Altermagnetic spintronics

Tomas Jungwirth

Institute of Physics, Czech Academy of Sciences & University of Nottingham, United Kingdom

Introduction

TJ, Fernandes, Fradkin, MacDonald, Sinova, Šmejkal
Newton A Cell Press journal
***1**, 100162 (2025)*

TJ, Sinova, Fernandes, Liu, Watanabe, Murakami, Nakatsuji, Šmejkal
nature
in press, arXiv:2506.22860

TJ, Sinova, Wadley, Kriegner, Reichlova, Krizek, Ohno, Šmejkal
nature physics
in press, arXiv:2508.09748

Experiments

Krempaský, TJ et al.
nature
***626**, 517 (2024)*

Amin, TJ, et al.
nature
***636**, 348 (2024)*

Reichlová, TJ, et al.
nature COMMUNICATIONS
***15**, 4961 (2024)*

Baďura, TJ, et al.
nature COMMUNICATIONS
***16**, 7111 (2025)*

Mencos, Badura, Beckert, Hernandez, Kounta, Petit, Guillemard, Rial, Baltz, Hueso, Sinova, Gomonay, TJ, Šmejkal, Michez, Reichlova, Casanova
arXiv:2512.17427

Dal Din, Usanov, Šmejkal, D'Souza, Guo, Amin, Campion, Edmonds, Polley, Leandersson, Telkamp, Krizek, Krempasky, Minár, TJ, Dil, Wadley
arXiv:2511.01690

Ordered phases: spontaneously break symmetry of Hamiltonian

Normal non-magnetic phase

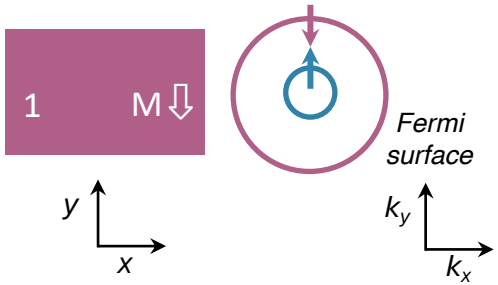
spin-space rotation symmetry

$$\frac{1}{2}\sum_{i\neq j}\frac{1}{4\pi\varepsilon}\frac{e^2}{|\mathbf{r}_i-\mathbf{r}_j|}$$

spin independent

Ordered phases: spontaneously break symmetry of Hamiltonian

Ordered ferromagnetic phase



Spontaneously broken spin-space rotation symmetry

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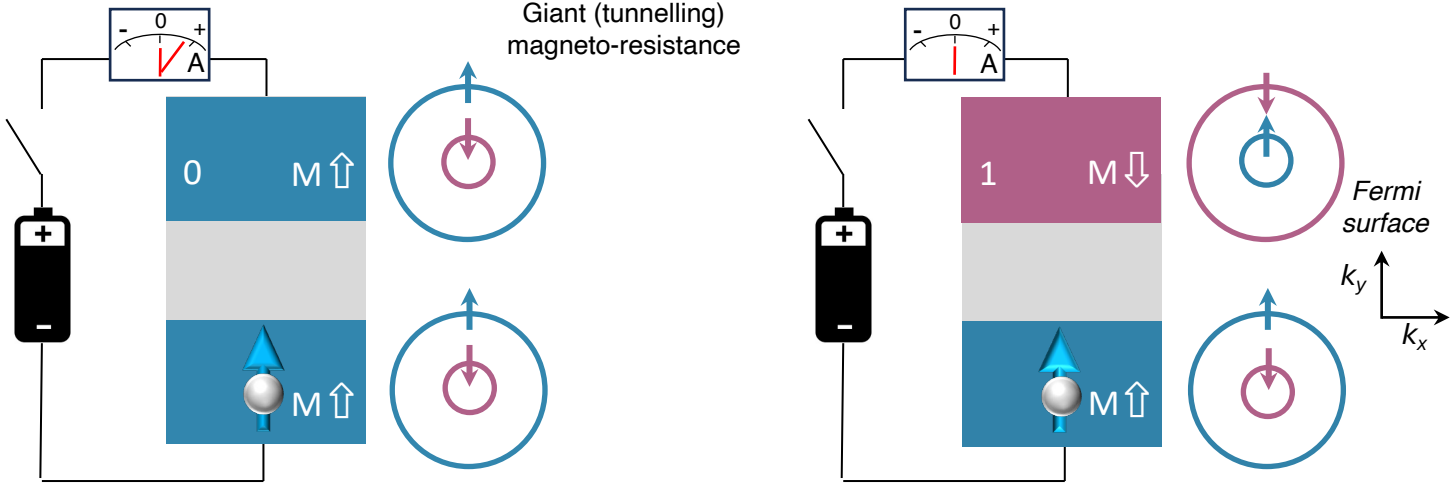
Ordered phases: spontaneously break symmetry of Hamiltonian

Ferromagnetic spintronics

Fert, Grunberg *Parkin*
Nobel Prize (2007) *Millenium Technology Prize (2014)*

Giant (tunnelling)
magneto-resistance



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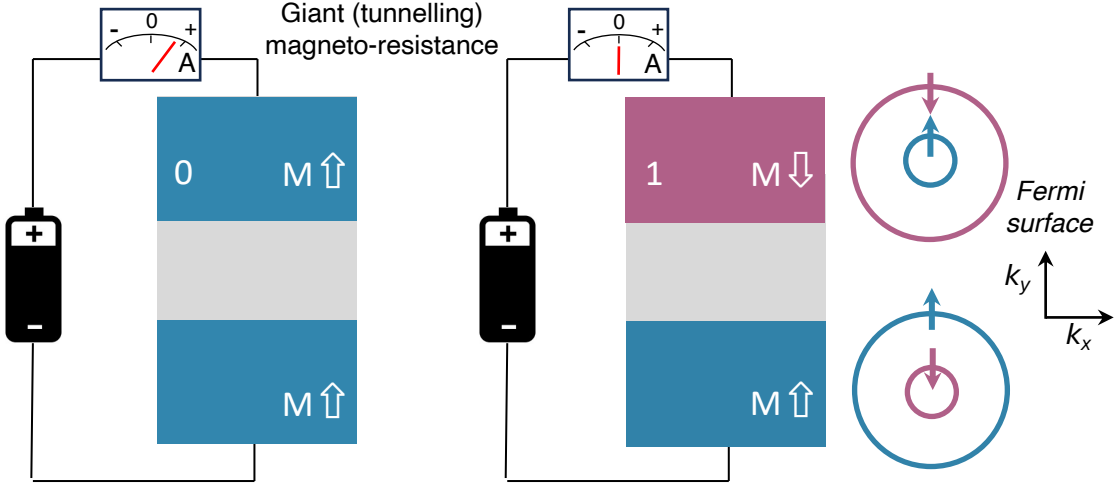

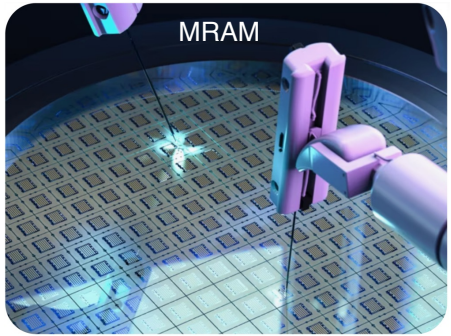

IBM, TSMC, Samsung, Global Foundries,…
Int. Roadmap for Devices and Systems (2023)

