

2 Dimensional van der Waals Spin-Orbit Torque Technology

2DSOTECH

Saroj Dash

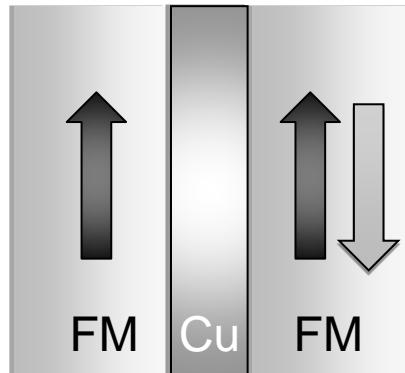
Chalmers University of Technology, Sweden

Partners of 2DSOTECH

Partner Number	Country	Institution/ Department	Name of the Principal Investigator (PI)	Name of the co-Investigators
1 <i>Coordinator</i>	Sweden	Chalmers University of Technology (CUT)	Saroj Dash	
2	Budapest	Budapest University of Technology (BME)	Peter Makk	Szabolcs Csonka, Endre Tóvári
3	Germany	Technische Universität München (TUM)	Christian Back	Lin Chen
4	Slovakia	Institute of Experimental Physics Slovak Academy of Sciences (SAS)	Martin Gmitra	
5	Germany	University of Regensburg (UR)	Jaroslav Fabian	
6	Netherlands	University of Groningen (RUG)	Marcos Guimarães	Jagoda Slawinska, Bart van Wees

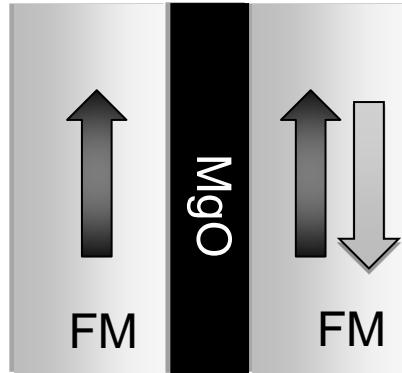
Spintronics

GMR



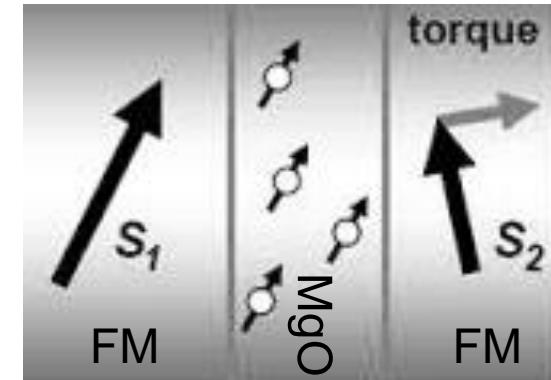
PRL 61, 2472(1988)
PRB 39, 4828 (1989)

TMR



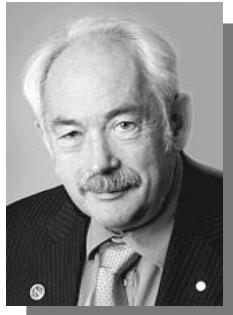
PRL 74 3273 (1995)
Nature Mater 3, 868 (2004)

STT/STO



Slonczewski, Berger (1996)

P. Grünberg



2007

Nobel prize for Physics

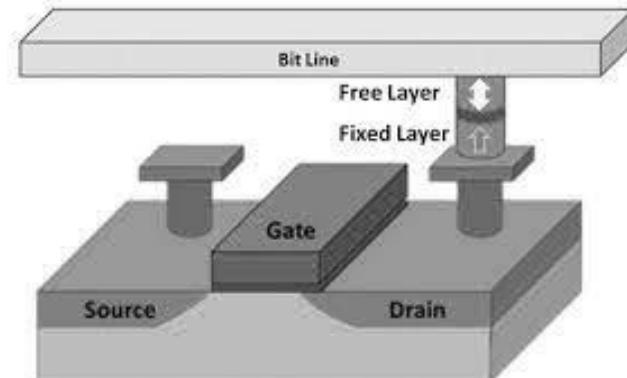
A. Fert



Hard disk



MRAM

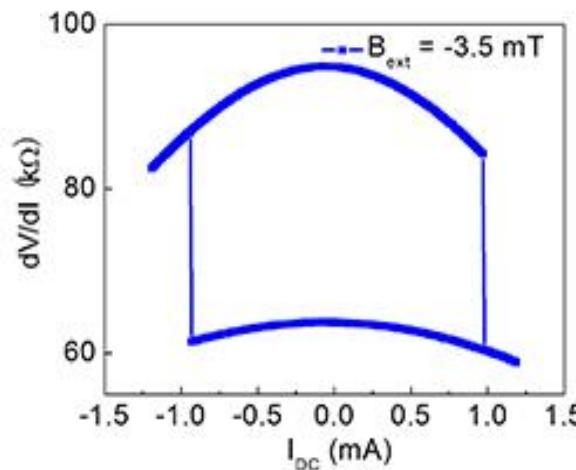
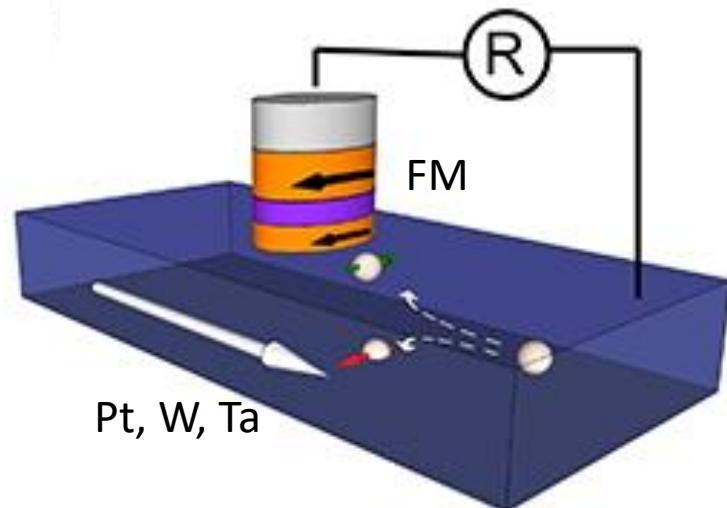


A. Fert, Rev. Mod. Phys. **80**, 1517 (2008)



Spin-orbit torque Magnetic Memory

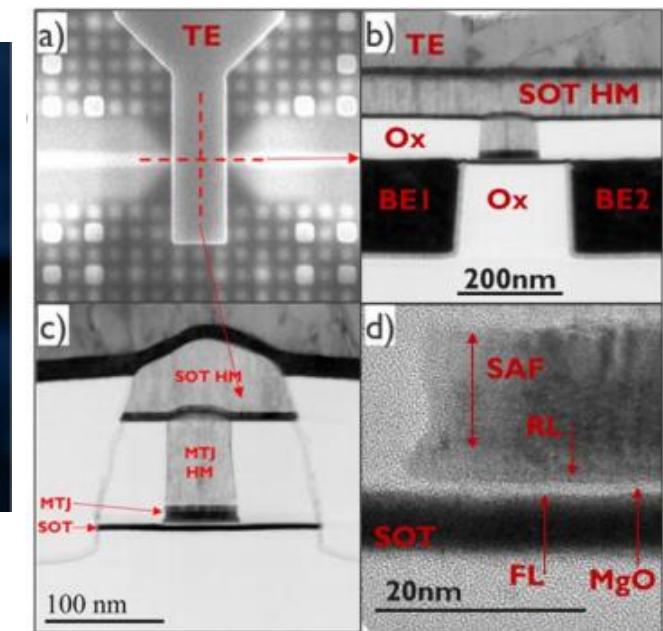
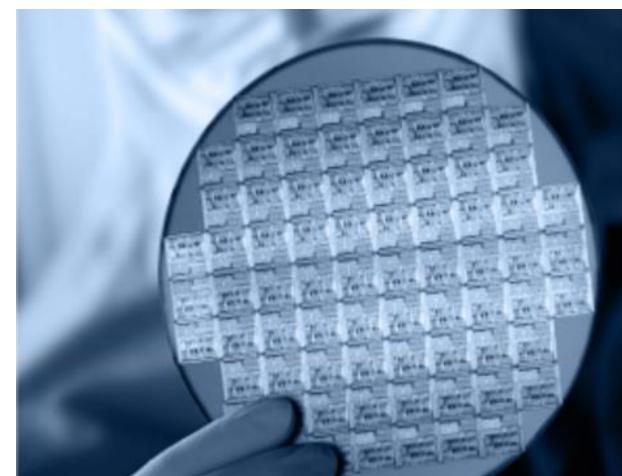
Spin-orbit torque (SOT)



