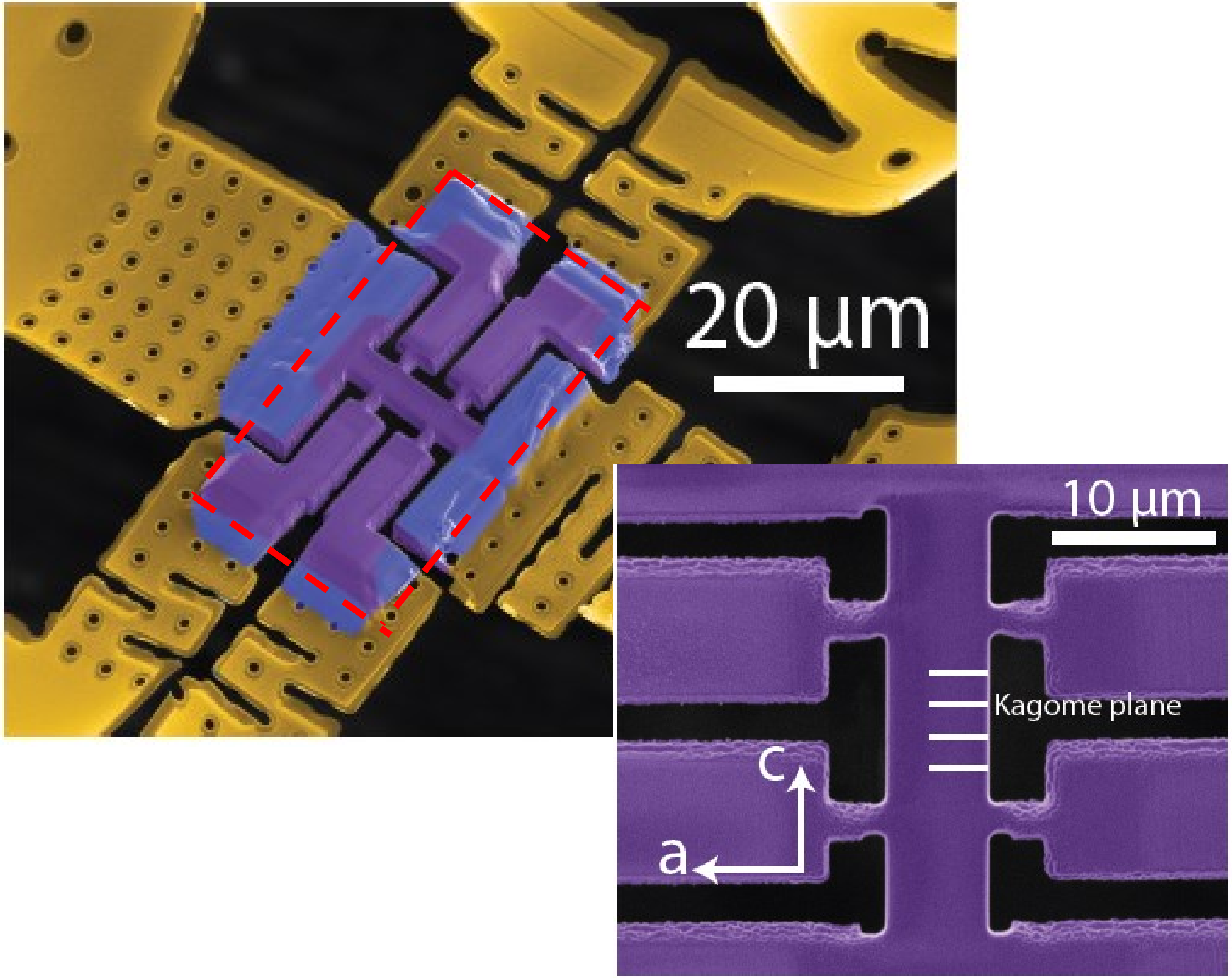
Different mechanism

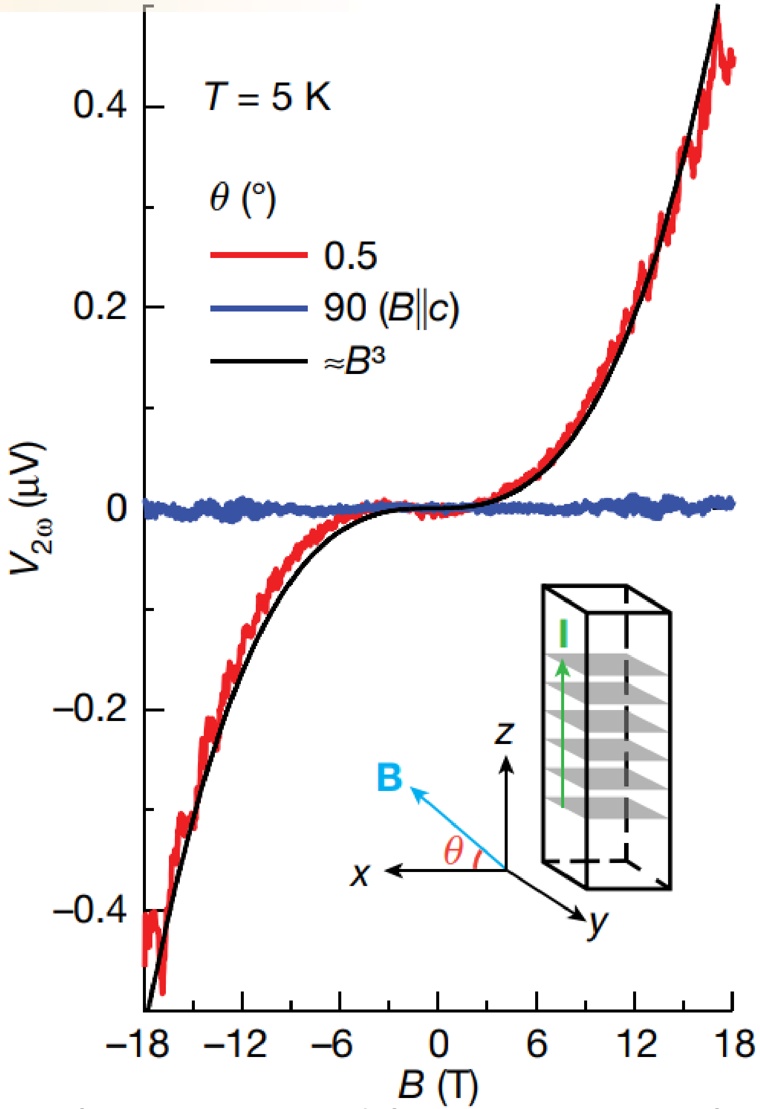
	Macroscopic shape	Crystalline structure	Magnetic structure
Origin of eMChA			
Examples	Bi-helix [1]	t-Tellurium [2] TTF-ClO_4 [3]	$CrNb_3S_6$ [4] MnSi [5]

Chirality of the system is defined by its structure/shape.

[1] G. L. J. A. Rikken et al., PRL 87, 236602 (2001).
[2] G. L. J. A. Rikken et al., PRB 99, 245153 (2019).
[3] F. Pop et al., Nat. Comms. 5, 3757 (2014).
[4] R. Aoki et al., PRL 122, 057206 (2019).
[5] T. Yokouchi et al., Nat. Comms. 8, 866 (2017).