✗ M → stray field

✗ M → GHz speed limit

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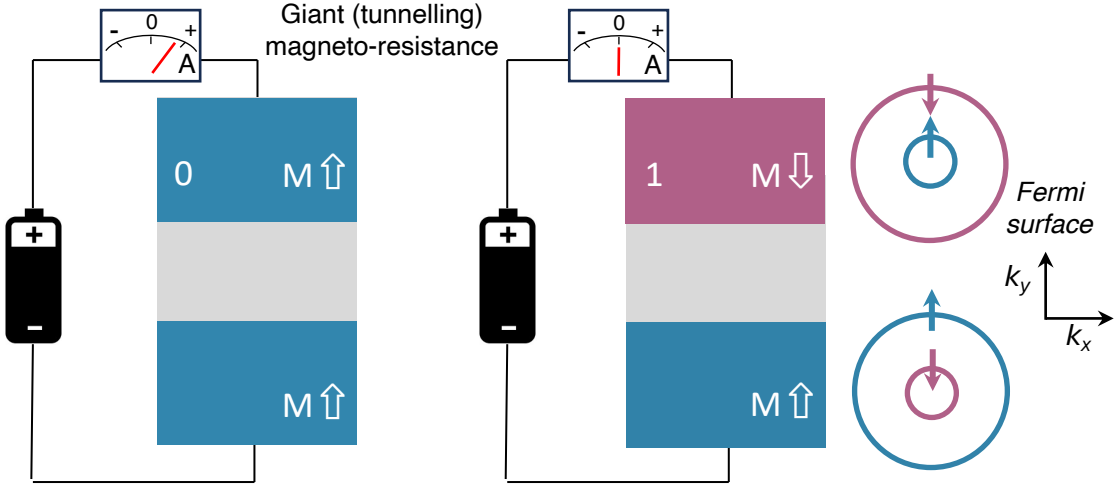
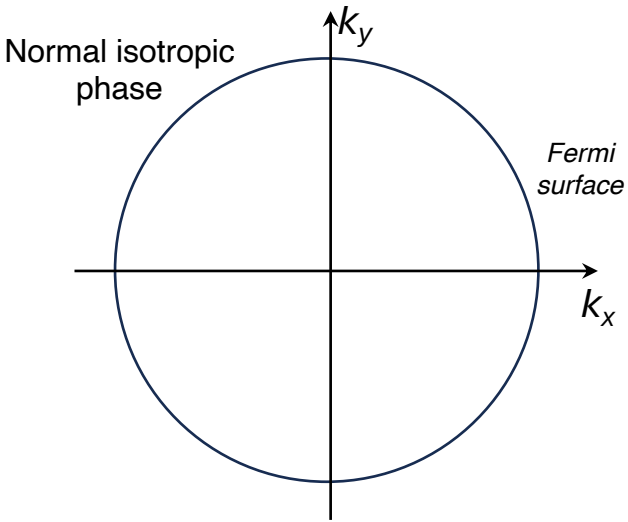


Electronic nematics

Perspective:
*Fradkin, Kivelson, Oganesyan, Science **315**, 196 (2007)*



Spontaneously broken spin-space rotation symmetry

$$\frac{1}{2}\sum_{i\neq j}\frac{1}{4\pi\varepsilon}\frac{e^2}{|\mathbf{r}_i-\mathbf{r}_j|}$$

spin independent & isotropic

real-space rotation symmetry

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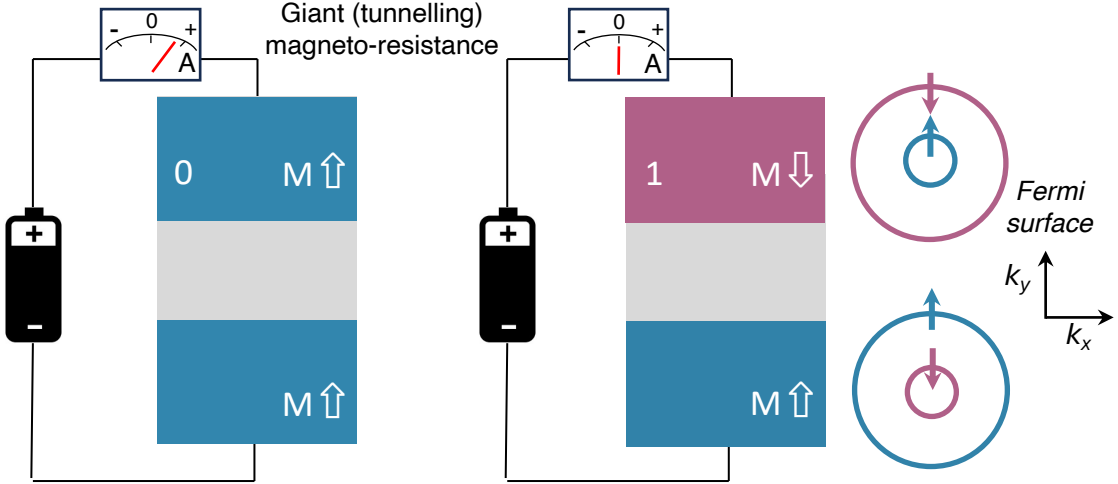

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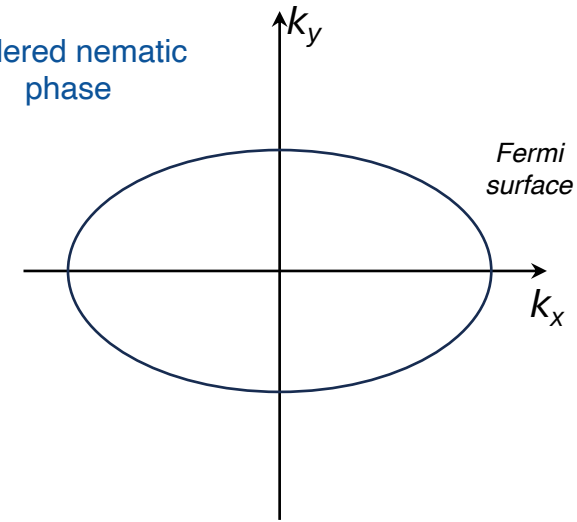
Ordered nematic phase



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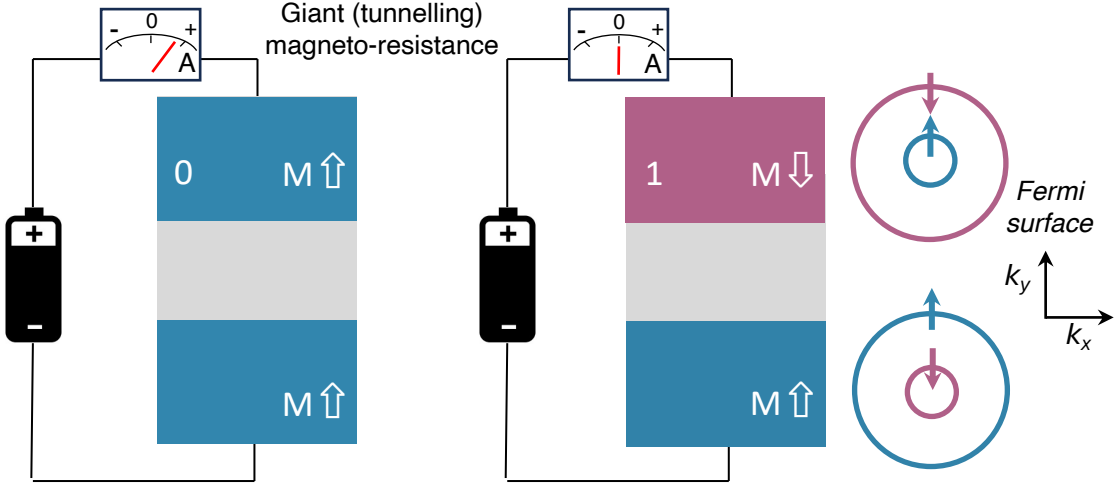

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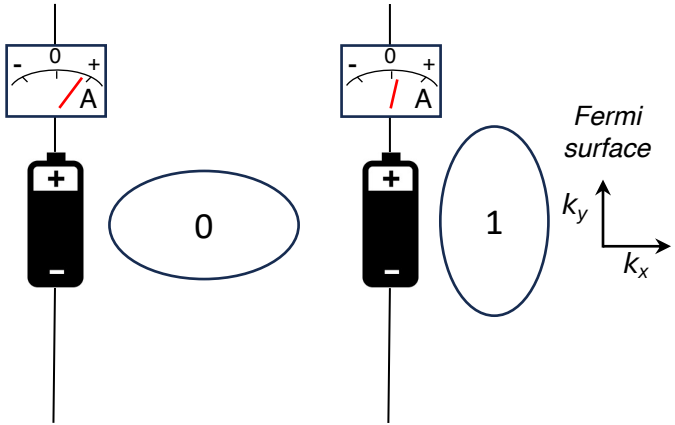
Resistivity anisotropy



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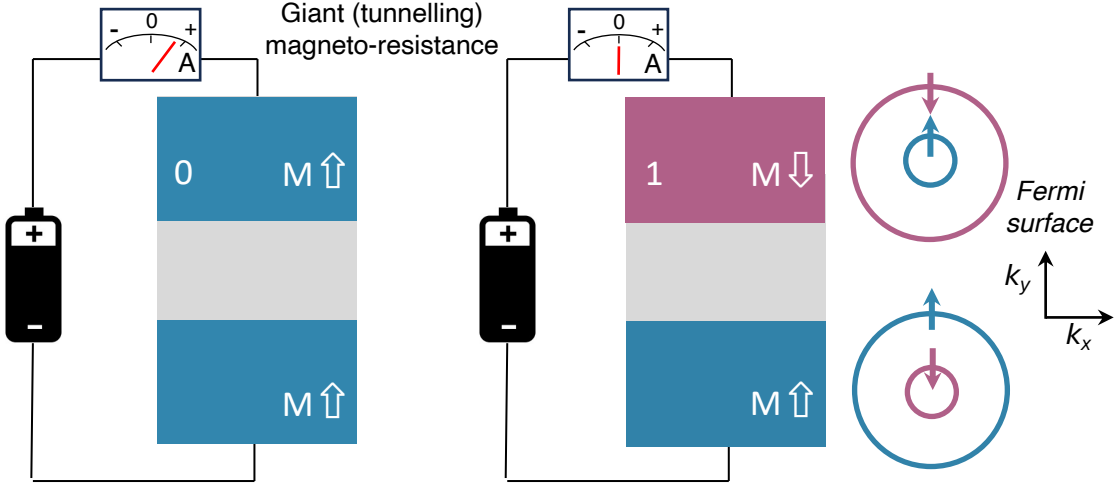