Miron et al., Nature 476, 189 (2011)

SOT-MRAM 300mm integration for low power and ultrafast embedded memories

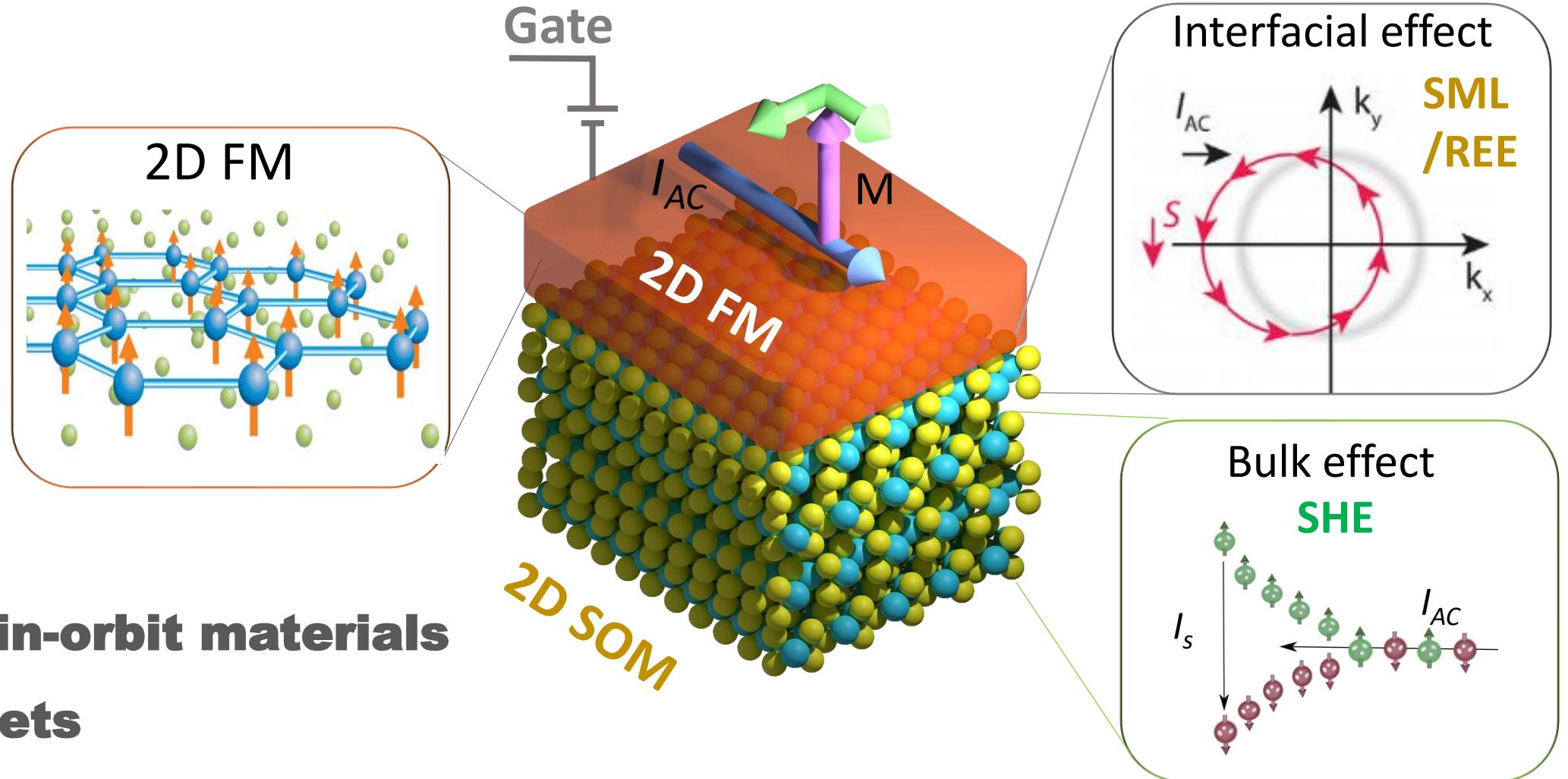
Can replace spin transfer torque (STT) !!



2018 VLSI Technology and Circuits, @ imec,

Need Larger current induced spin polarization for efficient SOT

Nature Electronics 3 (8), 446-459 (2020)

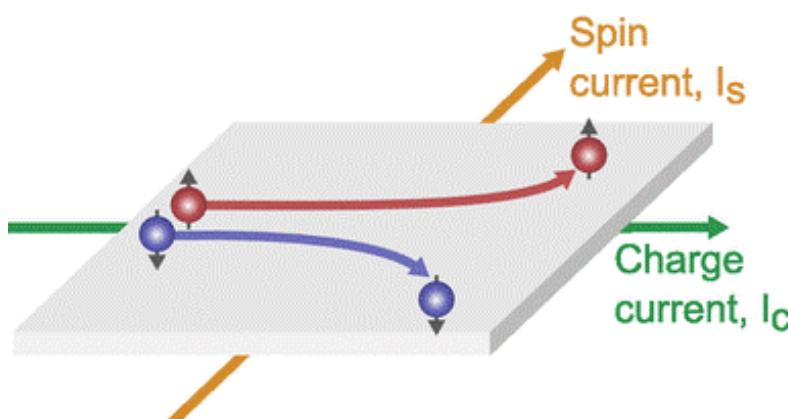


- **Novel spin-orbit materials**
- **2D Magnets**
- **Van der Waals heterostructures**
- **Interface Engineering**