Chiral-magnetotransport in CsV_3Sb_5

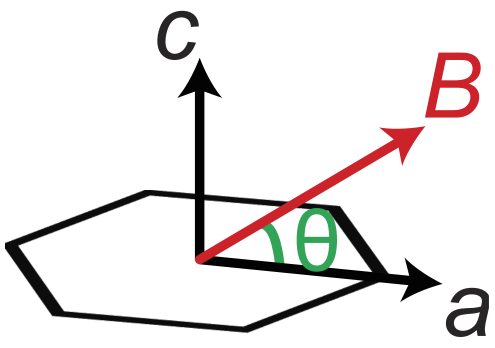


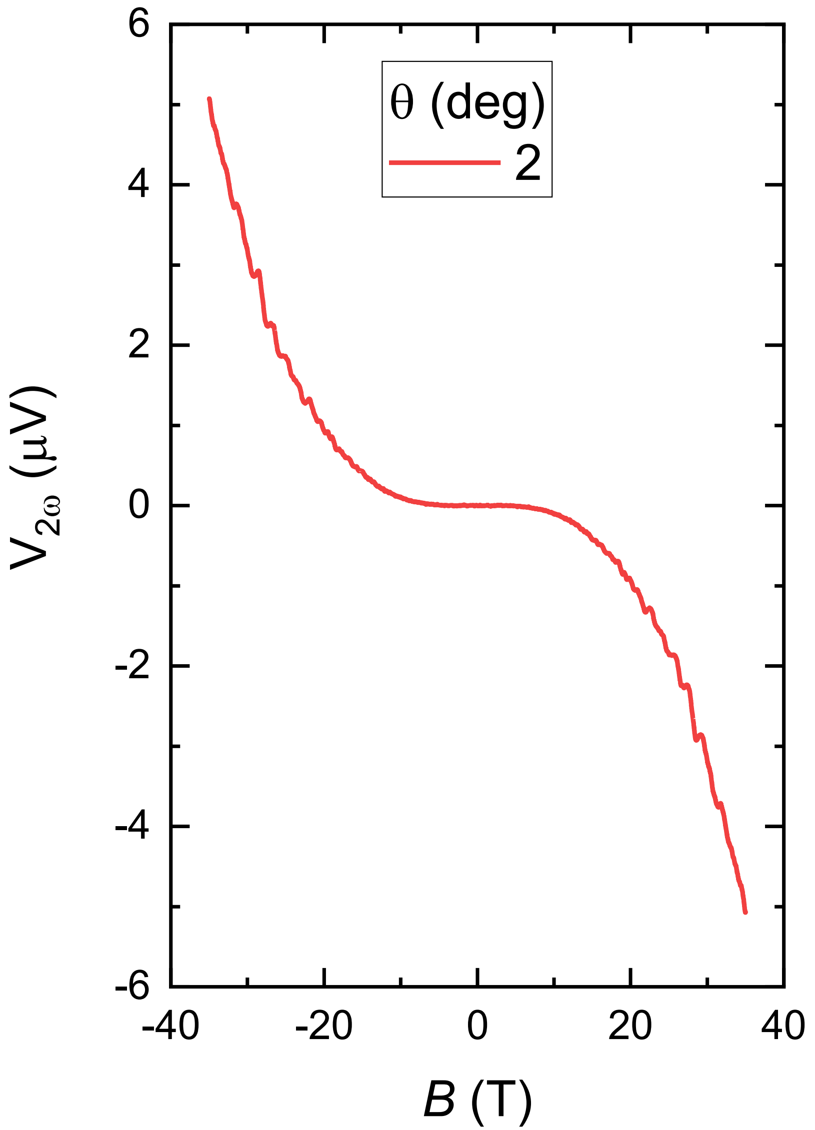


Clear second harmonic voltage with a B^3-dependence.

CG et al., Nature 2022

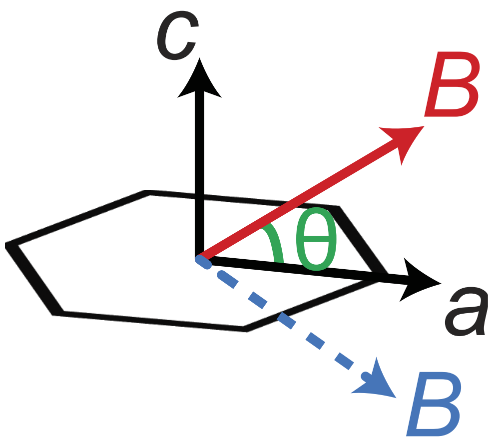
Switchable chiral-magnetotransport

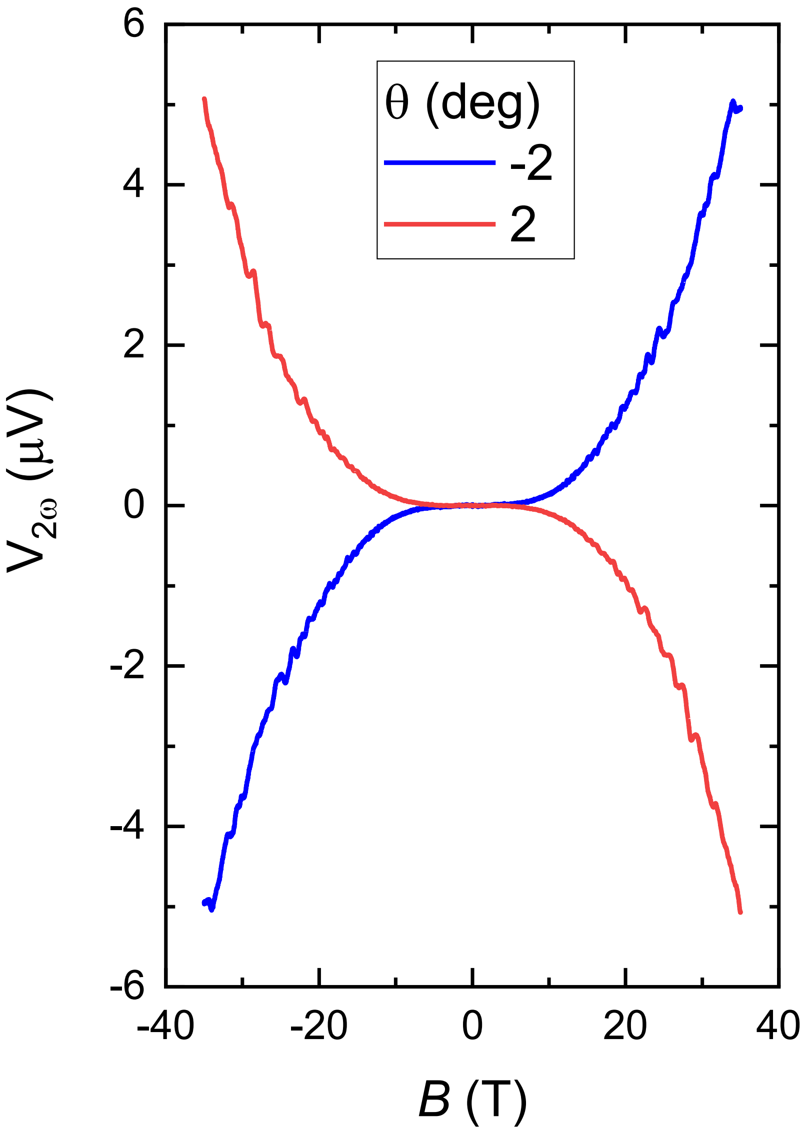




The sign of V2w is switched when the magnetic field is rotated across the Kagome plane.