Co, Fe, …@ room-T

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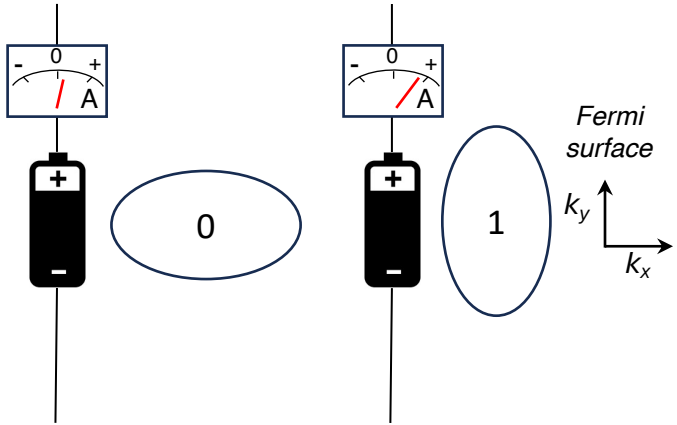

e.g. 2D GaAs near FQHE @ low-T & high-B

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Spontaneously broken real-space rotation symmetry

Altermagnetism: Unconventional spin-ordered phase

Reviews:
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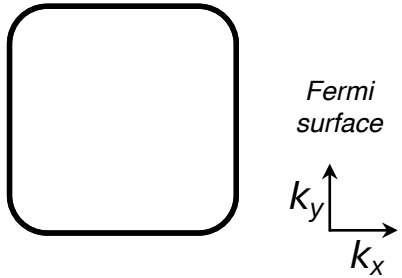

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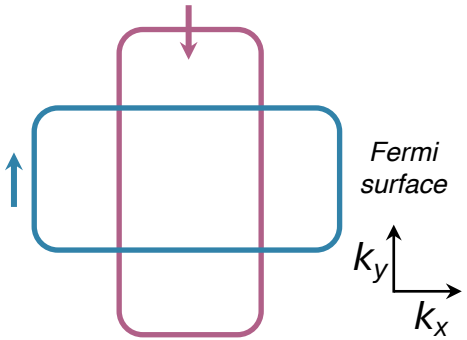

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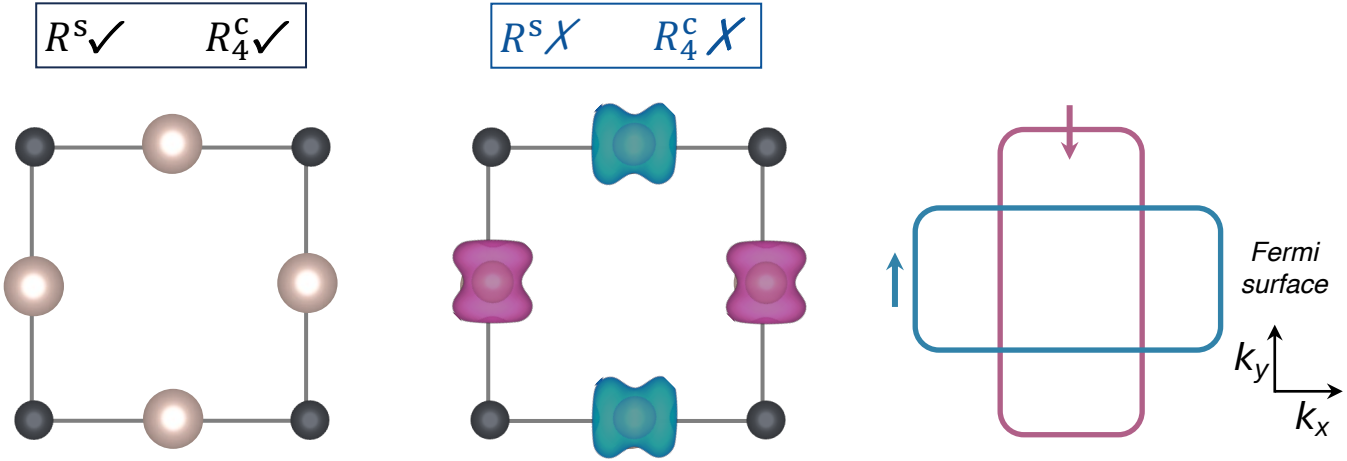

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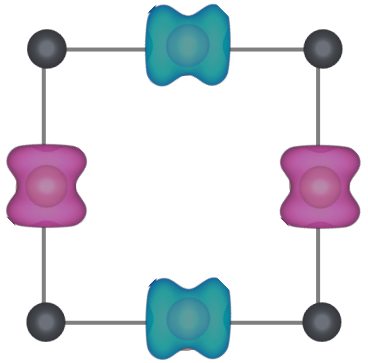
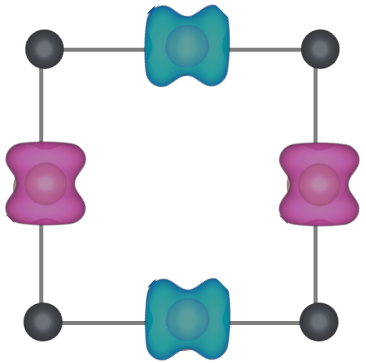
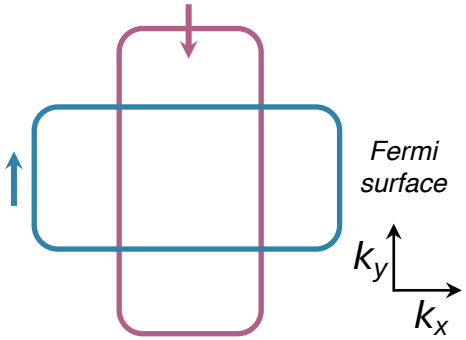
R^s ✗ R_4^c ✗







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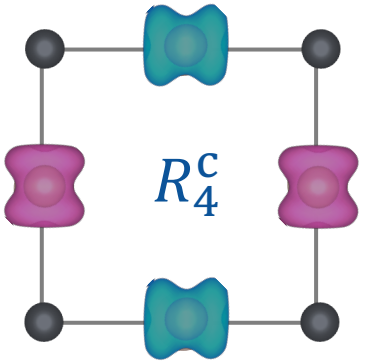
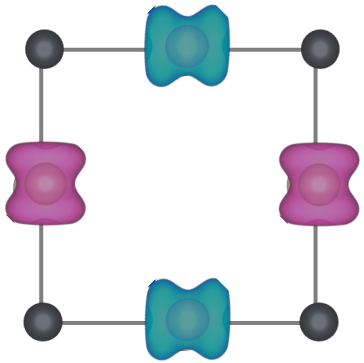
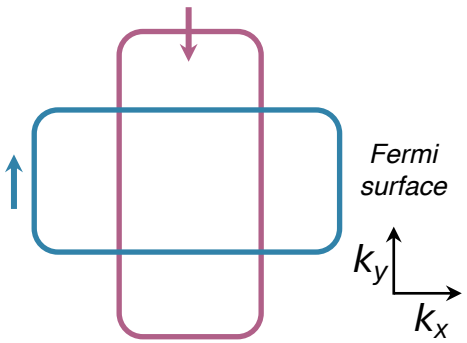
R^s ✗ R_4^c ✗







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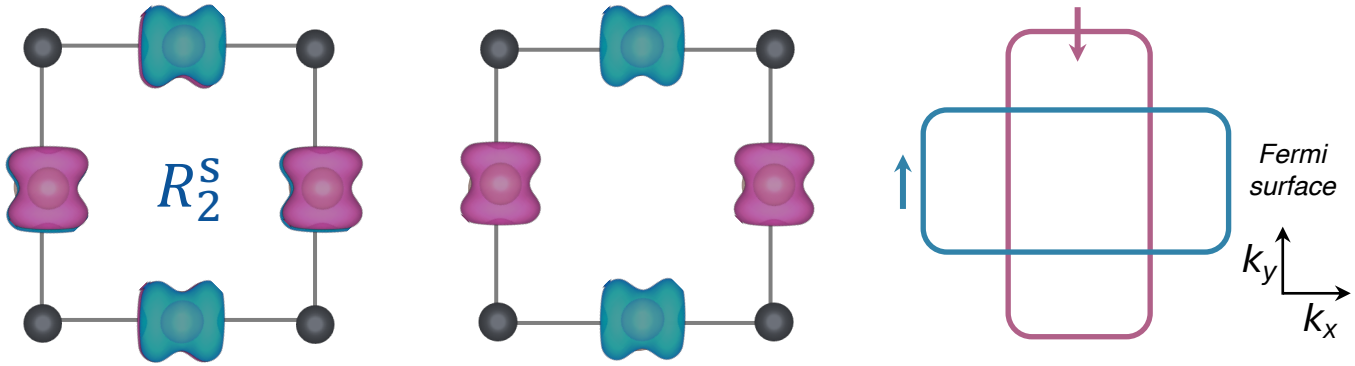
$R_4^c \checkmark \rightarrow M = 0$ $\quad R^s \times \quad R_4^c \times$