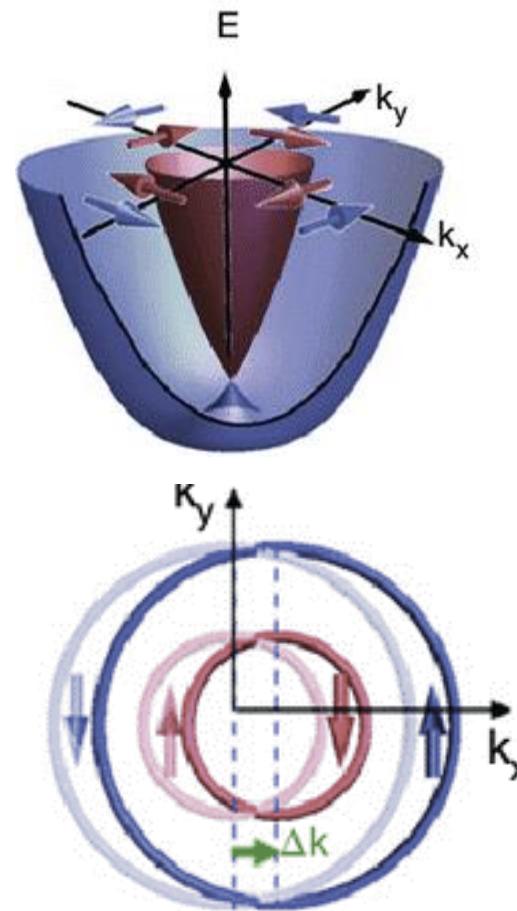
Charge-Spin conversion

Spin Hall effect

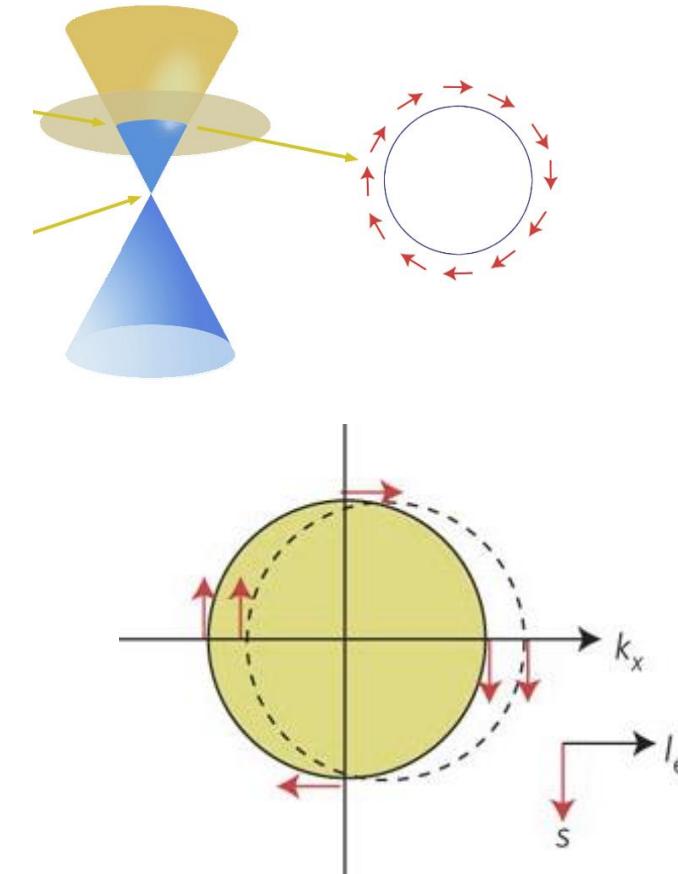
- Topological materials
- Large Berry curvature



Rashba Edelstein



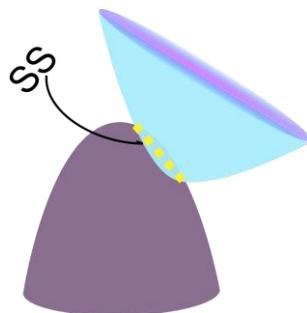
Spin-momentum locking



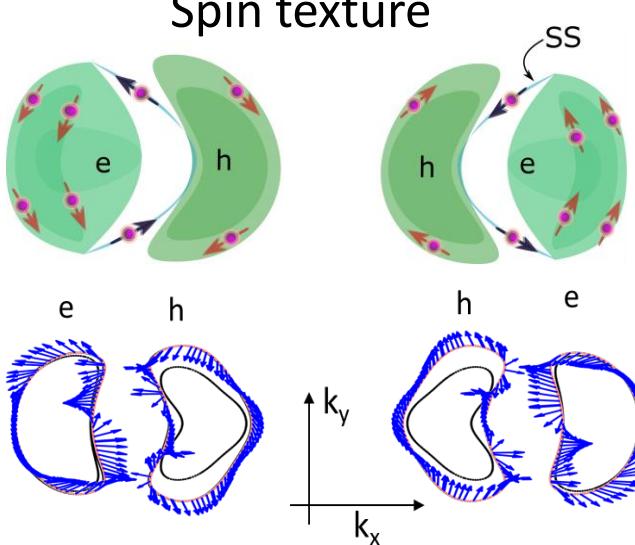
Predicted large and novel charge-spin conversion effects

Low symmetry semimetal WTe₂

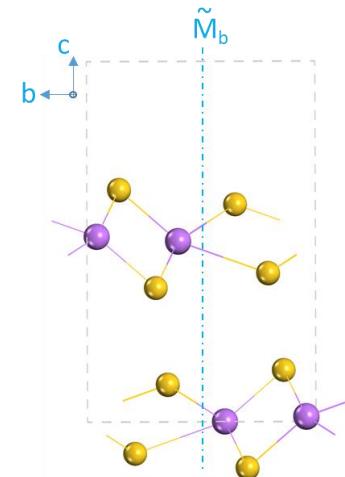
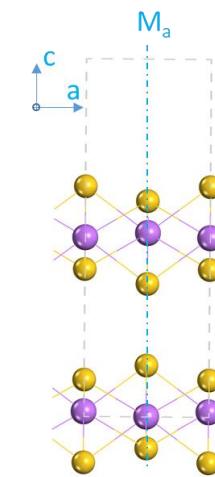
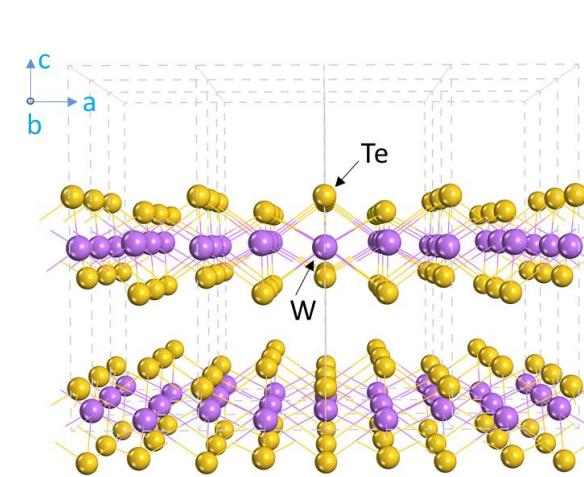
Type-II Weyl
band structure