Switchable chiral-magnetotransport





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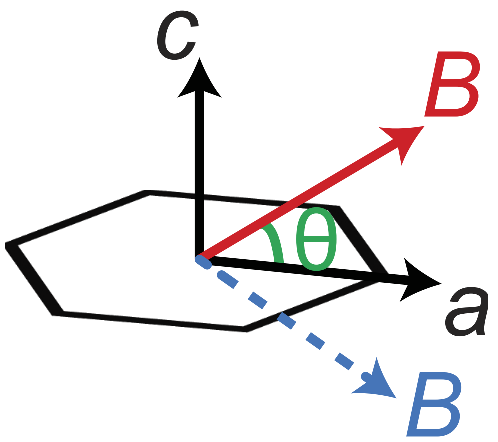
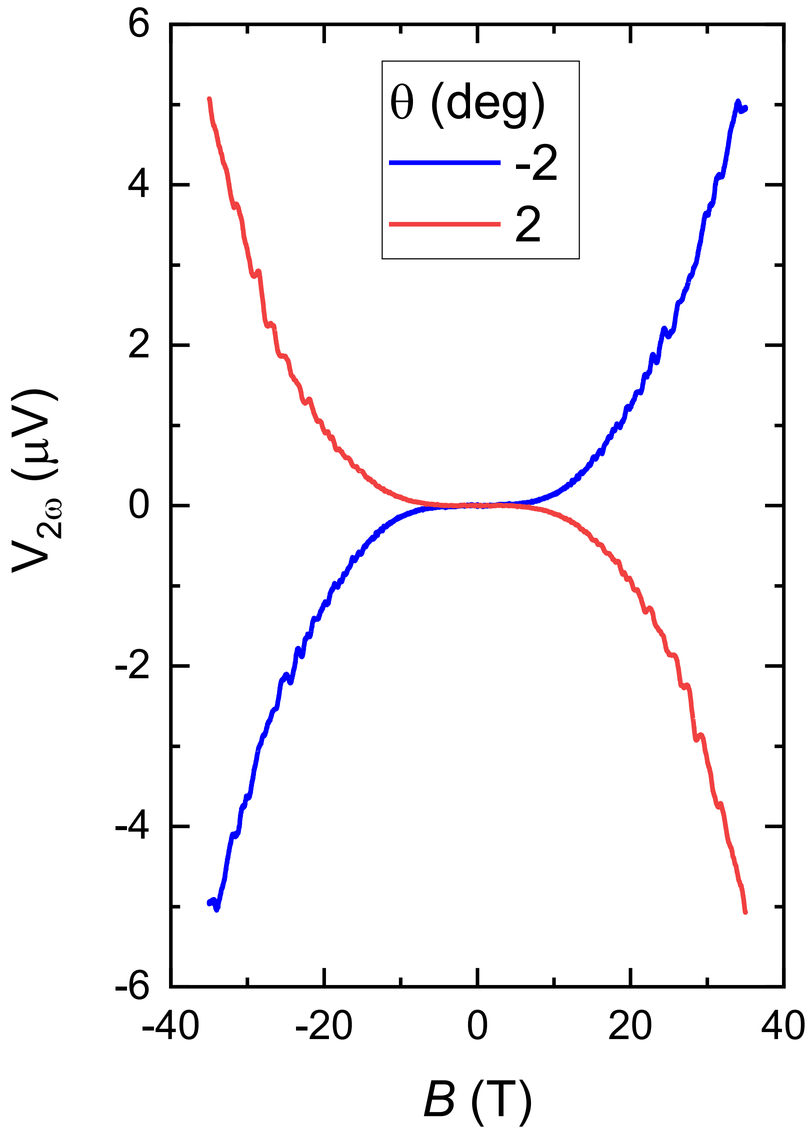
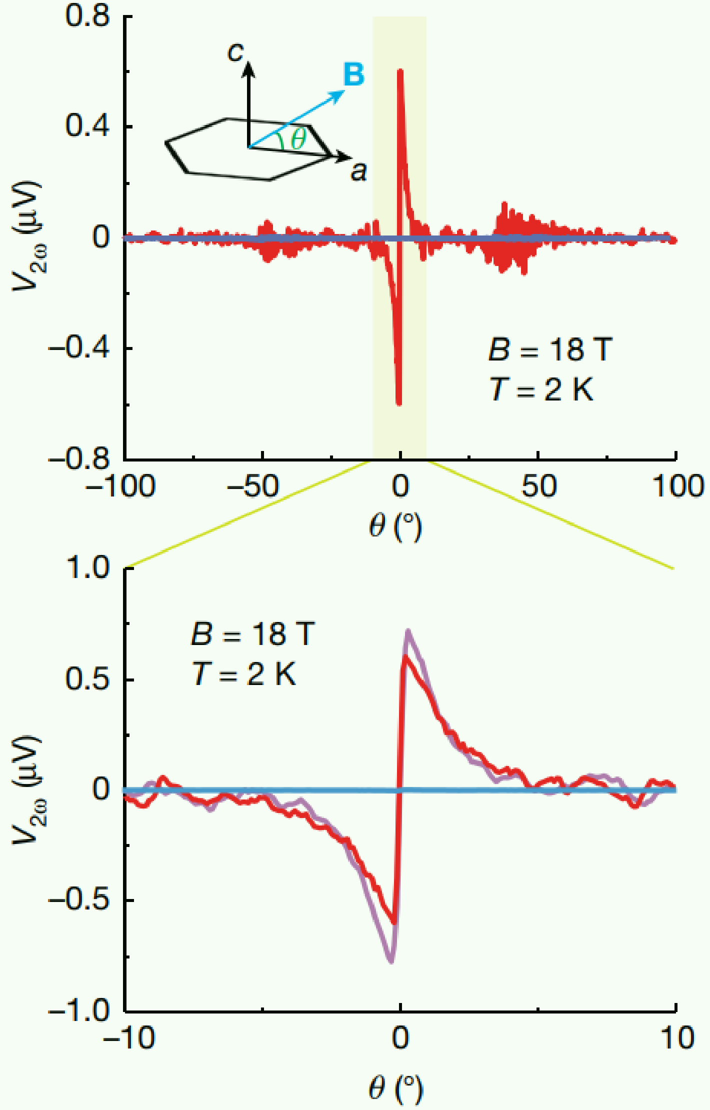