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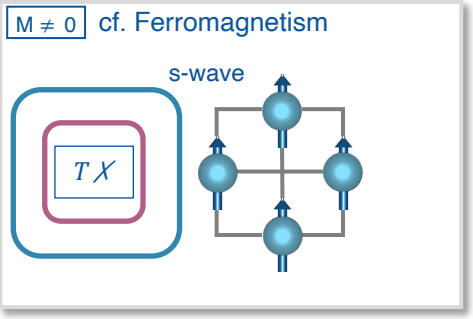
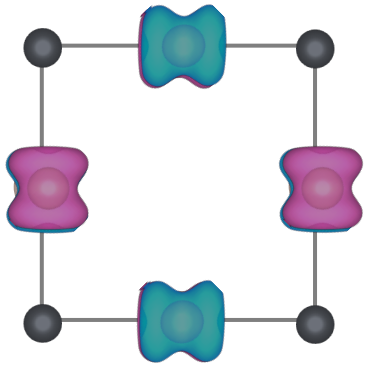
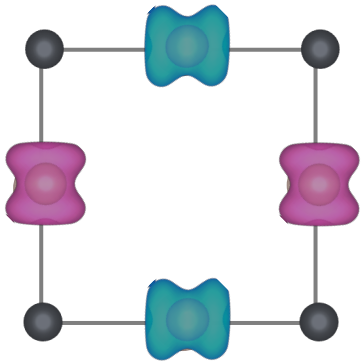
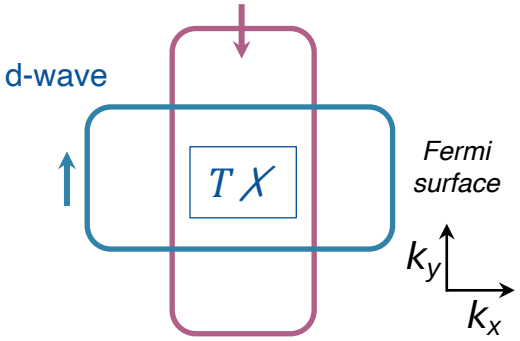
R^s ✗ R_4^c ✗

M ≠ 0 cf. Ferromagnetism









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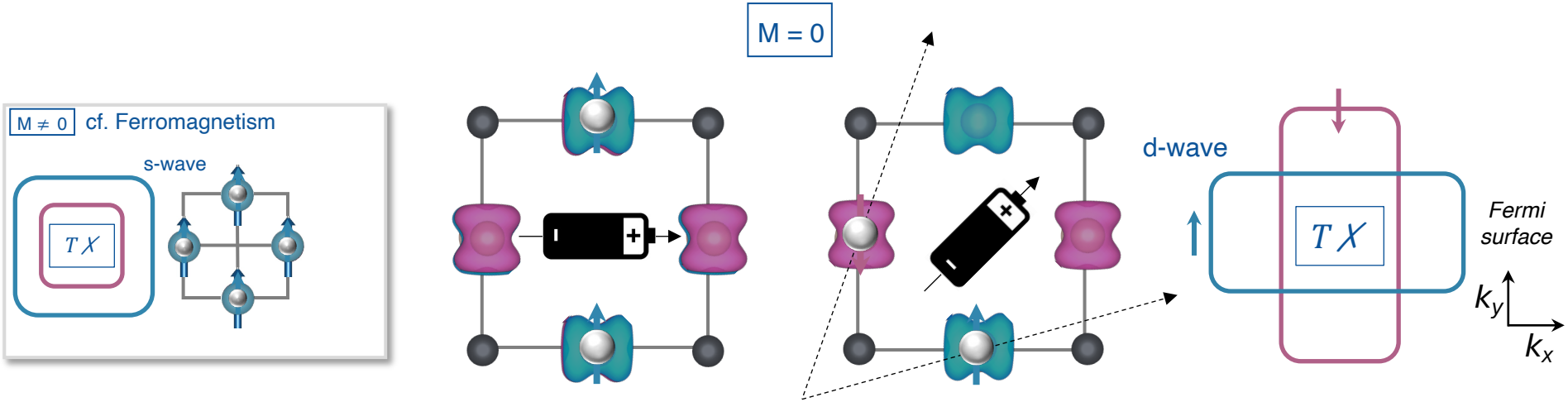

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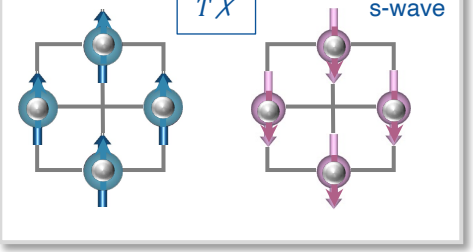
M ≠ 0 cf. Ferromagnetism

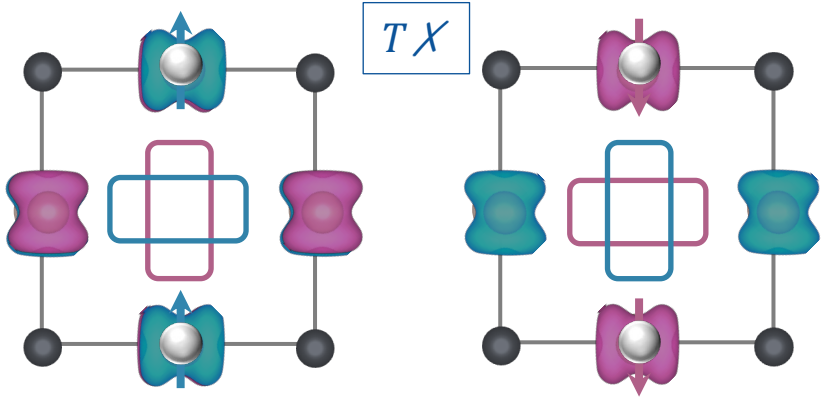
$T\mathcal{X}$

s-wave



M = 0

$T\mathcal{X}$



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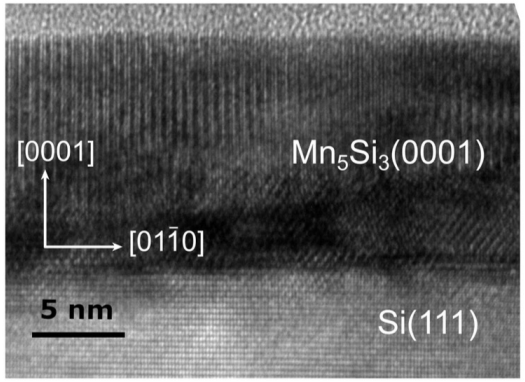
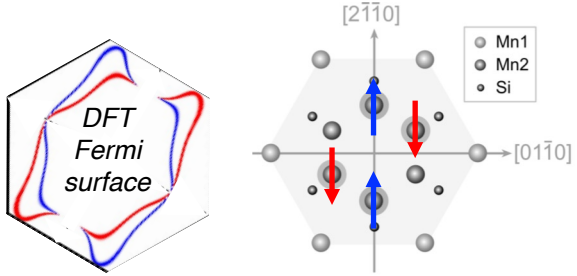
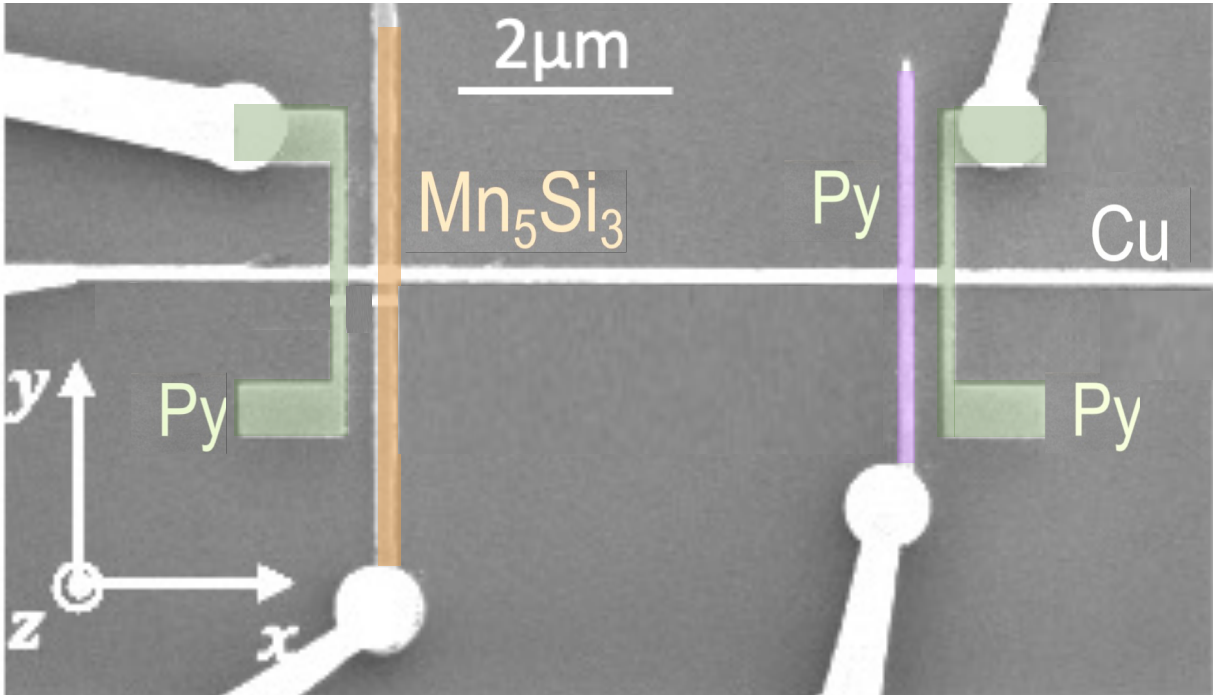
Electrical spin injection in lateral spin valve