Spin texture



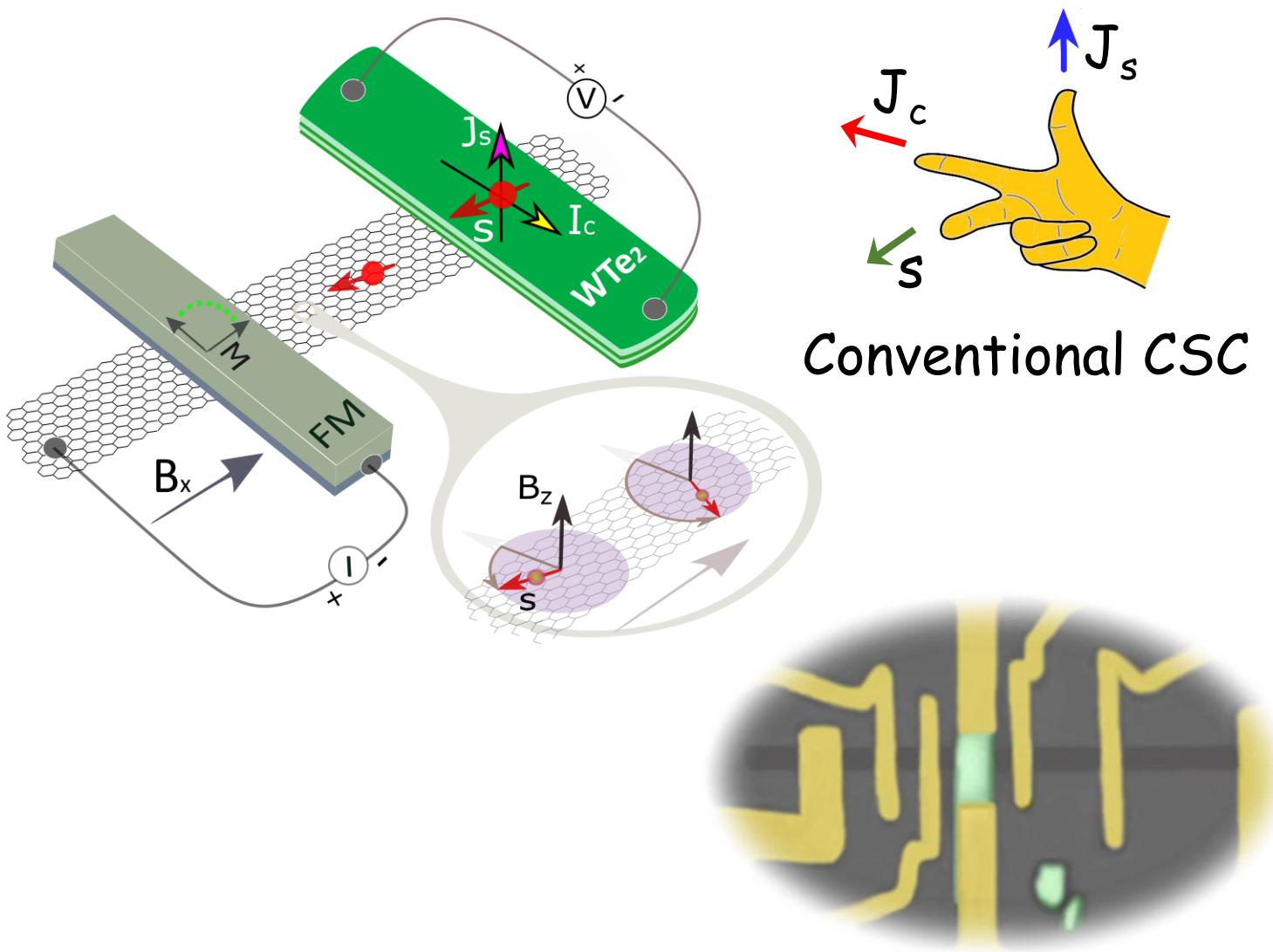
Crystal structure of T_d WTe₂



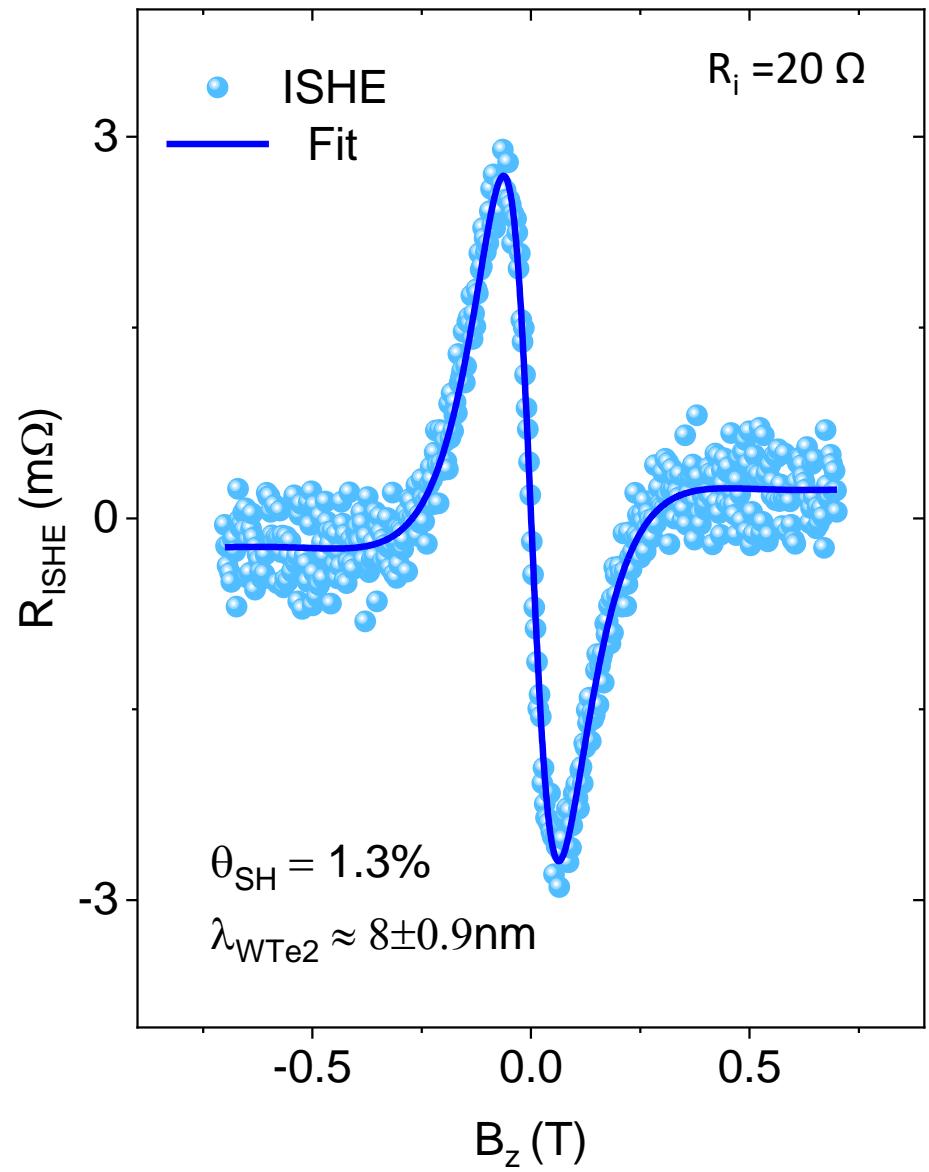
- Type-II Weyl semimetal candidate WTe₂
- Spin-polarized Fermi states (**Bulk & Surface**)
- Large spin orbit coupling
- Broken inversion symmetry

- Charge-spin conversion (CSC)
Spin Hall effect
Edelstein effect
Both conventional and unconventional CSC