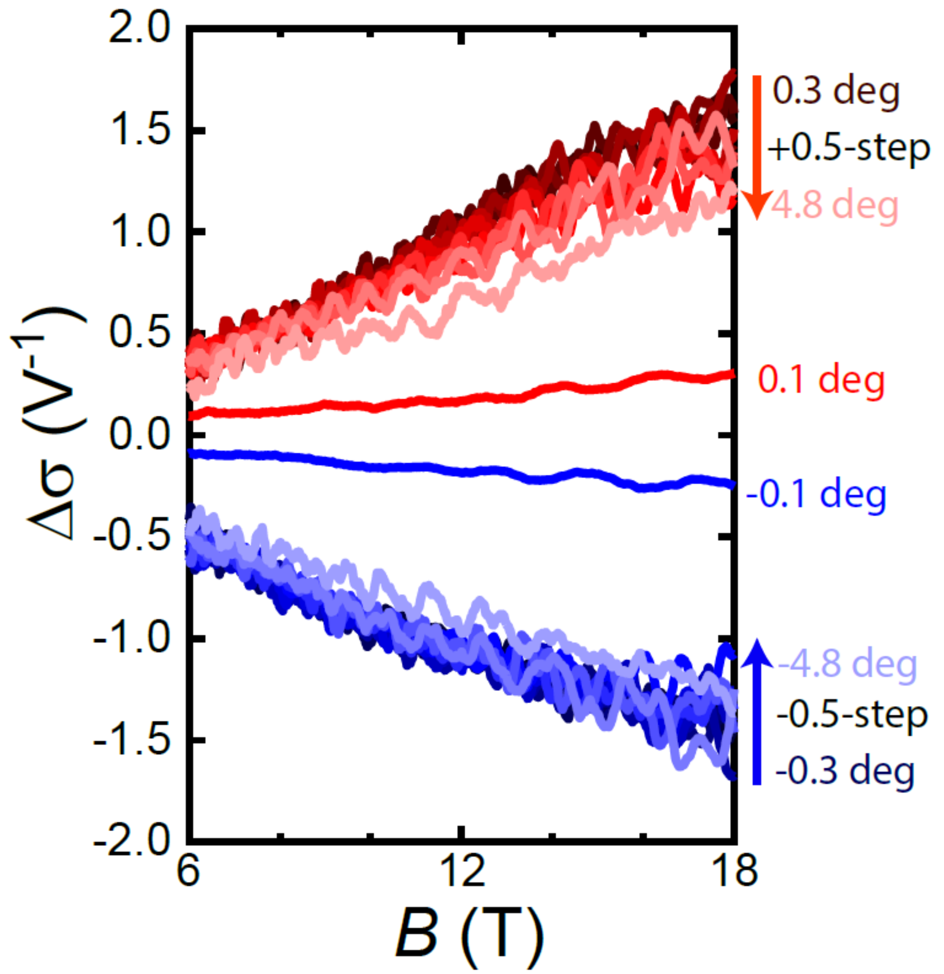


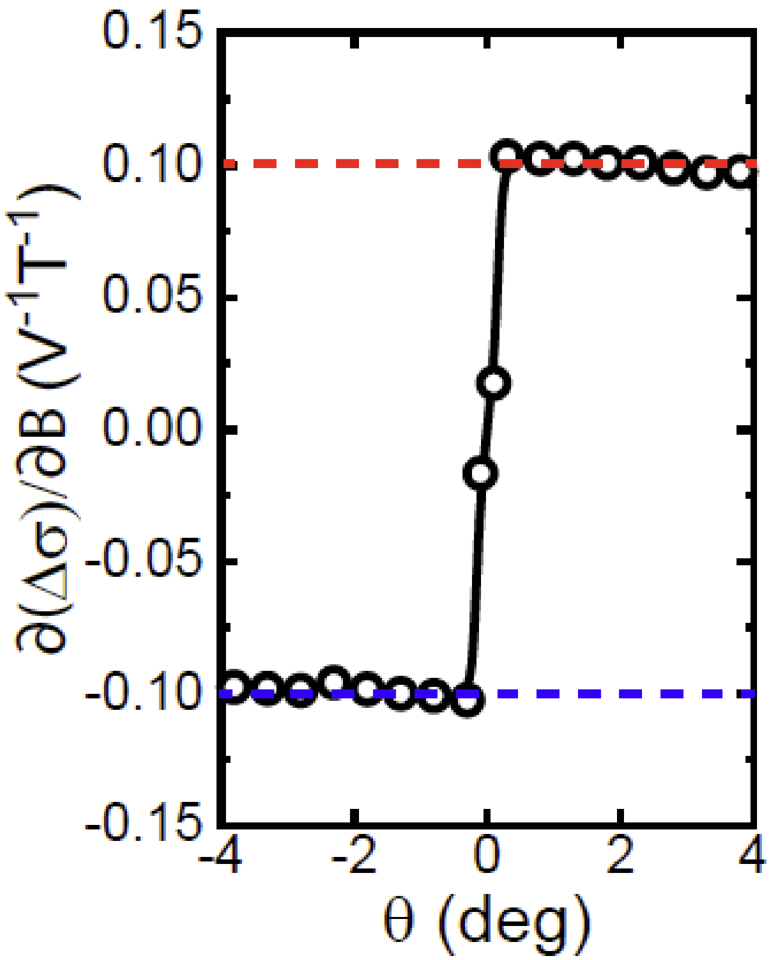


The sign of V2w is switched when the magnetic field is rotated across the Kagome plane.

A sharp sign change across the Kagome plane.