Mencos, TJ, et al., arXiv:2512.17427

Epitaxial thin-film Mn_5Si_3





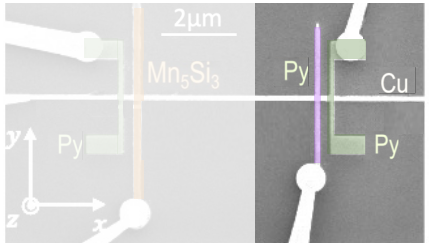


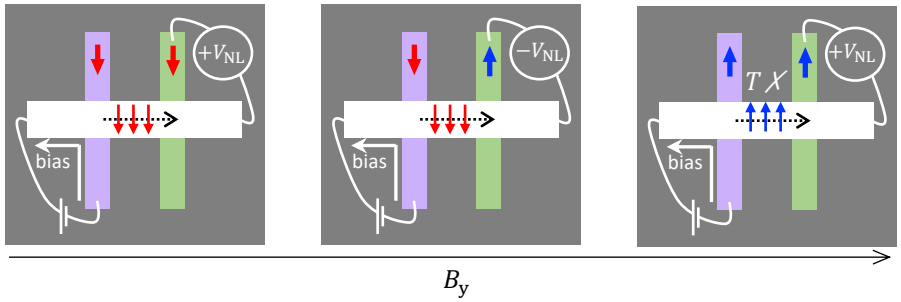
Candidate d-wave altermagnet

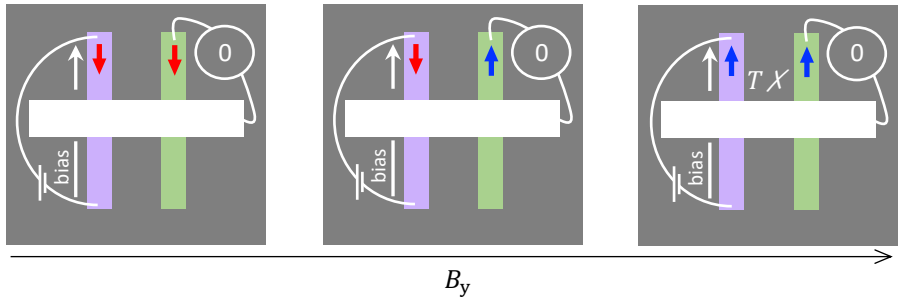
Reichlová, TJ, et al.,
Nature Commun. ***15****, 4961 (2024)*

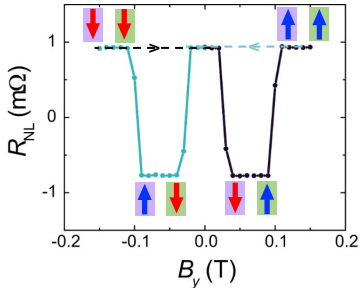
Electrical spin injection in lateral spin valve

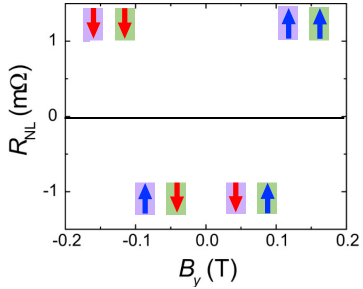
Mencos, TJ, et al., arXiv:2512.17427





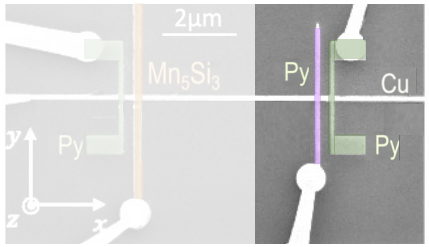


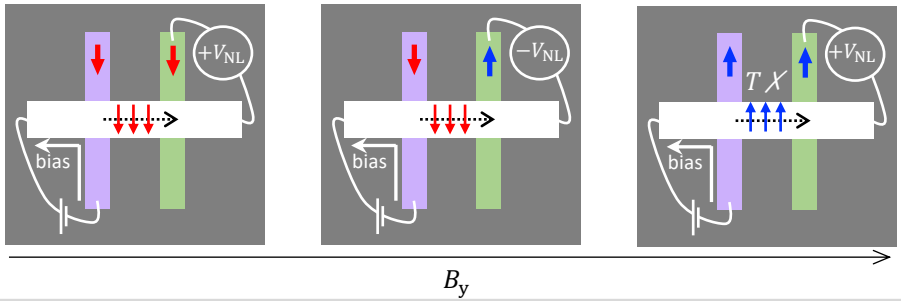


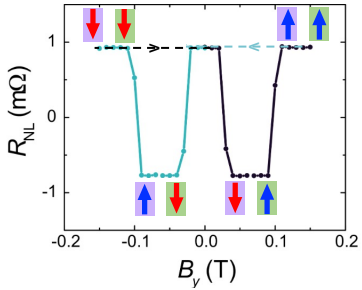


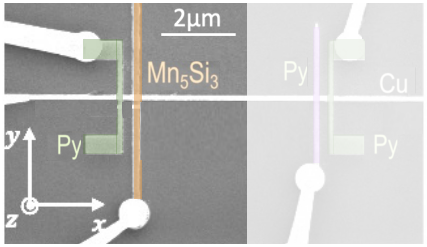
Electrical spin injection in lateral spin valve