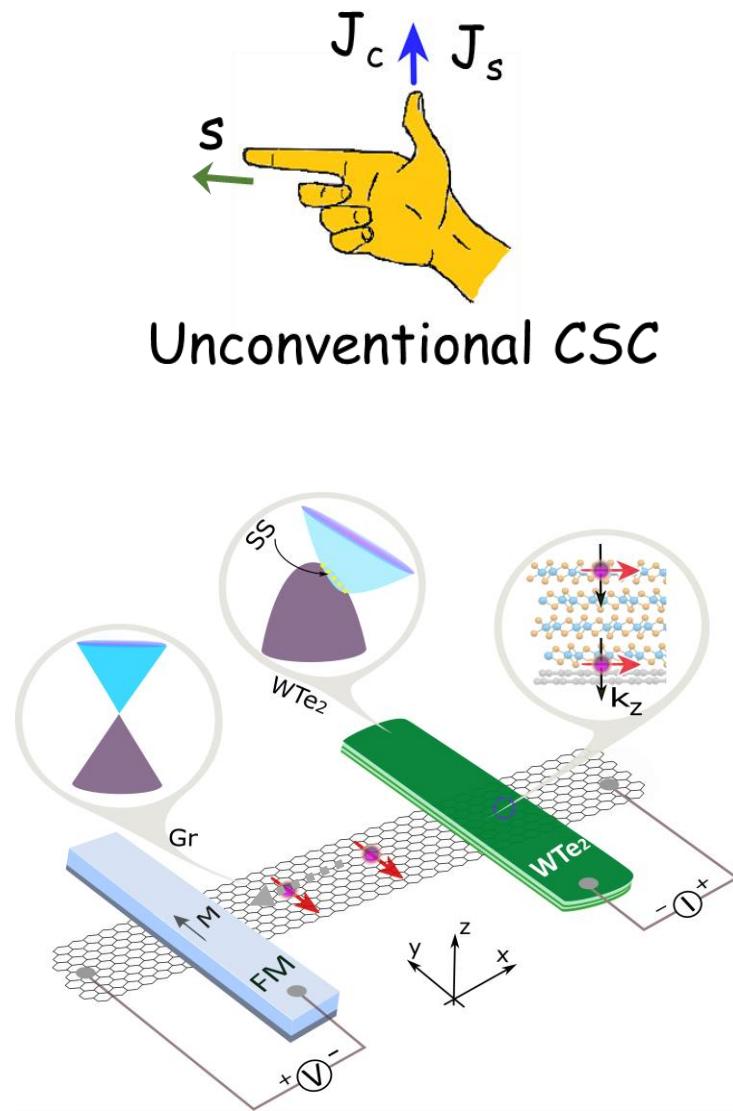
Charge-Spin conversion in WTe₂



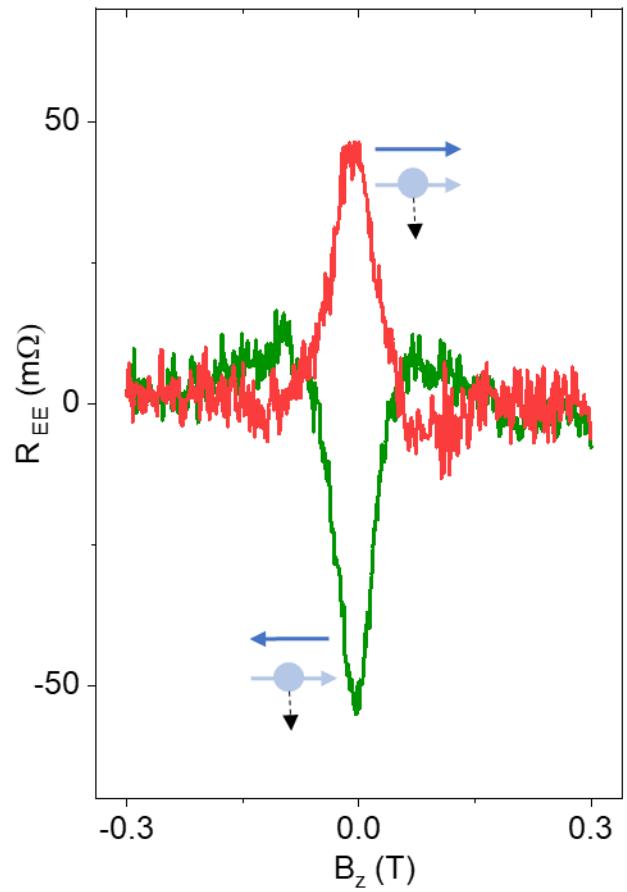
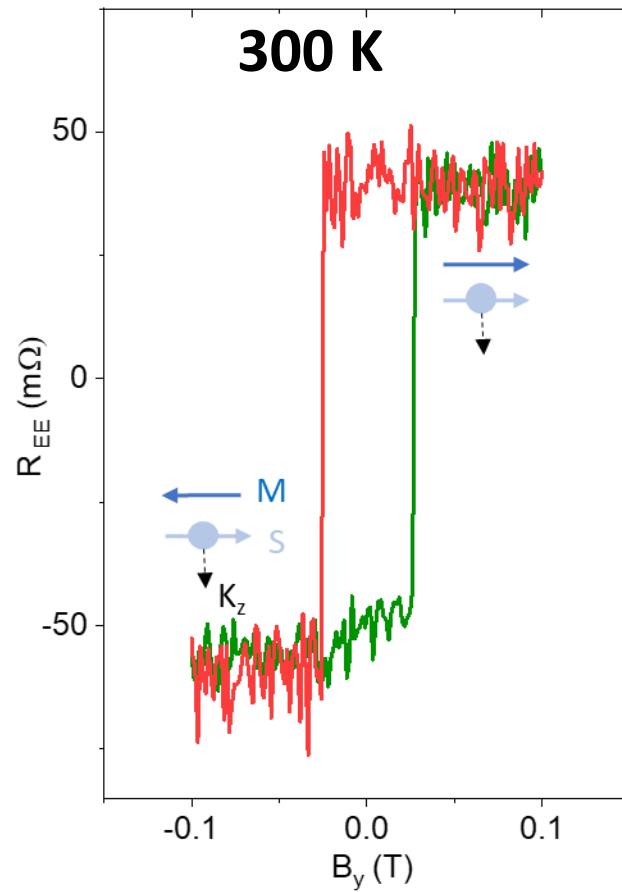
Zhao et al., SD, Physical Review Research 2 (1), 013286 (2020)
Applied Physics Letters 117 (24), 242401 (2020)