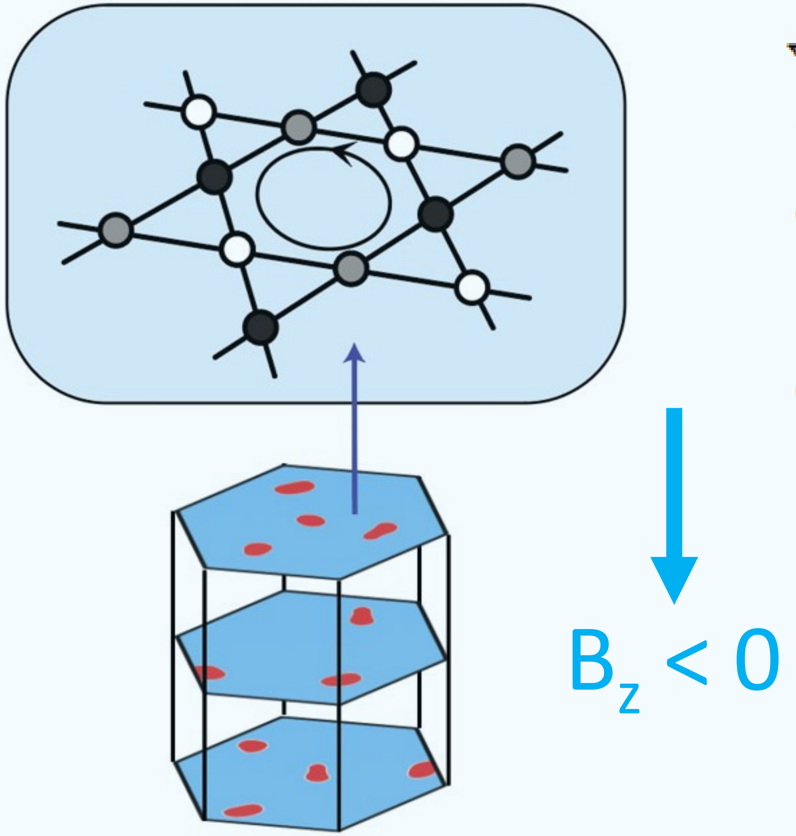
Switchable chiral-magnetotransport

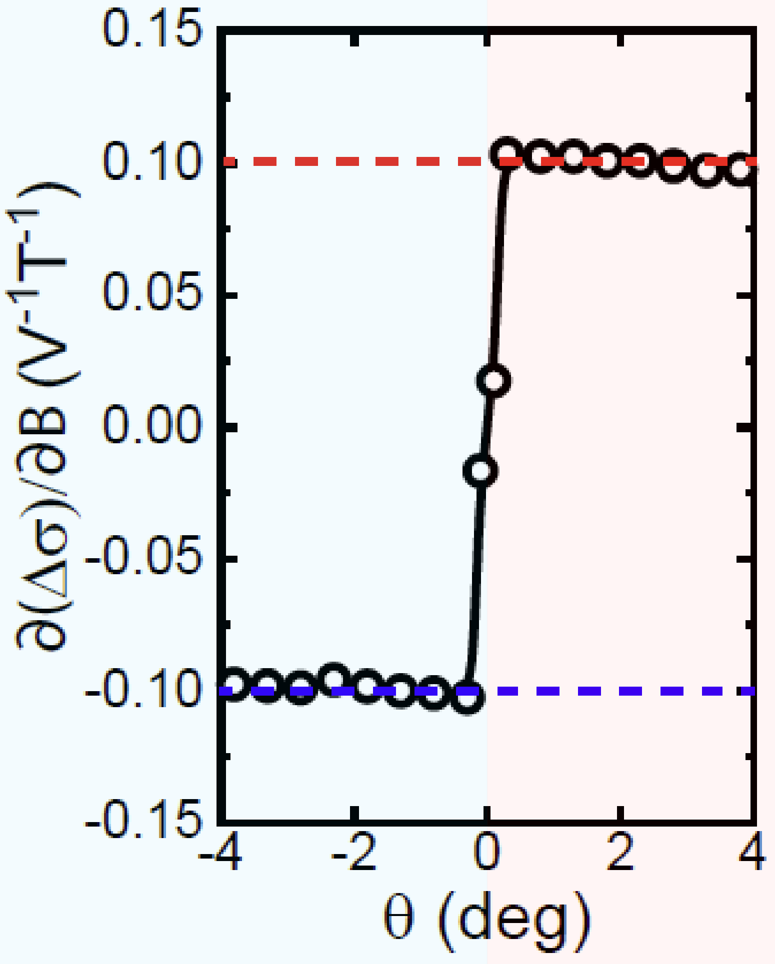


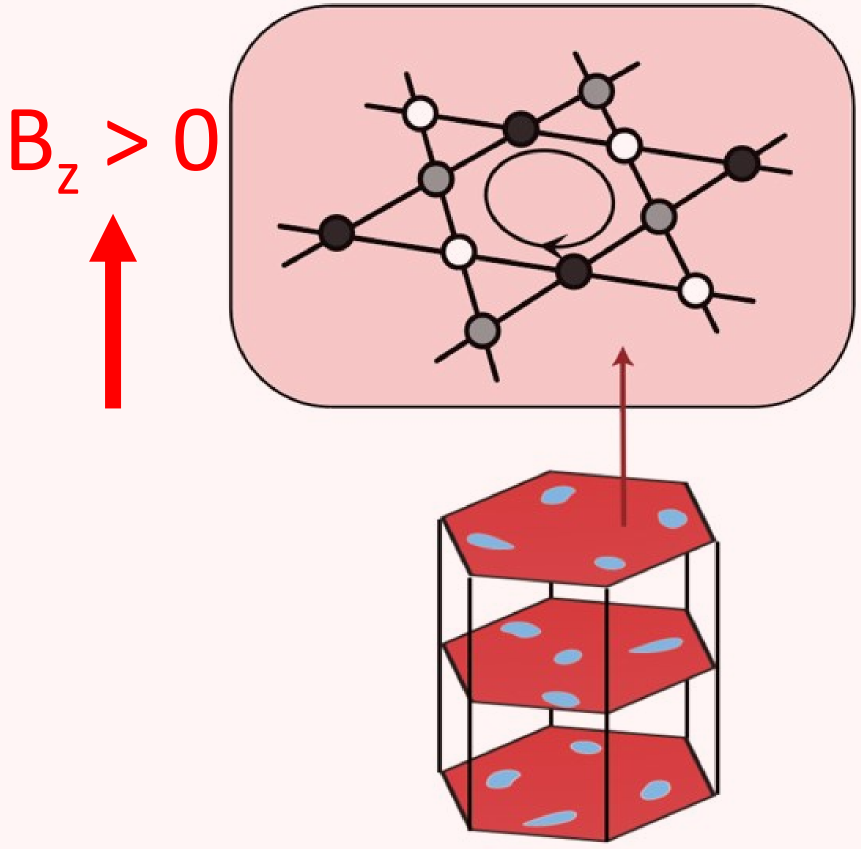


CG et al., Nature 2022

Switchable chiral-magnetotransport







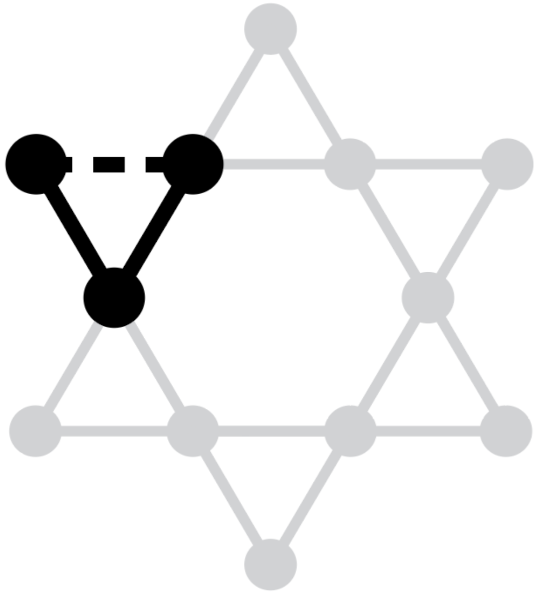
CG et al., Nature 2022

Uniaxial strain trivially locks the exciting path…

Magnetic field

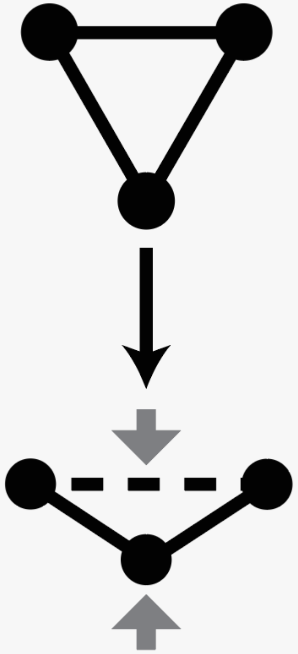
Light polarization

Atomic engineering

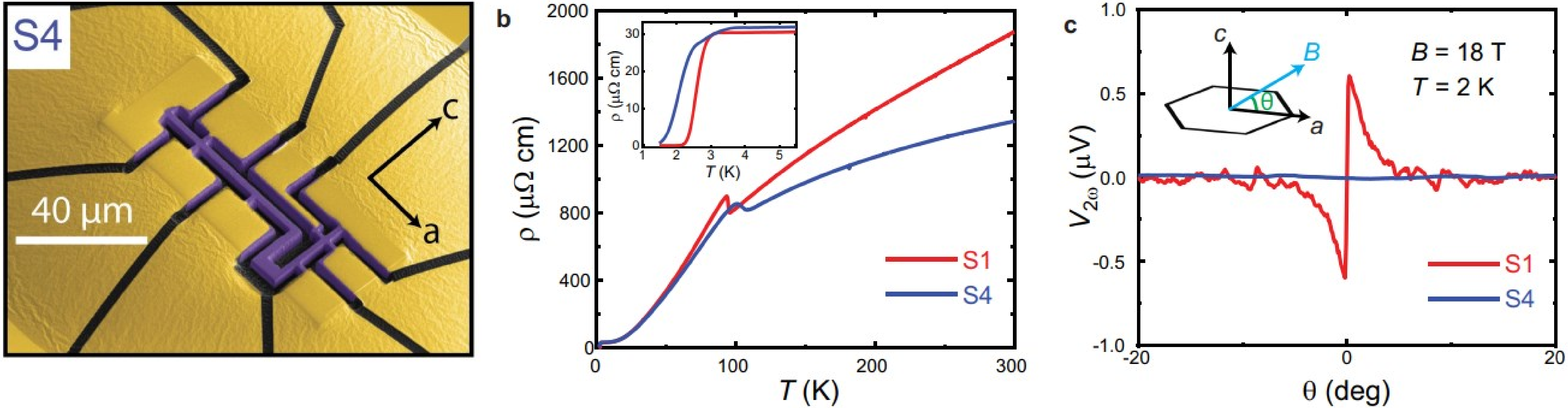


Electronic states **trivially locked by uniaxial strain** due to symmetry breaking.