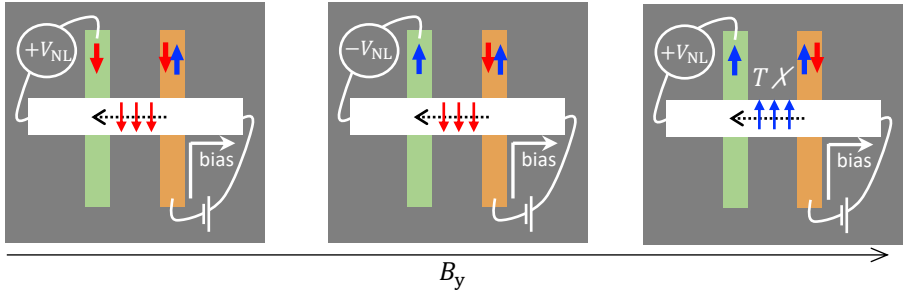
Mencos, TJ, et al., arXiv:2512.17427

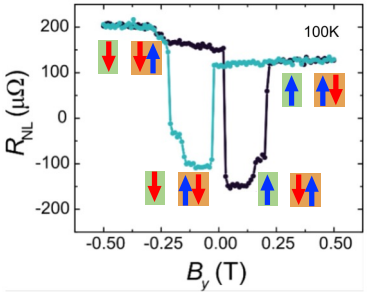


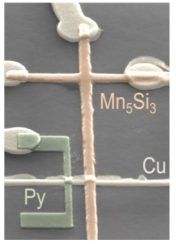


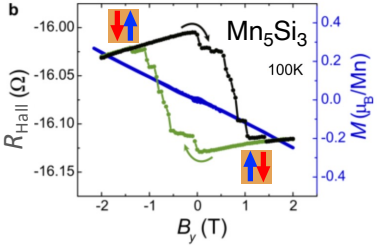






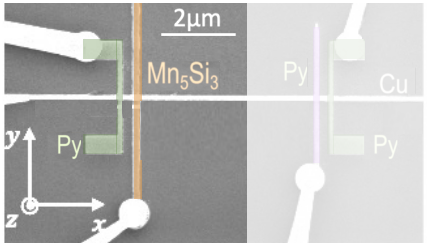


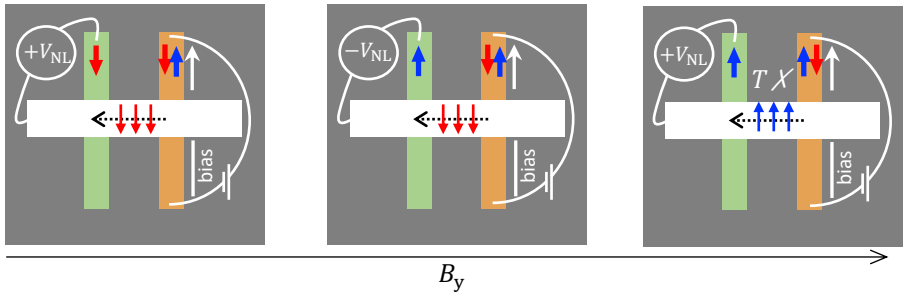


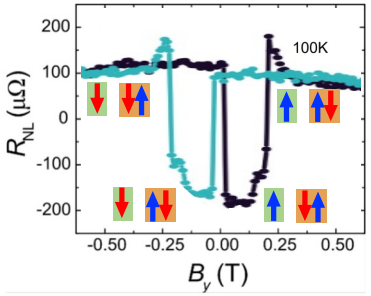


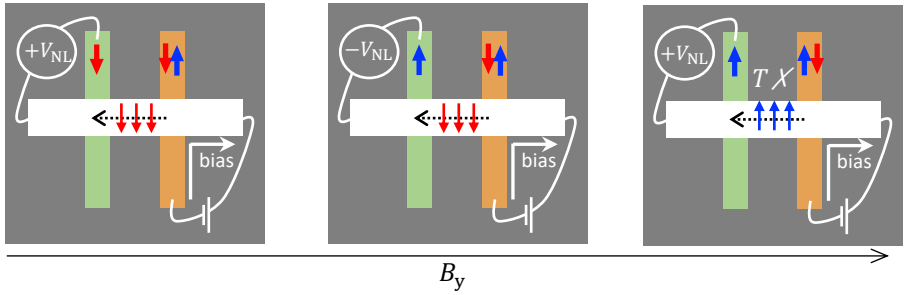
Electrical spin injection in lateral spin valve

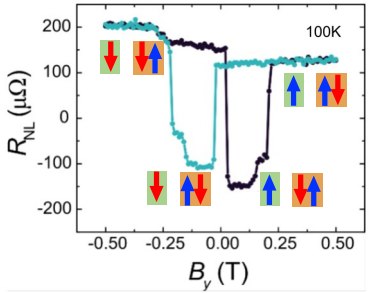
Mencos, TJ, et al., arXiv:2512.17427

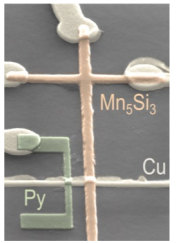


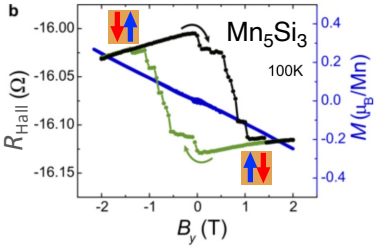












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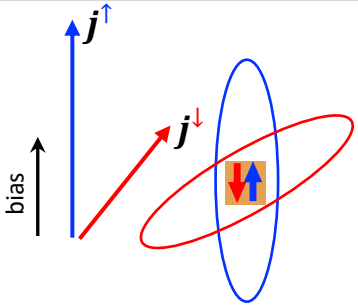
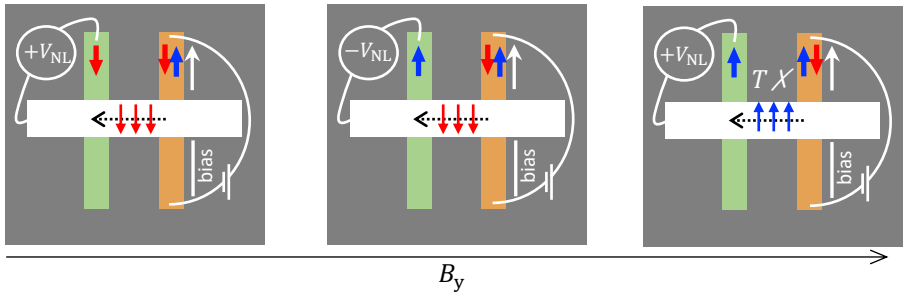
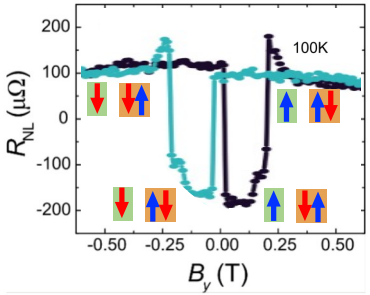
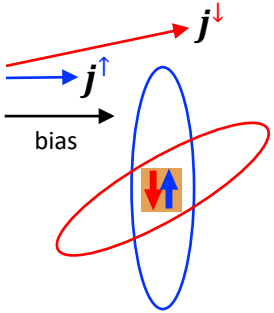
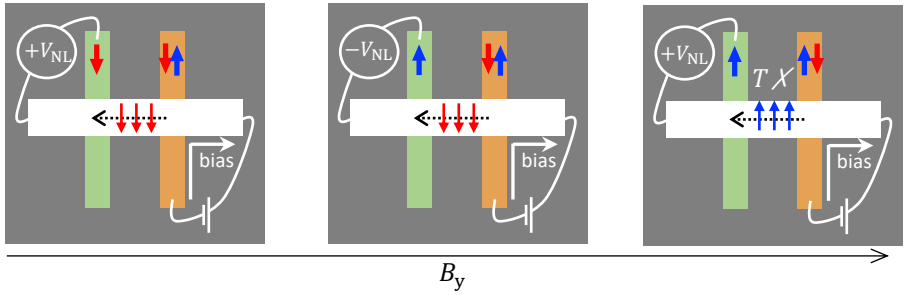
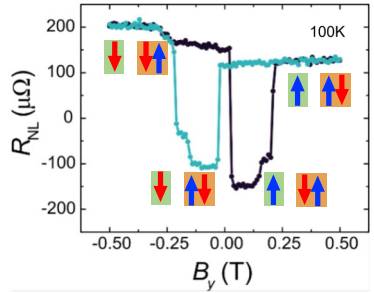




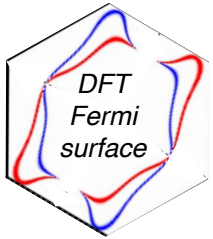


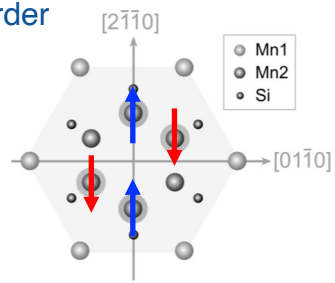


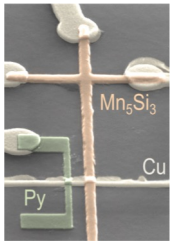


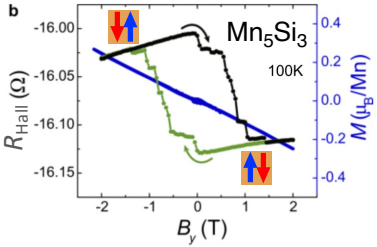


d-wave altermagnetic order







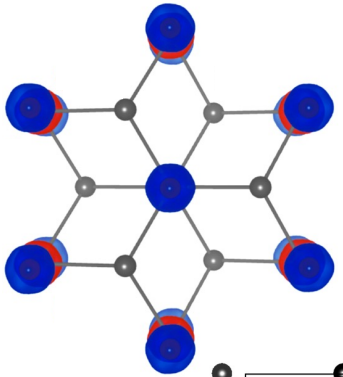


*Krempasky, TJ et al., Nature **626**, 517 (2024)*
*Amin, TJ, et al., Nature **636**, 348 (2024)*
Dal Din, TJ, et al., arXiv:2511.01690

d-wave & g-wave altermagnetism

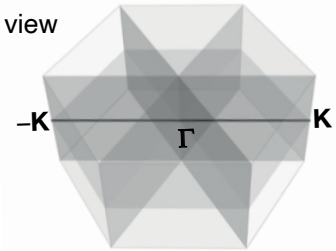
Room-T CrSb and MnTe altermagnets

$R_2^s R_6^c t_{1/2}^c$ ✓ → M = 0

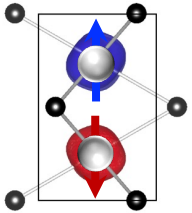


g-wave: 4 nodal planes

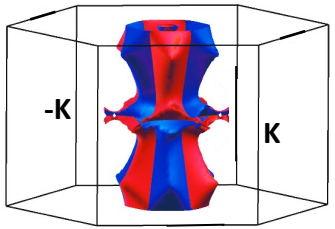
top view



side view



Fermi surface



Šmejkal, Sinova, TJ,
*PRX **12**, 031042 & 040501(2022)*

Krempaský, Dil, TJ et al.,
*Nature **626**, 517 (2024)*

$$\sum_i V_c(\mathbf{r}_i) + \frac{1}{2}\sum_{i\neq j}\frac{1}{4\pi\varepsilon}\frac{e^2}{|\mathbf{r}_i - \mathbf{r}_j|}$$