Unconventional Charge-Spin conversion in WTe₂

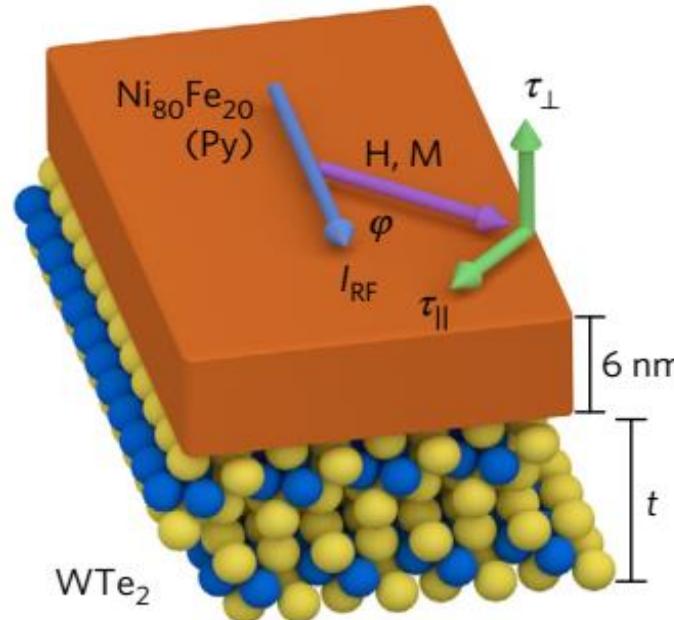


$R_i > 1 \text{ k}\Omega$

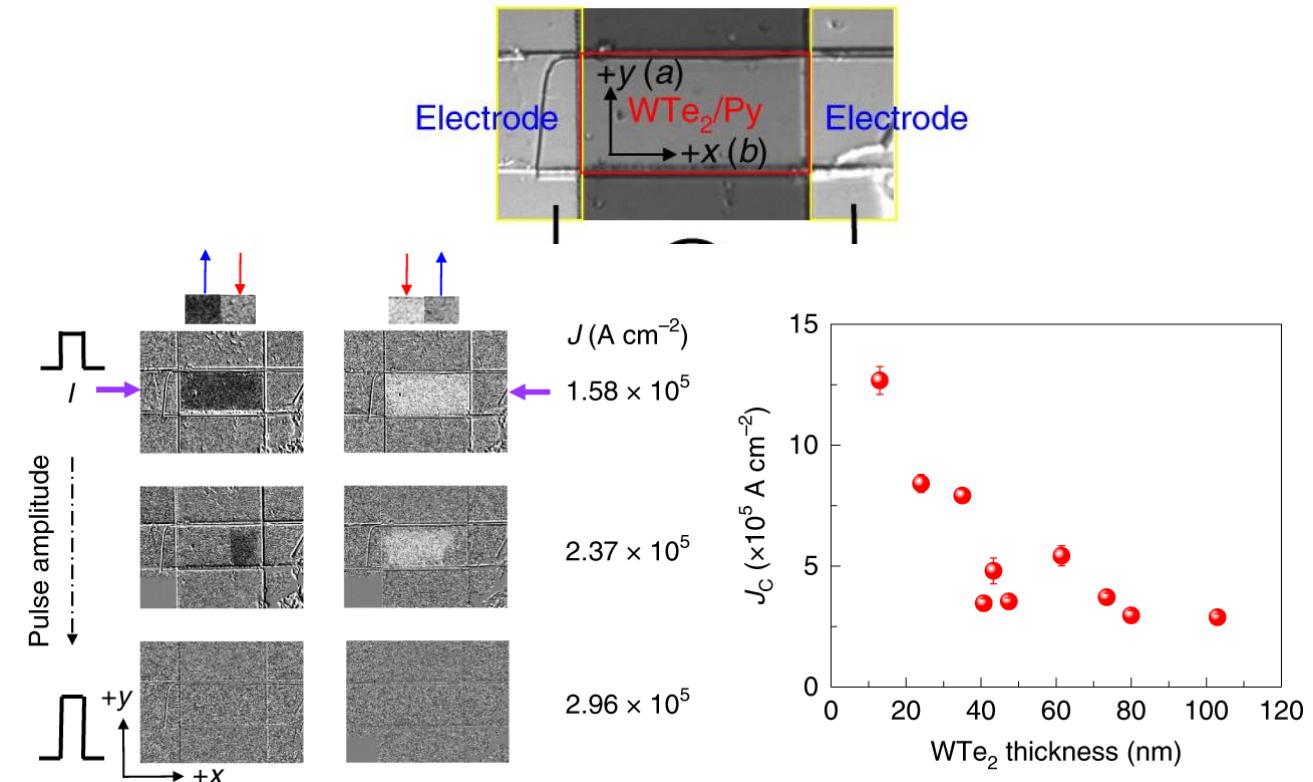


Spin-Orbit Torque

Spin–Orbit Torque and Switching in WTe₂/ferromagnet

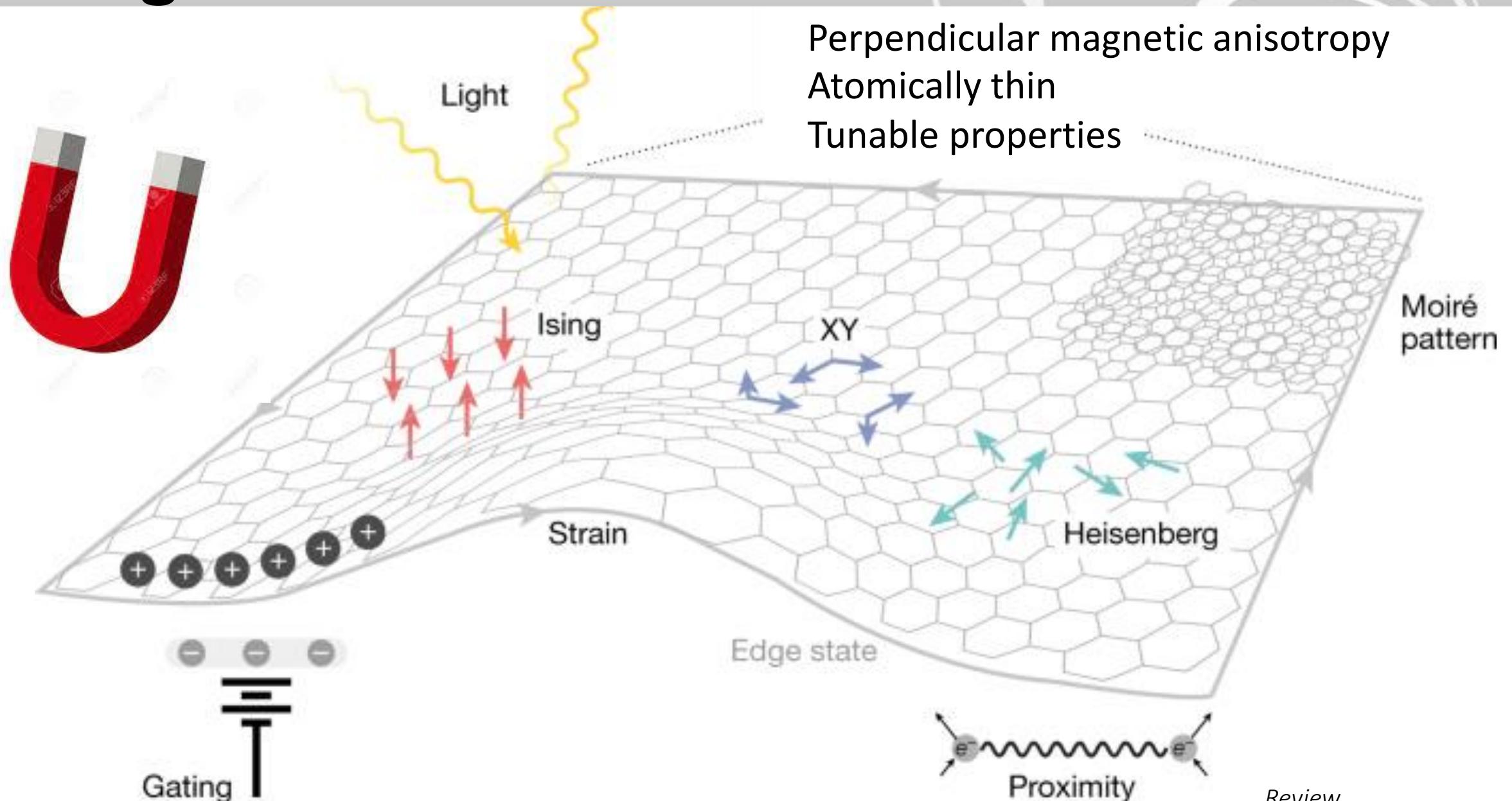


Generating an out-of-plane
antidamping torque when current is
applied along a **low-symmetry** axis of
 WTe_2 /Permalloy bilayers.



Spin-orbit-torque-driven magnetization switching
measurements

2D magnet



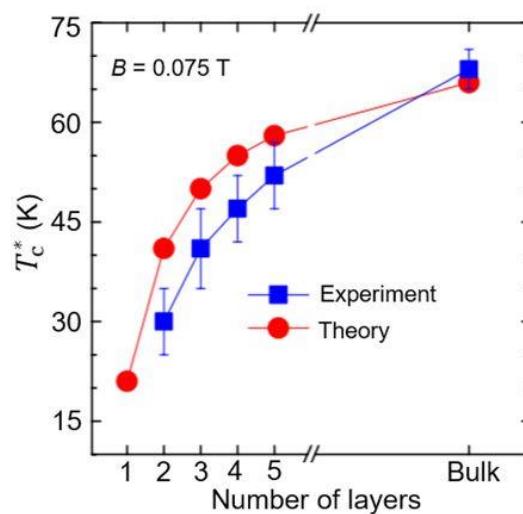
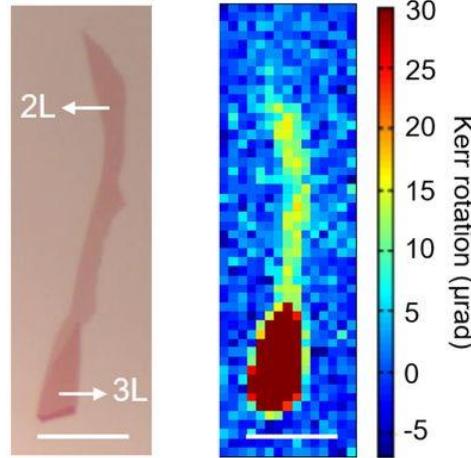
Review

Nature 563, 47–52 (2018)

2D magnet

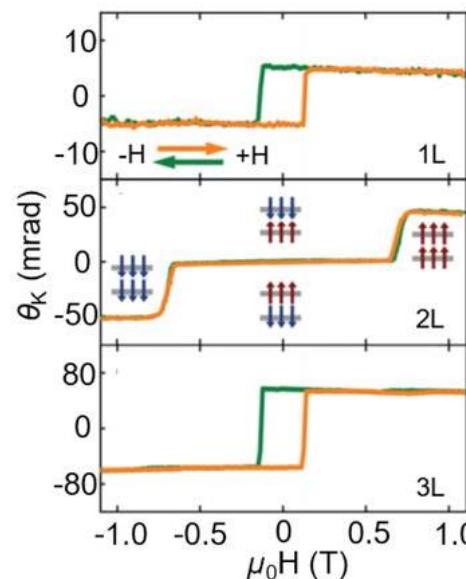
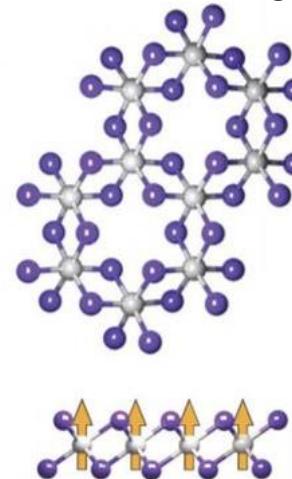
$\text{Cr}_2\text{Ge}_2\text{Te}_6$

Insulating: Proximity



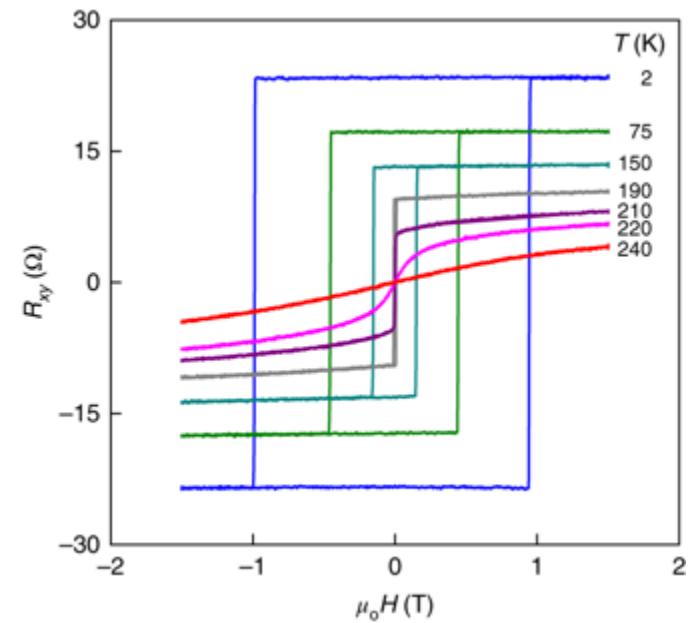
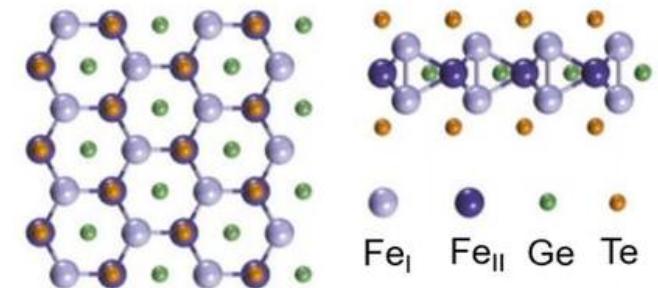
CrI_3