Uniaxial Strain/
Lattice distortion



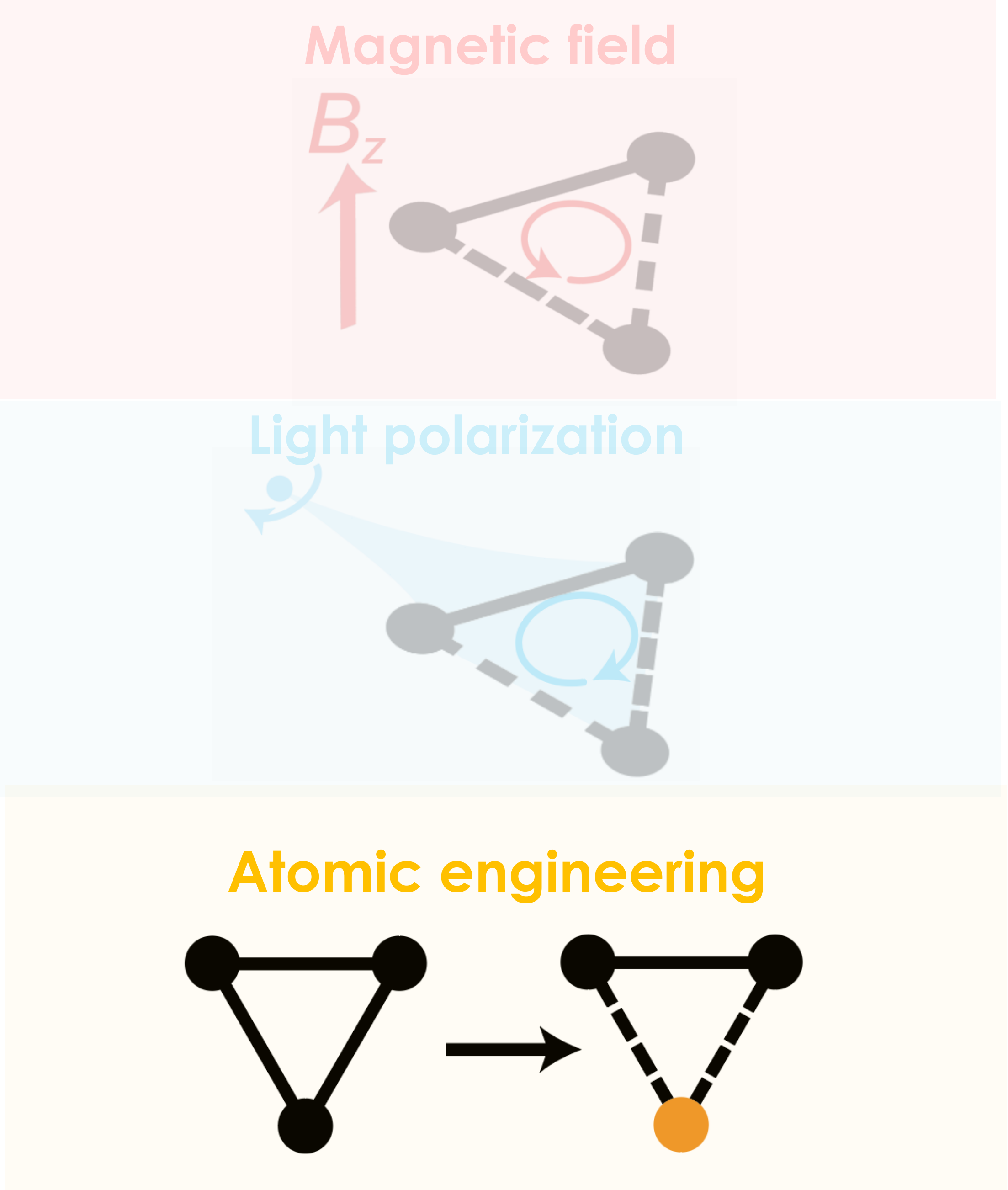
Strain-sensitivity

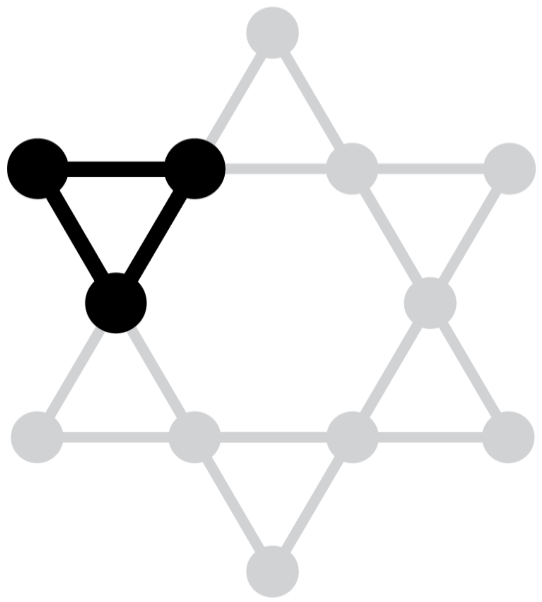


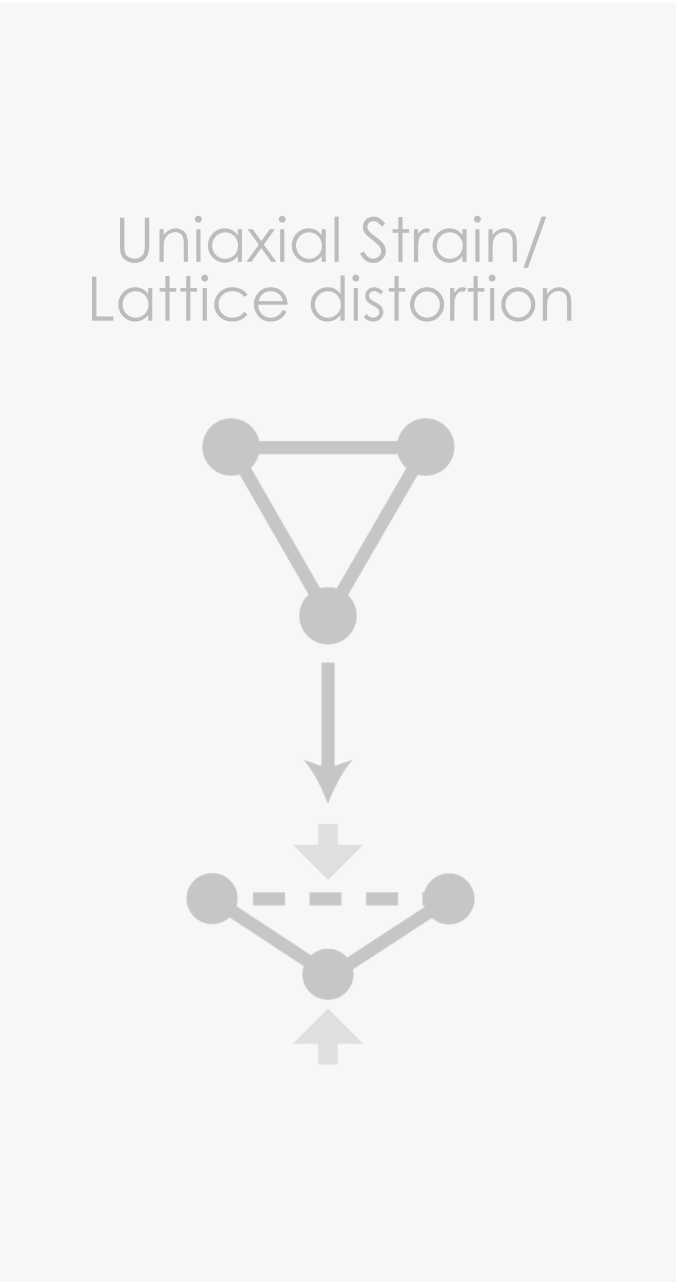
No Chiral transport signature is observed in the strained sample!!!