*Krempasky, TJ et al., Nature **626**, 517 (2024)*
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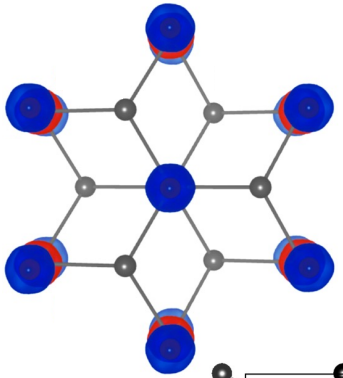
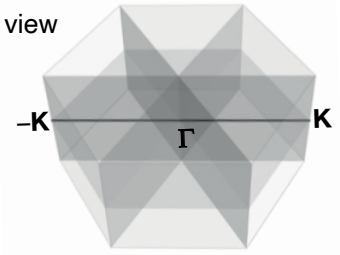
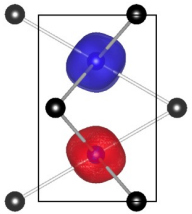
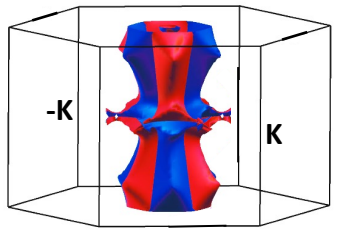
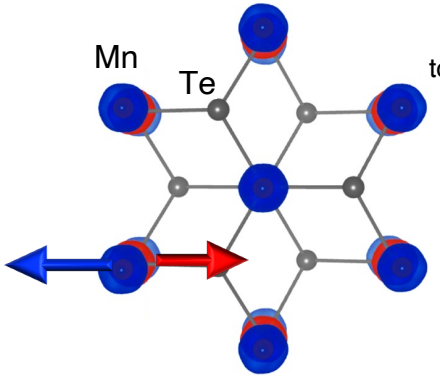


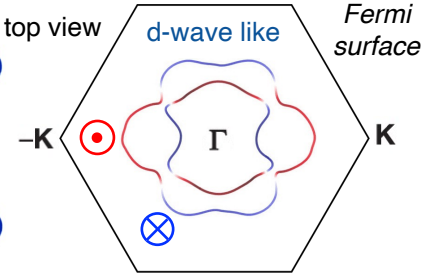
g-wave: 4 nodal planes

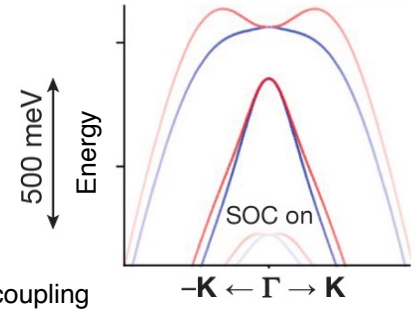












$$\sum_i V_c(\mathbf{r}_i) + \frac{1}{2}\sum_{i\neq j}\frac{1}{4\pi\varepsilon}\frac{e^2}{|\mathbf{r}_i-\mathbf{r}_j|}$$

Spin-orbit coupling

$$+\sum_i \frac{1}{2m^2c^2}\,\mathbf{p_i}\cdot[\mathbf{s_i}\times\nabla V_c(\mathbf{r_i})]$$

*Krempasky, TJ et al., Nature **626**, 517 (2024)*
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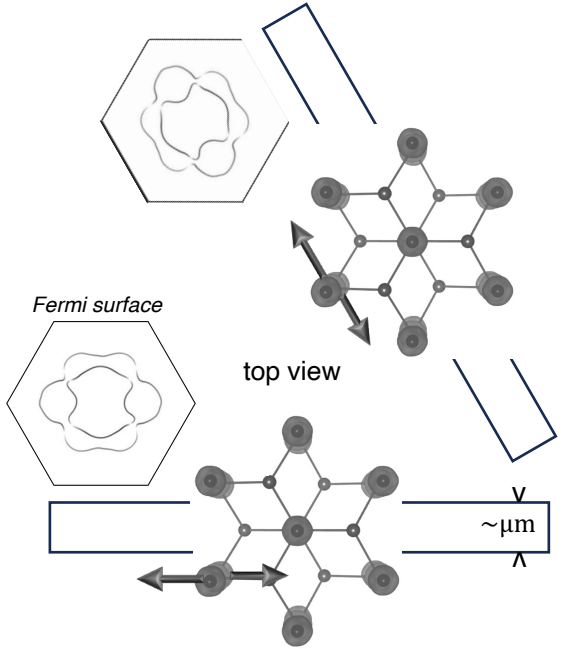