Semiconducting



Fe_3GeTe_2

Metallic: electrodes

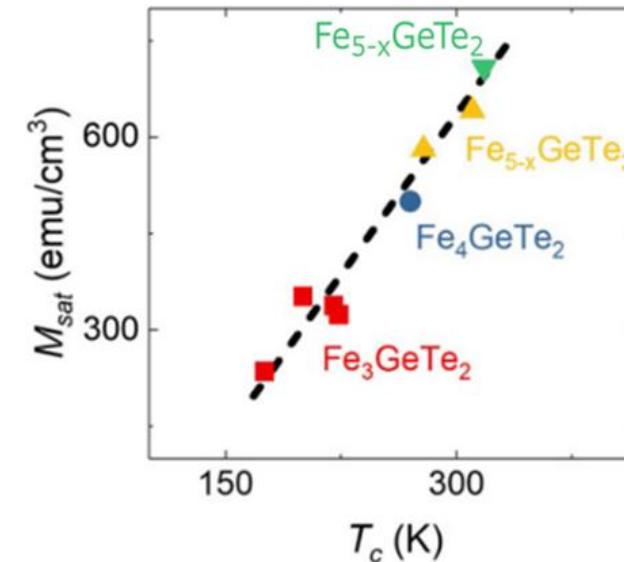
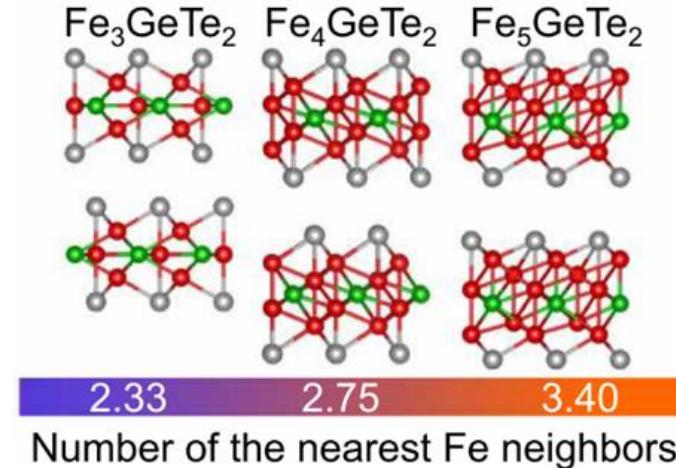
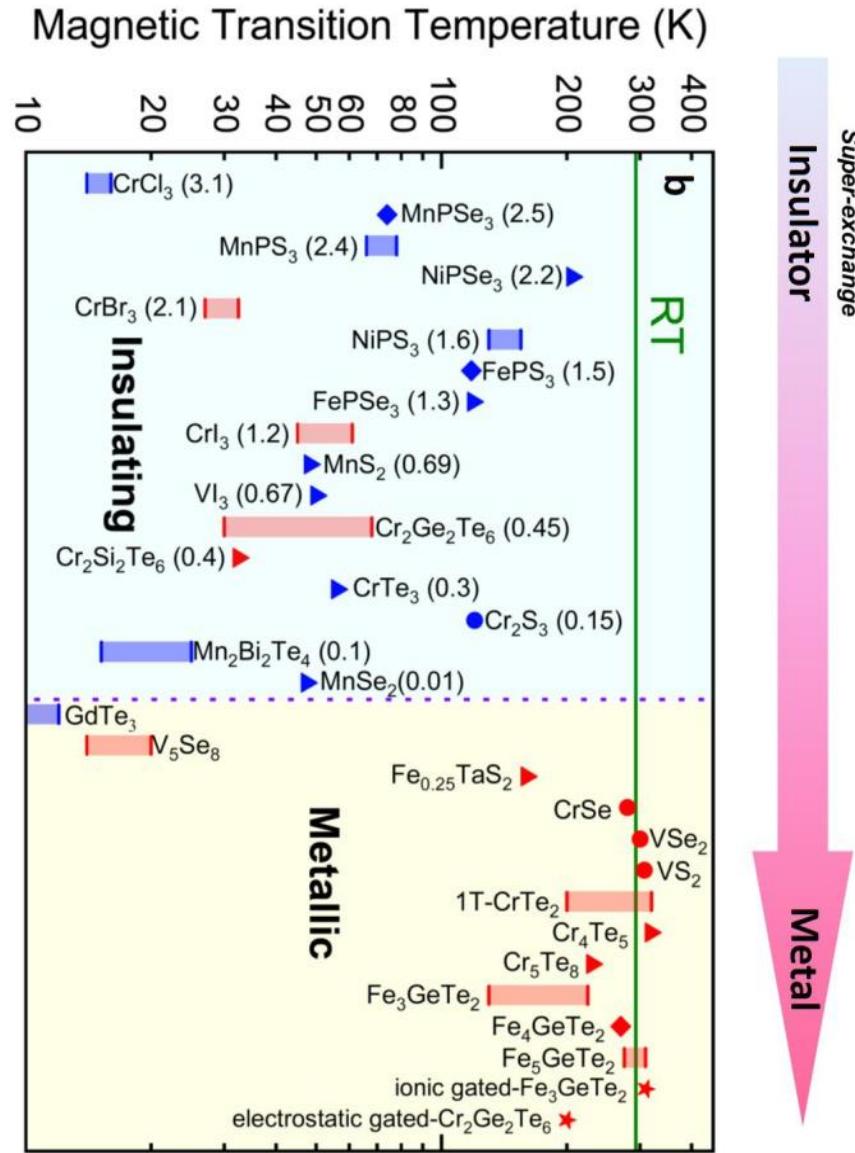


Review

Science 363, 6428, eaav4450 (2019).