CG et al., Nature 2022

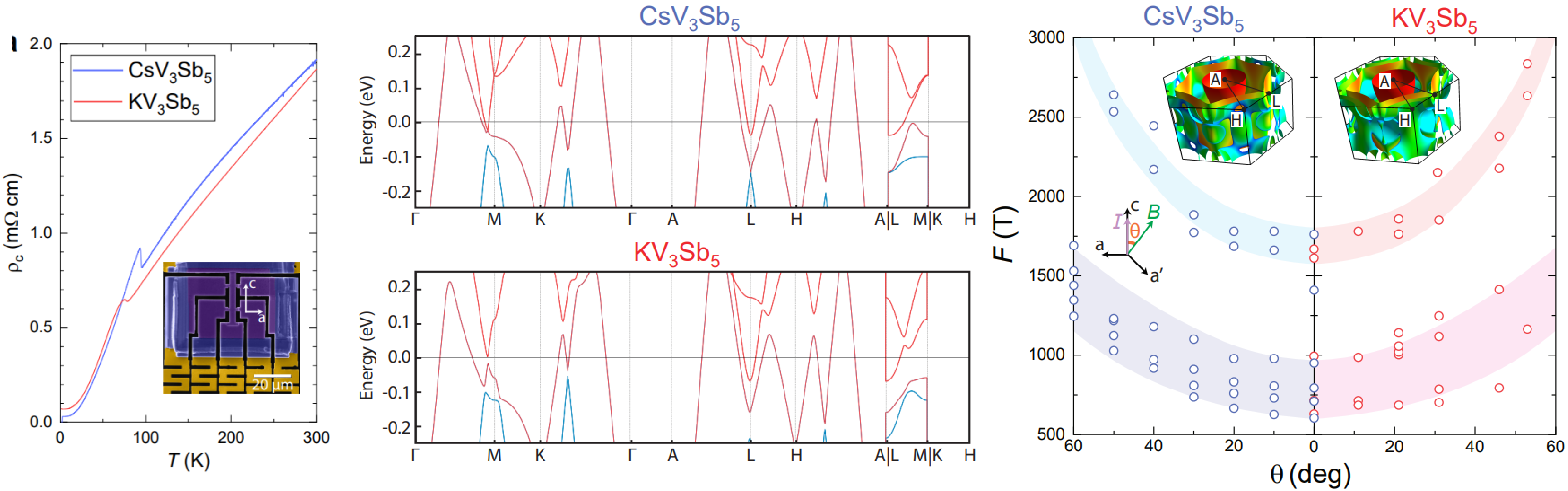
Atomic engineering







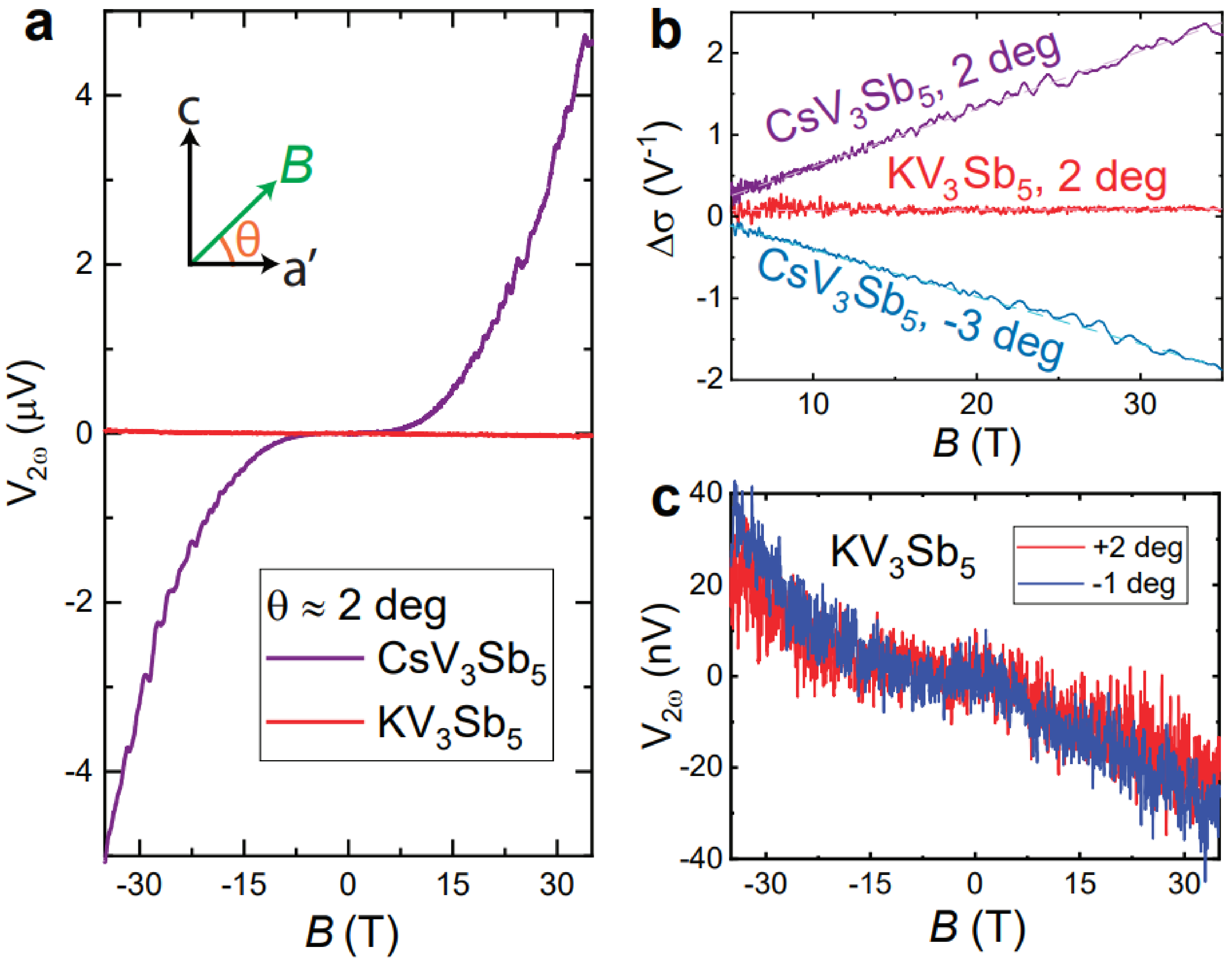
Comparison to KV_3Sb_5: Similarities



Resistivity, quantum oscillations, DFT… all electronic structure features looks quite similar.