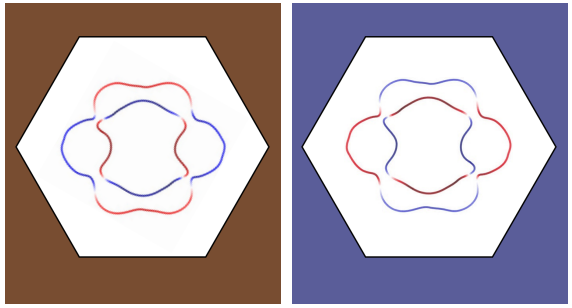

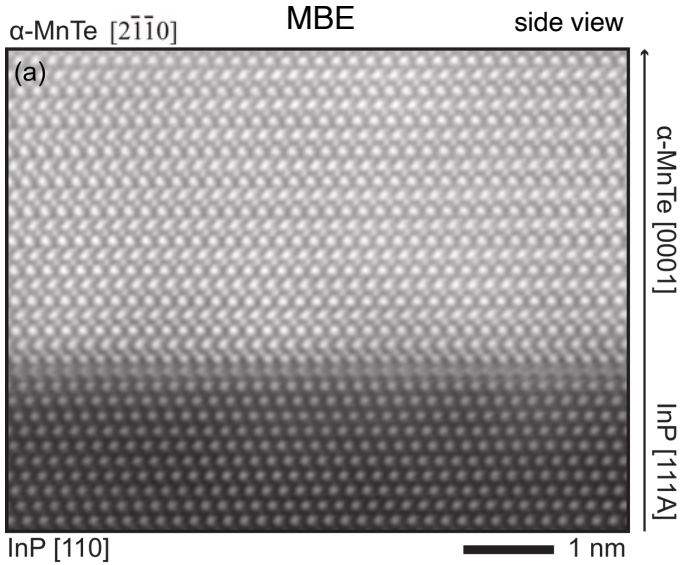

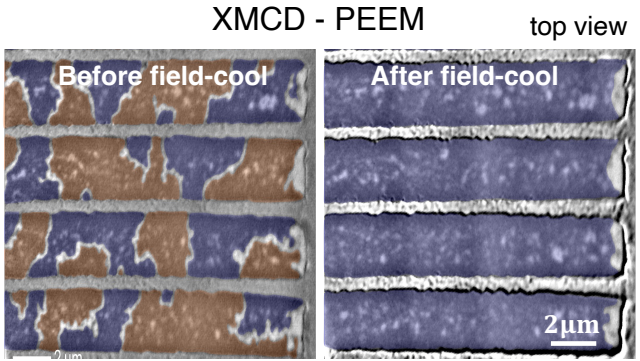

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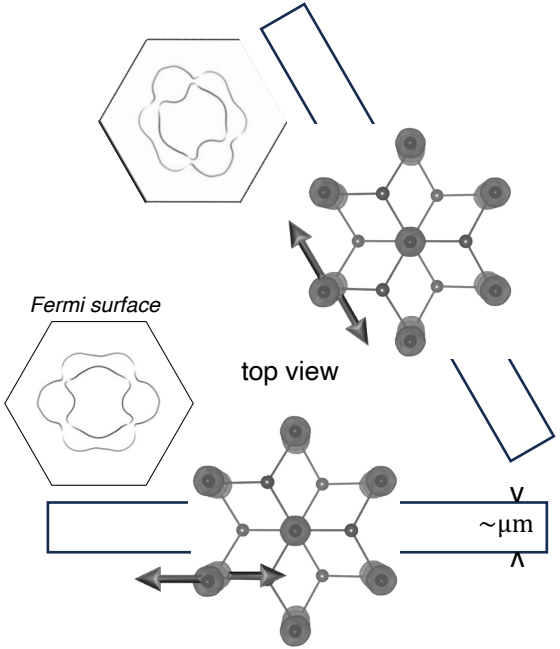
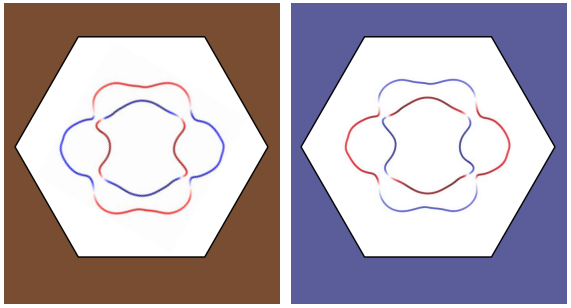
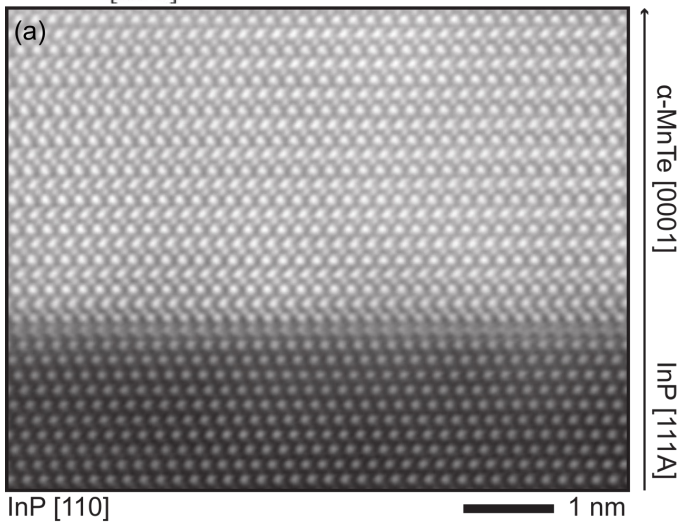
d-wave & g-wave altermagnetism





MBE



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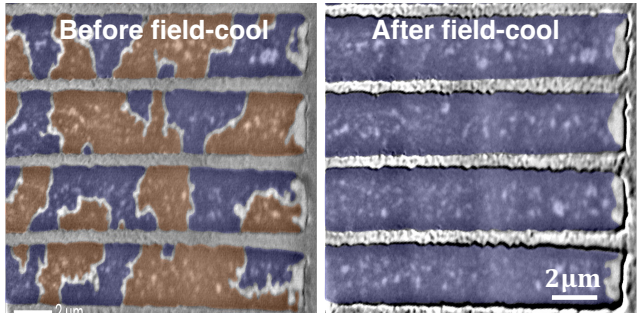
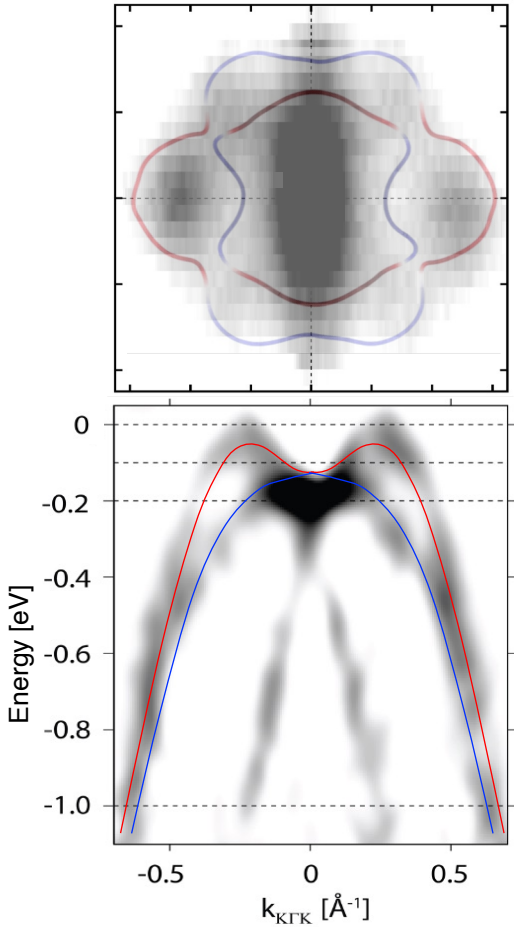


ARPES



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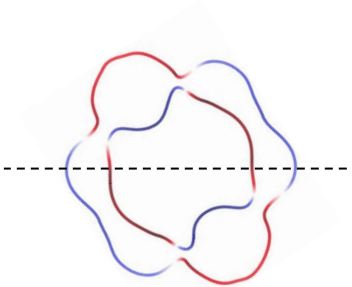

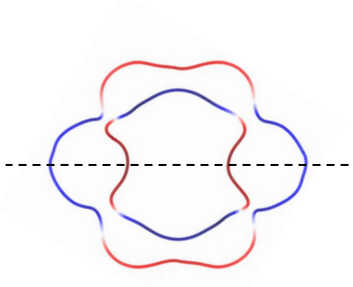

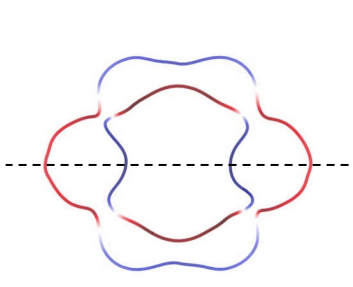

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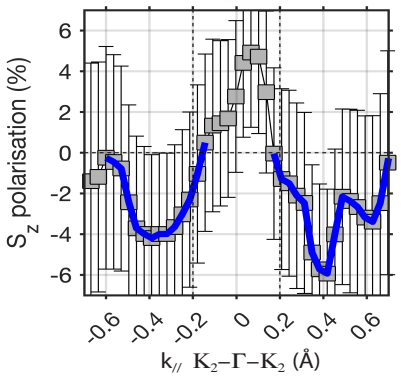

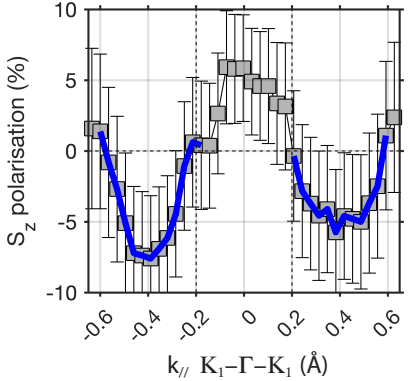

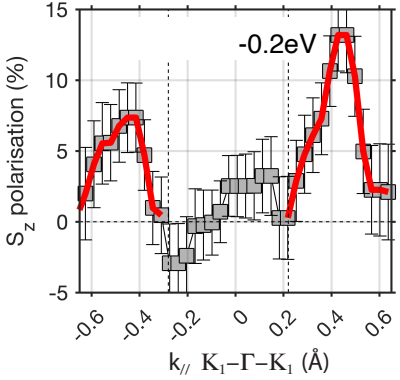

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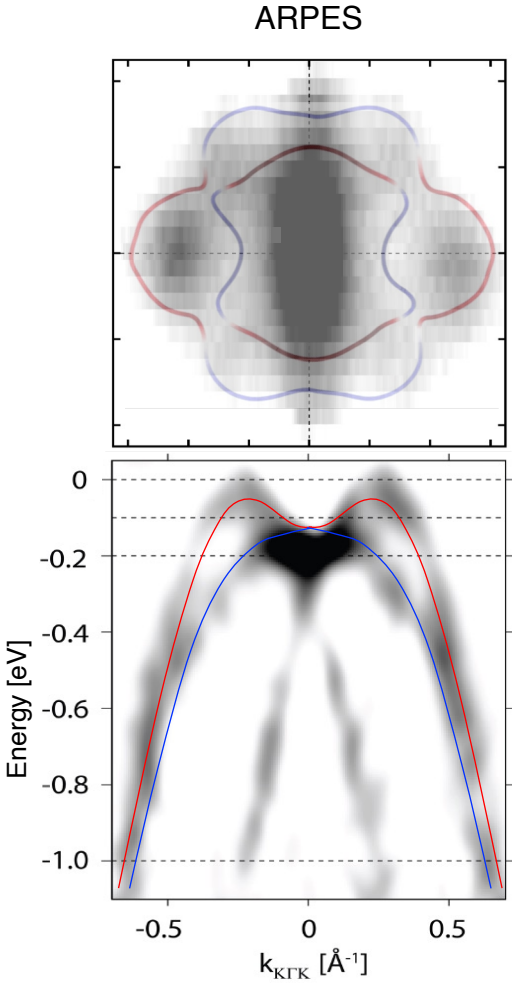

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