Room temperature van der Waals Magnet

Material System

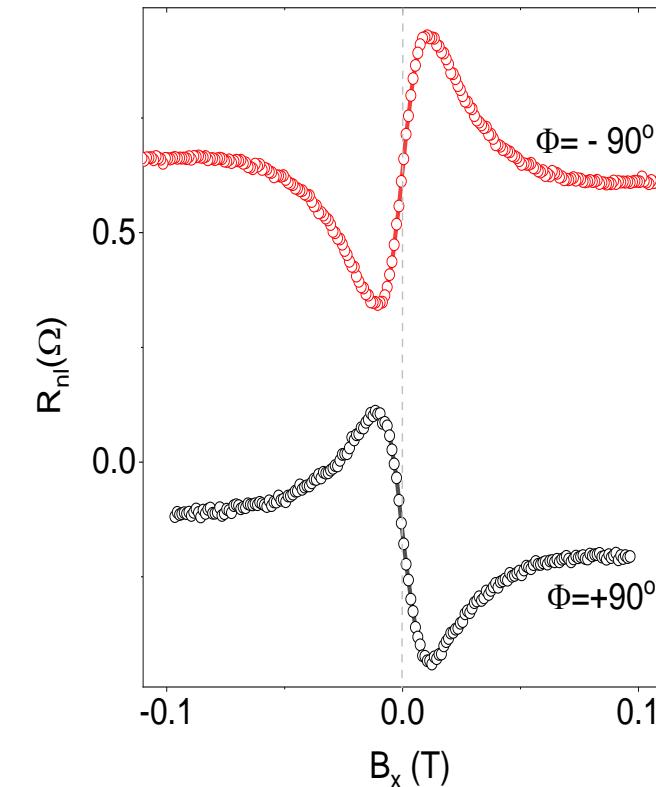
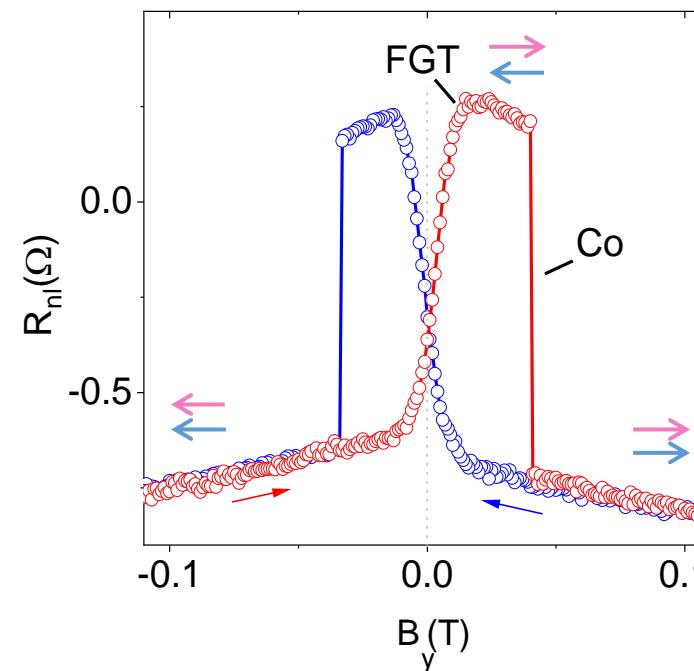
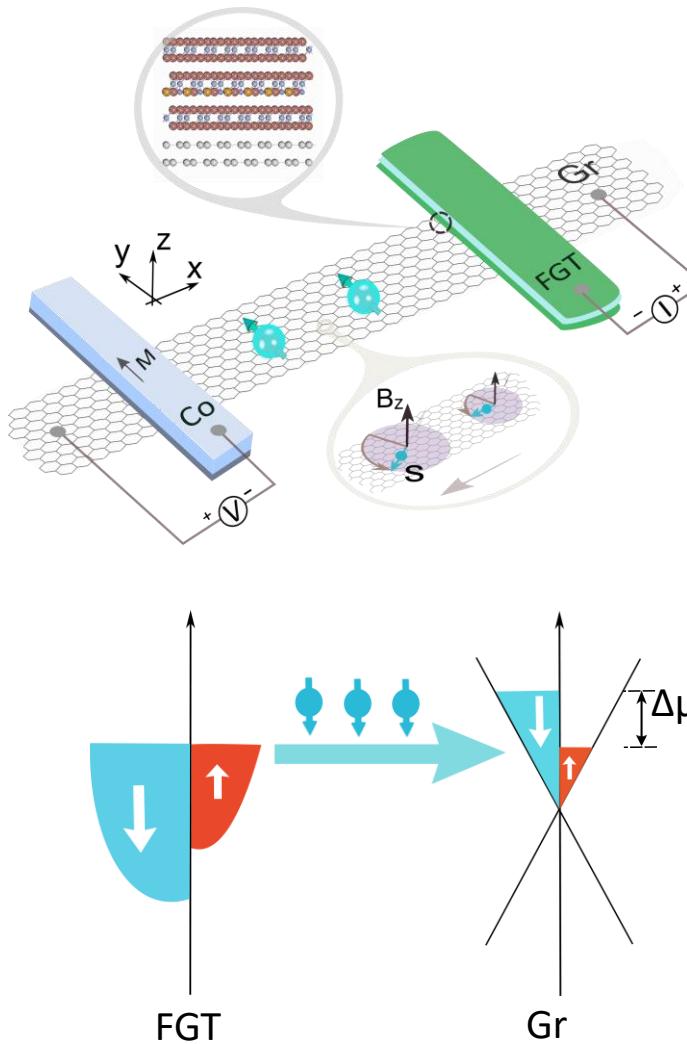


Fe₅GeTe₂

- ✓ Room temperature magnetic order
- ✓ High magnetization saturation

H.Kurebayashi, J. H. Garcia, S. Khan, J. Sinova & Stephan Roche
Nature Reviews Physics 4, 150 (2022)

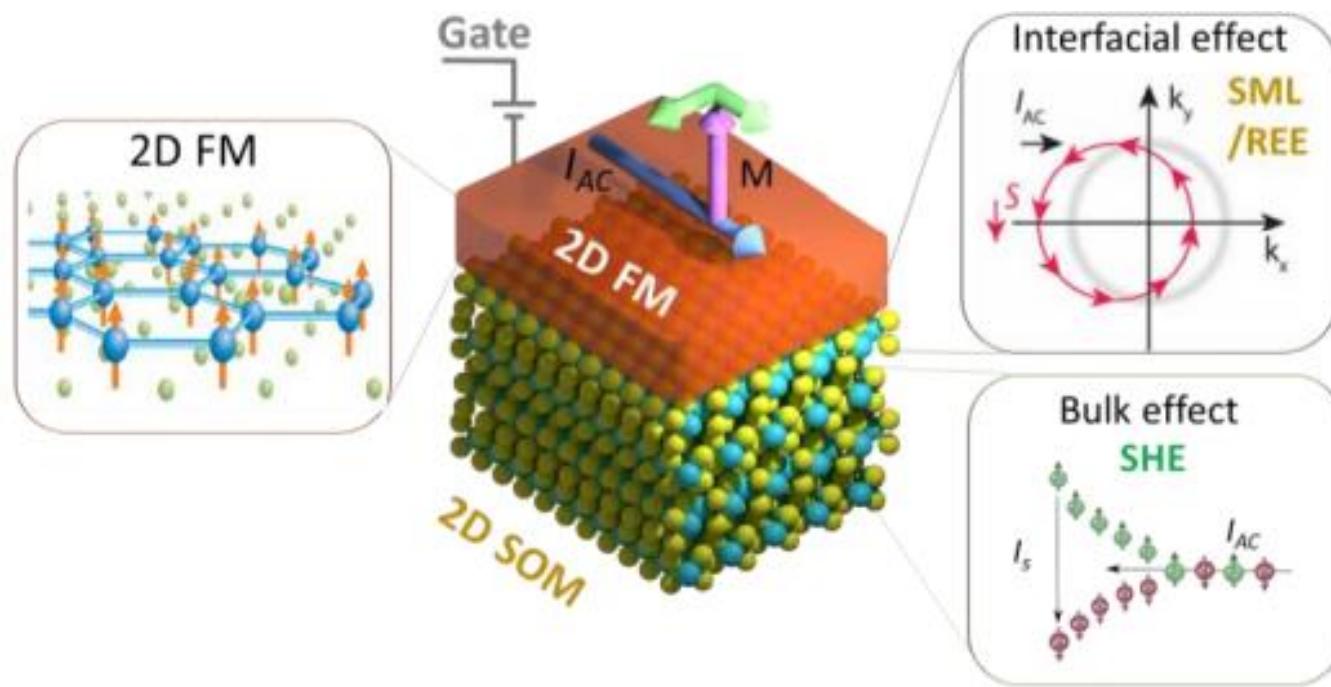
Room Temperature spin-valve with Fe_5GeTe_2



van der Waals Magnet based Spin-Valve Devices at Room Temperature

- Soft and Canted magnetization of Fe_5GeTe at room temperature
- Tunnel spin polarization of Fe_5GeTe up to $\sim 45\%$

2DSOTECH Objectives



The specific objectives of the 2DSOTECH project:

- To exploit low crystal symmetry 2D topological spin-orbit materials (SOM) for efficient and out-of-plane **charge-to-spin conversion** effects.
- To gain new fundamental knowledge of emerging **2D ferromagnets** (FMs) for ultrafast and gate-controlled **magnetization dynamics**.
- To engineer **proximity** exchange and spin-orbit interactions in SOM/(Gr)/2D FM heterostructures.
- To demonstrate and understand the **spin-orbit torque (SOT)** effects in **all-2D platform** consisting of SOM/2D FM heterostructures.
- To study the **time and spatially resolved switching dynamics** of 2D FM/SOM devices.
- To enhance the **SOT efficiency** by interface engineering and external electric field to further reduce the energy consumption.