CG et al., npj QM, 2024

Comparison to KV_3Sb_5: Major difference in Chiral transport

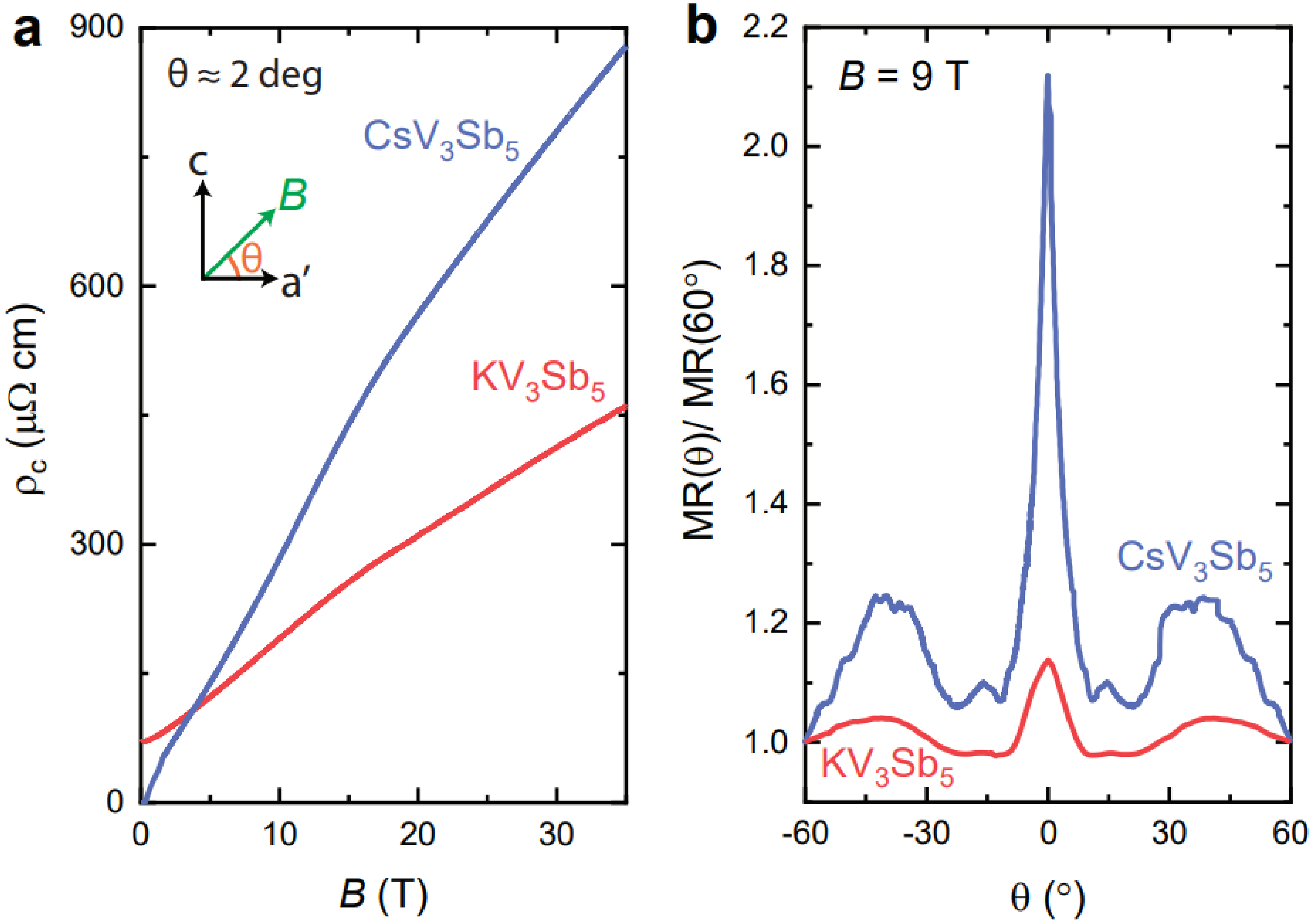


Significantly smaller chiral transport signature, and no switching!

Why?

CG et al., npj QM, 2024

Comparison to KV_3Sb_5: Possible origin of the difference

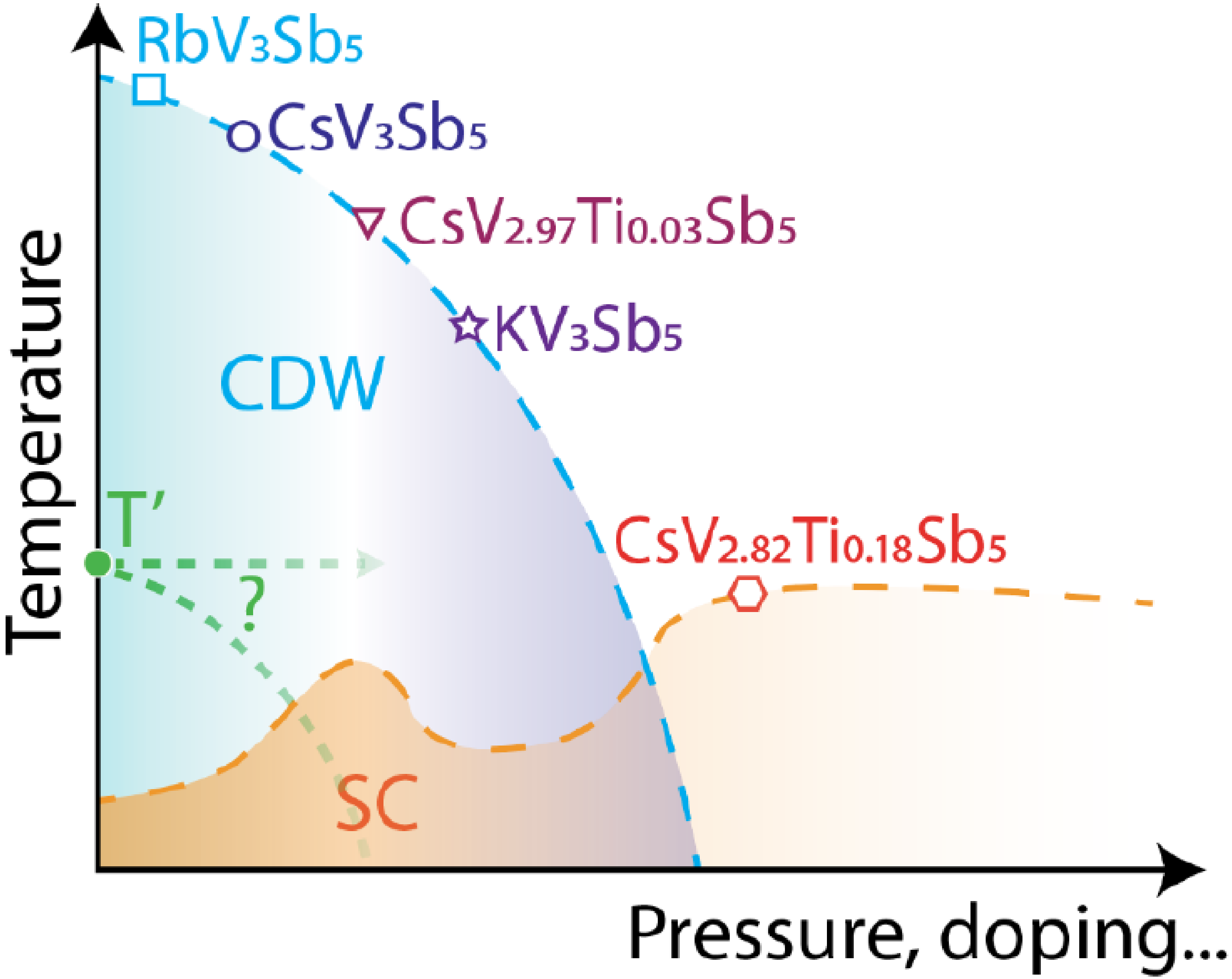


Similarity in electronic structure, yet enhancement of residual resistivity and suppressed AMR peaks:

- Enhanced impurity scatterings
- Impurity as pinning center of chiral domains
- Intrinsic difference between KVS and CVS by electronic chirality

CG et al., npj QM, 2024

Comparison to KV_3Sb_5: Possible origin of the difference



General phase diagram:

1. Is KVS located at the "wrong" side of the phase diagram?
2. Quantum criticality of orbital magnetism?